Study of hardened properties of hybrid fibre reinforced concrete using steel and glass fibre

Athira Anand1, a, Manish Jose2
1 M-Tech Student, Department of Civil Engineering, SJCET, Palai, Kerala, India
2 Assistant Professor, Department of Civil Engineering, SJCET, Palai, Kerala, India
a E-mail: athiradanand@gmail.com

Abstract. In the present study the effect of using hybrid microfiber reinforcement on the mechanical properties of concrete is studied. Concrete is an important construction material which has low tensile strength and flexural strength. It is proved that addition of fibers improve different properties of concrete like tensile strength and ductility. Improvement in performance by the use of more than one fibre in same concrete is studied here. Hooked steel fibers and glass microfibers (6mm and 12 mm) are used in this experimental study. Influence of each fibre and their combined effect is studied. Fibre is added by volume fraction and it is fixed as 0.5% of the total volume. Mechanical properties are tested by Indian standard methods. From the results it is found that the properties are improved by the use of hybrid fibre reinforcement in concrete

keywords: Fibre, Compressive strength, Split tensile strength, Modulus of rupture.

1. Introduction
Concrete is an important heterogeneous building material which is brittle in nature. It is very user friendly so that it can be moulded to any shape. It has a very long life span and economical too. Also fresh concrete can be moulded very easily. According to our need it can be cast into any strength and specification. Now a days even it is really easy to place concrete by pumping and all. Mechanized mixing and placing helps to reduce manpower also. All such reasons make concrete such a popular construction composite. Along with lot of advantages, like any other material it has some disadvantages too. Concrete has low tensile strength and is sometimes permeable to moisture and other chemicals. So it is vulnerable to corrosion. Cementitious mash up like concrete is made by the complex arrangement of different inclusions like pores, aggregates and micro cracks. Inclusions can be of different size and shapes. When subjected to load concrete behaviour depend on these inclusions i.e., their distribution and continuity. Occurrence of micro cracks at the aggregate mortar junction cause weakness in concrete. When exposed to load these micro cracks spread and result in brittle fracture in conventional concrete. It happens due to due to low tensile strength and ductility of concrete. These cracks occur during solidification due to different types of shrinkage. The width of these initial cracks seldom exceeds a few microns, but their other two dimensions may be of higher magnitude. When loaded these micro cracks spread due to stress concentration and gets expanded, also new cracks are formed. Failure is initiated by cracks in concrete which is governed by tensile properties. Experiment and numerical evaluation are the main methods of studying resisting cracks. Different methods have been used to resolve these problems. It include reinforcing, prestressing etc. Fibre reinforced concrete is one such method for improving the tensile
strength of concrete. It has been recognised that the addition of small, closely spaced and uniformly dispersed fibres to concrete would act as crack arrester and would substantially improve its static and dynamic properties. Fibres obstruct the weakness plane and prevent the propagation of cracks under the application of load and in turn failure or structure or member. Steel, glass, nylon, asbestos etc. are commonly used fibres. Fibres with high modulus of elasticity improve flexural and impact resistance. While reinforcements are laid according to design and standard construction practise, fibres are randomly distributed in matrix. It improve the properties of the matrix itself. It also improve the ductility and post cracking behaviour. They not only reduce the permeability of concrete. Thus reduce the intrusion of chemicals or moisture from external environment. Concrete in which two or more than fibres are added is called hybrid fibre reinforced concrete. Correct combination of different fibres improve the properties of concrete and also result in performance synergy. The objective of this study is to make use of the merits of two fibres, short steel fibres and glass micro fibres. The amount of fibre added is expressed by volume fraction. Performance of concrete before cracking is improved by the use of hybrid fibres. This happens due to the bridging action of fibres. The smaller fibre bridges micro cracks and controls their growth. Larger fibre is used to arrest the spreading of macro cracks. Bridging of macro cracks which increase later the ductility of the concrete. In present study 7 and 28 day mechanical properties are found out and compared.

