Evaluation of Effect of Polypropylene on the Mechanical Properties of Concrete

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Abstract—The main characteristic of concrete made of Ordinary Portland cement are its low strength in tension, brittle in nature, and its relatively high strength in compression. By embedding conventional steel bars in the concrete and to some extent by addition of sufficient volume of certain fibers, the tensile strength of concrete can be overcome. In this research, fiber reinforced concrete has been broadly studied. For this purpose, the results of some laboratory test in which fibers from Polypropylene (PP) woven bags used for evaluation of mechanical properties of concrete are reported. The fibers are simply cut from locally available Polypropylene woven bags up to 25mm fiber length. Exploring the possibility of re-cycling a waste material, that is produced in large quantities nowadays, while achieving an improvement in some mechanical properties of the concrete is the main aim of this paper. Properties of concrete with respect to effect of inclusion of various proportions of Polypropylene woven bag fiber on the concrete have been dealt in this study. An experimental program was carried out to explore its effects on compressive, split tensile test, flexural strengths of concrete. Concrete mix design of 1:2:4 has been used to make cylinder specimens for compression and split tensile tests and beam specimens for flexural test. Slump test was carried out for each mix at fresh state. A notable increase in flexural and tensile strengths was found. However, no significant change in compression strength was noted.

Keywords—Mix Design, Polypropylene, Compressive Strength, Flexrul Strengt, Mechanical Strength.

I. INTRODUCTION

One the most commonly used construction material in all over the world is concrete. In Pakistan, a wide range of civil engineering infrastructure including small and large buildings namely, large buildings, houses, bridges, storage tanks, dams and numerous other types of structures have been made of reinforced concrete.

Concrete is brittle in nature, weak in tension, and strong in compression. It has been noticed that tensile strength of plain concrete is only about 10% of its compressive strength. Reasons of cracks in concrete are generation of tensile stresses when concrete member is subjected to externally applied loads, environmental cause such as changes in temperature, or shrinkage in a member reaches the tensile strength of the material As the capacity of concrete to tensile strain is low, creation of tensile cracks in reinforced concrete flexural members containing conventional, non-pre-stress reinforcement is usually unavoidable. Cracks that can hardly be visible may be to some extent objectionable only because of its appearance, but cracks having greater width is dangerous because of its allowance of corrosive agents to attack the steel reinforcing bars. In the same way, leakage in structures such as dams, water tanks, and pools is due to excessively wide cracks In most of cases, failure of structures occurs due to these significant cracks. As repairing and reconstruction of these structures are time consuming and costly, the deterioration of such structures is of great concern. Thus, to increase overall safety of a structure and its useful life, there should some vital measures to control cracking of concrete. One the beneficial approach for reducing cracks in concrete and increasing its tensile straining capacity is usage of short discrete fiber in the concrete.

Short discrete fibers are distributed randomly in concrete mix. Those fibers act as an internal reinforcement that enhances the properties of composite material (concrete). Incorporation of short discrete fibers into a cement matrix has many reasons. However, the main reasons are improvement of toughness and tensile strength, and improvement of cracking deformation characteristics of the resultant composite. Types of fiber used in the concrete are the main factor on which these properties of Fiber Reinforced Concrete depend.

There are several different types of short discrete fibers that can be used to reinforce concrete. These include fibers from synthetic organic materials such as polypropylene or carbon, fibers from synthetic inorganic such as steel or glass, fibers from natural organic like cellulose or sisal to natural inorganic asbestos. Among those the most commonly used fibers for reinforcement of FRC are short discrete steel, glass, polyester and polypropylene fibers. Several properties of fibers such as diameter, specific gravity, young's modulus, tensile strength

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etc. are evaluated when selection of a particular type fiber is in question.

Since polypropylene fibers are chemically inert, they will not rust, corrode or rot, and will not absorb water. At the end of laboratory tests, it is concluded that flame spread on the surface of polypropylene fiber reinforced did not take place. Both fresh concrete properties and hardened concrete properties get affected by the introduction of polypropylene fibers in concrete Workability and rate of bleeding of fresh concrete are reduced with addition of polypropylene fibers in the concrete at fresh state. It may also increase the setting times for the concrete. However in hardened state, polypropylene fibers are responsible for reduction of cracks. They act as secondary reinforcement, and tend to mitigate propagation of cracks by bridging them and provide high resistance to crack propagation. Recently, fibrillated polypropylene fibers (lattice type structure when filament is opened up) have been introduced. Fibrillated polypropylene has a unique structure that is capable of providing three dimensional reinforcement to the cementitious matrix. Hence, enhancing tensile strength, tensile strain capacity and the improved resistance to impact and fatigue.

