Mechanical properties of concrete reinforced with graded pva fibers

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Abstract. Concrete is poor in tensile property due to its brittle nature. Improvement in the mechanical properties of concrete is carried by combining the rebars and fibers in concrete. Earlier research state that non-metallic fibres improve pre-crack performance and metallic fibers improve post crack performance. Short fibers resist the micro-cracks at an early stage and long fibers resist macro-cracks. The combination of short and long fibers makes the performance of concrete much effective. In this study, the investigation is done on non-metallic PVA fiber with the lengths of 6mm (Short fiber) and 12mm (Long fiber) by hybridization of fibers on 50MPa concrete. The investigation is done in two stages; in the first stage, the optimum dosage of fiber content and strength effectiveness of strengths is carried. Further, in the second stage the hybridization of fiber is done with the 30% SF + 70% LF, 50%SF + 50% LF, 70% SF + 30% LF for finding the optimum hybrid combination. Mechanical properties of concrete like flexural strength, split tensile strength, compressive strength is investigated. The results obtained by the hybridization of fibers are compared with the mono fiber performance and control mix. Improvement in strength parameters is observed in fiber hybridization. According to the fiber functionality, the hybrid combination of 30% SF + 70% LF showed desired results by improving the overall performance of concrete. More long fibers content improves the crack growth resistance than short fibers in concrete.

1 Introduction

Concrete stands simple construction raw material in construction field. Apart from concrete, many other materials with desired properties were used, but due to the many aspects, concrete was majorly used. Concrete is a heterogeneous mixture. Concrete had the property that it is strong in resisting the compressive forces and weak in resisting the tensile forces [1,2]. The above property shows the brittleness behaviour in concrete due to its nature it has risk allowance. Brittleness in any material shows the sudden failure without insisting at the start of the failure. For eradication of this type of failure in concrete we use steel rebars to increase the tensile strength in concrete [3]. On the economic aspect use of steel rebars at several stress stages [5]. Cracks formed maybe are of plastic shrinkage micro-cracks at an early age and micro cracks at later stages. Fibers of different lengths like short fibers are good at resisting the shrinkage cracks and improve the peak strength in the pre-crack region and lengthy fibers withstand the macro-cracks growth elongation and resilience the resilience in concrete after post crack region [6,7]. Fiber Reinforced Concrete are more effectively up to a limited range by the use of mono fibers. For resisting the fractures for a wide range like improving both pre and post crack properties is done by combining the different fibers [8]. The composition of fibers improves both tensile strength and toughness in concrete. Two or more combination of fibers exhibit the benefits of their individual properties and shows the synergic response [9]. This combination of fibers in concrete is characterized as H F R C. If the fibers of type with the different lengths and cross-sections, then concrete is labeled as G F R C (Graded fiber R C) [10]. Young's modulus property in fibers shows more variations in strengths [11]. A combination of various

are not effective, then fibers are used as a replacement of rebars for achieving more tensile strength and controls crack mechanism [4]. Fibers show improvement in strength effectiveness of mechanical properties like tensile and flexure strengths but only marginal improvement in compressive strength. Fiber materials are of two types one is metallic fibers like hooked steel fibers and the other are non-metallic fibers like poly vinyl alcohol, poly propylene, nylon, etc.., Fibers improves the concrete major outcome failures like brittleness, strain capacity, and crack growth resistance. The formation of cracks in concrete is caused by various parameters like properties of materials, age of concrete, and environmental effects. The formation of cracks in concrete remains a multi-scale development

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young's modulus fibers like low and high young's modulus shows more strength effectiveness and resisting the multi-scale cracks at various stress levels [12]. Low Young's modulus is achieved in non-metallic fibers for resisting the micro-level cracks and shrinkage cracks by increasing the peak strengths at lower levels. High Young's modulus is succeeded in metallic fibers for defying the macro breaks at higher stress points by increasing toughness in concrete. Poly Vinyl Alcohol (PVA) is a non-metallic fiber with low young's modulus of different lengths and circular cross-sectional fibers are used in this study. PVA fiber which is engineered and specifically designed for internal reinforcement are used in this investigative study. Formatting the title, authors and affiliations.

