Concrete reinforced with 0.1 vol% of different synthetic fibers

Anwar Khitab[1] , Muhammad Tausif Arshad[2], Nazakat Hussain[3], Kashan Tariq[4], Syed Amir Ali[5], Syed Minhaj Saleem Kazmi[6], Muhammad Junaid Munir[7]

[1,2,3,4,6,7]Department of Civil Engineering, Mirpur University of Science and Technology, Azad Kashmir, Pakistan
[5]Council for Works & Housing Research, Karachi, Pakistan
anwarkhitab@yahoo.com, chairman.ce@must.edu.pk

Abstract: This paper documents the effect of fibers type on different physical and mechanical properties of concrete. Four types of fibers, such as steel, polypropylene, glass, and carbon were investigated. The concrete specimens with and without fibers were cast and tested to watch the improvement of certain mechanical and physical properties like compressive, tensile strengths, workability and density. Fibers were added at the rate of 0.1 vol percent of concrete, while all the other ingredients were kept same at identical laboratory conditions. It was observed that type of fiber has huge impact on the workability of the concrete. Only steel fibers enhance the density of concrete, It was also found that the given fiber dosage enhances the early compressive strength of concrete but reduces the 28 days compressive strength. Steel fibers increase the tensile strength more than any other fiber used during this study. It was noticed that addition of fibers in concrete largely improves the failure pattern of the concrete subjected to compressive loads**.**

[Anwar Khitab, Muhammad Tausif Arshad, Nazakat Hussain, Kashan Tariq, Syed Amir Ali, Syed Minhaj Saleem Kazmi, Muhammad Junaid Munir. **Concrete reinforced with 0.1 vol% of different synthetic fibers.** *Life Sci J* 2013;10(12s):934-939] (ISSN:1097-8135). http://www.lifesciencesite.com. 152

Keywords: Concrete, fibers, type, effect, physical properties, mechanical properties, failure pattern.

1. Introduction

Concrete is a composite and brittle material that totally loses its loading capability, once failure starts. This deficiency of concrete can be overcome by adding discrete fibers (Song and Hwang, 2004). Together with fibers, the concrete is known as Fiber reinforced concrete abbreviated as FRC. FRC has found its applications in commercial, residential and hydraulic structures. At present, different materials like steel, glass, polypropylene, nylon, carbon and various natural materials like coconut and horsehair are being employed in concrete to make FRCs . The most popular among these are the steel fibers, followed by polypropylene, nylon, glass and carbon (Banthia, 2012 and Stevens, 1995). According to American Concrete Institute, steel fibers meant for concrete reinforcement are short, discrete lengths of steel of any cross section having an aspect ratio of 20-100 (ACI, 1996). Steel fiber reinforced concrete often abbreviated as SFRC displays much better performance than the same concrete without any fiber. Its compressive, tensile and flexural strengths are much higher (Banthia, 2012). That's why SFRC is frequently being used in slabs subjected to high traffic loads. Apart from steel fibers, numerous researchers from all over the world have also worked on other fiber-reinforced concretes and have suggested that mechanical properties of fiber reinforced concrete are much superior than the ordinary concrete (Zahra et al. 2014 and Song et al. 2005). They have reported that the brittleness and the low tensile strength associated with an ordinary concrete can be overcome by adding fibers (Vikrant at al., 2012). Fibers also prevent the development of cracks and show unique post-cracking performance before failure. While making FRC, it is vital that the fibers should be uniformly distributed throughout the concrete mix (Brown et al., 2012). The present work presents a comparative investigation among the synthetic fibers mentioned above. Fiber reinforced concrete specimens having same quantity of different synthetic fibers were investigated. As mentioned in the abstract, all fibers were added @ 0.1 vol% of concrete. The idea of fiber-reinforcement in construction materials is very old. Straw and horsehair were used in lime mortar and clayey tiles. In the beginning of the last century, asbestos fibers were incorporated for the first time in concrete. Knowing the health risks associated with asbestos (Nicholson et al., 1982), the use of asbestos fibers was abandoned. By 1970s, steel, glass, and synthetic fibers such as polypropylene and nylon fibers were explored for concrete (Sridhara et al., 1971). Search of new fibers for concrete continues even today. The popularity of FRCs lies in the fact that they tender special characteristics like crack-arrest and enhanced strengths, which are not possible to attain with ordinary concrete (Barzin, 2012). In the following, a brief introduction of the fibers, studied during the present project is presented.