Polypropylene reinforced concrete has been used in wide range of structures namely parking areas, drive ways, industrial floorings, water and other chemical storage tanks, walkways, pavements, roof screeds, mosaic flooring, structural concrete and also in pre-cast slabs in Pakistan. This application of Polypropylene fiber reinforced concrete in there is considered quit limited as compared to other countries. The main cause of usage these composite materials were to inhibit the cracking. However, because of less awareness, design guidelines and construction specifications, utilizations of PPFRC by the local construction industry are limited. Therefore there is a need to develop information on the properties of Polypropylene Fiber Reinforced Concrete (PPFRC) in which indigenous polypropylene fibers are used.

A. Problem Statement

In hardened state, ductility of Fiber reinforced concrete is more and its shrinkage is less as compared to ordinary concrete. In contrast, they have same aspect in hardened state In addition, as single crack is not able to propagate freely within the element, and is prevented in the element by 3-dimensional mesh reinforcement fibers. Thus, the impact resistance is improved.

Fractures and there is also a significant resistance to abrasion and chipping. Since fibers have sewing effect on the cracks, with this property of fiber the toughness and ductility of concrete is enhanced.

In the present paper the mechanical properties and behavior of concrete reinforced with polypropylene (PP) fibers obtained from waste polypropylene bags is studied. Different amount of PP fibers are utilized and striped in 25mm length. Comparisons of the behavior of specimens with and without fibers during compression, split tensile, and flexure tests have been analyzed.

B. Litrature Review

Utilization of randomly distributed fibers in composite material is not new. Since time immemorial, fibers such as straw, horsehair and other plant fibers were used to strengthen brittle materials [ACI 544.1R (1996)]. However, post 1960, much development has taken place in this respect and many fibers have been produced for improvement of most important mechanical properties of concrete. Large number of research has been carried out on fibers and, fortunately, the results of those researches showing the ability of these materials to improve the mechanical properties and durability of concrete. Modern developments and global interest on the subject took off during the following studies in the early 1960s by Romualdi on the use of steel fibers in concrete [Romualdi et al (1964), Romualdi et al (1969)]. Biryukovish used glass fibers in concrete in late 1950s.[Biryukovich et al (1965)]. After this initial work, a substantial amount of research, testing, development and industrial application of fiber as a reinforcement in concrete has taken place.

With introduction of new types of synthetic fibers, most of problems that were facing in mixing, workability and durability of reinforced concrete have been overcome. Polypropylene Fiber is one amongst them. Resistance against corrosive attack of environment and easily tailoring properties of polypropylene are considered the primary advantage of polypropylene fibers. From research and development in the petrochemical and textile industries polypropylene fibers are resulted and, in fact, these are man-made fibers

C. Different Tests and Results

A suitable concrete mix design of 1:2:4 was used in this experimental work. A large flat steel sheet served as smooth surface for mixing of concrete, and mixing for concrete was done mechanically by hand. The execution of fiber reinforced concrete mix for all mixtures was: first the aggregates (fine and course) were mixed, followed by cement, then gradually fiber was added to have homogeneous dispersion of fiber and at the end water was added and mixed for five minutes.

For this purpose five concrete mixtures/specimens were casted. Of these specimens, one was plain concrete and remaining four was Polypropylene Fiber Reinforced Concrete (PPFRC). The PPFRC mixes had fiber length of 25 mm and the different volume fraction of fiber was 0.25%, 0.5%, 0.75 and 1%.

II. WORKABILITY TEST AND RESULT

Conventional slump cone test was used to find out workability of fresh concrete. This test was performed on both concrete specimens without polypropylene that is termed as “control” specimens and concrete with polypropylene that is known as polypropylene fiber reinforced concrete specimens. For the PPFRC specimens, variables included length of polypropylene fibers (lf) and the volume fraction (Vf) of polypropylene fibers. The result of workability test of Plain Concrete (PC) and polypropylene fiber reinforced concrete (PPFRC) with different volume fraction (Vf) are presented below in figure 2 with their pictorial view in figure 1.

