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IMPACT RESISTANCE OF CONCRETE USING DOVETAILED FIBRES AND TYPE 2 SYNTHETIC FIBRES

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ABSTRACT

This paper investigates the relative performance of new dovetailed (DT) cross section fibres with regard to impact resistance and energy absorption of concrete. The DT fibres are compared to concrete made with other commercially available Type 2 (T2) fibre types and plain concrete. The two diameters of the prototype DT fibre as tested; are currently in their development stage and not commercially available at present.

The test examines two diameters of polypropylene DT fibres and a single size Type 2 structural synthetic fibre, to evaluate the relative mix performance. The parameters of the test are: compressive strength, flexural strength, energy absorption (toughness) measured with load and deflection and time dependant absorbed energy using a drop hammer impact test. Dosage rates for all samples were 6kg/m³ and 30kg/m³. The compressive strength test was carried out using plain concrete.

Impact tests showed that the peak force required to induce a crack in the beams, was generally increased with the addition of fibres to the concrete mix. Total energy absorption was also increased utilising a higher fibre dosage; with a 30 kg/m³ dosage displaying the greatest increase. The post crack toughness indices of the concrete utilising DT fibres at a 30 kg/m³ fibre dosage produced superior values to the other concrete types tested.

These findings suggest that the addition of DT fibres at the correct dosage will increase the impact resistance and energy absorption of concrete.

Key words: dovetailed fibres; Type 2 macro synthetic fibre; impact resistance; energy absorption; concrete; toughness.

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1. INTRODUCTION

Concrete is inherently strong in compression yet weak in tension, and if concrete is manufactured to a high strength it can be brittle. These properties can cause issues when loads are applied to the building that it is not designed to cope with such as accidental impact. The addition of reinforcement to concrete increases tensile strength to structural elements. Traditionally concrete reinforcement has been provided in the form of steel with the use of steel rebar and mesh, however there is an increasing move away from this with the use of fibre reinforcement becoming more prevalent because of the price increase of steel and the need to be cost effective and environmentally friendly in the current market [1]. Furthermore, steel reinforcement can corrodes over time therefore after a certain amount of time, the concrete may not be satisfactorily reinforced. However, this will not happen with synthetic fibre reinforced concrete (FRC). Fibre reinforcement offers a suitable alternative to the use of steel for crack control in concrete.

1.2. Fibre reinforced concrete

The use of fibres in concrete has been shown to increase the energy absorption of concrete. Fibres have the ability to redistribute forces within the matrix material, restraining the formation and extension of cracks. Alavi Nia et al [2] claim that the addition of fibres to the concrete increases its performance in many ways; increasing ductility, post crack flexural strength, tensile strength and resistance against dynamic and impact loads. Furthermore, they also claim that the use of fibres stops crack propagation in the concrete, and in addition, fibres reduce the likelihood of spalling and scabbing. Behloul and Guise [3] suggest that, ultra high performance fibre reinforced concrete (UHPFRC) delivers ductility that permits it be used without the use of any passive reinforcement in certain structural components, reducing raw materials and labour. Additionally, the use of fibre reinforced concrete can limit environmental impacts during the lifespan of the concrete structure when compared to that of steel. This is due to reduced degradation of the structure, which equates to lower maintenance requirements and increased total life cycle performance.

Hibbert and Hannant [4], suggest that compared to plain concrete, concrete which had polypropylene fibres contained in the mix, had an increased energy absorption of ten times in failure. Betterman et al, [5] also suggested that, the use of short fibres with a small diameter are more efficient in increasing the first peak stress and coping with post crack loads.

Tabatabaei et al [6] argue against the short fibre length argument for use, by stating that the addition of long carbon fibres (in excess of 100mm) to the concrete matrix significantly increases the blast resistance whilst reducing the amount of cracking. The resistance to spalling is increased by a factor of ten and the surface damage to concrete decreased on an average of 82%. Long fibres had not been commonly used previously as they could potentially segregate in the mix and decrease workability as well as ball within the mix.

Mo et al [7], claim that steel fibre reinforcement in concrete provide it with a higher impact resistance than when synthetic fibres are used. However, they also argue that steel fibres are liable to corrode and that using a hybrid of fibres will 'preserve the impact strength' of a structure and that by using hybrid fibres as opposed to solely steel fibres there is a lower density and this reduces the dead load of the structural members in a building.

The failure of the fibres has little to do with the strength of the concrete as it is the bond between the fibres and the concrete that will break first. However, the final post crack load is influenced by fibre orientation, fibre dosage, type of fibre used and the type of concrete used [8].

However, Zhang et al [9] claim that despite fibre reinforcement, concrete requires the use of strong coarse aggregate in the matrix in order to improve impact resistance as it acts as a barrier to crack propagation.