Hard Carbon Steel Fibers are being used in concrete since decades (Banthia, 2012). Although, not a replacement of the reinforcement bars, the use of steel fibers creates a concrete with much enhanced plastic, shear and ductile character (Hwang et al., 2013). Similar to aggregates in concrete, steel fibers also build a multi-dimensional matrix throughout the mix. When reinforced in all directions, the concrete design becomes much stronger. Steel fibers act as tiny reinforcement bars and restrain micro-cracking. The steel fibers used for the current project work are shown in the following Fig. 1 (a).

Polypropylene has a low density and is chemically inert. Its popularity is mainly attributed to excellent post-cracking performance. The major shortcomings of polypropylene fibers are low modulus of elasticity, poor bond with cement matrix, and combustibility. The polypropylene fibers have melting point (~150-200ºC) much lower than that of steel fibers (Ramakrishnan, 1987). As fire takes place, these fibers melt, creating voids in the concrete. Similarly water present in concrete pores vaporizes. In case of concrete without plastic fibers, water vapors will try to escape and if trapped, would exert pressure on surrounding concrete. This will create cracks and ultimately will lead to spalling of concrete. On the other hand, in fiber reinforced concrete, the voids created due to melting of polypropylene fibers would provide way for the water vapors to escape and hence the spalling of concrete is avoided. Polypropylene fibers used in project are shown in Fig. 1 (b).

The use of glass-fiber-reinforced concrete (GFRC) is an adaptation of the technology of using chopped glass fibers. Commonly used glass fibers are round and straight and have diameters of 0.005 to 0.015 mm, but these fibers can also be bonded together to produce larger ones with diameters as high as 1.5 mm (Wambeke et al., 2006). A major disadvantage of glass fiber is its reactivity in the alkaline cementitious environment (alkali-silica reaction). To overcome, the fibers are made from a special zirconium alkali-resistant (AR) glass. The strength of glass fiber is comparable to that of steel fiber, its density is lower, and its elastic modulus is about one third that of steel (Ramakrishnan, 1987). Glass fibers used in project are shown in Fig. 1 (c).

Carbon fibers are produced from petroleum pitches. These fibers are manufactured in strengths as high as steel fibers but have much low density, making the overall matrix light in weight (Chung, 2000). Carbon fibers are inert in aggressive environment, abrasion-resistant, stable at high temperatures, and possess relatively high stiffness. Carbon fibers used in project are shown in Fig. 1 (d).

2. Material and Methods

In order to achieve the desired objectives, four types of concrete specimen having the same quantity of the above mentioned four fibers were prepared. All fibers were added at the rate of 0.1 vol % of concrete. Additionally ordinary concrete specimens without fibers were also cast.

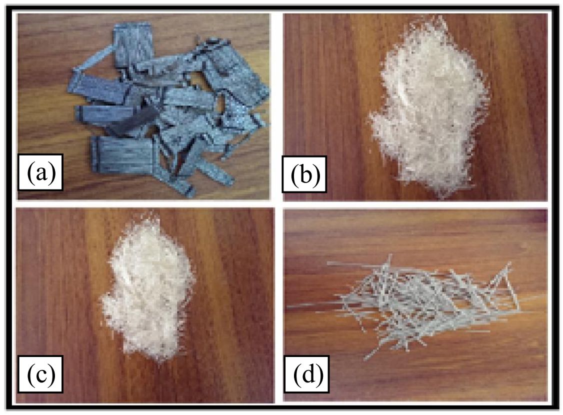

Figure 1. Fibers used in this study (a) Steel (b) Polypropylene (c) Glass (d) Carbon

The ordinary concrete mix was designed using ACI method 211.1-91(ACI, 1991). The design compressive strength was kept equal to 28 MPa [4000 Psi] at 28 days of age. The composition of concrete is presented in Table 1. The water to cement ratio of the designed concrete comes out to be 0.55, which is quite reasonable to produce concrete of significant workability. This high water content was selected to watch the effect of fibers to reduce concrete workability. This concrete composition makes the proportion of cement, fine and coarse aggregates as 1:1.6:3.3 by mass. The cement was purchased from a famous local brand, the sand was acquired from River Jhelum near Mangla dam in Kashmir and coarse aggregates were acquired from Margalla hills near Pakistani Capital Islamabad. It should be noted that the used coarse aggregates were acquired from a limestone quarry.