Figure: 1 Pictorial View of Fiber Reinforced Concrete Slump After Removal of Cone

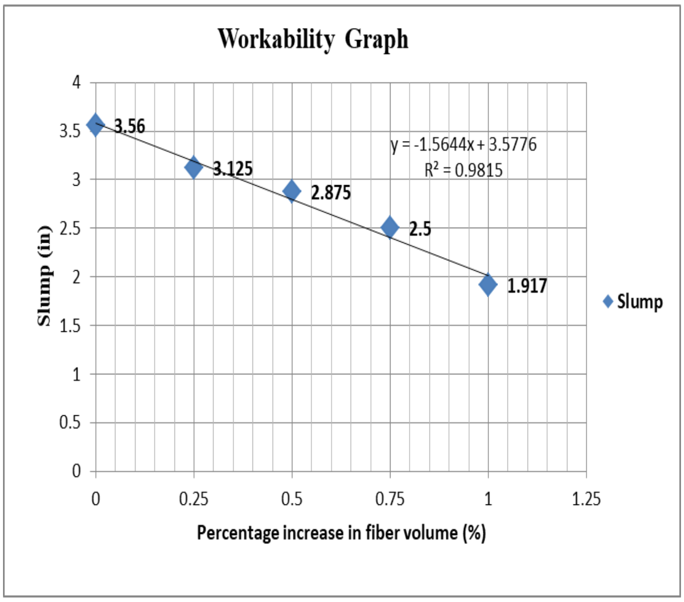

Figure: 2 Workablity Graph

III. COMPRESSION TEST AND RESULT

One plain concrete specimen i.e. "control" concrete and four polypropylene fiber reinforced concrete mixtures were subjected to compressive strength test. The five different mixtures were PCC, PPFRC-0.25%, PPFRC-0.5%, PPFRC-0.75%, and PPFRC-1% respectively. These were tested at the ages of 7, 14 and 28 days. Two replicate specimens were tested at each test age for each type of mixture.

Two specimen, at each of the test age, were taken out from curing, dried and were tested to get the load-stroke data. The results of compression test is shown in the figure 2.3-2.5 and the pictorial views of the failure surface of PC and PPFRC specimen are shown in figure 3 and 4 respectively.

From test data it is concluded that different volume fractions of fiber have their effect on the compressive strength of concrete. PPFRC-0.25% showed an increase of 3.73% of compressive strength in 28-days strength, and, besides this, all other PPFRC mixtures had less compressive strength than that of PCC. The cause of reduction in compressive strength of the mix is may be due to the presence of fibers in mixture which introduce more air voids and this also cause consolidation and compaction problems. The strength-time curve for PC and the four (4) PPFRC mixtures are shown in figure 8.

The main advantage of using polypropylene fiber in the concrete mixture is that these fibers are able to interlock the ingredients of concrete and, hence, hold the mixture together even after cracking and so prevents the effect of shattering force. On contrary, with approach of loading on PCC to its peak, cracks appear and as the loading continues the failure is occurred by the crushing of the concrete specimen at a relatively lower value of strain.

