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Strengthening of Concrete by Fibre Reinforcement

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ABSTRACT

With the advancement in civilization concrete has become one of main construction material. The concrete is observed to be quite strong in compression, however, its strength in tension is quite less. Concrete is a quasi-brittle material with low strain capacity. Reinforcement of concrete when provided with randomly dispersed fibers can tackle some of limitations of concrete especially related to concrete brittleness and poor resistance of crack growth Therefore constant efforts have been made by researchers, engineers and construction technologists to improve its tensile strength. In ancient time, many natural fibers (animal hairs and straw as reinforcement) have been used in concrete to improve its tensile strength. Fibres are normally used in concrete to improve its tensile strength, resistance to cracking and improve its ductility. Glass fibers were also earlier used to manufacture fibrous concrete. Fibre based concrete may be defined as a composite material made from concrete ingredient incorporating discrete, randomly dispersed fibers. Previous studies show that fibers generally increase the mechanical properties of concrete. In order to improve the mechanical bonding of fiber different shapes and configurations are used. Some of the modern fiber commonly used may have deformed shape and configuration. Polypropylene fibers were first used in 1960 by Solomon Goldfein to manufacture fibrous concrete. These fibers are used because of many advantageous properties like, it avoids the creation of micro-cracking in concrete and provide excellent crack reduction in early age concrete. Fibres decrease the water migration and also reduce segregation of mix. Almost all the commercially fiber reinforced concrete are normally manufactured using a single fiber. As the single fiber can only be effective in a limited range of crack opening and deflections. The benefits of combining organic (polypropylene and nylon) with inorganic fibers (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 fibers ranging from 0.1% to 0.4% along with 0.8% steel fibers on the behavior of fibrous concrete. The mechanical properties of the concrete such as compressive and tensile strength have been investigated.

INTRODUCTION

Concrete is known to be a brittle material when subjected to tensile stresses and impact loads, tensile strength of the concrete is approximately one tenth of its compressive strength. As a result of this, concrete members are unable to withstand such loads and stress that are usually encountered by concrete structural members. Usually, concrete members are reinforced with continuous reinforcing bars to withstand tensile stresses and to compensate for the lack of ductility and strength. The addition of steel reinforcement to concrete significantly increases its strength, but to produce a concrete with homogenous tensile properties and better micro cracking behavior, fibers are advantageous. The introduction of fibers in concrete has brought a solution to develop a concrete having enhanced flexural and tensile strength, which are a new form of composite material. At the micro-level, fibers inhibit the initiation and growth of cracks, and afterthe micro-cracks coalesce into macro-cracks, fibers provide mechanisms that abate their unstable propagation, provide effective bridging, and impart sources of strength gain, toughness and ductility.

Fibres are mostly discontinuous, randomly distributed throughout the cement matrices.

The randomly distributed short fibers are generally introduced into concrete to enhance its control crack system and mechanical properties such as toughness, impact resistance, ductility (post cracking), tensile strength etc. of basic matrix.

There are many kinds of fibers, such as metallic, synthetic, natural etc. which are being used in normal concrete . The term fiber based concrete (FBC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Different type of fibers in concrete changes the character of fiber based concrete. Further properties of fiber based concrete changes with varying concrete, fiber materials geometries, distribution, orientation and densities. When fiber is added to a concrete mix, each and every individual fiber receives a coating of cement paste. Modification of synthetic fiber geometry includes monofilaments, fibrillated fibers, fiber mesh, wave cut fiber large end fibers etc. This increases bonding with cement matrices without increasing in its length and minimized chemical interaction between fibers and the cement matrices.

LITERATURE REVIEW

The concept of using fibres in a brittle matrix was first recorded with the ancient Egyptians who used the hair of animals and straw as reinforcement for mud bricks and walls in housing.This dates back to 1500 B.C. (Balaguru et al, 1992).

Ronald F. Zollo (1997) presented an overview regarding the history and development of Fibre Reinforced Concrete 56 years ago. According to this report, in the early 1960s, the works on fibre reinforced concrete had been started. A lot of research work has been conducted by many researchers on different fashions. But these projects have studied about steel fibres alone. So far, there were only a few works which have studied the other fibres like nylon, plastic, rubber and natural fibres. But those researches are completely different from the current study, since they have concentrated along the material strength properties not on their strucutral behaviour.