Table 1. Ingredients per m^3 of concrete

Ingredients	Cement	Fine aggregates	Coarse aggregates	Water
Quantity (Kg)	366	575	1200	202 liters

The chemical composition of cement is presented in Table 2; the main components are calcium oxides, silica, alumina and iron oxide. The physical characteristics of aggregates are presented in Table 3. The described physical properties are fineness modulus, maximum aggregate size and specific gravity.

In the first phase, the sieve analysis work was carried out. For fine aggregates, frames 200 mm (8 in.) in diameter were used as per standard practice and for coarse aggregates, frames 300 mm (12 in.) were used (Neville, 2006). Before the sieve analysis, the aggregate samples were air-dried. The sieve analysis test for fine and coarse aggregates was carried out in accordance with the test method ASTM C136-05 (ASTM, 2005). The experimental results of the sieve analysis along with their comparison with ASTM C33 requirements are shown in Fig. 2(a) and Fig. 2(b) for fine aggregates and coarse aggregates respectively. Further, the fineness modulus of fine and coarse aggregates was determined from the sieve analysis test results obtained in phase 1. Next, the specific gravity was determined following the ASTM method C 127-12 (ASTMC127, 2012). The characteristics of the fibers used in the study are presented in Table 4.

Table 2. Characteristics of cement

Component of Cement	Percentage
Calcium Oxide, CaO	63.5
Silicon Oxide, SiO_2	21.8
Aluminium Oxide, Al_2O_3	5.1
Iron Oxide, Fe_2O_3	4.1
Magnesium Oxide, MgO	1.5
Sulphur Oxide, SO_3	2.1
Loss on Ignition, (LOI)	1.2
Specific surface	394 (m^2/kg)

Table 3. Characteristics of fine and coarse aggregates

Characteristic	Coarse aggregates	Fine aggregates
Fine Modulus	7.28	2.3
Max. Size (mm)	25	5
Specific gravity (g/cm^3)	2.62	2.6

Table 4. Characteristics of different fibers used for concrete reinforcement

Type fibers	Steel	Poly-propylene	Glass	Carbon
Dia. (µm)	80	18	20	25
Sp.gravity (g/cm^3)	7.8	0.94	2.5	1.7
Tensile strength (MPa)	1040	390	1450	1730
Strain at failure (%)	1.35	6	2.9	0.4

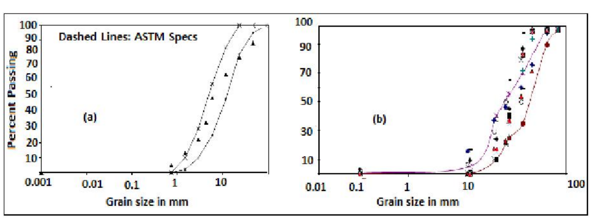

Figure 2. Grading Curves (a) Fine aggregates (b) Coarse aggregates

For this work first of all cylindrical specimens were prepared. A mix proportion of 1:1.6:3.3 with 0.55 water/cement ratio was used during the current work. The exact quantity of materials using ACI method 211.1-91(ACI, 1991) was determined and trial batches were cast and tested. All the concrete constituents were tested to check their conformity with relevant ASTM standards. Mixing of concrete was performed using a tilting drum mixer and specimens were placed and compacted with poker vibrator in steel moulds. Concrete cylindrical specimens 150 mm in diameter and 300 mm in height were cast. First of all ordinary concrete was prepared. After this fiber reinforced concrete cylinders were prepared by same procedure except that while mixing concrete in mixer machine fibers were also added in required quantity. After 24 hours the specimens were de-moulded and were immersed in water. The specimens were cured for 7 days and 28 days. After curing period, the specimens were tested on digital compression testing machine following ASTM C39 method (ASTMC39, 2012). In every case, three to five cylinders were tested and their failure loads were measured. The values described in this work are the average of three to five test specimens. The compressive strength was calculated as:

$$f_c' = \frac{Load\ at\ failure}{Cross\ sectional\ area}$$

For tensile strength test, again cylinder specimens of dimension 100 mm diameter and 300 mm length were cast. The specimens were de-moulded after 24 hours of casting and were transferred to curing tank wherein they were allowed to cure for 28 days. These specimens were tested under compression testing machine. In each category, three cylinders were tested and their average value is reported as per ASTM C 496 (ASTM, 2011). Split cylinder tensile strength was determined as follows: $f_t = \frac{2P}{\pi DL}$

