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Experimental Investigation of Properties of Polypropylene Fibrous Concrete

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Abstract*— Concrete is acknowledged to be a relatively brittle material when subjected to normal stresses and impact loads, whose tensile strength is only approximately one tenth of its compressive strength. As a result for these characteristics, concrete member could not support such loads and stresses that usually take place in majority of concrete structures. The introduction of fibres was brought in as a solution to develop concrete with enhanced flexural and tensile strength. Fibres are generally discontinuous, randomly distributed throughout the cementituous matrices. Fibre reinforced concrete has considerably enhanced toughness and strain at the peak stress due to bonding forces at the fibre-matrix interface. Almost all the commercially available fibre reinforced concretes are normally manufactured using a particular type of fibre. As the single fibre can only be effective in a limited range of crack opening and deflections. The benefits of combining organic (polypropylene and nylon) with inorganic fibres (steel, glass and carbon) to achieve superior tensile strength and fracture toughness were recognized about 30 year back. Thereafter much research was not undertaken, recently again there is renewed interest in this field. The aim of the present study is to investigate the effect of variation of polypropylene fibres ranging from 0.1% to 0.4% along with 0.8% steel fibres on the stress strain behaviour of fibrous concrete. The result shows that addition of polypropylene fibre has effect on the failure strain, with increase in polypropylene fibre volume fraction. The present investigation shows higher percentage of polypropylene fibre possesses higher toughness.

Index Terms—**Compressive Strength, Flexural Strength, Fibrous Concrete, Polypropylene, Steel Fibers, Stress Strain, Tensile Strength.**

I. INTRODUCTION

The term fibre based concrete (FBC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibres that are uniformly distributed and randomly oriented. When fibre is added to a concrete mix, each and every individual fibre receives a coating of cement paste. Modification of synthetic fibre geometry includes monofilaments, fibrillated fibres, fibre mesh, wave cut fibre large end fibres etc. This increases bonding with cement matrices without increasing in its length and minimized chemical interaction between fibres and the cement matrices. Fibres modify and enhance the mechanical properties and behaviour of concrete during its application. Fibre can be used with admixture such as super plasticizer, air entraining, retarding, accelerating etc and all type of cement and concrete mixtures. Fibres provide an effective secondary reinforcement for shrinkage and crack width control. Macro-cracks and potential problems are prevented and blocked when micro-cracks intersect fibres as concrete hardens and shrink. Crack width can be controlled by employing fibres in concrete. The main advantage of the polypropylene fibres is alkali resistance and high melting point (upto165^{0}C) and low cost. Advantages of steel fibre are it increases the ductility, toughness and impact resistance of the concrete. In general, fibres reduce the total crack area, maximum crack width and the number of cracks. As fibre volume fraction increases, effectiveness of fibre reinforcement increases. In present study polypropylene and steel fibres have been used. Polypropylene fibre offers good bonding power; enhance mechanical properties, long term durability and acts as true secondary temperature control device. These are non corrosive, chemically inert, and 100% alkali proof. These are low modulus, light density and small monofilament diameter. On the other hand, steel fibre improves structural strength, reduce steel reinforcement requirement, reduce crack width, and improve crack and abrasion resistance. Therefore, proper mixture of these two complementary fibres can make better mechanical properties of concrete. The use of a polypropylene fibre and steel fibre at relatively low volume fractions provides concrete with improved performance characteristics at reasonable cost. In present study the structural behaviour of the fibre based concrete using hybrid fibres has been conducted.

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II. LITERATURE REVIEW

About 3500 years ago, straws were used to reinforce sun-baked bricks for a 57m high hill of 'Aqar Quf, which is located near Baghdad. It is until the 1900's that asbestos fibres were developed, manufactured and widely used to augment mechanical properties of cement matrix as described by Bentur and Mindess (1990).

Balaguru and Shah (1992) reported that the modern developments of using straight steel fibres began in the early 1960's.

Chanh (2001) reported the result of experimental investigation on effects of steel fibre on mechanical properties of concrete. Steel fibres were generally found to have much greater effect on the flexural strength than on either the compressive or tensile strength, increases of more than 100% flexural strength has been reported. The increase in flexural strength was particularly sensitive, not only to the fibre volume, but also to the aspect ratio of the fibres, with

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higher aspect ratio leading to higher strength increases.

Yeol Choia et al. (2005) reported the result of experimental investigation into the relationship between the splitting tensile and compressive strength of glass fibre reinforced concrete (GFRC) and polypropylene fibre reinforced concrete (PFRC). The splitting tensile strength and compressive strength of GFRC and PFRC has been obtained at 7, 28 and 90 days. The splitting tensile strength of PFRC and GFRC approximately ranged from 9% to 13% of its compressive strength. The addition of glass and polypropylene fibres in concrete increases the splitting tensile strength by approximately 20-50%.