1.3. Dovetailed Fibres

Synthetic dove tailed cross section fibres (DT) are a relatively new fibre type, these are fibres with grooves in them running longitudinally shaped like a dovetail. Using DT fibres is seen to be more advantageous than using standard polypropylene fibres due to enhanced bond strength. Figure 1 displays the cross-sectional shape, and properties of DT fibres as used in this paper.

DT fibres have re-entrant features that increase the surface area by 1.9 times compared to circular fibres. DT fibres use the positive Poisson's contraction ratio in order to grip the fibre to the cement paste and provide an enhanced mechanical bond. Following this when tensile loads are applied to concrete containing DT fibres there is an inverse auxetic effect. Only the tops of the ridges of the DT fibres de-bond; the side's contract in and squeeze the concrete solidified within the groove [10]. The shape of the DT fibre allows for it to stretch and for its diameter to reduce and this produces a gripping effect that allows greater transfer of stress once the initial bond has been broken [8].

It has been shown through laboratory testing that DT fibres are superior to others in the re-distribution of impact forces in a beam [8].

Area = 0.7, Perimeter = 5.9   Area = 1.8, Perimeter = 9.1
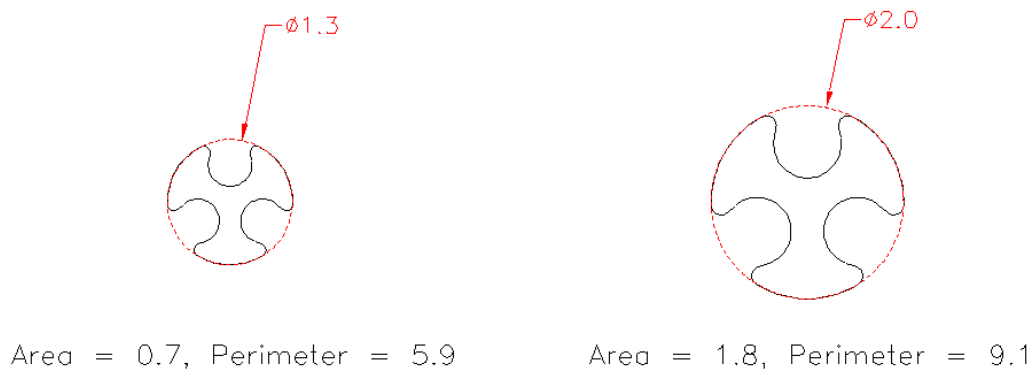
Figure 1. Cross-section of DT fibres

1.4. Type 2 macro synthetic fibres

Polypropylene fibres for use in concrete are classified within BS EN 14889. They fall into two categories: Type 1 (Monofilament < 0.3 mm diameter); and, Type 2 (Macro Synthetic > 0.3 mm diameter). The physical properties of Type 2 fibres are; a nominal filament diameter 0.9mm, 50mm fibre length, having an elastic modulus of 3500 N/mm^2 and a melting temperature of 175°C. Type 2 fibres used herein are a crimped fibre and were tested comparatively against DT fibres. The crimped features of the Type 2 fibre is displayed in Figure 2.
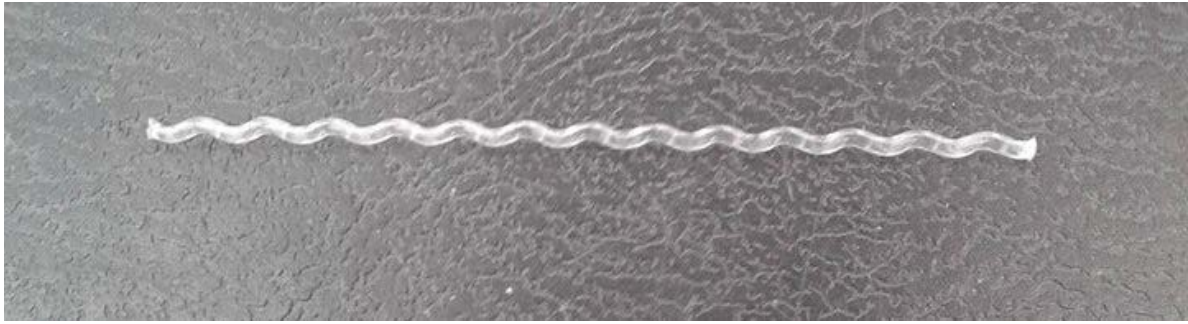
Figure 2. Type 2 macro synthetic fibre

Previous research shows that the use of polypropylene fibres in concrete increases energy absorption. There is still scope for research into the use of DT fibres in order to increase energy absorption of concrete, especially with regard to dosages of fibres in the design mix of concrete. It is hoped that due to the extra features that the DT fibres have this will further increase the energy absorption properties of concrete.

