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Shear and impact strength of waste plastic fibre reinforced concrete

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Abstract. This paper is aimed at determining the shear and impact strength of waste plastic fibre reinforced concrete. M30 grade of concrete is prepared with waste plastic door fibres cut into 5 mm width and aspect ratios of 30, 50, 70, 90 and 110. Fibres are used in a volume fraction of 0 to 1.5% with an increment of 0.25%. L shaped specimens are cast for shear strength tests and flat plates of size 250×250×30 mm are used for impact tests. “Drop ball method” is used for checking the impact strength. Shear strength is checked with L shaped specimens under UTM with a special attachment. It was found that up to 1.25% of waste plastic fibres can be effectively used for better strength of concrete both in shear and impact. Shear and impact strength were found to be increasing up to a volume fraction of fibres of 1.25%.

Keywords: concrete; waste plastic fibres; aspect ratio; volume fraction; plates; L shaped specimens; shear strength; impact strength; drop ball method

1. Introduction

Concrete is subjected to various types of loads during its life time. Though it can take very high compressive load, due to its low ductility and brittleness, it cannot resist high tensile, shear and impact loads. Fibres are added to improve the ductility of concrete. These discrete fibres dispersed randomly in the concrete resist the propagation of cracks and impart ductility to concrete. Steel fibres are most popular amongst the fibres which has proved to improve overall mechanical strength and durability. Researchers have conducted tests on strength and durability of several other types of fibres also. Polypropylene fibres are used often now a days in concrete to test their ability to resist strength and durability. In this study, an attempt is made to use waste plastic fibres in concrete to check their ability to resist shear and impact loads. Plastic is a non-biodegradable material which would release harmful gases if burnt. Hence, the disposal of plastic is a major concern all over the world. The plastic used here is obtained from waste plastic flush doors. It is cut into strips of 5 mm width. Five aspect ratios of 30, 50, 70, 90 and 110 are used for the

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investigation. M30 grade of concrete is prepared based on IS 10262-2009 code of practice. Plastic strips are mixed in the preparation of concrete in the volume fraction of 0.25 to 1.5% with an increment of 0.25%. L shaped specimens for shear and square plates for impact are cast and water cured for 28 days. L Shaped specimens are checked for shear strength under UTM with a special attachment. A steel ball of 1.374 Kg is used for impact test. The ball is dropped from a height of 1 meter at the center of the plate. Potential Energy required to cause the first crack and failure is calculated. The results are compared with the reference specimen to draw a conclusion.

2. Literature review

Energy absorption of fibre reinforced concrete is higher than that of conventional concrete. Even self-compacting concrete indicates a positive trend of energy absorption when fibres are introduced. (Senthil *et al.* 2016). Drop weight method to find the impact strength is a widely adopted method, where a ball of specific weight is dropped on the plates from a pre-determined height (Vijaya *et al.* 2016, Rehacek 2013). This method was suggested by the American concrete institute committee (ACI). Fibres have been extensively used by several researchers in concrete to improve its energy absorption and ductility. Most common types of fibres used are steel fibres (Perumal 2014), glass fibres (Kumar *et al.* 2014), hybrid fibres (Wai *et al.* 2014) or polypropylene and plastic fibres (Patel 2012). Shear tests were conducted on 'S' shaped push offs (Ghorpade *et al.* 2013) and L shaped specimens (Maroliya 2012). Shear strength on fibre reinforced beams, both deep (May and Chen 2016) and shallow (Bairagi and Modhera 2001) was also experimented. Tests were done on different grades of concrete, high performance concrete and concrete with admixtures which yielded positive results for fibre reinforced concrete.

Dropping height of ball was varied, hooked fibres were used in different percentages and a blow hammer of 9.5 kilogram was adopted on rectangular plates. The results showed that the energy absorbed was highest, both at first crack and failure when highest fibre volume (80 Kg/m^3 of concrete) was used (Rehacek *et al.* 2013).

