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ANALYSIS OF THE APPLICATION OF THE “DIGITAL LIGHT” RAPID PROTOTYPING PROCESSING FOR FUNCTIONAL RAPID MANUFACTURED COMPONENTS.

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ABSTRACT

Rapid Prototyping is widely known as being able to fabricate 3D objects with complex geometries directly from accurate digital CAD data. Rapid prototyping can shorten the product development cycle and improve the design process by providing rapid and effective feedback to the designer. This paper presents the findings of an investigation into the accuracy, build strength and detail of the EnvisionTec PerFactory^{TM} Digital Light Processing (DLP^{TM}) based system, applied to rapid manufactured parts. The multi-directional material properties of Rapid prototyping resins can be used by Finite Element analysis to predict the functional design parameters applied to rapid manufactured components.
The results will allow designers and manufacturing engineers to access the validity of the components and the range of applications for this new evolutionary system.

Key Words: Rapid Prototyping, Digital Light Processing, Accuracy, Rapid Manufacturing

1.0 INTRODUCTION

Rapid prototyping (RP) is widely regarded as being able to manufacture one off or small quantity of components in materials with properties other than the production materials.

The move from rapid prototyping to rapid manufacture can be attributed to many factors. The major influences are:

- The development of these systems in recent years has been to improve accuracy and repeatability of components produced by understanding the interaction of the manufacturing processes.
- The advantage of new materials, for example materials with reduced shrinkage and improved inter-molecular and inter-layer bonding, has increased the range of applications and the more accurate parts can be utilised for aerospace, automotive, medical and consumer products.
- The reduction in initial investment requirements, particularly in the low cost office based “3 D Printers” has improved the economics of application of RP parts as direct manufacture of components.
- The need for lean and rapid product development to remain competitive and meet ever more demanding customer requirements.

To be able to use these new rapid prototyping processes and materials as rapid manufacturing processes. Then we must first understand the capabilities and limitations of each and every process and materials used so the correct process and material can be matched to the application.

This research paper looks at the capability of the Stereolithography variant that is the EnvisionTech Perfactory™ Digital Light Processing System.

In the past, studies such as the “Implementation of Product Design by the Introduction of Rapid Manufacturing”, EPSRC GR/R13517/01 [1], have focused upon the Stereolithography SLA and Selective Laser Sintering SLS processes.

This paper complements this study by adding to the knowledge base of materials data for the DLP process and will allow designers to design for this new low cost process compared to traditional laser based Sterolithography process.

In the first instance, the materials properties of the Acryl ate resin used in the DLP process are investigates, and secondly, using this materials data allowed designers to assess their designs using Finite Element Analysis techniques[2], and finally, will validate the analysis with case studies.

2.0 THE ENVISIONTEC DLP PROCESS

The PerFactory® technique utilises the technology called Digital Light Processing (DLP™) developed by Texas Instruments [1]. The process uses a high-powered, precision light projector working on the DLP™ technology, to polymerise a photosensitive resin layer-by-layer [2]. This polymerization is similar to that the sterolithography SLA process, however the laser positioning galvanic mirrors used in SLA are replaced by a DLP™ projector [3] with a mercury lamp. The galvanic mirrors in SLA trace the exact contours of the cross section [4] and area fill, however the PerFactory® system builds each mask in discrete Voxels, approximating the boundaries. The method by which the Perfactory® and SLA techniques build a layer is shown in Figure 1. The build process projects a mask of white light and dark regions, the light region interacts with the resin changing its phase from liquid to solid. The process operates in the reverse to the SLA process by curing the resin against the silicon base plate, peeling the cured part, lifting and squeezing a new layer of polymer ready for the next layer. Pixel size is dependant upon the platform build area setting therefore for a 153.6 mm x build area they will be 1024 pixels providing a resolution or pixel size of 0.15 mm per pixel light source.

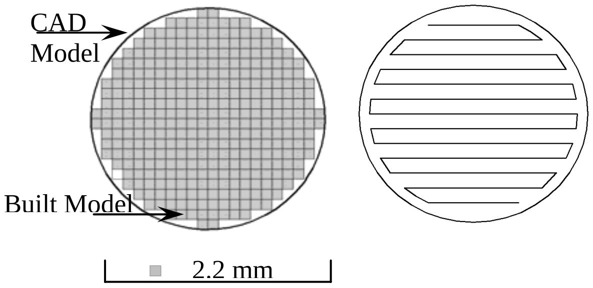

Figure 1 : Comparison of a layer built by the PerFactory® and SLA processes

1.1 Advantages of the PerFactory® Process

- Build time per layer is constant throughout the process, unlike techniques like SLS and FDM where layer-scanning time depends on the area of the layer [4,5]
- Economic material usage and low capital costs [2]
- Very few moving parts and consumable components
- Very little post processing is required, as nearly 100% curing is achieved during build
- The machine footprint is only 736.6 mm (l) x 482.6 mm (w) x 1244.6 mm (h) and can be used in an office environment, with no need for air conditioning.