Hsiea et al. (2008) reported the result of experimental investigation on Hybrid fibre-reinforced concrete with different kinds of fibres. The conclusions were drawn that the performance of Polypropylene hybrid fibre-reinforced was better than that of single fibre-reinforced concrete. When comparing with the normal concrete, the compressive, tensile & modulus of rupture of polypropylene hybrid fibre-reinforced concrete increased by 14.60-17.31 %, 8.88-13.35%; and 8.99-24.60% respectively. The result shows that there was increase of splitting tensile strength on addition of polypropylene fibre in concrete. This was due to numerous staple fibres bridging the micro cracks and preventing the expansion. When the tensile stress kept on increasing in the specimens, the stress was transferred to the monofilament fibres, which were coarser and stronger, so it can arrest the propagating of macro cracks and substantially improve the split tensile strength.

With the advent of growth in technology and industrialisation, the use of fibre based concrete has increased and is gaining faith. Fibre based concrete is also being used in the construction of various civil engineering structures i.e., structural and non structural forms.

III. EXPERIMENTAL PROGRAMME

To achieve the objectives of research programme, an experimental investigation has been carried out on FBC. The cubes, cylinders & beams have been cast with varying percentages of fibre volume fraction.

A. Material

- Cement: The cement is the main part of the concrete which imparts the strength to concrete. OPC-43 Grade cement was used in this study. All the tests on cement were carried out as per recommendations of IS: 12269-1989.
- Aggregate: One of the major contributing factors to the quality of concrete is the quality of the aggregates. In this study only the vital parameters of aggregates have been studied as per the procedures laid down in IS: 2386 (Part 1-8) for testing of aggregates for concrete.

S.No	Characteristics	Requirement as per IS 383 : 1970	Tested values
PHYSICAL PROPERTIES OF FINE AGGREGATE			
1.	Specific Gravity	2.6-2.7	2.64
2.	Fineness Modulus	2-3.5	3.022
3.	Water Absorption (%)	-	1.78
4.	Moisture Content (%)	-	0.50
5.	Grading	-	Zone II
PHYSICAL PROPERTIES OF COARSE AGGREGATE			
1.	Specific Gravity	2.6-2.7	2.68
2.	Fineness Modulus	5.5-8	6.55
3.	Water Absorption (%)	-	0.50
4.	Moisture Content (%)	-	Nil
5.	Texture	-	Rough

Table 1: Physical Properties of Aggregate

Polypropylene fibre: Polypropylene fibres which was provided by the FORTA Corporation. Polypropylene were used in present study, have good ductility, fineness and dispersion so they can restrain the plastic cracks. Polypropylene fibre which is twisted bundle multifilament Fibre having specific gravity 0.90, length 54mm and aspect ratio 158.8.

- Steel fibre: Steel fibres were used in present study which was provided by the APEX Corporation. It improves structural strength, reduce steel reinforcement requirement, reduce crack width and improve crack and abrasion resistance. Steel fibre which is Crimped shape steel fibre having, length 31mm and aspect ratio 60.78.
- Fibre Dosage: Based on data available/collected from previous studies, minimum dosage of 0.1% by volume of polypropylene fibres was used. Polypropylene fibre offered impressive results, even at considerably lower dosages by volume. (Fibre volume fractions % : 0,0.1,0.2,0.3,0.4)

Mix	Water (kg/m^3)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)
M30	191.58	425.733	574.51	1202.55
	0.45	1	1.34	2.82

Table 2: Final M30 Mix Design Details

B. Testing details

The test carried out on fibre based concrete are summarized as below

- Compression Strength
- Split Tensile Strength
- Flexural Tensile Strength

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COMPRESSION STRENGTH TEST

The compression strength of the concrete is very important parameter as it decides the other parameters like tension and flexure. So it is very necessary to carry out the test carefully on the specified testing machine. Compressive strength test were carried out on 150 mm x 150 mm x150 mm cubes with compression testing machine of 2000kN capacity. The specimen, after removal from curing tank was cleaned and dried. The surface of the testing machine was cleaned. The specimen was placed at the centre of the compression testing machine and load was applied continuously, uniformly and without shocks and the rate of loading was 14 N/mm^2 (140Kg/cm^2)/ minute i.e. at constant rate of stress. The load was increased until the specimen failed. The maximum load taken by each specimen during the test was recorded. The compressive strength was found after 7 and 28 days in order to compare the strengths for different percentage of fibres in concrete. From the results it is observed that the addition of the polypropylene fibre in the control mix has a little effect on the compressive strength. It is noted that the use of fibres increases the compressive strength of concrete when the polypropylene fibres were upto 0.2% and then reduction in compressive strength is observed.