The test results on impact resistance of high strength fibre reinforced concrete of M60 grade with 3 types of fibres viz coconut fibres, glass fibres and barchip fibres at 0.6% to 2.4% of binder volume in aggressive environment showed that the strength increased to a maximum of 63% when 2.4% of glass fibre was used (Wai 2014).

The effectiveness of ternary blends and hybrid fibres in improving the shear and impact resistance of fibre reinforced concrete was also studied. (Kumar and Prakash 2014).

In the absence of any standard methods, L shaped specimens were used (Bairagi and Modhera 2003), which gave results close to JSCE code values. The method was used to apply direct shear load (Maroliya 2012) in the experiments on behavior of reactive powder concrete in direct shear which was made use of in the present study with a slight modification. The method is simple and ensures reliable and consistent results. The specimens are designed to resist single shear as double shear does not happen in reality. Load was applied at the juncture through an M S Rod acting as a roller. Results were fairly accurate and reliable.

The polypropylene fibres were used to explore mechanical properties of fibre reinforced concrete. Major gain of strength of 47% was observed when L shaped specimens with 2% fibres were subjected to shear load. The specimens showed large number of fine cracks before failure. (Patel *et al*. 2012)

The aspect ratio of fibre does not affect the impact strength much; it is the volume fraction of fibres, shape of the fibres and the presence of admixtures that affect the performance of concrete. The behavior of reinforced concrete beams under impact loading using high mass-low velocity drop-weight system was also studied (May and Chen 2006). The impact force acting on the beams was measured using a load cell placed within the impactor. A high-speed data logging system was used to record the impact load, strains, accelerations, etc., so that time histories could be obtained. This research led to the development of computational techniques based on combined continuum/discontinuum methods (finite/discrete element methods) to permit the simulation of impact loaded reinforced concrete beams. The implementation has been within the software package ELFEN (2004).

Fibres benefit significantly in resisting shear which was proved experimentally and also analytically. (Barros *et al.* 2013).

Fibres contribute high strength at water-binder ratios of 0.25 to 0.40. Based on the test results, mathematical models were developed using statistical methods to predict 28-day flexural and splitting tensile strengths of HPFRC for a wide range of water cement ratios. On the basis of regression analysis of a large number of experimental results, the statistical models were developed. The proposed models were found to have good accuracy in estimating the tensile strength of high-performance fiber reinforced concrete, where 92% of the estimated values were within ±5% of the actual values compared (Ramadoss and Nagamani 2008).The resistance to the impact loading of the HPFRC and the HPFRC reinforced by the textile reinforcement was also compared (Vogel *et al.* 2016). by The samples (0.56 m×0.1 m×0.1 m) were experimentally tested in three-point bending, by using horizontal impact machine. It was observed that the samples of the HPFRC, reinforced by the glass fibre textile reinforcement, have greater resistance to impact loading

Experimental investigations were carried out to focus specifically to shear loading including failure mode, ultimate strength, first crack load and structural integrity when reactive powder concrete was used. A series of direct shear specimens having inverted “L” shape in shear failure plane were tested using optimized reactive powder concrete (RPC) The experimental results showed that RPC exhibits ductile failure mode, higher ultimate strength in addition to much improved structural integrity (Maroliya 2012).

3. Experimental programme

In this investigation, plates and L shaped specimens are cast and tested for shear and impact on M30 concrete with different percentage of fibres and aspect ratios.

3.1 Materials used and their properties

3.1.1 Cement

Ordinary Portland cement of 53 grade of specific gravity 3.15 was used. Specific gravity, fineness, standard consistency, setting time and soundness tests were conducted as per IS 4031-1988.

3.1.2 Coarse aggregate

Coarse aggregate obtained from local quarries, below 12.5 mm size was used. It had a specific gravity of 2.53 and water absorption of 0.15%.

Fig. 1 Waste plastic fibres

3.1.3 Fine aggregate

River sand obtained from nearby district Mandya is used for the present work which confirmed to zone II as per IS-383-1970. It had a specific gravity of 2.54, water absorption of 0.6% and fineness modulus of 2.90

3.1.4 Water

Ordinary potable water supplied in the pipe for general purposes is used in the current investigation.