Where f_t is tensile strength (MPa), P is failure load,, D is diameter of cylinder, and L is the length of cylinder.

is the number of individuals of least important species and E is the evenness index.

3. Results

The Characteristics of fresh fiber reinforced concrete are shown in Table 5. It can be observed that the addition of fibers has tremendously reduced the slump of the given concrete. On the other hand, there is no effect on the density except the steel fibers reinforced concrete, which showed 1.2 % increase in density. Apparently, this is due to high density of steel.

Table 4. Characteristics of fresh concrete

Type fibers	Slump (mm)	Density (kg/m^3)
Ordinary concrete	75	2470
Polypropylene	25	2472
Steel	40	2500
Carbon	25	2473
Glass	15	2484

It is evident that polypropylene, carbon and glass fibers greatly improve the cohesion of the material. That is why the slump value reduced drastically. And these results clearly authenticate the effectiveness of these fibers so far the inter-molecular cohesion is concerned. As observed from the experimental results, steel fibers have decreased the slump values. The reason is that SFRC also tends to hang together as in the case of the other fibers. With the incorporation of fibers (polypropylene, carbon and glass fibers) in concrete, the surface area increases. As the surface area increases, more water is absorbed and the concrete flowability is reduced resulting in a loss of slump. Therefore, the loss of slump due to steel fibers is solely due to hanging of steel fibers in between the aggregates and due to other fibers, it is also due to increase of surface area. In polymeric fibers, not only the fibers hold together the concrete mass but also absorb additional water causing tremendous loss of slump value. Another aspect, which is also very important, is the length of fibers. Many researchers have reported that longer fibers reduce the slump value to a greater degree than shorter fibers. It means that a 1.5 inch long fiber will reduce the slump more than a ¾ inch long fiber of the same type, at the same dosage level. But the study of this aspect was not the issue during this work. However, for the sake of information, the lengths of the fibers used are described in the Table 6. It is evident that fibers of same length were used in each case.

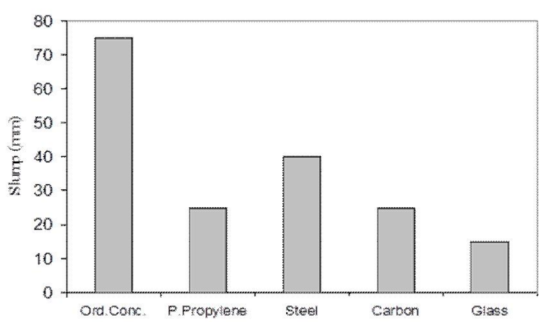

Figure 3. Slump (mm)

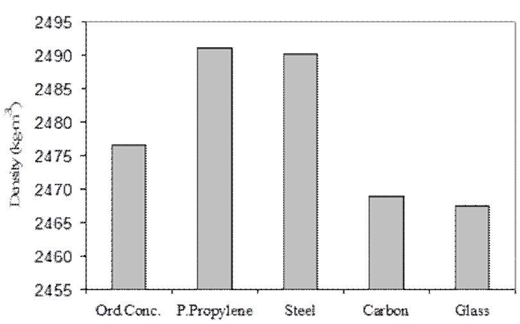

Figure 4. Density of fresh concrete (kg/m^3)

Table 1. Length of fibers

Type fibers	Length (mm)
Polypropylene	12
Steel	11
Carbon	13
Glass	13

The compressive strength of 7days and 28 days is graphically presented in Fig. 5 and 6 respectively. The compressive strength is more for fiber reinforced concrete at 7days than the respective strength of ordinary concrete. It reveals that fibers play an important role in increasing the early age strength of the concrete. However, the 28-days compressive strength of ordinary concrete is higher than that of corresponding fiber-reinforced concretes. In many research works it has been reported that the incorporation of fibers in concrete may lead to enhancement as well as degradation of compressive strength. The degradation of compressive strength occurs due to additional defects and difficulties in processing (Fennala, 1983).