2   MIX DESIGN AND QUANTITIES

The mix design of the test concrete is displayed in Table 1. Water demand will vary due to the need to change the type of fibre that is being used in each concrete batch. The water cement ratio for all of the concrete used is 0.5 for plain concrete without fibres. Potable water was used in the batching and the water quality was to BS EN 1008: 2002.

Each separate fibre dosage for each test was batched separately, although all the plain concrete for all tests was batched together. The mix was designed to ensure there was sufficient cement paste to fill the DT fibre grooves. Silica fume was used to act as a very fine filler and this ensured that the grooves within the fibres were all fully coated.

Table 1. The mix design

Material	Quantity (kg per m³)
Gravel < 20mm	1175
Sand < 4mm	670
Cement CEM1 42.5R	400
Silica Fume	40
DT Fibres	6
DT Fibres	30
Type 2 Macro fibres	6
Type 2 Macro fibres	30

3.0   TEST METHODOLOGY

The tests described herein include: two sets of impact tests, one set with 6kg/m³ of fibres and one set with 30kg/m³ of fibres; compressive strength tests; and flexural strength tests. The flexural strength and impact tests compare two types of DT fibres with a Type 2 polypropylene fibre and plain concrete. The compressive strength test examines plain concrete.

3.1. Impact Test

The first plain beam was used as a sample to establish the drop height of the TUP and its weight. The drop height of the TUP was 150.00 mm, with an additional mass of 5.00 kg added to the TUP to have a total mass of 8.730 kg. The impact (kinetic) energy of TUP was 12.913 J, with an impact velocity of 1.720 m/s. The impact test apparatus set up is displayed in Figure 3.
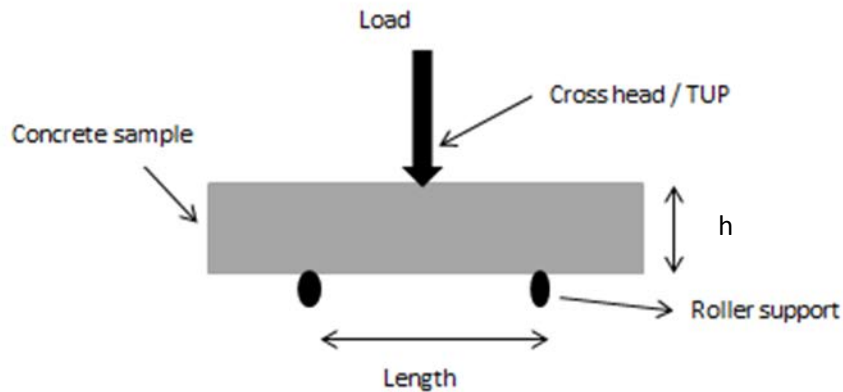
Figure 3. Impact test set up

3.1.1 Flexural strength and toughness

Flexural strength tests compared beams made of two types of DT fibres, standard type 2 polypropylene fibres and a plain concrete beams, which were tested under a three-point loading arrangement as Figure 3 until the first crack in the concrete was identified, the flexural strength was then calculated. The flexural strength tests were carried out in accordance to BS EN 12390-5:2009 using the centre-point loading method on the Lloyd LR100K Plus machine.

3.2. Compressive Strength Test

A compressive strength test was carried out on four cube samples of plain concrete. The tests were carried out to BS EN 12390-3:2009 using a calibrated ELE Compression Test Machine.

3.3   Test programme

The test programme is outlined in Figure 4 includes three sets of tests: impact tests, compressive strength tests and flexural strength tests. The total number of beams tested was forty eight in number.

The nomenclature of the samples is shown below and displayed in Figure 4..
P – Plain concrete
2 @ 6 – fibre reinforced with 2.0mm DT fibres at a 6 kg/m³ dosage
1.3 @ 6 - fibre reinforced with 1.3mm DT fibres at a 6 kg/m³ dosage
T2 @ 6 - fibre reinforced with T2 fibres at a 6 kg/m³ dosage
2 @ 30 - fibre reinforced with 2.0mm DT fibres at a 30 kg/m³ dosage
1.3 @ 30 - fibre reinforced with 1.3mm DT fibres at a 30 kg/m³ dosage
T2 @ 30 - fibre reinforced with T2 DT fibres at a 30 kg/m³ dosage