Banthia and Guptha [1] used steel polypropylene and carbon fibres to prepare hybrid fibre reinforced concrete and study their synergy effect. Hybrid concrete made with steel and polypropylene had better properties. Baricevic et al. [2] by finding the appropriate amount and proportion of fibres, made sustainable hybrid fibre reinforced concrete using recycled tire steel and factory made fibres. SHFRC with superior behaviour than usual FRC with factory made fibres was made. Use of fibres had no effect on workability when fibre volume was limited to 1.2%. It was also concluded that the properties of concrete in post cracking area is determined by the proportion of fibres. Chen and Qiao [3] studied influence of hybrid microfiber reinforcement in fracture and crack propagation. Steel fibres were used as macrofiber and polyvinyl alcohol was used as microfiber. Use of hybrid fibre increased the ability to withstand both formation and propagation of cracks. Deng and Li [4] conducted a study on the mechanical properties and fracture properties of concrete using steel and synthetic fibres. Results showed that better behaviour is obtained for hybrid concrete and had synergic effects. Lawler et al. [5] used poly vinyl alcohol fibre steel micro fibres and steel macro fibres to find the influence of fibre combinations in concrete. Hardened properties, water permeability and shrinkage crack resistance of concrete were studied. PVA hybrid had greater ultimate strength than steel hybrid by a reasonable margin. Mastali and Dalvand [6] studied the fresh and hardened properties of self-compacting concrete made with poly propylene and recycled steel fibre. They found out that there is reasonable increase in impact resistance and mechanical properties of concrete. Wang et al. [7] studied the influence of using different type and size of steel and polypropylene fibre to find out for which combination mechanical properties are better. Compared to conventional concrete hybrid concrete split tensile strength is improved by 44.34 % bending strength by 49.05 % and impact resistance 6.8 times. Yao et al. [8] conducted experiment on the mechanical properties of concrete after keeping the volume fraction of concrete constant as 0.5%. Three different hybrid concrete were made using carbon and polypropylene, carbon and steel, and polypropylene and steel. From the results concluded that carbon and steel had better performance because of similar modulus.

2. Objectives and scope

Different fibres have different effects on the properties of concrete. Some improve ductility, while some improve durability. Improvement depend on the fibre added, its proportion, orientation etc. In the present study two type of fibres are introduced in concrete and their impact on mechanical properties are compared with conventional plain concrete properties.

- To find out the design mix for
  - Conventional concrete
- Find the compressive strength for specimens of each individual mix
• Study the flexural behaviour of beam specimen made with each mix
• Study the split tensile strength of cylinder specimen
• Study the influence of addition of hybrid fibres from the test results

3. Materials and specimen

3.1 Materials

Study is performed using 53 grade Portland Pozzolana Cement. M sand used had a specific gravity of 2.63 and sieve analysis indicated that it is confirming to zone II. 20 mm coarse aggregate with specific gravity 2.75 is used. Materials were proportioned as per mix design. To improve workability and other properties admixture FOSROC SP 430 IS added. Two type of micro fibres were used. Glass fibre of length 12mm and 6 mm. Alkali resistant glass fibre is used which provide good durability. Hooked steel fibre 50mm length were used as macro fibre. Their physical properties are given in Table 1. The total volume fraction of fibres was kept to a maximum of 0.1 percent to maintain economical and workable mix.

| Fibre     | Length | Tensile strength(MPa) | Youngs modulus(GPa) | Elongation (%) | Combustibility  |
|-----------|--------|-----------------------|---------------------|---------------|----------------|
| Steel     | 50     | 2500                  | 210                 | 4             | Non combustible|
| Glass fibre 6 mm | 1700 | 73                    | 2.4                 | Non combustible|
| Glass fibre 12 mm | 1700 | 73                    | 2.4                 | Non combustible|

3.1.1 Fibres

Glass fibre is available in different forms such as E glass fibre, Alkali resistant fibre and ECR fibre for different needs. Alkali resistant glass fibre used is shown in figure below. Steel fibres are available in different forms like plain, corrugated, crimped, hooked, flattened etc. Hooked steel fibre used is shown in figure below.

Figure 1 Glass fibre
3.2 Mix and specimen

Each individual mix were prepared in 6 separate batches to determine the test results for individual properties. The cement, M Sand, aggregate and fibres were dry mixed for 2 minutes. Water and admixture were added and mixed for another 2 minutes in a concrete mixer.

3.2.1 Mix design

The strength and durability of concrete will depend on the materials and methods chosen with adequate mixing. By selecting the right mix proportion for the concrete, the concrete will good workability can be achieved. The mix design was according to IS: 10262 – 1982 guidelines for M25 mix including replacements are designed for the investigation. The mix design data and results are given below. Fibres are added by volume percentage. Their volume fraction in each mix is also given below in the following table.

