Traditional Korean Papermaking: History, Techniques and Materials

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Abstract

This study investigated the history of traditional Korean papermaking within its historical context: the relationship with the development of papermaking techniques in neighbouring countries were examined though primary focus was given to the development of materials and tools used.

In order to understand the characteristics of historical Korean paper and the development of tools and materials used over time, surveys on Korean and Japanese collections at the British Library and a private Korean collection were carried out. Korean objects dated between the 12^{th} and the 18^{th} century were examined. The data collected from the surveys was compiled in a database and analysed. The data analysis revealed that the thickness of paper was closely related to the thickness of bamboo splints used in manufacture of papermaking screens.

Research also included a summary of morphological characteristics and photomicrographs of fibres from nine indigenous plants which were used for traditional Korean papermaking. These standard fibre samples were used as reference to identify the fibres of unknown paper objects surveyed. This fibre identification confirmed the main material to be paper mulberry and, additionally, provided information on supplementary materials including rice straw, reed, hemp, and mechanical wood pulp of coniferous origin – a material that has not been recognised as one of the common supplementary materials in previous studies.

In order to provide a better understanding of the materials and tools used in traditional papermaking in Korea, three papermaking experiments were carried out. Firstly, a papermaking experiment was conducted using a mucilaginous substance derived from the roots of Hibiscus Manihot, which has been employed as a formation aid for considerable time in Korea and Japan. Paper samples were then analysed to investigate the physical influence of the substance on the sample sheets.

Secondly, a fixed laid screen was designed and sheets were produced using it. The intention here was to support a hypothesis which was proposed by the author in order to explain a possible chronological development of papermaking mould structure in China and its potential spread to neighbouring countries.

The last experiment was conducted to simulate a technique of papermaking with reclaimed paper. Although the use of reclaimed paper was recorded in early literature, details of the process were unknown.

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Acknowledgements

As a paper conservator I have been interested in the history of papermaking. Korea is one of a few countries to where papermaking was further developed at an early stage and therefore, has a long history of papermaking. Unfortunately little of this history has come to the attention of paper historians and conservators, especially outside Korea. I believe this study will aid understanding, not only of traditional Korean papermaking but also the development of papermaking in East Asia.

In the course of this study I have met many scholars and papermakers who generously helped me with their expertise. Without their support it would not have been possible for me to complete this study.

I would like to thank Brian Singer, Anne Bacon, Jane Colbourne, David Jacobs, Timothy Barrett and Colin Liddie for their consistent support throughout my study. I also want to express my thanks to William Sampson who allowed me the use of the papermaking facility at UMIST and advised me on the analysis of the results of the papermaking experiment.

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Glossary

- **Bal**: a Korean term for a screen. It can be made with splints of bamboo or stems of plants laced with silk threads or horse hair.
- **Balteul**: a Korean term for a supporting frame for a screen.
- **Bast fibre**: fibre collected from the inner bark or the Phloem of plants.
- **Chain line**: See 'Screen'.
- **Couching**: transferring a newly formed sheet from the mould to a prepared board or on a stack of previously removed sheets.
- **Deckle:** a papermaking tool used to retain pulp stock on the screen during the sheet forming process.
- **Dak** (or **Daknamu**): a Korean term for paper mulberry. Although it has been loosely applied to various species of paper mulberry it usually refers to *Broussonetia kazinoki Sieb*.
- **Dakpul**: a Korean term for a mucilaginous substance used as a formation aid in traditional papermaking. Various plants extracts were employed for the same purpose but the most well-known source for it is the roots of Hibiscus Manihot L. As a result, in Korea currently dakpul means the mucilaginous substance from the roots of Hibiscus Manihot.
- **Dochim**: traditional finishing process intended to modify the surface texture of the sheet. Not only to make the surface of the sheet smooth but also to reduce the absorption rate of the sheet. Therefore, after the process, the sheet becomes more suitable for writing.
- **Formation aid**: plant extracts which help fibres disperse evenly in the vat and therefore improve the uniformity of a sheet.
- **Goryeoji**: paper made in Goryeo
- **Hwangchokgyu**: a Korean term for Hibiscus Manihot L.

- **Lime**: hydrated or slaked lime, $Ca(OH)_2$, which was used for cooking raw materials in order to remove lignins.
- **Lye**: an alkali solution which is made from ashes of plants (Potassium Carbonate, K_2CO_3). It is also used in cooking raw materials in order to remove lignins.
- **Mould** (American: **mold**): usually implying the combined assembly of a supporting frame, screen and supporting ribs – a rigid mould comprising of a fixed screen and the flexible mould having a flexible screen.
- **Rib shadow**: thicker streaks in a sheet, particularly along areas where the supporting ribs were directly in contact with the screen.
- **Screen**: a rectangular sieve which retains fibres and allows water to drain through in sheet forming. Can be formed from textile, tightly laced splints of bamboo and plant stems or woven wire. It is often described as the 'mould cover'.
  - **Wove screen**: a screen made from textile or woven wire (wire mat made in the same manner as a woven textile) - leaves impressions of warp and weft of thread or wire in the paper produced.
  - **Laid screen**: a screen made by tying splints of bamboo or slender stems of plants together at intervals with horsehair or thread. In Europe, wire has been used instead of bamboo splints or stems of plants. This type of screen leaves characteristic impressions of laid and chain lines in the paper: the tightly packed bamboo splints produce the closely aligned '**laid lines**' - the horsehair or thread (spanning the frame at 90° to the bamboo) produces the impressions termed '**chain lines**'.
  - **Fixed screen**: denoting a laid screen which is permanently fastened to the supporting frame.
  - **Flexible screen**: denoting a laid screen which is detachable from the supporting frame.

- **Supporting frame**: a rectangular frame mainly constructed of wood though, in some cases, bamboo.
- **Supporting ribs**: slender wooden bars which are built-in as part of a supporting frame.

Korean and Chinese Dynasties mentioned in the text

Periods	Korea		China	
206 BCE – 7^{th} century	Three Kingdoms		Han	206 BCE – 220 CE
	Goguryeo	37 BCE – 668 CE	Three Kingdoms	220 – 280
	Baekje	18 BCE – 660 CE	Jin	265 – 420
	Silla	57 BCE – 668 CE	Southern and Northern	420 – 589
			Su	518 – 618
7^{th} – 10^{th}	Tongil Silla	668 – 935	Tang	618 – 907
10^{th} – 14^{th}	Goryeo	918 – 1392	Five Dynasties & Ten Kingdoms	907 – 960
			Song	960 – 1279
			Yuan	1271 – 1368
14^{th} – 20^{th}	Joseon	1392 – 1910	Ming	1368 – 1644
			Qing	1644 – 1911

The DVD submitted along with this written thesis includes:

- A database presenting information on the Korean and Japanese collections at the British Library
- Images of each object examined during the surveys
- Photomicrographs of fibres of objects examined and standard samples
- Two video clips of the sheet forming process

Declaration

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work.

Name: Hyejung Yum

Signature:

Date: October 20th, 2008

1. Introduction

Research aims

- To investigate the history of Korean papermaking and its development.
- To construct a database of characteristics of traditional Korean paper.
- To identify the predominant fibres used in making traditional Korean paper.
- To verify the function of the mucilaginous substance from the root of Hibiscus Manihot which has played a vital role in traditional papermaking in Korea, Japan and certain parts of China.
- To explore the possibility of the existence of a fixed laid screen prior to the inception of the flexible laid screen in China and the influence of such a device on traditional papermaking in Korea.

Paper can be defined thus: 'a thin, fibrous material formed from well-separated vegetable fibres suspended in water. The suspension being sieved with a screen, once dried, results in a compact, interwoven web of fibres'.

The ancient craft of papermaking has attracted the attention of many scholars and, as a result, a great deal of research has been carried out into the subject by art historians, paper historians, archaeologists and paper conservators. Nonetheless, most accounts of the history of papermaking have focused either on its origins in China or its development in Europe. There are still many areas which are relatively neglected and, therefore, have not been sufficiently covered by previous research. Traditional Korean papermaking is one such area.

The use of paper can be readily seen in Korean culture throughout its history, which suggests that the art of papermaking must have developed extensively in Korea at an early stage. Paper was an indispensable material of daily life. Traditional handmade Korean paper had a multitude of uses: it was used for calligraphy, books, and envelopes; for doors, walls, ceilings and windows; for furniture, such as wardrobes, cabinets, and chests; for craft objects, such as writing brush holders, umbrellas, lanterns, boxes, baskets, fans, and kites; and for clothing and shoes. Korea also appears to be the only country where paper has been used for covering floors. Traditional Korean paper was strong and durable - a strength owed to the sheet formation technique and the main material, paper mulberry.

Korea was involved in the spread of papermaking to the east and initiated Japan into the crafts of papermaking (Cho et al, 1996, p28). However, neither the origin of papermaking in Korea nor the techniques and tools used from the beginning are well known due to the lack of written records which have been handed down. It is not clear whether this lack of written information is due to the numerous invasions Korea had been through since the foundation of the country. In addition to this lack of continuity in primary, historical accounts of the craft, similarly, little scholarly research has been undertaken into traditional handmade paper in Korea.

The research presented here will explore the history of Korean papermaking along with its techniques, tools and the main materials used. The aim will be to provide a better understanding of traditional Korean paper by clarifying the specific papermaking process and characteristics.

Understanding traditional Korean papermaking is important to comprehend the history of papermaking in East Asia. Papermaking spread from China to Japan via Korea, after its introduction in each country, it was adapted to the individual location where technique and tools were modified in order to accommodate the respective indigenous materials of the regions. The materials and tools used in traditional Korean papermaking are the focus of this research, however, there were constant cultural exchanges made between these countries. Defining the characteristics of papermaking skills and materials in the country is not possible without an understanding of the characteristics of papermaking in its neighbouring countries. Therefore, papermaking tools and materials used in China and Japan are also investigated in detail to provide a broader context to this study. In this respect, this research will provide valuable information for research into the development of traditional handmade paper in China and Japan.

This research has been carried out mainly as a reference work for conservators though it would also provide valuable information for paper historians. Conservation is an interdisciplinary subject which requires knowledge about the history of the object as well as the history of materials and their characteristics defined through scientific analysis. In that sense this research will provide a better understanding of the features of traditional Korean papers along with papers of neighbouring countries.

Standard samples of most common materials used in traditional Korean papermaking have been prepared and it is hoped that this reference will provide sound guidance in future attempts to identify fibres in historic Korean papers. The characteristics of traditional Korean papers documented here are also intended to offer useful information to aid identification by the conservator confronted by such materials. In this, it is intended that the conservator can make more informed decisions in treatments based on a more sound understanding of the materials present in the object.

Research outline

Paper was invented in China around the 2nd century B.C (Kim, 2001, p75) and papermaking skills were then passed on to Korea[1] and from there subsequently to Japan (Lee, 2002, p45). As a result,

[1] There is no existing official written record of the delivery of papermaking skills from China to Korea but it has been

papermaking in these three countries is closely related. Korean paper was exported to China for sale from the 10th century onwards (Pan, 1978, p232) and as one of the main tributes to China, comments on traditional Korean paper are widespread in historic Chinese literature. Therefore, references to traditional Korean paper within Chinese scholarly works provide insights into characteristics and quality of traditional Korean paper which frequently were not recorded within Korea itself or where records have not survived to the present day. Additionally, evidence of papermaking practices illustrated in Chinese literature and Japanese Ukioe prints suggests how similar procedures within Korean papermaking might have been carried out.

The first aim of the research is the study of traditional Korean papermaking within its historical context. Additionally, the relationship with the development of papermaking techniques in neighbouring countries has been investigated.

The second aim of the research is to assemble key features of old Korean paper and build up a database which will help to understand the characteristics of traditional Korean paper and to establish whether there were any observable trends in their occurrence over time. The collection of such information serves as a basis to further understanding by methodical study and systematic analysis of old paper. Historical paper itself presents invaluable information on materials, tools and sometimes even techniques used. Furthermore, it was deemed essential to understand actual papermaking processes in order to comprehend certain features present in old papers. Hence, traditional paper mills in Korea were visited and interviews with papermakers were carried out. In producing the database, it was crucial to select a list of key objective criteria by which samples of historic paper could be assessed - the intention was, therefore, that further data could be added and used by other scholars in the field in future. It was also important to examine as many historic papers as possible to maximise the validity of the database. For that reason, 268 sheets of old

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widely accepted based on the cultural exchange between Korea and China in antiquity.

Korean paper were examined - the majority being sampled for fibre identification. In order to make comparisons between traditional Korean and Japanese papers, eighty-three sheets of old Japanese paper were also included in the survey.

In terms of investigating materials used for traditional Korean papermaking, two approaches were made. Primarily it is the identification of fibres from each paper sample which is intended to aid in comprehending the predominant and possible alternative sources of fibres used for traditional handmade paper. Additionally, clarification of the role of a formation aid in sheet formation was sought – specifically it is the mucilaginous substance from the root of Hibiscus Manihot, which is the most well known plant source of this type of substance.

The third aim of the research is the identification of sources of fibres used for traditional papermaking in Korea. In order to assist this aim, photomicrographs of standard fibre samples from the main and alternative materials used in traditional Korean papermaking were prepared.

Although photomicrographic references of some bast and grass (including cereal) fibres are available from previous research (Ilvessalo-Pfaffli, 1995; Catling & Grayson, 1982; Carpenter & Leney, 1952), these examples mainly focused on wood fibres and bast fibres commonly employed in European and American papermaking. In Korea, the main materials in handmade papers have been bast and grass fibres though research on fibre identification has not been well established inside Korea to date. As a result, any visual references of photomicrographs of papermaking materials in Korea are rather limited. Although the previous research into fibre identification conducted in Europe and America included some papermaking fibres also used in Korea, detail was restricted. Therefore, it is also important to provide supplementary visual resources of bast fibres and grass fibres which are more specific to traditional Korean papermaking. These will provide valuable information to this subject as well as being helpful in identifying unknown fibre samples.

For the purposes of this research, fibre identification was mainly carried out by examining the morphological characteristics of each fibre sample with a polarizing microscope alone. Viewed with slightly uncrossed polars, fibre characteristics are emphasised to aid inspection. Although the chemical staining of fibres can be helpful in narrowing down the group to which each fibre belongs, actual identification remains dependent on careful observation of the morphological characteristics of each fibre.

The fourth aim of the research is to clarify whether the mucilaginous substance from the root of Hibiscus Manihot enhances physical strength of a sheet. This fourth aim will be achieved by conducting a papermaking experiment. Furthermore other indigenous plants used as formation aids in Korea, China, and Japan will be investigated.

Mucilaginous substances from indigenous plants have been indispensable materials in traditional papermaking in Korea, Japan, and certain parts of China. However, it is not known when and where this type of substance was first employed in papermaking in those countries. There were different plants which had been used for the same purpose, however, the root of Hibiscus Manihot is the most well known and commonly used in Korea and Japan. Despite its excellent function as a formation aid, the mucilage from the root of Hibiscus Manihot lacks chemical stability and is easily affected by some external factors, readily losing its function. Therefore, previous analytical research on mucilaginous substances from plants has been mainly focused on not only understanding of the chemical components of the mucilaginous substances from the root of the Hibiscus Mahihot (Seishi & Uchino, 1954. On & Im, 1980) and the inner bark of Hydrangea Paniculata, Sieb (Seishi &Inano, 1955) but also finding substitutes which have the same effect with increased stability (Seishi & Nishikori, 1960. Seishi & Yoshino, 1961, 1963. Seishi &

Nishikori, 1965). It is believed that one of its functions is to increase physical strength of a sheet by improving the formation quality of it – a theory which has been widely accepted by many scholars (Pan, 1978, p326; Hughes, 1978, p84; Cho et al, 1996, p206).

The relationship between improvement of sheet formation and improvement in the physical strength of it remains unclear as there is little scientifically analytical information concerned with the nature in which the mucilage affects the strength of the sheet.

Traditional Korean paper is believed to have multi directional orientation of fibres due to the forming action employed (Cho et al, 1996, p100). In examination of this characteristic, instrumental analysis included a scanning electron microscopy (SEM) in order to examine surface characteristics and cross-sections of old Korean paper samples. However, SEM was employed only for the samples obtained from private collections as the analysis requires the removal of a small sample. Samples obtained from the British Library collections mostly involved a small collection of loose fibres and, therefore, were irrelevant to an understanding of paper formation in terms of surface texture or cross-section composition.

The fifth aim of this research is to explore types of moulds and screens used in Korea. A papermaking mould is the most important instrument in the art of papermaking. In Korea a flexible bamboo screen (supported by a wooden frame work and a few supporting ribs) has been the only form recognised as the traditional Korean papermaking mould and screen: the lack of a deckle was thought to be one of the defining characteristics of the traditional Korean papermaking mould (Field, 1987, p12. Lee, 2002, pp153-155).

However, when Hunter (Hunter, 1947, p96) made a research trip to China, Korea, and Japan in 1933, he reported that the Korean papermaking mould was like the common Chinese laid mould, consisting of a wooden frame, a flexible laid screen, and two deckle sticks. His report showed how closely papermaking tools and techniques might have been exchanged between these countries. In addition, Hunter's statement certainly brings into question previous ideas of the traditional Korean mould.

With the examination of the development of the mould in the region as a basis, within this research, a hypothesis is proposed regarding the possible existence of a fixed laid screen as a form which preceded the flexible laid screen in China. The potential influence of the device on traditional papermaking tools in Korea is assessed. A papermaking experiment with a fixed laid screen was designed and carried out in order to support the hypothesis. The methodology of recreating ancient processes established in experimental archaeology was explored and it provided a broader theoretical framework for the experiment with the fixed laid screen.

In support of the issues addressed in this research, all key research articles and books related to the main topics of this research are reviewed in order to justify it.

In Chapter 2 the history of papermaking is briefly reviewed from the inception of the art of papermaking in China to its spread to the Western world via Islamic countries. The way in which recent archaeological excavations have helped to understand and rectify any misconceptions related to the origin of paper in China and its development in other countries is examined.

Over 2000 years the basic principle of papermaking has remained without significant change. However, it was inevitable that slight modifications to papermaking tools, materials and techniques were made when the art of papermaking was delivered from one country to another. A good example of this is the way in which bamboo splints were soon replaced by wires in Europe due to the lack of availability of the former material there. Tracking the chronological spread of papermaking skills between countries helps to gain insight into how this ancient craft was adapted in each country and in different environments, and therefore, the reason for any variation made in materials and tools used. This also assists in comprehending any missing information in the development of papermaking in any country having incomplete records of practice.

Chapter 3 looks into the history, materials and techniques of traditional Korean papermaking. Its history is investigated from the 3rd century to the beginning of the 20th century, just prior to the country becoming a colony of Japan: after 1910, traditional Korean culture was effaced by the Japanese government and as a result, traditional Korean papermaking may have been much affected by Japanese methods.

Chapter 4 gives an overview of methodology employed in this research including the survey form design and the chosen analytical methods. The background of three papermaking experiments and their process is also discussed. In Chapter 5, based on the result of three papermaking experiments and the database from the survey, the characteristics of traditional Korean paper are discussed and summarised. Fibre analysis results are also discussed.

In Chapter 6, conclusions were drawn based on the analysis of the results from the survey on Korean and Japanese collections at the British Library, a supplementary survey on a private Korean collection and the results of the papermaking experiments. The characteristics of traditional Korean paper, the development of papermaking materials and tools were also summarised.

In the current research, all quotations from Korean texts were translated into English by this author, unless otherwise stated.

2. The Origin of papermaking in China and its spread towards Europe

2.1. The Origin of papermaking in China

According to an item of historic Chinese literature, 'History of later Han dynasty (後漢書, AD 425) written by Byumyup (范曄, 397 – 445), Ts'ai Lun conceived the idea of making paper from the bark of trees, textile waste, and fishing nets and presented it to the Emperor, Whajae (和帝) in AD 105 (as reported in Pan, 1978, pp34-35). For a long time Ts'ai Lun was believed to be the inventor of paper. However, this widely accepted account of history has been challenged by a series of archaeological excavations made since the beginning of the 20th century: several old Chinese papers were discovered, which provided convincing proof that paper was already in use before Ts'ai Lun's time.

In 1933, a Chinese archaeologist, Huang-Won-Pi (黃文弼) found a piece of paper made from hemp at an archaeological site of an old beacon mound at Singyangsung (新疆省) - a site which dates from the Han dynasty. The paper was discovered with a piece of wood on which the date BC 49 was written. The paper appears to be rather crude, exhibiting inclusions of thick, coarse hemp thread. Unfortunately this paper was destroyed during the war between China and Japan in 1930 – all that remains is a photograph and a short description of the find (Pan, 1978, p37).

In 1957, Perjiao province, nine pieces of paper made from hemp were found at an old tomb, Sianmyo (西漢墓, BC 141 – 87), which were buried during the West Han Dynasty. The size of these pieces was approximately 25 x 35 (cm) and the Chinese paper historian, Pan Chi-Hsing, believed them to have predated Ts'ai Lun's paper by at least two hundred years. Now displayed at the museum of Siansiyoung (陝西省), the location of the find has led to these examples being referred to as Perjiao paper (Kim, 2001, p74). In order to identify the material used in the paper, microscopic examination was carried out in 1965 and confirmed that the papers were made from hemp (mainly *Cannabis sativa L.* and a small amount of *Boehmeria nivea Gud*) (Pan, 1978, p38). Later in 1973, two pieces of hemp paper dated between BC 52 and BC 6 were found at an ancient army campsite in Jingwan (金關) near the Great Wall. Furthermore, five years later in 1978, in Jung-an city (中顔), Siansiyoung (陝西省) two pieces of paper were found inside a pot dated between BC 2 and BC 1. On examination, archaeologists thought that the paper must have been produced between BC 73 and BC 49 (Kim, 2001, p75). The following year, in 1979, eight pieces of paper were discovered at an archaeological site of an old beacon mound in Magwonman (馬圈灣) – a site dating from the Han dynasty. Further significant evidence suggesting some form of paper had existed before Ts'ai Lun's time appeared in 1986 – a piece of paper was among the objects found inside one of the tombs from the Han dynasty in Kanshusung (甘肅省), Pangmatan (放馬灘). The tomb was buried between BC 179 and 142, consequently confirming the paper as the oldest in the history of papermaking (Kim, 2001, p75). Kim (2001, p76) summarized the information regarding these important, early paper objects reported by Pan Jising (Table 1).

Table 1. Old Chinese papers dated before Ts'ai Lun

	Estimated Date	Found	Size (cm)	Thickness (mm)	Density (g/cm3)	Material
Raponyoiji (羅布淖爾紙)	BC 49	1933	4 x 10*	-	-	hemp (痲)
Pagyoji (灞橋紙)	BC 140 – 87	1957	10 x 10	0.10	0.29	hemp (痲)
Geumgwanji (金關紙)	BC 52 – AD 6	1973	9 x 21	0.22	0.28	hemp (痲)
Junganji (中顔紙)	BC 73 – 49	1978	6.8 x 7.2	0.22	0.28	hemp (痲)
Magwonmanji (馬圈灣紙)	AD 8 – 23	1979	17.5 x 18.5	0.29	0.30	hemp (痲)
Bangmatanji (放馬灘紙)	BC 179 – 142	1986	-	-	-	hemp (痲)

'*' Raponyoiji (羅布淖爾紙) was destroyed during the war with Japan and its picture was the only one left (Cho et al, 1996, p16)

It is clear (Table 1) that hemp was the main raw material used in the ancient craft of papermaking in China between BC 179 and AD 23 and Pan (1978, p54) reported that hemp remained as the most common material in papermaking before Tang dynasty (618 – 907) in China. Pan (1978, p43) also stated that the early hemp papers from Former Han (前漢) were low quality and could not be used for writing in the manner of baekgan (帛簡), silk cloth and flat pieces of bamboo. Baekgan (帛簡) was the official material for writing at that time and therefore, the early hemp papers were mainly used for wrapping. According to Jung (1998, p230) the inner bark of trees used by Ts'ai Lun must have been paper mulberry, and, therefore, papers made in the 2nd century were made with hemp and paper mulberry.

From the combined facts listed above, there is strong evidence against the common, simplistic belief in Ts'ai Lun's invention of paper. However, it should be noted that these archaeological specimens appear to be rather coarse and thus possibly not suitable as supports for writing. More accurately therefore, perhaps Ts'ai Lun should be notable as an improver of papermaking skills by introducing alternative papermaking materials.

2.2. The development of the papermaking mould in China

The mould is the fundamental tool in papermaking and it is important to understand the development of this mould in ancient China from the beginning of the industry. The early form of the Chinese mould must have been transferred to neighbouring countries along with the craft of papermaking, thus influencing the development of papermaking tools. Unfortunately, little written information on papermaking tools has been handed down and inevitably study of the subject has heavily relied on examination of old Chinese papers.

Despite of the lack of written information, it is believed that, at an early stage of papermaking, a rather simple papermaking mould must have been used. The wove mould – a piece of coarse textile being fastened to a rectangular bamboo frame – has been regarded as the oldest form of papermaking mould in ancient China (Hunter, 1947, p84. Pan, 1978, p55) (Figure 1).

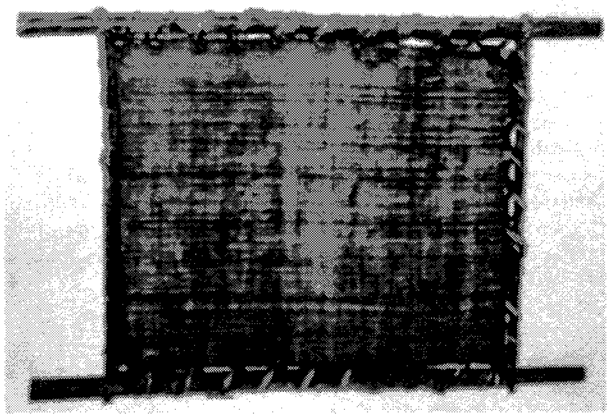

Figure 1. A wove mould (illustration from 'Papermaking' by Dard Hunter, p84)

Hunter (1947, p78-79) suggested two methods by which this type of mould might have been used to produce paper: one suggestion is that the mould might have been dipped into the water (a suspension of macerated fibres) and the stock scooped by drawing the mould horizontally upwards allowing water to drain through the textile to leave a layer of fibres on the screen. Alternatively, it is proposed that the mould may have been held flat and the suspension poured upon the screen to leave a thin layer of fibres remaining on the screen as the water drained. In either method, a thin deposit of felted fibres was accumulated on the screen and the newly formed sheet (together with the mould) was left in the sun for drying. As paper made on such a screen exhibits impressions of the warp and weft of the textile, any example of the period carrying such impressions can be assumed to have been made upon a wove mould.

Hunter (1947, p84) also reported that this type of mould has no supporting ribs attached to its bamboo frame. No deckle is used, as its mould – the bamboo frame – plays the role of the deckle by retaining the pulp stock on the screen while the water drains.

The main disadvantage of such a wove mould must have been that the newly formed sheet had to be left on the screen until it had completely dried since the coarse surface of a screen would not release a wet sheet without damaging it. Therefore, it would have been essential for papermakers to stock many moulds in order to produce a large quantity of paper. Presumably, the wove mould would have been commonly used until the introduction of the laid mould in China – the coarse textile was replaced by a rectangular sieve (a laid screen) made by lacing thin splints of rounded bamboo or stems of plants at intervals with silk tread or horse hair. Hunter (1947, p84) speculated that the laid mould was invented shortly after the wove mould.

A laid mould has a great advantage over the wove mould. The smooth surface of the laid screen (mould cover) could immediately release the newly formed sheet after the sheet forming process. As a result, papermakers could produce sheets continuously with one laid mould. The invention of this type of screen was a significant advance in the history of papermaking. Papers made on the laid mould generally have impressions of laid lines and chain lines: the impressions made by the splints of bamboo or plants stems are known as 'laid lines' - the impressions made by the stitches of silk thread or horse hair being 'chain lines' (Hunter, 1922, p588).

Regarding the structure of the laid mould, it has been believed that, unlike the wove mould, the bamboo screen was not fastened to its supporting frame (As the bamboo screen was not fixed to its supporting frame, this type of screen will be referred as 'a flexible laid screen' within this work). Pan (1978, pp95-96) stated that the mould which could produce sheets with the impressions of laid and chain lines consisted of three parts: a bamboo screen, a rectangular supporting frame, and a pair of wooden sticks as a deckle. (In the current study, this type of deckle will be referred as a two-stick deckle). In the laid mould, the role of deckle is not only to keep the pulp stock within the boundaries of the mould but also to hold the screen in place during the sheet forming process.

Pan (1978, pp95-96) also explained how these three components were assembled during the sheet forming process and disbanded for couching. For the sheet forming process, the screen was placed on the supporting frame. With the two deckle sticks placed on the two open edges of the screen, the papermaker would hold the assembly together to scoop into the vat - the loaded mould was brought up above the vat so water drained, leaving a thin layer of fibrous material on the screen. For couching, the two sticks were removed and the screen inverted so as to release the newly formed sheet onto a prepared board.

Additionally, Hunter's description (1947, pp86-88) of the construction of such a flexible laid screen could help to understand the reason why a two-stick deckle was used for such types of laid mould: the flexible laid screen consists of a number of bamboo splints (or sometimes stems of plants) tied along their lengths to form the rectangular sieve. Two bamboo rods (or wooden sticks) are tied to finish off the opposite ends of the screen. Due to the large diameter of these rods (relative to the bamboo splints), shallow barriers are formed at the margins when the screen is laid on its wooden frame. In order to prevent the pulp stock from seeping off the screen, two additional wooden sticks are required for the two remaining open sides (running parallel to the lacing stitches). Hunter (1947, p88) also reported that a two-stick deckle appears to have been employed in China around the 1930s.

The rectangular supporting frame always has several slender, wooden ribs (supporting ribs) at intervals across its length (Figure 2) in order to support the screen and keep it flat (Hunter, 1947, p88). The number of supporting ribs appears to vary depending on location of production but it seems as if there is no consistent design in this respect.

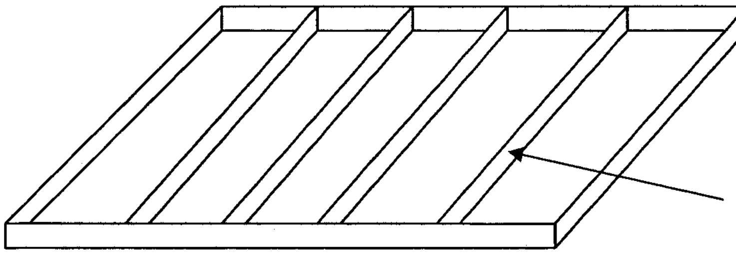

Figure 2. Rectangular supporting frame used in the laid mould

While the dates of introduction of these moulds are not known, based on the examination of old papers, Hunter (1947, p92) believed that a flexible laid screen has been used in China from as early as the third century onward. This theory was supported by another paper historian: Pan (1978, p288) reported that several unearthed papers carrying imprints of a textile mould cover had been found and were dated between AD 348 and 418. Furthermore, based on the impressions of laid and chain lines of old papers found at various archaeological sites, Pan (1978, p95) also suggested that a flexible laid screen was invented later than the Han dynasty (BC 206 – AD 220) and possibly during Jin and Southern and Northern dynasties (AD 220 – 588). For these paper historians, the imprint of laid and chain lines has served as crucial evidence in support of the idea that, from the third century, papers were made upon a laid mould with a flexible laid screen which is presumably more or less the same as the structure of the laid mould used in East Asia in modern day production.

However, it seems to be rather a drastic leap in logic to draw such a conclusion on mould structure mainly based on the impressions in old papers. The development of the papermaking mould has not been thoroughly studied yet and therefore, it is not clear whether such a laid mould was the only one which could leave the impression of laid and chain lines. It is equally possible that there might have been a different mould structure employed by the Chinese.

One of the earliest books describing the papermaking process in China is T'ien-Kung K'ai-Wu

(天工開物), written by the Chinese scholar, Sung Ying-hsing in 1637 during the Ming dynasty. It covers all the major industrial techniques of the 17th century in China. A facsimile copy of the original edition was printed in Shanghai and published in Beijing by Zhonghua Shuju in 1959. It was later translated into English in 1966 by E-Zu Zen Sun and Shiou-Chuan Sun - this English version includes all the copies of illustrations from the original book. In chapter thirteen, entitled 'Paper', the author explains the papermaking process with bamboo and paper mulberry. The section includes five illustrations describing some of the papermaking processes, such as harvesting and retting, cooking, sheet forming, couching, and drying. In the sheet forming illustration (p226), the papermaker is holding a mould, the cover of which appears to be comprised of thin splints laced with thread or horse hair: the mould cover clearly appears like a laid screen (Figure 3).

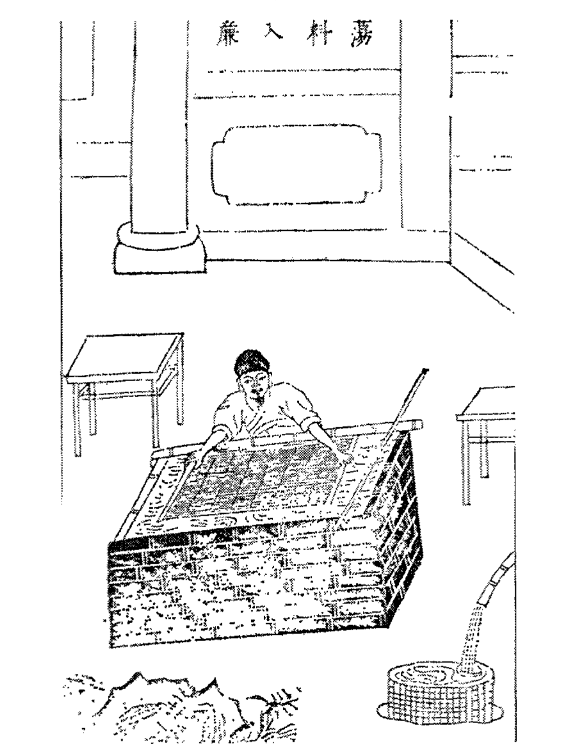

Figure 3. Sheet forming process

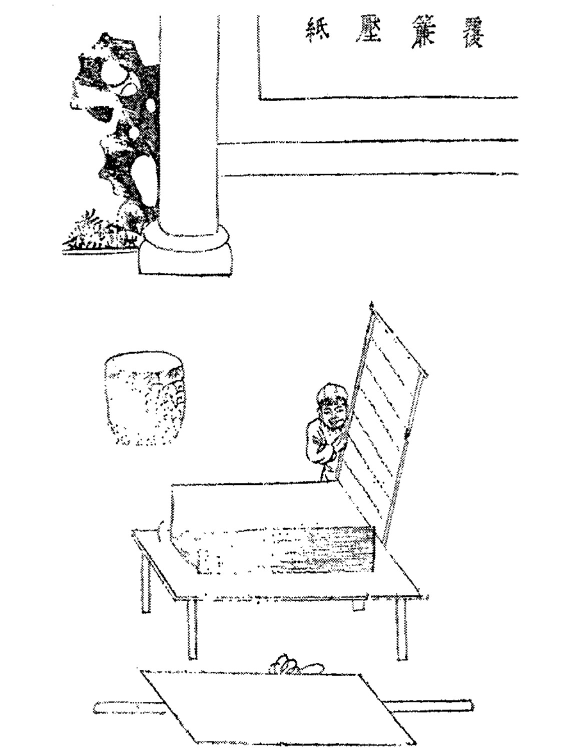

Figure 4. Couching process

As mentioned before, paper historians speculate that a flexible laid screen has been in use since the 3rd century in China, and therefore in the 17th century, it is natural to assume that the coucher (the worker whose job is the removal of the newly formed sheet from its mould) would be depicted holding a flexible laid screen. However, in the following illustration (p228) depicting the couching process, the coucher is holding the wooden framework covered with a laid type of screen - apparently the laid screen is fastened to its frame in the manner of the wove mould (Figure 4). Although Hunter (1947, p92) assumed that the illustration of couching was inaccurately drawn by the artist, it could be possible that this type of fixed laid cover had been used in China as a transitional form between a wove mould and the laid mould with a flexible laid screen at some point before T'ien-Kung K'ai-Wu was published.

Despite the efficiency of the laid mould, it appeared that the wove mould was not completely substituted by its descendant. McClure (1930, p119) reported that use of the 'wove' type of mould continued in certain parts of China – a fact evident from his visit to a paper mill in the village of Kam Ts'uen (甘村) (less than three hours by boat from Canton) in the late 1920s. The author (1930, p124) gave a detailed description of a wove mould:

> "... The screen consists of a piece of coarse cloth made of Ch'ue Ma (苧麻, Boehmeria nivea Gaud.) or Ramie, of a size exactly to fit the opening in the bamboo frame. The warp and woof threads of this cloth run about 5.9 to the cm. The threads themselves are about 0.8 mm in diameter. The screen is fastened in place in the following manner. Four smooth, slender, bamboo strips, 2 or 3 mm in diameter and as long as the edges of the screen, are prepared, sharpened on one end and threaded thru the cloth one along each edge, leaving a margin of about .5 cm, and piercing the cloth at intervals of about 5cm. The margins of the cloth are now lashed to the four sides of the bamboo frame by means of slender thongs of rattan wound spirally around the bars and piercing the cloth just inside the slender bamboo strips and at intervals of about 5 cm. The strips thus help to distribute the pull on the screen so that the tension is not all applied at the points where the thongs pierce the cloth.... "

Apparently this type of mould has still been employed in certain parts of Asia up to the present day (Traditional Paper Sheet Formation around the World).

While these two types of moulds have been mainly employed in China for considerable time, it seems as if small variations were made to the shape of the deckle in some rural areas in China. According to McClure (1986, p52), the mould commonly used in China around the 1920s consisted of three parts: a light frame with numerous supporting ribs, a flexible laid screen, and a U-shaped deckle. Although McClure referred to it as U-shaped, it is rather closer to a rectangular wooden frame minus one side - the two parallel sides being shaped like an elongated wedge.

The development of moulds in China can be summarized thus: a wove mould was the oldest form used from the beginning of the craft of papermaking - it was followed by a laid mould comprising of a flexible laid screen, a supporting frame, and a deckle.

2.3. The Spread of Papermaking to Islamic Countries

According to Baker (1991, pp28-35), in the middle of the eighth century the Arab world had reached its maximum size; to the East, its occupying power expanded almost to Samarqand in Transozania. The region was administered by local rulers on payment of tribute to the Arabs. The year 751 saw military conflict between Arab and Chinese armies on the banks of the Tharaz River - the Chinese army was defeated. Many Chinese survivors were captured and among these were papermakers. As was the custom of the period, prisoners of war were entitled to buy their freedom with their labour (Voorn, 1959, p32) – it is therefore possible to suggest that the spread of papermaking techniques towards Islamic countries was initiated in this manner.

At the beginning of the industry of papermaking in Islamic countries, the materials and tools used for papermaking must have been more or less the same as those used in China in the 8th century. Yet, little information pertaining to papermaking in Islamic countries had been known to Western world for a long time and this missing information seems to mislead the European paper historians regarding the history of papermaking materials. For example, Hoernle (1903, p664) reported that, until the end of the 19th century, it had been believed that the use of rags as a papermaking material started in Europe around the 13th century and before that time all paper was made of raw cotton fibres. This belief turned out to be a misunderstanding: in 1877-8, over 100,000 ancient manuscripts were found in Egypt and their dates extended over a period of 2,700 years (between the 14th century BC and the 14th century AD). A portion of the documents found were possessed by Archduke Rainer of Austria and referred to by the collector's name (Aitken, 1914, p207). Joseph Karabacek and Julius Wiesner, both professors in the University of Vienna, examined and classified the Rainer collection and confirmed that paper was never produced from raw cotton and linen rag fibres were predominant in old Arabic and European papers (Aitken, 1914, p208). Karabacek (1991, p34) reported that linen rags were the main material in Arab papers - the second most predominant papermaking material being hemp.

Regarding papermaking moulds being used by the Arabs, Karabacek (1991, p43) noticed three different types of impressions in the old Arab papers: the first had the impressions of laid and chain lines - the second had similar impressions but with no visible impressions of chain lines. The last exhibited impressions of very fine wire mesh similar to those produced by European wove moulds. These first two laid screens must have been made with splints of bamboo or plant stems as the presence of chain line impressions could depend on the materials used for lacing the splints. In the case of a laid screen laced with silk thread, the impressions of chain lines produced could be less noticeable than in that made with horsehair due to the difference in thickness between the two materials.

It is interesting that Karabacek found Arab papers carrying the impressions of wire mesh – an occurrence which suggests that the Arab papermakers used a wove mould. However, it has been believed that the 'wove' mould covering had originated in Europe with John Baskerville circa 1750 (Hunter, 1930, p215). According to Voorn (1959, p36), Karabacek's suggestion of the existence of Arabian wove moulds has been denied by other scientists and therefore, it seems this topic still remains open to debate.

Another interesting fact is that, according to Voorn (1959, p36), Arabian laid moulds were made of fine reed and had no deckles. As traditional Korean laid moulds (see Chapter 3) do not have a deckle, it is possible that a laid mould without a deckle once might have been commonly used in ancient China, long before the papermaking skills were transferred to Korea and Islamic countries.

2.4. The development of papermaking in Europe

Spain was probably the first European country in which papermaking was practiced. The earliest evidence of papermaking in Spain is presented in one of the documents in the Municipal Archives of Xativa (the ancient Saetabis and now called San Filipe), which referred to a paper mill carrying the name of its owner in the year 1036 (Subira, 1970, pp30-35). The city - set about 35 miles from Valencia - had abundant water and (ideal material for papermaking) linen. Despite there being only three or four paper mills in Xativa, the paper produced was praised for its superior quality. During the twelfth and thirteenth centuries, a paper industry subsequently evolved in Catalonia with Gerona and Manresa being the most prolific towns in the region's production (Clapperton, 1934, p72).

Around 1276, papermaking started to thrive at Fabriano near Ancona in Italy - the craft of papermaking subsequently spread to Switzerland and France where the first mill was set up near Montpelier (Aitken, 1914, p209). It was around 1495 that the first paper mill was established in England (Hunter, 1947, p216).

As papermaking skills were transferred to Europe many centuries after the laid mould was invented and established in China and Islamic countries, naturally, the first type of mould employed by European papermakers was a laid mould - the use of the wove mould in Europe came much later: according to Hunter (1947, p127), the first book printed on European wove paper – paper made upon a wove mould – was published in 1757. Unlike the wove screen used in China, the European wove screen was made of fine brass wire, interlaced on a loom like cloth - as a result, paper made on such wove screens carried impressions analogous to those formed by textile screens (Hunter, 1947, p127).

In general, a European papermaking mould consists of four main parts: a rectangular supporting frame, supporting ribs (Figure 6) and a screen which is either laid or wove (Figure 5). In order to form the sheet, a second rectangular wooden frame – the deckle (Figure 7) – is situated on top of mould to form raised boundaries for containing pulp stock (Figure 8).

Figure 5. An example of the European Wove mould.

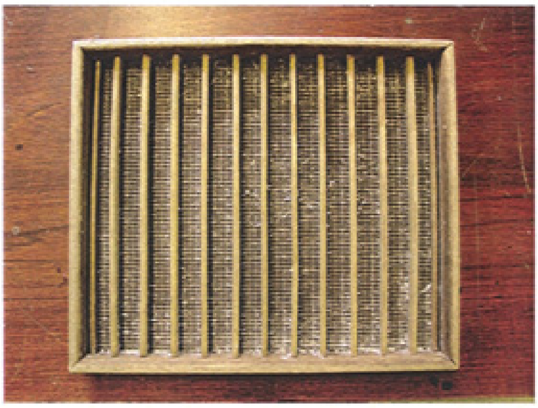

Figure 6. The back of the wove mould exhibiting supporting ribs crossing its length.

Figure 7. Deckle for the wove mould.

Figure 8. The deckle positioned on the wove mould.

As discussed in the section 2.2, in China, the structure of the mould largely depended on the type of screen used: a wove screen was always fastened to a rectangular bamboo frame and had no supporting ribs. In the case of the flexible laid screen, it was made as an independent article and was therefore detached for couching. By contrast, the European papermaking screen is permanently fastened to its wooden supporting frame, whether wove or laid (Hunter, 1947, p114). Therefore, the only difference between the European laid and wove mould is the screen - their structures being the same.

It is not clear whether a flexible laid screen has ever been produced in Europe. How European moulds developed so differently from those employed by the Chinese is one of the unanswered questions in papermaking history.

Hunter (1947, p114) tried to find the explanation by suggesting that European papermakers substituted the laid mould with a fixed screen for the Oriental laid mould with a flexible laid screen as fixing a laid screen to its supporting frame was more suited to sheet formation using rag fibres. Nonetheless, it is not clear whether his suggestion was based on any practical experiments. He also assumed that when papermaking technology was introduced to Spain (around 1150), the

European papermaker probably used bamboo screens as in China, though metal wires soon replaced bamboo as it was not readily available. Furthermore, it is presumed that later, iron wire was again substituted by brass (Hunter, 1930, p198).

For European papermaking mould, supporting ribs were intrinsic part for both the wove and laid screen as the wooden frame and supporting ribs were usually assembled before a mould cover (screen) was added (Hunter, 1947, p135) (Figure 9).

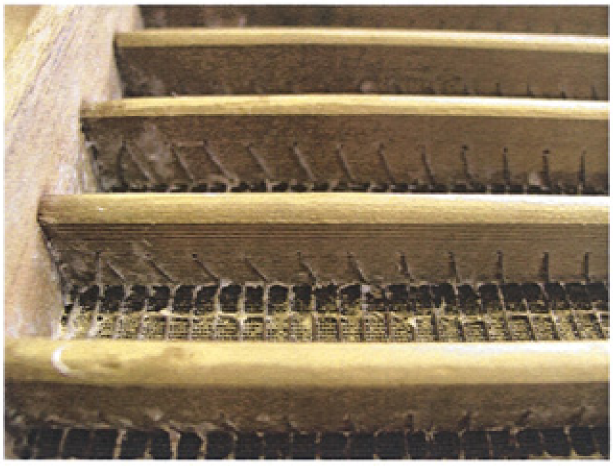

Figure 9. Close-up of the supporting ribs in Figure 6. The picture shows the detailed construction of the wove mould.

Generally European moulds tend to have more supporting ribs than the East Asian counterparts. This difference could be attributed to the different physical characteristics of bamboo splints and wire, which have been the main materials for Asian mould covers and European mould covers respectively. Bamboo splints are flexible and resilient. As a result, bamboo splints are durable to the repetitive hydraulic pressure of pulp stock during the sheet forming process without being distorted easily. Conversely, wire can be easily bent by any physical pressure and lacks 'memory' to restore to its initial form once distorted. Wires can be readily affected by the hydraulic pressure of pulp stock and it is this property of the material which appears to justify the extra physical support provided by additional supporting ribs.

Nevertheless, it does seem that European moulds did not have so many supporting ribs from the beginning of the papermaking industry in Europe. According to Loveday (2001, p38) the early Spanish mould did not have enough supporting ribs to withstand the weight and hydraulic pressure of the water and pulp stock draining through its wire screen – consequently the wire sagged, causing distorted mould marks at the centre of the sheet.

Particularly in Europe, the deckle is an essential component of the papermaking mould – its role being to retain the pulp stock while the water drains through the screen. It usually determines the size of sheet produced (Hunter, 1940, p1166) which conforms to the inner dimensions of the deckle.

In the sheet forming process, European papermakers use two moulds and one deckle: the papermaker places a deckle on the mould and, with the complete assembly, scoops the vat stock from the near side, lifting it horizontally from the vat. While the water drains through the screen, the papermaker shakes the mould in order to encourage the fibres to become extensively matted. With only the drained, matted fibres left on the screen, the papermaker removes the deckle and hands the mould to a coucher. The papermaker continues to the next sheet with a second mould and the same deckle (Hunter, 1947, pp177-178). Each sheet requires only one scooping – a method quite different from the sheet forming process in Korea and Japan which involves several scoops of vat stock.

3. Traditional Papermaking in Korea

3.1. The transfer of papermaking from China to Korea

There is no written information concerning when and how papermaking skills were transferred to Korea from China; yet due to their geographical proximity (Figure 10), it must have followed shortly after Ts'ai Lun improved papermaking techniques. Still, several hypotheses have been proposed by paper historians.

Figure 10. Map of the Three Kingdoms of Korea, at the end of the 5th century[2]

The theory that papermaking skills were transferred to Korea around the 2nd century AD is derived from a linguistic approach: the main material for traditional Korean papermaking has been paper mulberry (*Broussonetia kazinoki Sieb*). Its Chinese character is '楮' and its pronunciation in Korean is 'jeo' meaning 'dak' or 'daknamu' (both meaning 'paper mulberry tree'). However, in Korea, paper mulberry has commonly been named and pronounced 'dak' for a considerable time. According to Jung (1998, p231), in ancient China, the character '楮' was pronounced 'tag' or 'taig' between the 2nd BC and the 2nd AD. Because of the similar pronunciation between 'dak' and 'tag' or 'taig', paper mulberry must have been known to Koreans while it was still referred to

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[2] From Wikimedia Commons. http://upload.wikimedia.org/wikipedia/commons/thumb/7/77/Three_Kingdoms_of_Korea_Map.png/477px-Three_Kingdoms_of_Korea_Map.png, accessed 15th April, 2008.

as 'tag' or taig' in China. Based on this, Jung (1998, p232) suggested that the papermaking method using paper mulberry might have been transferred to Korea along with the name of the material around the 2nd century AD.