3.1.5 Super plasticizers

Master GleniumSKY8233, a produce of BASF chemicals was used to reduce the water cement ratio by 20%. Its specific gravity was 1.08, pH value >6 and optimum dosage was 0.7% by weight of cement as obtained by trials.

3.1.6 Plastic fibres

Waste flush door plastic was used in the current investigation to prepare plastic fibres. Fibres have a thickness of 0.7 mm and cut into a width of 5 mm. The density of plastic was 1.152 g/cm^3. Length of the fibres were 21 mm, 35 mm, 49 mm, 63 mm and 77 mm for aspect ratio of 30, 50, 70, 90 and 110 respectively. Plastic rolls are manufactured in Coimbatore city in South India. As per the dealer's specifications, 10 to 15% percent of the produce gets damaged while transportation, cutting and fixing. The thickness of the plastic sheet varies between 0.66 mm to 0.73 mm, and average thickness was taken as 0.7 mm. Its density was obtained by pychnometer method.

3.2 Mix design

Mix design was carried out as per IS 10262-2009 for M30 grade of concrete. The mix proportion arrived at was as follows (For m^3 of concrete):

Cement	391.97 Kg
Fine Aggregate	936.42 Kg
Coarse Aggregate	827.14 Kg
Water	176.4 litres
Super Plasticizer	2.75 Kg

Fig. 2 L Shaped shear specimens

Fig. 3 Plates for impact testing

Trial mixes were carried out for 100 mm slump and strength after 28 days was checked and found to be suitable for M30 mix.

3.3 Preparation of specimens

To cast the L shaped concrete specimen, a wooden block of size 150×75×75 mm was made use of which was placed in 150 mm mould during casting. The waste plastic fibers were obtained by cutting used flush door. The fibers were added to the concrete mix of M30 grade in different percentages ranging from 0.25% to 1.5% with aspect ratio of 30, 50, 70, 90 and 110. Plates were cast using special square moulds of 250 mm side and 30 mm thick (Fig. 2). Concrete was mixed in power mixer and compacted on table vibrator. A total of 93 cubes and 93 plates were cast as the specimens for testing. Specimens were air cured for 24 hours and water cured for 28 days.

3.4 Testing of specimens

L cubes were tested for shear load under UTM with the help of a special attachment (Fig. 2) which would keep the specimen in position for shear load. Load is applied at the juncture of L shaped specimens through a mild steel rod placed at the junction. The type of load applied was single shear. Load required to fracture the specimen by shear at the juncture was noted. The shear strength was calculated by the formula

$$\text{Shear Strength} = \frac{\text{Load}}{\text{Shear area}} \ \text{N/mm}^2$$

Drop weight method was used to check the impact strength of plates. A 1.374 kg steel ball was

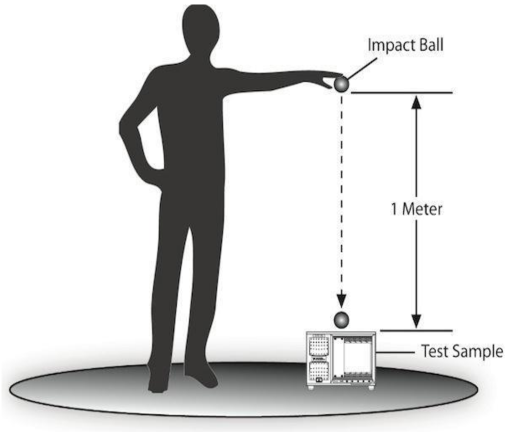

Fig. 4 Impact test

Fig. 5 Shear loading

Fig. 6 Sheared specimen

Table 1 Shear strength (MPa) variation with % of fibre

	Percentage of fibre						
AR	0	0.25	0.5	0.75	1	1.25	1.5
AR30	4.2	4.37	4.57	5.41	6.23	6.17	5.98
AR50	4.2	4.49	5.48	6.47	7.07	7.33	6.97
AR70	4.2	4.48	4.64	5.8	6.58	7.05	6.88
AR90	4.2	4.32	4.72	5.72	5.91	6.26	6.16
AR110	4.2	4.26	4.62	5.52	6.12	6.15	5.59

dropped (free fall) from a height of 1 meter exactly on the center of the plate. The number of blows required to cause the first crack and complete failure was noted down. The impact energy is calculated by the formula