Figure 4. Test programme

4.0   RESULTS

4.1 Slump Tests

Each set of beams was batched individually and this resulted in 14 different batches of concrete being produced. It was obser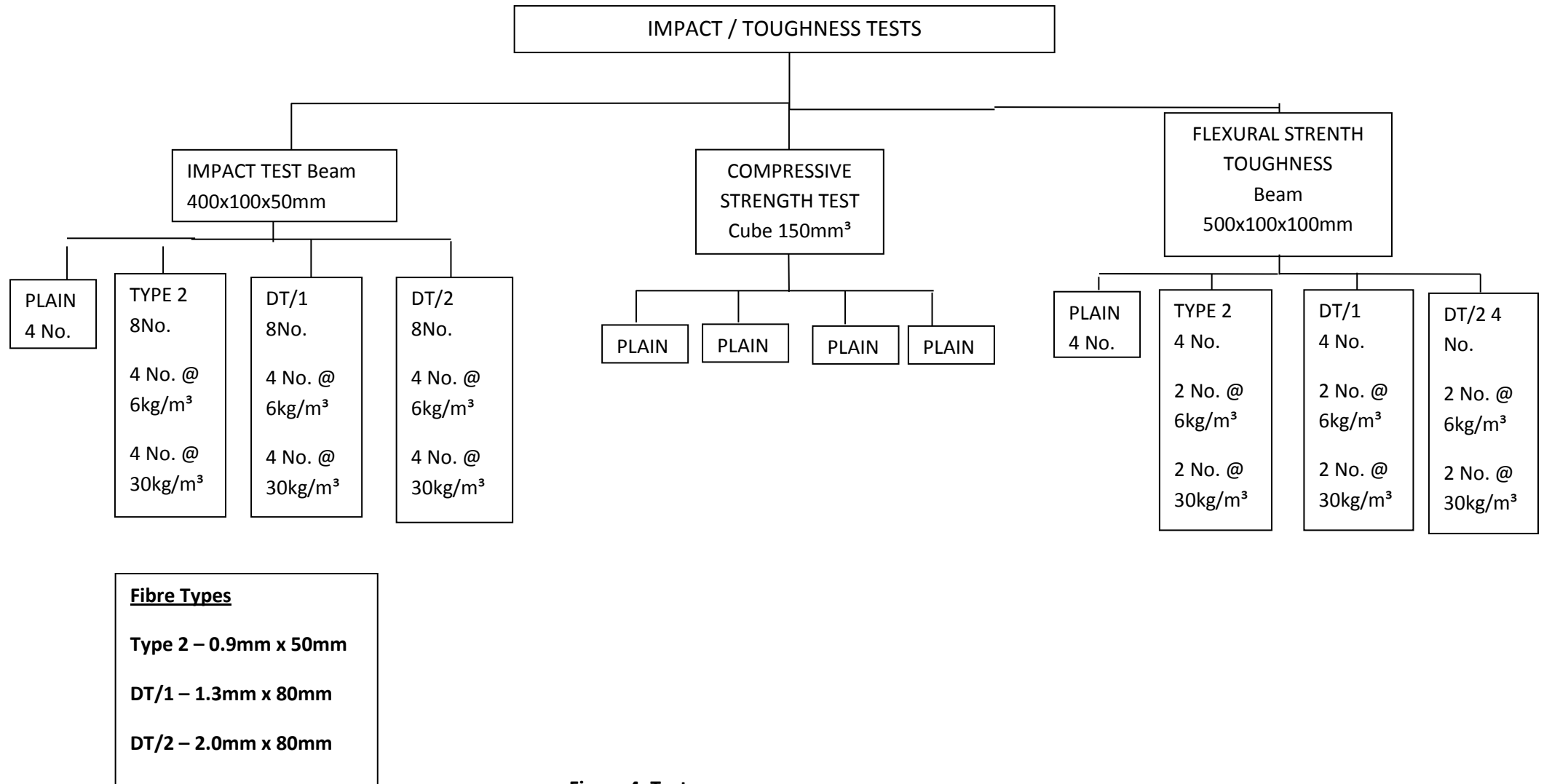ved that the greater the fibre dosage, the lower the slump became. The 30 kg/m³ fibre dosages showed negligible slump values. During the batching the water cement ratio was the approximately the same for each batch, although the high fibre doses required a 3% extra water to create a greater volume of cement paste to coat the fibres. Therefore the differences in slump are mainly to be due to the fibre dosages. The slump test results are displayed in Table 2.

Table 2. Slump test results.

Batch	Slump (mm)
Flexural – Plain	120
Flexural – 2 @ 6 kg/m³	67
Flexural – 2 @ 30 kg/m³	Negligible
Flexural – 1.3 @ 6 kg/m³	90
Flexural – 1.3 @ 30 kg/m³	Negligible
Flexural – T2 @ 6 kg/m³	64
Flexural – T2 @ 30 kg/m³	Negligible
Impact - Plain	92
Impact - 2 @ 6 kg/m³	60
Impact - 2 @ 30 kg/m³	10
Impact – 1.3 @ 6 kg/m³	45
Impact – 1.3 @ 30 kg/m³	Negligible
Impact - T2 @ 6 kg/m³	44
Impact - T2 @ 30 kg/m³	Negligible

The fibre dosage at 30 kg/m³ affected the workability properties of the concrete and the fibres started to 'ball' within the mix which prevented a good surface finish being achieved.