The origin of papermaking in Korea might be closely related to the introduction of Buddhism in the Korean peninsula. Until the 7th century, the Korean peninsula was subdivided into three kingdoms: Goguryeo (高句麗), Baekje (百濟), and Silla (新羅). Buddhism was first introduced in Goguryeo. According to Samguksagi (三國史記) volume 18, in 372 the king of Former Qin, Fujian (符堅) sent a monk, Sundo (順道), who brought Buddhist sutras and Buddhist images to Goguryeo. In return, the King Sosurim (小獸林) sent an envoy with presents (as reported in Jung, 1998, p247). Later Buddhism was also introduced into Baekje (百濟) in 382, and into Silla (新羅) between the 5th and 6th centuries (Jung, 1998, p248). The introduction of Buddhism must have resulted in an influx of Buddhist texts and sutras in these kingdoms, encouraging the development of papermaking and printing techniques (Jung, 1998, p249). According to 'The Story of Papermaking History' (造紙史話, Yu & Rim, 1983), Marananta (摩羅難陀), a monk from Eastern Qin(晉), brought many books to Baekje (百濟) and presented them to king Chimru (枕流) also introducing papermaking techniques in 384. From this point, papermaking skills spread in the Korean peninsula (as reported in Cho et al, 1996, p25). Therefore, based on the dates of the introduction of Buddhism into the Three Kingdoms, papermaking techniques must have been known to Koreans by at least the 4th century.

Another theory is that papermaking skills were transferred to Korea sometime during the third century: Bak (1981, p107) reported that Wangin (王仁), a scholar from Baekje (百濟) delivered ten volumes of Noneo (論語) and one Cheonjamun (千字文) to Japan in 285 AD. This event is dated around 180 years later than Ts'ai Lun's (蔡倫) development in papermaking techniques and therefore, supposing those books were made with paper, Bak suggested that papermaking skills would have been transferred to Korea in the year 285 AD.

Also suggestive of the early history of papermaking in Korea was a piece of paper retrieved from 'Chaehyeopchong', an old tomb from the Nakrang period (108BC – 313AD) which was excavated by 'Joseongojeokyeonguheo' (朝鮮古蹟硏究會) in 1931. The only reference to the find describes it as 'a lump of material which looked as if it was paper made with paper mulberry which had been dampened and became a lump' (Lee & Gu, 1999, p19). Based on this example of ancient paper, Lee & Gu suggested that papermaking skills were delivered to Korea during the Nakrang period. However, Cho (Cho, et al, 1996, p23) argued that there was no evidence to make the assumption that the paper was made in Korea as it might have been brought in from China.

According to Pan (1978, p231) Chinese paper must have been known to Vietnam and Korea as early as the later Han period (25 – 220 AD) because these two countries were geographically connected to China and there were frequent cultural and economical interchanges among them. He presumed that by the Six Dynasties (220 – 588) the influx of Chinese books into Korea (Bekje, Sinla, and Goguryeo) must have occurred, and based on this, Pan suggested that papermaking must have started in Korea between the 4th and 5th century.

Based on these hypotheses, papermaking might have been initiated in Korea at any time between the 2nd and the 5th century but further research is needed in order to provide more accurate dating.

3.2. The development of papermaking in Korea

3.2.1. Three Kingdoms and Tongilsinla (1st century BE – 935 AD)

As reviewed in the previous section, it is generally agreed that during the Three Kingdoms period, papermaking must have been transferred to the Korean peninsula from China. It is not difficult to imagine that, at its beginnings, techniques in the papermaking industry must have been more or less the same as those practiced in China. Jeong (1997, pp241-242) speculated that papermaking materials must have been prepared by grinding with 'yeonyae' (碾磑, a stone hand mill) as in ancient China. In fact, 'yeonyae' (碾磑) was one of four items which were delivered to Japan by Damjing (曇徵), a monk from Goguryeo(高句麗) - the event was recorded in Ilbonseogi (日本書記, History of ancient Japan):

> "... in 610 AD, Damjing (曇徵), a monk from Goguryeo(高句麗) came to Japan as an envoy, he knew not only ogyeong (五經) but also how to make colouring, paper, ink sticks and a stone hand mill (碾磑). Therefore, stone hand mills started to be made in Japan from this time. ..." (as reported in Jeong, 1998, p240)

Jeong (1998, p242) thought that 'yeonyae' (碾磑) might be related to the other three items which were stationery and therefore, 'yeonyae' could be an implement for papermaking. As a stone hand mill was used in China for papermaking during the Su (隋) and Tang (唐) periods, it might be possible that it was also used in ancient Korea with subsequent delivery of the same technique to Japan. Based on this hypothesis, Jeong suggested that, around the 7th century, the papermaking process in Korea, China, and Japan must have been the same and that paper was made by a stone hand mill which was used for grinding raw materials to produce macerated fibres, separated from the lignin binding them together.

There is little written information which could provide insights into the early period of papermaking in ancient Korea. Therefore, the study of papermaking before the beginning of the 10^{th} century largely depends on the examination of papers from this period. Unfortunately, to date, only five paper objects have been discovered from this period in Korea: one from the Three Kingdoms period (1 BC – 668 AD) and four from the Tongilsinla period (668 – 935 AD).

The oldest extant paper found in Korea is Beophwagyeong (法華經), a Buddhist sutra which is believed to have been made in Goguryeo(高句麗) before 668 AD. It has been kept in North Korea and little information is known about it. The work was once displayed in an exhibition of 'Goguryeo' in Japan and, based on the exhibition catalogue, Jeong (1997, pp75-76) reported that its paper was white and compact with even thickness and its surface seemed to be well pounded in order to render it suitable for writing. The material used for the paper was identified as 'ma' (麻, hemp). No other paper has been found from the Three Kingdoms period, but the sutra certainly reflects that papermaking techniques in the Korean peninsula must have been well developed by the end of 7th century.

There are four old papers from the Tongilsinla period: Mugujeonggwangdaedaranigyeong (無垢淨光大陀羅尼經), Sinrabaekjimukseohwaeomjyeong (新羅 白紙墨書 大方廣佛華嚴經), Baekjimukseotarani (白紙墨書 陀羅尼), and Mugujeonggwang nejae tarani (無垢淨光 內在 陀羅尼). They will be referred to as objects 1, 2, 3, and 4 respectively. Park (1999, pp145-159) reported information connected with these objects and their characteristics as summarised in Table 2.

The density of paper provides a clue to judge whether the paper went through 'dochim' (搗砧), the traditional finishing process whereby the surface of the paper is made smooth by pounding whilst still slightly damp. In the case of sheets made with the bark of paper mulberry (particularly those made from material fibrillated solely by pounding), this finishing process was essential to render the final product suitable for writing. Park (1992, p156) examined the density of a paper made in a traditional way with paper mulberry before and after the dochim process: after the finishing process, its density increased from 0.36 (g/cm^3) to 0.76 (g/cm^3). Based on this, objects 1 and 2 were most likely to have been finished by the 'dochim' process to some degree. Thus, it would seem likely this traditional pounding process must have been in use by the 8th century in

Korea.

Table 2. Old Korean papers dated before the 9th century

	Object 1	Object 2	Object 3	Object 4
Date	704 – 751 AD	754 – 755 AD	The 8th century	The 8th century
Size (H x W mm)	67 x 546	269 x 473	245 x 480	?
The number of laid lines in 3 cm	16	20	18-20	?
Thickness (mm)	0.08	0.05	0.058* (0.019, 0.058, 0.077, 0.059)	?
Density (g/cm^3)	0.815	0.64	0.48* (0.48, 0.6, 0.29)	?
Material used	Paper mulberry	Paper mulberry	Paper mulberry	Paper mulberry and hemp
Comments	Found in 1966. It is the earliest known extant printed Buddhist text. 12 sheets were joined but the 12th sheet's width was 422mm.	Date of find not known. Consisting of 43 sheets.	Found in 1995. The object consists of several sheets (from a very fine, high quality paper to a rough, low quality one) - the size given above is the largest among them. '*' is the average taken in each measurement.	Found in 1996. The object appeared to be stuck to the three sides of inside a box and hardened due to deterioration.

Regarding the materials used, paper mulberry must have emerged as the main papermaking material at sometime between the 7th and the 8th century and it is likely that Korean papermakers started to develop their own papermaking techniques with paper mulberry during this period. This becomes clearer when these papers are compared with the material used in ancient China: Pan (1978, pp268-271) presented information on 23 papers made between 304 and 960 AD from Donhwang (敦煌), 18 of them were made with 'ma' (麻, hemp). In addition, a study of 31 papers made between 265 AD and 907 AD from Singang (新疆) showed that 25 of them were also made with 'ma' and the rest were made with the inner bark of mulberry or paper mulberry (Pan, 1978, pp283-286). Hence, while hemp had been the main material for papermaking in China until the beginning of the 10^{th} century, paper mulberry started to be predominantly used as a papermaking material in Korea from the 8^{th} century onwards. As mentioned before, Jeong (1998, p242) stated that, until the beginning of the 7^{th} century, papermaking skills in ancient Korea must have reflected those in China but around the middle of the 8^{th} century, Korea most likely had developed its own papermaking skills. Jeong also reported that the fibres of object 1 were rather short indicating that the bark of paper mulberry was finely cut and pounded during the papermaking process. By contrast, the fibres of object 2 and later dated paper objects mostly appeared to be uncut and long, which implies that the fibrillation of paper mulberry was achieved by pounding (and possibly with some cooking, see p35) but without cutting.

The only paper name known from the Tongilsinla period is Baekchuji (白硾紙) - its name suggests that the paper was white, '白' and went through the finishing process, dochim, '硾' (Cho et al, 1996, p37). This indicates that papermaking skills were good enough to produce white sheets and that the 'dochim' process was also well refined.

For a long time, traditional Korean paper had a reputation for being white and strong with a smooth surface due to its long fibres and traditional finishing process, 'dochim' (搗砧). From the middle of the 8^{th} century the inner bark of paper mulberry became the main material and fibrillation of it was achieved by pounding without grinding or cutting in order to make strong and durable paper. Additionally, the traditional finishing process, 'dochim' (搗砧) was practised by the 8^{th} century. Although there is no written evidence for the use of plant extracts as formation aids, without the addition of a formation aid, it would have been impossible to produce a sheet of even thickness with paper mulberry. It is therefore most probable that, when paper mulberry became the predominant papermaking material in 8^{th} century Korea, the use of plant extracts might have commenced.

Regarding papermaking tools, the structure of papermaking moulds in Korea must have been more or less the same as in China, since it is believed that, before the middle of the 8^{th} century, Korean papermaking techniques were the same as Chinese. From Table 2 above, not much information is available regarding papermaking moulds during this period except that laid screens, which could produce the impressions of 5.3 to 6.6 laid lines per centimetre, were employed. Information on the number of laid lines can be used, to some extent, to infer what type of screen was used for the formation of the paper. Bamboo and stems of reeds or other plants have been the main materials used for papermaking screens for a considerable time in Korea, China and Japan. Using stems of plants, such as reed, must have saved considerable time for screen makers as plant stems - naturally smooth and round in section - were ready for use. By contrast, preparation of bamboo splints necessitated several steps before attaining a degree of suitability for the papermaking screen.

Based on an examination of old Chinese papers, Pan (1978, p97, p216) stated that a number of laid lines in the region of 5 – 7 per centimetre indicates that the screen was made with some kind of reed such as *Achnatherum splendens Ohwi* – a plant which mainly grows in northwest China where bamboo does not grow easily. A count of laid lines between 9 and 15 (per centimetre) indicates that the papermaking screen was made with bamboo. Meanwhile, after carrying out an extensive survey on Islamic paper, Loveday (2001, p61) reported that sheets made on a reed screen typically contained 5 to 7 laid lines and sheets made on a grass mould had 7 to 8 laid lines. She also stated that sheets made towards the end of the 18th century in Persia had up to 16 laid lines, indicating the use of wire mould. According to Loveday (2001, p38) *Andropogen micranthus* was often used for the production of papermaking screens in India as it grows abundantly in India, Samarqand and further west into the Islamic world - reeds and dried grasses were used for the laid cover. Raitt (1930, p151) suggested that the Persians must have used the stems of *Andropogen micranthus* for the flexible part of the mould. Therefore, it is clear that while bamboo has been a common material for construction of the papermaking screen, each country also employed their own indigenous plants which have thin and long stems suitable for papermaking screens.

In Korea, stems of eulalia (*Miscanthus sinensis Anderss*) have been a suitable substitute for the purpose (Hunter, 1947, p94). Eulalia (*Miscanthus sinensis Anderss.*) is a native plant in Korea and commonly grows in fields and mountains. In order to understand the characteristics of a screen made with stems of eulalia, a miniature papermaking screen was made with them. The screen was specifically ordered from a traditional screen maker who was asked to use only the finest stems for the screen. In observing the screen it could be said that the stems of eulalia could produce a screen with up to 6 laid lines per centimetre and therefore, if a screen produces more than 7 laid lines per centimetre, it has probably been made using bamboo. However, this does not necessarily mean that screens producing less than 7 laid lines were made with eulalia as screen makers could produce bamboo splints of differing thickness - it is possible to produce bamboo splints of the same thickness as stems of eulalia.

As old Korean papers made before the 9th century appeared to have 5.3 to 6.6 laid lines per centimetre, it might be said that these laid screens made with either bamboo or stems of eulalia were used at that time. However further investigation is needed to discover whether there are different species of eulalia (*Miscanthus sinensis Anderss.*) which may produce thinner stems whilst being strong enough for use in papermaking screens.

3.2.2. Goryeo dynasty (918 – 1392)

Hence the papermaking industry was well established by the 8th century in the Korean peninsula, and it was during the Goryeo dynasty that papermaking was further developed and its production output increased. Buddhism, which was introduced into the Korean peninsula around the 4th century, became the main religion of Goryeo and the Goryeo government accepted many copied Buddhist canonical texts from Sung (宋) and Georan (契丹) - soon after, these Buddhist texts were carved in woodblocks for printing (Park, 2002, p73). It was the golden age of publishing printed texts, especially during the 11th and 12th centuries: woodblock printing was initially used for publishing Buddhist texts but was later employed for publishing material on other subjects (Park, 2002, p72). Several projects publishing the complete collection of Buddhist Sutras were organized by the Goryeo government: the 8th king, Hyeonjong (顯宗, 1010 – 1031) commanded that woodblocks be made of Buddhist canonical texts and during his reign the number of carved Buddhist Sutras reached five thousand – a collection referred to as chojodaejanggyeong (初雕大藏經). Later, approximately one thousand volumes of Buddhist Sutras were brought from Georan (契丹) in 1063 and the 11th king, Munjong (文宗, 1046 – 1083) commanded them to be published along with the Buddhist Sutras which had already been collected. In 1232 chojodaejanggyeong (初雕大藏經) was burnt and destroyed when the Mongol empire invaded Goryeo. Due to the Mongol invasions, the Goryeo government was facing a national crisis and, in order to overcome the difficulties of the time, the Goryeo government decided to publish the complete collection of Buddhist Sutras, hoping faith in Buddha would save their country. Consequently, the whole collection of the Tripitaka was carved onto 81,155 woodblocks and the carving took 16 years – a body of work known as the 'Palman Daejanggyeong' (Eighty-Thousand Tripitaka, 八萬大藏經) (Park, 2002, pp67-79).

It was also this period which saw the beginning in use of movable type with metal characters in Goryeo. The first record of movable type with metal appeared to be in the preface of Sangjeongyemun (詳定禮文) written by Choeyuneui (崔允儀) – a book believed to have been published between 1234 and 1241. Therefore, movable metal type was already in use during the

13th century in Goryeo. The earliest text printed with movable type metal characters is Jikjisimcheyojeol (直指心體要節) printed in 1377, now housed in the French National Library in Paris (Kim, 2001, p122).

These highly advanced printing techniques in Goryeo naturally led to flourishing publication industry and, consequently, it must have spurred the further development of papermaking. Unfortunately, as very little has been written about papermaking techniques, tools and materials used during this period, research on the subject is rather scarce. Furthermore, any examination of records of old papers from the period is also limited. Only brief descriptions related to papermaking in Goryeo can be found in Goryeosa[3] (高麗史, History of Goryeo) and Goryeodojyeong (高麗圖經, 1123).

According to Goryeosa (高麗史, History of Goryeo) the Goryeo government started to exhort farmers to cultivate paper mulberry trees (the main material used for paper since the Tongilsinla period) all over the country from 1145(as reported in Cho et al, 1996, p38). As paper mulberry grew easily, the Goryeo government encouraged farmers to plant paper mulberry in the areas such as banks of fields and steep slopes where other crops could not be cultivated (as reported in Lee, 1998, p235). While the Goryeo government encouraged people to make paper, the government also introduced 'jiso' (紙所) – papermaking factories set up in the provinces where environmental and geographical conditions were suitable for papermaking. Jiso supplied papers as local tribute to the government for official use (Lee & Gu, 1999, p26). It is also during this period that paper made in Goryeo started to be exported to China. However, due to the intolerable, heavy tribute duty demanded by the Mongols, the downfall of the Goryeo kingdom came about and consequently the prosperity of papermaking started to decline with the wane of the Goryeo kingdom.

[3] The history of Goryeo which was compiled during the Joseon period.

A book, Goryeodojyeong (高麗圖經, 1123) written by Seojyeong (徐兢), an envoy from Sung (宋) dynasty, provides some insight into papermaking tools and materials used in Goryeo. According to this text, lime was used for cooking the bark of paper mulberry – and for cleaning the cooked bark 'jahoejang' (紫灰奬) was used. A small pond for sun bleaching (漂塘), as well as a cooking pot (煮釜), and a screen (抄簾) were additionally mentioned as features and implements in the papermaking process (as reported in Cho at al, 1996, pp38-39). It is hard to know what 'jahoejang' (紫灰奬) was as Cho gives no further explanation - the word appears in no other literature related to papermaking in Korea. The Chinese characters used to denote the substance mean 'recommended purple coloured ash' and therefore, it might in fact be some form of plant ash obtained by burning stems of plants - the method currently used in traditional papermaking.

The same text was also cited in Jeon's work (1996, p38) though with a slight difference: Jeon reported that for cooking the bark of paper mulberry, the juice of wood ash (木灰汁) and 'jahoejang' (紫灰奬) were used – papermaking implements noted were the cooking pot (煮釜), a small pond for sun bleaching (漂塘) and a screen (抄簾). Jeon also did not give any additional explanation of 'jahoejang' (紫灰奬). Furthermore, neither scholar gave detailed information about the location of the text within Goryeodojyeong. One of the translated Korean versions of Goryeodojyeong was examined in order to check how 'jahoejang' (紫灰奬) was translated though the book appeared not to include the same information.

According to Pan (1978, p19), using lime and the alkaline solution obtained from wood and plant ash was commonly used for cooking raw materials from the Han dynasty (206BC – 220AD) in China and it is therefore possible that the same method might have been used in papermaking in Goryeo. Therefore, 'jahoejang' (紫灰奬) could be lime or an alkali solution obtained from wood ash. Although this type of alkali treatment must have been practiced prior to documentation in this 12th century book, this is the earliest written account showing that a chemical treatment was used to cook raw materials for papermaking in the Korean peninsula and it reflects the technical development of papermaking in Goryeo. Chemical treatment with alkali is still one method used, even in Europe, for purging lignin and hemicelluloses from raw materials in preparation of fibres for papermaking.

Goryeodojyeong (高麗圖經) additionally gives descriptions of a paper folding fan and another papermaking material (other than 'daknamu', *Broussonetia kazinoki Sieb*) - they are as follows:

> "For a white folding fan (白摺扇), the ribs of the fan were made with bamboo and they were covered with a sheet of paper made with 'deungnamu' (*Wisteria floribunda*) and sometimes it was decorated with nails of silver or brass. A fan having more ribs was regarded as a better one. People, who were doing errands or busy working, carried it either inside their jackets or sleeves, so that it was handy for use (volume 29, 供張, 白摺扇)."

> "For making paper, 'daknamu' was not solely used but 'deungnamu' is often mixed with it and the surfaces of sheets are smooth due to the finishing process and there are several grades given to sheets depending on their quality (volume 23, 雜用, 土産)."

These descriptions showed that 'daknamu' (*Broussonetia kazinoki Sieb*) was the main material and 'deungnamu (*Wisteria floribunda*)' was often used as a supplementary material used in papermaking at the time, implying that papermaking skills were further developed and papermakers became capable of adapting new materials for their products. Although the use of 'deungnamu (*Wisteria floribunda*)' seems to have started during the Goryeo period in the Korean perninsula, deungnamu was used as a papermaking material in China much earlier. According to Pan (1978, p107), paper made with deungnamu (*Wisteria floribunda*) became popular in China during Sui (隨, 581 – 618), Tang (唐, 618 – 907), and Five Dynasties (五代十國, 581 – 960).

However, it became less popular and disappeared after the Tang period because it grew more slowly than other paper making materials and therefore, there was a limit to the amount of deungnamu papermakers could obtain.

The first citation above indicates that such paper folding fans were in widespread use by people in Goryeo. Folding paper fans made in Goryeo must have been known within China and are likely to have become popular there. According to Pan, (1978, pp232-233) paper folding fans made with Goryeoji (高麗紙 - paper made in Goryeo) were favoured by the Chinese from the Sung dynasty. In addition, there was a folding fan shop and paper folding fans made like those in Goryeo were more convenient than fans made with white silk or feathers which were produced in China at that time. The second citation showed that the finishing process must have become an essential part of papermaking in Goryeo. No record describing the finishing process, 'dochim' (擣砧) from the Goryeo period has yet been found but it could be seen in Gobanyeosa (考槃餘事), written by Doyeung (屠隆), a scholar of the Ming (明) dynasty. It included the finishing process, Chubaekji (槌白紙) which was regarded as the same technique as 'dochim'. The following is a description of the dochim process as it appeared in Gobanyeosa (考槃餘事).

> "... Prepare the roots of Hwanggyuhwa (黃葵花, the flower of Hwangchokgyu) and extract the juice of it by treading them. Prepare a big bowl of water and add one or two spoons of the juice to it and mix them well. Using this liquid do not let sheets stick together and their surface become smoother. If too much juice is added to water it is not good as sheets will stick together. The actual method is to pile ten dried sheets and generously apply the liquid on the top sheet and then pile another ten dried sheets. Sheets can be piled up to one hundred. If sheets are rather thick then the liquid is applied every seventh or eighth sheet and if sheets are thin then the liquid can be applied less frequently. Press the whole pile with a thick stone board and leave it overnight. Later when the pile is opened sheets will appear to be evenly damp. If they are too damp then dry them in shade, otherwise, put them on a flat stone board and beat the pile with a wooden club about a thousand times and then separate them and leave them in shade to dry. Later pile them together and press them with a stone board and leave the pile

overnight. Following day repeat the beating process. After the whole process the surface of sheets should be shiny like Nabji (蠟紙)...... (Translated into Korean by Choe Hyeju, 1986, p108)"

Although the finishing process described above must be largely similar to the one executed during Goryeo period, it is likely that the juice from the roots of Hwanggyuhwa (黃葵花, the flower of *Hibiscus manihot, L*) was not used during the Goryeo period. It has been speculated that use of hwangchokgyu started in papermaking in the Korean peninsula around the 19th century (See the history of formation aids). Yet, before pounding the pile of sheets, it was crucial to make each sheet slightly damp otherwise the papermakers could not obtain the right surface texture in the sheets. Therefore, other plant extracts or water alone must have been employed instead of the juice from the roots of hwanghyuhwa.

Apart from the finishing process, 'dochim' (搗砧), no written information about any surface processing used by the papermakers in Goryeo has been found. However, in 1997 several pieces of paper were excavated from tombs of the Goryeo dynasty in Hyeon-gokri, Danyang, Korea: according to An & Park (1999, pp92-94) the paper surfaces were very smooth – all of them appeared to be coated with some sort of wax –there were small, regularly arranged holes. Their report did not give further information about these paper objects as the function of these waxed papers was not identified. However, the discovery of these waxed paper objects is significant as it certainly showed that coating paper with wax was practised during the Goryeo dynasty. It seems as if coating the surface of the sheet of paper with Beeswax (蜜蠟) was also practiced in China. According to Pan (1978, pp126-127), among the documents found from Donhwang (敦煌), there were sheets coated with beeswax and they were presumably made sometime between the 7th and 8th centuries. As the same type of coating technique was carried out in China much earlier than in Goryeo, it is possible that this specific coating technique was also delivered from China to Goryeo. In any case, it showed that the same coating technique was used in both countries.

As insufficient written information on papers produced during Goryeo dynasty exists inside Korea, any comments made on Goryeo's paper by foreign scholars have provided invaluable information which could reflect the characteristics of ancient Korean paper at that time.

Paper from Goryeo was commonly termed 'Goryeoji (高麗紙) and must have been well known to China as during the Sung dynasty, Chinese scholars liked to gift Goryeoji to each other. It was also during this period that paper from Goryeo started to be exported to China (Pan, 1978, p232). Pan also stated that the Yuan (元) dynasty sent an envoy to Goryeo several times in order to obtain papers for Buddhist Sutras. Chinese people often used Goryeoji as a supporting board for books because it was firm and strong. Jinyu (陳槱), a scholar from Northern Sung (960 – 1126) described Groyeoji in Buhwonyarok (負暄野錄) thus:

> "...paper made in Goryeo was clean, compact, and strong like Naenggeum (冷金), a letter paper which was sprinkled with gold powder, from Chok (蜀) (as reported in Lee & Gu, 1999, p27)".

Though Chinese people favoured Goryeoji because of its strong but fine quality, it seems as if the actual materials used for papermaking in Goryeo might not have been well known to the Chinese. Gobanyeosa (考槃餘事), written by Doyeung (屠隆), includes information on Goryeoji:

> "Goryeoji is made with silkworm cocoon (繭綿) and its colour is white like silk. Its strength and firmness is like silk. When one writes on it, the colour of the ink appears to be more beautiful. As this type of paper cannot be obtained from China Goryeoji is very valuable" (translated into Korean by Choe Hyeju, 1986, p106)"

The author's statement that the material used for Goryeoji was silkworm cocoon must have been a guess based merely on its colour and characteristics. In fact, there is no record which indicates silkworm cocoon was ever used for papermaking in East Asia and in any case, it is unlikely to be employed as a papermaking material. According to traditional Korean papermaker, Jang Sung-u, it is impossible to produce a sheet of good strength and firmness with silkworm cocoon: in order to prove the point, he carried out an experiment to form a sheet of paper with silkworm cocoon - the result of the experiment proving that the material was not a suitable material for papermaking. However, this statement certainly reflects how highly valued Goryeoji was by Chinese scholars and how good the quality of it was.

Among the names given to papers of the Goryeo period are 'Sanghwaji' (霜華紙), 'Seonjaji' (扇子紙), 'Jamunpyuji' (咨文表紙), 'Baekmyeonji' (白綿紙), 'Deungpiji' (藤皮紙). In addition 'Seokchuji' (石硾紙), 'Gyeonji' (繭紙), 'Acheongji' (鵝青紙) were made in both the Goryeo and the Joseon periods (Cho et al, 1996, p39). Lee (2002, p53) also noted certain other papers from the Goryeo period, such as 'Gojeongji' (稿精紙), 'Hwangmaji' (黃痲紙), 'Chojuji' (草注紙), and 'Jukcheongji' (竹青紙). Although some of these names are suggestive of the material used in production of the paper, it seems this convention was not always applied. For example, the name 'Deungpiji' (藤皮紙) referred to the source of 'deungnamu' (*Wisteria floribunda*) - the name of 'Gojeongji' (稿精紙) implied the paper was made with rice straw. Similaraly, 'Jamunpyuji' (咨文表紙) – derived from 'Jamun' (咨文 - meaning 'official document used for foreign relation'), was used in the production of official documents. However, in the case of 'Gyeonji', (繭紙) although its name suggested that it was made with silk cocoon, it is more likely the name was given due to its characteristics of strength and whiteness. Therefore, it can be said that names were given either by their chief characteristics, the materials used or their usages. Most of these paper varieties seem to have the common characteristics of being compact and strong.

According to Cho (1996, p38) these characteristics of Goryeoji could be seen in some documents kept in the Songgwang temple (松廣寺) in Korea. However, he did not report these characteristics in detail.

Regarding information related to papermaking moulds during this period, a Japanese scholar, Seki Yoshikuni (關義城) reported that, in the case of paper formed on bamboo screens, the number of laid lines in one centimetre was approximately ten - the intervals between chain lines being in the region of three centimetres. By contrast, in sheets produced on screens made with stems of plants, the number of laid lines in one centimetre was generally four and the intervals of chain lines 3.3 centimetres. Apart from these more typical figures, Yoshikuni also reported that, overall, the number of laid lines in other examples greatly varied, with counts of 4, 5.6, 6.6, 8 and 9 (per centimetre) and chain lines intervals of 3.6, 19.7, 22.7, and 24 centimetres recorded (as reported in Cho et al, 1996, p39).

This report showed that the papermaking screen became more refined than those in the previous period (See Table 2): until the Tongilsinra period, the number of laid lines per centimetre was between 5.3 and 6.6 but during the Goryeo period, the number of laid lines per centimetre appeared between 4 and 10. It is worth noting that the intervals of chain lines are unusually large and it seems as if the Chinese recognized this as one of the characteristics of Korean paper in earlier times: according to Pan (1978, p233) some Korean papers were called 'hwalyeomji' (a paper made with a screen which has wide but evenly arranged intervals of lacing threads) due to its wide, evenly arranged chain lines.

To summarise, papermaking was further developed during the Goryeo dynasty and the characteristics of the paper were whiteness, smoothness, strength (due to the finishing process, 'dochim' (搗砧) and the main papermaking material, paper mulberry - characterised by its long fibres. From this period, other supplementary materials started to be employed such as 'deungnamu (*Wisteria floribunda*)', bamboo, and rice straw. Furthermore, papermaking screens were made not only with bamboo but also stems of other plants. Such screens produced a sheet with chain lines at wide, even intervals.

3.2.3. Joseon dynasty (1392 – 1909)

At the beginning of the Joseon period, the demand for paper greatly increased due to the reformation of the governmental system. Furthermore, based on the accomplished printing techniques from the Goryeo dynasty, publications thrived during this period. In 1415 the Joseon government established 'Jojiseo' (造紙署), a papermaking department intended to control the manufacture of paper. Originally Jojiseo was installed to produce paper money - the quality of paper money produced in different provinces varied and thus, Jojiseo served to improve the quality and consistency of it (Kim, 2002, p59). Later the organisation took charge of producing the high quality paper needed for foreign relations with China (Kim, 2003, p8). Before the establishment of Jojiseo, the supply of paper for the government mostly relied on local tribute (Kim, 2003, p29). Over time, Jojiseo produced paper of high quality, not only for official uses (including paper money) but also paper tribute to China (Kim, 2002, p61). Installing Jojiseo was an epoch-making event in papermaking history in the Korean peninsula as the government could directly control and maintain papermaking systems and, therefore, papermaking skills were easily refined and improved.

According to Joseonwangjosilrok (朝鮮王朝實錄) (Joseonwangjosilrok translated into Korean, 1997), the official record of the Joseon dynasty (1392 – 1909) during the 15th century, the Joseon government had made an effort to introduce new papermaking techniques and materials from neighbouring countries (particularly China) in order to improve papermaking methods. In 1412, Sin Deukjae (申得財), a skilled Chinese papermaker from Sukju(肅州), was invited by the Joseon government to teach Korean papermakers how to make Chinese style paper. In return, rice and cotton cloth were given to him (Taejongsilrok vol 23, 12th year, 17th January). Although his visit was made three years before Jojiseo was installed, it is possible that the techniques he introduced must have been transferred and subsequently practiced in Jojiseo.

No written record of the techniques imported from China at this point have been found but records reveal what papers were produced in1424. Therefore, it is noted that Jojiseo produced 'jukyeopji' (竹葉紙, paper made with leaves of bamboo), 'songyeopji' (松葉紙, paper made with leaves of pine trees), 'gojeolji' (稿節紙, paper made with rice straw), and 'pojeolji' (蒲節紙, paper made with stems of cattails) (Sejongsilrok, vol 25, 6th year August). It is suggested that Sin Deukjae might have introduced the technique of using leaves of various plants. Although during the Goryeo period, other papermaking materials began to be used, this record shows that a wider range of plants were used in papermaking from the beginning of the Joseon period in order to satisfy the increased demand for paper required for publication. The quality of paper produced in Jojiseo must have improved greatly in the following fifteen years - a record from 1430 states:

> "... when Jojiseo was established it was said that the quality of paper made in Jojiseo was not thought as good as those made in Namwon (南原) and Jeonju (全州) but now the quality of paper from Jojiseo became very high so that paper from Namwon (南原) and Jeonju (全州) was not preferred anymore...(Sejongsilrok vol 49, 12th year, 11th September)"

However, the Joseon government must have continuously faced difficulties in supplying enough paper for official use and publication as other records illustrate a constant effort to introduce new materials for papermaking. In 1430, King Sejong (世宗) commanded the dispatch of an official to Daema (對馬) island in order to obtain Japanese paper mulberry (倭楮) for making paper used in book publishing (Sejongsilrok vol 49, 12th year, 29th August). Furthermore, in 1434, King Sejong commanded the preparation of 300,000 gwon[4] of paper for publishing Jachitonggam (資治通鑑), using other materials in conjunction with paper mulberry. The following information also shows the scale of publication by the government:

> "Prepare 300,000 gwon of paper for printing Jachitonggam (資治通鑑): 50,000 gwon should be prepared by Jojiseo, 105,000 gwon by Gyeongsangdo (慶尚道), 78,000 gwon by Jeonrado (全羅道), 33,500 gwon by Chungcheongdo (忠淸道), and 33,500 gwon by Gangwondo (江原道). … as stems of rice straw, wheat, barley straw, skin of bamboo, and stems of hemp are materials which can be easily prepared, if these materials are mixed with paper mulberry in the ratio of 5 to 1, then, the sheets made with the mix would have enough strength for printing and also paper mulberry will be saved (Sejongsilrok vol 65, 16th year, 17th July)."

Additionally, records state that, in 1451, 5,000 gwon of Yumokji (柳木紙), a paper made with willow tree (*Salix koreensis*), was levied from four provinces (Gyeongsangdo, Jeonrado, Gangwondo and Chungcheongdo) (Munjongsilrok, vol 4, 1st year, 10th October). This information shows that willow tree was one of the common materials used in papermaking at that time. However, it is not clear whether Yumokji (柳木紙) was made solely with willow tree. Although the name indicates the use of that particular raw material, it is not uncommon for a paper (comprising additionally of paper mulberry) to carry a name which refers to just one of the constituent materials. Similarly, other papers are named in the same manner, such as Jabchoji (雜草紙, made with a mixture of grass, tree-bark and papermulberry), Taeji (苔紙, made with a mixture of spirogyra and paper mulberry).

In consideration of this nomenclature, it is possible that Yumokji (柳木紙) might have been made with a mixture of paper mulberry and willow tree inner bark, since the Chinese characters mean 'willow tree paper'.

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[4] Gwon is a unit for handmade paper in Korea. One gwon means twenty sheets of traditional handmade paper. Therefore, 300,000 gwon is 6,000,000 sheets.

In 1464, when an envoy of China visited the Joseon government, one of the government officials, Bak wonhyeong (朴元亨), questioned him on the Chinese papermaking technique. The envoy mentioned that Hwangji (黃紙), a yellow paper for everyday use, was made with a mixture of soft bamboo leaves and the bark of the mulberry tree, and Baekji (白紙), a white paper for official documents, was only made with the bark of the mulberry tree. In response to this, King Sejo commanded Jojiseo to produce sheets using the materials cited by the Chinese envoy (Sejosilrok vol 33, 10th year, 22nd May). Unfortunately no record of the test results has been found (Yu, 1990, p27).

A further attempt was made by the government to introduce Chinese papermaking techniques in 1475. King Seongjong (成宗) commanded Bakbi (朴非), an official papermaker, to go with an envoy to Beijing in order to learn the contemporary papermaking techniques there (Seongjongsilrok vol 51, 6th year, 19th January). According to his report, he visited three paper mills. One was located about 10 kilometres outside Habdaemun (哈大門) – here, the main material in papermaking was raw hemp. The reported process was as follows:

> "Raw hemp was finely cut and soaked in water. Then it was mixed with lime and cooked until it became soft. The cooked hemp was washed thoroughly to remove lime and ground in a millstone (石磑). The finely ground hemp was put in a basket made with very fine strips of bamboo and washed again and taken out of the water. The drained pulp was put in a vat and mixed with clean water. Finally sheets were made but no glue (膠) was used.
>
> In the case of the Jubonji (奏本紙), it was reported that people in the southern part of China cut and gathered bamboo shoots when the shoots grew to about the size of a bull's horn. These were then finely cut, washed, mixed with lime and left to stand in a barrel. Approximately five to six days later the material was cooked and washed thoroughly in a bamboo basket before it was pounded until soft and put into a sack and washed again. With the prepared pulp in a vat, it was mixed with a mucilaginous solution, 'hwaljosu' (滑條水) and, finally, the sheets were formed. Hwaljo (滑條) was the plant from which

roots and stems were pounded and soaked in water to make glue (膠) – a mucilaginous substance. Regarding Chekji (冊紙), paper intended for the production of books, the manufacturing process followed that described for Jubonji (奏本紙), except with the addition of rice straw to the bamboo shoots.

Another paper mill was located about eight kilometres outside Jeongyangmun (正陽門), its main material was also raw hemp with the papermaking process the same as above. In the case of Chekji (冊紙), bamboo shoots and rice straw were also finely chopped and mixed with lime and the same processes were followed. Regarding Jubonji (奏本紙), if one geun (斤)[5] of rice straw was mixed with an amount of processed bamboo shoots necessary to make one thousand sheets, the resulting paper would be desirably white.

The final paper mill documented by Bakbi was located near the river Taejaha (太子河) outside Dongmun (東門) of Yodong (遼東). The main materials favoured here were raw hemp and the bark of the mulberry tree processed by mixing with wood ash and lime before cooking. After this stage, the material was dried in the sun and subsequently beaten to remove the lime and skin of the bark. Finely cut and placed in a bamboo basket, the material was washed, then ground and washed again. The mucilaginous solution (滑條水) was finally added and the sheets - often used for book paper - were formed.

The Chinese character '膠' means animal glue though it seems as if the character has also been used to indicate a plant extract. Pan (1978, p124) explained that, during the Tang dynasty (618 – 907), Chinese papermakers started to use animal glue which was used either for tub sizing or engine sizing and animal glue substituted starch paste which was used at an early stage of Chinese papermaking. Later, plant extracts were also used for the same purpose.

These records provided an insight into 15th century Chinese papermaking and also reflect the papermaking techniques that must have been employed in Joseon at this time. It is interesting to note that none of these three paper mills visited by Bakbi (朴非) used paper mulberry, the main material for papermaking in Joseon. Furthermore, contrary to paper production from bamboo shoots and rice straw, Chinese papermakers did not use plant extracts as an aid for papermaking

[5] A unit for weight used in ancient Korea and China. One 'geun' is equivalent to 600 grams.

with raw hemp. The reason for this may be due to the different implements employed for fibrillation: in the case of raw hemp, a millstone (石磑) was used to grind the material but a mortar was used for pounding rice straw and bamboo shoots. Grinding would produce finer particles which would have slowed down the drainage of water through a bamboo screen and as a result, adding a mucilaginous solution must have significantly further retarded the speed of the sheet forming process.

Thus far, the supplementary materials used in papermaking during the 15th century were investigated based on the records from the Joseonwangjosilrok. It is clear that techniques of papermaking using mixed materials were well developed and a wide range of materials, such as rice straw, wheat and barley straw, willow tree, leaves of pine and bamboo, cattails, Japanese paper mulberry and hemp, were used. Furthermore, the suggestion of the specific ratio of paper mulberry to other materials reflects a good understanding of the optimum proportion of paper mulberry to supplementary materials, not only to produce papers of enough strength for printing but also to economise on use of paper mulberry.

The search for suitable materials for papermaking must have continued to the 16th century. One of the interesting materials used during this period is green alga, spirogyra (*Spirogyra turfosa Gay*). According to Joseonwangjosilrok, in 1541, Kim Anguk (金安國), a senior member of the government, made Taeji (苔紙), which was made with paper mulberry mixed with spirogyra and presented to the king (Jungjongsilrok, vol 95, 36th year, 25th June). It appears that green alga was also used for traditional papermaking in China: according to Pan (1978, p93), production of this type of paper started in the Seojin (西晉, 265 – 316 AD) period and continued through the Tang and Sung dynasties. The authour also stated that other countries made the same kind of paper - among them, the most famous one was produced in Joseon. Therefore, Taeji made in the Joseon must have been well known to China since the middle of 16th century.

As there is no written record of Korean papermaking techniques before the 17th century, Yu (1990, pp23-41) compared these 15th century Chinese papermaking methods with existing information on the 17th century Korean papermaking methods described in Saekgyeong (穡經, 1676). Saekgyeong is a book on agriculture written by the late Joseon period Korean scholar, Bak Sedang (朴世堂, 1629 – 1703). Under the title of 'Jobukjibeob' (造北紙法) (Method for making paper in northern area), three papermaking processes were described. According to Yu's report, the main materials in 17th century Korean papermaking were rice straw, oat straw, and the bark of paper mulberry or old paper made with paper mulberry. The papermaking process with oat straw was as follows:

> "Oat straw was shaped into small lumps and piled inside an iron pot. With the lumps of oat straw placed in the pot, lime was mixed in - lye (alkaline material, probably potash) was then added to the mixture. This was cooked for two nights and one day - during cooking, more lime was added if the initial quantity appeared insufficient. Once the straw was well-cooked, it was transferred to a bamboo basket and soaked in water to remove all traces of lime. The oat straw was later removed from the water and squeezed, placed in a mortar and pounded for three to four days. Three mal[6] of the dried oat straw powder and one and half a geun of old paper made with paper mulberry were put in a vat and mixed well. Plant extracts (glue) were added and the sheets were finally formed (as reported in Yu, 1990, p34)."

In the second described method (taking rice or oat straw as the principal ingredients), a slightly different papermaking process is documented:

> "Rice or oat straw was finely cut and any nodes were removed. Lye was mixed with the material before placing it into an iron pot to be boiled for around six days – once cooked, the straw was ground with a millstone and the pulp strained through a sieve. The sheets were made with a mixture of two doe[7] of powder from the processed straw combined

[6] A unit of volume used in ancient Korea. One 'mal' is approximately equivalent to 18 litres.
[7] A unit of volume used in ancient Korea. One 'doe' is one tenth of one 'mal'.

> with one doe of paper mulberry. The use of raw paper mulberry could produce a strong sheet though in the use of paper mulberry derived from old paper, sheet strength would be compromised (as reported in Yu, 1990, p34)."

The last method is described thus:

> "Rice or oat straw was beaten and powdered clamshell or lime was added to it whilst water was sprinkled onto the mix. Ten or twenty days later, the straw was boiled for approximately half a day before being pounded over a similar duration. In this way labour could be greatly saved. In this case it was not necessary to remove any nodes of straw. Finely pounding straw was good enough for papermaking (as reported in Yu, 1990, p35)."

Although the translated text describing the last method did not state the reason why this technique could save labour, it is likely that such an alkaline treatment must have digested lignin and reduced the need for extensive pounding or further mechanical action. It is rather strange that the latter two methods did not include any washing process, though it is not clear whether the washing process was omitted from the original text. However, based on the first method, it is more likely that between the cooking and the beating processes, the material must have been thoroughly washed in order to remove any residual alkali from the lime and the lye (potash).

From the comparison, Yu (1990, p35) concluded that the only difference between the 15th century Chinese techniques and the 17th century Korean techniques was whether paper mulberry was added to the main materials or not. The Chinese mainly used raw hemp, bamboo shoots and rice straw, whereas rice straw, oat straw, and paper mulberry were chiefly used in Korea. It is also interesting to note that the Chinese used a millstone (石磑) in grinding raw hemp and in Korea this was used for grinding rice or oat straw. The information clearly shows that paper mulberry was an essential material for papermaking during the Joseon period. Papermaking processes in Joseon were more or less the same as the Chinese techniques which were used 200 years before.

It is clear that the Joseon government improved papermaking skills by adapting new papermaking materials from China and Japan and a wider range of plants were used for papermaking from the 15th century. However, it seems as if the government failed to maintain the quality of paper produced in Jojiseo over time. According to Jungjongsilrok (vol 54, 20th year, 15th May), in 1525 there was a recorded complaint from an official about the quality of papers made in Jojiseo and it was suggested the officials in charge of this should be questioned and punished.

Between 1592 and 1598 there were two major Japanese invasions and later in 1627 there was a further invasion of the Manchu. During this period many cultural assets were destroyed. The facilities in Jojiseo were also badly damaged and official papermakers were scattered – after the invasions, Jojiseo suffered serious problems in reinstating a community of skilled papermakers and it took around half a century to recover (Kim, 2003, pp38-39). Consequently, major setbacks occurred in paper supply to the government leading the government to impose a further levy on paper produced within the three southern provinces, Jeolrado, Gyeongsangdo and Chungcheongdo (Lee, 1958, p206). However, due to the new taxing system known as Daedongbub (大同法)[8] in the late Joseon period, the local government was, to some extent, liberated from the pressure of producing and providing paper to the government, therefore, they did not need to maintain Jiso which used to produce papers for the government. Consequently, the enforcement of Daedongbub resulted in disintegration of the Jiso. At the same time, people made less effort to retain fields for the cultivation of paper mulberry (Kim, 2003, p49) –many fields in the three southern provinces had been converted to produce seed grain crops and consequently the local officials encountered a lack of the main material, paper mulberry (Lee, 1962, pp204-205).

[8] In the early Joseon period, local governments had to regularly send local products to the central government. However, at the introduction of Daedongbub, instead of local products, a tax was levied as a form of rice. In the case of areas where rice did not grow, textiles could be presented to substitute payment in rice.

According to Kim (2003, p70), from the beginning of the Joseon period, it was common that Buddhist monks in the three southern provinces worked in the papermaking industry in order to maintain their monasteries and to achieve self-sufficiency in paper production for the publication of Buddhist texts. Under such conditions, Buddhist monasteries became an important source of paper supply for the local government and in 1700, half of the required paper supply for the government was obtained from these monasteries (Cho et al, 1986, p48). At the beginning of the 18th century, private markets were developed all over the country and along with it the demand of paper from public had greatly increased. Under the circumstances, private papermaking mills began to develop dramatically (Kim, 2003, pp92-96).

It appeared that the quality of paper produced during the early Joseon period was regarded as being as good as that from Goryeo though, from the middle of the 15th century, the quality of paper started to decline (Cho et al, 1996, p46). In the 18th century, written accounts showed that some Korean scholars criticized papers produced at the time: the main criticism was concerned with the papers being too thick for printing or painting. Additionally, another issue regarded the sizes of paper (Cho et al, 1996, p49): Bakjega (朴齊家:1750 – 1805), a scholar in the last Joseon period, criticized the quality of paper in a book, Bukhakui (北學議, 1778) by writing

> "There is no standardized size for papermaking screens in this country, which leads people to waste paper especially when papers were cut and prepared for books. If a sheet was cut in half, it is too big for a book, consequently, the surplus is usually discarded, and if a sheet was cut in thirds then the pieces are too small not leaving enough margins. Furthermore papers produced from eight provinces have all different sizes and it is difficult to estimate how much paper was wasted because of this problem. Although paper is not only used for books but the size of books should be considered and the size of paper should be decided accordingly… (as reported in Cho et al, 1996, pp49-50)"

This is one of few written accounts related to papermaking moulds. It reflects that, while the papermaking industry was thriving, there was a lack of standardized sizing of papermaking screens. The rapidly developed private papermaking mills might have guarded their own skills and techniques in order to differentiate their products from others. As a result in such circumstances, it might have been difficult for papermakers to reach agreement about standardizing the size of papermaking screens.

No further written information from early literature has been found. However, there are two recent research papers which were produced in order to understand the nature of papermaking screens used during the Joseon period.

Jung (1985) studied the characteristics of papers used for books in the early Joseon period. For her research she examined 100 paper objects dated mainly between the 14th and the 15th centuries and recorded the characteristics of each paper including the number of laid lines in one centimetre, the interval of chain lines, the thickness and the material used. The results showed that the number of laid lines in one centimetre slightly varied over a period of production: 4 – 9 lines are from 1361 to 1418, 4 – 11 from 1419 to 1450 and 3 – 9 from 1451 to 1494. The intervals of chain lines were 23 mm, 17mm, and 17 – 18 mm respectively.

Son (2005) also investigated the characteristics of papers used especially for documents during the Joseon period (1392 – 1909). She conducted a survey on approximately 1500 old documents dated between the 15th and 19th centuries and recorded the impressions of laid and chain lines (the number of laid lines in three centimetres and intervals of chain lines), the density, and the materials used for each sheet. According to her survey results, the number of laid lines could be divided into two groups: 3.3 and 5.7 lines per centimetre. She suggested that the paper which exhibited approximately 3.3 laid lines per centimetre might have been made upon a screen made with the stems of Korean grass (eulalia, *Miscanthus sp*) - the other papers, exhibiting approximately 5.7 laid lines per centimetre might have been made on a screen of bamboo splints. Although both screen types often appeared to be used in the same period, the number of laid lines generally increased towards the end of the Joseon period. The survey results also revealed that intervals of chain lines were very irregular and the presence of double chain lines was consistently noticeable throughout the Joseon period: generally the intervals between chain lines became narrower towards the end of the Joseon period – particularly, intervals of less than 15 millimetres appeared more frequently after 1820.

It is worth noting that the intervals of chain lines became much narrower and more irregular than those papers made in the Goryeo period. Furthermore, it seems as if during Joseon period, screens made with rather thick stems of eulalia or other plants were used.

Jeong (1985), identified fibres from 49 sheets out of 100 and the results showed a wide range of materials (including paper mulberry, hemp, rice straw, jute, mulberry, gampi, bamboo, cotton, and barley straw) were used during this period. Most of them appeared to be made with a mixture of two or three materials. Among the materials used, the most common was paper mulberry (identified in 24 sheets), followed by hemp (included in 17 sheets). Her research showed that, during the early Joseon period, a wide range of materials was used in paper for books. On the other hand, according to Son (2005), the materials used for documents during the Joseon period were solely paper mulberry and no supplementary materials were identified.

Therefore, it can be said that supplementary materials were commonly used with paper mulberry for papers made for printing as the publishing of books required mass production of paper - conversely, papers for documents were regarded as more important and as a result, papers of better quality were used.