Figure: 3 Failure of Plain Concrete Under Compression

Figure: 4 Failure of PPFRC Under Compressive Load

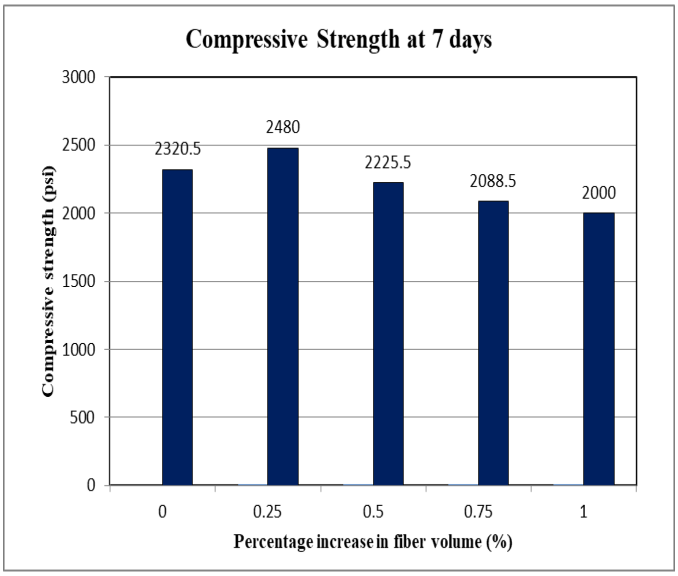

Figure: 5 Compressive Strength at 7 Days

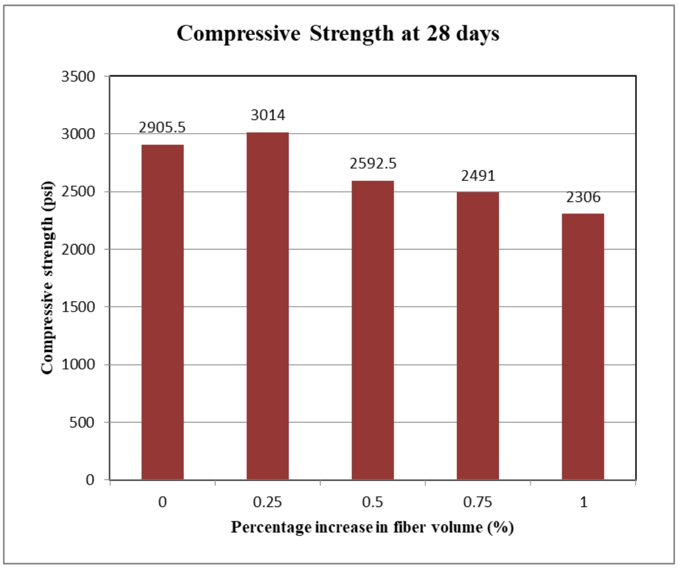

Figure: 7 Compressive Strength at 28 Days

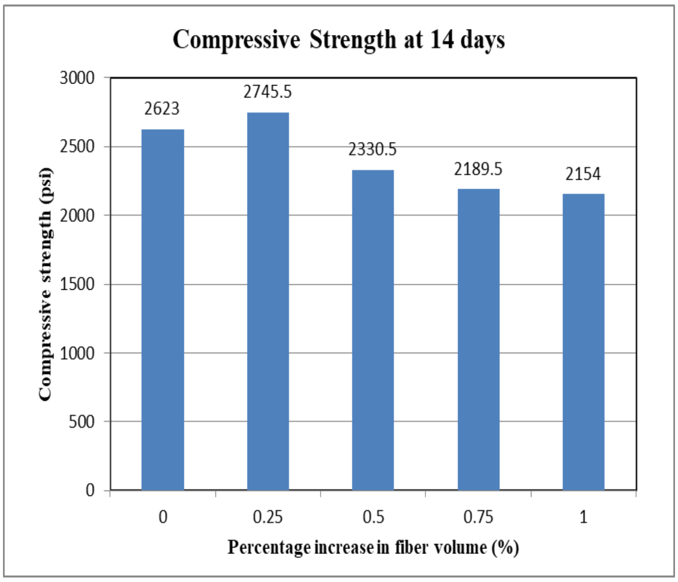

Figure: 6 Compressive Strength at 14 Days

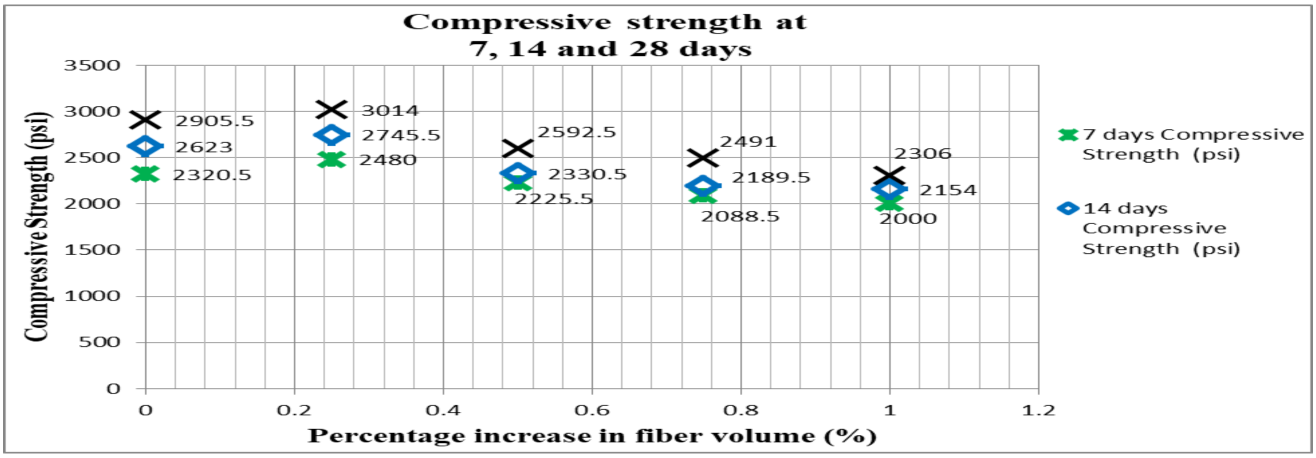

Figure: 8 The Strength-Time Curve for PC and the Four (4) PPFRC Mixture

IV. SPLITTING TENSILE TEST AND RESULT

One plain concrete specimen i.e. "control" concrete and four polypropylene fiber reinforced concrete mixtures were subjected to compressive strength test. The five different mixtures were PCC, PPFRC-0.25%, PPFRC-0.5%, PPFRC-0.75%, and PPFRC-1% respectively. These were tested at the ages of 7, 14 and 28 days. Two replicate specimens were tested at each test age for each type of mixture.