4.2. Compressive Strength

Results of the compressive strength test are displayed in Table 3. The tests were carried out on the plain concrete samples in accordance with BS EN 12390-3:2002. This was because a previous study showed that as fibre dosage increased; compressive strength decreased [11] and to determine this the strength of the control/reference concrete was required. The cubes samples were 150mm x 150mm x 150mm in size.

Table 3. The compressive strength of the cubes used.

REFERENCE	PLAIN CONCRETE COMPRESSIVE STRENGTH (N/mm²)
1	38.05
2	44.70
3	36.11
4	46.11
Mean	**41.24**
Standard Deviation	**4.91**

The compressive strength results showed that cubes suffered satisfactory failure in accordance with BS EN 12390-3:2002, with a more or less equal cracking on each side with very little damage to the top and bottom which were in contact with the platens of the machine. None of the samples suffered

from unsatisfactory failure as defined in BS EN 12390-3:2002, therefore all of the results were permissible for use. The characteristic strength of the concrete was derived as follows:

K value x standard deviation for the batch = characteristic strength. 1.64 x 4.91 = 8.05 (K value = 1.64 for 5% defective) Characteristic strength = 41.24 – 8.05 = 33.2 N/mm^2.

4.3. Impact tests

The impact tests were carried out on four samples of each fibre dosage and type with 28 beams being tested in total; the results are displayed in Table 4. All the beams tested had different densities but this should not have any effect on the results of these tests.

Table 4. displays the impact test results of the concrete samples.

Beam ref	Length mm	Width mm	Height mm	Density kg/m^3	Peak Force N	Impact Energy Joules	Time Micro seconds
P	400	100	35	2169.2	17468.760	6.413	0.570
P	402	100	63	2176.7	18474.038	10.024	0.625
P	400	105	65	2197.1	14953.124	6.497	0.576
P	401	101	40	2105.9	15130.302	7.473	0.699
Mean			**50.75**	**2162.2**	**16506.556**	**7.602**	**0.618**
2 @6	402	100	55	2204.8	21571.143	-1.473*	2.022
2 @6	401	104	45	2028.5	17757.546	11.681	6.447
2 @6	400	103	63	1961.0	16621.647	11.032	4.668
2 @6	400	100	37	2423.4	14127.647	7.949	0.801
Mean			**50**	**2154.4**	**17519.496**	**10.221**	**3.485**
1.3@6	400	100	42	2022.1	17336.425	6.594	0.588
1.3@6	402	103	60	2272.0	18993.076	7.792	0.804
1.3@6	401	100	40	2123.3	15608.501	7.268	0.690
1.3@6	400	104	63	2023.7	23706.897	12.940	3.528
Mean			**51.25**	**2110.3**	**18911.225**	**8.649**	**1.403**
T2@6	402	101	47	2067.9	16741.342	8.162	0.684
T2@6	400	100	45	2279.6	26142.452	8.887	0.480
T2@6	400	100	60	1980.4	22551.430	12.295	2.175
T2@6	400	102	60	1976.2	22723.440	8.974	0.558
Mean			**53**	**2076.1**	**22039.666**	**9.580**	**0.974**
2@30	402	102	45	1680.1	17950.819	11.945	6.852
2@30	400	100	40	1890.6	16732.129	8.437	1.731
2@30	400	102	60	1875.1	23308.136	12.134	3.142
2@30	400	102	55	2005.1	21532.958	12.243	3.093
Mean			**50**	**1862.7**	**19881.011**	**11.190**	**3.705**
1.3@30	400	103	45	1807.8	24199.743	11.972	3.492
1.3@30	400	103	55	1940.6	27194.123	12.176	3.519
1.3@30	400	100	35	1561.5	9433.178	11.348	5.640
1.3@30	400	102	65	1911.3	17138.041	8.753	2.949
Mean			**50**	**1805.3**	**19491.271**	**11.062**	**3.900**
T2@30	402	103	45	1705.6	21497.233	13.082	6.510
T2@30	400	103	65	2020.7	22321.024	11.146	3.942
T2@30	400	100	55	2206.2	20894.183	12.031	4.156
T2@30	400	102	35	1617.7	22764.566	12.234	6.720
Mean			**48**	**1781.3**	**21869.252**	**12.154**	**5.754**

*disregarding this result as it was a mechanical error and therefor a statistical outlier.

Table 5 displays the standard deviations of the peak force for each set of tests. The standard deviation allows for any results that are statistical outliers to be identified and removed from the analysis of the results. Any result that is twice the standard deviation, higher or lower, from the average for the set was identified as an outlier.