According to the terminology adopted by American Concrete Institute (ACI) Committee 544, there are four catagories of Fibre Reinforced Concrete namely 1) SFRC (Steel Fibre Reinforced Concrete), 2) GFRC (Glass Fibre Reinforced concrete), 3) SNFRC (Synthetic Fibre Reinforced Concrete) and 4) NFRC (Natural Fibre Reinforced Concrete). It also provides the information about various mechanical properties and design applications. Cement and Concrete Institute also published the clasification of FRC in their website. Based on their classification, Fibres are classified into Glass, Steel, Sythetic (includes Acrylic, Aramid, Carbon, Nylon, Polyster, Polyethylene, Polypropylene) and Natural Fibres.

Mechanical Properties

Kukreja et al (1980) conducted some experiments and reported that, based on the results of three methods such as split tensile test, direct tensile test and flexural test, split tensile strength test was recommended for fibrous concrete. Also increase in tensile strength and post cracking strength, toughness were reported.

Researchers like Goash et al (1989) studied tensile strength of SFRC and reported as inclusion of suitable short steel fibres increases the tensile strength of concrete even in low volume fractions. Optimum aspect ratio was found as 80 and the maximum increase in tensile strength was obtained as 33.14% at a fibre content of 0.7% by volume. Also it was reported that cylinder split tensile strength gave more uniform and consistent results than the modulus of rupture test and direct tension test.

Sabapathi and Achyutha (1989) stress - strain characteristics of steel fibre reinforced concrete under compression. Cube compressive strength and Initial Tangent Modulus of Elasticity were obtained and equation for stress-strain relation was also proposed.

Distribution and orientation of fibres in FRC significantly affects the properties of FRC. Based on this concept, Paviz Soroushian and Cha-Don Lee (1990) have carried out some investigation, by counting the number of fibres per unit cross sectional area of SFRC specimen incorporationg various volume fractions of different fibres. Theoretical expressions were derived for the number of fibres per cross sectional area in fibre reinforced concrete as a function of volume fraction and length, assuming the cross sectional boundaries as the only factors distributing the 3-D random oriention of fibres. They made comparisions between number of fibres per cross sectional area and the reorientation fibres in concrete due to vibration.

To ascertain the tensile strength of fibre reinforced concrete, a simple test set up was introduced to replace the costly direct tensile strength test apparatus by Youjiang Wang et al (1990). Methodology and testing procedure were also given. But it requires a servo controlled testing machine.

Ganesan and Ramana Murthy (1990) ascertained the stress - strain behaviour of short, confined, reinforced concrete column with and without steel fibres. The volume fraction of 1.5% with aspect ratio of 70 of steel fibres was used. The variable of the study was percentage reinforcement of lateral reinforcement. The strain at peak loads was increased to certain extent.

Ziad Bayasi and Paviz Soroushian (1992) reported that the rhelogical properties of SFRC are significant. The large surface area and interlocking property of fibres lead to the formation of balls among theconcrete during mixing which can create damage to the hardened material properties. An experimental investigation was conducted by them to study the fresh concrete properties of concrete with different types of steel fibres. It was concluded that the fresh concrete workability preoperties of FRC were significantly affected by fibre reinforcing index. At a specific fibre reinforcing index, crimpled fibres seem to give slightly higher value than plain fibres.

Balaguru and Shah (1992) have reported that the fibres that are long and at higher volume fractions were found to ball up during the mixing process. The process called 'balling' occurs and causes the concrete to become stiff and a reduction in workability with increase volume dosage of fibres. This has a tendency to influence the quality of concrete and strength. Mechanical properties of high strength fibre reinforced concrete were also studied by Faisal F Wafa and Samir A. Ashour (1992). They tested 504 test specimens for different mechanical properties such as compressive strength, split tensile strength, flexural toughness and modulus of rupture.

The mix was designed to achieve compressive strength of 94 N/mm^2. Three volume fractions of steel fibres such as 0.5%, 1.0% and 1.5% were selected. It was concluded that no real workability problem was encountered upto the addition of 1.5% volume fraction of fibres in concrete. Steel fibres enhanced the ductility and post cracking load carrying capacity of high strength concrete. Some emprical relations were proposed in terms of volume fraction of fibres and compressive strength of conventional concrete.Similar to the studies on steel fibre reinforced concrete, some researches have also been carried out by the researchers on synthetic fibre reinforced concrete. Ziad Bayasi and Jack Zeng (1993) conducted some experiments on workability and mechanical strength properties. Fibrillated polypropylene fibres of length inch and % inch at three volume fractions,0.1, 0.3 and 0.5% were used in concrete and workability properties such as slump, inverted slum cone, air content and mechanical strength properties such as compressive, impact and flexural behaviour were studied.