Regarding density of the sheet, Son (2005, pp86-92) reported that good quality papers showed higher density implying that they were refined in the finishing process, 'dochim', whereas low quality papers demonstrated low density of 0.2 – 0.3 (g/cm^3). From Park's examination (p34) it was clear that a paper with density lower than 0.4 g/cm^3 was unlikely to have received the finishing process. Therefore, it seems as if only high quality document papers had gone through this final step. The thickness of papers used for documents was generally between 0.1 and 0.2 millimetres. In examples produced before the war, Imjinwaeran (壬辰倭亂, 1592 – 1598), the thickness of sample papers was between 0.3 and 0.8 millimetres though just after the war, thickness decreased to between 0.1 and 0.2 millimetres – a characteristic which remained until the later Joseon period.

The chief characteristics of paper from the Joseon period are the whiteness and strength as seen in Goryeoji. Although paper mulberry was still the main material for papermaking, a wide range of plants were also used including, rice straw, barley straw, oat straw, bamboo, the bark of pine tree, hemp, bark of mulberry, spirogyra, leaves of willow tree (*Salix koreensis*), reed (*Phragmites communis*). Until the middle of the 15th century in Joseon, the quality of paper produced had been maintained at the same high standard as in Goryeo but its quality had started to decline towards the end of the 15th century. Due to several invasions by Japan and China between the end of the 16th century and the beginning of the 17th century, the papermaking industry had been greatly damaged like other industries. It was not until the 18th century - along with the development of a new market in the country - that private papermaking mills started to rapidly develop.

3.3. Papermaking materials

Fibre sources

Paper mulberry has been the main material in traditional papermaking in Korea - its Korean term being 'dak' or 'daknamu'. The two species of paper mulberry are 'Daknamu' (*Broussonetia kazinoki Sieb*) and 'Kgujinamu' (*Broussonetia papyrifera Vent.*) - both belonging to the *Moraceae* family. Lee (2002, p95) reported that both are native to Korea, whereas, according to Jeon (1996, p46) 'Daknamu' (*Broussonetia kazinoki Sieb*) is native to Korea but 'Kgujinamu' (a plant yielding lower quality fibre than 'Daknamu'.) originally came from Japan in the distant past.

Therefore, there is a debate as to whether both of them are of Korean origin though, at least, 'daknamu' must be native to Korea. In any case, the species have been crossbred with each other over time and consequently it has proved difficult to distinguish one from the other for the purpose of this current research. More often, Daknamu is the only one usually mentioned as the main papermaking material in papermaking literature. However the common name is usually not accompanied by the botanical name and therefore, it is difficult to understand which of the two species is indicated by the authors.

Growing to a height of about three metres, 'Dak' naturally appears throughout the country, favouring sunny hillsides and banks of fields. The colour of its bark is yellowish brown to brown and its leaves usually shoot alternately. The length of the leaves is between five and twenty centimetres with an oval or elongated oval shape. Rather rounded at the shoot, these also tend to be forked into two or three parts, their tips are long and sharp with a serrated edge. Short hairs at the shoot disappear as the leaf grows - along the length of the leaf, this hair growth diminishes though the tip of the leaf is rough.

'Kgujinamu' grows naturally throughout the country to a height of five to ten metres. The colour of the bark is greyish brown and its leaves shooting alternately or symmetrically on the branch. The length of the leaves is between seven and twenty centimetres though they tend to be wider than 'Daknamu' leaves. The leaf – with hair growth on both sides - is also forked into three or five parts with serrated edges.

(http://209.85.135.104/search?q=cache:umXEvF2jVEcJ:www.sanrimji.com/contents.jsp%3Fwebzine_id%3D711%26item_id%3D15145%26year%3D2003%26month%3D10+%EA%BE%B8%EC%A7%80%EB%82%98%EB%AC%B4&hl=en&ct=clnk&cd=5&gl=uk, accessed 27th February, 2007). Although 'dak' grows readily throughout the country, it was once cultivated when the papermaking industry was thriving. In Sanrimgyeongje (山林經濟) a description of how to plant paper mulberry was recorded as follows (as reported in Kim et al, 1992, p17):

> "It is good to plant doc (paper mulberry) in dry land near heap of stones. Dig a hole in the ground and lay it down and cover it with heaps of soil. It is better to put a stone on it rather than tread on it. If its stem grows then bend and bury the stem under the ground and then press it with a stone. Later roots will come out from the buried stem. Several years later plough near the area where roots are and exposure the roots. New sprout will come out from the exposed roots…."

According to Cho et al (1996, p5), paper mulberry is a difficult material to work in mechanised papermaking. It is noted that paper mulberry fibres have a tendency to twist and become flocculent when subjected to sustained physical impact. Due to this characteristic, Hollander beaters and refiners (the most common machines for beating and agitating pulp) are unsuitable in the papermaking processes.

'Samjidak' (oriental paperbush, *Edgeworthia papyrifera Sieb. Et Zucc*) is another material commonly used for traditional papermaking in Korea (Lee, 2002, p95). Jeon (1997, pp57-58) reported that it belongs to the *Thymelaceae* family. In Korean, 'samji' meaning three branches refers to the characteristic manner in which the branches split into three as it grows and 'dak' means paper mulberry tree. 'Samjidak' has been cultivated and used in traditional papermaking in Korea for a significant time though there is no record showing where and how it was cultivated. It grows naturally in Japan, southern costal areas of Korea, and in China. Lee (2006, p18) reported that samjidak is native to China.

'Sanpbongnamu' (mulberry, *Morus bambycis Koidz*) belongs to the *Moraceae* family and grows naturally all over East Asia. While the leaves are used for feeding silkworms, the inner bark of the mulberry has been in use in papermaking for a considerable time. Despite its abundance and its similarity to paper mulberry (both belonging to the same family, *Moraceae*) it was not employed as the main papermaking material in Korea. According to Kim et al (1992, p22) in the case of mulberry trees, the distances between sprouts are too close and therefore, the fibrous texture around them tends to be hard to fibrillate, causing difficulty in producing sheets of good uniformity.

Formation aid (Dakpul, a Korean term for formation aid)

Before investigating the history of the use of mucilaginous substances in Korea and its neighbouring countries, it is important to review the definitions of 'size' and 'formation aid' since the mucilaginous substances were sometimes referred to as a sizing material by western scholars (Voorn, 1961, p48). Formation aid could be defined as 'viscous but not sticky plant extracts which help fibres disperse evenly in a vat and, therefore, improve the uniformity of a sheet'.

According to the 'Glossary of Papermaking Terms' by the British Association of Paper Historians (BAPH) (1989), the definition of size is 'originally a solution of glue or gelatine but later any substance that reduces the rate at which paper absorbs water or ink'. Unlike 'size', there is no definition of 'formation aid' on the site. Elsewhere, the definition of 'formation aid' is similarly elusive among sites related to the subject of papermaking. This is perhaps because the use of formation aids is almost exclusive to traditional papermaking in Korea, Japan, and China - a counterpart is absent from traditional European papermaking. It is this absence which therefore may explain why European paper historians have often misunderstood the role of the formation aid - instead seeing it as a sizing material.

Therefore, in summary, both sizing and formation aids are additives in papermaking, yet their main, intended functions are different. The size is added with the intention of increasing resistance to liquid penetration into the paper, causing ink to remain largely on the surface of the paper. The main function of the formation aid is to facilitate even dispersion of the fibres in water and to improve the uniformity of a paper.

For a significant period of time, mucilaginous substances from indigenous plants have been employed in traditional handmade paper in East Asia. Such additives have been regarded as a key ingredient, enabling East Asian papermakers to produce sheets with fine yet even thickness, especially with long-fibred pulp, such as paper mulberry. Despite their long history of use as formation aids, the location and period in which the use of these additives began in papermaking have not been identified. The question about these origins has, thus far, been left unanswered.

Today, in the production of paper by traditional techniques in Korea and Japan, the predominant source for the formation aid is the root of Hibiscus Manihot. Its mucilage has multi functions which are frequently mentioned by East Asian paper historians.

Firstly, entanglement of fibres is prevented, thus they are diffused more uniformly in water (Narita, 1954, p42. Kojii, 1959, p2. Hughes, 1978, p84. Nishi, 1984, p19. Jeon, 1996, p120. Lee, 2002, p102), allowing papermakers to make thin, even sheets (Hughes, 1978, p84. Kubota, 1978, p19. Jeon, 1996, p120. Lee, 2002, p102).

Furthermore, during sheet formation, the increased viscosity of the water slows its drainage through the screen, allowing papermakers enough time to manipulate the papermaking mould, spreading pulp more evenly across the screen. (Narita, 1954, p42. Hughes, 1978, p84. Kubota, 1978, p24). In other words, by adjusting the amount of mucilage, papermakers could control the speed of drainage. It is the nagashi-zuki sheet forming technique (described below) which exploits the use of the mucilage in this way, allowing sheet thickness to be controlled finely by increasing it incrementally in layers. (Kojii, 1959, p3. Lee, 2002, p104).

It is also believed that the mucilage improves the physical strength of the paper (Hughes, 1984, p84. Kubota, 1978, p24. Nishi, 1984, p19. Jeon, 1996, p121. Lee, 2002, p104) and is said to increase hardness in the finished sheet (Kubota, 1978, p24. Lee, 2002, p104). Additionally, according to Nishi (1984, p19), fibres are interlocked more tightly as the sheet is formed. Leaving hardly any noticeable residue on the surface of the paper, the additive improves the surface sheen of the final product, making it more lustrous. (Nishi, 1984, p19. Jeon, 1996, p121).

Though not so directly connected to the characteristics of the final product, the formation aid is additionally beneficial to the papermaking process in certain ways. Fibres are held in suspension for longer and thus prevented from sinking to the bottom of the vat, saving on labour needed to stir the vat stock frequently (Narita, 1954, p42. Kojii, 1959, p3. Kubota, 1978, p24. Nishi, 1984, p19. Jeon, 1996, p121. Lee, 2002, p104).

A sheet formed using the mucilage is also said to be more easily separable from the screen for couching (Kubota, 1978, p24. Nishi, 1984, p19). Similarly, the mucilage also prevents adhesion between newly formed sheets, enabling them to be piled and pressed together without the need for any interleaving material - the stacked sheets remain easily separable while still damp. (Kojii, 1959, p3. Hughes, 1978, p84. Jeon, 1996, p121. Lee, 2002, p104).

Although playing a vital role in traditional papermaking in East Asia, these types of natural plant extracts appear to have never been employed by European handmade papermakers for the same purpose. Papermaking is not a home-grown industry in Europe. It is a well-known fact that the art of papermaking was invented in China (Hunter, 1947, pp48-50), and from there it spread to Europe via Arab countries. Although Arabian papermakers learned the art of papermaking in the middle of the 8th century (Weir, 1957, p45), not until nearly 300 years later was papermaking practice begun in Europe (in Spain) around the 11th century (Clapperton, 1934, p71). While the basic principles of papermaking by hand have remained unchanged over 2000 years, many variations developed in the practice on its way to Europe. Whether the degree of variation was slight or considerable, it must have been inevitable in order to adapt the papermaking industry, which requires abundant native materials.

As an example, the manner in which European papermakers dealt with problems of fibre dispersion is an interesting contrast to that of Eastern papermakers. Relying more on frequent agitation of pulp, a pole was initially used to agitate the vat stock. Subsequent improvement was achieved by adding a wooden disk pierced with holes to that pole – thus, stirring efficiency was increased. In the late eighteenth century, a mechanical agitator was developed for better consistency in the vat stock (Hunter, 1947, p175-176). There is no record showing that plant extracts were employed as a formation aid in handmade paper in Europe. Therefore, it is possible that the use of a formation aid was a technique never known to European handmade paper producers.

Origin of the Formation Aid in Papermaking in East Asia

It is not clear when such mucilaginous substances were introduced as formation aids in East Asia as little written information has been found to date.

Japanese paper historians (Yamada, 1971. Kubota, 1978) believe that the use of a mucilaginous substance was introduced by Japanese papermakers. Yamada (1971) suggested that the idea of employing mucilaginous plant extracts came to Japanese papermakers in their observations of gampi fibres. According to Machida (1958, pp1021-1023), the hemicelluloses of gampi fibres are hydrophilic polyuronides and tend to increase the areas of intimate contact between fibres and fibrils during the sheet forming process. Additionally the hemicelluloses in conjunction with plant mucilage caused fibres to disperse well in water improving the uniformity of the fibre mat. Where gampi was used, it was noted that fibres dispersed well in the vat and did not easily sink – the fibres naturally contained substances which altered the viscosity of the water, allowing the fibres to disperse more evenly, because gampi also contains a great quantity of hemicelluloses. Conversely, when paper mulberry or mizumata fibres were used, the fibres did not disperse well. It is this contrasting behaviour which led Japanese papermakers to understand the role of plant extracts, giving rise to the use of certain substances in paper production with paper mulberry. Japanese historians also believe that the use of plant extracts led Japanese papermakers to invent the nagashi-zuki technique (Machida, 1959, pp29-30)

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At this point it is pertinent to explain the contrasting sheet forming techniques used in Japan, as it seems the use of plant extracts affected the development of papermaking techniques. These might give useful clues as to the history of the formation aid in neighbouring countries.

There are two different techniques in papermaking in Japan, one being tame-zuki, the other nagashi-zuki - the main differences between these two techniques are clear. Narita (1954, pp42-43) states that both techniques are traditional Japanese methods but that nagashi-zuki is suitable for making thin paper whereas tame-zuki is suited to the production of thick paper. Yamada (1971) believed that the tame-zuki technique was the first technique transferred to Japan from China but the nagashi-zuki method is of Japanese origin.

Barrett (1983, pp51-52) described them in detail noting the similarity between tame-zuki and European papermaking. The pulp stock, scooped once from the vat, is gently shaken to send ripples running across the mould from side to side and then from front to back until all water is drained through the screen, leaving fibres in an even layer. In the case of the tame-zuki, technique, the single scoop of pulp stock remains on the screen until the water drains completely. Therefore, the amount of pulp stock taken up in that single scoop determines the thickness of the paper formed. Significantly, as no plant extracts are involved in this forming technique, water tends to drain rapidly.

In the nagashi-zuki technique, the spread of pulp across the screen is achieved as in the tame-zuki technique. However, formation of the sheet requires several scoops. For each of these scoops, a consistent, fine layer of fibres is allowed to settle across the screen. On formation of each such layer, excess pulp stock is usually ejected over the deckle. In this case, the papermaker achieves variable thickness between sheets by varying the number of subsequent dippings (scoops).

In contrast to the tame-zuki technique, the sheet-formed by the nagashi-zuki technique requires the use of a formation aid. The mucilaginous substance thickens the pulp stock and retards drainage, allowing the papermaker to manipulate the mould before casting excess pulp back into the vat. Barrett (1983, p60) stated that a thin, uniform sheet could be made only when a mucilaginous solution was used in combination with the sheet-forming action of nagashi-zuki.

One of the oldest pieces of literature containing papermaking information in Japan is Yeon-Hee-Sik (延喜式), an official record made by the government in 927. Volume thirteen includes information about papermaking materials and processes and the duration of each step (reported in Akinori, 1999, p192). The papermaking process is divided into five steps: cutting, cooking, selecting impurities, beating, and forming. However, this early record does not contain information regarding tororo-aoi or other plant extracts, suggesting that a formation aid had still not been introduced in Japan by the middle of the 10th century. Therefore, it could be assumed that the tame-zuki technique was predominantly used until that point in Japan. One of the earliest pieces of literature which might provide a record of the use of plant extracts in Japanese papermaking is 'History of Japan' written by Kaempfer, a German traveller and physician. He reported that an infusion of rice and viscous plant extracts were used for Japanese papermaking in the late 17th century (Kaempfer, 1727, pp23-24).

The theory proposed by Japanese paper historians', in summary, states that the production of a sheet with long fibred material required plant extracts in order to make fibres disperse well in water. However, adding a viscous substance greatly slowed down the forming process (i.e. the drainage of water through the screen) and therefore, the Japanese invented a new forming technique, the nagashi-zuki, a technique unique to Japan. However, Nishi (1978) contested the opinion that the use of plant extracts in papermaking was of Japanese invention. He found Chinese material called 'tororoaoi' 'ouren' (黄蓮) - Japanese also referred to it as 'ouren' in the Kyusyu province and therefore, he thought its Chinese name was adapted when it was transferred to Japan.

It would seem therefore, among academics, there has been disagreement concerning the invention and subsequent transfer of use of this technology in papermaking in East Asia. Significantly, experimentation conducted in support of this research has shown that it is difficult to produce a fine sheet of even thickness without a formation aid. This is especially true in the use of long fibres such as paper mulberry, since their long fibres tend to become entangled in water without a formation aid. Additionally, drainage of water (of low viscosity without the formation aid) is too fast to spread pulp evenly across the screen. Therefore, it seems reasonable to suggest that any thin paper comprised of paper mulberry is likely to have been made with the aid of a mucilaginous substance and by a technique similar to nagashi-zuki.

According to Pan Ji-sing (1978, p319), Chinese papermakers originally conceived the idea of using a formation aid. In this account, it was starch paste that producers started to add to the vat in order to facilitate effective dispersion of fibres in water and also to prevent them sinking to the bottom of the vat. Although there is no officially accepted theory regarding the period of use of starch paste in China, the oldest paper on which starch paste was applied dates from 384A.D. Pan also states that the use of starch paste had continued until Qing dynasty (1644 – 1911) even after Chinese papermakers started to use plant extracts as formation aids. An early written account of the use of plant extracts in papermaking can be found in Gyesinjabsic (癸辛雜識) written by Ju-Mil (1232 – 1309), a scholar of the Southern Sung period (1127 – 1279). It states that plant extracts were employed in papermaking at least from the 13th century in China (Pan, 1978, p319).

In Korea, the earliest written information about the use of plant extracts could be seen in Sanlimgyeongje (山林經濟), a concise agricultural encyclopaedia, written by Hongmanseon (洪萬選) (1643-1715), a scholar from the late Joseon dynasty. Here it is noted that a mucilaginous substance from the bark of the elm tree or the roots of Hibiscus Manihot was added to the vat stock (as reported in I & Gu, 1999, p45).

Kim S. (2001, p52) states that nagashi-zuki was not a technique unique to Japan. According to him, the tame-zuki style had been employed in certain parts of China, countries in South East Asia, and in Europe. However, in producing a fine sheet, Korean papermakers have employed a similar technique to the nagashi-zuki method since the Tong-il-Silla period (668 – 935 AD) – an idea which seems to be supported in the examination of old Korean papers from the 8th century. For example, the oldest known extant written Buddhist text in Korea is Daebanggwangbulhwaeomgyeong (大方廣佛華嚴經券, 754 AD). At the end of the text there is a brief written record, balmun (跋文), of the type which can usually be found at the end of any publication or written record. Balmun often includes summarised information based on the main text or any information related to the main body of work. Therefore, details such as the date, author, and the reason for publishing it are listed. In this case, among other descriptions, there is a sentence indicating that, for the purpose of this particular Buddhist sutra, paper mulberry was grown with perfumed water. It shows the degree of extreme care taken for preparing special sheets for the sutra (as reported in Jung, 1998, p236).

A Japanese paper historian, Akinori (1989) examined this item and reported that its paper support was very white and lustrous with few impurities or coarse fibres. It was also thin but quite dense and when held to the light, sheet thickness appeared quite uniform. The ink used for the text did not show any bleeding which suggested that its surface must have been processed. Akinori also noted that the paper support demonstrated the highly accomplished papermaking skills in Korea by that time (as reported in Park, 1999, p149). In this examination, it was confirmed that the material used for the sheet was paper mulberry, indicating that this 8th century Korean paper must have been made by a similar technique to nagashi-zuki, using a formation aid.

Regarding written information about the use of plant extracts in papermaking, the first Chinese record of usage of formation aids appeared much earlier than those of Korea or Japan. However, as there is not sufficient written information on the origin of formation aids, examination of old paper could provide supplementary information to elucidate the history of the use of plant extracts. Further research is necessary to draw any conclusions as to which country initiated the use of plant extracts as a formation aid for papermaking in East Asia.

<u>Plants Employed as a Formation Aid in East Asia</u>

Mucilaginous substances as formation aids were commonly called 'dakpul' in Korea and in Japan and China 'neri' and 'hwalsu (滑水) respectively. These are all vernacular terms for formation aids. In Korea 'dak' means paper mulberry tree and 'pul' means vegetable glue and its name shows the use of mucilaginous substance has been particularly related to the papermaking with paper mulberry.

Although there have been a wide range of plants used as formation aids in East Asia, the plant most commonly known and probably most preferred as a formation aid is *Hibiscus Manihot* (or *Abelmoschus manihot, Medicus*). It is an annual plant - belonging to the *Malvaceae* family – sown between the beginning and the middle of May, usually being harvested sometime between October and November before the frosts. Its flower - pale yellow to white with a dark purple centre - blooms around August or September. As the mucilaginous substance is derived from its roots, continued pruning is necessary to minimise excessive growth of leaves and stems - such growth results in smaller roots and thus, lower yield. Alternatively, root growth is similarly encouraged by the removal of buds from the plant around July to August (Jeon, 1997, pp124-126). It is known to be native to China (Hwangchokgyu (黃蜀葵) in Chinese) (Narita, 1954, p40) and must have been spread into Korea (referred to as 'dakpul' or Hwangchokgyu in Korean) and Japan where it is known as tororo-aoi. Its roots yield a clear mucilaginous substance similar to egg white in appearance and viscous though not sticky. Although its root was mainly used for the purpose, it appeared that sometimes the whole plant of Hwangchokgyu (not only its root but also its stem and leaves) was used to produce the mucilage in Korea (Paper trade journal, 1900). According to previous research (On & Im, 1980) the chemical composition of the mucilage is Poly-L-Rhamno-D-Galacturonic acid (Poly-uronide), a copolymer of D- Galacturonic acid and L-Rhamnose (The ratio of D-Galacturonic acid to L-Rhamnose being 2:1). It has also been found that unlike other vegetable gums, this mucilaginous solution is unstable; its viscosity greatly reduced by increases in temperature, exposure to oxygen, carbon dioxide, and mechanical agitation.

Written information on various species of plants used as a formation aid in Korea is rather scarce. Some Korean researchers believe that the roots of Hwangchokgyu might have been predominantly used from the middle of the 19th century (Lee & Gu, 1999, p45. Cho et al, 1996, p45). According to Ojuyeonmunjangjeonsango (五洲衍文長箋散稿), a 19th century encyclopaedia written by Igyujyeong (李圭景, 1788 – ?), a scholar of Joseon, 'a dakpul a so-called 'Ililhwa' (一日花) looks similar to Hwangchokgyu but it is different from Hwangchokgyu' (as reported in Kim, 2003, p108). Furthermore, in Mangiyoram (萬機要覽, 1808), 'the root of Ililhwa is one of the goods supplied to Jojiso' (as reported in Kim, 2003, p108). From these records, there must have been a plant commonly used as dakpul until sometime in the 19th century before Hwangchokgyu was predominantly used for a formation aid in Korea. Unfortunately there is no further information about Ililhwa but it might be a variant of Hwangchokgyu and belong to the same family of *Malvaceae* (or mallow family).

Another source of a mucilaginous substance in Korea was the bark of *Ulmus coreana Nakai* which is thought to have been commonly used as a formation aid until the beginning of the 19th century (Cho, et al. 1996, p45). *Ulmus coreana Nakai*9 belongs to the *Ulmaceae* family and grows naturally in Korea, China, and Japan (Kim, T. 1980). On and Im (1983) conducted a papermaking experiment in order to test the suitability of the mucilaginous substance from the root of *Ulmus coreana Nakai* as a formation aid in Korean paper-making. In the test, the mucilaginous substances from *Ulmus coreana Nakai* root, *Hibiscus Manihot* root, and sodium polyacrylamide were used and their effects on paper were compared. The results showed that the effect of these three substances on the paper produced was similar in terms of thickness, tensile strength, stretching ratio, and absorbency rate. The differences between test results were however negligible, and therefore, the mucilage of *Ulmus coreana Nakai* was proven to be as effective as

[9] Its more commonly used name is *Ulmus davidiana var. japonica Nakai.*

the mucilage of Hibiscus Manihot.

Apart from 'Hwangchokgyu', Jeon (1996, p128) also reported other plant sources used as raw materials for formation aids used in Korea. The range noted include the bark of 'namusuguk' (*Hydrangea paniculata*), the root of 'teologalpinamu' (*Acanthopanax rufinerve*), the root of 'odongnamu' (*Paulownia coreana*), the root of 'neureupnamu' (*Ulmus coreana Nakai*), the stem of 'namomija' (*Kadsura japonica*), and the stem of 'seoksan' (*Lycoris radiate*)[10]. The above author also reported that the mucilaginous substance from the bark of 'namusuguk' tends to be used in summer as its viscosity is less affected by heat than the mucilage produced from the root of 'hwangchokgyu'.

Another plant substituted for Hwangchokgyu in Korea was briefly mentioned in an article featured in Paper Trade Journal (1900):

> 'Although when the takpul cannot be obtained, the leaves and stems of a creeper called 'Kam-ou-ter' are used but this yields a size greatly inferior to that obtained from the takpul.'

However, as no such word exists in Korean, it seems the word, 'Kam-ou-ter' must have been derived from an English pronunciation which had, in turn, been mistakenly deemed a close approximation of an actual Korean sound. The term is therefore unrecognizable, and there appears to be no plant with an approximate pronunciation. Nonetheless, it might be possible to suggest *kadsura japonica (L) Dunal* as the plant referred to here. As a climbing plant which naturally grows in southern Korea, Japan and Taiwan, it was extensively used as a formation aid in Japan.

In Japan, according to Hughes (1978, p85), the plant most commonly employed as a substitute for

[10] The author did not include botanical name of each plant and the botanical names were searched for this research and added.

tororo-aoi is *Hydrangea paniculata, Sieb.* (Nori-utsugi in Japanese), a wild shrub of the saxifrage family. A mucilaginous substance from its inner bark serves the same function as the extract from the root of Hibiscus Manihot, the resulting material was found to be composed of a copolymer of arabinose, galactose, rhamnose and D-galacturonic acid (Machida & Inano, 1955, p631). *Althaea officinalis, L.* (marshmallow), *Althaea rosa* (hollyhock), *Abelmoschus esculentus* (okra), and *Hibiscus manihot, L* (rose mallow) are other varieties of tororo-aoi and related plants used for formation aids (Hughes, S.1978, p85). Hughes (1978, p84) reported that the botanical name of tororo-aoi was *Abelmoschus manihot, Medicus,* which is usually regarded as a synonym for *Hibiscus manihot L* but in his article he reported *Hibiscus manihot L* as one of other varieties of tororo-aoi.

However, Nishi (1984, p16) reported that sanekazura (*kadsura japonica (L) Dunal*) was used as a formation aid for a long time though from the end of Meiji period (1868 – 1912) to the middle of Showa era (1926 – 1989) tororo-aoi had been substituted for sanekazura and become popular. According to Machida (1972, pp2-4) there were two other plants used for the same purpose: 'hogari' (or 'tororoshiba', *Lindera glauca Blume Sieb. Et Zucc*) and 'mizuna' (or 'uwabamisou', *Elatostemma involucratum, Sieb. Et Zucc*). In order to obtain a viscous liquid from 'hogari', its leaves were crushed and soaked in water overnight. 'Mizuna' was used when 'tororoaoi' was not available in summer and the mucilage of this plant gave a more glossy appearance to the surface of the paper.

In China, as mentioned previously, the use of natural plant extracts as a formation aid must date at least from the Sung dynasty (960 – 1279). Ju-Mil (1232 – 1309), from Southern Sung mentioned in his book, Gyesinjabsic (癸辛雜識)

"... when a sheet is formed the root and stem of Hwangchokgyu (黃蜀葵, Hibiscus

Manihot) should be used. Newly prepared mucilage from it makes the sheet forming easier. Otherwise, sheets stick together and it is difficult to separate them. If there is no Hwangchokgyu available then Chinese kiwi fruit (楊挑藤, *Actinidia chinensis Planch.*), 槿葉, wild grapes (野葡萄) could be used as a substitute for it as they also prevent sheets from sticking to each other" (as reported in Pan, 1978, p319).

Another source of mucilage was the bark of Chinese elm (*Ulmus parvifolia*) and its use was mentioned in Mullisosik (物理小識, ca.1643) written by Bang-iji (方以智, 1611 – 1671), a philosopher of the Ming dynasty:

"… if one wants to make sheets with paper mulberry, put the pulp of paper mulberry into water and add the mucilage from the root of Hwangchokgyu… or use the bark of Chinese elm … the juice of Chinese kiwi fruit is used in Gwangsin (廣信) and it is due to its slippery characteristics…." (as reported in Pan, 1978, p322).

From the above records it is clear that juices of certain types of fruits and the bark of Chinese elm were used as a formation aid along with the root of Hibiscus Manihot in China. A wide range of plants were employed for the same purpose but the most commonly used plants were Hwangchokgye, Chinese kiwi fruit, Modongchung (毛冬青, *ilex pubescens Hook.*), and Chinese elm (Pan, 1978, p322).

It is apparent that many indigenous plants had been used as a formation aid by traditional papermakers in East Asia and it seems as if most of them have lost favour among papermakers over the years and eventually Hwangchokgyu (*Hibiscus Manihot L.*) became predominant.

It is interesting that the root of Hibiscus Manihot has been recognized as the most common source and probably the only plant known to western paper historians as a formation aid in traditional papermaking in Korea, Japan and China. However, it was only at the end of the 19th century that the mucilage from the roots of Hibiscus Manihot became popular and took the place of other indigenous plants which were previously employed for the same purpose in Korea and Japan. Based on the information above, it could be said that Hwangchokgyu was initially used as a formation aid in China and its use must have spread to Korea and Japan at a later date. Furthermore, it should be noted that the choice of plant extract as a formation aid must be closely related to both the material and the forming technique used. Papermaking with long fibres such as paper mulberry must have required the use of a formation aid. In China, paper mulberry has been employed for papermaking for a long time but it has never been the most common material. Since the Sung dynasty, bamboo has been extensively used for traditional papermaking in China – thus, use of a formation aid might not have been necessitated due to the relatively short bamboo fibres which are likely to have caused fewer problems in sheet formation.

Reclaimed paper

Reclaimed paper appeared to be a common material in papermaking in Korea, Japan and China. A written record of reclaiming waste paper in China could be found in T'ien-Kung K'ai-Wu (English translated version, 1966, p227).

> "After the ink and colours of waste paper are washed off, the paper is reduced to pulp by soaking in water and transferred to the pulp tank for making new paper. This process of papermaking not only eliminates the expensive operations of cooking and straining but also loses very little of the waste paper so used. This procedure is not popular in south China where bamboo is abundant and cheap. In the north, however, even small strips or odd pieces [of waste paper] are saved for reprocessing, the product being known as 'resurrected' paper."

According to Pan (1978, p145) there is an earlier record of reclaiming waste paper than that in T'ien-Kung K'ai-Wu: Munheontonggo (文獻通考) written by Maseoim (馬瑞臨) from Yuan dynasty (1271 – 1368) reported that, during the Southern Sung dynasty (1127 – 1279), reclaimed paper was used.

Narita (1954, p8) also reported that recycling waste paper was quite common during the Heian period (794 – 1191): a document referred to a product as dark grey-coloured paper because the sole material used for papermaking was waste paper. Hunter (1947, p54) also reported that, in Japan, a method of reclaiming waste paper was reported as early as 1031. However, neither author mentioned the primary source of the information.

In Korea, the earliest description of reclaiming paper could be seen in Yongjaechonghwa (慵齋叢話), essays written in 1525 by Seonghyeon (成俔), a scholar from Joseon dynasty. It said that on every New Years day and Hansik (寒食), one of the governors of Goryeo would send servants to cemeteries to gather paper to be used for papermaking in order to earn money. Using reclaimed paper for papermaking must have been continued through the Joseon dynasty. According to Joseon Wangjosilrok, volume 7 (p313, Sejosilrok vol 15, 5th year, 18th February), there are several records of appeals to King Sejo to prohibit papermakers from using old papers for papermaking since papermakers stole governmental documents and books in order to use them as a papermaking material. By using old papers, papermakers could omit certain papermaking processes such as cooking and beating. Furthermore, the record stated that the quality of recycled paper was so low and, being weak, it did not last long.

3.4. Papermaking mould

It is difficult to ascertain what type of mould was first employed for papermaking in ancient Korea – speculation is only possible based on other information related to the subject. The first mould used in the Korean peninsula might have been a laid mould since use of this form continued from the third century onwards in China and papermaking skills were transferred from China to Korea by the 4th century. Additionally, Hunter (1947, p94) reported that in Korea, there was no counterpart of the wove type of mould which he witnessed in Kwangtung Province, China.

Since, inside Korea, there is not sufficient information to comprehend the whole development of papermaking moulds, in this section papermaking moulds employed in Korea and also its neighbouring countries were examined. Through constant cultural exchanges made between Korea, China and Japan, their papermaking skills had been closely related and as a result, have similarities. As Chinese moulds were discussed in Chapter 2, in this section, the main focus is given to Korean and Japanese moulds.

While the essential components of a laid mould – a flexible laid screen, a rectangular wooden frame, supporting ribs and deckle – could be easily found in Korean and Japanese moulds, it appeared that some variations were made on the shapes of deckle and the way their laid moulds were assembled.

Firstly, it was confirmed that in China, no deckle was used for a wove mould and a two-stick deckle and a three sided frame were used with the laid mould. In traditional Korean papermaking, no deckle is used where the flexible laid screen is employed (Amile, 1997, p33) and it is this which has been regarded as the traditional Korean papermaking mould (Lee, 2002, p153. Cho et al, 1996, p70).

Such an assembly consists of a 'bal' (a flexible laid screen) and a 'balteul' (a rectangular wooden frame with supporting ribs) (Figure 11, 12). Figure 12 shows how these components are assembled as a Korean laid mould prior to the sheet forming process.

Figure 11. A miniature of balteul (a supporting frame having two supporting ribs).

Figure 12. A bal –made with stems of eulalia – was placed on the balteul.

The bal is usually made with splints of bamboo or stems of plants laced with horse hair or silk thread - today fine fishing line is used in lacing. Therefore, in terms of the materials used and the way it was made, a Korean laid screen is more or less the same as the Chinese. Still, the Korean laid screen has several defining characteristics: after examination of hundreds of Korean papers dating from the 16th century onwards, Hunter (1947, p96) reported that the intervals of chain lines were often narrow and irregular and run the length of the mould. Accordingly, the laid lines run parallel to the shortest dimension of the frame in contrast to other East Asian moulds. Another feature of a Korean laid screen is the way in which the terminations of stitches (of horse hair or silk thread) are staggered along the centre of the screen (Figure 13). Furthermore, all four edges of bal are usually wrapped with a piece of white cotton fabric (Figure 12) though whether this was a traditional feature or a more recent addition is not known.

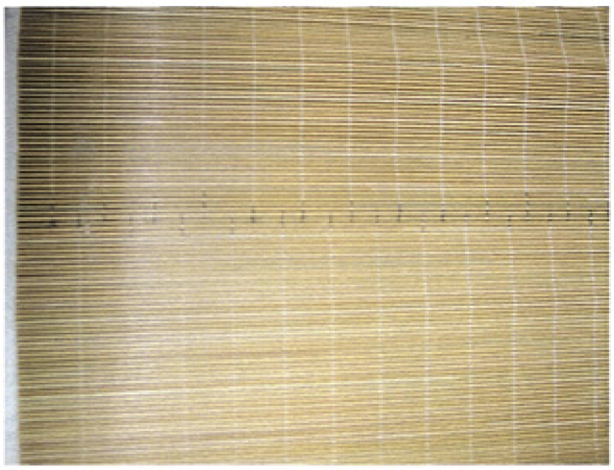


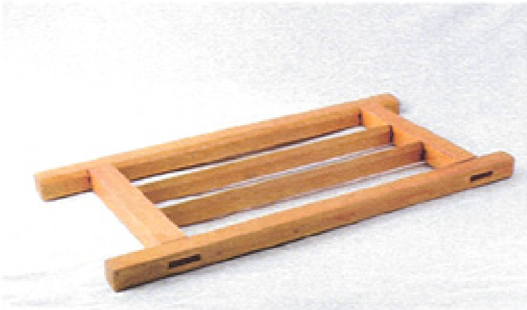
Figure 13. Shifting alignment of chain lines in the centre – Korean screen.

A balteul has several supporting ribs ('jirangdae' in Korean) which are normally wedge shaped in order to reduce the area in contact with the bal, otherwise paper produced would exhibit strips of thicker lines along the supporting ribs. The vertical rails (the longer side) of balteul have protruding ends (Figure 11) – on one side, ends are slightly longer than the others allowing the papermaker to hold the supporting frame and screen during the sheet forming process.

Figure 14. A Korean style mould (without screen) being placed in the vat (photo taken at Jangjibang, a traditional papermaking mill in Gapyeong, Korea).

Figure 14 shows a balteul being placed in the vat: for the sheet forming process, the middle of the far side (relative to the papermaker) rail of the balteul is tied with a rope and hung from a horizontal wooden bar approximately one foot above the vat - thus, the far side of the balteul is suspended approximately several centimetres above the vat stock. Consequently, during the sheet forming process, the far side of the screen is never submerged in the vat stock and the pulp is scooped only at remaining three sides of the frame.

Instead of using a rope, it appeared that sometimes a wooden support – by being placed in the vat – was also used to prop and balance the far side of the mould (Field, 1987, p12). However, until now, the reason why such a support was used has not been investigated. One possible reason



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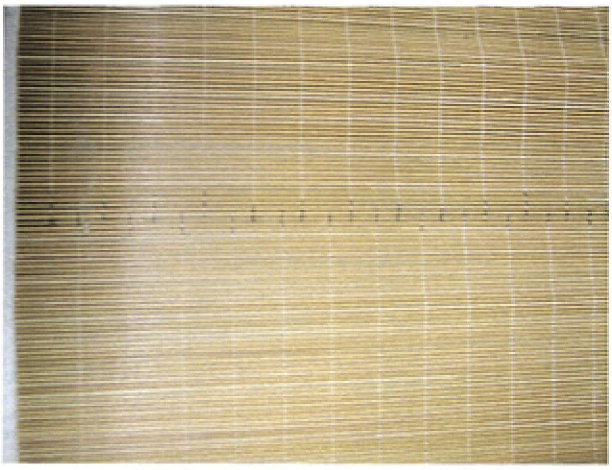

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Instead of using a rope, it appeared that sometimes a wooden support – by being placed in the vat – was also used to prop and balance the far side of the mould (Field, 1987, p12). However, until now, the reason why such a support was used has not been investigated. One possible reason could be that, traditionally, Korea produced sheets of relatively larger sizes. As paper was also used for floors, such large sheets must have been the part of papermakers' regular production. Forming a large sheet is not easy for one person as the forming process involves multiple scoops of the pulp stock and extensive manipulation of it - therefore, when large sheets were made, the forming process must have required two papermakers. Such a scene was vividly captured by Hunter (1947, pp96-97). Two images in his book show how the papermaking process was conducted when large sheets were required. However, the actual sheet forming process requires skilled papermakers, unlike other processes which could be carried-out by untrained people. Quite possibly, this might explain why Korean papermakers started to use a wooden support or a rope as a secondary support to the mould. Forming a large sheet with such an aid would have increased productivity as each skilled papermaker could work by himself.

With no deckle, stock tends to flow quickly across the loaded mould towards the opposite side of the screen before being discharged – thus papermakers are left little time to manipulate the screen. In order to hold the pulp stock longer on the screen, some papermakers slightly modified their balteul by attaching very thin wooden strips to the vertical rails to form a very shallow wall. In a sense, this could be seen as a modified version of the two-stick deckle.

Although this rather simplified structure of a laid mould – a flexible laid screen (bal) and a supporting frame (balteul) – was the only one known as a traditional mould in Korea, it appeared that two different types of deckle were also employed in Korean papermaking. According to Hunter (1947, p96), a two-stick deckle - which was used in China - was also noticed in Korea during approximately the same period (circa 1930s). The use of a two-stick deckle has not been noted by paper historians in Korea though Hunter's report provided useful information in the investigation of different types of deckle used in the country. Furthermore it showed that the craft of papermaking in Korea was closely related to Chinese methods.

The second form of deckle is a rectangular wooden frame used in Korea sometime before the 20th century (Paper Trade Journal, 1900). In the Paper Trade Journal article, the papermaking mould was described as follows:

> "The apparatus for forming the sheets of paper from the sized emulsion of fibres in the tub consists of a very fine bamboo screen or blind, which rests on a slight framework of wood. Before dipping it into the tub, the workman places on the screen a rectangular of wood, which rests on the edges of the screen and forms low walls…"

While, it is not known whether these various type of deckles were simultaneously used or had been employed one after another, both the two-stick deckle and rectangular wooden frame deckle seem to have disappeared from Korea around the beginning of the 20th century. Paper historians in Korea tend to refer only to the mould without a deckle as the traditional papermaking mould (Lee, 2002, p153. Jeon, 1996, p130. Cho et al, 1996, p70).

Meanwhile, a Japanese laid mould (known as a traditional mould) has quite a different structure from the Korean one. Such a device has the deckle – an open rectangular frame – hinged to its supporting wooden frame and two handles are attached to the deckle for an easy grip - a flexible laid screen rests on the supporting frame and the deckle is placed on the screen with the assembly being locked with two metal clips (Figure 15, 16).

Figure 15. A supporting frame and hinged deckle having two handles.

Figure 16. A flexible laid screen is in place and the assembly is locked with two metal clips.

According to Hunter (1947, p98) this type of mould was the most common but he also reported (1947, p103) the use of a second type. This other device consisted of a rectangular wooden frame (the same size as its lower frame) though without hinges or handles. This variation was also found in all papermaking districts of Japan. It is likely that such a mould was a transitional form – the hinged version being more advanced in its execution.

In modern times, the most widely known Japanese style of mould is the one with the hinged deckle having two handles but the history of this type of mould may not be long. In Hunter's book (1947, pp98-100) there are several Ukio-e prints dated between the late 17th and the middle of the 19th century depicting the sheet forming process. In these prints, all papermakers hold rather small rectangular wooden frames of shallow depth (Figure 17). None of the moulds has a hinged deckle or handles, but they appear to be similar to the second style, consisting of an open rectangular frame. This seems to suggest that the hinged deckle must have been a later improvement, probably arriving in the late 19th century.

Figure 17. 'The picture of Nagashi-zuki drawn in 1770', an Ukioe print from the book, 'Japanese Paper-making' written by Narita Kiyofusa, 1954.

One of the prints featured in Hunter, in fact, originates from Kamisuki Chohoki [A Handy Guide to Papermaking], one of the oldest pieces of Japanese literature related to papermaking and translated into English in 1948. The work gives a brief description of how the mould was assembled along with simple drawings of the papermaking mould, screen and other tools. The account notes that this late 18th century papermaking mould consists of a bamboo screen and two rectangular, wooden frames made with cryptomeria (Japanese cedar). One frame is slightly smaller than the other allowing it to fit inside – the structure appears to have three supporting ribs. The accompanying text states:

> "... The mat is spread over the outer frame and pressed firmly into place with the inner frame. The bamboo mat, made of finely cut strips of bamboo, like mizuhiki, is laced together with horsehair, as shown. ..."

This unusual structure of mould appears to be quite common in Japan at least up to the late 18th century, since three ukio-e prints in Hunter's book (1947, pp98-99) depict the assembly in very similar ways. In the interests of expediency, Kamisuki Chohoki described how the papermaker used a pair of moulds, rapidly forming sheets as follows:

> "The entire mould containing the moulded paper is set on the mold holder (ketamotase) at one's left, and allowed to drain; then a second mold is dipped, the paper from the mold just placed on the holder is couched, and the operation repeated as before. With practice, great speed may be attained.... "

Although there is no coucher present in the scenes depicted in the prints, one must have been present to assist the papermaker – working by himself, it would have been apparently impossible for the papermaker to couch the previously formed sheet while, simultaneously dipping a second mould.

Unfortunately, no more detail of the couching process is included in this account. It is quite possible that each time a sheet was formed, the inner frame was taken out and the screen picked up for couching. However, it seems more likely that papermakers couched the newly formed sheet without removal of the screen – a step which would have considerably slowed production. Additionally, removal of the screen might have presented a risk of damaging the wet sheet.

Therefore, no exact account of the couching procedure is available – though in speculation, the following technique is suggested as plausible: a raised, clean platform is prepared – the dimensions of this raised surface being slightly less than the inner dimensions of the smaller frame. As the depth of the deckle is rather shallow, couching could be carried out by inverting the whole mould assembly and ensuring good contact between the newly formed sheet and the platform. With a gentle rocking motion, the sheet could be easily released from the smooth bamboo screen.

Conventionally, with the flexible laid screen, couching is achieved by picking the screen up whilst the newly formed sheet remains on the screen. The screen alone is inverted (the sheet still remaining on the screen) and, from one edge, the newly formed sheet is lowered onto the previously couched sheet or platform. In this, the newly formed sheet makes gradual contact with the surface below.

However, in the hypothesis above, though the screen itself is essentially a flexible one, it is firmly fixed between a supporting frame and a rectangular deckle (the inner frame) and is effectively rigid. The screen cannot be rolled and therefore, complete contact is immediately made between the newly formed sheet and the platform. In this respect, the technique may have been similar to the European couching process. In any case, this late 18th century Japanese mould structure is certainly different from the contemporary one and it is interesting to trace this development of the papermaking mould in Japan.

Now it is apparent that three different types of mould structure have been employed in traditional Korean papermaking: a flexible laid cover with a two-stick deckle, a rectangular wooden frame deckle, and the mould with no deckle. Although a flexible laid screen without deckle (which has been regarded as a traditional Korean papermaking mould) appears to be unique in Korea, apparently, other types of deckle had also been used until the beginning of the 20th century. Even though their origins are not yet known, examples of the same type of mould structure employed in neighbouring countries certainly reflect that the development of papermaking tools in the three countries of Korea, China, and Japan must have been closely related.

3.5. The traditional papermaking processes

As the development of the papermaking processes in Korea has not yet been thoroughly studied, it is difficult to firmly establish any variations made over time. Therefore, in this section, accounts of papermaking processes are limited to those which are currently regarded as traditional papermaking processes.

Harvesting paper mulberry

A year old 'dak' is usually harvested between November and February when the fibres of the inner bark are well formed and the moisture content of the bark is sufficient to facilitate easy peeling (Figure 18). When 'dak' is cut, the diagonal cross section is cut near the ground and facing south in order to encourage the 'dak' to sprout the following year. One-year-old dak has tender fibres which are suitable for papermaking whereas older dak has stronger and tougher fibres and also tending to have a more spotted bark. Such imperfections demand additional work for their removal after cooking.

Figure 18. Harvested dak (the picture was taken at a papermaking mill in Jeonju, Korea).

Steaming

The harvested dak is then steamed as the steaming process makes for easier removal of the skin of the raw dak. The steaming process is as follows: raw dak is placed in a large iron cauldron filled with water and then covered with a thick piece of textile or straw mat in order to retain the steam. Heating should be continuous for around seven hours - oak tree wood is the preferred fuel in providing heat.[11] When the dak is sufficiently steamed, it is removed from the cauldron and the skin stripped off. In cold weather, sometimes steamed dak is wetted and left outside overnight - the icy layer formed between the skin and the inner wood further aiding removal of the skin (Kim et al, 1992, p27).

At the end of the 19th century the task of stripping off the skin of dak was a task shared among farmers when they were not engaged in other farming duties. Two connected, gourd-shaped pits were dug in a field. In the smaller pit, bunches of firewood were piled and small stones placed on top of them. In the larger pit, branches of pine were placed at the bottom and the harvested dak was piled on top – an additional layer of pine leaves and twigs and lastly soil sealed the stack. The wood in the smaller pit was then lit causing the stones to become very hot. The smaller pit was covered with soil and the fire extinguished with water – the heat of the stones and the water producing steam. The steam was drawn rapidly to the adjoining, larger pit before cooking the dak and softening it (Cho et al, 1996, pp51-52).

Stripping and making 'baekpi (white bark)'

The softened bark was removed by hand. The stripping began from the bottom part of each length: the bottom part was held with one hand and the outer bark peeled off in strips with the other. The bark was then dried in the sun - this prepared bark, or 'heukpi' (黑皮, black bark) consists of three layers: the outermost layer a dark brown, the middle green and the inner a whitish colour. In papermaking it is the outer two layers of heukpi which are to be removed with the inner, whitish 'baekpi' (白皮, white bark) part alone needed.

In order to obtain baekpi, it is essential that the heukpi is soaked in water for approximately 10 hours before its two outer layers are scraped away with a knife (Lee, 2002, p128) (Figure 19) the white inner bark is then sun-dried (Figure 20). Either as heukpi or baekpi, the dried raw material

[11] Sung-woo Jang, a traditional Korean papermaker interviewed by the author in 2004.

can be stored for two or three years until required (Kim et al, 1992, p28).

Figure 19. A papermaker scraping the outer layers of cooked dak. (The picture was taken at Jangjibang)

Figure 20. The white inner bark hung for drying. (The picture was taken at Jangjibang)

Cooking

Before cooking the dried baekpi needs to be soaked in water for a day or two in order to make it soft and to aid the cooking process. It is then roughly cut with a sickle to reduce length, thus preventing it from becoming entangled during cooking. For cooking 'baekpi', lye[12] is obtained from ashes of the stems of plants, such as soybeans and chilli or the husks of buckwheat. Approximately ten to fifteen kilograms of ash can produce sufficient alkali solution to cook sixty kilograms of baekpi. Adding lye aids in turning the lignin and hemicelluloses in the bark into water soluble substances whilst additionally increasing the boiling point of the solution. A large earthenware pot with holes in its base has a piece of fabric placed in it - the ashes are put into the pot and warm water added until it becomes clear (Figure 21, 22). The piece of fabric acts as a strainer to obtain the yellowish liquid alkali. Papermakers check the solution by feel, rubbing it between a thumb and index finger – a slippery consistency (suggestive of soapy water) is thought to be sufficiently alkaline, normally giving a pH of approximately 11.

[12] Lye means alkali and, in this case, plant ash which contains potassium carbonate.