Table 5. Standard deviation for impact test, peak force results

Beams	Standard Deviation (mean)
Plain	1741.99
2 @ 6	3097.71
1.3 @ 6	3482.78
T2 @ 6	3900.15
2 @ 30	3061.32
1.3 @ 30	7920.47
T2 @ 30	835.53

4.3.1. Observations of the impact test

Plain beams snapped in half instantly on the impact of the TUP. This was the expected result due to the width of the beams being only 50mm and having no reinforcement at all therefore offering very little resistance to the impact force.

When testing beams with a 6 kg/m³ fibre dosage it was observed that although the impact from the TUP was causing a crack through the concrete beam the fibres in the beam retained the load transfer capability. The beams with a 30 kg/m³ fibre dosage displayed a hairline crack through the beam which can be seen in Figure 5.

Figure 5. Hairline crack in 30 kg/m³ fibre dosage sample

The plain beams were used as a benchmark to compare all the peak forces of the fibre beams. The increases in peak force were; 6% (2@6), 15% (1.3@6), 34% (T2@6), 20% (2@30), 18% (1.3@30) and 32% (T2@30). The results show that the highest mean peak force was for the beam samples with a fibre dosage of 6 kg/m³ with standard T2 polypropylene fibres with the average force of the 4 samples being 22039.666 N. The mean peak forces and times are displayed in Figure 6.2.

All of the total impact energies increased when compared to that of plain concrete. The results are as follows: 34% (2@6), 14% (1.3@6), 26% (T2@6), 47% (2@30), 46% (1.3@30) and 60% (T2@30). This finding shows that the higher the dosage of fibres in the concrete mix; does increase the impact resistance of concrete with much higher impact energies being observed in the test results for concrete

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samples with a 30 kg/m³ fibre dosage. T2 fibres with a 30 kg/m³ recorded the highest mean total impact energy with a mean average of 12.154 Joules being measured.
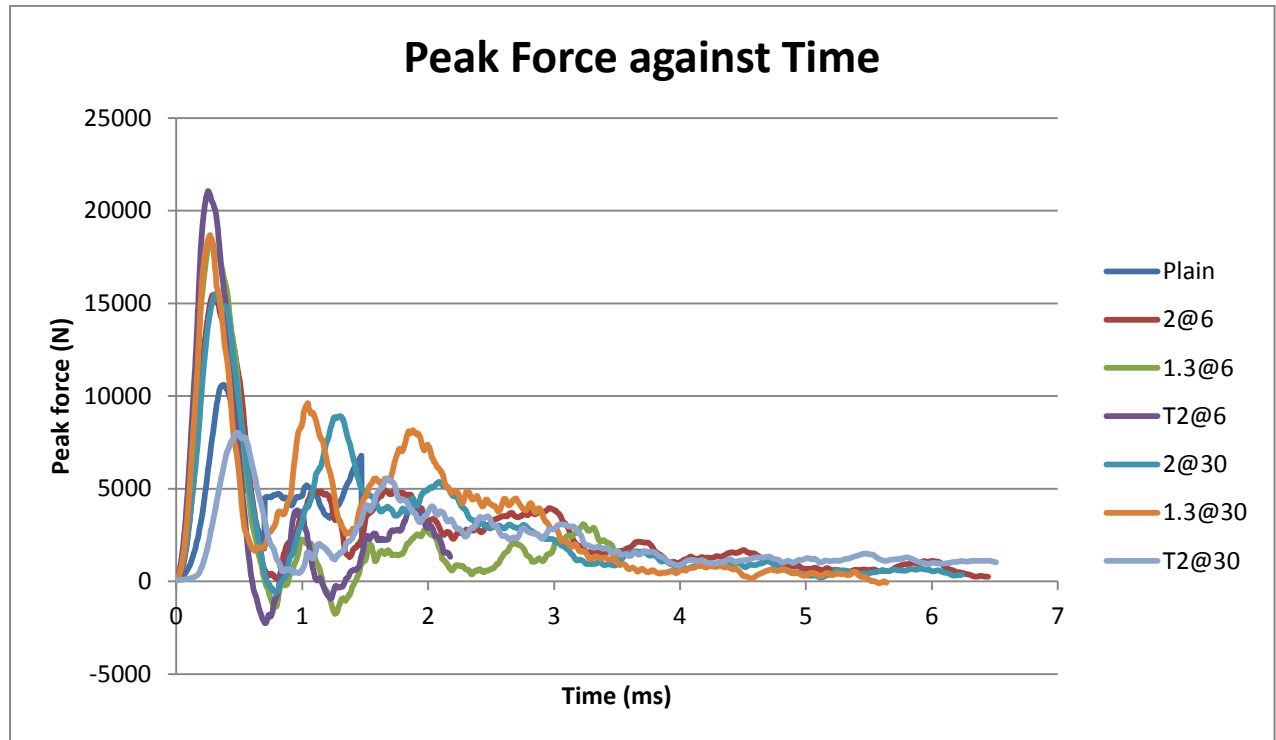

Figure 6. Comparison of peak force against time

The recording of the peak forces does not provide the full picture of the impacts tests; as many of the higher dosage samples barely cracked. The area under the force/time charts for each set of beam samples was calculated. Area under a curve can be equated to toughness or impact resistance. The total energy absorbed, is displayed in Table 6.