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

Generally, when used in structural application, steel or synthetic fiber in concrete should only be used in supplementary role to inhibit cracking, to improve resistance to impact or dynamic loading and to resist material disintegration. In the beginning, it was used for pavement construction and industrial slabs. But recently, it is being used in wide range of structures such as airplane runways, industrial slab, water tanks, canals, dam structures bridges etc. The use of fiber reinforced concrete (FRC) has increased in structures because the fibers in concrete improves the toughness, flexural strength, impact strength as well as the failure mode of the concrete. Moreover, fiber reinforced concrete has considerably increased toughness and strain at the peak stress due to bonding forces at the fiber-matrix interface.

FINDINGS

The results obtained from the experiments conducted on fibrous concrete and also compared with conventional plain concrete. The comparisons of mechanical properties and behavior include the compressive strength, flexural strength.

Size of cubes 150mm X 150mm X 150mm

Concrete mix used M30 grade

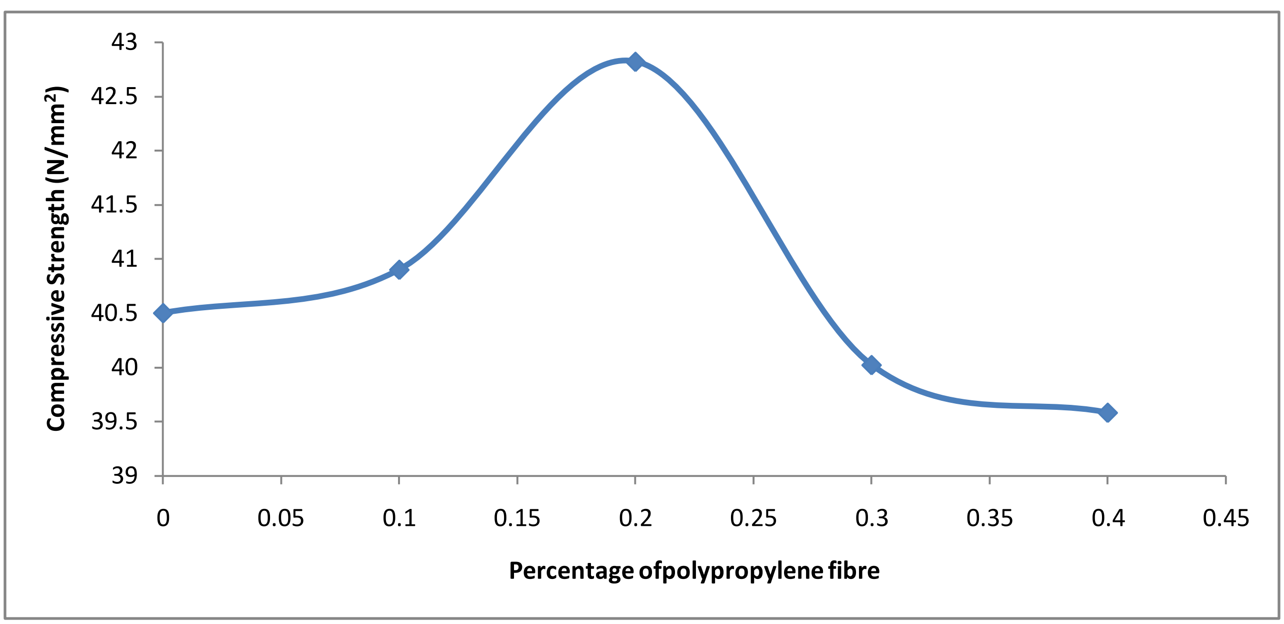
Percentage of steel fibers 0.8% (with aspect ratio 60.78)

Table 1.1: Test results for compressive strength at 28 days

S. No.	Percentage of polypropylene fiber along with 0.8% steel Fiber	Load at failure (KN)	Compressive strength(N/mm^2)
1	0%	896.40	39.84
2	0%+0.8%	911.25	40.50
3	0.1%+0.8%	920.25	40.90
4	0.2%+0.8%	963.45	42.82
5	0.3%+0.8%	900.45	40.02
6	0.4%+0.8%	890.55	39.58

It is observed that the use of fibers increases the compressive strength of concrete when the polypropylene fibers were upto 0.2% and then reduction in compressive strength is observed. An increase in 7.5% in compressive strength occurs when the percentage of polypropylene fiber increases upto 0.2%. The decrease in compressive strength is observed when percentage of fibers increases beyond 0.2%. The increase in the compressive strength is due to the increase in bonding effect of fiber with matrix. With the increase in percentage volume of fiber beyond its optimum value (which is 0.2% in present case) compressive strength decreases, this is due to the increase in interference of fiber with each other. This will produce internal voids in concrete mix which leads to decrease the total density of mix and thereby decrease the compressive strength of the mix.