Figure 21. Wood ashes are poured into an earthenware pot. (The picture was taken at Jangjibang in Korea)

Figure 22. Collecting the alkali solution. (The picture was taken at Jangjibang in Korea)

Cooking starts with the boiling of the water and alkali solution in a large cauldron until the temperature reaches approximately 80°centigrade - the 'baekpi' is then added. Cooking the 'baekpi' lasts for about three to four hours – if a strip of the 'baekpi' can be torn by pulling with both hands (Figure 23), then the cooking is complete and the fire extinguished. The cooked 'baekpi' is not removed immediately but left in the solution for several hours.

Figure 23. A papermaker checking the cooked baekpi (the picture was taken at Jangjibang, in Korea)

<u>Washing and light bleaching</u>

When the cooked 'baekpi' is taken out of the cauldron it is placed in running water in order to remove the lye and any soluble derivatives of lignin and hemicelluloses. To improve the colour of ‘baekpi’, light bleaching is achieved by spreading the ‘baekpi’ in a stream on a day with good sunlight - in cloudy weather this process can take around a week though around 5 days in better light conditions. From time to time the bark is turned to provide even exposure to sunlight. Bleaching in this manner causes the ‘baekpi’ to whiten without damaging fibres.

Removing dirt and specks

After sun-bleaching in a stream, the baekpi is put in a shallow bamboo basket filled with water and any impurities are removed. Each strip is taken out of the water and carefully examined for impurities - defects in the bark caused by disease or scars, pieces of outer bark, and dirt are removed by hand with the assistance of blunt knives, sometimes used to scrape the surface. A time-consuming process, the task is usually undertaken by middle-aged women (Figure 24).

Figure 24. Removing dirt and dark specks from the baekpi (the picture was taken at Jangjibang, Gapyeong, Korea).

Beating

In order to break down the ‘baekpi’ into loose fibres, it is lightly squeezed, placed on a flat stone (Figure 25) or a wooden board and beaten with a mallet (Figure 26) until well spread out and softened, this usually takes around an hour. During the beating, water is occasionally poured onto the ‘baekpi’ as this helps the beating process. The degree of fibrillation can be checked by dropping a small portion into water and mixing well - if the fibres disperse well in water without much clumping, then the material is ready to be used in sheet forming. The fully beaten 'baekpi' produced at this stage is called 'dakjuk'. It should be noted that the fibres of paper mulberry remain long.

Figure 25. A flat, square stone with a wooden mallet (at a papermaking mill, Jeonju, Korea).

Figure 26. A half way beaten Baekpi (at Jangjibang).

<u>**Preparation of formation aid**</u>

To obtain mucilaginous substance from dakpul (*Hibiscus Manihot*), the roots are thoroughly washed with water and placed in a stone mortar or on a wooden board and pounded (Figure 27). The well crushed roots are left in water over night as a viscous substance is secreted from the roots (Figure 28), the material is then sieved and the mucilaginous solution is ready for use.

Figure 27. Pounding the root of dakpul (at Jangjibang).

Figure 28. Clear, viscous mucilage from the crushed and soaked roots (at Jangjibang).

The freshly prepared mucilaginous solution should be used immediately as it easily goes bad, particularly in summer. Though the roots can be dried and stored for later use, these generally yield a lesser quantity of the mucilaginous substance. Extracting the mucilaginous substance from dried roots is achieved in the procedure described above though, prior to pounding, the raw material should be well soaked in water (Kim et al, 1992, p23) The resulting solution is multi-functioned as discussed in chapter 4.

Preparation of vat stock

Well beaten fibres of 'baekpi' are put into a square container (a vat) filled with clean water and the vat stock is well stirred with a bamboo stick until all the fibres are evenly dispersed (Figure 29). A certain amount of 'dakpul' (the mucilaginous substance from the roots of *Hibiscus manihot, L*) is added to the stock. The amount of 'dakpul' added relies on the papermaker's experience. The vat stock is again well mixed to give an even thickness.

Figure 29. A papermaker stirring the vat stock with a bamboo stick. (The picture was taken at Jangjibang, Gapyeong, Korea).

Sheet forming process

Initially, the papermaker scoops the pulp stock by pulling the mould towards him and quickly spreads the pulp stock toward the far side casting off the excess stock by elevating his side of the mould. This first dipping will form the base of a sheet and is followed by several side-to-side dips

- each time any excess pulp stock is cast off to the opposite side (Figure 30, two short video clips of a sheet forming process are included in the attached DVD).

Figure 30. Casting off the excess stock (during sheet forming process, the picture was taken at 'Sinhyeonse Hanji' in Korea)

The number of side dips depends on the thickness desired by the papermaker. However, the thickness which could be achieved by the number of side dips is limited: when a deposit of fibres reaches to certain thickness, it blocks the gaps between the bamboo splints of the screen. As a result, the screen loses its function as a sieve, failing to increase the thickness of the fibre deposits.[13] Due to the manner of scooping, the far side of the screen tends to hold less pulp deposits, making the thickness of the sheet slightly uneven.

Couching

The papermaker lifts the near side of the screen which is then turned upside down for couching the sheet. Beginning at one short edge, the newly formed sheet (along with the screen) is gently laid onto a thick wooden board (Figure 31).

[13] This practical information was given during the interview with Jang Seongu, a traditional Korean papermaker at Jangjibang, Gapyeong, Korea.

Figure 31. A papermaker couching a newly formed sheet onto the pile of the previously couched sheets. (The picture was taken at Jangjibang in Korea)

Before, removing the screen from the pile, the papermaker rolls a thick, round wooden stick across the screen (in the direction of the shortest dimension of screen and paper) (a short video clip of the process is included in the attached DVD). Some scholars reported that this process was done in order to remove the water quickly from the newly formed sheet (Lee, 2002, p160. Kim et al, 1992, p32) though Jang Seongu, a traditional Korean papermaker, explained that it was not done for removing water but for eliminating any air bubbles trapped between the newly formed sheet and the previous one. He also explained that from the bottom, the first three or four sheets tend to trap air bubbles underneath and therefore, rolling a thick, round wooden stick helps to remove the trapped air bubbles.

As mentioned in the sheet forming process, a single sheet tends to have a slightly uneven thickness. Therefore, in order to balance the gradual uneven thickness, the sheets are stacked so the thicker side of one sheet is placed over the thinner portion of the next making one thicker sheet of even thickness. After pressing, they are removed from the stack together and dried as one. A paper made in such a way is called Ihapji (meaning a paper made by laminating two single sheets together).

The shifting alignment of stitches of thread in the centre of the bamboo screen is a result of this particular forming and couching processes. If the laminated sheets were not orientated in this manner, the impressions of the chain lines of the two sheets would correspond exactly to the other making the impressions more pronounced and resulting in a distinctively weak portion of the sheet. By rearranging the chain lines in the middle this problem could be avoided and the intervals of impressions of the chain lines on the sheet might appear as half that of the intervals of the chain lines of the screen.

Depending on the desired thickness, a paper can be made with three or four layers being laminated together in the same manner. Between each freshly formed sheet (or groups of two or three sheets depending on the desired thickness of a finished sheet), the papermaker places a string or a thread ('begae' in Korean) along the near side, short edge of each sheet. After pressing, this provision enables easier separation of the sheets for drying.

Pressing (squeezing water)

When 400 to 500 sheets are stacked, another wooden board is placed on top of the pile. Several heavy stones are placed on top of the wooden board and the whole pile is left overnight - the process removes approximately 70 % of the water from the sheets. It is ideal not to leave the paper longer than 12 hours before separating the sheets for drying - left longer, the mucilage contained in sheets begins to deteriorate (Kim et al, 1992, p32) (Figure 32).

Figure 32. A pile of sheets covered with a wooden board and pressed with heavy stones (The picture was taken at a traditional paper mill in Jeonju, Korea).

Drying

After pressing, each sheet is lifted from the pile with the aid of a thin bamboo stick and placed on a wooden drying board. As each sheet is still damp it easily sticks to the board. While placed on the board, a brush is used for smoothing all wrinkles from the sheet. Brushing should be done lightly to avoid roughening the surface of the sheets (Figure 33).

Figure 33. Placing wet sheets on a wooden drying board (The picture was taken at Sinhyeonse Hanji, in Korea).

In earlier times, occasionally drying was carried-out on the floor inside the house as traditional Korean heating was achieved by under-floor systems. The floor would be covered with thick vegetable oiled papers, and each sheet was separated from the pile and placed on the heated floor to dry. In 'Jeolra' and 'Gyeongsang' provinces drying large sheets such as 'jangpanji' (paper especially made for covering a floor) was often done in an open area: each sheet was placed on stones near a stream and any creases made during the drying process were flattened though the finishing process, 'dochim' (Lee, 2002, p165).

Finishing process

The traditional finishing process, 'dochim' (搗砧) was described in the section 3.2.2.
The 'dochim' (搗砧) process can be compared with calendering in modern western papermaking as it modifies the surface texture of the sheet making it glossy and smooth. Although this type of finishing process was also used in ancient China and Japan, it has been most extensively executed in traditional Korean papermaking. Since the 8th century, papermaking with paper mulberry was done without cutting or grinding, which resulted in intact, fairly long fibres. Due to these long fibres, sheets made by traditional methods must have been highly absorbent which was not an ideal quality for writing – additionally, writing would have been hampered by the surface nap.

This finishing process must therefore have been essential to make paper more suitable for writing. The main purpose of the process was to make the surface of the sheet smooth and, more importantly, to reduce the absorption of ink so that the ink was not easily spread on the paper. In order to investigate how the finishing process affects the paper in terms of density, smoothness, and absorption, Akinori (1999b, pp191-209) conducted an experiment. His results showed that while both 'dochim' and calendering increased density and smoothness of each sample, calendering did not reduce absorption. The 'dochim' process dramatically decreased the absorption of ink in papers made with hemp, gampi, and paper mulberry. From the results he speculated that pounding slightly dampened sheets increases the hydrogen bonding between fibres making the contact area between the fibres greater. Therefore, it is made more difficult for water or ink to penetrate into the paper. Meanwhile in the case of calendaring, the process could increase density of the sheet and set fibres closer. However, as the modern process is undertaken while the sheets are dry, less hydrogen bonding could occur between fibres and consequently calendering could not reduce absorption of the sheets. Although the 'dochim' process slightly decreased the strength of the sheets, the smoothness and absorption of the paper greatly improved the paper which became more suitable for writing.

4. Methodology and background to papermaking experiments

4.1. Survey of the Korean and Japanese collections

Aims and objectives of the survey:

Literature related to the subject of traditional Korean papermaking is so scarce that it is difficult to comprehend the whole development of papermaking and any variations made over the period in Korea. Existing historical literature concerning the materials and techniques of traditional Korean papermaking is often incomplete and falls short of describing the entire processes or including details of tools used. In order to establish clearer understanding of the history of traditional papermaking and its development in Korea, it is necessary to collect as much supplementary information as possible.

Old paper itself is a primary source for research into the history of papermaking. Most handmade papers bear the impression of the mould with which they were made. That impression, along with other characteristics of the paper, offer useful information on papermaking materials and tools used. On occasions, useful clues as to the papermaking technique are evident. Therefore, a database of such characteristics can provide invaluable information, helping to identify any historical trends in papermaking practice.

The aim of the survey is to collate information on the characteristics of old Korean paper and to present this as a database. Additionally, the database is intended to provide a point of reference in understanding and contextualising old Korean papers of unknown date.

The British Library has a considerable amount of old Korean books dating from between the 15th and 20th century - the survey was mainly carried out on those books whose dates are known among those responsible for the Korean collection. In order to supplement data on the characteristics of paper dated before the 15th century, an additional minor survey was conducted on a private collection in Korea. The data collected from this secondary survey relates to items dated between the 11th and 14th centuries, though most of their exact dates are rather ambiguous. However, a degree of credence was given to these dates after consultation with Nam Gwon-Hi - an expert on the science of bibliography and a professor at the Department of Library and Information science at Gyeongbuk University in Korea.

As discussed before, the development of traditional Korean papermaking had been closely related to Chinese and Japanese papermaking especially in terms of the materials and tools used. While the main material of traditional papermaking in China was grass fibres (in particular bamboo), the main material in Korea and Japan has been paper mulberry. Since both countries extensively used paper mulberry in traditional papermaking, the papermaking techniques employed in Korea and Japan must have been similarly developed. Consequently, understanding Japanese papers was considered to provide a better understanding of any missing elements in the history of papermaking in Korea. Thus, a small number of Japanese books at the British Library were also included in the survey.

In order to understand materials used for the Korean and the Japanese papers, a small amount of sample fibres were taken from each paper with permission of curators. For information on the materials used for old Chinese papers, previous research was used as a reference.

To sum up, the aims of the survey are as follows:

- To build a database of characteristics of traditional Korean paper
- To identify papermaking materials and any trends in their use over time through fibre analysis
- To discover any variation in papermaking screen and mould structure

Designing a survey form

Any similar surveys conducted by other scholars were reviewed as a preliminary step in designing a survey form. At the same time, any established standard survey form for this type of research has been sought. The website of International Paper Historians (IPH)[14] provides a form of 'International standard for the registration of papers with or without watermarks' which is intended to be a technical standard for data recording. Although it appears to be designed and updated to accommodate different types and origins of paper, the form is too complicated to be appropriate to this current research, including too many fields which are not relevant to historical Asian handmade paper. Consequently, with available examples taken as a basis, a new form has been designed and tailored to this research.

The validity of this type of survey relies on the objectivity of its methods as well as the quantity of dated samples examined. The survey form was designed to include any relevant criteria for describing paper characteristics as comprehensively as possible and to exclude any information based on subjective judgement.

It is intended that the standardization of the survey form will provide invaluable information on the characteristics of each collection. Thus, it additionally stands as a means for drawing comparisons between collections.

The survey form consists of 23 fields - they are as follows:

1. **Collection:** Initial of the collection [BL (British Library), DU (Durham University), etc] and nationality of the object.
2. **Catalogue No.**: This is a unique code given to the each object at museum. It can be used as a key word.

[14] http://www.paperhistory.org/standard.htm

3. **Title**: The title of the object.
4. **Date**: The recorded or published date of the object. If the object does not have a correct date then an estimated date was recorded.
5. **Dimensions**: Size of the object (height x width) measured in centimetres.
6. **Type/Format:** Format was recorded as manuscript, woodblock, moveable type etc. Also whether a book or a single sheet.
7. **Binding**: Many Asian books were rebound according to the Western style at the British library. In such cases, the top and bottom edges were often trimmed and thus, the size of the object has been altered.
8. **Page**: The number of the page examined is noted where the object is a book.
9. **Layers**: In the case of books, individual leaves often consist of folded sheets whereas documents or letters are on single sheets. In certain cases, a loose sheet may be comprised of a laminate of several layers of paper.
10. **Thickness (μm)**: Thickness is measured with a micrometer. The nature of handmade paper is rather uneven throughout the sheet. In order to obtain an average thickness of a sheet, six points were measured (two points at the bottom edge, two points at the vertical edge and two points at the top edge).
11. **Density of fibre**: In the case of the single leaf in a book, it is difficult to calculate its density as the sheet cannot be separated from that book. Although there is the potential to introduce subjectivity, the density of such sheets is assessed by examination with the naked eye while the sheet is held to the light or against a light box.
12. **Surface Characteristics**: Surface characteristics based on observation with the naked eye.
13. **Characteristics of paper**: Tactile characteristics such as softness or crispness. Certain paper has a distinctive sound: for example, Gampi paper has a distinct rattle when gently shaken. Similarly, the sheet containing paper mulberry and a high percentage of rice straw pulp is crisper than that made with paper mulberry alone.

14. **Quality of pulp (Distribution of fibres)**: The degree of beating the pulp appears to have undergone. Insufficiently beaten pulp tends to have coarse fibres which are not properly separated into individual fibres and remained bundled. Therefore, if many coarse fibres are present, insufficient beating during the papermaking process is indicated.

15. **Impurity (shrives & unbeaten fibres)**: Impurities in the fibre furnish such as coarse fibres from the outer bark of the plant source are noted.

16. **Characteristics of Chain lines**: Chain lines are imprinted marks from threads or horse hair used for binding bamboo splints. The intervals of chain lines in traditional handmade paper often appear to be random. Therefore, measurements of all intervals are taken from right to left to assess the degree of regularity in the intervals throughout the sheet.

16-1 Direction: horizontal or vertical.

16-2 Clarity: how clearly chain lines can be seen, categorised from distinct to invisible.

16-3 Intervals: measurement between chain lines.

16-4 Thickness: thickness of chain lines in millimetres. The finest and the widest chain lines are measured using a ruler.

16-5 Character: chain lines usually run parallel to each other though in some instances appear to be rather convergent.

17. **Characteristics of Laid lines**: Laid lines are imprinted marks formed by bamboo splints or plant stems which comprise the mould.

17-1 Clarity: overall clarity. Whether laid lines clearly appear through the sheet.

17-2 Number of laid lines per centimetre: In order to obtain an average number of laid lines in one centimetre, the number of laid lines in 4 centimetres is counted and the count divided by four.

17-3 Thickness: thickness of laid lines.

17-4 Visible with: light source under which the laid lines become most visible - transmitted, raking, and a normal reflected light conditions are employed. In most cases, transmitted light renders the impression of laid and chain lines clearly visible though thicker papers reveal this characteristic more readily in raking light.

17-5 Counted from: in the most cases, observation is easier from the side of the sheet which was formed directly in contact with the papermaking screen.

18. Showing distinctive fibre directions: Whether the main fibre direction is noticeable with the naked eye.

19. Trace of supporting ribs in the mould: In certain cases, the mould has been constructed in such a manner that the supporting ribs are in direct contact with the screen. The sheet formed in such a mould generally exhibits a greater density of fibres deposited around that area along the ribs. The chain lines in such a paper are therefore accompanied by shadowy, thicker lines. Such information can be useful in understanding the structure of the mould used. (e.g. how many ribs were used in the mould, how closely they were placed etc.) According to Hunter (1978, p121) the rib shadow appears to be common in European antique laid paper produced before about 1800 due to the common mould structure.

20. Process of surface finishing: The presence of additional surface treatment applied to the sheet such as sizing, burnishing, calendaring etc.

21. Images: In order to record colour and texture, a photograph is taken of each paper sample. A template with a 4 x 6 cm aperture was prepared and a mini standard colour chart and scale included for reference.

22. Fibre sample: the decision to take samples from pages was based on the uniqueness of the sheet. In cases where a particular sheet resembled any previous pages, a fibre sample was not taken and the decision noted.

23. Comments: Miscellaneous characteristics which are not recorded in the above fields.

Survey method

It is often the case that a given book was printed on more than one paper type exhibiting a variety of impressions of laid and chain lines and even different materials. In order to include as many different types of sheets used as possible, every page of each volume is initially checked with the naked eye. Subsequently, selected pages are closely examined and their characteristics recorded on the survey form.

4.2. Fibre analysis

Identifying fibres has been a common method to obtain important information on the materials used for each paper. By analysing enough samples of a known date, a database can be built up which would provide useful information on what type of raw materials had been used over time in traditional Korean papermaking. Once the trend of raw material use is understood, this might also help to deduce the approximate period during which the paper was produced for those papers of unknown date.

It is important to select the most effective methodology for fibre identification as the amount of fibre samples taken from each object is very limited - the use of several different methods in fibre identification is not an option.

Fibre analysis has mainly relied on microscopic examination and staining tests. The most common staining method appears to be the Graff 'C' stain: according to Lee (2006) C-stain exhibited most diversified colour reactions to different fibre samples. He reported that the colour reaction of paper mulberry to C-stain was reddish brown, whereas hemp and jute fibres appeared to be brown and dark purple respectively. The author regarded C-stain as a useful tool for identifying fibres and stated that Wilson's stain could be used as a supplementary method for identifying fibres which were difficult to identify with C-stain.

Another researcher, Son (2005) also employed C-stain to identify fibres from 1500 old Korean papers especially used for documents dated between the 15th and the 19th centuries and reported that all the papers tested were solely made paper mulberry. Son explained the reason why she chose this staining method for her research was that C-stain was used as an International standard because nearly all papermaking fibres could be identified by their colour reactions to C-stain.

As this staining method seems to be well accepted as a useful tool for fibre identification by other scholars, in this current research, the colour reactions of C-stain to six fibre samples (four bast fibres and two grass fibres) from papers (hemp and flax) and raw materials (paper mulberry, sandak, rice straw, and barley straw) were recorded in order to evaluate its effectiveness. Fibres from the raw materials were prepared in the same way as the standard samples were prepared (See the following section). C-stain was prepared in accordance with Technical Association of the Pulp and Paper Industry (TAPPI) Official standard T 401 (See appendix 2).

The results of the test are as follows (Figures 34 – 39).

Figure 34. Paper mulberry (raw) exhibiting deep reddish brown to reddish purple colour. Loose primary walls in light bluish-grey (x200).

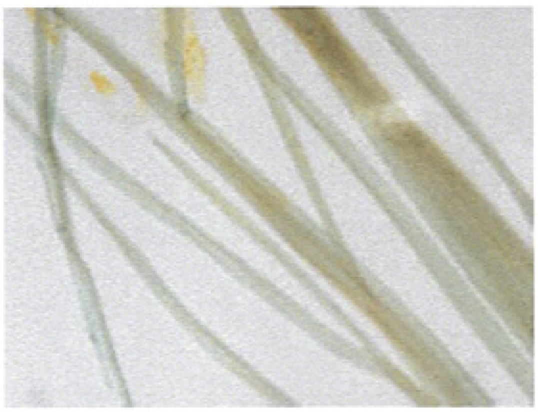

Figure 35. Sandak (raw) exhibiting light blue to grayish blue (x200).

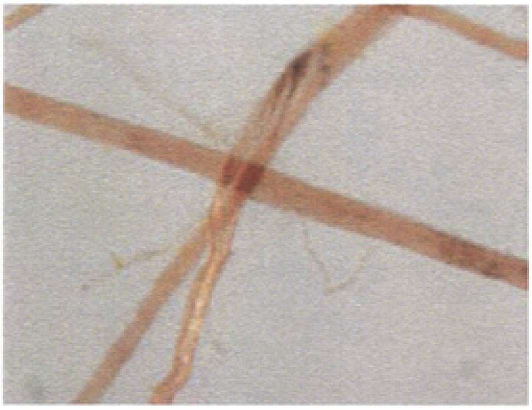

Figure 36. Flax exhibiting light reddish purple (x200).

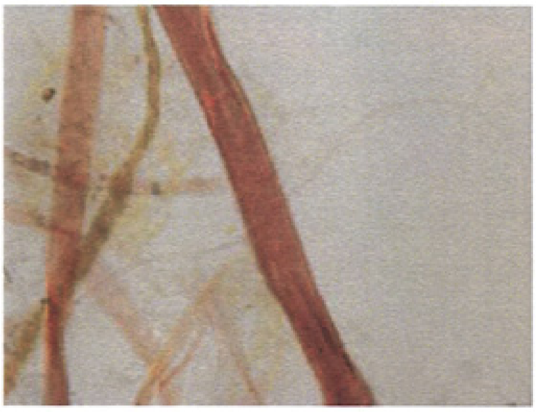

Figure 37. Hemp exhibiting deep reddish purple (x200).

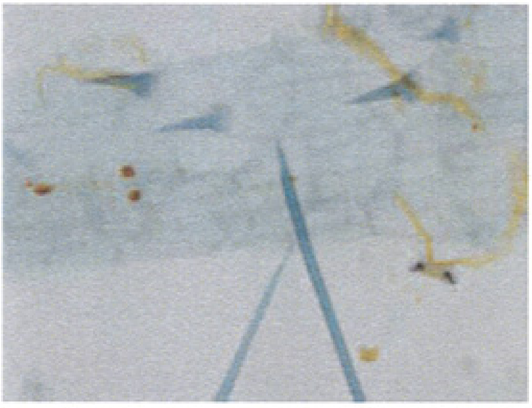

Figure 38. Barley straw exhibiting grayish-blue fibres and prickle hairs. Thin-walled parenchyma cells also appear to be light blue (x400).

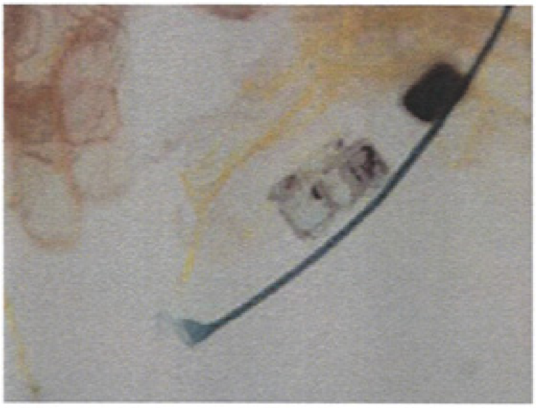

Figure 39. Rice straw exhibiting dark grayish-blue. Thin-walled, rectangular parenchyma cells appeared to be light reddish brown (x400).

From their colour reactions it is easy to distinguish bast fibres from grass fibres except in the case of sandak. Although the results show that C-stain gave slightly different colour reactions from paper mulberry, hemp, and jute, the colours are so similar that it would be difficult to differentiate one from the other when paper mulberry and hemp or jute are present in one paper. Loose primary walls of paper mulberry become more easily noticeable after staining, however, not all paper mulberry fibres have them. Thus, identifying fibres with C-stain alone would give restricted results and it is advisable to combine this technique with other conventional methods.

Only recently has a new analytical technique with Attenuated Total Reflectance (ATR) spectroscopy been explored by conservation scientists in fibre identification. Garside & Wyeth (2003, pp269-275) applied Attenuated Total Reflectance (ATR) spectroscopy to identify bast fibres which have similar chemical components. The characterisation method is achieved in calculating ratios based on the overall organic content, the lignin content and the cellulose content. It was found that native fibres showed clearer characteristics than processed ones due to their higher lignin contents; however, for each of the species of fibre, the ratios fell within characteristic ranges. The use of ATR spectroscopy in fibre identification appears to be of great value in the exclusion of subjectivity which often cannot be avoided where conventional techniques are applied in fibre identification. However, since the analysis was carried out with textile threads and (as noted by the authors) the method may give ambiguous results with fibres in paper where additives and/or sizing materials are present in the paper. Furthermore, the ATR spectroscopy technique is not a readily available facility for many paper conservators. Significantly, an extensive database is required in order to obtain a standard spectrum of each fibre sample, therefore, more preliminary research is needed before this technique is adapted to identifying papermaking fibres.

The most conventional and commonly practiced technique for identifying fibres is examining morphological characteristics of fibres using a polarizing microscope. In the current research this technique was selected for fibre identification since it seems to give relatively detailed and reliable results compared to other techniques reviewed above.

In order to identify unknown fibre samples from historical paper objects, it is crucial to understand all distinctive features of fibres from each plant used for traditional Korean papermaking. In this current research this was achieved by:

- Making standard fibre samples from raw materials used for papermaking in Korea and recording their morphological characteristics.
- Summarising (from previous studies references relating to fibre identification) the morphological characteristics of each plant.

These summarised features will be used to compare the fibre samples from the survey in order to identify the material used.

Therefore, it is crucial to understand which morphological features of papermaking fibres have diagnostic values: for fibre identification, the most valuable characteristics are those not easily affected in the papermaking processes. Catling and Grayson (1982) evaluated the main morphological characteristics of vegetable fibres which had been regarded as important factors for identifying vegetable fibres by previous researchers. Their work provided more refined key features which have better diagnostic values in identifying fibres. Their evaluation can be summarized as follows:

- Cell wall and lumen features may be useful.
- The forms and distributions of crystals and silica are useful in the identification of vegetable fibres.
- The features of cross-markings can provide information on the whole structure from which the fibres have been taken.
- The shapes of fibre cell ends tend not to be very useful character in identifying plant fibres.
- As dislocations occur in all fibre species observed during their study, dislocation is not a useful characteristic in identification of plant fibres.

While the above authors presented the key features of important diagnostic value in the main vegetable fibres, their work does not give reference to any grass fibres which are commonly used for papermaking in East Asia.

Marja-Sisko Ilvessalo-Pfaffli (1995) compiles the information on papermaking plants needed by the fibre analyst for identification purposes including 117 fibre species. His work presents the structure of the raw materials as well as the identification features of the individual cells. Also presented are comprehensive illustrations of important features of each fibre along with useful information on identification and differentiation characteristics between species. The author provided useful guidance on features. Although the book covers a wide range of wood and non-wood papermaking fibres, it does not have information on other varieties of paper mulberry, the main material in traditional papermaking in Korea and Japan. Therefore, it remains essential to obtain more comprehensive information on bast and grass papermaking fibres from Korea in order to identify fibres from unknown samples of traditional Korean paper. This current research seeks to provide this information.

Sang-Jin Park (2001) identifies fibres from 33 historic Korean books dated between the 11^{th} and the 19^{th} century. As 14 samples were prepared from raw materials used in traditional Korean papermaking, this paper contributes important information on the subject. He divided them into four groups: group A, B, C, and D. The group 'A' included paper mulberry, hemp, Samjidak, mulberry, Kgujibpongnamu, Deungnamu. Group 'B' included bamboo, rice straw, Kudzu vine, reed, and willow. Group 'C' included Sandaknamu and fibres from coniferous trees. Lastly, group 'D' was cotton. Identification was made based on his observations of three features: the number of cross markings in 1 millimetre, width and fibre shape (i.e. whether rather straight or wavy). 500 fibres from each sample were examined and the number of cross markings in one millimetre of fibres was counted. The results are summarized in Table 3.

Table 3. Features of fibres from 14 raw materials used in traditional Korean papermaking

Name	No. of cross markings	Width of fibre (μm)	Shape	Comments
Paper Mulberry	7.21±2.96	11.32±3.29	Wavy	-
Hemp	15.04±5.01	14.69±8.89	Smooth and relatively straight	-
Samjidak	3.37±0.82	6.34±2.18	Wavy	-
Mulberry	3.21±0.52	9.70±3.12	Smooth and relatively straight	-
Kgujibpongnamu	1.13±0.34	8.98±2.25	Smooth and relatively straight	-
Deungnamu	2.11±0.37	7.41±1.79	Smooth and relatively straight	-
Bamboo	None	6.33±2.22	-	Small rectangular parenchyma cells, recticulate vessel element.
Rice straw	None	4.21±1.68	-	Dumb-bell shape silica body (width:10.7 μm), not many rod shape of cells.
Kudzu vine	None	11.71±4.99	-	Vessel element.
Reed	None	6.30±1.87	-	Recticulate vessel element. Dumb-bell shape silica body. Many rod like shape of cells.
Willow	None	9.30±2.42	-	Crystals.
Anpi	None	24.55±5.26	Generally translucent fibres with smooth surface. Fibres look slightly bent and relatively longer than the fibres of coniferous tree.	-
Coniferous tree	None	35.93±10.64	Fibres are short and in many cases the surface of fibre has wrinkles and bordered pits.	-
Cotton	None	-	Ribbon like shape.	-

From the relationship between the width and the number of cross markings in one millimetre, Park found that the wider the fibre, the more frequently cross markings occurred and therefore, he used this finding as an identifier of hemp fibre. The author also commented that fibres from hemp, paper mulberry, mulberry, mitzumata, and Japanese wisteria all exhibited cross-markings and these might be a morphological characteristic resulting from 'processing' rather than an intrinsic, natural feature of the fibres. Park did not specify what kind of 'processing' he referred to and left his statement rather ambiguous. Catling (1982, p4) defined the term, 'cross-markings' as 'the attached wall remains of neighbouring cells' or 'the impressions on the fibre cell wall made by neighbouring cells which have been removed during processing'. Therefore, cross-markings should be regarded as an intrinsic part of fibre walls. Whether processing increases the number of cross markings on fibres has not been scientifically verified.

According to Park's analysis, the materials used for sheets in books were mainly paper mulberry and hemp. Before the 15th century, sheets were usually made with paper mulberry and hemp though during the 15th century rice straw, gampi and cotton were more frequently used. From the 16th century paper mulberry and hemp returned as the predominant materials. The author also reported that a tracheid cell of coniferous tree was found from a 13th century Korean paper and suggested further research needed to be done as there was little possibility that fibres of coniferous tree could have been included during traditional papermaking process at that time.

Park concluded that the main material for books was paper mulberry, often in combination with hemp fibre. However, as all standard samples were described only with Korean names (with no regard to botanical names) credibility and comparability of this research was somewhat compromised. Furthermore, the number of objects examined was too small to draw any substantial conclusions on trends in use of papermaking materials in Korea.

More recent work on fibre identification of old Korean paper was conducted by Lee (2006). Lee presented a summary of fibre length and width characteristics of plants which appeared to be used in traditional papermaking in Korea (Table 4).

Table 4. Features of raw materials used in Korean papermaking

Name	Habitat/ Part	Fibre length (mm)		Fibre width (μm)	
		Range	Average	Range	Average
Paper mulberry (*Broussonetia Kazinoki Sieb*)	Korea	3.0 – 16.5	8.7	14.0 – 41.0	22.5
	Japan	5.5 – 21.0	9.0	10.5 – 30.0	20.3
Paper mulberry (*Broussonetia papyrifera*)	China	3.0 – 20.0	9.3	12.5 – 43.5	26.0
	Thailand	5.5 – 20.5	10.5	24.5 – 35.0	30.2
Samjidak (*Edgeworthis papyrifera*)	Korea	1.6 – 6.0	4.0	9.0 – 32.5	20.5
	China	2.5 – 4.0	3.0	7.5 – 20.5	18.0
	Japan	3.0 – 5.0	3.5	10.0 – 30.0	20.0
Mulberry (*Morus bombycis*)		2.7 – 29.0	12.2	12.5 – 59.0	30.2
Deungnamu (*Wistaria floribunda*)		0.9 – 2.6	1.7	8.8 – 23.0	17.5
Red pine (*Pinus densiflora*)	Inner bark	1.0 – 2.7	1.8	9.3 – 24.8	18.6
	Needles	0.5 – 1.5	1.0	10.5 – 27.5	20.6
Willow (*Salix purpurea*)		0.7 – 1.8	1.5	8.4 – 21.0	16.6
Bamboo (Phyllostachys pubescens)	Whole stalk	1.5 – 3.1	2.5	7.5 – 27.0	19.7
	Rind	1.5 – 2.9	2.3	11.5 – 21.5	20.5
	Woody core	1.3 – 2.2	1.5	10.0 – 15.0	13.8
	Membrane	0.3 – 1.9	1.2	13.0 – 20.5	16.9
Hemp (*Cannabis sativa*)	Bast fibre	5.0 – 45.0	10.2	10.0 – 51.0	19.1
	Core	0.5 – 4.5	1.7	8.0 – 72.0	22.5
Jute (*Corchorus capsularis*)	Bast fibre	0.5 – 4.8	2.4	10.0 – 25.0	16.3
Cotton (*Gossypium arboretum*)	Lint	1.0 – 49.0	16.0	10.5 – 38.0	17.4
	Bark	0.5 – 10.6	3.1	8.0 – 23.0	18.0
	Core	0.4 – 2.7	1.5	8.5 – 27.0	22.6
Rice straw (*Oryza sativa*)	Whole	0.4 – 3.5	1.4	4.0 – 16.0	7.7
Oat straw (*Avena sativa*)	Stem	1.3 – 3.4	2.0	8.3 – 33.1	24.8
	Blade	1.0 – 3.0	1.5	7.9 – 31.5	23.8
Adlay (*Coix lachrymajobi*)	Stem	1.5 – 3.2	1.6	7.5 – 29.7	22.3
	Blade	1.5 – 3.7	2.5	7.0 – 30.5	23.2
Reed (*Phragmites communis*)	Whole	1.0 – 3.0	1.5	8.0 – 20.0	18.3
Rush (*Cyperus exaltatus*)	Stem	2.3 – 5.0	3.4	4.8 – 19.5	14.5
	Blade	1.0 – 2.7	1.8	6.5 – 26.0	19.4
Cattail (*Typha orientalis*)	Stem	1.2 – 4.5	1.7	7.2 – 29.0	21.6
	Blade	0.6 – 2.5	1.0	7.5 – 30.5	23.0

As both species of paper mulberry, *Broussonetia kazinoki* and *Broussonetia papyrifera* have grown in Korea for a long time and have cross-fertilised with each other, it is not clear why the raw materials for both species of paper mulberry were obtained from different countries. Lee did not state what criteria were applied to select raw materials. However, his research still provides valuable information on the characteristics of fibres from the materials which were used as a substitute for paper mulberry and, furthermore, the data is meaningful as the standard samples were mainly taken from plants in Korea.

Lee's research additionally included staining techniques for identifying fibres which were discussed earlier.

On establishing the characteristics of fibre samples, the author analysed only five Korean papers and identified their materials using his data. It appeared that one of the lining papers included fibres exhibiting the window-like pits seen in the tracheid cell of pine tree wood. This suggested that the paper was made with a mixture of paper mulberry and the inner bark or Xylem of the pine tree. Lee did not specify the age and origin of his samples, however, as he mentioned papermaking experiments using a wide range of raw materials during the period of Japanese colony (1910 – 1945), it is possible that all samples could have been from the beginning of the 20th century.

Standard fibre samples from raw material

Nine reference specimens were collected from Korea from local plants used for papermaking in order to identify the fibres in the paper surveyed at the Korean collection. These include paper mulberry (*Broussonetia kazinoki Sieb*), 'samjidak' (oriental paperbush, *Edgeworthia papyrifera Sieb. Et Zucc*), mulberry (*Morus alba*), 'sandak' (*Wikstroemia trichotoma*), pine tree (*Pinus densiflora S. et Z.*), bamboo (*Phyllostachys pubescens*), rice straw (*Oryza sativa*), barley straw

(*Hordeum vulgare var. hexastichon*), and eulalia (*Miscanthus sinensis Anderss*). Historically, eulalia must have been more likely used for screen making due to its smooth, long, and thin stems. However, from the 15^{th} century, a wide range of plants were used as papermaking materials in the Korean peninsular and eulalia must have been commonly available for papermakers. Therefore, it was decided to include photomicrographs of eulalia fibres in the current research. Hemp and flax have a long history as papermaking materials in Korea and Europe and therefore, their photomicrographs are also included. Hemp fibres were taken from a 100 percent hemp paper made in the University of Iowa, Center for the Book (UICB) Paper Research and Production Facility. The photomicrographs of flax were taken from a standard slide at Burt Hall, Northumbria University.

In order to break down the specimens into loose fibres, a small sample of each plant was refluxed in a 1% aqueous solution of potassium hydroxide (KOH) for between 1 and 10 hours depending on the sample. This particular method was used because of its similarity to the traditional technique of boiling in wood ash to break down the stems. When the samples were cooked they were rinsed with distilled water and mounted using the method described below.

A tiny fragment of each paper sample was placed on a microscope slide and a drop of distilled water added to help in the separation of the fibres using a pair of dissecting needles. Then the slide was placed on a hot plate until the water completely evaporated, a cover slip was placed on top of the fibres and a drop of melt mount was applied to one side of cover slip.

Methodology

<u>Polarising microscope</u>

The morphological characteristics of the fibres from each sample were examined with a JNOEC XS-201 polarising microscope which enabled clear observations of the fibres by changing the angle of the analyser. Photomicrographs were obtained with a Nikon Coolpix camera, typically at magnification of 250x or 400x. This method has been the most conventional method for identifying fibres yet it requires great experience.

Scanning electron microscope (SEM)

In order to examine the surface characteristics and the layer structure of the objects, each object was observed with a FEI Quanta 200 Environmental Scanning Electron Microscope (ESEM) and photographs taken typically at a magnification of 200x. Such examination requires removal of a small sample of paper from each object, thus causing a degree of damage – the objects from the Korean and Japanese collections at the British Library were excluded from this test. However, small samples of 38 objects dated between the 13th century and the 17th century from a private collection were donated for the current research.

Characteristics of standard samples

In this section, the characteristics of standard fibre samples are summarized based on observations and additionally, any previous reports made by other scholars.

Paper mulberry (*Broussonetia Kazinoki Seib*)

There are two species of paper mulberry: one is *Broussonetia Kazinoki Seib* and the other is *Broussonetia Papirifera.* Microscopical examination of fibres from both plants revealed that their morphological characteristics were more or less the same making it difficult to distinguish one from the other (Yum, 2001, pp98-99). Paper mulberry fibres are characteristically thick-walled and vary in width. The lumen is narrow and discontinuous (Figure 40). The surface of it is smooth (Figure 40, 41). Some fibres show faint, infrequent cross-makings (Figure 40), whereas others have dislocations and many cross-markings of varying thickness (Figure 42). There are also wide, thin-walled, ribbon-like fibres with faint cross-markings. Many fibres are enveloped in a thin, transparent membrane which has been recognized as a most distinctive characteristic of paper mulberry. The standard sample also exhibits prismatic cuboid crystals (Figure 43), rhombic crystals (Figure, 44) and thin-walled rectangular parenchyma cells (Figure 45). Apart from a presence of rhombic crystals, these observations are similar to those reported (Ilvessalo-Pfaffli, 1995, p348).

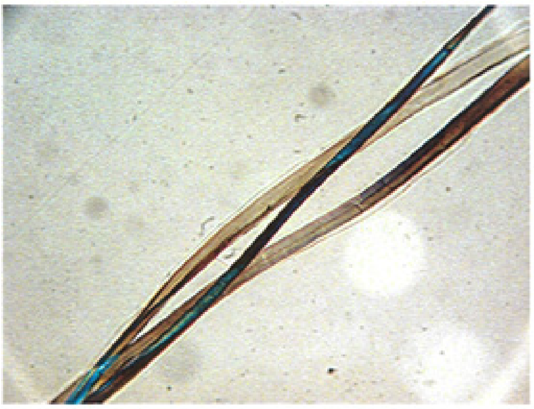

Figure 40.Fibres with loose primary wall (x250)

Figure 41. Fibre with smooth surface and faint cross-markings (x250)

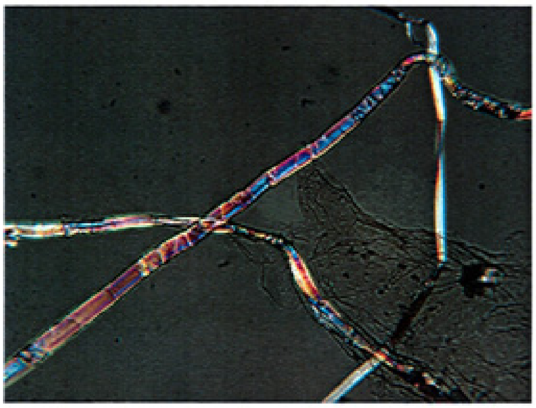

Figure 42. Fibre with frequent cross-markings and varying in width (x250)

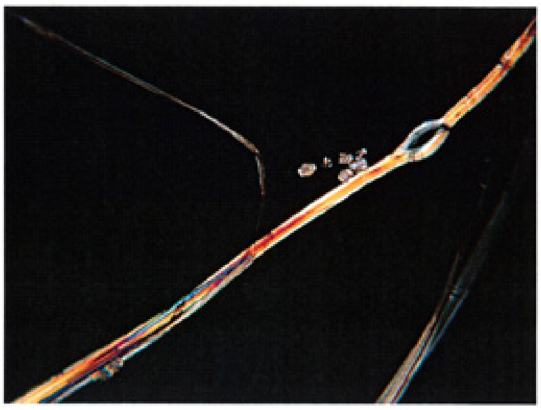

Figure 43. Prismatic cuboid crystals (x250)

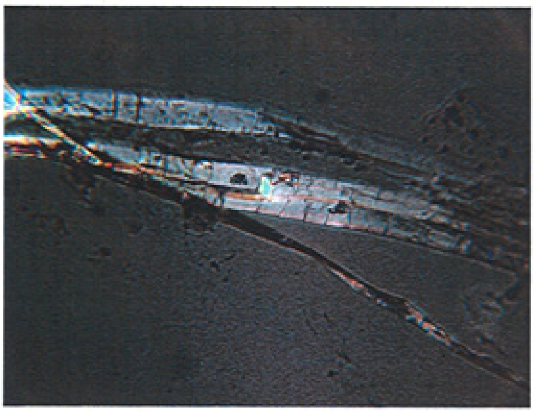

Figure 44. Rhombic crystal (x400)

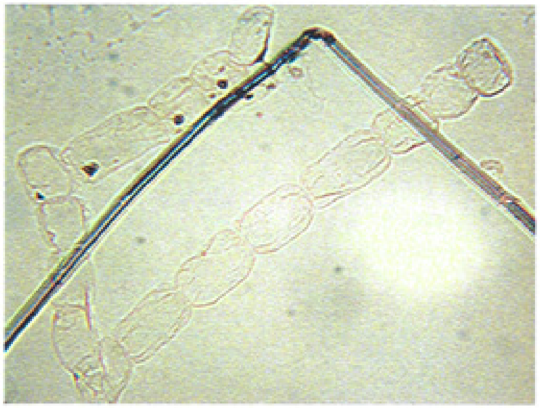

Figure 45. Thin-walled rectangular parenchyma cells (x250).

Figures 40 – 45. Cells and fibres found in the standard sample of Paper mulberry

Samjidak (*Edgeworthia papyrifera*)

Fibres are narrower than those of paper mulberry. Cross-marking are very faint (Figure 46, 47, 48) and most fibres have smooth surface. Irregular shaped crystals are also observed (Figure 48). Samjidak fibres are characterized by a broad central portion (Ilvessalo-Pfaffli, 1995, p350).

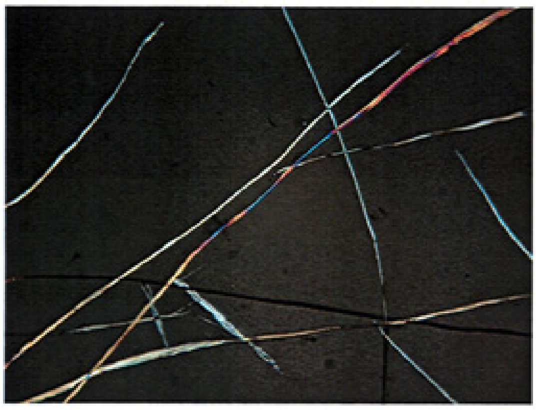

Figure 46. Fibres with smooth surface and even thickness (x100).

Figure 47. Fibres with rather faint cross-markings (x250).

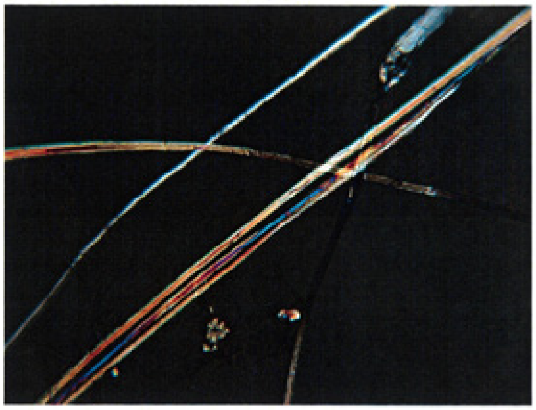

Figure 48. Irregular shape of crystals (x250).

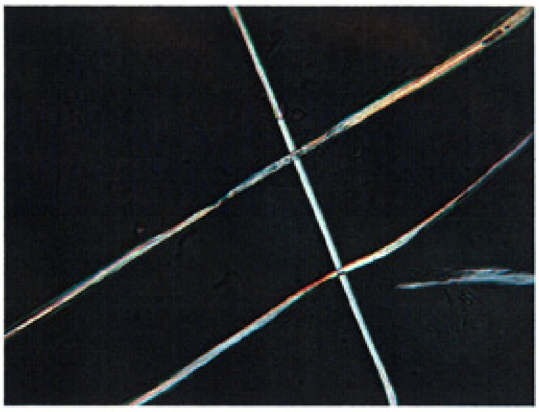

Figure 49. Fibres with varying thickness (x250).

Figures 46 – 49. Cells and fibres found in the standard sample of Samjidak

Mulberry (*Morus alba*)

Mulberry fibres show similar characteristics to the fibres of paper mulberry as both belong to the same family, *Moraceae*. Most mulberry fibres are thick-walled and have a smooth surface (Figure 50). Some fibres show rather faint cross-markings (Figure 50, 51) but others have very clear cross-markings (Figure 52, 53). Like paper mulberry fibres, many fibres are enveloped in a thin, transparent membrane (Figure 50, 51) and prismatic cuboid crystals are present (Figure 54). However, it contains an elongated hexagonal-shaped crystal (Figure 55) which is slightly different from the rhombic-shaped crystal found in paper mulberry. According to Lee (2006, p37) it is possible to differentiate mulberry fibres from the fibres of paper mulberry because mulberry fibres are longer than those of paper mulberry. Samples examined here seem to agree with the findings of Lee though he did not report his findings in such detail and made no reference to any crystals.

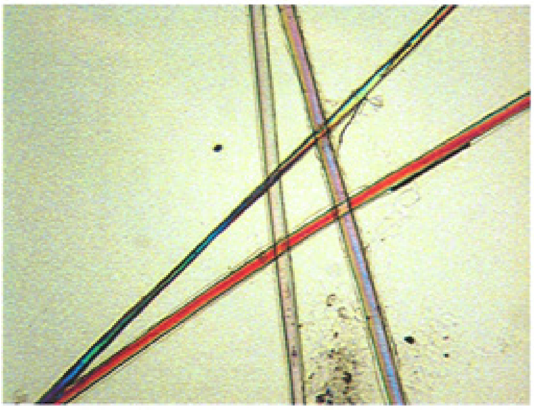

Figure 50. Fibres with smooth surface and loose primary walls (x250).

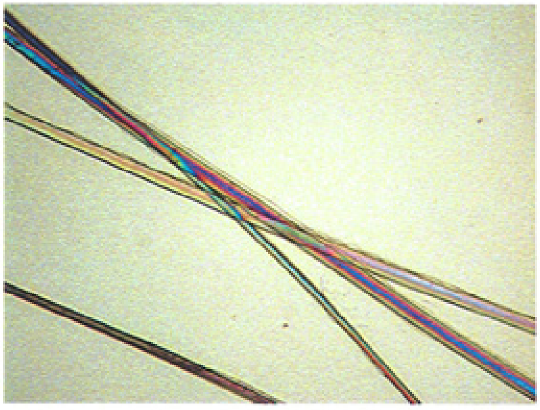

Figure 51. Fibre showing narrow lumen and a loose primary wall (x250).