Table 6. Average area under force/time impact chart

Beam Sample	Average area under graph
1. Plain	5100
2. 2 @ 6	30526
3. 1.3 @ 6	13266
4. T2 @ 6	10732
5. 2 @ 30	36829
6. 1.3 @ 30	38007
7. T2 @ 30	39917

The results in Table 6 show that all of the beam samples with fibres in the concrete matrix have higher energy absorption than the plain samples. More importantly they show that when a 6 kg/m³ fibre dosage was used the energy absorption increased with the fibre diameter with 2.0 mm diameter showing the best results, furthermore it suggests that the DT fibres are functioning as they were designed with the grooves in the fibres gripping and transferring more of the force after the initial bond has been broken.

However, the results show the opposite for the beam samples with a 30 kg/m³ fibre dosage with the smaller in diameter and shorter Type 2 macro synthetic fibres showing by far superior results. This suggests that by using such a high fibre dosage, such as 30 kg/m³, the DT fibres do not have enough concrete filler in their grooves and therefore do not function as effectively as they could at a smaller dosage.

T2 fibres carried the highest impact force. However, the sample beams containing a fibre dosage of 30 kg/m³ displayed few signs of cracking. The results show that high fibre dosages do not have an ability to transfer a high peak force, however, they do have a high impact resistance as the total impact energy absorbed is increased as the fibre dosage is increased and there is a very small degree of cracking.

The area under the curve shows that at a lower fibre dosage DT fibres with a larger diameter have the greatest ability to absorb impact energy but at a high dosage they don't function as expected.

4.4. Flexural Strength

The flexural strength tests were carried out on 18 beams in accordance to BS EN 12390-5:2009. Table 7 displays the flexural strength of the samples.

Table 7 Flexural Strength results

Sample Reference	Length mm	Width mm	Height mm	Mass kg	Density kg/m³	Maximum load kN	Flexural strength N/mm²
P	502	100	102	10.9	2129	12.614	5.46
P	502	102	102	11.3	2164	12.596	5.34
P	502	105	105	11.6	2096	15.512	6.03
P	501	103	103	11.5	2164	12.420	5.11
Mean				**11.3**	**2138**	**13.286**	**5.49**
2 @6	503	104	101	10.8	2044	12.723	5.40
2 @6	502	105	100	11.4	2163	10.809	4.63
Mean				**11.1**	**2104**	**11.766**	**5.02**
1.3@6	502	105	100	11.2	2125	11.896	5.10
1.3@6	502	100	100	10.9	2171	11.509	5.18
Mean				**11.1**	**2148**	**11.703**	**5.14**
T2@6	503	97	102	10.7	2150	7.8271	3.49
T2@6	503	102	100	10.7	2086	9.8371	4.34
Mean				**10.7**	**2118**	**8.8321**	**3.92**
2@30	503	105	100	11.3	2140	14.096	6.04
2@30	502	102	105	10.5	1953	9.5353	3.82
Mean				**10.9**	**2047**	**11.8157**	**4.93**
1.3@30	501	102	101	10.3	1996	8.8411	3.82
1.3@30	503	102	104	9.7	1818	9.5113	3.88
Mean				**10.0**	**1907**	**9.1762**	**3.85**
T2@30	503	101	104	10.9	2063	8.6783	3.57
T2@30	505	100	101	10.9	2158	8.7828	3.87
Mean				**10.9**	**2111**	**8.7306**	**3.72**

Plain beams had the highest mean flexural strength at 5.49 N/mm² with the flexural strengths of 2.00mm and 1.3mm DT fibres with 6 kg/m³ dosage also being relatively high with results of 5.02 N/mm² and 5.14 N/mm² respectively. The flexural strength of the beams with a fibre dosage of 30

kg/m³ was low due to the high fibre dosage as there was not enough fine concrete in the beams to provide a satisfactory fibre cement paste bond. Adding any reinforcement reduces the area of concrete which provides less resistance to tensile forces during the test which reduces flexural strength. However, the fibres in the beam samples served their purpose and held the beams together after cracking; this can be seen in Figure 7.