2. Research significance

In this study polyvinyl alcohol fibers of 6mm and 12mm of 0.06mm diameter are investigated. This is termed as graded PVA fiber in length and tensile strength. The idea of hybridization of fibers is applied by following the particle packing theory which resembles that the well-graded aggregates give the effective desired results than uniformly graded aggregates. Similarly, the fibers of different types give more appropriate results than using mono fibers. Hybridization of fibers helps more in counteracting the multi-scale crack growth at any stress levels. In any structure formation of cracks is common to resist those types of failure by gradation or hybridization of fibers. Gradation of non-metallic PVA fiber of different lengths are used. The optimum dosage of PVA fiber is investigated in this study. GFRC counteracts both micro and macro cracks by giving the peak strength, tensile strength and toughness of concrete.

3. Experimental study

3.1 Materials

Materials used are OPC 53 grade cement by following IS 12269 [13] with the specific gravity of 3.14 and consistency of 32%. Mineral admixture of flyash by following IS 3812 [14] and it is produced from thermal stations. Fine aggregate as river sand by following IS 383 [15] with the fineness modulus of 2.66 and specific gravity of 2.68. Coarse aggregate of crushed granite by following IS 383 with the fineness modulus of 6.8 and specific gravity of 2.78. Superplasticizer of complaint SP430 by following IS 9103 [16] for desired strength with minimum water content. Potable is water is used for mixing and also for curing purposes. Non-metallic fibers of polyvinyl alcohol as shown in fig (1) is used and the properties of PVA fiber are Tabulated below (1).

Fig. 1. PVA fibers

Table 1 Properties of fiber

Property	Poly Vinyl Alcohol
Fiber code	PVA
Length	6mm ,12 mm
Diameter	0.06 mm
Aspect ratio	100,200
Specific gravity	1.3
Elastic modulus (GPa)	40
Tensile strength (MPa)	800
Fiber geometry	Straight
Fiber cross-section	Circular

3.2 Mix design proportions

Concrete of 50MPa mix proportion is designed by following IS 10262 [17]. The proportions are mentioned in Table 2.

Table 2 Mix proportion of 50MPa per cubic meter

Grade of concrete	Cement (kg/m^3)	Flyash (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
50MPa	430	100	670	1000	196

3.3 Mixing and curing

Mixing of concrete is done in the mixer of a capacity of 100kg. The mixture of cement and fly ash are mixed thoroughly till achieving of uniform colour. Fine aggregate (FA) and coarse aggregate (CA) are placed in mixer and allowed it to mix for some time. After perfect mix then cementitious material is added and let to be a mix. Dosage of PVA fiber is added in the mix and required water content is added according to mix proportion and mixed thoroughly for 2 minutes to achieve the desired mixture of concrete. Superplasticizer is added for better workability as per IS 456 [18]. The concrete is placed in the moulds and followed by vibration using a table vibrator. The detailed specifications of the casting moulds are shown in Table 3. and the specimens are shown in fig (2). After the placing, the specimens are remolded after 24hrs and allowed for curing process for 28 days. All the specimens are get tested for knowing the mechanical

properties. The average of the three specimens results in the strength of that mix.

Fig. 2. Specimens for testing

Table 3 Dimensions of casting spécimens

Strength Property	Specimen	Dimensions (mm)
Flexural strength	Prism	100 x 100 x 500
Compressive strength	Cube	150 x 150 x 150
Split tensile strength	Cylinder	150 x 300

3.4 Volume proportions of mono and hybrides composites

This experimental investigation is done in 3 stages. In the stage1 the mono-PVA fiber of 6mm is used and the optimum dosage is calculated by conducting the volume fraction of 0.05, 0.1, 0.15, 0.2% and changes in the strength effectiveness of mechanical properties are studied. In the second stage, the mono PVA fiber of 12mm is used with the volume fraction of 0.05, 0.1, 0.15, 0.2% find of optimum dosage and change in strength effectiveness of mechanical properties are investigated. In the third stage, the combination of graded PVA fiber of 6mm and 12mm lengths with different percentages of mix is used. The three various percentage of volume proportion are considered in this study they are of 30% Short fiber (SF) + 70%Long fiber (LF), 50%SF + 50%LF, 70%SF + 30%LF with the fiber fraction of 0.15% as optimum dosage. The strength effectiveness of mechanical parameters is also achieved in this third stage. All three stages are carried out and investigated in this study.