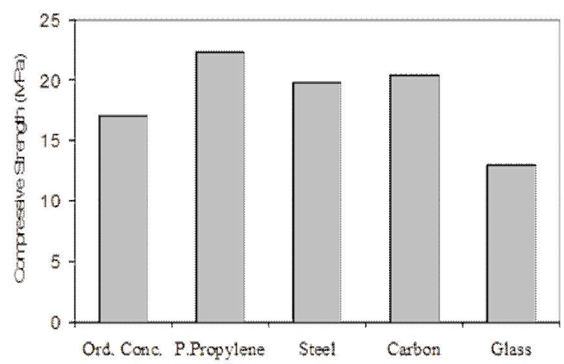

Figure 5. Compressive Strength (MPa) 7 days

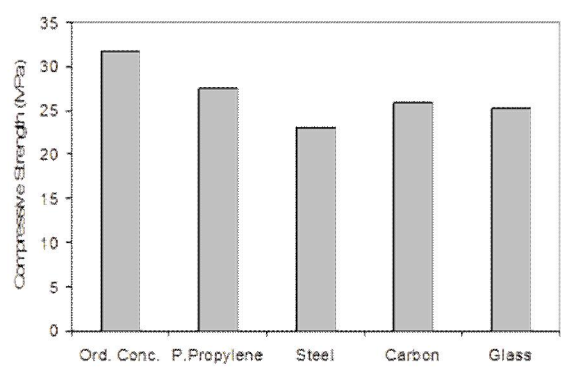

Figure 6. Compressive Strength (MPa) 28 days

The tensile strength of 7days and 28 days is graphically presented in Fig. 8. The maximum tensile strength is achieved with Steel fibers whereas; the carbon fibers have minimum effect on the tensile strength. During the compressive strength tests it was noted that the failure of specimen was gradual, and despite the occurrence of excessive vertical cracks, the specimen still did not break into pieces and held its integrity while no-fiber concrete failed with excessive cracks. The failure pattern in FRC and ordinary concrete are shown in Fig. 8.

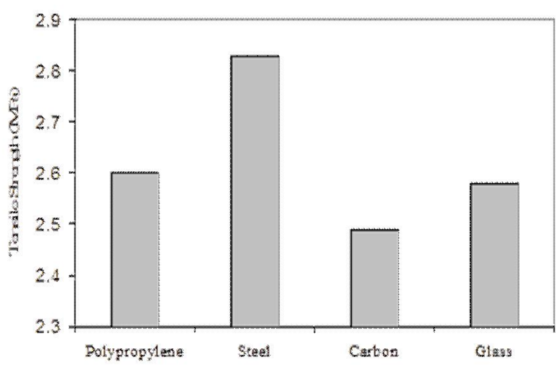

Figure 7. Tensile Strength (MPa) 28 days

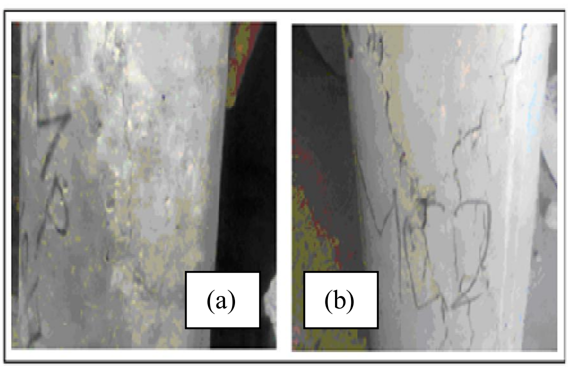

Figure 8. Failure (a) FRC (b) Ordinary concrete

5. Conclusions

Synthetic fibers are quite adoptable with the local concrete materials. All the four fibers with given length drastically reduce the slump values as compared to the same concrete without fibers. However the other three fibers reduce slump more than the same quantity of steel fibers. Fibers largely increase the intermolecular cohesion of concrete. Except steel, fibers have no remarkable effect on concrete density due to the lower density of fibers. Maximum compressive strength is attained by using polypropylene fibers and minimum strength is attained with glass fibers. Fibers increase the early compressive strength of concrete but decrease the 28-days compressive strength. Maximum split cylinder tensile strength is obtained with steel fibers. This effect might be due to high tensile strength of steel as compared to the other three fiber materials.