Figure 7. DT fibres holding concrete sample together

Comparing the flexural strength to the plain beams, the flexural strength reductions were; 8.6% for 2@6, 6.4% for 1.3@6, 28.6% for T2@6, 10.2% for 2@30, 29.9% for 1.3@30 and 32.2% for T2@30. The T2 flexural strength at 6 kg/m³ was a lot lower than expected and gave similar results to that of a 30 kg/m³ fibre dosage. The flexural strength for the 2.00mm DT fibres at a 30 kg/m³ dosage was higher than expected and this may be due to taking an average value between two samples..

Although plain concrete had the highest flexural strength and concrete with a high fibre dosage had the lowest, the plain concrete showed no residual strength whereas fibre reinforced concrete did and held the concrete together. This shows that the fibres have served their function by keeping the concrete from fragmenting when energy is applied.

4.5 Post Crack Toughness

The post crack toughness of the concrete beam samples is calculated from the load and deflection charts that were produced in the flexural strength tests. The toughness indices of the concrete were calculated by dividing the total area under graph by the area defined up to the first crack loading. The results for the post crack toughness will be limited to 20mm deflection based on ASTM 1018 stating that a test should be terminated at δ x 10.5 (δ – first crack). The average post crack toughness for each set of beams are displayed in Table 8.

Table 8. Post crack toughness indices

Sample Reference	Post Crack Toughness Indices	Mean Value
Plain	0	0
Plain	0	
Plain	0	
Plain	0	
2 @ 6	3.83	4.21
2 @6	4.59	
1.3 @ 6	2.92	3.35
1.3 @ 6	3.77	
T2 @ 6	16.08*	9.04*
T2 @ 6	1.99	
2 @ 30	18.57	21.52
2 @ 30	24.46	
1.3 @ 30	20.35	83.28*
1.3 @ 30	146.21*	
T2 @ 30	9.72	11.64
T2 @ 30	13.55	

Two toughness indices have provided very high values as marked with an asterisk.   The post crack toughness indices of the concrete samples show that concrete beam samples with a 30 kg/m³ fibre dosage have superior post crack toughness, even though they have an inferior flexural strength to samples with a 6 kg/m³. If the starred results are ignored it still be seen that DT fibres provide higher post crack toughness than Type 2 macro synthetic fibres. DT fibres with the larger 2.00mm diameter provided better results than DT fibres with a 1.3mm diameter. Plain concrete showed no residual strength with negligible post crack toughness indices.

5.0   CONCLUSION

The peak force for the impact tests did not indicate a definitive difference between fibre types and dosages. There was an increased mean peak force in all samples in comparison to plain concrete. However, observations of the behaviour of concrete samples during the impact tests showed that when concrete with a 30 kg/m³ fibre dosage were subject to impact they only had a hairline crack compared to the 6 kg/m³ that had much larger cracks or ruptured completely, however the T2 fibres performed as well as DT fibres.

The post crack toughness indices calculated from the flexural strength test results shows that the DT fibres do increase concrete toughness at both fibres dosages compared to plain concrete samples and perform better than T2 fibres. 2.00mm diameter DT fibres at a 30 kg/m³ fibre dosage displayed the best results for post crack toughness.

DT fibres showed higher energy absorption than T2 fibres at 6 kg/m³ with the 2.00mm diameter DT fibre being the superior. However, at a 30 kg/m³ fibre dosage T2 fibres were superior to DT fibres. This indicates that at a higher fibre dosage the DT fibres do not function effectively due to there not being enough fine cementitious material to fill the grooves of the DT fibres.

Using a fibre dosage of 30 kg/m³ has detrimental effects on the workability of the concrete with the concrete proving very difficult to fit in the moulds. Using a 30 kg/m³ fibre dosage for concrete in construction would not be viable unless it was used with a sand cement mix.

The addition of DT fibres allows for the load to be increased after the first crack for a short period of time before the concrete fails. This work shows that the addition of dovetailed fibres to the concrete mix does improve the impact resistance in comparison to plain concrete and also shows that by adding DT fibres to concrete, toughness also increases.

The concluding recommendation is that if you wish to increase the impact resistance, toughness and energy absorption of concrete using dovetailed fibres, a 2.00mm diameter DT fibres should be used with a fibre dosage between 6 kg/m³ and 30 kg/m³ in a mix with sufficient fine material to coat the fibres and fill the longitudinal flutes.

6.0 RECOMMENDED FURTHER WORK

Following this investigation, further work that is recommended is:

Carry out tests on concrete with DT fibres comparing them to steel fibres and other types of synthetic fibres; this will identify the performance of DT fibres against a wider variety of fibre reinforcement using at least 6 samples per variable tested.

7.0   REFERENCED WORK

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