$E = N \times m \times g \times h$

Where, E=Impact energy

N=Number of blows

m=Mass of the ball

g=Acceleration due to gravity

h=Height of drop

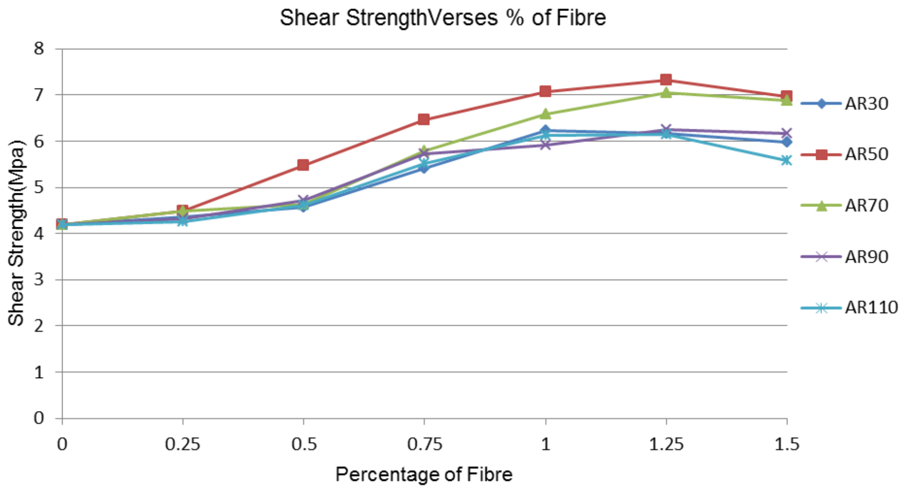

Fig. 7 Shear strength variation with percentage of fibre

Table 2 Impact strength variation with percentage of fibre for first crack

% of Fibre	1st crack AR30	1st crack AR50	1st crack AR70	1st crack AR90	1st crack AR110
0	26.96	26.96	26.96	26.96	26.96
0.25	31.45	31.45	35.95	35.95	35.95
0.5	40.44	44.93	53.92	44.93	44.93
0.75	49.42	53.92	58.41	58.41	58.41
1	53.92	58.41	76.38	76.38	67.39
1.25	71.89	80.87	80.87	76.38	71.89
1.5	71.89	76.38	76.38	76.38	71.89

Table 3 Impact strength variation with percentage of fibre for failure

% of Fibre	Failure AR30	Failure AR50	Failure AR70	Failure AR90	Failure AR110
0	40.44	40.44	40.44	40.44	40.44
0.25	58.41	62.9	49.42	49.42	49.42
0.5	80.87	85.37	94.35	94.35	89.86
0.75	98.85	103.34	94.35	94.35	98.85
1	112.32	116.83	125.8	125.8	121.31
1.25	134.79	134.79	148.27	148.27	134.79
1.5	125.8	130.3	143.78	134.79	130.3

4. Results

The shear strength test results are given in the Table 1.
The impact strength results are given in Tables 2 and 3 for first crack and failure.