1.2 Limitations of this technique

- Build size is limited to a volume of 190mm x 152mm x 230mm (height)
- The technique is new to the market
- Supports are required, resulting in need for manual post processing
- Raster XY image – layer image formed by rectangular light pixels
- Short life of projector bulbs – approximately 700 hours. Cost - £300 per bulb
- Cost of Acrlate R5 Resin £150 per litre.

1.3 Test sample preparation

The test samples were manufactured in the three major axis, figure 3 shows a x-z axis build and figure 4 shows the build slice procedure.

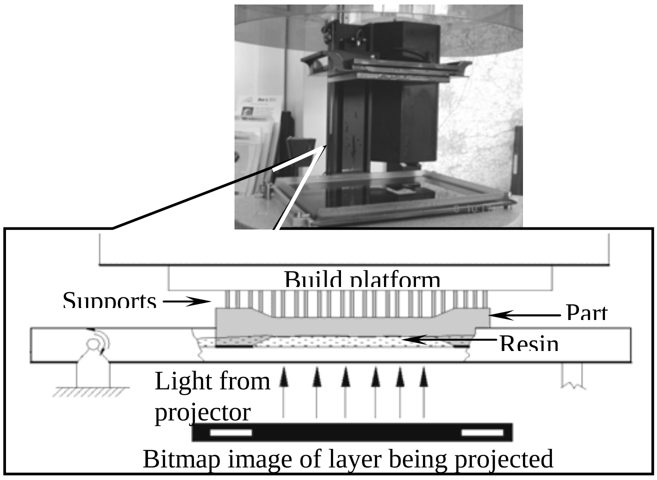

Figure 3 : The PerFactory machine

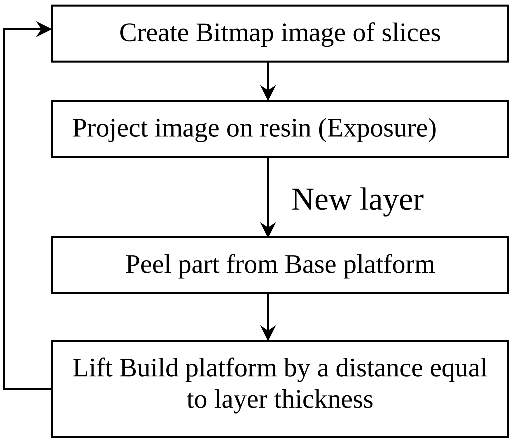

Figure 4 – The part building process

The part can be built in any of the six orientations x, y and z, as shown in Figure 4a and 4b.

The orientation is chosen considering the following factors:

- Geometry of the part
- Surface finish requirements
- Areas to be supported (Faces in contact with the support end up with a rougher finish)

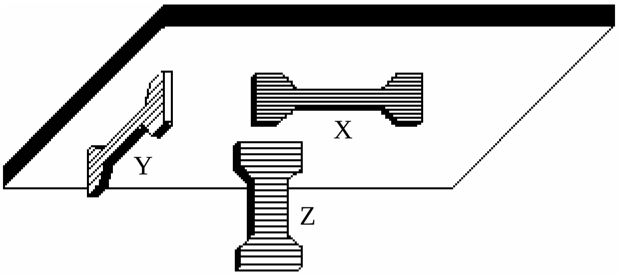

Figure 4a : Different build orientations

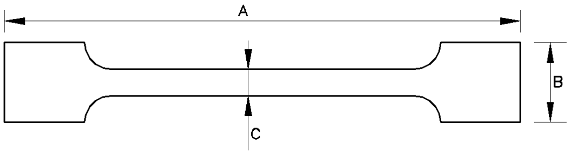

Figure 4b: The test specimen

3.0 Build Parameters

The build parameters set have been derived from previous part optimisation [4,5] studies undertaken, Table 1 shows the build parameters utilised to produce the specimens with Acrylate R5 resin.