SPLITTING TENSILE STRENGTH TEST

The splitting test is easy to perform and gives more uniform results compared to the other tension test. In this test (IS 5816-1999), a specimen was loaded in a compression on its side along a diameter plane. Failure occurs by the splitting of the cylinder along the load plane. In an elastic homogeneous cylinder this loading produces a nearly uniform tensile strength across the loaded plane. For studying the split tensile behaviour, cylinders of fibrous concrete were tested on universal testing machine in pg structures lab of PEC University of Technology. The failure load was observed and the strength was calculated. From the results it is observed that with the increase in the polypropylene fibres upto 0.3% the split tensile strength increases.

FLEXURAL STRENGTH TEST

Concrete members are not generally subjected to direct tension. However, in flexural members, though tension is taken by reinforcement, yet knowledge of tensile strength of concrete is essential to determine first crack load. Of all types of cracks, flexural cracks are largest in width. Cracks not only create discontinuity but also allow environmental agents to penetrate into the core of the structure leading to corrosion of the reinforcement etc, Flexural tensile strength or modulus of rupture of concrete has been determined by applying the failure load on prismatic specimen of size 100 mm x 100mm x 500 mm, using the beam testing machine of 5 tons capacity. The flexural strength of the specimen can be expressed as the modulus of rupture f_t. Modulus of rupture is calculated from following expression

$$f_t = \frac{pl}{bd^2}$$

When 'a' is greater than 133 mm for a 100 mm specimen, or

$$f_t = \frac{3pa}{bd^2}$$

If when 'a' is less than 133 mm but greater than 110 mm for a 100 mm specimen.

Where

b = measured width in cm of the specimen,

d = measured depth in cm of the specimen at the point of failure,

l = length in cm of the span on which the specimen was supported,

p = maximum load in Kg applied to the specimen

If 'a' is less than 110 mm for a 100 mm specimen, the results of the test shall be discarded.

From the results it is observed that with the increase in polypropylene fibre, the flexural strength increases. However, it is noticed that the rate of increase of flexural strength is more as compared to compressive strength. The results show that optimum dosage for flexure is 0.3% of polypropylene fibre along with 0.8% of steel fibre.

IV. STRESS STRAIN RELATIONSHIP

In present study the stress-strain response for fibre based concrete has been plotted as below:

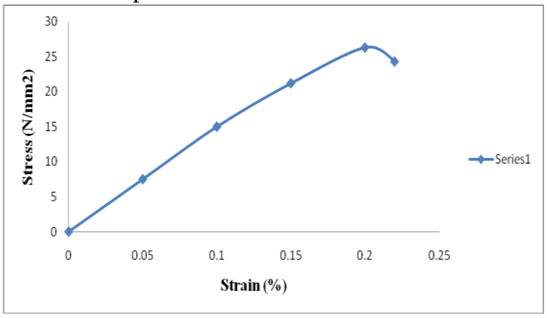

Fig 1: Stress-strain response for concrete with 0% polypropylene fibre

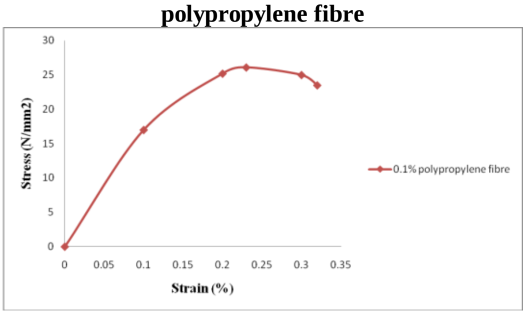

Fig 2: Stress-strain response for concrete with 0.1% polypropylene fibre

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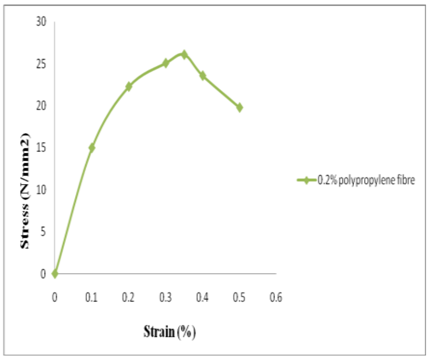