Two specimens, at each of the test age, were tested and the load-stroke data was obtained and tensile strength of each specimen was computed.

The splitting tensile test results indicated that for both PC and PPFRC the post-peak behavior is not same and the inclusion of PP fibers in the concrete increases the post-peak deformation capacity and enhances the post-cracking strength of PPFRC in tension.

After appearance of first crack in the PPFRC member, fibers begin their action. The PP, first, starts bridging these cracks, and, then, do not allow further opening by restraining them. Thus, load carrying capacity a structural member is improved beyond cracking. Aftermath of first crack, a decrease in the stress is observed that shows the stress transfer from concrete to randomly distributed fibers, and as they have elongating characteristic, the fibers take the applied load. (See Figure 9) When the elongation of fibers exceeds their permissible range i.e. the breaking of the fibers under axial tension, cylindrical concrete specimens is failed.

It is found from test results that only PPFRC-0.25% and PPFRC-0.5% showed an increase of 7.1% and 8.29% of tensile strength in 28-days strength. And remaining PPFRC specimens had less tensile strength as compared to PCC. The cause of reduction in tensile strength of the mix is may be due to the presence of fibers in mixture which introduce more air voids and this also cause consolidation and compaction problems. The effect of various amounts of PP fibers (Vf) on concrete mixand average strength-time curves for these concrete mixtures is shown in Figure 10- 3.5.