Fig 1 Variation of compressive strength at 28 days v/s percentageof polypropylene fiberflexural strength



Size of beams 100mm X 100mm X 500mm

Concrete mix used M30 grade & Percentage of steel fibers 0.8% (with aspect ratio 60.78)

Table 1.2: Test results for flexural strength at 28 days

S. No.	Percentage of polypropylene fiber along with 0.8% steel Fiber	Load at failure (KN)	Flexural strength(N/mm^2)
1	0%	11.68	4.65
2	0%+0.8%	12	4.9
3	0.1%+0.8%	13.92	5.67
4	0.2%+0.8%	15.49	6.21
5	0.3%+0.8%	18.00	7.25
6	0.4%+0.8%	14.80	5.90

It is observed that with the increase in polypropylene fiber, 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 fiber along with 0.8% of steel fiber.

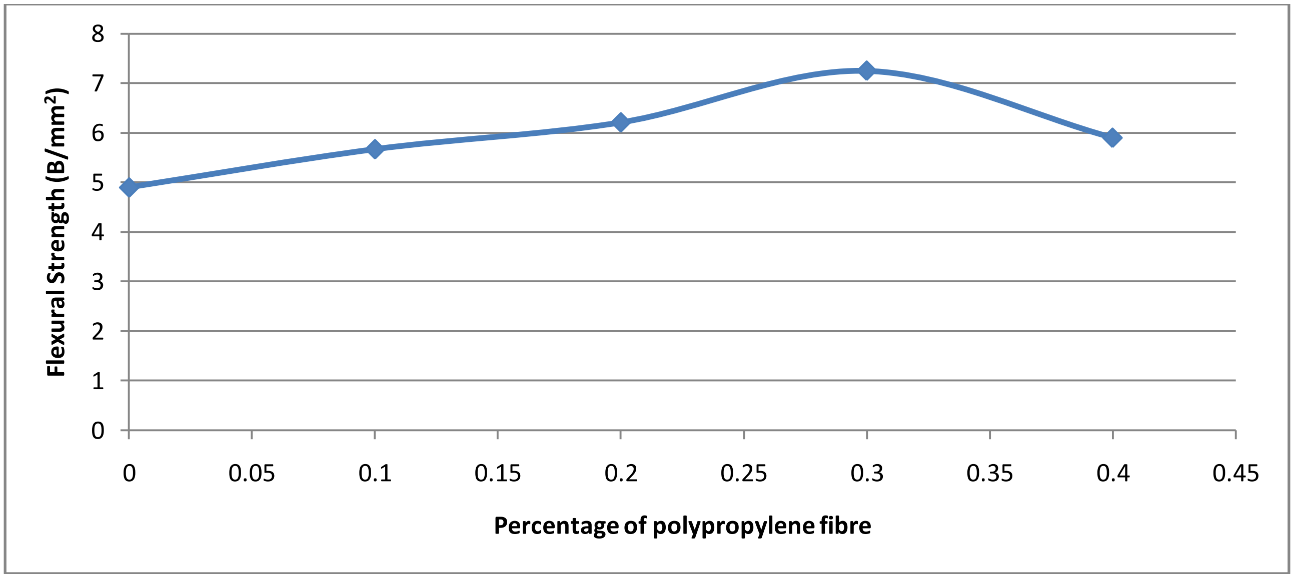


Fig 2 Variation of flexural tensile strength at 28 days v/spercentage of polypropylene fiber

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. Hybrid (steel + polypropylene) fiber showed about 5.7% increase in compressive strength.

2. It is observed that polypropylene fiber have not contributed significantly towards compressive strength.

3. The maximum gain in compressive strength was achieved for 0.2% polypropylene fiber. Thereafter increase in fiber content has marginally reduced the compressive strength.

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