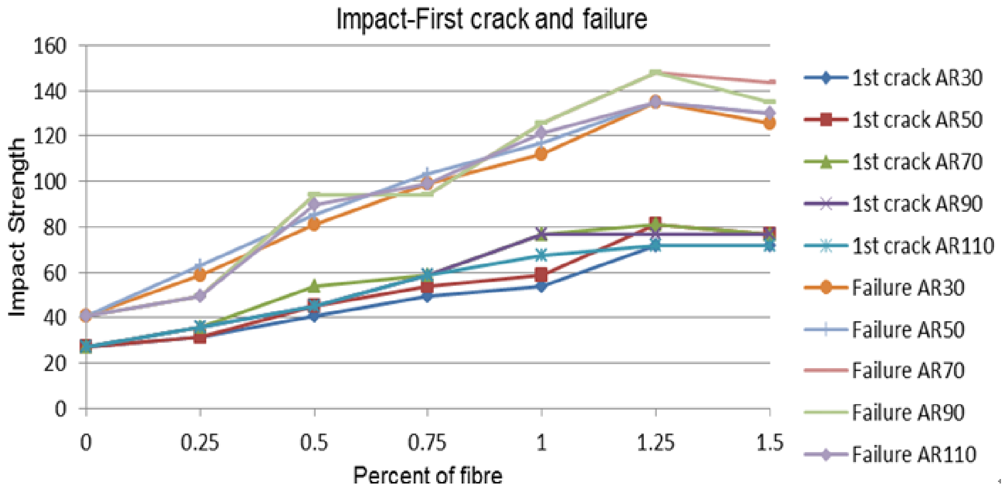

Fig. 8 Impact strength variations with percentage of fibre at first crack and failure

5. Discussions on results

Based on the experimental investigations, following observations were made:

Plastic fibres can be effectively used in concrete to resist shear and impact loads. Though the workability reduces, the strength increases with increase in percentage of fibers. Among all the aspect ratios used, viz 30, 50, 70, 90 and 110, 50 is found to be more suitable for resisting shear loads. Shear resisting capacity was maximum at 1.25% fibers for both aspect ratios. Percentage increase in shear strength was 74.5 for AR 50 at 1.25% percentage of fibre. Multiple cracks appeared at this stage and brittle shear failure was not observed. Having long fibres helped neither in shear nor in impact as have been observed by the results. Aspect ratio 50 is sufficient to bind the cracks. Beyond 1.25%, there was marginal decrease in shear strength. Though it was not a clear failure, there was separation of the plate parts just held in position by fibres, not allowing it to part due to the presence of fibres and considered as failure.

There appears to be a strong correlation between shear and impact strength of waste plastic fibre reinforced concrete. They both exhibit the maximum strength at 1.25% of fibre. Crack resisting capacity increases several folds. The energy absorbed at first crack was 26.96 joules in normal conventional concrete which increased up to 80.87 joules for first crack and 148.27 for complete failure for aspect ratio 70 at 1.25% of fibre. Increase in impact strength was approximately three times for first crack and 3.67 times at failure respectively at 1.25% fibres for aspect ratios of 70. After 1.25%, there is gradual decrease in impact strength and remained almost constant for 1.5% of fibres. Aspect ratio 50 and 70 showed similar trend and values of strengths. But, unlike shear strength, aspect ratio did not affect the impact strength much. It was the percentage of fibre which decided the final energy absorption ability of waste plastic fibre reinforced concrete. The results are comparable with other research results with slight differences in percentage of fibre for optimum strength. The variation could be attributed to the quality of waste plastic fibre, tensile strength of fibre and adhesive ability of fibre with concrete.

6. Conclusions

The following conclusions could be drawn from the present investigation.

1. The optimum percentage of waste plastic fibres that can be adopted in concrete for best resistance against shear and impact is 1.25.

2. The maximum increase in shear was found to be 74.5% for 1.25% of waste plastic fibres with aspect ratio 50. Multiple cracks developed and strain hardening of the material lead to less load carrying at 1.5% of fibre.

3. The maximum impact strength was found to be increased by three times and 3.67 times for first crack and failure at 1.25% of waste plastic fibres in concrete of aspect ratio 70. The percentage of waste plastic fibre was the deciding factor in absorption of energy at failure rather than aspect ratio.

4. The shear and impact strength for aspect ratios 50 and 70 were similar and comparable.

5. The energy absorption ability of waste plastic fibre reinforced concrete between first crack and failure was increasing exponentially in impact.

The main objective of this study was to find alternate ways to dispose plastic waste. Steel fibers are used extensively in several structures and its useful ness in strength and durability is already proved. Plastics are a cheaper alternative. The experiments have shown that it also serves the purpose well by imparting ductility to concrete. The plastic fibers can very well be used in concrete for impact resisting structures like roads and flooring.

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