Figure: 9 Pictorial View of PPFRC Specimen Under Split Tensile Test

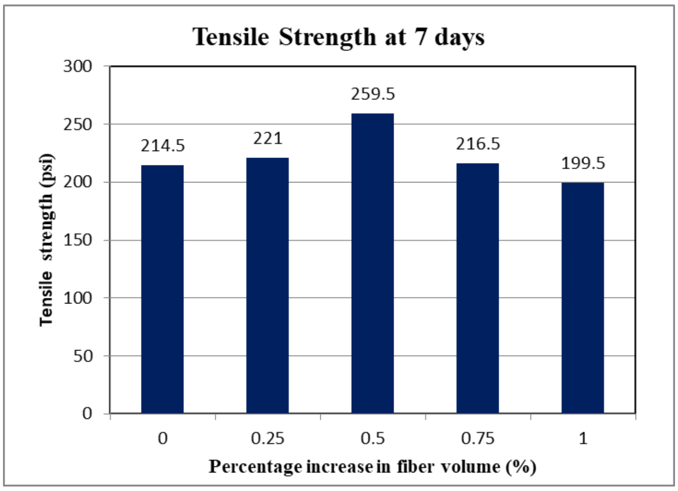

Figure: 10 Tansile Strength at 7 days

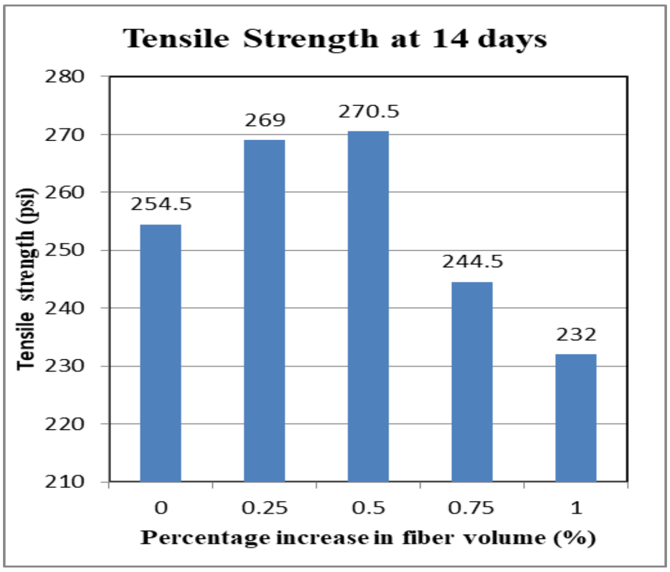

Figure: 11 Tansile Strength at 14 Days

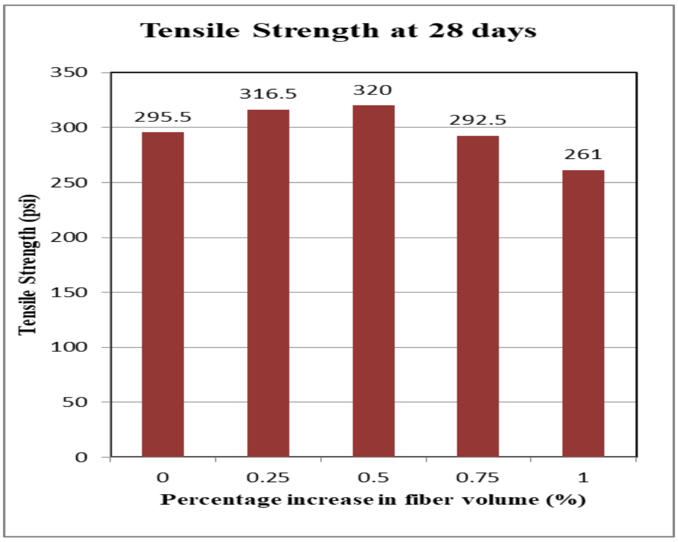

Figure: 12 Tensile Strength at 25 Days

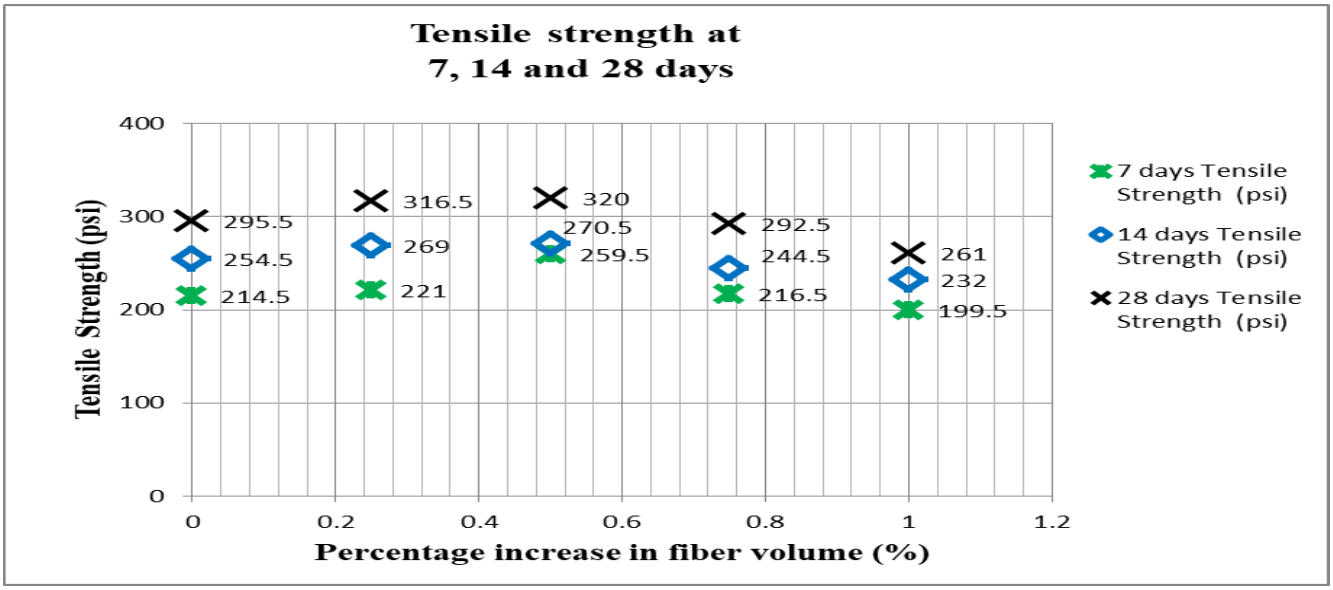

Figure: 13 Various Amounts of PP Fibers (Vf) on Concrete Mixand Average Strength-Time Curves

V. FLEXURAL (INDIRECT TENSILE) TEST AND RESULT

The beams having dimensions 4'' x 4'' x 18.5'' were casted and undergone the flexural test. The number of beam specimens was five and the test was performed at different ages i.e. 7, 14, 28 days respectively.

At the test age, two (2) replicate specimens were tested with the Universal Testing Machine.

The loading assembly and test set –up is shown in Figure 14 Flexure test and tensile splitting test show the indirect tensile behavior or strength of the specimen. Under flexure test, the behavior of PP and four different PPFRC beams were same as was in case of splitting tensile strength test. Load-deflection behavior of all PPFRC beams was determined to be same as that of plain concrete "control" beams; this condition was before taking place of first crack. Just after the appearance of the first crack, Failure of "control" beams suddenly happened load-defection behavior showed a steep and sharp drop after the peak (maximum) load and thus exhibited little or no post-cracking deformation capacity (Figure 17).

When first crack occurred in PPFRC, in the load-deflection curve a drop is noticed. This is an indication of transferring load from the matrix to the fibers and afterwards the beams continue to withstand a portion of the load with increasing deformations and widening of the cracks. The continuation of resistance from PPFRC beams towards load with increasing deformation is due to the elongation characteristic of randomly distributed discrete fibers and when fibers reach their maximum elongation, failure of PPFRC beams occurs.