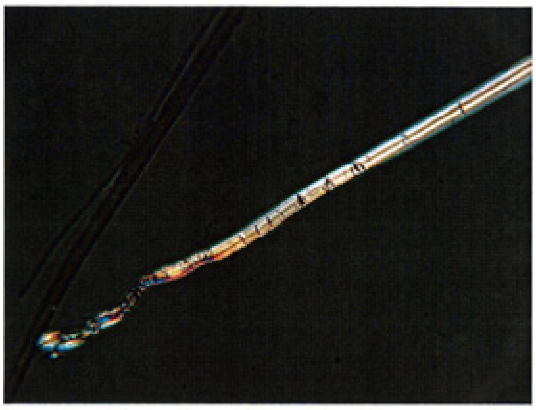

Figure 52. Fibre with clear cross-markings (x250).

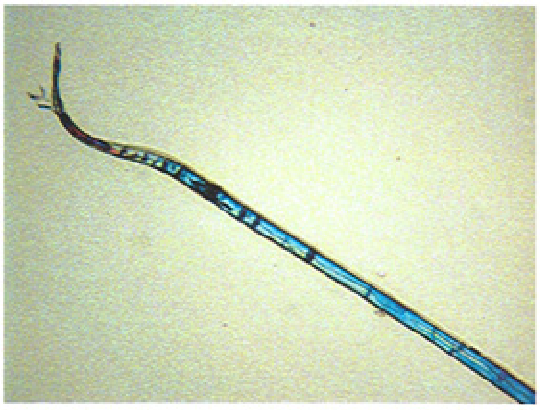

Figure 53. A fibre with tapering end and frequent, clear, cross- markings (x250).

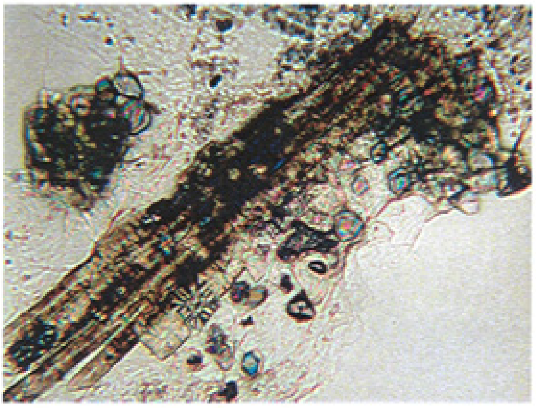

Figure 54. Prismatic crystals and small rectangular parenchyma cells (x250).

Figure 55. An elongated hexagonal shaped crystal (x400).

Figures 50 – 55, Cells and fibres found in the standard sample of Mulberry

Rice Straw (*Oryza sativa*)

Typical rice fibres are narrow and short with needle-like pointed ends (Figure 56). Thin-walled, various shaped parenchyma cells are common (Figure 57, 58). Its epidermal cells are long and narrow with small papillae[15] (Figure 57). Figure 59 also shows prickle hairs which are short having round bases with sharply pointed tips. Annular vessel elements and separated ring cells are also present (Figure 60). An irregular shaped associated cell was noticed (Figure 61). According to Park (2002, p150) dumb-bell shaped silica bodies are present both in rice and reed but the dumb-bell shaped silica bodies of reed are approximately twice the size of those of rice. More importantly, Park reported that the structures of dumb-bell shaped silica bodies in rice are at right angles to the fibres, whereas, in the case of reed they appear to be parallel to the fibres. Therefore the structure of dumb-bell shaped silica bodies in rice can be regarded as a key factor for the differentiation of rice from other grass fibres.

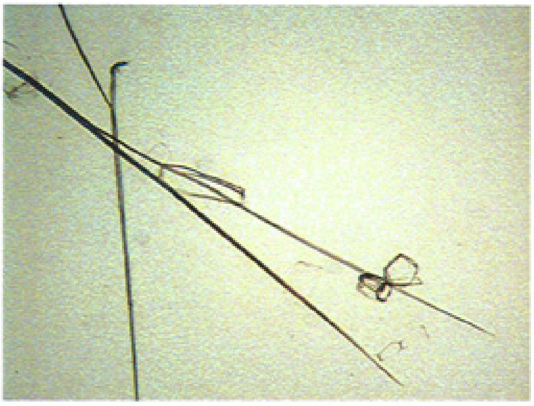

Figure 56. Rice fibres with pointed ends (x100).

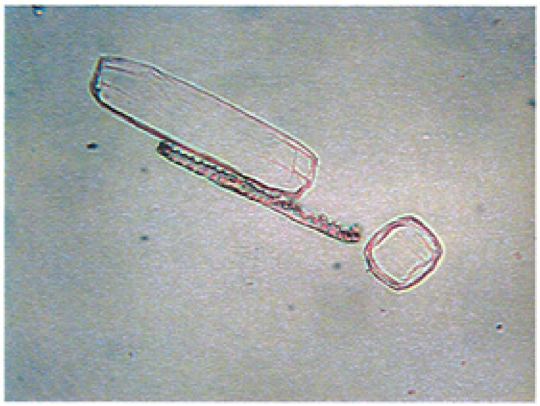

Figure 57. A narrow, long epidermal cell and two thin-walled parenchyma cells (x250).

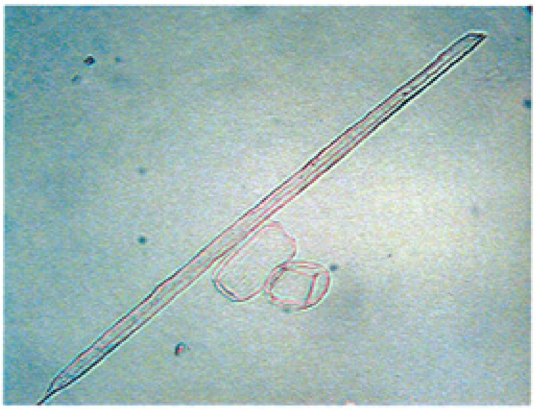

Figure 58. A long, narrow parenchyma cell and short, thin-walled parencymas (x100)

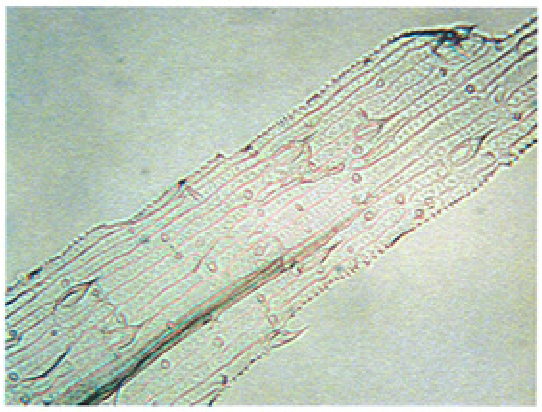

Figure 59. Epidermis showing long epidermal cells and prickle hairs (x250).

[15] Papillae are protrusions from the outer walls of epidermal cells - they have various shapes.

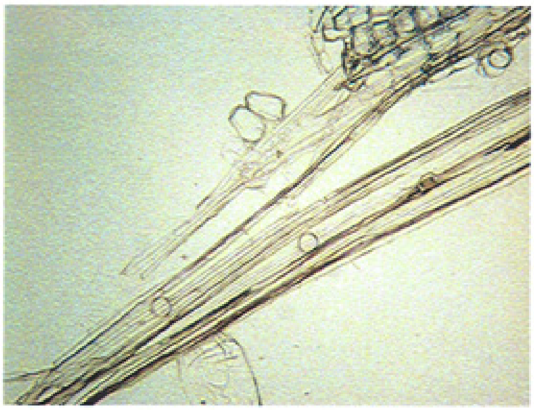

Figure 60. Ring-thickenings from an annular vessel element (x250).

Figure 61. Irregular shape of associated cell (x250).

Figures 56 – 61. Cells and fibres found in the standard sample of Rice straw

Barley Straw (*Hordeum vulgare var. hexastichon*)

Fibres are narrow and thick-walled (Figure 62). Irregularly shaped epidermal cells are present as well as regularly shaped ones (Figure 63, 64). Epidermal cells are thicker and shorter than those in rice (Figure 63). Various sizes of thin-walled parenchyma cells are also noticeable (Figure 66). Its prickle hairs appear to be slightly longer than those from rice straw (Figure 65). No previous research on fibre identification included photomicrographs of barley fibres and therefore, these images could provide a basis for identifying paper including barley.

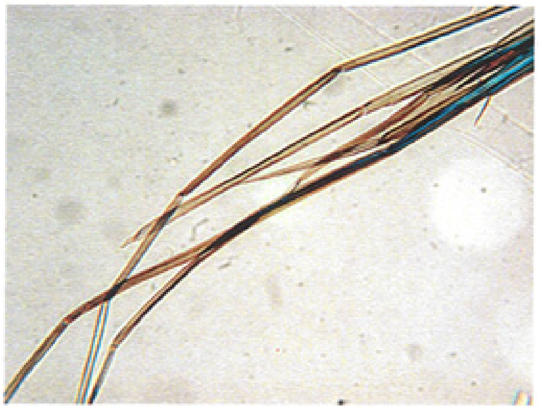

Figure 62. Narrow, thick-walled fibres (x250).

Figure 63. Epidermis showing stomata, a prickle hair and serrated epidermal cells (x250).

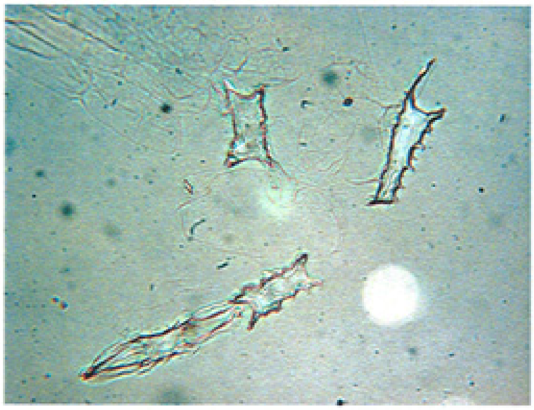

Figure 64. Irregular shaped epidermal cells (x400).

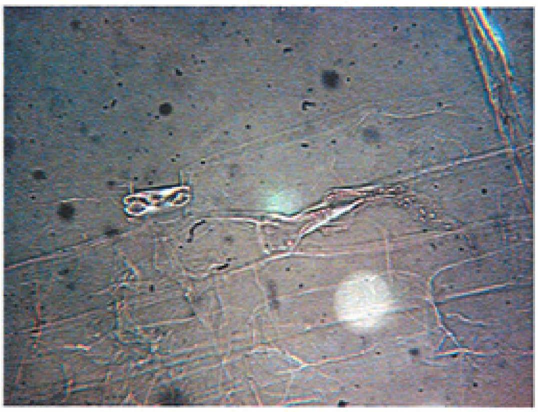

Figure 65. A hair and a dumb-bell shaped guard cell (x400).

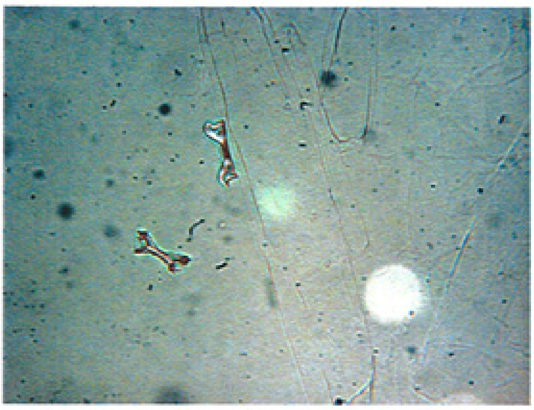

Figure 66. Dumb-bell shaped silica bodies and thin-walled parenchyma cells (x400).

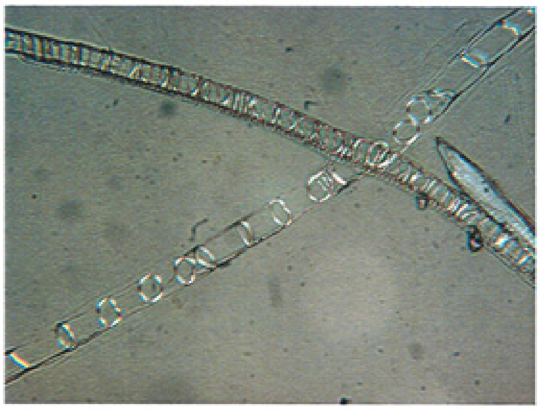

Figure 67. Annular shaped vessel elements (x250).

Figures 62 – 67, Cells and fibres found in the standard sample of Barley straw

Sandak (*Wikstroemia trichotoma*)

Sandak belongs to the *Thymelaeaceae* family. It grows up to 1.5 metres in height and its main habitat is in the south coastal areas of Korea (Lee, 2002, p98). Its fibres are thin with a smooth surface and faint cross-markings which are well spaced (Figure 68, 69, 70, 71). Dislocations are also not clear. Ilvessalo-Pfaffli (1995, p350) reported that fibres from the members of the family *Thymelaeaceae* could be identified by the broad central portions of fibres - characteristic of the members of the *Thymelaeaceae* family.

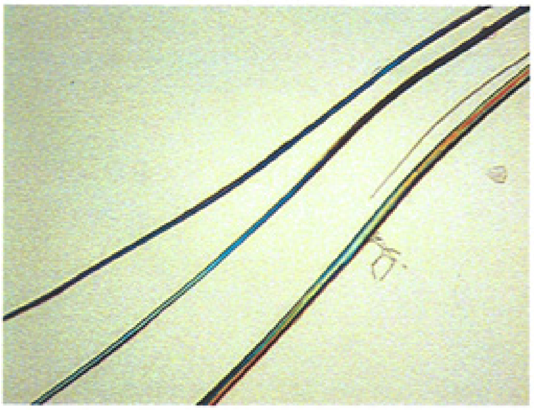

Figure 68. Fibres showing smooth surface (x250).

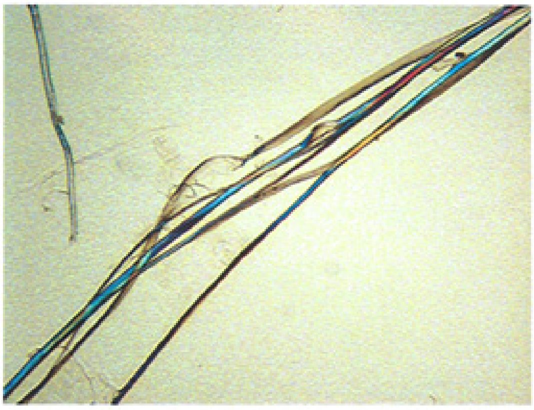

Figure 69. A group of fibres (x250).

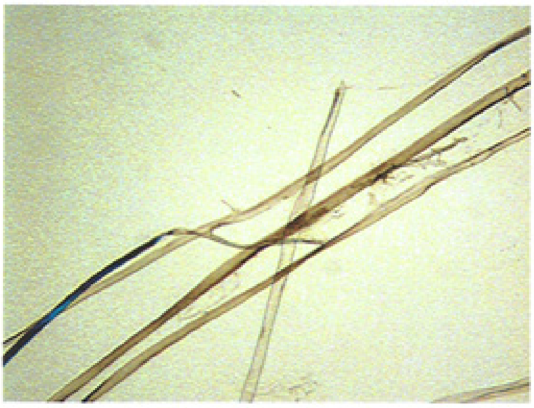

Figure 70. Wide, thin-walled fibres with varying thickness (x250).

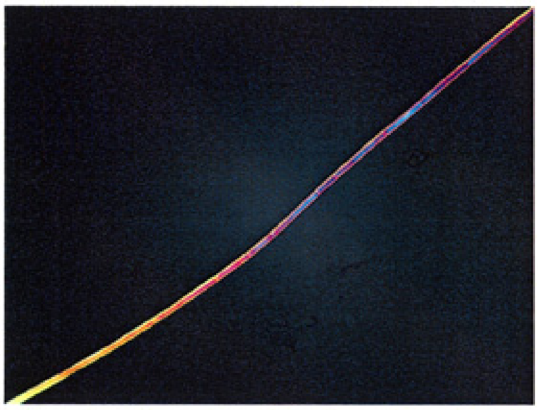

Figure 71. A fibre showing cross-markings and narrow lumen (x250).

Figures 68 – 71. Cells and fibres found in the standard sample of Sandak

Bamboo (*Phyllostachys pubescens*)

Bamboo fibres are fairly narrow with blunt or needle-like pointed ends (Figure 72, 73). No cross-markings or dislocations were observed. Bamboo fibres could be identified by very wide vessel elements (Figure 74) and small, rectangular, thick-walled parenchyma cells (Figure 75, 76, 77). Among grass fibres, bamboo has relatively long fibres compared to others (Ilvessalo-Pfaffli, 1995, p274). Bamboo also shows abundant parenchyma cells.

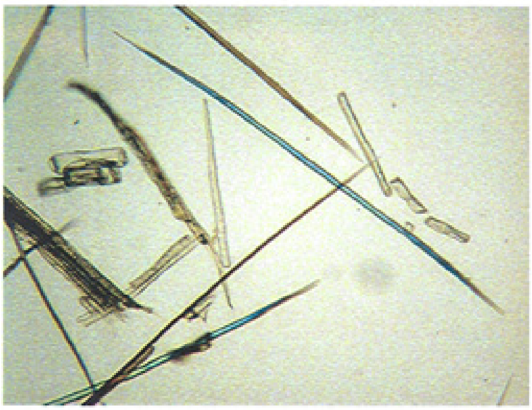

Figure 72. Bamboo fibres with rather blunt ends (x100).

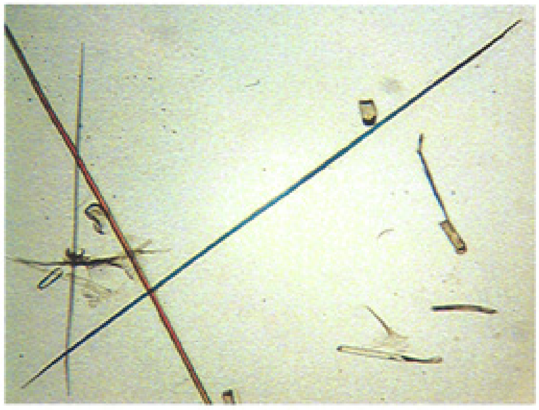

Figure 73. Fibres with needle-like pointed ends (x100).

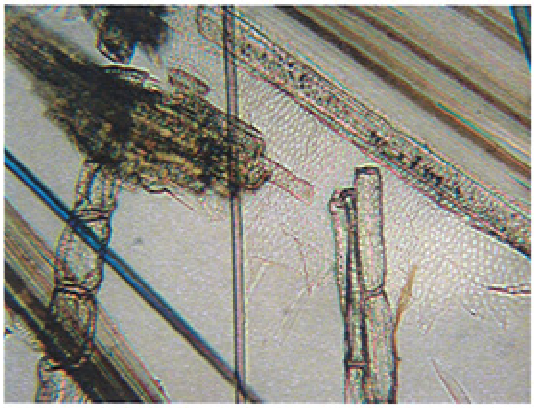

Figure 74. A very wide pitted vessel element and rectangular parenchyma cells (x250).

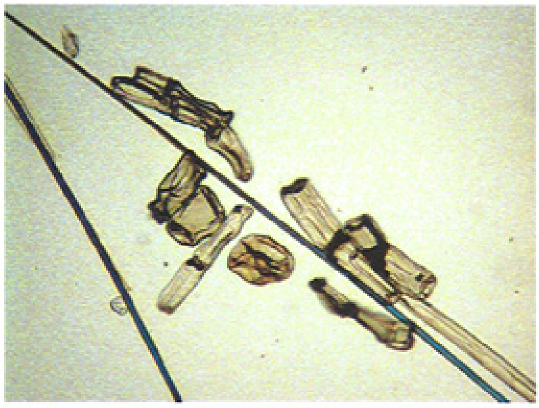

Figure 75. Small, rectangular, thick-walled parenchyma cells (x250).

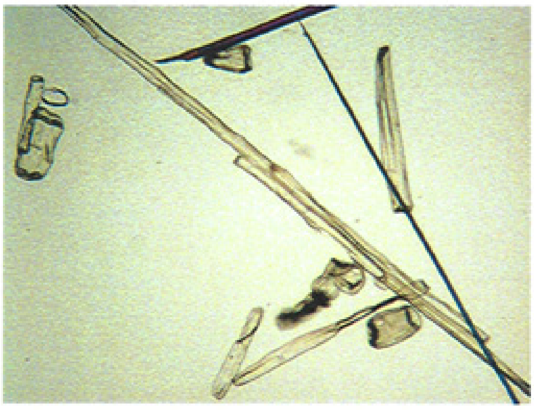

Figure 76. Long and short parenchyma cells and a ring-thickening from an annular vessel element (x250).

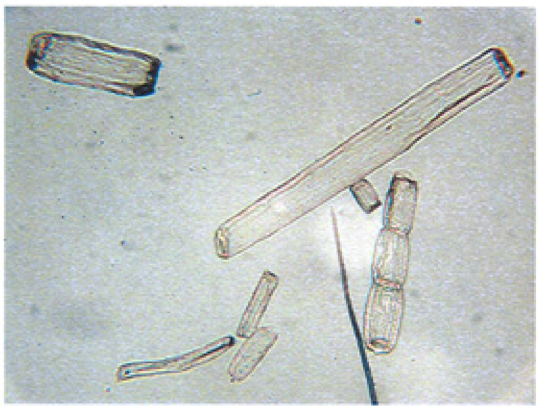

Figure 77. Small, rectangular, thick-walled parenchyma cells (x250).

Figures 72 – 77. Cells and fibres found in the standard sample of Bamboo

Pine (*Pinus densilflora S.et Z*)

Korean red pine grows all over the country except the far most north highland in Korea. Its tracheids have clear bordered pits which show two concentric rings (Figure 78). Some bundles of fibres also exhibit criss-cross patterns under slightly crossed polars (Figure 79). Some tracheids exhibit both windowlike and pinoid pits (Figure 80, 81). According to Ilvessalo-Pfaffli (1995, p160), *Pinus densiflora* can be distinguished from the common pines by the combination of windowlike and pinoid ray parenchyma pits. The inner bark of pine also has irregular shaped crystals (Figure 83).

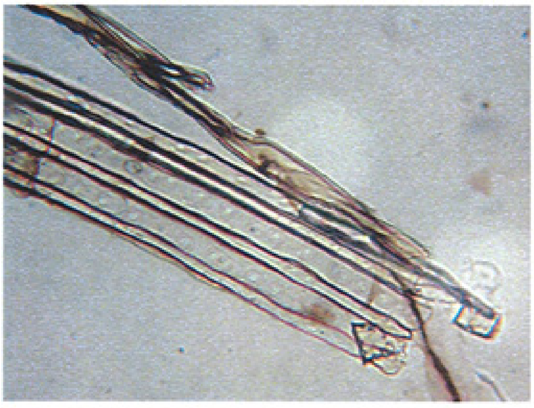

Figure 78. A bundle of longitudinal tracheids showing bordered pits (x250).

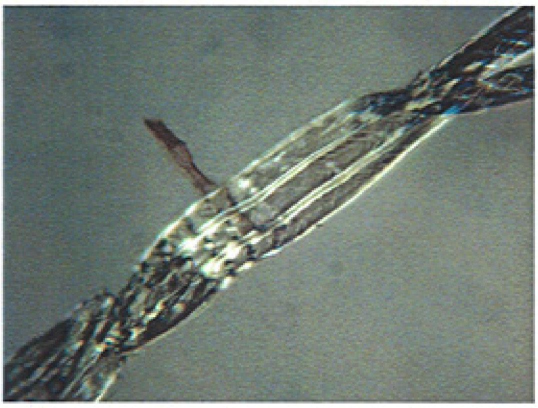

Figure 79. Fibres showing criss-cross patterns (x250).

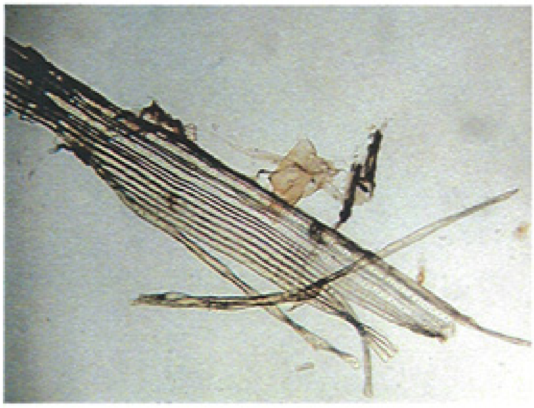

Figure 80. A bundle of longitudinal tracheid showing bordered pits and window-like pits (x100).

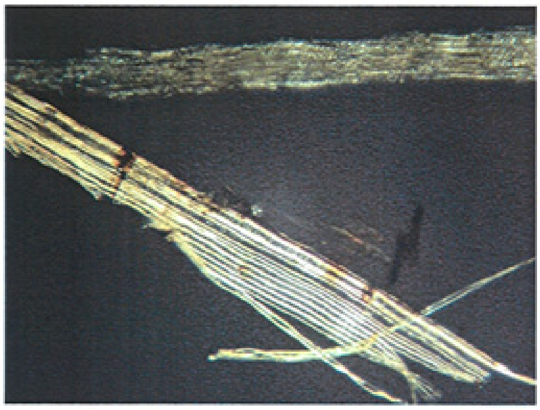

Figure 81. The same fibres under cross polar (x100).

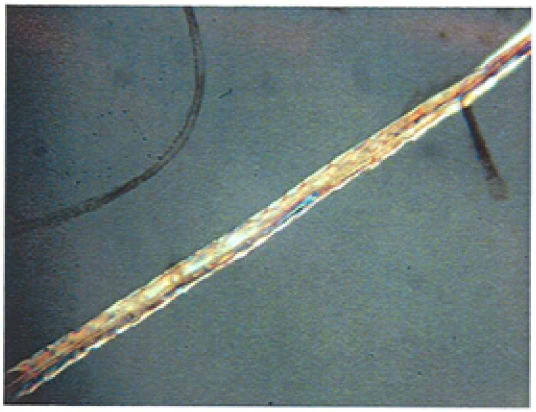

Figure 82. Fibres from a pine leaf (x250).

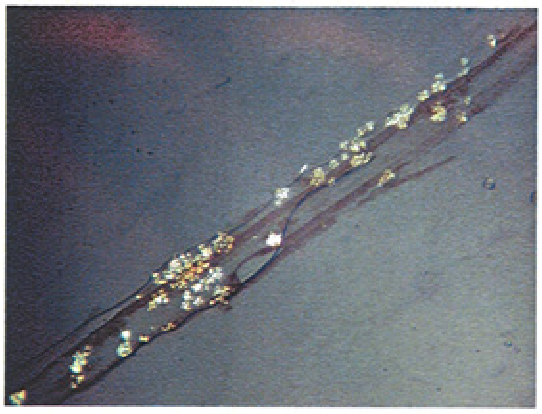

Figure 83. Cluster of irregular shaped crystals from the inner bark of pine (x250).

Figures 78 – 83. Cells and fibres found in the standard sample of Pine

Flax (*Linum usitatissimum*)

Flax fibres are long and narrow and their widths tend to vary along their length (Figure 84, 85). The lumen are very narrow (Figure 84) and tend to run in the centre. Flax fibres show cross-markings and longitudinal striations.

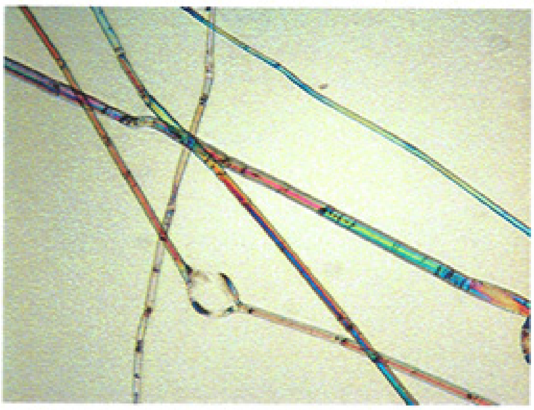

Figure 84. Fibres with narrow lumen and clear cross-markings (x250).

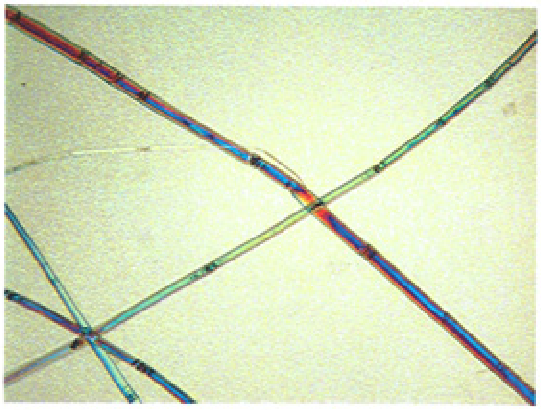

Figure 85. Fibres with well spaced cross-markings (x250).

Figures 84, 85. Cells and fibres found in the standard sample of Flax

Hemp (*Cannabis sativa*)

Hemp fibres are long, thick-walled. Some cross marks extend completely across the fibre cell (Figure 86), others cross only part. Cross-markings are very frequent (Figure 87). Fibres also show longitudinal striations and swellings. Ilvessalo-Pfaffli (1995, p338) also reported that there is a wide range of wall thicknesses and lumen widths though, frequently, the lumen occupies between one-third and one-half of the cell and generally, the width of the lumen is more or less constant except for a narrowing towards the ends of the cell. Dislocations are frequent and pronounced. Differentiation is possible only in pure pulp. Fibres of hemp and flax can be distinguished from the other common bast fibres, except for sunn (*Crotalaria juncea*), by the prominent and frequent dislocations (Ilvessalo-Pfaffli, 1995, p338).

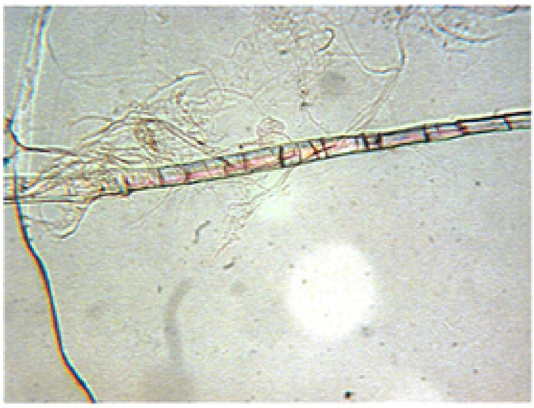

Figure 86. A fibre with clear cross- markings and longitudinal striations (x250).

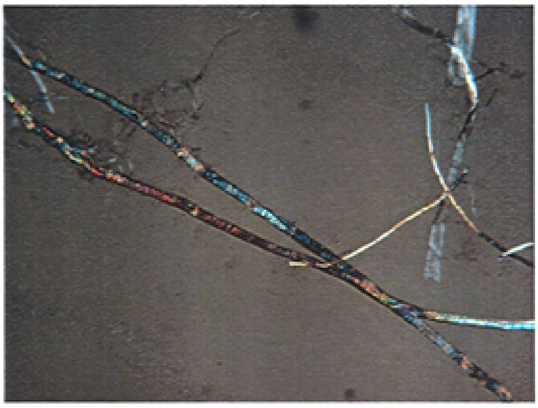

Figure 87. Fibres showing very frequent cross-markings and longitudinal splits (x100).

Figures 86, 87. Cells and fibres found in the standard sample of Hemp

Eulalia (*Miscanthus sinensis Anderss*)

Eulalia fibres are thin and narrow (Figure 89). Figure 88 shows prickle hairs, dumb-bell shaped silica bodies, and serrated, long epidermal cells.

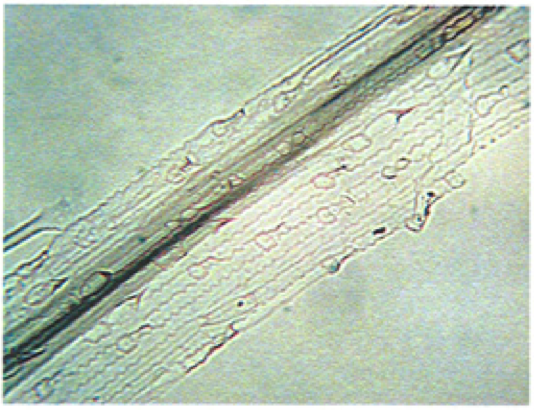

Figure 88. Epidermis showing long epidermal cells, prickle hairs and cubic-shaped silica bodies and dumb-bell shaped silica bodies (x250).

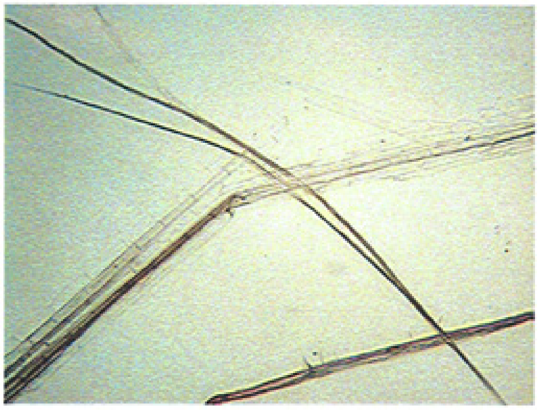

Figure 89. Thin, narrow fibres and regular shaped epidermal cells (x250).

Figures 88, 89. Cells and fibres found in the standard sample of Eulalia

4.3. Papermaking Experiments

4.3.1. Function of the formation aid in Traditional papermaking in East Asia.

As mentioned in section 3.3, the use of the mucilaginous substance from the root of *Hibiscus Manihot* has been believed to increase the physical strength of the paper sheet by improving the uniformity of it. However, there has not been any scientific analysis which supports the speculation about this specific function of the mucilage and it has been left open to question whether improving the uniformity of a sheet could directly lead to an increase in its strength. If this is the case, the question remains of how much additional strength is gained. Although improvement of physical strength has been continually cited (along with other functions of the mucilage as a formation aid), it seems as if no further attempt has been made to explain it. Hughes (1978, p84) explained the common belief stating, 'it helps bind the fibres to each other, thereby strengthening the paper'. Therefore, it could be interpreted that the mucilaginous substance enhances stronger fibre bonding, thus resulting in the increased physical strength of the sheet. Thus, the main purpose of this experiment is to find out how the mucilaginous substance influences sheet forming quality and, in turn, physical strength in the end product.

The mucilaginous substances have mainly been used in traditional papermaking in Korea, Japan, and China. Necessarily, for scientific analysis, it is essential to make sheets of the same weight and thickness – in samples made by the traditional sheet forming techniques, it was deemed difficult to achieve absolute consistency between the papers produced. Therefore, a papermaking machine was used in order to provide the same conditions for the production of each sheet, thus minimising any differences between sheets in terms of weight and thickness. Test sheets were prepared according to British Standards: sheets were 60 grams with an area of approximately $200cm^2$. The papermaking experiment was conducted at the Paper Science laboratory in the School of Materials at University of Manchester Institute of Science and Technology (UMIST) using a Standard 159-mm-diameter sheet machine with stirrer.

For the experiment, three types of fibres of different lengths were selected: paper mulberry, flax, and softwood (pine). The experiment was designed so that two types of paper were produced from each fibre. Thus, of each fibre type, one sheet was formed with the addition of the mucilaginous solution from the root of Hibiscus Manihot and the other without. Apart from the addition of the mucilage, both sheets were to be made under the same conditions and with the same papermaking machine. The sheets formed without the formation aid were made by adding 7.0 litres of water to produce the pulp. However, when a test sheet was produced with flax and the mucilaginous solution, drainage became excessively slow. In response to this, sheets with mucilage added were made by halving the quantity of water (3.5L). All handmade sheets were prepared according to TAPPI test method T205.

Paper mulberry produces relatively long fibres and, therefore, it has been essential to add a mucilaginous substance when the vat stock was prepared. In the absence of this additive, all fibres become entangled, causing great difficulty in producing a sheet of even thickness. Flax and softwood were included in this experiment to investigate whether the mucilaginous substance has the same influence on short fibres as it has on paper mulberry.

In Europe, rags (linen or cotton) were the major papermaking raw materials until the late eighteenth century (Hunter, 1978, p.309). Although the average length of natural flax fibre is longer than the average length of paper mulberry fibre (Sisko and Pfaffli, 1995, p299), rags usually went through a severe fermenting process and several stages of the beating process that were crucial to produce a fine quality paper of even thickness. As a result, those processes considerably shortened the length of rag fibres (Barrett, 1989, p12). Only in the middle of the 19th century was wood pulp employed for papermaking in Europe (Hunter, 1947, p376), the length of wood fibres is even shorter than that observed in rag fibres. It seems as if traditional European papermakers were able to produce relatively fine paper without the aid of plant extracts. However, this experiment intended to find out whether the formation aid is equally beneficial to the sheet produced with short fibres by improving the uniformity of the sheet as well as physical strength.

Preparation of materials

Paper mulberry (*Broussonetia kazinoki Sieb*)

Dry baekpi (the innermost bark of paper mulberry) was obtained from Korea. 56g of it was cooked in two litres of 1% potassium hydroxide (KOH) solution (pH 13.5) for two hours and then left in cold water for approximately two days. During this time the water was changed several times in order to remove any solublised lignin and residual chemicals. Subsequently, the pulp was gently squeezed and placed on a wooden board for beating. It was beaten with a mallet until all individual fibres separated easily in water - water was occasionally sprinkled over the pulp in order to help the process. A small amount of pulp was occasionally added to water and agitated with a glass rod as an indication of whether sufficient beating had been carried out.

However, it appeared impossible to produce sheets of similar thickness or similar weight with the prepared paper mulberry fibres without addition of the formation aid. Paper mulberry fibres readily clumped together, making it impracticable to divide into the same quantity or weight. In order to avoid this problem, dry baekpi was cut to 5mm lengths before cooking and another attempt was made. In traditional papermaking in Korea or Japan, the cutting of the dried bark into such short lengths would rarely happen. For the purpose of this experiment, cutting was intended to reduce the tendency of fibres to group, while such a length remained sufficient to provide information on the Zero-span Tensile index.

On this occasion, 45g of dry baekpi was cut to 5mm lengths and cooked for an hour in 2.5 litres of 1% solution of potassium hydroxide (KOH, pH 13.5). After cooking, the remaining steps were undertaken as above. In this case, the mulberry (cut to 5mm) was relatively well dispersed in water but still exhibited the same tendency to group together as the uncut mulberry fibres. However, as average length was considerably shortened, it was less difficult to quantify the amount of pulp for each sample sheet during the experiment. Furthermore, it became easy to produce sheets with relatively even thickness.

Flax (*Linum usitatissimum*)

Prepared flax was obtained from the Centre for the Book at the University of Iowa[16]. The material was fermented for eight weeks, then cooked and beaten in accordance with 206 Canadian Standard Freeness (CSF). It was washed during beating and then concentrated and dewatered.

Pine

The bleached, softwood pulp (*Lapponia* Pine) was obtained from the Paper Science laboratory in School of Materials at UMIST.

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[16] Timothy Barrett generously offered the prepared flax for this experiment.

Roots of *Hibiscus Manihot*

Fresh roots of *Hibiscus Manihot* were obtained from Korea[17]. Before pounding, they were thoroughly washed to remove any dirt or soil. Six roots (196.30 grams) were pounded on a wooden board with a mallet and then placed in 2 litres of cold water (18.5°C). The container was covered and left in a cool place over night. The following morning, the mucilage was sieved twice in order to remove any solid inclusions and impurities. After sieving twice, the mucilage remained lumpy like egg white, making it difficult to quantify it. Therefore, the mucilage was sieved twice more through a cloth. Eight litres of stock (3% of pulp consistency) was prepared and approximately 700 ml of mucilaginous solution was added to each pulp. The viscosity of the mucilage was measured using a Brookfield Viscometer, giving a direct measurement in centipoises. Two sets of three of measurements were made on two samples of mucilage from the root. An average of each set of measurements was calculated.

Prior to the tests, all paper samples were stored at the laboratory for at least 24 hours where the environment was controlled (50 % of relative humidity and 23°C of temperature). The weight of the sheets was determined gravimetrically and their thickness measured using an electronic micrometer (ISO 5270:1999). Tensile testing was carried out on 15 mm wide strips between jaws set 100 mm apart using an Instron 4411 universal testing machine according to standard ISO 1924-2:1994 (Figure 90). Zero-span tensile testing was carried out on strips of width 20 mm using a Pulmac Zero Span Tensile Tester (Model ZST-15) (as per ISO 15361:2000).

[17] Fresh roots of Hibiscus Manihot was given by Jang Seongu, a traditional Korean papermaker in Gapyeong, Korea.

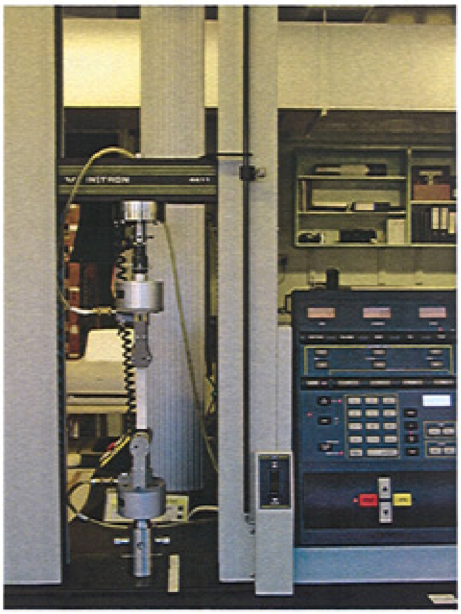

Figure 90. Tensile testing machine (Instron 4411 universal testing machine)

Analysis of samples

Sampson (2003, pp1-9) explained that the long-span (or tensile strength) test provides information on the contribution of both fibre strength and bond strength to the tensile behaviour of the strip. Conversely, the short-span (or zero-span) test provides a measure of fibre strength only. Therefore, from the results combined, bond strength could be ascertained by the following method. In order to investigate the influence of the mucilage on inter-fibre bonding, the tensile strength and the zero-span tensile strength of each sample was measured. The equation for bonding contribution is as follows:

Tensile strength, T (Nm^{-1}) is equal to the failure load, F_{fail} (N) divided by sample width, ω(m)

$$T = F_{fail} / \omega$$

Tensile Index, T (Nmg^{-1}) is equal to the Tensile strength, T(Nm^{-1}) divided by grammage, β (gm^{-2})

$$\mathrm{T} = T / \beta$$

Zero-span Tensile Strength (Z) and Zero-span Tensile Index (Z) are calculated in the same way as for Tensile strength test. The equation for 'bonding contribution to tensile strength (B)' is

$B = TZ / (Z - T)$ and its unit is also Nmg^{-1}.

Beta-radiography Image Recording was employed to examine the sheets so as to compare to what degree the mucilaginous substance improved the uniformity of the sheets compared with those without the mucilage.

4.3.2. Papermaking with a fixed laid screen

Experiment in Context

Most previous studies have tended to describe the various types of screens and moulds employed in different countries rather than any possible chronological development of them or any interrelation between them.

To understand historic phenomena, emulation of ancient processes of manufacture has been commonly employed by archaeologists in experimental archaeology. Mathieu (2002) defined experimental archaeology as 'a sub-field of archaeological research which employs a number of different methods, techniques, analyses, and approaches within the context of a controllable imitative experiment to replicate past phenomena (from objects to systems) in order to generate and test hypotheses to provide or enhance analogies for archaeological interpretation. According to Coles (1979, pp160-161), in order to generate analogies and hypotheses for archaeological interpretation, archaeologists have drawn on three chief sources for evidence: the first source is the extant artefacts themselves with the second being information from historic records. The third source of evidence is experimental archaeology.

Due to the broad variety of phenomena replicated in this sub field, Mathieu (2002) divided experimental archaeological research into four groups, according to the types of phenomena which can be replicated or simulated. The groups are denoted object replication, behavioural replication, process replication, and system replication and defined thus:

- Object replication involves the production of a replica that has certain characteristics in common with the original object.
- Behavioural replication involves the reproduction of past behaviours and activities, including the reproduction of past methods of use.
- Process replication entails the reproduction of past processes including natural and cultural processes from small-scale to large-scale.
- System replication involves the reproduction of numerous processes in living systems.

The main aim of this experiment is to evaluate the function of a fixed laid screen in terms of whether a fixed laid screen could produce the same impressions in paper as the flexible laid screen. However, there is no known extant ancient papermaking mould and screen from the 8th century or before that time and no contemporary written information regarding the materials and mould construction. Consequently, in this experiment a fixed laid screen was constructed to a specification chiefly based on information from two sources. The first source is represented in the simple descriptions of a fixed screen offered by a small number of paper historians (See below). The second is the papermaking illustration from T'ien-Kung K'ai-Wu. Detail provided by these sources combined is minimal though it is felt that information is sufficient to produce a fixed laid screen which can be categorised as a functional replica according to the definition put forward by Mathieu (2002, pp2-3). According to the above definition (denoted by the term 'objects replication') the production of the functional replica does not necessitate authenticity in every aspect providing the object is created with functionally suitable materials and production techniques.

As an essential component, the screen was comprised of splints of bamboo. Used in traditional papermaking in East Asia, such a specification can probably be considered authentic, or at least functionally suitable. Regarding the mould frame, wooden members were chosen as the material has been one of the most common materials employed in tool construction with continuing use in traditional papermaking in China, Korea and Japan to the current day. The manner of forming the sheet with a fixed laid screen followed that of the flexible laid screen. Therefore, it is believed that in this work the validity of the experiment was achieved by first producing a replica papermaking device which has certain, main characteristics and a functionality common to what has been speculated regarding the original object. Additionally, as far as possible, further authenticity was intended in employing the techniques of early East Asian papermakers in the use of this tool.

In this section, the background of this experiment is explained by exploring the development of papermaking screens. Additionally, a hypothesis on the existence of a fixed laid screen (a laid screen fastened to its wooden frame) in China and its possible influence on other countries will be examined. It is intended that this will also assist in an understanding of the development of the papermaking mould and screen in Korea.

Hunter (1922, pp587-588) suggested that there were two different types of papermaking moulds at an early stage of papermaking and he put them in chronological order. According to him, the first one is the oldest papermaking mould employed by Chinese papermakers. This "wove" type mould consisted of a piece of coarse textile and was bound to a rectangular bamboo frame with bamboo strips. Its operation and disadvantages were discussed in the chapter 2. Because of the increase in demand for paper and due to the low efficiency of this type of mould, papermakers needed to improve the productivity of their papermaking process beyond what was achievable by this method.

The second type of mould had a screen being constructed of a smooth and firm material that would release the wet sheet easily. Such a screen was made with splints of bamboo or stems of plants stitched together with silk thread or horsehair. Its smooth surface enabled papermakers to release a newly formed sheet immediately from the cover, allowing them to constantly form sheets with the same mould. This laid screen was fastened to the supporting ribs of the frame with flaxen threads. Hunter suggested that the Persians should be credited with inventing this type of mould. Unfortunately, he did not mention the source of this idea. However, it seems as if his theory clearly affected other contemporary scholars: Dr McClure (1930, p116) recapitulated Hunter's theory of two main steps in the development of the papermaking mould. McClure also pointed out that this type of fixed laid screen was probably the first to reach Europe as the mould structure in Europe is still of this fixed type. Hunter's book (1947) seems to include most of his previous work and it is interesting to note that he did not include the information about the second type of mould nor the ingenuity of the Persians claimed in his previous articles.

McClure (1930, p116) stated that the third type of mould which still in use today. It consists of three parts: a supporting frame, a flexible screen (made with splints of bamboo or stems of plants laced with horse hair or silk), and a deckle. This screen is not rigidly bound to the frame, and McClure regarded this type of mould as a most significant step in advancing the development of papermaking moulds.

Hunter was not the only one who believed the laid screen was a contribution made by the Persians. W. Raitt (1930, pp149-150) even thought that Persia was the origin of the 'suction transfer deckled mould'. Though a rather ambiguous term, according to the author's description, the mould consists of a wooden framework, two deckle sticks and a flexible laid screen made with the stems of *Andropogen micranthus* laced with horsehair. He also believed that, prior to this Persian invention, the only mould used by the Chinese was a crude cloth mould. Nonetheless, he did not give any evidence to support his suggestion either.

Due to the discovery of ancient Chinese papers unearthed from various archaeological sites (as reported by Pan, 1978, p95), the theory about Persia's contribution toward conceiving the use of bamboo splints and other plant stems for mould covers (suggested by Hunter, McClure, and Raitt) could be easily dismissed, since it was only in the middle of the 8th century when papermaking skills were transferred to Islamic countries (Hoernle, 1903, p668. Garnett, 1903, p3). However, the possible existence of mould structure, with a laid screen fixed to its wooden frame, is intriguing. As a transitional form between the ancient wove mould and the laid mould with a flexible laid screen, a mould constructed in this way could provide a possible explanation for the development of European papermaking moulds which have evolved differently from the East Asian one. While East Asian screens/mould covers have been separable from their frame, European screens have been fastened to their mould.

The initial idea of the possible existence of a fixed (attached) laid screen was taken from the illustration of a couching scene in the English version of T'ien-Kung K'ai-Wu.

Although it is difficult to imagine that a flexible laid screen was not commonly in use until the 17^{th} century in China, certainly this illustration raises the question of whether a fixed laid screen might have been employed sometime before flexible laid screens were in use. Hunter (1947, p91) simply dismissed this illustration by regarding it as a plain mistake made by the artist. However, possibly it was not a mistake and the fixed laid screen actually existed as a transitional form of screen between the wove and flexible laid screen. This assumption could greatly help to understand why European papermakers have used the wooden frame/fixed wire screen mould because (in terms of the cover being permanently fixed to its frame) there is far greater similarity between it and the fixed laid screen illustrated in T'ien-Kung K'ai-Wu.

In order to support the hypothesis of fixed laid screen use in China, two approaches were made; firstly an attempt was made to verify the sheet forming and couching processes described in the English translated version of T'ien-Kung K'ai-Wu , and secondly a papermaking experiment with a fixed laid screen was carried out. A facsimile copy of the original edition prefaced 1637, printed in Shanghai and published in Beijing by Zhonghua Shuju in 1959 was chosen for the verification at the British Library.