Parameter	**Value**
Separation Distance µm	3000
Positioning Velocity msec	1000
Separation Velocity msec	1000
Exposure Time msec	9000
Work area mm	152 * 120
Layer thickness µm	50

Table 1 : Build parameters

The samples where manufactured in the **x** – y, **x** – z, **y** – z, **y** - x, **z** – x and **z** – y where the bold axis indicates the major axis of length for the sample.

4.0 THE MATERIALS TESTING AND RESULTS

4.1 Testing Procedure

Tensile strength tests on the specimens were conducted on the Monsanto Tensometer, the results for each axis over a sample of 12 parts averaged are shown in Table 2.

Direction	Young’s modulus *10^9 N/m^2	Poisson’s Ratio	Tensile Strength *10^6 N/m^2
X - Y	2.00	0.35	65
Y - X	2.20	0.38	67
X - Z	2.70	0.39	68
Z – X	2.35	0.39	68
Y – Z	2.40	0.37	67
Z - Y	2.54	0.38	69

Table 2 : Results of tensile test in 6 planes

A matrix was then produced to apply the corresponding Young’s modulus, Poisson’s ratio and Tensile Strength to each of the test components under investigation; this proposed that the component was analysis as if it was in each of the six orientations. Therefore each finite element analysis was repeated six times to evaluate the best orientation for the production component.

5.0 THE FINITE ELEMENT ANALYSIS (FEA)

5.1 Background to Finite Element Analysis

Design analysis is a software tool for simulating physical behaviour on a computer. Will it break? Will it deform? Will it get too hot? These are the types of questions for which design analysis provides accurate answers. Instead of building a prototype and developing elaborate testing regimens to analyze the physical behaviour of a product, engineers can elicit this information quickly and accurately on the computer. The application of design analysis can minimise or even eliminate the need for physical prototyping and testing; the technology has gone main stream in the manufacturing world over the past decade as a valuable product development tool and has become present in almost all fields of engineering. Design Analysis employs the finite element analysis (FEA) method to simulate physical behaviour of a product design.

The FEA process consists of subdividing all systems into individual components or "elements" whose behaviour is easily understood and then reconstructing the original system from these components. This is a natural way of performing analysis in engineering and even in other analytical fields, such as economics. For example, a control arm on a car suspension is one continuous shape. An analysis application will test the control arm by dividing the geometry into elements, analysing them, then simulating what happens between the elements.

The application displays the results as colour-coded 3D images, red usually denoting an area of failure, and blue denoting areas that maintain their integrity under the load applied.
Engineers use design analysis for just about every type of product development and research effort imaginable. Analysing machine designs, injection moulded plastics, cooling systems, products that emit electromagnetic fields, and systems that are influenced by fluid dynamics are just some examples of how companies leverage design analysis.

The design analysis procedure can be broken down into a series of steps

- Decide upon the analysis type i.e. static analysis
- Generation of 3D CAD model of component
- Reduction of component to reduce complexity by looking for symmetry, removal of detail i.e. text etc
- Assigning material properties this case in x, y and z axis directions
- Applying restraints that hold the component
- Applying forces or deflections to reflect real world loading
- Creating a mesh of elements
- Running the analysis
- Refining the mesh in key critical areas
- Re-running the analysis
- Verification of analysis results by hand calculations or physical testing

5.2 Application of FEA to Non-Isotropic Structures

The following Non-Isotropic components were considered. The restraints and loading for part 1 shock strut, figure 5a, 5b as both tensile and compressive load, part 2 as a tensional load held at the larger bore and loaded through the pin hole.

Other parts analysed included a garage door opening bracket and a tensile test piece these will not be shown here.