Flexural strength of specimens was computed when the load-stroke data was obtained. In Figures 15- 17 the graphical representation of effect of various volume fraction on the average flexure strength of the concrete mixtures is shown. It has been showed that some of PPFRC beams have greater flexural strength as compared to PP beam, but the peak flexure strength of PCC beams is higher than that of PPFRC beams. Among the PPFRC beams with different Vf of PPF, the beams with Vf 0.25% (7.2 Kg/m3) of the 25 mm long PPF showed greatest deformation (vertical displacement). Numerically the PPFRC-0.25% beams showed the average vertical displacement of about 29.67% greater than that of control beams. The displacement ductility is improved by the introduction of PPF.

Figure: 14 Pictorial View of Loading Assembly for Flexure Test

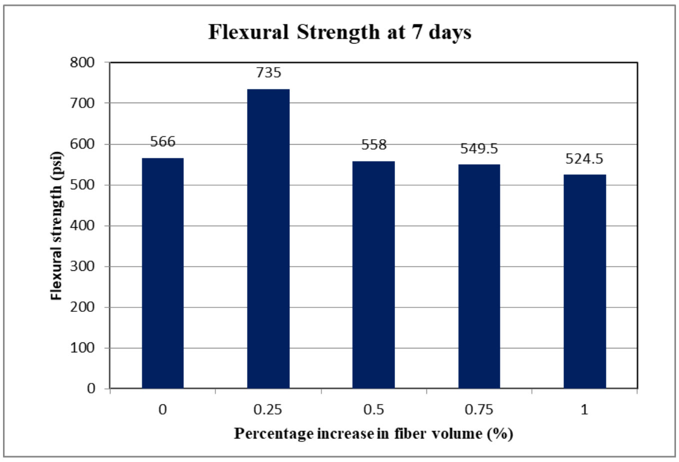

Figure: 15 Flexural Strength at 7 days

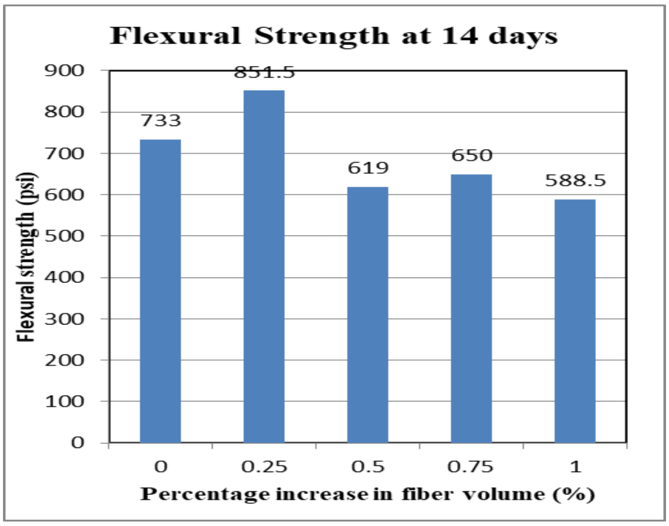

Figure: 16 Flexural Strength at 14 Days

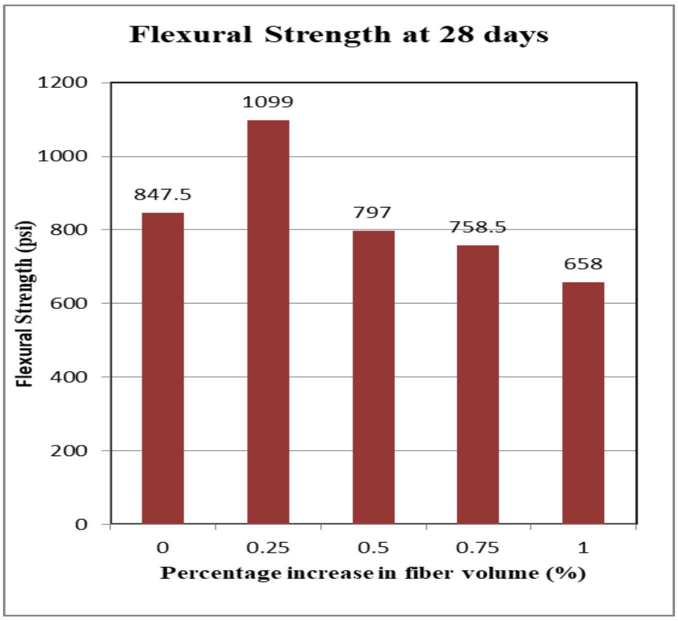

Figure: 17 Flexural Strength at 28 Days

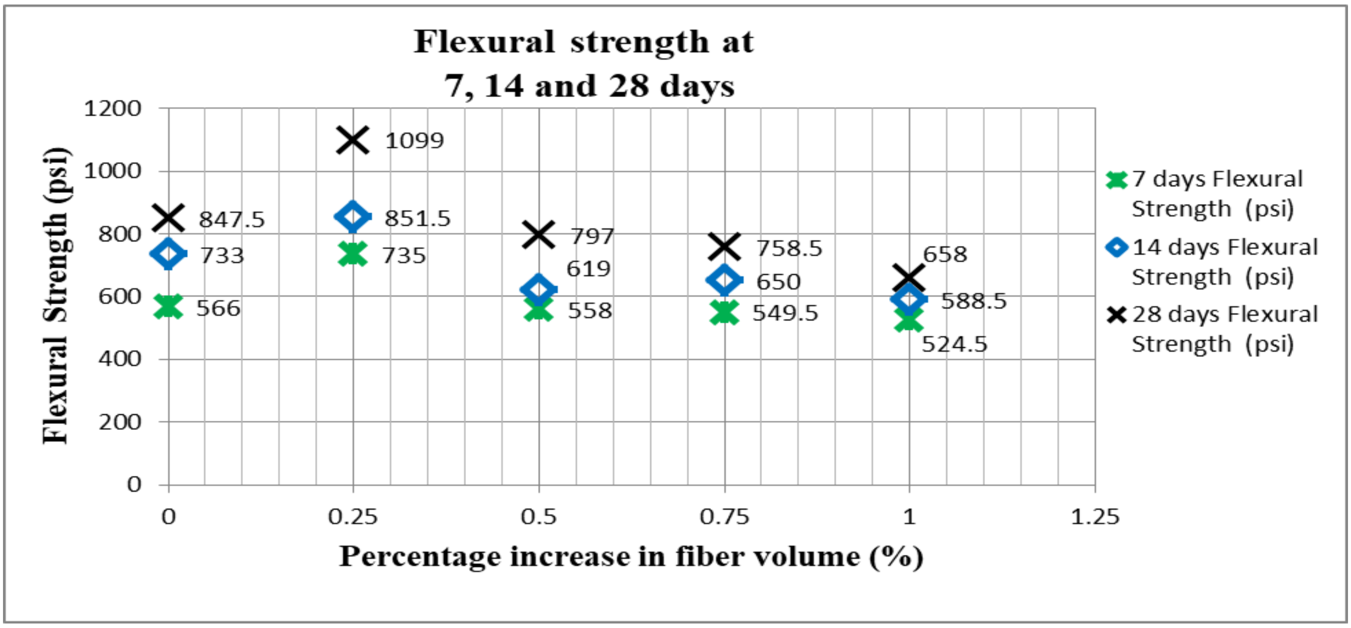

Figure: 18 Flexural Strength at 7,14,and 28 Days

VI. CONCLUSION AND RECOMMENDATIONS

Workability of the concrete mixture as well as flow characteristics of concrete mix are reduced with the addition of polypropylene fibers in the mix; however segregation and bleeding of concrete mixture are reduced too.

Careful attention and control should be taken while mixing, placing, finishing and consolidation of the polypropylene fiber reinforced concrete (PPFRC) because the performance of PPFRC is highly affected by these.

Compressive strength of plain concrete has improved very little with the addition of polypropylene fibers.

Mode of failure of plain concrete and PPFRC is different under compression. In case of PPFRC, cracks are arrested by fibers, inhibit the fast growth of cracks and smear the cracks over a larger area.

Post peak behavior of PPFRC is significantly improved from a perfect brittle behavior for plain concrete to a relatively ductile behavior under tension. The addition of PPF fibers increases the post peak deformation capacity by bridging the cracks that appear as the concrete reaches its tensile strength.

In flexure loading (indirect tensile loading), the improvement in the behavior due to the addition of the PPF is the similar to that in tension. The plain concrete beams exhibit a very brittle behavior, whereas PPFC beams showed ductile failure (increased deformation capacity) with formation of smeared and wide cracks.

Polypropylene fibers (PPF) usage should be advised and encouraged in different types of civil infrastructure.

In order to achieve cost effectiveness, PPFRC should be used in combination with plain concrete.

Studies related to the effect of PPF on the long term shrinkage and time dependent mechanical properties should be conducted.

This study was conducted on plain concrete. Beneficial effects of PPF on reinforced concrete for structural applications should also be studied.

Similar comprehensive studies should be conducted for hybrid FRC i.e. combination of Steel and Polypropylene fibers.

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