Table 2 Mix design

| Target mean strength | 31.6 N/mm² |
|----------------------|------------|
| Water Content        | 140 liters |
| Cement Content       | 350 kg/M³  |
| Fine aggregate content | 758.727 kg/M³ |
| Coarse aggregate content | 1245.5 kg/M³ |

3.2.2 Volume of fibres

Fibres are added by volume percentage. Their volume fraction in each mix is given below.

Table 3 Volume fraction

| Test series | Steel | Glass(6) | Glass(12) |
|-------------|-------|----------|-----------|
| C mix       | 0     | 0        | 0         |
| G1          | 0     | 0.5      | 0         |
| G2          | 0     | 0        | 0.5       |
4. Experimental program and testing
In order to find the mechanical properties of concrete cube specimens of size 150mm x 150mm x 150mm, cylinder specimens of size 150mm diameter and 300mm height, and prism of size 500mmx10mmx100mm were casted using cast iron moulds. Concrete was mixed as per design were filled in the specimen moulds layer by layer and compacted by vibration. Specimens were cured for 28 days and surface dried before testing.

![Figure 3 specimens](image)

5. Results and discussion
As specified earlier hardened properties of conventional concrete i.e., control mix is compared with fibre reinforced and hybrid fibre reinforced concrete. Results obtained are discussed here

5.1 Compression testing
Mixing fibre in concrete can increase porosity at same time can limit crack growth. Addition of fibres have two opposite effects on concrete. Considering the results here due to hybrid fibre compressive strength is increased. 3 specimens were tested for each mix to find 28 day strength in CTM.

| Mix  | Compressive strength N/mm² |
|------|-----------------------------|
| C mix | 27.3                        |
| G1   | 28.02                       |
| G2   | 27.91                       |
| S    | 29.43                       |
| SG1  | 32.8                        |
| SG2  | 32.1                        |
5.2 Split tensile strength
Split tensile strength of the cylinder specimens was obtained by the test in CTM. From the results it is clear that tensile strength is increased by the addition of fibre.

Table 5 Split tensile strength of concrete

| Mix   | Split tensile strength N/mm² |
|-------|------------------------------|
| C mix | 3.2                          |
| G1    | 3.58                         |
| G2    | 3.39                         |
| S     | 3.09                         |
| SG1   | 4.24                         |
| SG2   | 4.12                         |

5.3 Flexural strength
3 prism specimens were tested for each mix in flexural testing machine. Results obtained from the test show that flexural strength is increased by the addition of fibre.
Table 6 Flexural strength of concrete

| Mix  | Flexural strength N/mm² |
|------|-------------------------|
| C mix | 5                       |
| G1    | 6.4                     |
| G2    | 6.6                     |
| S     | 6.7                     |
| SG1   | 6.96                    |
| SG2   | 6.88                    |

Figure 6 Flexural strength of different mixes

6. Mode of failure
Crack and failure pattern of PCC and fibre reinforced concrete have some difference. In PCC crack formed initially enlarges and result in failure while in hybrid fibre reinforced concrete several cracks are formed. Due to the addition of fibre the failure mode is transformed from brittle to a little ductile.

Figure 7 Failure pattern for PCC

Figure 8 Failure pattern for HyFRC
7. Conclusion
This paper presents the results of experimental studies conducted on the properties of different concrete specimens. Mix compositions were reinforced with single and hybrid fibre. Volume fraction of each fibre was fixed as 0.5 % to obtain economical and workable mix. Based on the test carried on cube cylinder and prism specimen the following conclusions are highlighted.

- Compressive strength is improved by the addition of fibres. Maximum increase in compressive strength is 20.14% for SG1. It may be due to the influence of glass fibres. Glass fibres brought down the permeability and shrinkage.
- Split tensile strength is also improved by the addition of fibres and maximum increase is for SG1 which is 32.5%
- Flexural strength is also increased by the addition of fibres and maximum increase is 39.2% obtained for SG1
- Hybrid fibre reinforced mix with 6mm short fibre is found effective, because of the short length they can bridge the cracks without being ruptured and hence carry higher load.

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