Verifying the Original Text of the Papermaking Section in 'T'ien-Kung K'ai-Wu'

The verified part read

> 'The screen used for the manufacture of paper sheets is made of a rectangular frame covered with a mat woven of finely split and polished bamboo. The worker holds the screen with both hands and submerges it in the fibre suspension of the pulp tank so that some of the latter remains on top of the screen.... The screen is then inverted and the paper is dropped onto a wooden board until many such sheets have been piled together...' (p227)

From the text above it is not indicated whether the screen was fastened to its mould or not. However, it was also not clear whether the original text included any specific information about the screen and mould structure. It might be possible that some details were simply dismissed by the translators by mistake as it is usually difficult to translate technical literature of traditional papermaking if the translators are not familiar with the subject. On the other hand, Sung Ying-hsing, the author of 'T'ien-Kung K'ai-Wu' was a scholar, and it was more likely that he did not practice or participate in any papermaking processes, as a result, it could be possible that he did not pay much attention to the mould structure, thus failing to describe it in detail.

When the translated version was compared with the original text line by line, it was obvious that one sentence appeared to be missing in the translation: "展卷张开时,下有纵横架匡" meaning, "When the mat is unrolled and opened up, underneath there is a frame-like, horizontal and longitudinal grid." Therefore a correct translation of the paragraph would read:

> 'The screen used for the manufacture of paper sheets is made of a rectangular frame covered with a mat woven of finely split and polished bamboo. When the mat is unrolled and opened up, underneath there is a frame-like, horizontal and longitudinal grid. The worker holds the screen with both hands and submerges it in the fibre suspension of the pulp tank so that some of the latter remains on top of the screen.... The screen is then inverted and the paper is dropped onto a wooden board until many such sheets have been piled together...'

From the additional information, it became apparent that the screen (mould cover) must have been a flexible laid screen.

Although it turned out that the couching illustration did not accurately reflect the accompanying text, this issue led to another question related to the publication system in ancient China. It was fairly common for woodblocks in good condition, to be used again at a later date. It is quite possible that the woodblocks used for the illustrations could have been carved decades before the book was published. It is therefore conceivable that the illustrations, in fact, were produced when the type of papermaking mould depicted was predominantly used. However, this issue lies beyond the scope of this research and should be left for further research in the future.

Papermaking Experiment With a Fixed Laid Screen

The reason for European papermakers electing to use a fixed mould cover while most Eastern papermakers had been using the detachable, flexible laid cover is one of the unanswered questions of papermaking history. The materials used for both mould covers are also different, but the reason why bamboo splints were substituted for metal wires in Europe can be easily understood as bamboo was not a readily available material in Europe. Consequently, European papermakers were forced to employ something other than bamboo for the manufacture of mould covers.

However the question still remains: Why did European papermakers fix the wire cover to its mould? It is a question which leads one to ask numerous others. As Hunter (1947, p114) suggested, was it because this type of mould structure was more suitable for forming a sheet with the predominant material, rag fibre? Was it not impossible for them to make a flexible laid cover using wires? Were the Europeans aware of the flexible bamboo screen? Had there been any transitional form between the East Asian style and European style?

One possible hypothesis is that when papermaking knowledge was transferred to Islamic countries in 751 AD, Chinese papermakers were using not a laid mould with a flexible laid screen, but rather a laid mould with a fixed laid screen whose structure was closer to the conventional European mould. Then this hypothesis could immediately be confronted by the theory that a flexible laid screen has been employed in China as early as the third century onwards as Hunter and Pan suggested (section 2.2). In fact, the impressions of laid and chain lines on old paper objects were the only evidence leading to the conclusion of the early use of a flexible laid screen in China and while the development of mould structure has not been thoroughly understood yet, it may be too early to draw any conclusions from these impressions on paper - it is not clear whether the flexible laid screen mould was the only variety that could leave such impressions. If a fixed laid screen could still make the same impression of laid and chain lines on the paper produced then this impediment to the hypothesis could be dismissed. Therefore, in order to support the hypothesis of fixed laid screen use in China before 751 AD, a papermaking experiment was carried out.

Initially, the idea of a mould with a fixed laid cover being used in China was conceived from the illustration of T'ien-Kung K'ai-Wu – it was an anomaly which served as the motivation to conduct this experiment even though the translation of a missing sentence subsequently indicated that a flexible screen was in use. Through a search of the literature, it became clear that at the beginning of the 20th century, some paper historians believed a mould with a fixed laid cover was a transitional form between the wove type of mould and the mould with the flexible laid cover. However, this intriguing idea seems to have been largely neglected by other paper historians: few paper historians paid attention to the topic and there has been no attempt made to develop the theory further or prove it.

This current research proposes that a fixed laid cover might have been in use at a certain stage of the development of papermaking in China as a transitional form between the wove-type mould and that with a flexible laid screen. This experiment therefore, aimed to establish whether such a mould could have produced sheets with impressions of laid and chain lines, indistinguishable from the sheet formed on the flexible screen. Previously, paper historians viewed these impressions as evidence of the use of flexible screens as early as the 3rd century. Nonetheless, if screen impressions imparted by both types are essentially the same, it is not possible to rule-out the use of a fixed laid screen in China prior to the 8th century migration of papermaking techniques to Islamic countries. Certainly, the existence of such a transitional mould design in the East during this period, might explain why the European mould evolved as a fixed screen mould as papermaking techniques were transferred westward.

Therefore, the aims of this experiment are

- To construct a papermaking mould with a fixed laid screen and propose its possible use as a transitional form between an ancient wove type and a flexible laid screen.
- To compare the impressions on papers left by a mould with a flexible laid screen and a fixed laid screen.
- To examine whether impressions of laid and chain lines on paper have any distinctive

quality sufficient to be used as evidence that the paper was made upon a flexible laid screen.

- To investigate whether pulp fibre length is related to sheet formation quality on the different types of screen. For example, Hunter speculated that a fixed laid screen works better for short fibres, such as flax.
- To give credence to the theory that the fixed, laid cover mould was the first to reach Islamic countries and is thus, connected to the traditional European papermaking mould.

The papermaking experiment was conducted at the papermaking laboratory of the University of Iowa, Oakdale campus, in the United States. Timothy Barrett, a research scientist and adjunct professor at the Centre for the Book at the University of Iowa, is an expert on Japanese and European papermaking. He was consulted on practical issues related to papermaking for this experiment. Furthermore, he is a skilled papermaker and made all the sample sheets for the experiment.

This experiment was primarily designed to examine impressions made by a fixed laid screen as well as by a flexible laid screen, yet it was decided to also include further investigation into the role of the formation aid. Thus, the effect of the mucilaginous substance on the production of sample sheets was assessed. There were two main reasons for this: firstly, production of sheets with paper mulberry requires the use of a formation aid. Secondly, the previous experiment (see section 5.2.1) with the mucilage proved that the mucilaginous substance works for both short and long fibres by improving uniformity of fibre arrangement in the sheet. However, sheets produced for this purpose were made with a papermaking machine for instrumental analysis. Consequently it was difficult to appreciate the whole function of the mucilage as a formation aid in the context of traditional handmade paper production. Hence, the addition of a mucilaginous solution was included as another factor to be assessed.

In order to faithfully replicate the conditions of traditional papermaking, certain materials and aspects of technique were considered in order to validate the experiment. European papermakers have traditionally used interleaving sheets during the couching process of newly formed sheets. Hunter (1947, p181) reported that the origin of using interleaving material was not known, and no special wool cloths were made for papermaking until the eighteenth century; however, some sort of woven material was used as early as the 13th century. Although more traditional materials used for the interleaving sheets were made with various types of animal hair (Hunter, 1947, p181), for the experiment, sheets of cotton cloth were prepared and cut to a size slightly bigger than the screen. Prior to use as interleaving sheets, these were dampened with water and pressed.

By producing sheets both with and without the use of an interleaving layer, it was intended that the experiment could also demonstrate one of the functions of the mucilaginous solution, which allows freshly made sheets to be piled and pressed together without any interleaving material. With the use of this additive, the sheets can be easily separated whilst still damp. Additionally, the work was expected to reveal whether the mucilaginous substance works for short fibres such as flax in the same way it works for long fibres such as paper mulberry. In this respect, it was believed that results might explain why there is no evidence that plant extracts were used for traditional papermaking in Europe - no clearer explanation has been given for this to date.

Adding the right amount of mucilaginous solution was crucial, especially in the case of flax, since the solution considerably reduced the speed of pulp drainage, making sheet forming itself very slow and difficult. However, even a small amount of the solution improved the uniformity of the sheets. As the experiment was focused on drawing comparisons between the impressions left by a fixed and a flexible laid screen, the amount of mucilage added to each stock was not monitored.

Design of a screen and mould:

For the experiment, a bamboo screen was ordered from a traditional screen maker in Korea. Their outer dimensions were 40 by 33 centimetres, producing a sheet with impressions of eight laid lines per centimetre. Oak was selected for the supporting frame - a hardwood, it is durable in continuously wet conditions. Three rib supports were installed at intervals between 9.5 and 10 centimetres. The cross section of the supporting ribs was slightly wedge shaped but not completely pointed. The area being in contact with the screen was 5 millimetres in width.

During the experiment, the same bamboo screen and its supporting frame were used as both a fixed laid screen and flexible laid screen. To make a fixed laid mould, the bamboo screen was tied to the supporting frame along the top and bottom rails as well as the ribs using a cotton thread spaced at about six points (Figure 91, 92).

Figure 91. A fixed laid screen – a bamboo screen was fastened to its supporting frame with tread. Two deckle sticks were also placed on the vertical edges of the screen.

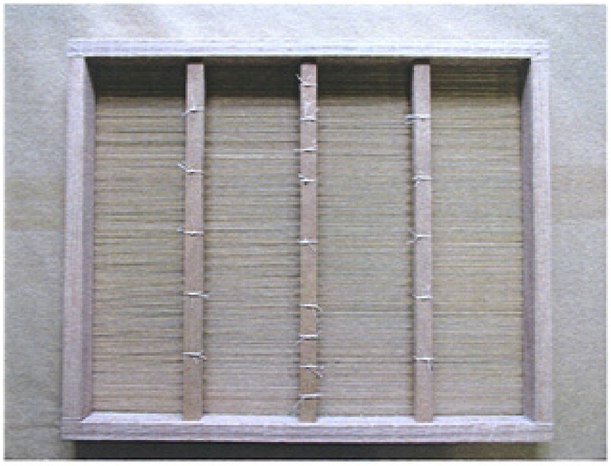

Figure 92. The back of the fixed laid screen.

Two deckle sticks were also prepared for the experiment in order to hold the screen in position (for a flexible laid mould) and at the same time to make it easier for the papermaker to hold the whole mould structure (Figure 91).

The choice of the two-stick deckle for this experiment was motivated by the intention to simulate a traditional Korean papermaking technique, in terms of excess pulp stock being cast off the mould away from the papermaker. However, it was regarded as an insignificant matter providing the two types of sheet were made under the same conditions (excluding, of course, the necessarily different conditions imposed by the different screen types).

Selection of fibre source

In order to make comparisons between long-fibred and short fibred materials, three different types of fibre were selected; paper mulberry, unfermented flax and fermented flax. Fibres of unfermented flax are relatively longer than those of fermented flax[18]. At the early stage of papermaking in Europe, the beating process might not have been well developed – Wiesner's examination (using microscopy) of the Archduke Rainer's collection revealed that fibres from

[18] All the materials were kindly provided by Timothy Barrett, a research scientist and adjunct professor at the Centre for the Book at the University of Iowa.

European papers were fairly long until the 14th century (as reported in Aitken, 1914, p208). The reason for the inclusion of fibres of different lengths in this experiment is to understand how they behave differently using the Asian style mould and formation aid.

Papermaking Procedure

21 sample sheets were made - their conditions are shown in the table below.

Table 5. Paper samples and their conditions

	A flexible laid screen		A fixed laid screen	
With formation aid	With interleaving	Without interleaving	With interleaving	Without interleaving
Kozo	3	4	3a	4a
Fermented Flax	7	8	7a	8a
Unfermented Flax	11	12	11a	12a
Without formation aid				
Kozo	2	1	2a	1a
Fermented Flax	6	5	6a	5a
Unfermented Flax	10	9	10a	9a

Sample sheets produced with a flexible, laid mould were made first - the screen was then tied (using cotton thread) to the supporting frame along the top and bottom rails as well as the ribs. Knots were made at intervals at about five to nine points along the supporting ribs (Figure 92).

Two to three sample sheets were made with the same material and under the same conditions (Figure 93 – 97).

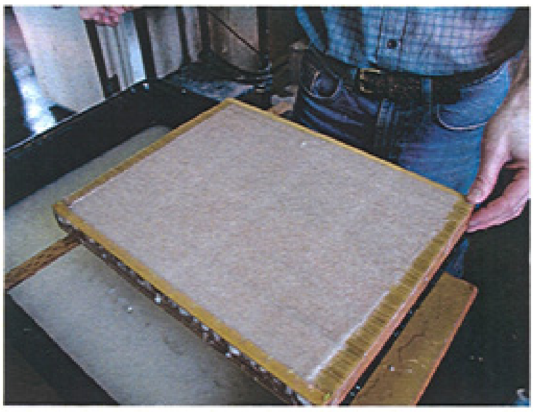

Figure 93. A sheet made with a flexible laid mould, without fermented flax or formation aid.

Figure 94. Couching a sheet made upon a flexible laid mould.

Figure 95. Sheet forming with a fixed screen mould, paper mulberry and formation aid.

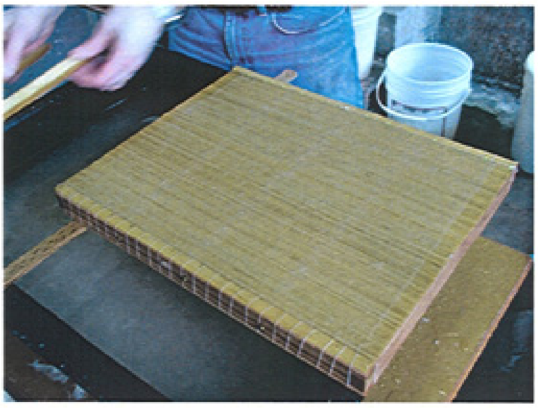

Figure 96. After the deckle sticks were removed.

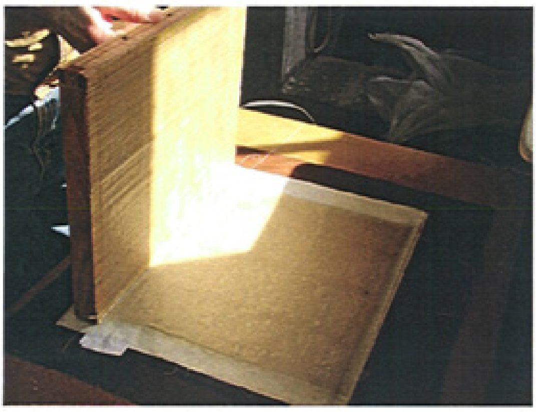

Figure 97. Aligning the fixed screen mould for couching.

The surface where couched sheets were placed was prepared with a wool felt – the sheets were interleaved with slightly dampened pieces of cotton cloth. After couching, a thread was laid along one edge of the newly couched sheet to allow for easy separation after the pile was pressed. Most sample sheets were air dried, though some sheets made with paper mulberry were dried on a stainless steel wall.

When sample no. 5 was made, it became very clear that, after being piled and pressed, sheets made with fermented flax did not have enough strength to be separated without interleaving materials. Therefore, it was decided not to make the intended three, additional sheets (5a, 8, 8a) with fermented flax.

Method of examination

Records of impressions left on the paper could be achieved by two methods: Beta-radiography, and transmitted light photography. Both of these are often used for recording watermarks in old papers. In the event that ink or other media is present on the sample paper, Beta-radiography is capable of providing better results as media will not be recorded. However, using transmitted light is an easy way of examining the impressions in unmarked paper. As, the test samples were blank sheets, it was decided to use transmitted light for examination and to record the impressions of each sheet.

4.3.3. Papermaking with reclaimed paper

In order to understand the manufacturing process using waste paper, a pilot experiment in papermaking was carried out at Jangjibang, a traditional paper mill in Gapyeong, Korea.

An old book (printed in the 19^{th} century) was used for this experiment:

The book was disbound and leaves were placed in cold water and left for 5 hours. In order to wash off the printed ink, the soaked leaves were beaten on a stone plate using a wooden club for about half an hour (Figure 98).

Figure 98. The soaked leaves were beaten with a wooden club.

The beating process alone removed a considerable amount of ink from the paper as the ink was made of carbon powder bound with glue. After the pulp was thoroughly washed with water, it was mixed with the same amount of fresh paper mulberry pulp and 20 sheets of paper were then made with a laid mould with a flexible laid screen with no deckle.

5. Results and Discussions

5.1. Survey result

The data collected from the survey was stored in a database which was designed using Microsoft Office Access software. The database allows for users to access the survey data and not only to read the information of each individual object but also to select information from the whole survey data. (The database has been saved, along with the photomicrographs of fibres collected from the objects during the survey, in a DVD submitted along with this written thesis.)

5.1.1. Result from the analysis

The survey results were primarily analysed in order to investigate any variation in papermaking screens and mould structure and therefore the main focus was given to draw the characteristics of the impressions of laid and chain lines and their variations over time.

The results of the analysis are as follows:

<u>Relationship between thickness of paper and the number of laid lines</u>

It has been acknowledged (mainly by papermakers) that a screen made with finer splints could produce thinner sheets. However, this belief has not been verified by examining old paper objects and therefore, in the current research the survey data was statistically analyzed to find out whether there is any direct connection between two factors: the thickness and the number of laid lines per centimetre. In the analysis, all data (Korean and Japanese) was included. Table 6 presents the result of the analysis.

Table 6. Correlations between the thickness and the number of laid lines per centimeter

		Thickness	No. of Laid lines per cm
Thickness	Pearson Correlation	1	-.203(**)
	Sig. (2-tailed)	.	.000
	N	344	297
NoOfLaidLinesIn4cm	Pearson Correlation	-.203(**)	1
	Sig. (2-tailed)	.000	.
	N	297	303

** Correlation is significant at the 0.01 level (2-tailed).

From the data presenting the number of laid lines per centimeter and sheet thickness, the Pearson's Correlation coefficient was calculated - the analysis showed that the two variables are significantly related.

Figure 99 illustrates how the thickness of Korean paper had varied between the 12th and the 18th century.

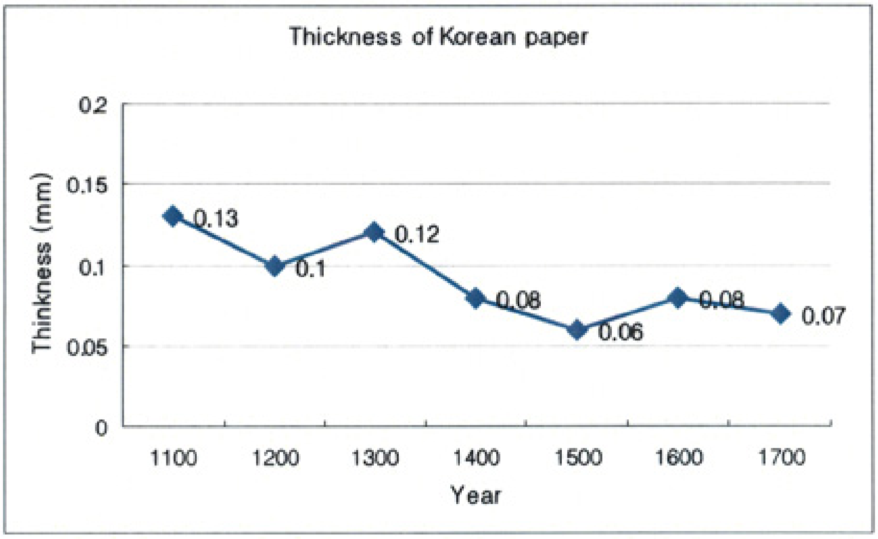

Figure 99. Thickness of Korean paper between 12th and 18th century.

It appears that from the 12th century the thickness of Korean paper decreased (Figure 99) greatly from a range between 0.13 and 0.10mm to between 0.06 and 0.08mm and had remained thus up to the 18th century. However the objects dated before the 15th century were mainly documents and the paper used for such items appeared to be much thicker than the paper used for books. Therefore, the graph does not necessarily represent the change in thickness of paper between the 12th and the 18th centuries. It could be interpreted that, for books, relatively thinner sheets were used than those for documents. It is more likely that document sheets were made by laminating more than two sheets whereas sheets for books were single. The general thickness of sheets for printing books in Korea from the 15th century to the 18th century was between 0.06 and 0.08mm.

Figure 100 shows how the number of laid lines (in 1 cm) in Korean papers had varied over time. Again, after the 15th century, the number of laid lines seemed to be rather settled between 5.3 and 5.8 with no dramatic change occurring. However, when this graph is examined in conjunction with the variation of thickness in sheets during the same period (Figure 99), it is clear that the thinner sheets were made with the screen producing a higher number of laid lines, as confirmed by statistical analysis as mentioned above.

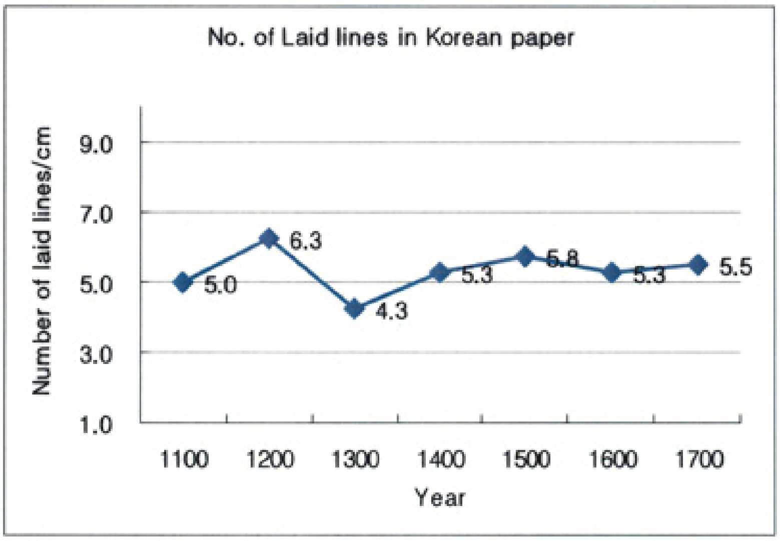

Figure 100. The number of laid lines per centimetres of Korean paper between the 12th and 18th century.

Regarding the intervals of chain lines, generally most Korean paper exhibited very irregular intervals of chain lines. They could be categorized into two groups: one is showing very frequent chain lines and their intervals were less than 2 centimetres. The second group shows relatively regular intervals which were between 2.5 and 3 centimetres. However, these appeared randomly so it is difficult to establish any trend over time.

In the case of Japanese papers Figure 101 presents how the thickness of Japanese paper had varied between the 12th and the 18th century.

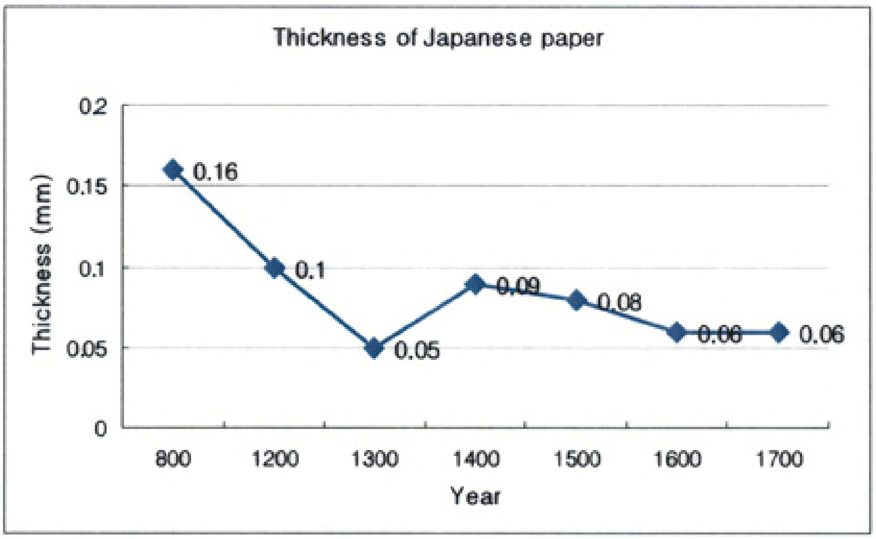

Figure 101. Thickness of Japanese paper between 9th and 18th century.

It appears that from the 15th century the thickness of Japanese paper gradually decreased (Figure 101) from a range of 0.09 to 0.06. Although the thickness of paper decreased dramatically between the 9th century and the 14th century, the number of objects was not sufficient to draw any firm conclusion on the variation made during that period. It is interesting to see that the paper used for books in Japan has a similar thickness to those of Korean book papers from the 15th century onwards.

Figure 102 illustrates how the number of laid lines (in 1 cm) in Japanese papers had varied over the same period. It appeared that, from the 15th century onwards, the number of laid lines gradually increased from 4.3 to 6.5. Although the number of laid lines had decreased considerably between the 9th century and the 15th century, the number of objects examined from the period was not sufficient to draw any conclusion.

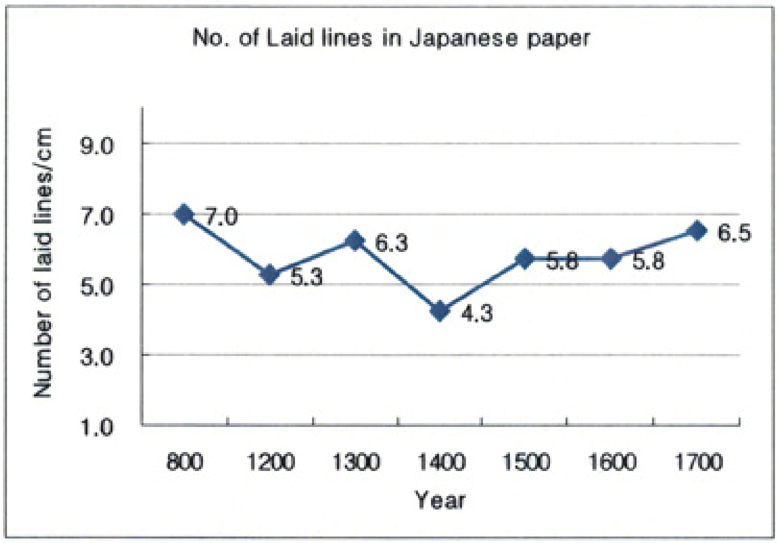

Figure 102. The number of laid lines per centimetres of Japanese paper between the 9th and 18th century.

In general, Japanese papers exhibited more regularly spaced chain lines. The intervals of chain lines were between 35 and 55 but with more regular arrangement. This is the most distinctive difference between the Korean and the Japanese papers.

Shadows of supporting ribs

Examination of shadows of supporting ribs could provide useful information about the structure of the mould used in producing the paper. Hunter (1947, p123) thought that rib shadows were caused by a peculiar suction of the wedge shaped ribs as the mould was lifted from the vat. Apart from this comment on it, no further explanation was given to that phenomenon. During the papermaking experiment with the fixed laid screen, it became clear that the suction seemed to be caused due to a capillary action: the supporting ribs were in direct contact with the back of the screen which made the drainage of water through the screen faster in the contacted area. In other words, the direct contact of the ribs to the screen would break the surface tension of water when the mould and the newly formed sheet were lifted from the vat. In the papermaking experiment with the fixed laid screen, the supporting ribs were a wedge shape with a flat top, 5 millimetres in width. The sheets produced with the mould had rib shadows of approximately two centimetres in width. This information could therefore be used to deduce the thickness of the top edge of the supporting ribs in the mould. However, in order to understand how rib shadows are affected by the size and shape of the supporting ribs, further experiments need to be undertaken in the future.

In general, paper made with short fibres tends to have clearer outlines of rib shadows. It is not difficult to notice dark streaks positioned either side of laid lines in paper made before the 19^{th} century in Europe. The main material was rag (mostly linen) which had relatively short fibres due to the thorough cutting and beating associated with the European process. On the other hand, papers made in Korea and Japan also had rib shadows though this is more difficult to spot due to the use of paper mulberry. Paper mulberry produced long fibres and its fibrillation was mostly achieved by beating with mallet which helped to preserve its long fibres.

For the current research, the survey was mainly carried out on books which made it even harder to identify the presence of rib shadows in sheets: all leaves were folded in half and bound and therefore they could not be unfolded for examination. Still it was noticed that 16 sheets from the Korean collection and 8 sheets from the Japanese collection at the British Library exhibited rib shadows (Figure 103). During the survey it was observed that the chain lines of most sheets were intended to run vertically. However, it seems as if there was no strict rule for cutting sheets intended for book binding. In figure 103 the rib shadow ran horizontally in the same direction as the chain lines.

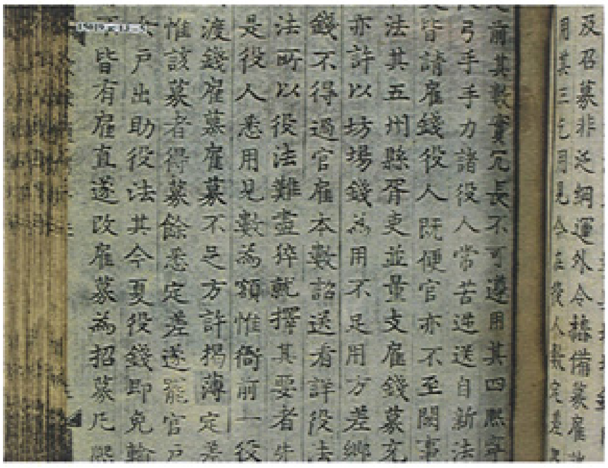

Figure 103. Rib shadow in Korean book (15019a)

The details of 24 sheets showing rib shadows are summarized in Table 7, 8.

Table 7. Japanese papers showing rib shadows.

Catalogue No	Date	Page	Description
Or.81.c.10	1279	(1 – 3)	1.5 - 1.8cm in width. From the right edge 23cm. Each sheet has one.
Orb30/171	1364	(7 – 19)	Two thicker lines at front page. Distance between them is 65-70mm.
		(7 – 14)	One thicker line 17-20mm in width. One in front.
		(4 – 18)	Three thicker lines about 15mm in width and intervals are 65-70mm.
		(4 – 10)	Two thicker lines about 15mm in width and 65-70mm interval between them.
		(3 – 3)	There are three vertical thicker lines along chain lines: about 15-20mm in width and 150mm and 60-70mm intervals.
Orb30/195	1616	(序 – 1)	There are three rib shadows. Their thickness are between 12 and 16 mm and intervals are 100 and 95 mm. Quite distinctive but do not appear throughout the length of the sheet.
16124.b.7	1682	112	One 17mm in width along chain lines but discontinuous.

Table 8. Korean papers showing rib shadows.

Catalogue No	Date	Page	Description
15201.e.13	1455	(記 －4)	In the centre between two chain lines there is a slightly thicker area.
		(後序 －4)	Not very clear but in the centre there is a horizontal line which appears to be slightly thicker about 20mm in width; another is about 30mm in width down to the bottom.
		(上 －37)	There is one along a chain line though its outline is not clear enough to measure.
		(廟式 －9)	This rib shadow is discontinuous and its outline is not clear though it is approximately 20mm in width on the front right side.
15253.e.1	1550	(8 – 16)	It appears to be slightly thicker than the rest of the sheet: its outline is not clear but 17mm in width between two chain lines.
15019.a	1558	(13 – 2)	30-50mm in width. Very thick but its outline is irregular. It runs along a chain line.
		(13 – 14)	Approximately 20mm in width between two chain lines.
		(13 – 5)	25mm in width. Its outline is not clear.
15296.e.5	1583	(8 – 12)	There is a long thicker section but this part is not printed – possibly the reason it looks whiter than the rest of the sheet.
		(4 – 39)	There is a thicker part; its shape is irregular and slightly discontinuous.
16015.c.4	(1600)	(7 – 17)	17mm in width between two chain lines. It appears to be slightly thicker along the length.
		(10 – 9)	25mm in width. In the upper part of the sheet it is quite clear though towards the lower portion becomes less clear.
		(9 – 16)	15mm in width. In the upper part of the sheet it is very conspicuous but towards the lower part becomes faint.
		(9 – 2)	17.5mm in width between two chain lines. It appears to be slightly thicker.
15334.f.2	1686	(3 – 10)	About 25mm in width along the chain lines. Appears to be slightly thicker.
15211.b.1	(17C)	(9 – 36)	20mm in width along chain lines. Slightly thicker than the rest of the sheet.

According to the data (Table 8), the width of the rib shadow was between 15 and 30 mm though most of them did not have clear outlines.

It is interesting to see (Table 7) that Japanese paper showed more than one rib shadow in each sheet and their intervals were between 65 and 100 millimetres. Meanwhile, Korean paper showed one rib shadow in a sheet and they are less clear than those in Japanese papers. Understanding the characteristics of rib shadows is crucial in order to comprehend the features of mould structure and its development over time. Although the number of sheets carrying rib shadows is not great enough to draw any firm conclusion but from the data, it can be said that the Japanese mould generally had more frequent supporting ribs and the intervals between supporting ribs of the Korean mould must have been greater than in Japanese moulds.

5.1.2. Other information

<u>Sheets made with reclaimed paper</u>

As mentioned before, recycling waste paper must have been common in traditional papermaking in Korea. During the survey, several sheets showed that waste paper was used in the papermaking process.

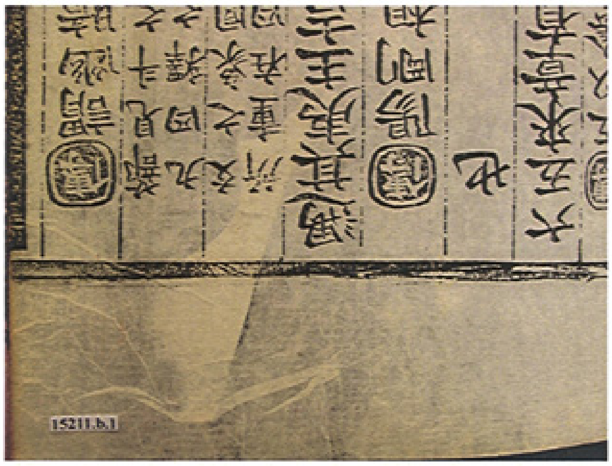

Figure 104. A piece of waste paper included in a sheet made in the 17th century

Although there is no historical account of how to recycle paper inside Korea, it is believed that waste paper might have been reduced to pulp before it was included in the vat. However, noting the appearance of the sheets including quantities of waste paper, there was no sign that reclaimed material had been processed before it was mixed with new stock. The edges of such inclusions remained sharp (Figure 104). In light of the condition of these inclusions, it would appear that un-inked scraps of paper have been used, at least on occasions, without being re-pulped.

Short double chain lines

There were sheets with very short double chain lines: while one line appeared to be normal appearing across the length of the sheet, accompanying lines appeared over short lengths, particularly at the edges of sheets (Figure 105).

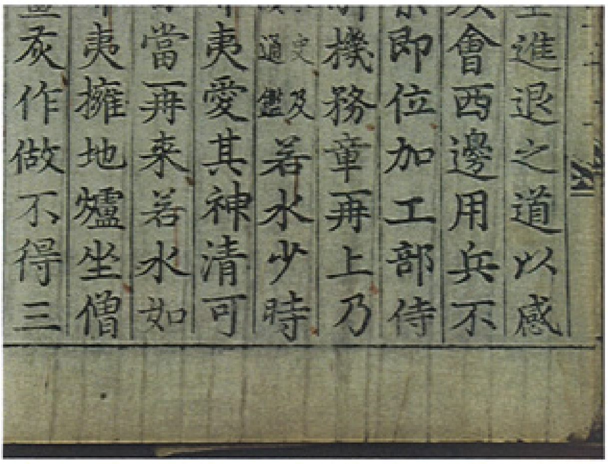

Figure 105. Short double chain lines on the edge of a sheet

According to Son (2005, p81), the end of the screen was the most frequently handled by papermakers and this habit would wear out that section of the bamboo splints or plant stems. In order to support the weakened part of the screen, papermakers reinforced the area by lacing with thread and it is these repairs which are responsible for the shorter chain lines. In an illustration of a Korean screen in Hunter's book (1947, p95), it is easily noticeable that this type of repair was undertaken at the short edges of the screen. These short double chain lines seem rather common and with the explanation from the previous research this occurrence is easily understandable. However sometimes there were sheets with an opposite impressions (Figure 106) – some chain lines did not reach to the edge of the sheet which cannot be explained with the explanation mentioned above.

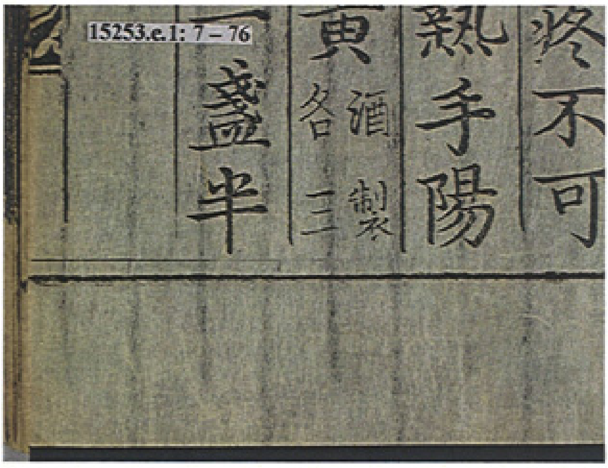

Figure 106. Chain lines appear to be alternatively short and do not extend to the edge

In this case, every second chain line does extend to the edge and it is difficult to understand why only alternate lines are truncated.

Impressions made by drops of water

There were sheets with round spots scattered across the sheet (Figure 107). These spots were caused by drops of water falling on the newly formed sheets.

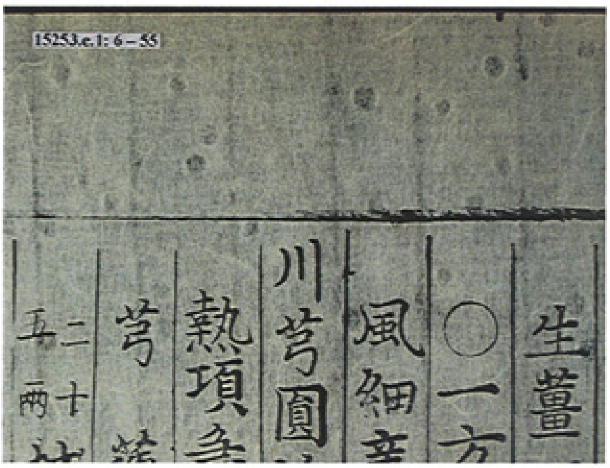

Figure 107. The impression of drops of water.

5.2. Fibre identification

The survey was conducted on 351 sheets in total (268 of Korean paper and 83 of Japanese paper) but fibre identification was carried out only on 252 samples (184 of Korean papers and 69 of Japanese paper). Several photomicrographs were taken for each sample during the examination with a polarizing microscope and the observations and identities are recorded in Appendix 1.

Identification of materials used

Through extensive examination of fibres, several interesting features were found. Firstly, most of the examined fibre samples appear to include fibre enveloped in a loose primary wall which has been regarded as a key characteristic in theidentification of fibres of paper mulberry (*Broussonetia kazinoki Sieb* and *Broussonetia papyrifera Vent*). However, from the examination of standard samples it was confirmed that mulberry (*Morus alba*) fibres also have the same features. Lee (2006, p23) stated it would be possible to differentiate paper mulberry fibres from mulberry fibres based on their differences in length. Nonetheless, it is not practical as fibre length varies widely even in one species and also fibres are often damaged during the fibrillation process. Therefore, the materials of any paper showing fibres with a loose primary wall have been identified as the bast fibres from *Moraceae* family. It is worth noting that fibres from *Moraceae* presented diverse features (Figures 108 – 113) during the examination.

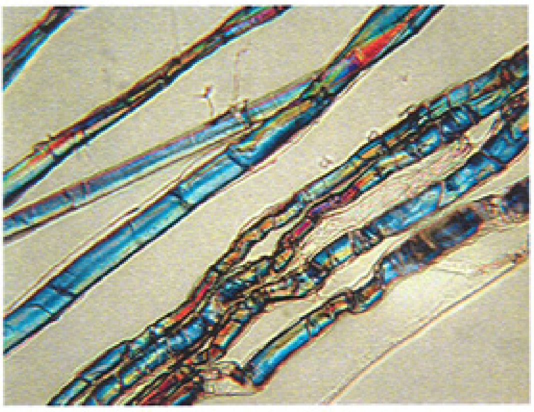

Figure 108. A group of fibres from *Moraceae* family. Most of them show a clear loose primary wall. Some of them have distinctive dislocations and frequent cross-markings (x250). (Korean collection at British Library, 15320d38(目-3), the 17th century)

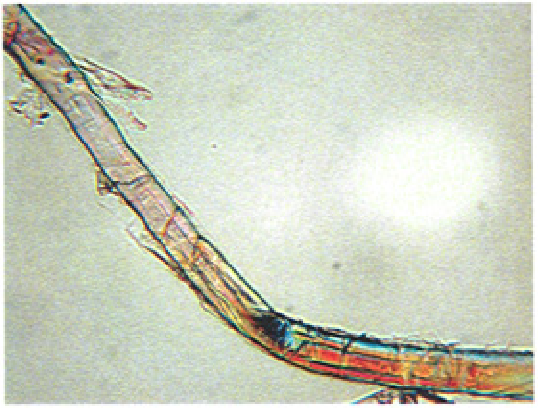

Figure 109. A fibre with loose primary wall and with clear longitudinal splits (x400). (Korean collection at British Library, 15315e9(4-18), the 16th century)

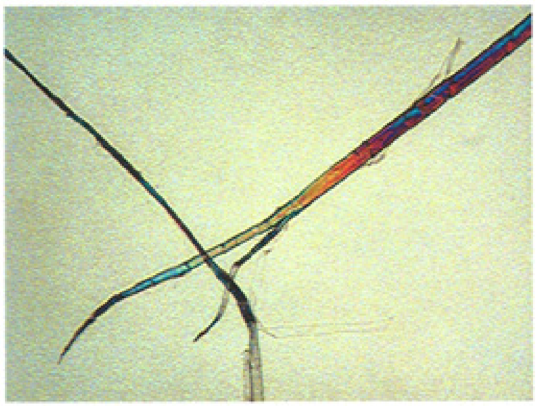

Figure 110. A fibre with split ends (x250). (Korean collection at British Library, 15315e11(2-21U), the 16th century)

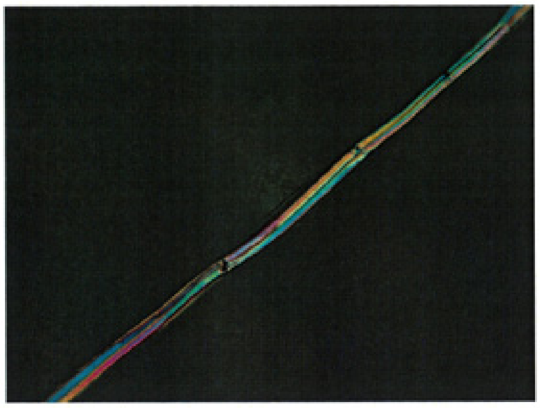

Figure 111. A fibre with smooth surface and well spaced cross-markings (x250). (Korean collection at British Library, 15315e11(1-5L), the 16th century)

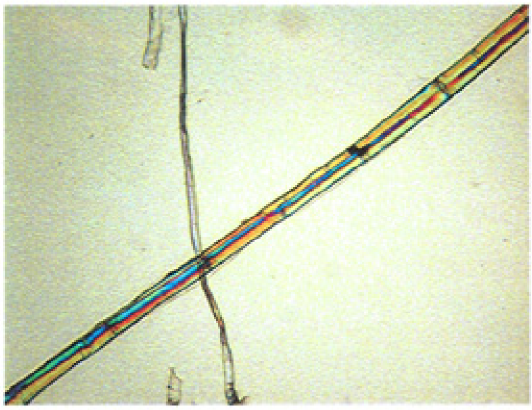

Figure 112. A fibre with clear, narrow lumen and rather faint cross-markings (x250). (Korean collection at British Library, 15320d38(2-9), the 17th century)

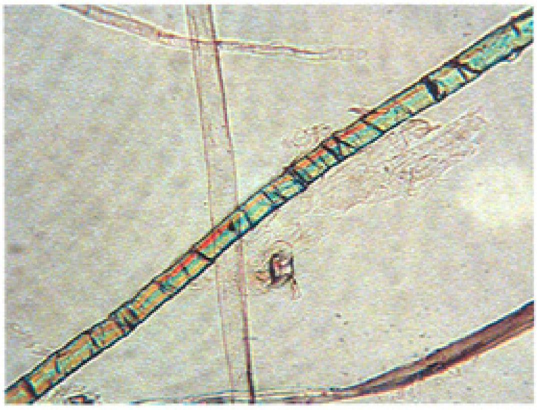

Figure 113. A fibre with clear, frequent cross-markings (x250). (Korean collection at British Library, 15260b22(20), the 16th century)

Secondly, one of the important findings is the presence of two specific types of crystals: prismatic cuboid and rhombic shape crystals were often found in the samples examined (Figure 114).

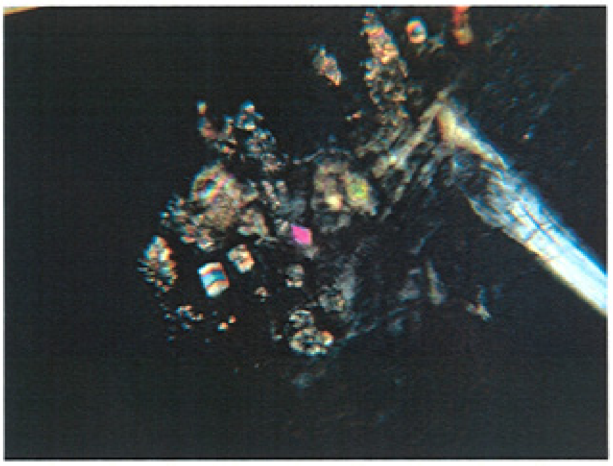

Figure 114. Example of rhombic and prismatic crystals (x400). (Korean collection at British Library, Or81e10(上-10), the 17th century)

As these crystals were also discovered among the standard fibre samples prepared from the raw materials of paper mulberry and mulberry, this finding could be useful in the identification of fibres of the *Moraceae* family. In particular, the rhombic shape crystals, seemingly related to the fibres of paper mulberry, have not been reported in any previous research. In fact, either prismatic cuboid or rhombic shaped crystals (or both in some cases) were observed in 17 percent of Korean papers and in 50 percent of Japanese papers examined. It is also interesting to note that the percentage of Japanese papers having prismatic cuboid or rhombic shaped crystals is much higher than the percentage of Korean papers which exhibited those crystals. According to Ilvessalo-Pfaffli (1995, p298), crystals are usually dissolved and removed during alkaline pulping and therefore, the papers including the crystals might have been treated by a chemical pulping process which included the use of a weaker alkaline solution or had received only mechanical and/or non-alkaline treatment.

As all standard samples were prepared by cooking in a solution of potassium hydroxide (KOH), if the crystals had resulted from any chemical reactions, then all standard samples would have included the same type of crystals. However, the prismatic cuboid and rhombic shaped crystals were only found with fibres of the *Moraceae* family. Therefore, the presence of the prismatic cuboid and rhombic-shape crystals may have important diagnostic value.

Thirdly, the analytical results showed that approximately 30 percent of Korean sheets examined (59 sheets out of 184) were made with mixed materials and the materials used over time are summarized in Table 9.

Table 9. Summary of identified materials in Korean papers

Period	Materials identified (apart from paper mulberry)	No. of object	No. of examined	Percentage (%)
13 – 14C	Grass fibres (mainly rice straw), wood pulp.	3	13	23
15C	Grass fibres (mainly rice straw), wood pulp, gampi.	20	42	47
16C	Grass fibres (reed), wood pulp, hemp, cotton.	16	71	22
17C	Grass fibres (reed), wood pulp, hemp.	9	40	22
18C	Grass fibres (rice straw, reed, and unidentified grass), wood pulp.	11	18	61
Total		59	184	

According to the data from the survey the percentage of papers containing mixed materials appeared high during the 15th and the 18th centuries. The 15th century was the period in which the Joseon government had made a great effort to introduce foreign papermaking techniques and to search for new materials which could be used for papermaking and, therefore, the high percentage of paper made from mixed materials in the 15th century must have resulted from such political conditions. It is interesting to see that the percentage of mixed fibre papers decreased during the 16th and the 17th centuries but later in the 18th century it increased again to 61 percent. The most common supplementary materials through the periods appeared to be grasses including, rice straw and reed, whereas hemp, cotton and gampi appeared to be minority materials.

Table 10. List of objects which include mechanical wood pulp

Country of Origin	Date	British Library Catalogue No.	Page No.	Total
Korea	1498	15287e2	表 – 2	15 (out of 184)
			3 – 1	
	1501/2	15324e4	2 – 7	
	1519	15315e9	3 – 14	
			4 – 18	
	1550	15253e1	6 – 55	
	1570	18113e8	上 – 17	
	1583	15296e5	8 – 12	
	1668	Or81a1	6 – 19	
			11 - 1	
	1778	Or6998	4 – 6	
			4 – 16	
			7 – 20	
			10 – 5	
			11 – 78	
Japan	1616	Orb30/195	3上 – 4	1 (out of 68)

Lastly, and most interestingly, was the discovery of wood pulp being used as a supplementary material from the 15th century through to the 18th century in Korea. It appeared that 15 samples of Korean paper dated between 1498 and 1778 included fibres of mechanical wood pulp mixed with paper mulberry. Furthermore, one 17th century sample out of 68 fibre samples from Japanese papers also included mechanical wood pulp mixed with paper mulberry (Table 10).