3.5 Test Methods

The tests performed in this study are compressive, flexural and split tensile strength. Compressive strength test is done by following the IS 516 [19] the test is done in compressive testing machine through the specimen size of 150 x 150 x 150mm. Placing of the specimen as per specifications and allowed the rate of loading 14 $N/mm^{2/}$min as shown in fig (3). The average result of the three specimens is the strength of the mix. Flexural strength test was done by concluding IS 516 it is done in flexural strength test equipment with the prism of size 100 x 100 x 500mm. Test performed by 4-point loading with the loading rate of 180kg/min shown taking part in figure (4). Split tensile strength is done by following IS 516 test is done in the UTM with the cylindrical specimen of 150mm diameter and 300mm length. The weight is employed throughout the length of the specimen & weight utilized with the load up ratio of 1.2-2.4N/mm^2/min shown in figure (5). All the strength parameters of the concrete mix are calculated by the above test procedures. For getting the appropriate results of the strength parameters the test procedures should be done carefully.

Fig 3 Compressive strength

Fig. 4. Flexural strength test on prism

Fig. 5. Split tensile strength test on cylinder

4. Results and discussions

4.1 Mechanical properties of non-metallic mono-FRC

The results obtained in the investigation of mono PVA fiber of 6mm and 12mm lengths individually are discussed in detail. Fiber tested with the volume fraction of 0.05%, 0.1%, 0.15%, 0.2%. The optimal dosage obtained by mono PVA fiber of both lengths is at 0.15% of capacity fraction. After the optimum dosage of the volume fraction if fiber content is increased then it results in the decrease of the mechanical properties. So optimum dosage is fixed for the fiber content. The strength effectiveness of compressive strength of the mono PVA fiber of 6mm and 12mm at optimum dosage is 4.2% and 6.1% correspondingly as equated to control mix of grade 50. Results are not much effective because fiber increases both split tensile & flexural strengths but the minimal growth in compressive strength. The strength effectiveness of split tensile strength of the mono PVA fiber of 6mm and 12mm at the optimum dosage is 12.4% and 16% respectively as compared to the control mix of same grade. By this fiber content there is good growth in the strength effectiveness of tensile strength. Strength effectiveness of flexural strength of mono PVA fiber of 6mm and 12mm at the optimum dosage is 15.7% and 22.6% correspondingly as

matched to the nominal mix of 50MPa. The obtained improvement in strength effectiveness of flexural strength is much desirable. The adding of mono PVA fiber is much effective in increase of strength effectiveness of flexural strength from the above three mechanical properties of concrete. The optimum dosage and the strength effectiveness of every volume fraction of mono PVA fiber is given in detail in the Table 4,5. and showed in the graphical representation in Fig.6,7. As compared with the strength effectiveness of 12mm PVA fiber shows more effectiveness than 6mm due to its fracture elongation resistance of macro cracks. The functionality of short fibers is resisting the micro-cracks and long fibers resist the macro cracks. So 12mm is more desirable.

Table 4 Mechanical properties and Its strength effectiveness of Mono 6mm PVA fiber

Mix ID	Compressive Strength (MPa)		Split Tensile Strength (MPa)		Flexural Strength (MPa)	
	*F*ck	Strength effectiveness (%)	*F*st	Strength effectiveness (%)	*F*ft	Strength effectiveness (%)
CM	58	-	4.6	-	6.2	-
PVA 0.05	58.7	1.2	4.84	5.3	6.60	6.5
PVA 0.1	59.5	2.6	4.90	6.6	6.89	11.1
PVA 0.15	60.4	4.2	5.17	12.4	7.17	15.7
PVA 0.2	60.0	3.4	4.98	8.2	7.02	13.2

Table 5 Mechanical properties and Its strength effectiveness of Mono 12mm PVA fiber