Fig 3: Stress-strain response for concrete with 0.2% polypropylene fibre

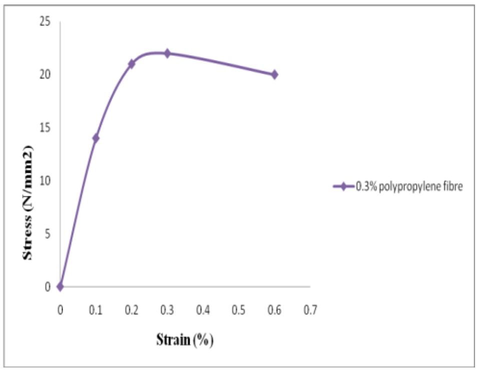

Fig 4: Stress-strain response for concrete with 0.3% polypropylene fibre

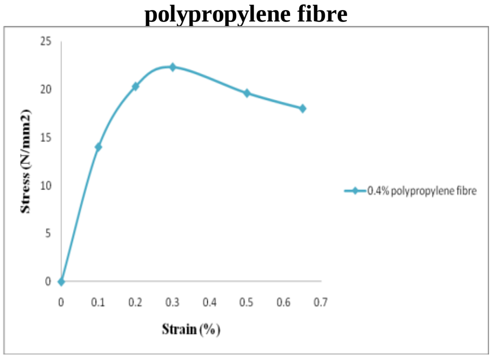

Fig 5: Stress-strain response for concrete with 0.4% polypropylene fibre

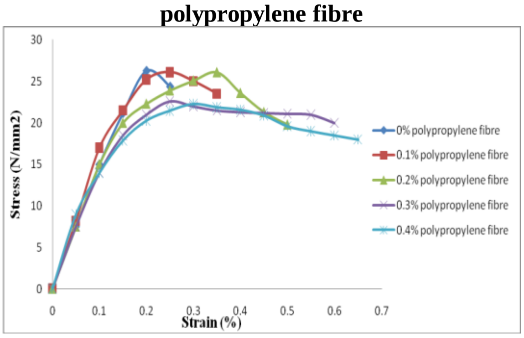

Fig 6: Stress strain response of FBC at different volume fraction of polypropylene fibre

Above graph shows there is significant change in strain of the concrete due to addition of fibres. Descending portion of the curve becomes more and more flatten as the fibre volume fraction increases. The relationship with different volume fraction of polypropylene fibre is shown in Fig. 1.1 to 1.5. Two different behaviour patterns are obtained as shown in stress strain curve. The stress-strain behaviour of the specimens containing polypropylene fibre upto 0.1% behaves in a similar trend to the control specimen. For these cases which contains 0% and 0.1% polypropylene fibre behaves like a brittle material for which the total energy is generated is elastic energy. However, non linear behaviour is seen for the other specimens which contain more than 0.1% of polypropylene fibre. Here, once the peak stress is reached the specimens continues to yield as shown in figure 1.6. Therefore it can be stated that concrete with higher percentage of polypropylene fibre possess higher toughness, since the generated energy is mainly plastic. Also it was found that as fibre volume increase failure strain also increases, which leads to more area under the curve, thus enhancing the toughness of the concrete.

V. CONCLUSION

Based on experimental investigation and analysis of results obtained, the following conclusions may be drawn broadly:

1) Steel-polypropylene mix shows a slight increase in the compressive strength as compared with the plain concrete.
2) The maximum gain in compressive strength was achieved for 0.2% polypropylene fibre. Thereafter increase in fibre content has marginally reduced the compressive strength.
3) Hybrid FRC (steel + polypropylene) shows an increase in split tensile strength as compared to the plain concrete.
4) The maximum gain in split tensile strength was achieved for 0.3% polypropylene fibre. Thereafter increase in fibre content has marginally reduced the split tensile strength.
5) The maximum gain in flexural strength was achieved for 0.3% polypropylene fibre. Thereafter increase in fibre content has marginally reduced the flexural strength.
6) From the present study it is observed that the optimum dosage of polypropylene fibre fraction is 0.3%.
7) Stress-Strain relationship showed that there was marginal increase in strain. Stress-Strain relationship shows that strain increases as the percentage of polypropylene fibre increases. As fibre volume increases failure strain also increases, which leads to more area under the curve, thus enhancing the toughness of concrete.

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AUTHOR’S PROFILE

Dr. S K Verma is currently Associate Professor in Civil Engineering at PEC University of Technology, Chandigarh. He is having experience of more than 30 yrs in teaching, research and structural designing and construction supervision and other areas of Civil Engg. He has handled structural consultancy jobs of various agencies of different states and central Government. He has teaching experience of more than 25 years at PEC University of Technology, Chandigarh at both undergraduate and postgraduate level. Earlier he has worked with Bharat Petroleum Corporation Ltd (BPCL) and International Airports Authority of India (IAAI). He has done his BE (Civil Engg) with Honours and ME (Structural Engg) from PEC Chandigarh and completed his doctorate from IIT Roorkee He has published many research papers in national and international journals and conferences. He has guided more than 40candidates for M Tech thesis and 4 candidates are working for their PhD. He is fellow member of Institution of Engineers (FIE) life member of ISWE, ISCMS and ISTE. He is a member of several professional bodies.

Monika Dhakla is currently pursuing Ph.d in Civil Engineering at PEC University of Technology, Chandigarh. She is having experience of more than 3 yrs in research and structural designing. She has worked with Larsen and Toubro Construction (EDRC) earlier. She has done her BE (Civil Engg) with Honours from Kurukshetra University and ME (Structural Engg) from PEC Chandigarh.

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