In the history of papermaking, mechanical wood pulp (or ground wood) has been considered to have been first introduced in Europe by Friedrich G. Keller in 1844 (Paper Making, 1950, p68). According to Hunter (1947, p376) Keller used a revolving wet grindstone for fibrillation of blocks of wood. Due to this mechanical grinding process, the pulp consisted of broken fragments of fibre and bundles of fibres and it is rare to find intact, fibres. The majority of wood pulps are derived from coniferous trees, in particular the spruces and the pines (Paper Making, 1950, p68) – fibres obtained from conifers mainly consist of those cells known as tracheids (also called longitudinal tracheids or fibres), long narrow cells with closed ends and bordered pits (Ilvessalo-Pfaffli, 1995, p15). In identification, haloes (bordered pits exhibiting two concentric rings) surrounding the pores can be easily noticeable – additionally, sometimes remnants of the medullary rays crossing one or more fibres may be present (Paper Making, 1950, p44) (Figure 115).

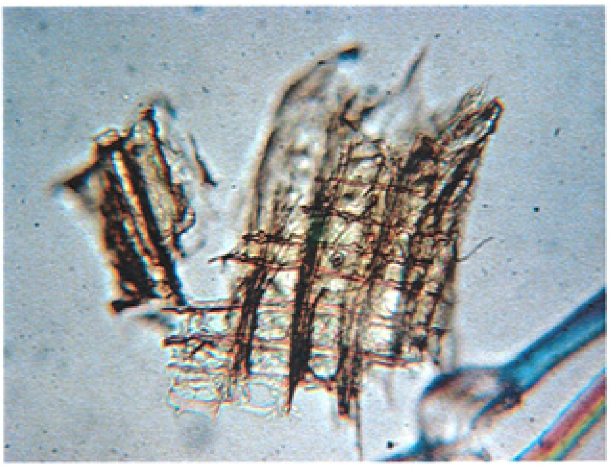

Figure 115. Mechanical wood pulp showing medullary rays crossing fibres (x250) from British Library Korean collection, 15253e1(6-55) in the 16th century

As the main material of traditional papermaking in East Asia has been the inner bark of shrubs such as paper mulberry, mulberry, and grasses such as straw and bamboo, the use of wood pulp in traditional papermaking has not been much considered to date. However, most of the photomicrographs of the sixteen samples listed in Table 10 clearly show bordered pits which appear as stationary crosses under cross-polars (Figure 116, 117) because the cellulose molecules are arranged in elongated crystals which radiate from the centre.

Figure 116. Clear bordered pits in broken wood fibre (x250) from British Library Korean collection, Or6998(10-5) in 1778.

Figure 117. bordered pits under cross-polar (x250). The same sample as Figure 114.

The microphotographs of 15 wood pulp fibres were compared with the standard fibre samples derived from a twig and leaves of pine. Among them, those which showed clear bordered pits revealed great morphological resemblance to the standard fibre samples of pine especially in the way bordered pits were arranged. The tracheids from the inner bark of pine tree appeared to have rather thin walls (Lee, 2006, p24) whereas most of the wood pulp observed in the examination had thick walls. Therefore, although old paper names indicating that inner bark and leaves of pine were used in papermaking during the Joseon period, based on the observation of fibres of wood pulp in the analysis, it could be said that pine wood was more frequently used since tracheids were found.

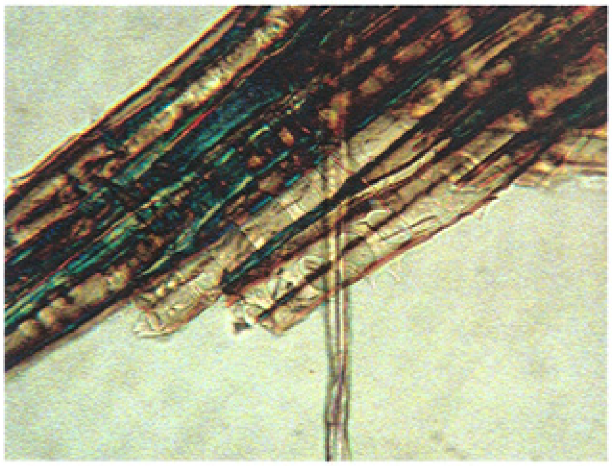

Figure 118. Window-like pits of tracheids from the sample (x400), British Library Korean collection, 15324e4 (2-7) in 1501.

One of the samples exhibited clear window-like pits on tracheids (Figure 118) appearing quite similar to the window-like pits of tracheids seen in pine material, especially *Pinus sylvestris L.* which is widely distributed, ranging from central and northern Europe to eastern Asia (Ilvessalo-Pfaffli, 1995, pp126-127). However, according to Ilvessalo-Pfaffli (1995, p160), the window-like pits of *Pinus sylvestris L.* are similar to those of *Pinus densiflora* which is the common red pine in Korea and therfore, this wood fibre could originate from a red pine (*Pinus densiflora*) or from *Pinus sylvestris L.*

Others showed a translucent layer with criss-cross pattern covering their bordered pits on the tracheids (Figure 119, 120, 121).

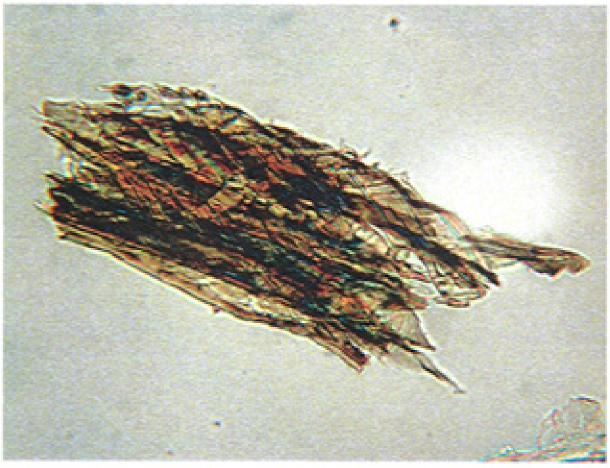

Figure 119 wood pulp from Korean paper, 15315e9(4-18) in 1519

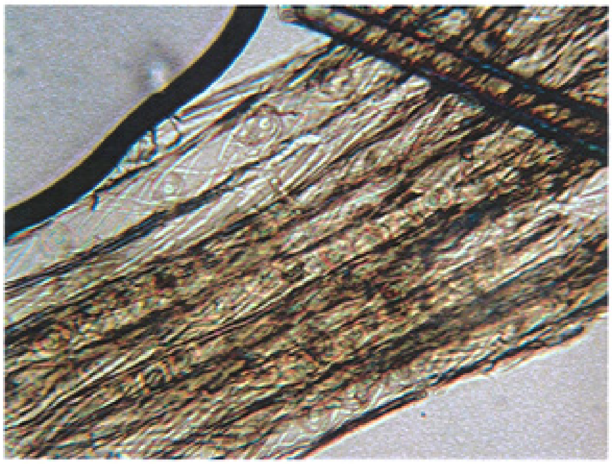

Figure 120 wood pulp from Korean paper, 15296e5(8-12) in 1583

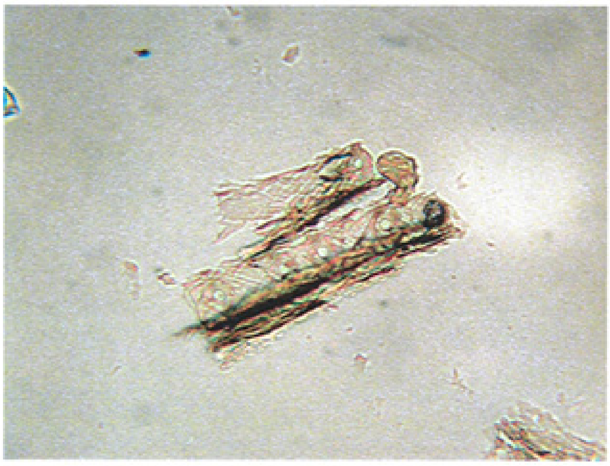

Figure 121 Wood pulp from Korean paper, Or6998(4-6) in 1778

These fibres look quite similar to the fibre found in one of the Japanese papers (Figure 122).

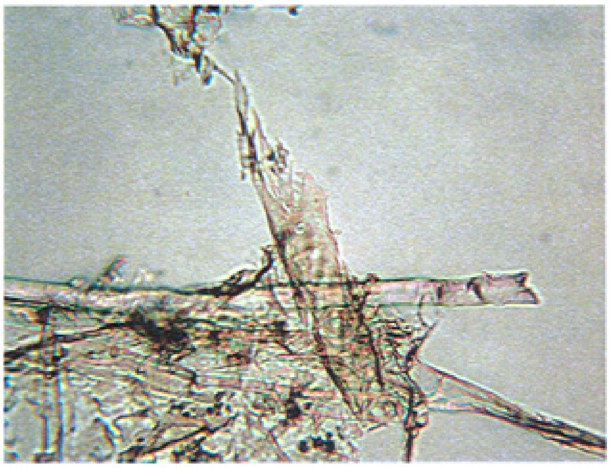

Figure 122 Wood pulp from Japanese paper, Orb30/195(3上-4) in 1616

Therefore, it can be said that, whatever it was, the same type of coniferous wood must have been used for traditional papermaking in both countries.

Previously there was a report on the finding of a tracheid cell of softwood in old Korean paper: Park (2003, p154) reported that a tracheid cell of a coniferous tree was found in a 13th century Korean paper. He suggested further research needed to be done as there was little possibility that fibres from coniferous tree could have been included during the traditional papermaking process at that time. No written information related to the process of wood pulp in traditional papermaking in Korea has been identified to date. Yet some historical accounts on papermaking in Korea showed that certain parts of a coniferous tree were used: as mentioned before, in 1424 'songyeopji' (松葉紙, paper made with leaves of pine tree) was made in Jojiseo and also according to Lee (2003, p65) the bark of pine tree was used for papermaking during the Joseon period where it was called 'songpiji' (松皮紙, paper made with the bark of pine tree). Unfortunately these papers have not been identified and it is difficult to establish how they would appear. Fibres from pine leaves and from pine inner bark had been prepared in the reference materials but none had been recognised in the historical papers. There is the possibility that the authors of these historical accounts may have meant wood, including bark and leaves.

In order to find out whether a sheet made with a mixture of wood pulp and bast fibres has any distinctive features which could be used for differentiating it from other papers made with different materials, the colour and texture of the thirteen objects were examined and compared. However, they did not show any consistent characteristics. For example, some of them were very discoloured and had many tiny speckles (Figure 123) which might result from inclusion of leaves or bark residues. Others were rather white in colour and did not have any such speckles (Figure 124) and perhaps only wood was used in the production of these.

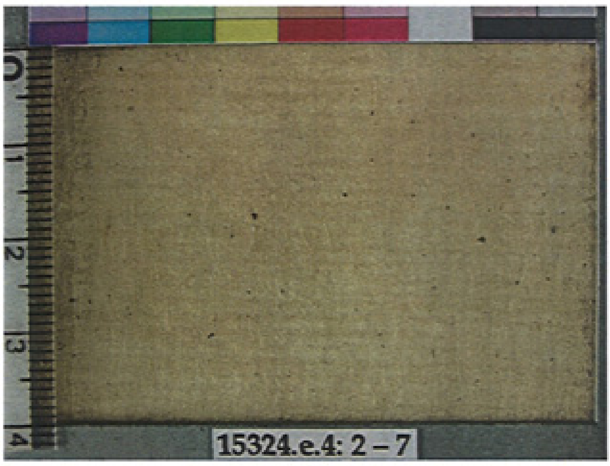

Figure 123. Korean paper, 15324e4(2-7) in 1501/2 exhibiting dark speckles

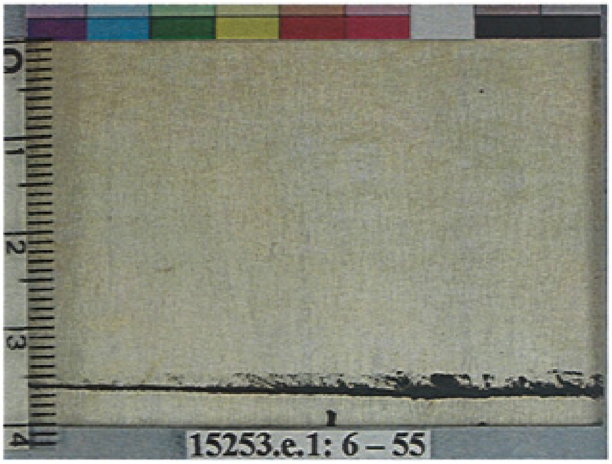

Figure 124. Korean paper, 15253e1(6-55) in 1550 exhibiting no speckles

Therefore, it seems as if the colour and texture of a sheet were not much affected by the addition of wood pulp.

As Park (2003) reported, a tracheid was found in a 13th century Korean paper and this current research confirmed that wood pulp was one of the supplementary materials used in traditional Korean papermaking between the 15th and the 18th centuries. Therefore, it can be concluded that the mechanical wood pulping technique was well developed in Korea from the Goryeo dynasty and it became more popular throughout the Joseon period.

Meanwhile, about 25 percent of Japanese papers appeared to be made with mixed materials – such occurrences are summarised in Table 11.

Table 11. Summary of identified materials in Japanese papers

Period	Materials identified (apart from paper mulberry)	No. of object	No. of examined	Percentage (%)
8C	Bast fibres other than paper mulberry	1	1	100
13C	Grass fibres, gampi.	3	7	43
14C	Grass fibres.	3	15	20
15C	Grass fibres.	1	5	20
16C	Grass fibres including rice straw.	6	13	46
17C	Grass fibres, wood pulp.	3	27	11
18C	-	0	1	0
Total		17	69	

The summary showed that grass fibres had been the main supplementary material in Japan between the 13th and the 17th centuries. However, the number of sheets examined was not sufficient enough to draw a more reliable conclusion. One of the most interesting findings was that wood pulp was discovered mixed with paper mulberry in one of the 17th century papers and it showed the same morphological characteristics as those wood pulp fibres discovered in the Korean papers. It may be possible that both countries started using wood pulp long before mechanical wood pulp was introduced to papermaking in Europe. Another possibility is that this particular sheet of paper in the Japanese artefact was imported Korean paper.

Twisted fibres

Ten objects from the Korean collection and four objects from the Japanese collection appear to include twisted fibres which imply a possible use of reclaimed textile materials in papermaking.

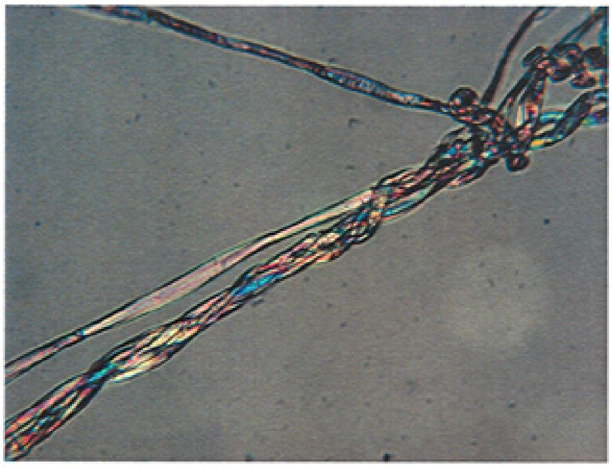

Figure 125. Fibres from British Library Korean collection, Or81a1(11-1) in 1668.

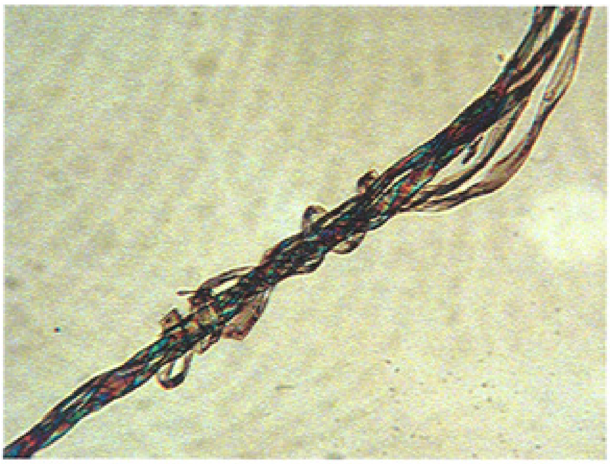

Figure 126. Fibres from British Library Korean collection, 15315e11(5-17L) in 1529.

It is rather difficult to identify what type of bast fibres they were because they often appear to be tightly wound around each other (Figure 125, 126). However, some of them show a loose primary wall (Figure 127) suggesting the threads are from bast fibres, in particular *Moraceae* family. It should be considered that both paper mulberry and mulberry have a transparent membrane enveloping the fibres and it is difficult to differentiate one from the other.

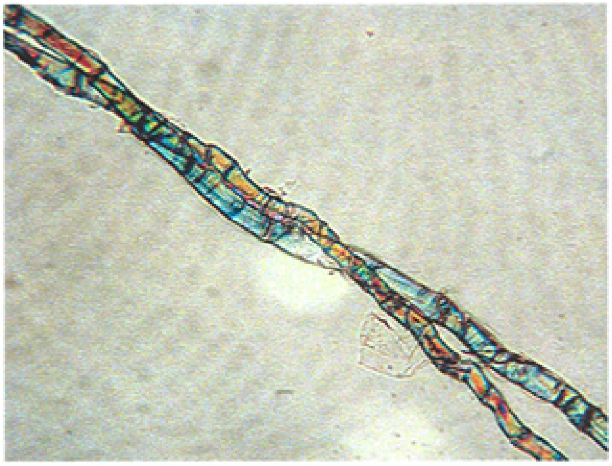

Figure 127. Twisted fibres with a loose primary wall, from British Library Korean collection, 15211b1(10-13) in the 17th century.

It appears that paper mulberry was commonly used, in Korea, for making a textile despite the heavy demand for its use in papermaking. Evidence for the use of fibres of paper mulberry for weaving can be seen in Haedongnongseo (海東農書) written by Seohosu (徐浩修) in 1798:

> … remove the bark of paper mulberry and cook it and beat it to make paper. Furthermore threads can be made with it and then they are bleached in order to make cloth (as reported in Kim, 2003, p107).

<u>Images by Scanning Electron Microscope (SEM)</u>

38 samples of paper dating from between the 12th century and the 17th century were examined using a SEM. The images taken with SEM clearly show whether the object went though the traditional finishing process, 'dochim' (搗砧). A sheet finished by this process appears to be much flattened across its surface (Figure 128).

Figure 128. Surface character of a sheet (14th century) made with 'dochim' process

In fact, with the naked eye the sheet appears to be very compact and smooth without showing many open porous spots (Figure 129).

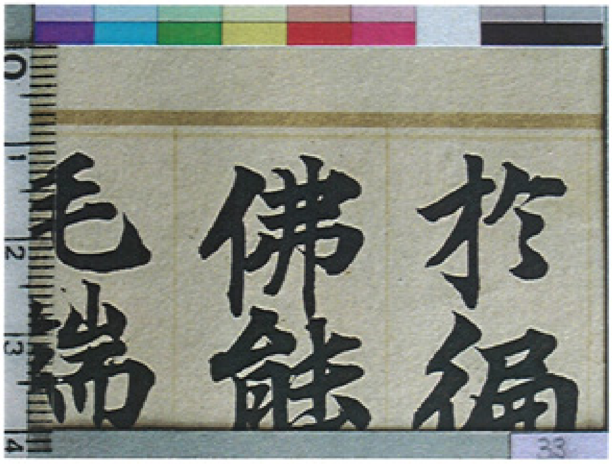

Figure 129. Surface character of a sheet made with 'dochim' process

However, not all the samples examined were treated by this traditional method as some show rather porous surface with SEM (Figure 130). Indeed, during the survey, it was noticed that all papers used for books appeared not to have been finished by the 'dochim' process.

Figure 130. Surface texture of a sheet (14^{th} century) without 'dochim' process

Due to the laborious nature of the 'dochim' process, only sheets intended for more important uses must have undergone this step – highlighting the severity of such work, Kim (2003, pp12-13) reported that in Jojiseo, the government imployed criminals for 'dochim' process.

Regarding cross-sections of samples, images taken with the SEM did not reveal much detail as most of them are rather thin. However, some of these cross-sections revealed that the sheets consisted of several layers (Figure 131) which must have resulted from the traditional sheet forming and couching processes.

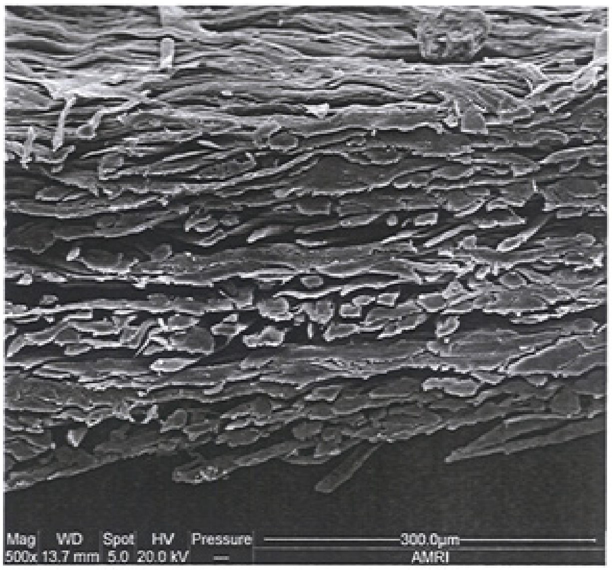

Figure 131. Cross-section of a sheet made in 1507 showing several layers

5.3. Results of papermaking Experiments

5.3.1. Function of the formation aid

An average of each set of measurements was calculated (Table 12). The results for the two samples of the same solution were more widely different than the three measurements for each sample. This may reflect the heterogeneous nature of the root extract.

Table 12. Viscosity measurements of the formation aid

	Measurements (Revolutions per minute)	Results (cP)	Average (cP)
Sample 1 (21°C)	20rpm (Spindle no.3)	45	42
	20rpm (Spindle no.4)	40	
	50rpm (Spindle no.5)	40	
Sample 2 (22°C)	20rpm (Spindle no.3)	65	67
	50rpm (Spindle no.4)	65	
	50rpm (Spindle no.5)	70	

Analysis of the paper samples

The data (Table 13) was analysed in the following way: standard deviations were calculated using formula 1 and from these 95% confidence limits were calculated (95% of the data should fall within 2 standard deviations of the mean). Each quantity including; tensile index, zero-span tensile index, and two versions of bonding index and density data were each plotted against fibre type (Figures 132 – 136). The figures include error bars which show the 95% confidence limits and therefore represent the range within which 95% of the data was expected to fall. Hence, if the error bars for two groups of data lie in the same range, then the difference between the data was not considered statistically significant.

$$s = \sqrt{\frac{\left(\sum_{i}(X_i - \overline{X})^2\right)}{n-1}}$$

Formula 1 experimental standard deviation

Table 13. The summary of tests results

		Grammage (g m-2)	Tensile Index (N m g-1)	Zero-span Tensile Index (N m g-1)	Thickness (mm)	Density (g cm-3)	Bonding Index (N m g^{-1})	Bonding Index 2
Flax	Average	65.7	27.7	109.2	119.4	0.550	22.1	
	95% Confidence	0.2	0.6	3.9	1.5	0.007	1.2	
Flax with M(3.5L)	Average	63.3	21.7	103.6	114.2	0.554	17.9	18.1
	95% Confidence	0.9	1.0	4.3	1.2	0.009	1.3	1.17
Softwood	Average	65.1	67.6	162.0	106.4	0.612	47.7	
	95% Confidence	1.4	1.8	7.1	2.4	0.019	2.5	
Soft with M(3.5L)	Average	64.7	55.8	152.8	100.2	0.646	40.9	41.5
	95% Confidence	0.3	4.1	10.0	1.0	0.007	4.1	3.58
Mulberry	Average	69.6	40	225.2	176.7	0.394	34.0	
	95% Confidence	3.5	3.59	13.5	10.4	0.029	3.7	
Mul with M(3.5L)	Average	63.9	46.2	214.6	145.1	0.440	38.0	38.3
	95% Confidence	0.32	1.84	8.22	3.35	0.011	3.3	4.32

The test results suggest that adding the mucilaginous solution reduced the Tensile Index for the flax and the softwood but not for the paper mulberry, where the Tensile Index was slightly increased (Figure 132). There were small changes in the Zero-span Index for all pulps (Figure 133), but these were not statistically significant because Zero-span is an indication of fibre strength and therefore, the influence of the inclusion of mucilage was not expected to give any significant change to Zero-span results.

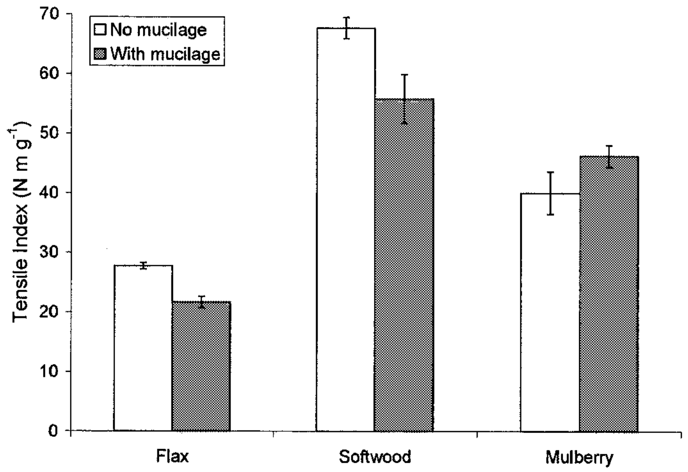

Figure 132. Tensile Index of the samples

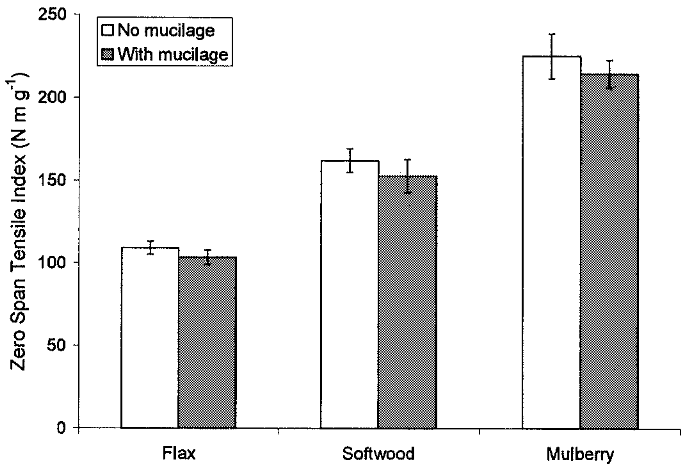

Figure 133. Zero-Span Tensile Index of the samples

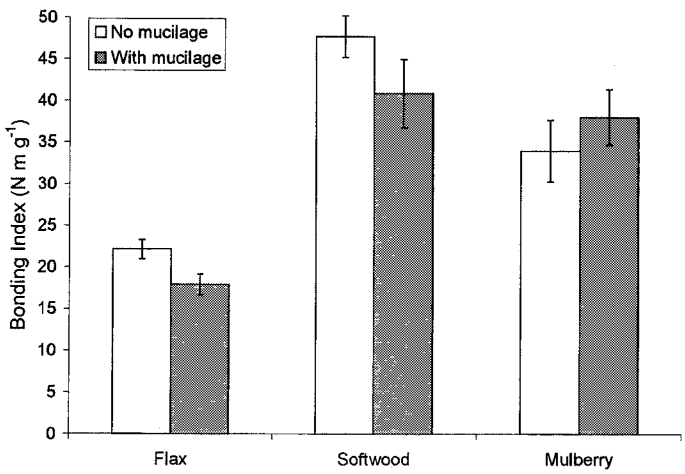

Figure 134. Bonding Index

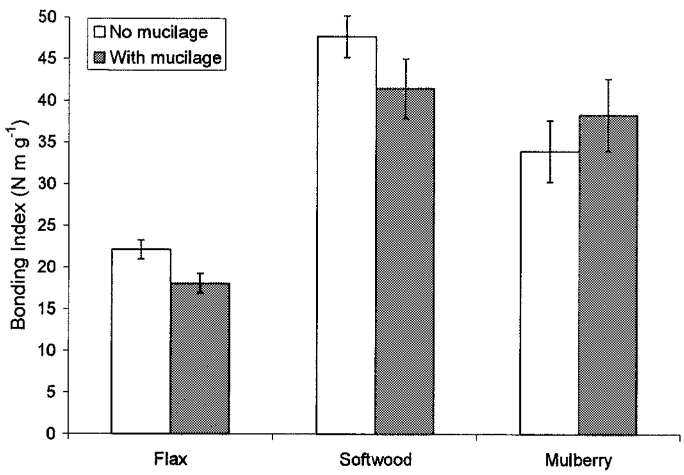

Figure 135. Bonding Index (2)

However, the Bonding Index (2) (Figure 135) was calculated using the Zero-span data for the 'no mucilage' sheets with the tensile index for the 'with mucilage sheets' in order to make sure that the observed influence in the Bonding Index (B) was not due to the change in the Zero-span Index. The observed effect for the Bonding Index (B) was the same.

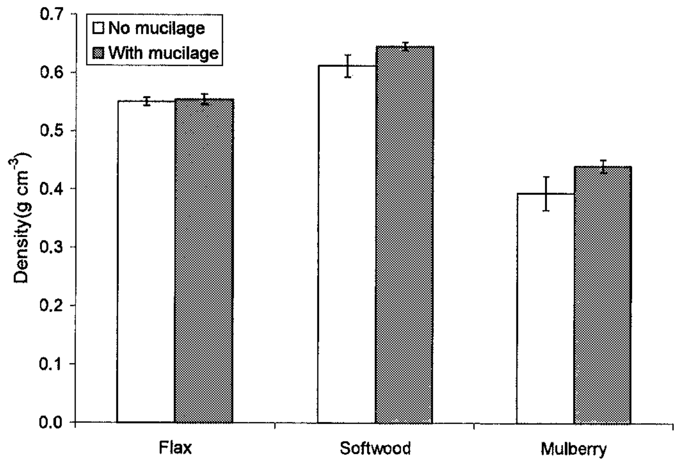

Figure 136. Density

While the density of the sheets formed with flax was not affected by the addition of the mucilaginous solution, the density of sheets made with softwood and paper mulberry was slightly increased by the mucilage (Figure 136). In general (and understandably), increased density goes with increased strength because the degree of contact between fibres increased with density and thus the increased Tensile Index of paper mulberry with mucilage. However, in the case of the sheets made with softwood, while its density was increased, its strength decreased slightly which suggested that the strength of bonds at regions of fibre contact had decreased. This rather contradictory result might be connected with the difference in fibre lengths between paper mulberry and softwood. Yet, it is hard to draw any conclusion without further analysis.

The images from Beta-radiography Recording showed that the sheets with the mucilage appeared to have more even thickness than sheets without the mucilage (Figure 137, 138). Therefore it is evident that this mucilaginous substance improves the uniformity of each sheet regardless of the length of fibres.

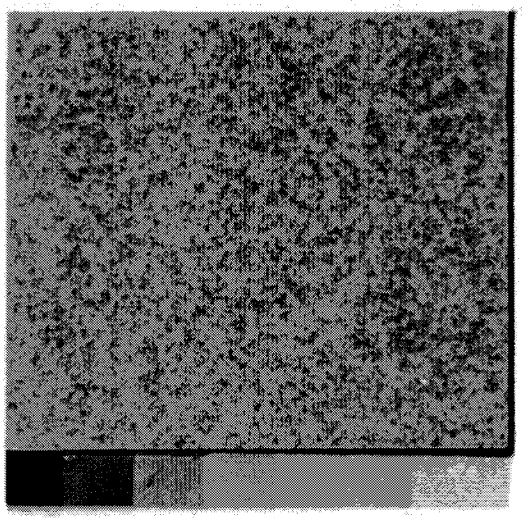

Figure 137. A sheet made with Flax without formation aid

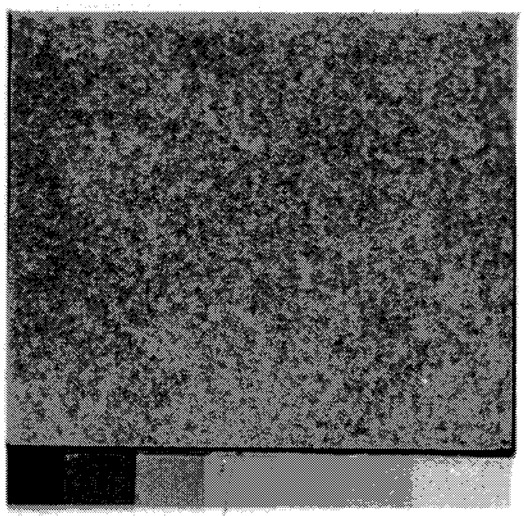

Figure 138. A sheet made with Flax with formation aid

<u>Discussion</u>

From the test results it is clear that this mucilaginous substance greatly improves the uniformity of each sheet regardless of the length of fibres. However, the substance clearly reduces fibre bonding in a sheet made with flax and softwood. This result contrasts with the commonly accepted belief that the mucilaginous substance enhances fibre bonding: many scholars presumed that a formation aid could improve the thickness of a sheet and therefore the strength of sheet would be increased. Nonetheless - in the case of paper mulberry with an addition of mucilaginous substance - its thickness improved as did fibre bonding. Therefore, it can be said that improving the uniformity of the sheet does not equate to the increase of fibre bonding strength within it. It is possible that the length of fibre could be another factor affecting the strength of a sheet.

From the experiment it is clear that the mucilaginous substance from the root of *Hibiscus Manihot* is an effective diffusion media in papermaking. Among conservation treatments, pulping is a useful treatment for repairing partial losses of paper support without very noticeable conjunction. For pulping, it is important to prepare a well dispersed stock and also to control the speed of drainage on a low pressure table. Addition of the mucilaginous substance from the root of *Hibiscus Manihot* could be an effective additive in pulping treatment.

5.3.2. Papermaking with a fixed laid screen

Result of experiment

In the experiment, several facts were confirmed - they are as follows:

In general, a fixed laid screen could produce sheets with impressions of laid and chain lines. There was no noticeable difference in the impressions made with a fixed laid screen or a flexible laid screen. (Figures 139 – 142).

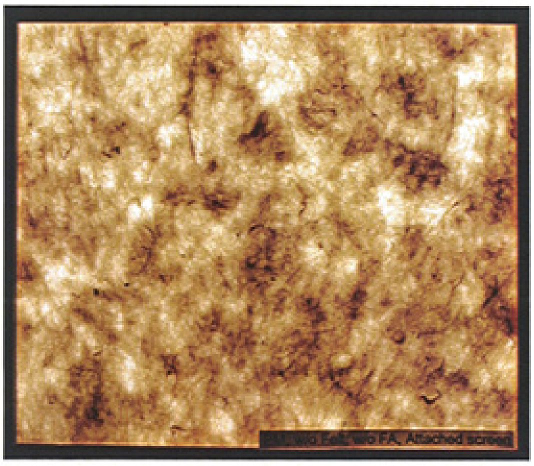

Figure 139. A sheet made with paper mulberry, without felt, without formation aid and with a fixed screen.

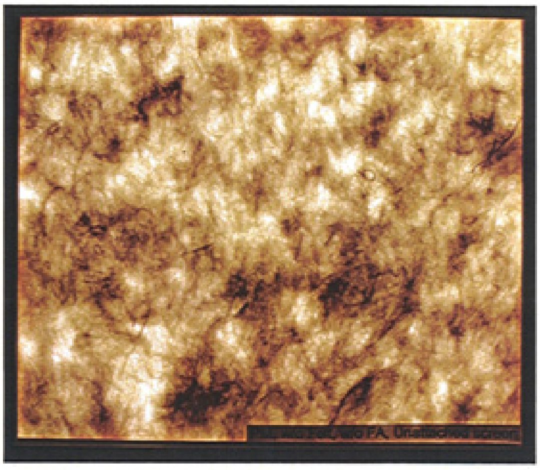

Figure 140. A sheet made with paper mulberry, without felt, without formation aid and with a flexible screen.

Figure 141. A sheet made with paper mulberry, without felt, with formation aid and with a fixed screen.

Figure 142. A sheet made with paper mulberry, without felt, with formation aid and with a flexible screen.

In fact, a fixed laid screen appears to be more effective/faster during the couching process taking less time for couching than the detached laid screen. For short fibres such as fermented flax, the use of interleaving felts is essential to separate the sheets after pressing. However, in the case of unfermented flax and paper mulberry, they were easily separated without interleaving layers, after pressing, regardless of the addition of the formation aid.

Generally, the addition of a mucilaginous substance appeared to improve the thickness of all sheets but the degree of improvement depended on the length of fibres. In the case of paper mulberry – which has the longest fibres among them – the difference in uniformity of sheets between sheets with and without formation aid is clearly noticeable (Figures 139, 141). Sheets made with unfermented flax appeared to be similar to those of paper mulberry (Figure 143, 145) as their uniformity of thickness was greatly improved.

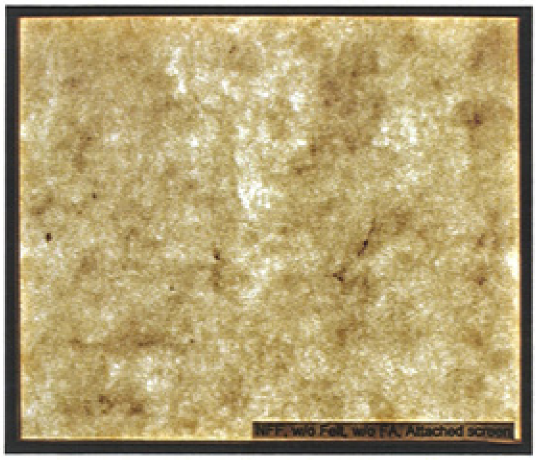

Figure 143. A sheet made with unfermented flax, without felt, without mucilage, and with a fixed laid screen.

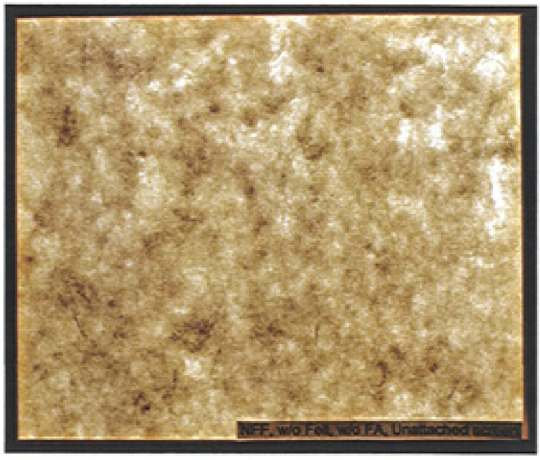

Figure 144. A sheet made with unfermented flax, without felt, without mucilage, and with a flexible laid screen.

Figure 145. A sheet made with unfermented flax, without felt, with mucilage, and with a fixed laid screen.

Figure 146. A sheet made with unfermented flax, without felt, with mucilage, and with a flexible laid screen.

On the other hand, it appeared that sheets made with fermented flax – the shortest of fibres among the group – tend to be less affected by the addition of the formation aid: sheets made without formation aid showed relatively even thickness (Figures 147, 149). Yet, the addition of the formation aid allowed the papermaker to form a thin sheet of even thickness (Figures 149, 150). Although the sheets with formation aid appeared uneven and thin in small areas throughout the sheet, this phenomenon was more likely to have been caused by an excessive amount of formation aid added.

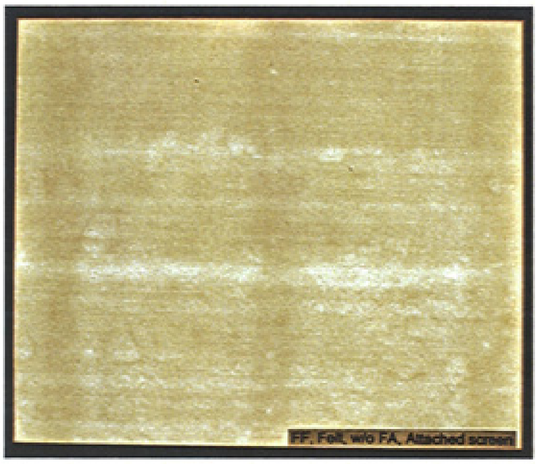

Figure 147. A sheet made with fermented flax, felt, without formation aid, and with a fixed screen.

Figure 148. A sheet made with fermented flax, felt, without formation aid, and with a flexible screen.

Figure 149. A sheet made with fermented flax, with felt, with formation aid, and with a fixed screen.

Figure 150. A sheet made with fermented flax, with felt, with formation aid, and with a flexible screen.

Although the bamboo screen was tightly fixed with nylon line, during the papermaking process, the untied part became loose. After couching the sheet, the loose part of the fixed screen slightly sagged though this affected neither the sheet forming process nor the couching.

One of the functions of the mucilaginous solution of the root of Hibiscus Manihot often listed by East Asian paper historians is that it usually makes a newly formed sheet easily separable from the screen (Kubota, 1978, p24. Nishi, 1984, p19). However, sheets without formation aid were still easily released from the screen during the couching process.

Sometimes it was difficult to separate sheets from the cotton interleaving sheet. An isolating material - such as those woven from animal wool – would have presumably been more suited to this purpose.

Discussion

From the experiment results it is clear that the impressions on papers left by the mould with a flexible laid screen and fixed laid screen were the same. There were not distinctive differences in the impressions made by both moulds.

The results also proved that a fixed laid screen was not more suitable than a flexible screen for forming a sheet with short fibres such as flax or rag fibres as Hunter (1947, p114) has suggested.

The experiment was designed based on the hypothesis that a mould with a fixed laid screen was used in China before the middle of the 8th century and this type of mould could produce a sheet with impressions of laid and chain lines identical to the impressions produced by a mould with a flexible laid screen.

The theory of the early use of a flexible laid screen from the 3rd century onwards in China relies solely on the impressions left on old papers. Because there is no extant papermaking mould from the 3rd century, examining old papers may be the only possible way to understand the structure of moulds used at that time. However, this rather rushed conclusion could have been wrong and detrimental to future research on the development of papermaking moulds as it seems to have left little room for other possibilities.

The result of this experiment did not provide any specific way of identifying impressions made by the flexible laid screen though it proved, at least, that a different structure of mould – a mould with a fixed laid screen – could leave the same impression in paper as the mould with a flexible laid screen. The impressions made by the fixed laid screen and flexible laid screen were indistinguishable. Therefore, impressions on old paper should not be used as evidence to support the theory that a mould with a flexible laid screen was used from the 3rd century in China.

The experiment also demonstrated that a fixed laid screen could function as well as a flexible laid screen. If a fixed laid screen was dominantly used in China before the year 751 when the skills of papermaking were transferred from China to Islamic countries, then the mould that was known to Islamic papermakers would also have been a fixed laid screen. The theory of the possible use of a fixed laid screen in China before the middle of the 8th century could be helpful to explain why European papermakers had started to use moulds with fixed covers - there are great similarities between these variations.

Despite its long history, papermaking is a practical subject with very little written information relevant to it - old paper is the primary source for the study of the history of papermaking. However, to appreciate certain features of the material requires a practical approach. It is this approach which motivated this experiment and led to the simulation of old papermaking processes, using tools and materials that were reportedly employed at that time.

Furthermore, if the fixed, laid screen mould was commonly used in China by the middle of the 8th century, it is possible that this type of papermaking mould could have been introduced to Korea as the early papermaking method used in Korea appeared to be very similar to the Chinese method.

5.3.3. Papermaking with reclaimed paper

Although the pulp became much brighter after beating and washing, it still had a grey tone and, from this experiment, it can be speculated that cooking with lye might be useful to remove the ink thoroughly. It would also be useful to measure tensile strength of this paper and compare it with that of paper made of pulp from fresh material.

6. Conclusions

Korea has a long history of papermaking. Due to its geographical situation – being adjacent to China – Korea could adapt the advanced Chinese culture from an early stage. Several archaeological discoveries made in the 20th century have confirmed that papermaking, one of the greatest inventions of the ancient Chinese, was already practiced around the 2nd century BC in China. Although the origin of papermaking in the Korean peninsula is not known, based on the cultural exchanges between two countries, it is believed that the papermaking skills must have been transferred to the Korean peninsula by the 4th century at the latest.

Until the 7th century, the papermaking skills in Korea were presumably similar to the Chinese methods: hemp was the main material and a stone hand mill was used to grind raw materials to produce fibres. From the 8th century Korean papermakers started developing their own papermaking techniques: paper mulberry became the main material - its long fibres were preserved as fibrillation was mainly achieved by pounding which allowed papermakers to produce strong and durable paper. It was also during the 8th century that a traditional finishing process, 'dochim' started to become an essential part of the whole papermaking process in order to make the surface of the sheet smooth and compact and, therefore, more suitable for writing.

The Goryeo dynasty (918 – 1392) represents a golden age of publishing printed texts: woodblock printing was initially used for publishing many Buddhist texts but was later employed for publishing material on other subjects. It was also this Goryeo period which saw an emergence in the use of movable type with metal characters. These highly advanced printing techniques in Goryeo naturally led to a flourishing publication industry spurring further development of papermaking. Consequently, during the Goryeo period, papermaking skills in the Korean peninsular had been perfected: the characteristics of the paper in Goryeo were whiteness, smoothness, strength (due to the finishing process, 'dochim' (搗砧) and the main papermaking material, paper mulberry - characterised by its long fibres). Because of this fine quality, papers made in Goryeo started being exported to China from the 10th century onwards. Although 'deungnamu (*Wisteria floribunda*) was the only supplementary material specifically confirmed by written documentation, based on the names of papers produced during the Goryeo period, it can be speculated that rice straw, bamboo, and hemp were also used.

Regarding papermaking tools, papermaking screens were made not only with bamboo but also stems of other plants. Such screens produced a sheet with chain lines at wide, even intervals. It was also during this period that the first information regarding chemical pulping processes using mild alkaline solutions were recorded.

During the Joseon period (1392 – 1909), the papermaking industry became larger and more developed – in this, a wider range of materials were used for papermaking. This progression was achieved by the government through Jojiseo, an official organization in charge of the production of paper for foreign relations with China. The government had continuously faced a lack of paper supply and in order to deal with such problems, the Joseon government introduced Chinese papermaking techniques. Furthermore the government also made an effort to adapt new papermaking materials from Japan. Techniques of papermaking using mixed materials were well developed during this period and a wide range of materials, such as rice straw, wheat and barley straw, willow tree, leaves of pine and bamboo, cattails, Japanese paper mulberry and hemp, were used. Records of the specific ratio of paper mulberry to other materials reflect a good understanding of the optimum proportion of paper mulberry to supplementary materials, not only to produce papers of sufficient strength for printing but also to economise on use of paper mulberry. The papermaking industry flourished during the 15th century but after two serious invasions from Japan and China in the 16th century, the industry did not recover until the 18th century. Along with the development of private markets all over the country, private paper mills started to thrive from the 18th century.

Regarding papermaking screens and moulds, the laid mould without deckle has commonly been regarded as a traditional papermaking mould in the Korean craft. However, through investigation into the previous research on Korean papermaking, it was confirmed that in Korea, two additional types of deckle – a two-stick deckle and a rectangular frame deckle – were also used around the beginning of the 20th century. It is not known whether they were simultaneously used or had any chronological order of use due to the lack of information about the development of Korean moulds. However, as a two-stick deckle and a rectangular frame deckle were also noticed in China and Japan respectively, it is clear that the development of papermaking moulds in Korea was closely related to its neighbouring countries.

A Korean screen has a distinctive characteristic – one being that the stitches of horse hair or silk thread are staggered in the middle of the screen. Additionally, in contrast to most Asian papermaking screens, the Korean device has a length nearly twice that of its width with chain lines running the length of the mould. This is possibly a feature which developed as a consequence of the unique sheet forming technique: the far side of a supporting frame is always suspended from a rope (attached at the centre of the member) in substitution for a wooden support. Using a wooden support or a rope allows the lone papermaker to more easily manipulate the relatively larger mould though, at the same time, it also imposes limitations on the manner in which pulp stock is scooped. As a result, the single sheet tends to be slightly uneven in thickness. To compensate (in order to achieve a sheet of even thickness) the papermaker makes one thick sheet by laminating two single sheets. In this, the screen is rotated (through 180 degrees) during the couching process with the joined sheets being orientated in such a way that the thicker portion of the individual sheet will be overlaid onto the thinner portion of the other. The staggered arrangement of stitching in the centre of the screen thus diminishes visibility of the combined (overlapped) impressions of chain lines where the two single sheets are laminated.

An analysis of the data collected from surveys on Korean and Japanese collections at the British Library and a private Korean collection provided useful information on historical Korean paper. One of the findings is a direct correlation between the thickness of the sheet and the number of laid lines. Papermakers and related scholars have long known that the thicker the splints of a screen, the thicker the paper produced with it. This is due to the fact that the screen with thicker splints tends to drain water more quickly from the vat stock, leaving papermakers less time to manipulate the mould and thus spread the pulp evenly on the screen. However, this theory has not previously been supported with an analytical method based on actual collections. This current research investigated the correlation between the thickness of the sheet and the number of laid lines by statistical analysis of the data - the result showed that these factors are significantly related and provides a firm grounding for the above theory.

Furthermore, from the analysis of the survey data, the thickness of sheets in Korean books generally appeared to be between 0.06 and 0.08 millimetres and the number of laid lines per centimetre between 5.3 and 5.8. The intervals between chain lines appeared to be narrow and irregular. In the case of historical Japanese paper, the thickness of sheets for books appeared to be similar to Korean examples but the number of laid lines per centimetre was slightly higher than those in Korean papers. In addition, the intervals of chain lines appeared to be wider and more regularly arranged than Korean paper.

During a sheet forming process, rib shadows – lines along which fibres are more densely accumulated in the sheet – are usually caused by supporting ribs being in direct contact with the underside of the papermaking screen. Compiling information about this characteristic can provide a better understanding of the structure of the papermaking mould used at that time. From the survey data, it was noticed that 16 observed pages from the Korean collection and 8 pages from the Japanese collection at the British Library exhibited rib shadows. Interestingly, the Japanese paper carried more than one rib shadow in each observed page with their intervals being between 64 and 100 millimetres. By contrast, Korean paper samples exhibited one rib shadow in the page. In observing the comparative frequency of these marks in pages of Japanese paper, it would appear the Japnese mould generally had more frequent supporting ribs and the intervals between supporting ribs of the Korean mould must have been greater than in Japnese moulds.