Mix ID	Compressive Strength (MPa)		Split Tensile Strength (MPa)		Flexural Strength (MPa)	
	*F*ck	Strength effectiveness (%)	*F*st	Strength effectiveness (%)	*F*ft	Strength effectiveness (%)
CM	58	-	4.6	-	6.2	-
PVA 0.05	59.2	2	4.93	7.1	6.71	8.2
PVA 0.1	59.8	3.1	4.99	8.4	7.40	19.3
PVA 0.15	61.5	6.1	5.34	16	7.60	22.6
PVA 0.2	60.4	4.2	5.06	10.1	7.22	16.4

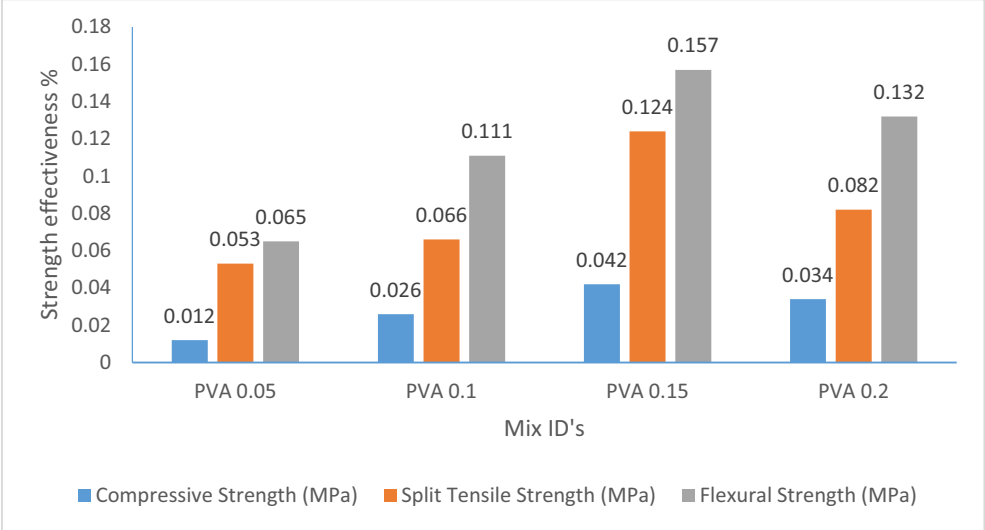

Fig. 6. Strength effectiveness of 6mm PVA fiber with respect to control mix

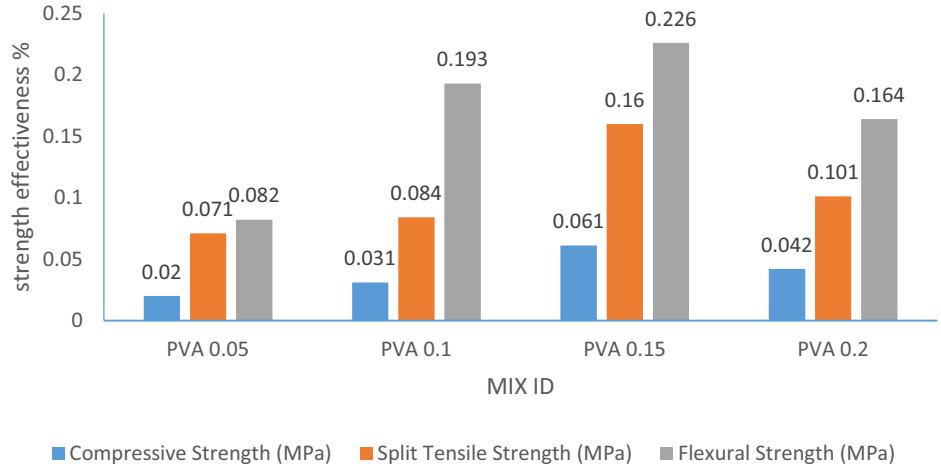

Fig. 7. Strength effectiveness of 12mm PVA fiber with respect to control mix

4.2 Mechanical properties of non-metallic graded FRC

. The results of the investigation done for the graded PVA fiber by a combination of lengths 6mm and 12mm are discussed. The different lengths of the PVA fiber are combined with the different percentages of mix. The combinations considered in this study are 30% Short fiber (SF) + 70% Long fiber (LF), 50% SF + 50% LF, 70% SF + 30% LF. The above combinations are done with the fiber volume fraction of 0.15%. The strength effectiveness of mechanical parameters is obtained. The obtained results of the above combinations are shown in detail in Table 6. and showed in the graphical representation in Fig. 8. From above combination 30% SF + 70% LF combination have a desire increase in strength effectiveness of mechanical parameters in 50MPa concrete mix than the other two combinations. Strength effectiveness of 30% SF + 70% LF combination the compressive strength is 10.4% and