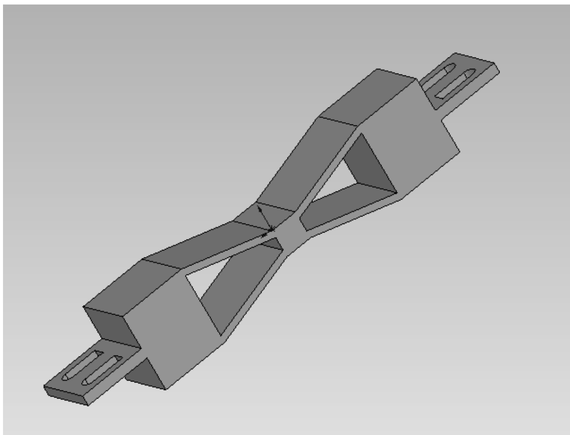

Figure 5a : Part 1 Shock Strut

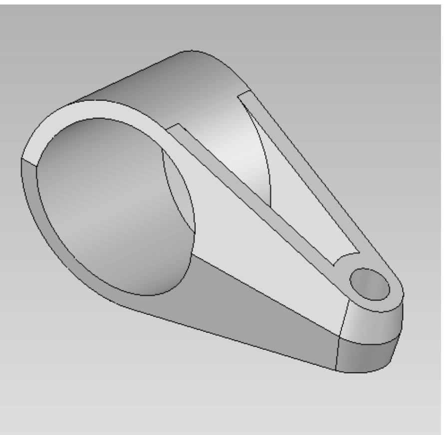

Figure 5b: Part 2 Rocker Arm

The loadings of 15,000 N where applied the analysis load values shown in Table 3 reflect the test carried out on the shock strut, Part 1, these where then repeated for the subsequent parts.

6.0 CASE STUDIES

The Case studies were undertaken to apply the material properties to real components not just tensile sample pieces. The FEA analysis can be seen for Part 1 and 2 in figures 6a, 6b. The tabulated analysis results are shown in table 3 shows the verification of the analysis for the Von Misses Stress and displacement.

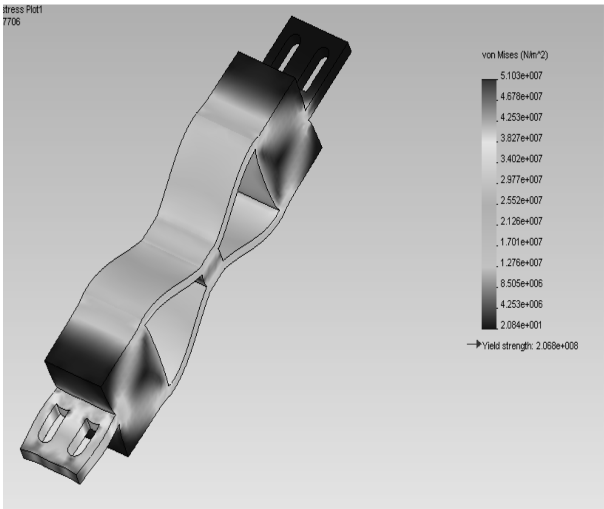

Figure 6a: FEA analysis Part 1 in compression

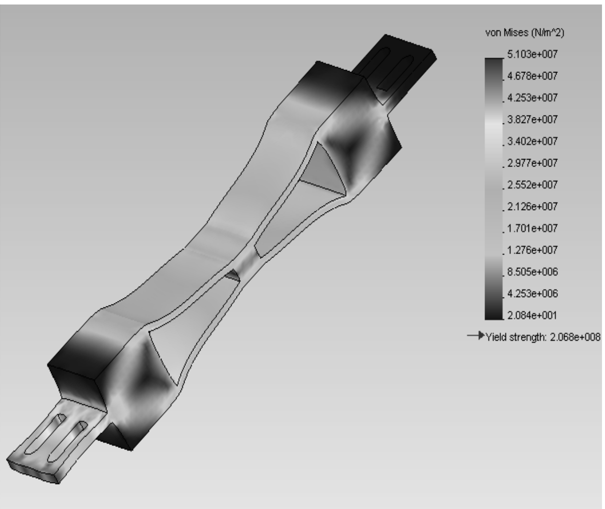

Figure 6b : FEA analysis Part 1 in tension

Test/ Major Plane	1 X – Y	2 Z – Y	3 Y - Z	4 Y - X	5 X - Z	6 Z - X
Max stress (* 10^6 N/m^2)	32.00	33.71	32.69	32.57	32.03	33.00
Displacement (mm)	5.15	4.148	4.515	4.509	5.158	4.148
Factor of Safety (F.O.S)	6.5	6.135	6.326	6.349	6.456	6.268

Table 3: Results for Part 1 in six possible orientations

The results indicate that least stress and therefore the highest Factor of safety was in the build X – Y direction, however the least strain was found to be in the Z – Y or Z – X direction.

7.0 CONCLUSIONS

Extensive build orientation testing of the materials properties has been undertaken to establish key materials properties for each of the possible build orientation. These results have been incorporated into the FEA analysis for several parts.

This paper has shown how physical prototypes manufactured from the PerFactory process can be analysed taking into account the different unique directional materials properties that many RP process inherently possess.

The example part chosen showed the best orientation for build for strength to be orientation 1 i.e. in the x – y plane however for strain the best orientation was found to be in the either the z - y or z – x plane.

Tensile tests were undertaken and results are indicated in section 4 above.

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