Acknowledgements:

Authors are grateful to the Department of Civil Engineering, Mirpur University of Science & Technology, Mirpur, Azad Kashmir, Pakistan for financial support to carry out this work.

Corresponding Author:
Dr. Anwar Khitab
Department of Civil Engineering
Mirpur University of Science & Technology, Mirpur, Azad Kashmir, Pakistan.
E-mail: anwarkhitab@yahoo.com,
chairman.ce@must.edu.pk

References

1. Song, P S, Hwang, S. Mechanical properties of high-strength steel fiber-reinforced concrete. Construction and Building Materials. 2004; 18(9):669-673.
2. Banthia, N. FRC: Milestone in international Research and development, proceedings of FIBCON2012. ICI. Nagpur, India, February 13-14; 2012: 48-53.
3. Song, P S, Hwang, S, Sheu, B C. Strength properties of nylon and polypropylene fiber reinforced concretes, Cement and Concrete Research . 2005 35(8):1546-1550.
4. Zahra, S T, Jeffery, S, V, Darwin, I K, Benjamin, P G. 2014, Comparative impact of four long carbon fiber reinforced concretes, Materials & Design;2014; 55: 212-223.
5. Sridhara, S, Kumar, S, Sinare, M A. Fibre Reinforced Concrete, Indian Concrete Journal.1971; 45(10): 428-430.
6. Nicholson, W J, Perkel, G, Selikoff, I J. 1982, Occupational exposure to asbestos: Population at risk and projected mortality-1980–2030, American Journal of Industrial Medicine.182; 3(3): 259–311.
7. Barzin, M, Mechanics of Fiber and Textile Reinforced Cement Composites.2012;CRC Press.
8. Hwang, J, Lee D H, Ju, H, Kim, K S K, Seo, S, Kang, J. Shear Behavior Models of Steel Fiber Reinforced Concrete Beams Modifying Softened Truss Model Approaches, Materials.2013; 6(10): 4847-4867.
9. Wambeke, B W, Shield C K, 2006, Development Length of Glass Fiber-Reinforced Polymer Bars in Concrete, ACI Structural Journal. 2006; 103(1): 11-17.

10. Chung, D.D.L., 2000, Cement reinforced with short carbon ®bers: a multifunctional material, Composites: Part B 31 (2000), 51-526.
11. ACI Committee 544.1 R-96, State of the Art Report on Fiber Reinforced Concrete, ACI Manual of Concrete Practice.1996.
12. Vikrant, S, Kavita, S, Deshpande, N V, Investigation of Steel Fiber Reinforced Concrete on Compressive and Tensile Strength, International Journal of Engineering Research &Technology. (IJERT).2012; 1(3).
13. Brown, J, Atkinson, T, Propex Concrete Systems (International), United Kingdom, proceedings of FIBCON2012, ICI, 2012;Nagpur, India.
14. Stevens, D J, Testing of fiber reinforced concrete, American Concrete Institute,1995.
15. Ramakrishnan, V, Materials and properties of fiber reinforced concrete, Proceedings of international symposium on fiber reinforced concrete. 1987;December 16-19, Madras, India.
16. ACI Committee 211.1-91, Standard practice for selecting, proportioning for normal, heavyweight, and mass concrete, Part 1, ACI Manual of Concrete Practice. 1994.
17. Neville, A M,Properties of concrete, 4th edition, Longman Scientific and Technical. 2006.
18. ASTM C136-05, Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. 2005.
19. ASTM C39/C39M-12a, Standard Test Method for compressive strength of cylindrical concrete specimens. 2012.
20. ASTM C496/C496M-11, Standard Test Method for splitting tensile strength of Cylindrical Concrete Specimens, 2011.
21. ASTM C127-12, Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate. 2012.
22. Fennala, D A, Naaman, A E, Stress strain properties of fibers reinforced concrete in compression, Journal of ACI, proceedings. 1983;82(4),:475-483.

12/20/2013