During the survey, fibre samples were obtained from most of the examined pages of the Korean and Japanese books in order to investigate and identify materials used in the papermaking in both countries over time. For this, standard fibre samples from local plants used in traditional Korean papermaking were prepared - their morphological characteristics were examined and recorded and photomicrographs produced. The standard samples include paper mulberry (*Broussonetia kazinoki Sieb*), 'samjidak' (oriental paperbush, *Edgeworthia papyrifera Sieb. Et Zucc*), mulberry (*Morus alba*), 'sandak' (*Wikstroemia trichotoma*), pine tree (*Pinus densiflora S. et Z.*), bamboo (*Phyllostachys pubescens*), rice straw (*Oryza sativa*), barley straw (*Hordeum vulgare var. hexastichon*), and eulalia (*Miscanthus sinensis Anderss*). Both paper mulberry and mulberry belong to the same family, *Moraceae* and the use of mulberry as a papermaking material has a long history in Korea and China. However, as its use was only limited to East Asia, mulberry was usually excluded in the most previous studies carried-out outside East Asia. The research presented here provided photomicrographs of mulberry fibres and – from microscopic examination – the morphological characteristics of mulberry fibres appeared to be very close to those of paper mulberry: a thin, transparent membrane around the fibres has been recognized as a most distinctive characteristic of fibres from paper mulberry and this feature is also observed in mulberry fibres. In the case of barley straw, photomicrographs have hardly been included in any previous studies and therefore, providing such information may prove important for any future research.

Through the examination of standard samples of fibres of *Moraceae* family it has been found that a rhombic shaped crystal and an elongated hexagonal shaped crystal were present in paper mulberry and mulberry respectively. Another type of crystal which was commonly observed in both fibres of paper mulberry and mulberry was a prismatic cuboid-shaped variety. In fact, 17 percent of Korean paper and 50 percent of Japanese papers appeared to include either a prismatic cuboid-shaped crystal or a rhombic-shaped crystal (or both in some cases) and therefore, the presence of these crystals seems to have a diagnostic value for identifying fibres of the *Moraceae* family.

Based on the examination of these standard fibre samples, the current research confirmed that the main material for traditional papermaking in Korea and Japan was paper mulberry and several supplementary materials, such as rice straw, hemp, reed, and coniferous wood pulp were also used. In Korea, the percentage of papers containing mixed materials appeared relatively higher during the 15^{th} and the 18^{th} centuries. The 15^{th} century was the period in which the Joseon government had gone to great effort to introduce foreign papermaking techniques and to search for new materials which could be used for papermaking – the high percentage of paper made from mixed materials in the 15^{th} century appears to reflect these political conditions. It is interesting to observe that the percentage of mixed fibre papers decreased during the 16^{th} and the 17^{th} centuries but later in the 18^{th} century it increased again to 61 percent.

Within this research, one of the significant discoveries, by fibre analysis, was the use of coniferous wood pulp as a supplementary material in traditional Korean papermaking: it appeared that 15 out of 184 fibre samples of Korean paper dated between 1498 and 1778 included fibres of coniferous wood mixed with paper mulberry. Additionally, one 17th century sample out of 68 fibre samples from Japanese papers also included coniferous wood fibres mixed with paper mulberry. Although the historical account of papermaking provided information on the occasional use of the leaves and the inner bark of pine as a papermaking material, the use of wood pulp has not been recognised as a common supplementary material in Korea. The result of the fibre identification revealed that a coniferous wood – possibly, red pine (*Pinus densilflora S.et Z*) – was commonly used as a supplementary material for traditional papermaking from the 15th century onwards in Korea. Taking into consideration the previous discovery of coniferous wood in a 13th century paper, it is possible to suggest that the use of coniferous timber in papermaking started from the Goryeo dynasty.

It has been commonly believed that the use of wood as a supplementary material in papermaking was first proposed in the Occident: in Europe, the idea of using wood pulp in papermaking was conceived during the beginning of the 18th century but it was not until the middle of the 19th century that wood pulp was used as a papermaking material on an industrial scale. The dates of most of these Korean papers containing wood fibres precede the use of wood pulps in European papers.

This study also focussed on the function of the formation aid, the mucilaginous substance from the root of *Hibiscus Manihot*, which is known as an essential material in traditional papermaking in Korea and Japan. Although the root of *Hibiscus Manihot* has been the most well known source for the formation aid in Korea and Japan, a literature review revealed that it was only in the 19th century that use of this plant for this purpose became predominant – prior to this time, many other indigenous plants had been employed as a formation aid in Korea, Japan, and China.

The mucilage is known to be multi-functioned: firstly, the mucilage influences more uniform dispersion of fibres in water, preventing them from becoming entangled. Secondly, by adjusting the amount of mucilage and thus the viscosity of the water, the papermaker can control the speed of drainage during the sheet forming process. Thirdly, the mucilage improves the surface sheen of the final product making it more lustrous. Lastly, it is commonly believed that the mucilage improves the physical strength of the sheet.

In order to investigate the third function of the mucilage, a papermaking experiment was designed and conducted using a mucilaginous solution obtained from the root of Hibiscus Manihot: for the experiment, three types of fibres of different lengths – paper mulberry, flax and a modern-day commercially produced bleached kraft pine (softwood) – were selected. From the experimental results it is clear that this mucilaginous substance noticeably improves the uniformity of sheets regardless of the length of fibres. However, the substance evidently reduces fibre bonding in a sheet made with flax and softwood. This result contrasts with the commonly accepted belief that the mucilaginous substance enhances fibre bonding: many scholars presumed that a formation aid could improve the thickness of the sheet and therefore the strength of sheet would be increased. Nonetheless - in the case of paper mulberry with an addition of mucilaginous substance - thickness improved, as did fibre bonding. Therefore, it can be said that improvement of the uniformity of the sheet does not equate to the increase of fibre bonding in it. It is possible that the length of fibre could be a more influential factor in determining the overall strength of the sheet.

An additional pilot experiment in papermaking was carried out in order to comprehend the manufacturing process using waste paper such as that derived from old books. The result of the experiment revealed that the beating process alone could remove a considerable amount of ink from the paper. However, after washing, the pulp still exhibited a grey tone and therefore, it was speculated that cooking with lye might be significant in achieving a thorough removal of the ink.

Due to the perishable nature of papermaking tools, such as bamboo screens and their wooden supporting frames and the lack of written information on the subject, studying the development of papermaking tools from the inception of papermaking in China to the present day has largely relied on examination of the impressions left on historical papers. Through a literature search, it became clear that, at the beginning of the 20th century, some paper historians believed a mould with a fixed laid cover was a transitional form between the mould with the flexible laid cover and the wove type mould. However, this intriguing idea seems to have been neglected by other paper historians and no further attempt has been made to develop the theory or substantiate it. While no further research has been done on the subject, it has been believed that the mould with the flexible laid screen has been used from the 3rd century onwards in China. This theory is chiefly based on the fact that some papers from the 3rd century carried the impressions of laid and chain lines.

In response, this current research proposed that a fixed laid cover might have been in use at a certain stage in the development of papermaking in China as a transitional form between the wove-type mould and that with a flexible laid screen. The experiment therefore, aimed to establish whether such a mould could produce sheets with impressions of laid and chain lines, indistinguishable from the sheet formed on the flexible screen: if screen impressions imparted by both types are essentially the same, it is not possible to rule-out the existence of a fixed laid screen in China prior to the 8th century migration of papermaking techniques to Islamic countries.

Therefore, a functional replica of a fixed laid screen – a screen made with bamboo splints fixed to a rectangular wooden frame – was prepared in order to evaluate the function compared to that of the flexible screen. The result of this experiment did not reveal any specific method of identifying impressions made by the flexible laid screen and so demonstrated that both flexible and fixed structures of mould could leave the same impression in paper. This result would seem to discredit the predominant assumption that such impressions in old paper are evidence that the flexible laid screen mould was the only one in use from the 3rd century in China.

This revision of the predominant, current understanding of developments in the craft at the time leads to an interesting proposal: the existence of such a transitional mould design in the East during this period, might explain why the European mould evolved as a fixed screen mould as papermaking techniques were transferred westward. If a fixed laid screen was dominantly used in China before the year 751 when the skills of papermaking were transferred from China to Islamic countries, then the mould that was known to Islamic papermakers would also have been a fixed laid screen. This alternative account would in turn explain the use of moulds with fixed covers by European papermakers – there are great similarities between these variations. Furthermore, if the fixed laid screen was commonly used in China before the middle of the 8th century, then use of this type of screen must have transferred to Korea during the same period since it has been speculated that, until the 7th century, papermaking techniques (in terms of materials used and the manner in which these materials were fibrillated) were more or less the same in both countries.

In reiteration, the result of this experiment is meaningful since it questioned the central evidence on which the conventional theory of early flexible laid screen use was based. The counter argument that such screen impressions offer no indication of the screen used in production (whether flexible laid or fixed) was empirically substantiated. As a result, the subject is reopened to question and potentially facilitates debate among paper historians on this aspect of the development of the craft.

Despite the long history of papermaking in Korea, its history, materials and techniques have not been thoroughly investigated and, as a result, the subject has hardly been introduced to paper historians and conservators outside the country. This study not only provided general information on the subject but also sought a more comprehensive understanding of it through scientific analyses and practical experiments.

However, in closing, it is apparent that there are pertinent areas which require more thorough investigation; though, due to time limitations, some methods of analysis and experimentation have remained beyond the scope of work carried out here. It is the completion of this work which has highlighted further areas of research which might be developed more thoroughly in order to continue a deeper understanding of traditional papermaking techniques and materials used in Korea.

A major focus has been the development of equipment employed in the papermaker's craft and the correlation of that development with the material produced. With respect to this intention, it is felt that, one omission here is detail with regard to the rib shadows observed in papers and the manner in which these are affected by the size and shape of the supporting ribs. It is acknowledged that further papermaking experiments would add further refinement to current collective understanding.

Finally, in relation to papermaking materials, additional questions have arisen (as a consequence of this work) regarding characterisation through analytical and instrumental techniques. Most significantly, it is suggested that, through the use of the Scanning Electron Microscope (SEM) more extensive characterisation of crystals (those of the prismatic cuboid and rhombic varieties associated with the Moraceae family) could be of value. This, in conjunction with Energy Dispersive X-Ray (EDX) techniques could provide detail regarding elemental composition as a basis to identification.

Appendix 1

Results of Fibre Identification

Collection	Shelf mark	Date	Page	Observation	Identified material
Korean	Orb.40/94	1420	(23)10	**A**: a long epidermal cell. **B**: a long epidermal cell and a thin-walled parenchyma cell. **C**: a fibre with loose primary wall. **D, E**: thin-walled parenchyma cells.	Bast fibres from *Moraceae* family and Straw (possibly rice straw).
			LP	**A**: long epidermal cells and round, thin-walled parenchyma cells. **B**: fibres with loose primary wall. **C**: a group of fibres with low magnification.	Bast fibres from *Moraceae* family and Straw (possibly rice straw).
	15315.e.6	1455	(2)3	**A**: a fibre with loose primary wall. **B**, **C**: epidermal cells with a large papilla. **D, E**: epidermal cells and dumb-bell shape silica bodies. **F**: epidermal cells and rectangular shape parenchyma cells.	Bast fibres from *Moraceae* family and Rice straw.
			(4)14	**A**: a prismatic crystal. **B, C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(4)17	**A, B**: fibres with loose primary wall. **C**: a prismatic crystal.	Bast fibres from *Moraceae* family.
			(5)6	**A**: a loose primary wall, varying width along the length, narrow lumen, well spaced cross markings. **B**: annular shaped vessel element. **C**: group of long epidermal cells. **D-J**: continuously taken images of fibres with smooth surface, centred very narrow but even lumen, well defined cell wall, tapering end. **K**: some thick-walled parenchyma cells. **L**: bundle of thin fibres.	Bast fibres from *Moraceae* family, rice straw and unidentified fibres.
			(7)6	**A**: a long epidermal cell. **B**: a fibre with loose primary wall. **C**: a long epidermal cell and a square shape epidermal cell. **D, E**: epidermal cells. **F**: a short fine fibre.	Bast fibres from *Moraceae* family and Straw (possibly rice straw and barley straw).
			(8)16	**A**: long epidermal cells. **B, C**: fibres with varying thickness and frequent cross-markings.	Bast fibres and Straw.

	15201.e.13	1455	(上)5	**A-C**: fibres with loose primary wall	Bast fibres from *Moraceae* family.
			(上)9	**A-E**: fibres with loose primary wall	Bast fibres from *Moraceae* family.
			(上)21	**A**: a fibre with loose primary wall. * Some twisted fibres.	Bast fibres from *Moraceae* family.
			(上)31	**A**: fibres with loose primary wall. **B-F**: continuous images of twisted fibres.	Bast fibres from *Moraceae* family.
			(上)37	**A**: fibres with loose primary wall. **B-M**: continuous images of a fibre with not clear cross markings.	Bast fibres from *Moraceae* family.
			(中)4	**A-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(中)12	**A, B**: fibres with loose primary wall. **C**: a group of long epidermal cells	Bast fibres from *Moraceae* family and Straw.
			(中)15	**A-C**: fibres with loose primary wall. **D**: rhombic crystals.	Bast fibres from *Moraceae* family.
			(中)19	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(中)26	**A, D**: fibres with loose primary wall. **B, C**: fibres with pitted cell wall, clear lumen, loose primary wall.	Bast fibres from *Moraceae* family.
			(下)14	**A**: fibres with loose primary wall. **B**: a fibre with loose primary wall which has white particles.	Bast fibres from *Moraceae* family.
			(後序)4	**A, B**: fibres with very frequent cross markings and irregular shape.	Bast fibres from *Moraceae* family.
			(紀)14	**A:** associated cells. **B, C:** fibres with a loose primary wall. **D:** thin fibres with rather even thickness.	Bast fibres from *Moraceae* family and possibily Gampi.
			(紀)17	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	15326.a.3	1471	56	**A**: fibres with loose primary wall. **B**: broken, thin fibre with not clear lumen	Bast fibres from *Moraceae* family.
			90	**A, B**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			115	**A, F**: fibres with loose primary wall. **B-E**: twisted fibres.	Bast fibres from *Moraceae* family.

	15257.e.16	Late 15C	(上)36	**A**: a ring from vessel element. **B**: fibres with frequent cross markings, discontinuous lumen, smooth surface. **C**: fibres with smooth surface and well spaced cross-markings.	Bast fibres from *Moraceae* family and Straw.
			(上)40	**A**: a fibre with longitudinal split.	Bast fibres from *Moraceae* family.
			(上)53	**A-C**: fibres with well defined wall and occasional cross markings, and smooth surface. **D-F**: annular shape vessel element.	Bast fibres from *Moraceae* family and Straw.
			(上)61	**A-D**: fibres with loose primary wall. **E, F**: annular shape vessel element.	Bast fibres from *Moraceae* family and Straw.
			(下)7	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(下)13	**A-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(下)24	**A-C**: fibres with loose primary wall. **E, F**: long epidermal cells and thin-walled parenchyma cells.	Bast fibres from *Moraceae* family and Straw (possibly rice straw).
	15287.e.2	1498	(表)2	**A**: a fibre with loose primary wall. **B, C**: fibres showing occasional biseriate arrangement of small bordered pits and their images under cross polar. **D**: long epidermal cells.	Bast fibres from *Moraceae* family, Straw and wood pulp.
			(3)1	**A**: pitted vessel element and a fibre with narrow apertures. **B-D**: fibres from mechanical wood pulp. **E**: fibres with loose primary wall.	Bast fibres from *Moraceae* family and wood pulp.
			(7)17	**A, B**: fibres with loose primary walls. **C**: Epidermis.	Bast fibres from *Moraceae* family.
			(10)10	**A, B**: spiral vessel elements. **C**: dumb-bell shape silica body. **D**: a fibre with loose primary wall. **E-J**: fibres with loose primary wall and white particles on their surface.	Bast fibres from *Moraceae* family and Straw.
			(13)6	**A, B**: fibres with loose primary wall. **C**: a rhombus shape of crystal. **D**: a ring cell from vessel element. **E**: annular shape vessel element. **F**: stomata, and epidermal cells. **G**: epidermal cells.	Bast fibres from *Moraceae* family and Straw.
			(14)6	**A**: fibres with loose primary wall (white particles on the surface of fibre). **B-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.

			(16)5	**A, B**: epidermal cells. **C**: a fibre with loose primary wall.	Bast fibres from *Moraceae* family and Straw.
			(16)10	**A**: spiral vessel element. **B, C**: fibres with occasional cross-markings and rather even thickness.	Bast fibres from *Moraceae* family and Straw.
			(22)3	**A, B**: spiral vessel elements. **C, D**: continuous images of one fibre which shows great changes in terms of thickness and the number of cross-markings. **E**: crystals. **F**: a fibre with loose primary wall.	Bast fibres from *Moraceae* family and Straw.
	15324.e.4	1501/2	(序)1	**A**: fibres with loose primary wall. **B**: epidermal cells.	Bast fibres from *Moraceae* family and Straw.
			(序)7	**A, B**: fibres with loose primary wall. **C**: a group of fibres.	Bast fibres from *Moraceae* family.
			(序)47	**A-K**: continuous images of a fibre with loose primary wall, discontinuous narrow lumen and varying thickness.	Bast fibres from *Moraceae* family.
			(1)8	**A**: epidermal cell. **B**: a fibre with longitudinal striations. **C**: spiral vessel element.	Bast fibres and Straw.
			(1)19	**A-C**: rectangular shape parenchyma cells. **D, E**: fibres with loose primary wall. **F**: a prismatic crystal.	Bast fibres from *Moraceae* family.
			(1)25	**A, B**: fibres with loose primary wall, longitudinal splits.	Bast fibres from *Moraceae* family.
			(1)36	**A-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(2)5	**A-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(2)7	**A, B**: fibres with loose primary wall. **C-E**: tracheids showing clear bordered pits. **F**: window-like pits. **G**: an unknown fibre.	Bast fibres from *Moraceae* family and wood pulp.
			(2)39	**A, B**: fibres with loose primary wall. **C**: a rhombic shape crystal. **D**: a prismatic crystal.	Bast fibres from *Moraceae* family.
			(2)54	**A, B**: fibres with loose primary wall. **C**: a prismatic crystal.	Bast fibres from *Moraceae* family.

			(3)40	**A, B**: a fibre with loose primary wall. **C**: a rhombic shape crystal.	Bast fibres from *Moraceae* family.
			(5)8	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	15113.e.2	1500?	5	**A, B**: fibres with loose primary wall and pits.	Bast fibres from *Moraceae* family.
	15260.b.22	1519	20	**A, C**: fibres with loose primary wall. **B**: a fibre with narrow lumen, frequent and clear cross markings, and loose primary wall. **D**: small rectangular shape of parenchyma cells.	Bast fibres from *Moraceae* family.
			41	**A**: a fibre with smooth surface, narrow lumen. **B**: a long needle shaped hair. **C, D**: a rhombic shape crystal and prismatic crystal. **E**: a needle shaped hair with low magnification.	Bast fibres from *Moraceae* family and unidentified material.
	15315.e.9	1519	(2)1	**A**: a fibre with loose primary wall, very frequent but faint diagonal marks apart from clear cross markings. **B**: a fibre with varying thickness and loose primary wall.	Bast fibres from *Moraceae* family.
			(2)16	**A-C**: a fibre with very frequent cross markings and longitudinal splits. **D**: a fibre with loose primary wall. **E**: a fibre split into two separate fibres.	Bast fibres from *Moraceae* family and hemp.
			(2)24	**A**: a fibre with loose primary wall. **B-E**: a fibre with longitudinal splits and not clear cross markings.	Bast fibres from *Moraceae* family.
			(2)29	**A-C**: fibres with loose primary wall and frequent cross markings. **D, E**: spiral vessel element.	Bast fibres from *Moraceae* family and Straw.
			(3)9	**A**: a fibre with loose primary wall and short longitudinal splits. **B**: a small square crystal and a fibre with loose primary wall.	Bast fibres from *Moraceae* family.
			(3)14	**A**: fibres with loose primary wall. **B, C**: mechanical wood pulp.	Bast fibres from *Moraceae* family and wood pulp.
			(4)18	**A-C**: fibres with loose primary wall and longitudinal splits. **D**: fibres with bordered pits and criss-cross pattern outside.	Bast fibres from *Moraceae* family and wood pulp.
	15315.e.11	1529	(序)FE	**A**: a rhombic crystal. **B**: prismatic crystal and fibres with loose primary wall.	Bast fibres from *Moraceae* family.

			(序)25U	**A**: a fibre with loose primary wall. **B**: twisted fibres.		Bast fibres from *Moraceae* family.
			(序)25L	**A**: a fibre with loose primary wall. **B**: a ribbon-like, twisted fibre. **C**: a fibre with longitudinal striations and splits.		Bast fibres from *Moraceae* family and cotton.
			(1)5U	**A, B:** fibres with loose primary wall. **C, D:** spiral shape vessel elements. **E, F:** fibres with low magnification.		Bast fibres from *Moraceae* family and grass fibre from straw.
			(1)5L	**A**: a fibre with loose primary wall. **B**: a fibre split into two fibres.		Bast fibres from *Moraceae* family.
			(2)2U	**A**: a fibre with loose primary wall. **B**: a fibre with regularly spaced diagonal cross markings. **C**: a group of fibres.		Bast fibres from *Moraceae* family.
			(2)2L	**A-C**: fibres with loose primary wall.		Bast fibres from *Moraceae* family.
			(2)21U	**A**: a fibre split into two fibres. **B**: one end of fibre' A' shows loose primary wall. **C, D**: a fibre with loose primary wall.		Bast fibres from *Moraceae* family.
			(2)21L	**A, B**: fibres with loose primary wall.		Bast fibres from *Moraceae* family.
			(3)17U	**A, B**: fibres with loose primary wall.		Bast fibres from *Moraceae* family.
			(3)17L	**A-F**: continuous images of a fibre with longitudinal striations and very frequent cross markings and trace of loose primary wall. **G**: the same fibre with low magnification. **H**: fibres with loose primary wall.		Bast fibres from *Moraceae* family.
			(5)2U	**A-C**: fibres with loose primary wall. **D**: twisted fibres.		Bast fibres from *Moraceae* family.
			(5)2L	**A-C**: a fibre with loose primary wall.		Bast fibres from *Moraceae* family.
			(5)17U	**A-D**: fibres with loose primary wall.		Bast fibres from *Moraceae* family.
			(5)17L	**A, B**: fibres with loose primary wall. **C-E**: continuous images of twisted fibres.		Bast fibres from *Moraceae* family.
			(6)8U	**A**: a fibre with a serrated outline. **B-F**: continuous images of one fibre which has a loose primary wall. **G**: a fibre with small particles on its surface.		Bast fibres from *Moraceae* family.

			(6)8L	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(8)13U	**A-C**: a fibre with loose primary wall. **D**: a fibre with longitudinal splits.	Bast fibres from *Moraceae* family.
			(11)4U	**A-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(11)13U	**A, B**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(11)19U	**A-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(14)7U	**A**: a fibre with loose primary wall and a fibre exhibiting uniserial ladder which must be an accidentally included animal hair. **B**: a fibre with loose primary wall.	Bast fibres from *Moraceae* family and an animal hair.
			(18)22U	**A**: fibres with loose primary wall and a rhombic crystal. **B**: thin-walled small, rectangular parenchyma cells and dumb-bell shape silica bodies which are parallel to fibres. **C**: a fibre with loose primary wall.	Bast fibres from *Moraceae* family and grass fibres from reed.
			(19)1L	**A, B**: fibres with loose primary wall. **C**: twisted fibres.	Bast fibres from *Moraceae* family.
	15253.e.1	1550?	(6)30	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(6)55	**A-C**: fibres with loose primary wall. **D-J**: longitudinal tracheids showing clear bordered pits.	Bast fibres from *Moraceae* family and wood pulp.
			(7)5	**A, B**: fibres with loose primary wall. **C-F**: continuous images of a fibre with longitudinal striations and splits and loose primary wall.	Bast fibres from *Moraceae* family.
			(7)76	**A-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(8)16	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	15019.a	1558?	(7)33	**A, B**: fibres with loose primary wall. **C**: a prismatic crystal.	Bast fibres from *Moraceae* family.
			(9)7	**A**: fibres with loose primary wall. **B**: a prismatic crystal. **C**: cluster crystals.	Bast fibres from *Moraceae* family.
			(13)2	**A-D**: fibres with smooth surface and frequent cross-markings and narrow lumen.	Bast fibres from *Moraceae* family.
			(13)5	**A, B**: fibres with loose primary wall. **C**: crystals.	Bast fibres from *Moraceae* family.

			(13)14	**A-D**: fibres with loose primary wall. E: small parenchyma cells.	Bast fibres from *Moraceae* family.
	Orb.40/75	1569		**A**: a fibre with loose primary wall, a rhombic crystal, and a thin-walled parenchyma cell with bulbous wall. **B**: cluster crystals.	Bast fibres from *Moraceae* family.
	15113.e.8	1570	(上)13	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(上)17	**A-C**: fibres with loose primary wall. **D, E**: fibres with bordered pits and their images under cross polar.	Bast fibres from *Moraceae* family and wood pulp.
			(上)19	**A-C**: fibres with loose primary wall. **D**: a fibre with loose primary wall and split into two.	Bast fibres from *Moraceae* family.
			(下)31	**A-D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	15296.e.5	1583	(2)6	**A, B**: fibres with loose primary wall. **C**: a rhombic crystal and a prismatic crystal. **D**: cluster crystals. **E**: cluster crystals with high magnification.	Bast fibres from *Moraceae* family.
			(2)50	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(4)39	**A, B**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(8)12	**A**: a fibre with loose primary wall. **B, C**: fibres with bordered pits covered with criss-cross pattern. **D-G**: long hairs and unknown fibres. **H**: thin fibres with well-spaced cross-markings and even thickness.	Bast fibres from *Moraceae* family, wood pulp and grass fibres from unidentified material.
	15532.a.4	1583	(0)3	**A-C**: thin and rather translucent fibres.	Bast fibres and gampi.
			(3)1	**A**: a thin and flat fibre without showing lumen.	Bast fibres.
			(3)7	**A**: fibres with loose primary wall. **B-D**: fibres with frequent cross-markings.	Bast fibres from *Moraceae* family.
			(7)3	**A**: rhombic crystals. **B**: a fibre with loose primary wall. **C**: the fibre (B) with low magnification.	Bast fibres from *Moraceae* family.
	Or.81.a.1	1668	(1-1)0	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(1-1)5	**A**: a fibre with loose primary wall. **B**: low magnification of fibre A. **C**: a fibre split into two.	Bast fibres from *Moraceae* family.

				D: fibre 'C' with low magnification.	
			(2-4)2	**A-D**: thin fibres with occasional dislocations and cross markings.	Samjidak.
			(2-6)9	**A-C**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(2-6)19	**A-C**: fibres with loose primary wall. **D**: mechanical wood pulp.	Bast fibres from *Moraceae* family and wood pulp.
			(3-11)1	**A**: a fibre with loose primary wall and some patterns on its surface. **B-F**: images of twisted fibres. **F**: fibres with bordered pits.	Bast fibres and wood pulp.
			(3-11)6	**A-E**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	15334.f.2	1686	(0)FE	**A, B**: fibres with loose primary wall. **C**: crystals. **D, E**: fibres with smooth surface in low magnification.	Bast fibres from *Moraceae* family.
			(1)33	**A, B**: fibres with loose primary wall. **C**: fibres with smooth surface, very narrow, even, lumen and tapering ends. **D, E**: thick-walled parenchyma cells.	Bast fibres from *Moraceae* family and unidentified material. (C-E are the same fibres in '15315e6(5-6)').
			(3)19	**A, B**: fibres with loose primary wall. **C**: cluster crystals and a rhombic crystal.	Bast fibres from *Moraceae* family.
			(3)33	**A**: fibres with loose primary wall, a rhombic crystal. **B**: fibres with loose primary wall. **C**: a fibre with loose primary wall, a prismatic crystal.	Bast fibres from *Moraceae* family.
			(4)10	**A**: fibres with loose primary wall. **B, C**: difficult to identify.	Bast fibres from *Moraceae* family.
			(4)17	**A, B**: fibres with loose primary wall. **C**: crystals.	Bast fibres from *Moraceae* family.
	Or.81.e.13	1692	(10)4	**A-D**: continuous images of a fibre with loose primary wall. **E, F**: fibres with loose primary wall. **G, H**: a twisted fibre.	Bast fibres from *Moraceae* family.
			(10)15	**A, B**: fibres with loose primary wall. **C**: stomata, epidermal cells. **D**: epidermal cells. **E**: epidermal cells and thin-walled parenchyma cells. **F**: partly annular or spiral shape vessel	Bast fibres from *Moraceae* family and grass fibres from reed.

				element. **G**: 'F' with low magnification.	
			(10)29	**A-I**: continuous images of two fibres with loose primary wall. **J, K**: a fibre with very frequent cross-markings and loose primary wall. **L, M**: fibres with loose primary wall. **N, O**: fibres with loose primary wall and crystals. **P**: a group of fibres with low magnification.	Bast fibres from *Moraceae* family.
	Or.81.a.3	17C	(7)3	**A, B**: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(7)14	**A, B**: fibres with loose primary wall. **C**: a short, broken fibre with many longitudinal splits.	Bast fibres from *Moraceae* family and hemp.
	Or.81.e.10	17C	(上)3	**A, B:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(上)10	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(上)24	**A, B:** fibres with loose primary wall. **C:** crystals.	Bast fibres from *Moraceae* family.
			(上)80)	**A, B:** fibres with loose primary wall. **C:** a rhombic crystal and a prismatic crystal. **D:** cluster crystals.	Bast fibres from *Moraceae* family.
	15320.d.38	17C?	(目)3	**A, B:** fibres with loose primary wall. **B:** fibres of uneven thickness.	Bast fibres from *Moraceae* family.
			(2)9	**A, B:** fibres with loose primary wall. **C:** spiral shape vessel element. **D:** parenchyma cells.	Bast fibres from *Moraceae* family and grass fibre.
			(11)8	**A:** fibres with loose primary wall. **B:** cluster crystals. **C, D:** fibre with narrow lumen.	Bast fibres from *Moraceae* family.
			(16)8	**A:** fibres with loose primary wall. **B, C:** annular shape vessel element. **D:** pitted vessel element.	Bast fibres from *Moraceae* family and grass fibre.
	15211.b.1	17C?	(0)26	**A:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(目)0	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(2)25	**A, B:** fibres with loose primary wall. **C:** prismatic crystals. **D:** a rhombic crystal.	Bast fibres from *Moraceae* family.
			(8)31	**A:** a fibre with loose primary wall. **B:** crystals.	Bast fibres from *Moraceae* family.

			(9)36	**A, B:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(10)13	**A:** fibres with loose primary wall. **B, C:** different part of twisted fibres. **D:** a twisted fibre with a trace of primary wall.	Bast fibres from *Moraceae* family.
			(10)16	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(13)1	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(14)34	**A-D:** fibres with loose primary wall. **E:** thick-walled parenchyma cells.	Bast fibres from *Moraceae* family.
			(22)16	**A-C:** fibres with frequent cross-markings and occasional partial longitudinal splits. **D:** a fibre with frequent cross-markings and dislocation. **E:** a fibre with smooth surface and even thickness.	Bast fibres.
			(22)78	**A, B:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	16015.c.4	17C?	(1)9	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(7)17	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(9)16	**A-C:** fibres with loose primary wall. **D:** pitted vessel elements. **E:** a netlike vessel element and thick-walled, rectangular parenchyma cells. (D, E look like mechanical wood pulp).	Bast fibres from *Moraceae* family.
	Or.30/319	1769	(2)19	**A-D:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(5)22	**A-C:** fibres with loose primary wall. **D:** difficult to identify.	Bast fibres from *Moraceae* family.
	Or.6998	1778	(0)26	**A, B:** fibres with loose primary wall. **C:** a fibre with longitudinal splits. **D:** twisted fibres.	Bast fibres from *Moraceae* family.
			(1)43	**A, B:** fibres with loose primary wall. **C-I:** crystals.	Bast fibres from *Moraceae* family.
			(1)55	**A:** fibres with loose primary wall. **B:** a rhombic crystal. **C:** dumb-bell shaped silica bodies in epidermis. **D:** prickle hairs in epidermis. **E, F:** difficult to identify but they are the same as some fibres from '15296e5(8-12) F, G'.	Bast fibres from *Moraceae* family and grass fibres.
			(2)93	**A:** fibres with loose primary wall and irregular shape of particles on the surface. **B-C:** fibres	Bast fibres from *Moraceae* family.

				with loose primary wall.	
			(4)6	**A, B:** fibres with loose primary wall. **C, D:** longitudinal tracheids showing bordered pits.	Bast fibres from *Moraceae* family and wood pulp.
			(4)16	**A, B:** a fibre with loose primary wall. **C-H:** longitudinal tracheids showing bordered pits.	Bast fibres from *Moraceae* family and wood pulp.
			(5)48	**A:** a fibre with loose primary wall. **B:** high magnification of 'A'.	Bast fibres from *Moraceae* family.
			(7)20	**A:** a fibre with loose primary wall. **B-E**: longitudinal tracheids showing bordered pits.	Bast fibres from *Moraceae* family and wood pulp.
			(8)13	**A:** fibres with loose primary wall. **B:** epidermis. **C:** prickle hair. **D:** dumb-bell shaped silica body.	Bast fibres from *Moraceae* family and grass fibres.
			(9)93	**A:** a fibre with loose primary wall. **B, C:** stomata prickle hairs, silica bodies in epidermis. **D:** prickle hairs, silica bodies, in long epidermis. **E:** thin-walled parenchyma cells. **F:** long epidermal cells. **G:** short and more rectangular shape epidermal cells.	Bast fibres from *Moraceae* family and grass fibres.
			(10)5	**A, B:** fibres with loose primary wall. **C-F:** longitudinal tracheids showing bordered pits.	Bast fibres from *Moraceae* family and wood pulp.
			(10)63	**A:** fibres with loose primary wall. **B, C:** a fibre with loose primary wall and tiny particles on the surface. The particles look like starch grains. **D:** thin-walled parenchyma cells. **E, F:** long epidermal cells.	Bast fibres from *Moraceae* family and grass fibres.
			(11)78	**A, B:** fibres with loose primary wall. **C, D:** pitted vessel elements. **E:** a bundle of unidentified fibres.	Bast fibres from *Moraceae* family and wood pulp ('E' looks similar to the fibres, '15278e2(3-1)', '16015c4(9-16)'.
			(15)8	**A:** a fibre with loose primary wall. **B:** a fibre with longitudinal splits. **C:** stomata and	Bast fibres from *Moraceae* family and

				epidermal cells.	grass fibres.
			(附下)13	**A:** a fibre with loose primary wall. **B:** a thin-walled parenchyma cell. **C:** long narrow parenchyma cells. **D:** netlike vessel element. **E:** a ring cell. **F:** a stomata and epidermis.	Bast fibres from *Moraceae* family and grass fibres.
	Or.81.e.11	1798	(5)19	**A, B:** fibres with loose primary wall. **C:** prismatic crystals. **D, E:** a rhombic crystal.	Bast fibres from *Moraceae* family.
	Nam	13 – 14C	3	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
		13 – 14C	7	**A:** a fibre with loose primary wall. **B:** long epidermal cells. **C:** long epidermal cells and a thin-walled parenchyma cell. **D:** long epidermal cells and a group of fibres.	Bast fibres from *Moraceae* family and grass fibres.
		13C	8	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
		14C	10	**A, B:** fibres with loose primary wall. **C:** a prismatic crystal.	Bast fibres from *Moraceae* family.
		13C	11	**A, B:** fibres with loose primary wall. **C, D:** fibres with smooth surface, even thickness, narrow lumen, and well-spaced cross-markings.	Bast fibres from *Moraceae* family.
		14C	17	**A-E:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
		1460	20	**A, B**: a fibre with loose primary wall and pitted vessel elements. C: a thin fibre.	Bast fibres from *Moraceae* family and grass fibres.
		13C	23	**A:** a fire with loose primary wall. **B:** low magnification of A. **C:** a fibre with loose primary wall and a rhombic crystal.	Bast fibres from *Moraceae* family.
		1250	27	A: crystals. B: a rhombic crystal. C, D: fibres with loose primary wall.	Bast fibres from *Moraceae* family.
		15 – 16C	31	**A:** fibres with loose primary wall. **B:** a rhombic crystal. **C:** a prismatic crystal. **D, E:** flower shaped associated cells, epidermal cells, and short thin fibres. **F:** a rectangular shape epidermal cell. **G:** a short thin fibre, an epidermal cell. **H:** spiral vessel element.	Bast fibres from *Moraceae* family and grass fibres.
		14C	32	**A:** a fibre with loose primary wall, a rectangular parenchyma cell. **B, C:** long epidermal cells. **D:** a thin-walled parenchyma cell, a long epidermal cell. **E:** a epidermal cell with small	Bast fibres from *Moraceae* family and grass fibres.

				papilla. F: annular shape vessel element. **G, H:** flower shaped associated cells.	
		13 – 14C	34	**A-C:** fibres with loose primary wall. **D:** a fibre split into two. **E:** a fibre with frequent diagonal cross-markings.	Bast fibres from *Moraceae* family.
		14C	35	**A:** a fibre with loose primary wall. **B:** long epidermal cells. **C:** epidermal cells. **D:** an epidermal cell. **E:** epidermal cells.	Bast fibres from *Moraceae* family and grass fibres.
		14C	36	**A-D**: a fibre with loose primary wall and frequent cross-markings.	Bast fibres from *Moraceae* family.
		14C	37	**A-D:** fibres with loose primary wall. **E:** a thin-walled parenchyma cell.	Bast fibres from *Moraceae* family.
Japanese	Or.60.d	762 – 9		**A, B**: fibres with well spaced cross-markings and longitudinal splits. **C, D**: fibres with loose primary wall.	Bast fibres from *Moraceae* family and other bast fibres.
	Or.64.b.4	1213	2	**A-E:** twisted fibres. **F:** a flat fibre with not well defined lumen with occasional cross markings. **G:** stomata, a prickle hair in epidermal cells. **H:** a fibre with a trace of loose primary wall.	Bast fibres from *Moraceae* family and grass fibres.
			LP	**A:** a fibre with loose primary wall. **B, D:** prismatic crystals. **C:** spiral shape vessel element.	Bast fibres from *Moraceae* family and grass fibres.
	Orb.30/82	1220		**A, B:** fibres with loose primary wall. **C:** a prismatic crystal. **D:** a rhombic crystal.	Bast fibres from *Moraceae* family.
	Or.81.c.13	1252	19	**A:** a broken split fibre. **B:** a fibre with loose primary wall. **C:** a pitted fibre split into two. **D:** a prismatic crystal.	Bast fibres from *Moraceae* family.
	Or.81.c.10	1279	3	**A:** a fibre with loose primary wall. **B:** a fibre with well-defined lumen and well-spaced cross markings. **C:** a group of fibres.	Bast fibres from *Moraceae* family.
	Or.64.b.8	1280	4	**A-C:** fibres with loose primary wall. **D:** a fibre with varying thickness.	Bast fibres from *Moraceae* family.
			15	**A-L**: continuously taken images of one fibre which has well-defined lumen, smooth surface and even thickness but not clear cross-markings. **F:** a fibre with loose primary wall. **M:** a	Bast fibres from *Moraceae* family, other bast fibre and possibly gampi.

				fibre with not clear cross-markings and smooth surface. **N:** the fibre, 'A-L' with low magnification and very fine fibres.	
	Or 30/215	1333 – 92	240	**A, B:** fibres with loose primary wall. **C:** a rhombic crystal and a prismatic crystal. **D:** twisted fibres.	Bast fibres from *Moraceae* family.
			315	**A, B:** fibres with loose primary wall. **C:** a rhombic crystal and a prismatic crystal.	Bast fibres from *Moraceae* family.
			352	**A:** a fibre with frequent cross-markings, varying thickness and a broaden centre. **B:** the fibre 'A' with low magnification. **C:** a fibre with smooth surface and well-spaced cross-markings and narrow lumen. **D:** the fibre 'C' with low magnification.	Bast fibres from *Moraceae* family.
			458	**A, B:** fibres with loose primary wall. **C:** a rhombic crystal. **D:** a prismatic crystal. E: short white needle shape crystals.	Bast fibres from *Moraceae* family.
			483	**A:** fibres with loose primary wall. **B:** a prismatic crystal. **C:** a piece of woven material or mechanical wood pulp.	Bast fibres from *Moraceae* family and unidentified material.
			485	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	Or.81.c.5	1334	116	**A:** fibres with loose primary wall. **B:** a prismatic crystal. **C:** a star shape vessel element.	Bast fibres from *Moraceae* family.
			144	**A, C:** a fibre with loose primary wall. **B:** a prismatic crystal.	Bast fibres from *Moraceae* family.
	Orb 30/210	1350 – 70	41	**A, B:** fibres with loose primary wall. **C-F:** fibres with pits and loose primary wall.	Bast fibres from *Moraceae* family.
			73	**A, B:** fibres with loose primary wall. **C:** a rhombic crystal. **D:** a prismatic crystal.	Bast fibres from *Moraceae* family.
			82	**A-C:** fibres with loose primary wall. **D:** rhombic crystals. **E:** epidermal cells. **F:** epidermal cells under cross polar.	Bast fibres from *Moraceae* family and grass fibres.
	Orb.30/171	1364	(3)3	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(4)18	**A-C:** fibres with loose primary wall. **D:** difficult to identify.	Bast fibres from *Moraceae* family and unidentified material.

			(7)14	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	Or.64.b.15	1370	37	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	Or.75.g.20	1412		**A-C:** fibres with loose primary wall. **D, E:** fibres with low magnification.	Bast fibres from *Moraceae* family.
	Or.59.bb.4	1493	26	**A-C:** fibres with loose primary wall. **D:** a prismatic crystal.	Bast fibres from *Moraceae* family.
			35	**A, B:** fibres with loose primary wall. **C:** pitted vessel elements.	Bast fibres from *Moraceae* family.
			50	**A, B:** fibres with loose primary wall. **C:** a fibre with frequent diagonal cross markings and longitudinal splits. **D:** a group of fibres.	Bast fibres from *Moraceae* family.
	Orb.30/174	1499		**A-C:** fibres with loose primary wall. **D:** a rhombic crystal.	Bast fibres from *Moraceae* family.
	Orb.30/219	1528	?	**A, B:** fibres with loose primary wall. **C:** rhombic crystals. **D:** a prismatic crystal.	Bast fibres from *Moraceae* family.
			14	**A, B:** fibres with loose primary wall. **C:** dumb-bell shaped silica body. **D:** a rhombic crystal.	Bast fibres from *Moraceae* family and grass fibres.
	Or.81.c.22	1529	28	**A, B:** fibres with loose primary wall. **C:** epidermal cells. **D:** a group of fibres with low magnification.	Bast fibres from *Moraceae* family and grass fibres.
	Orb.30.173	1533	3	**A-C:** fibres with loose primary wall. **D:** a rhombic crystal and a prismatic crystal. **E-G:** long epidermal cells. **H, J:** parenchyma cells. **I:** thin-walled parenchyma cells. **K:** a group of thin sort fibres.	Bast fibres from *Moraceae* family and grass fibres.
	Orb.30/193	1554	4	**A:** a fibre with loose primary wall. **B, C:** epidermal cells. **D:** epidermal cells and dumb-bell shape silica bodies.	Bast fibres from *Moraceae* family and Rice straw.
			5	**A, B:** fibres with loose primary wall. **C:** a group of fibres.	Bast fibres from *Moraceae* family.
	Or.75.f.26	1530-70	24	**A:** a fibre with loose primary wall. **B, C:** spiral shape vessel element.	Bast fibres from *Moraceae* family and grass fibres.
			93	**A, B:** fibres with loose primary wall. **C, D**: rhombic crystals. **E:** a prismatic crystal.	Bast fibres from *Moraceae* family.

	Or.59.bb.5	1599	FE	**A:** a fibre with loose primary wall and a prismatic crystal.	Bast fibres from *Moraceae* family.
			26	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			47	**A, B:** fibres with loose primary wall. **C:** a prismatic crystal.	Bast fibres from *Moraceae* family.
	Orb.30/86	1599	3	**A, B:** fibres with loose primary wall. **C:** a rhombic crystal.	Bast fibres from *Moraceae* family.
			18	**A, B:** fibres with loose primary wall. **C, D:** epidermal cells. **E:** epidermal cells and dumb-bell shape silica bodies. **F:** epidermal cells and a dumb-bell silica body.	Bast fibres from *Moraceae* family and Rice straw.
	Orb.30/179	1605	(1)11	**A, B:** fibres with loose primary wall. **C:** a prismatic crystal. **D:** a rhombic crystal.	Bast fibres from *Moraceae* family.
			(4)19	**A:** a fibre with loose primary wall. **B:** a rhombic crystal. **C:** a fibre split into two.	Bast fibres from *Moraceae* family.
			(5)6	**A, B:** fibres with loose primary wall. **C:** a rhombic crystal and prismatic crystals. **D:** twisted fibres.	Bast fibres from *Moraceae* family.
			(6)2	**A-E:** fibres with loose primary wall. **F:** a prismatic crystal.	Bast fibres from *Moraceae* family.
			(8)3	**A-R:** continuous images of one fibre. **S:** fibres with loose primary wall and starch grain in polarised light. **T:** a prismatic crystal. **U, V:** epidermal cells.	Bast fibres from *Moraceae* family and unidentified material.
			(8)8	**A, B:** fibres with loose primary wall. **C:** a prismatic crystal. **D:** a rhombic crystal.	Bast fibres from *Moraceae* family.
			(9)9	**A-D:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	Orb.30/195	1616	(序)1	**A, B:** fibres with loose primary wall. **C:** a prismatic crystal.	Bast fibres from *Moraceae* family.
			(2上)35	**A-C:** fibres with loose primary wall. **D:** a prismatic crystal.	Bast fibres from *Moraceae* family.
			(2下)8	**A, B:** fibres with loose primary wall. **C:** a prismatic crystal. **D:** a fibre split into two.	Bast fibres from *Moraceae* family.
			(2下)21	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(2下)25	**A-C:** fibres with loose primary wall. **D:** a rhombic crystal. **E:** a prismatic crystal.	Bast fibres from *Moraceae* family.
			(3上)4	**A, B:** fibres with loose primary wall. **C:** a prismatic crystal. **D, E:** tracheids showing bordered pits covered with criss-cross pattern.	Bast fibres from *Moraceae* family and wood pulp.

			(4上)20	**A, B:** fibres with loose primary wall. **C:** some needle shape crystals. **D:** a rhombic crystal and a prismatic crystal.	Bast fibres from *Moraceae* family.
			(㤗)6	**A-C:** fibres with loose primary wall. **D:** a prismatic crystal.	Bast fibres from *Moraceae* family.
	Orb 30/197	1623	(1)3	**A:** a fibre with loose primary wall. **B-H:** twisted fibres.	Bast fibres from *Moraceae* family.
			(3)9	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(3)36	**A, B:** fibres with loose primary wall. **C:** prismatic crystals.	Bast fibres from *Moraceae* family.
			(4)6	**A, B:** fibres with loose primary wall. **C:** a fibre with longitudinal splits.	Bast fibres from *Moraceae* family.
			(4)50	**A:** a fibre with loose primary wall. **B:** a fibre split into two. **C:** parenchyma cells. **D:** parenchyma cells.	Bast fibres from *Moraceae* family and grass fibres.
			(7)18	**A-C:** fibres with loose primary wall. **D:** a group of fibres.	Bast fibres from *Moraceae* family.
			(10)3	**A-C:** fibres with loose primary wall. **D:** a prismatic crystal.	Bast fibres from *Moraceae* family.
	Orb.30/164	1629	(上)8	**A:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(上)14	**A-D:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			(下)19	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
	16124.b.7	1682	13	**A-C:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.
			108	**A-C:** fibres with loose primary wall. **D:** a prismatic crystal.	Bast fibres from *Moraceae* family.
	16218.d.23	1700	(上)30	**A, B:** fibres with loose primary wall.	Bast fibres from *Moraceae* family.

Appendix 2

Preparation of Graff "C" stain

A. Aluminum chloride solution of 1.15 sp gr at 28°C, made by adding about 40g of $AlCl_3 \cdot 6H_2O$ to 100ml of water.

B. Calcium chloride solution of 1.36sp gr at 28°C, made by adding about 100g of $CaCl_2$ to 150 mL of water.

C. Zinc chloride solution of 1.80 sp gr at 28°C, made by adding 25 mL of water to 50g of dry $ZnCl_2$ (fused reagent grade sticks in sealed bottles, or crystals). Do not use $ZnCl_2$ from a previously opened bottle.

D. Iodide-iodine solution, made by dissolving 0.90g of dry KI and 0.65g of dry iodine in 50 mL of water. The KI and iodine are first thoroughly intermixed and crushed together. Dissolve by adding the required amount of water drop by drop with constant stirring.

Mix well together 20 mL of solution A, 10 mL of solution B, and 10 mL of solution C; add 12.5 mL of solution D and again mix well. Pour into a tall, narrow vessel and place in the dark. After 12 to 24 h, when the precipitate has settled, pipet off the clear portion of the solution into a dark bottle and add a leaf of iodine. Keep in the dark when not in use.

Preparation of Wilson's stain

A. 1.5g of Iodine (I_2) and 70g of Cadmium Iodide (CdI_2) are dissolved in 100 ml of distilled water at 43°C.

B. A mixture of 15mL of 37% Formaldehyde (HCHO), 140g of Calcium Nitrate Hydrate ($Ca(NO_3)_2 \cdot 4H_2O$), 40g of Cadmium Chloride Hydrate ($CdCl_2 \cdot 2.5H_2O$).

Mix well together A and B.

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