strength effectiveness of split tensile strength is 30.2% and strength effectiveness of flexural strength is 36.2% as compared to control a mix of concrete 50MPa. Flexural strength of the graded PVA is more, split tensile strength is desirable and the compressive strength have only a marginal increase. The short fibers resist shrinkage and micro-cracks and long fibers resist the macro cracks, so the combination gave many desirable results which are having more percentage of long fibers for resisting the macro cracks for increasing the strength parameters of concrete.

Table 6 Mechanical properties and Its strength effectiveness of Graded PVA fiber

Mix ID	Compressive Strength (MPa)		Split Tensile Strength (MPa)		Flexural Strength (MPa)	
	*F*ck	Strength effectiveness (%)	*F*st	Strength effectiveness (%)	*F*ft	Strength effectiveness (%)
CM	58	-	4.6	-	6.2	-
PVA 0.15, 6mm	60.4	4.2	5.17	12.4	7.17	15.7
PVA 0.15, 12mm	61.5	6.1	5.34	16	7.60	22.6
30%L + 70%S	62.2	7.2	5.44	18.2	7.68	23.8
50%L + 50%S	62.8	8.2	5.64	22.6	8.02	29.3
70%L + 30%S	64.0	10.4	5.99	30.2	8.44	36.2

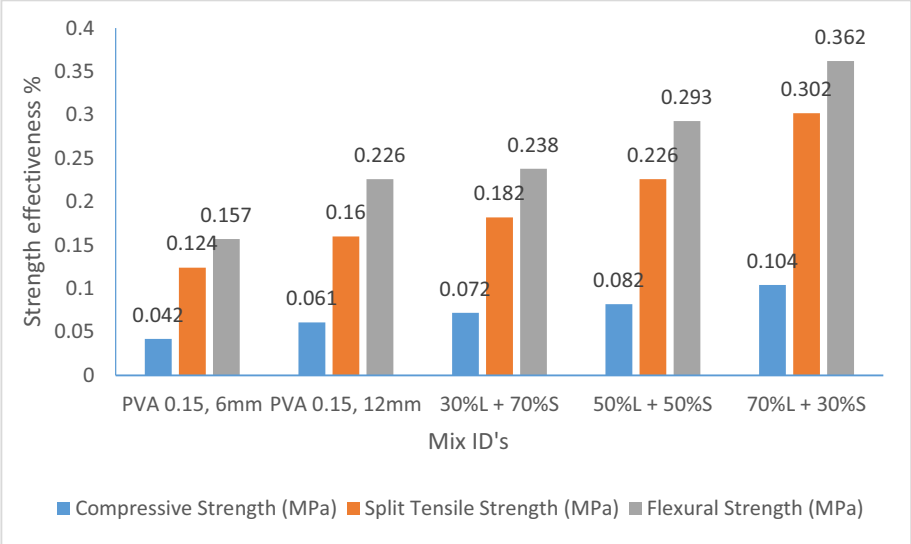

Fig. 8. Strength effectiveness of graded PVA fiber with respect to control mix

5.Conclusions

In this study the strength properties of concrete like flexural, split tensile, compressive strength and its effectiveness of PVA fiber reinforced concrete are investigated. From the above obtained results, the c decisions are:

- The optimum dosage of non-metallic mono PVA fiber of individual lengths 6mm and 12mm are obtained at 0.15% fiber. On increase of above 0.15% the strength parameter reduces due to the more fiber content is replaced by cement.
- Improvement in strength effectiveness of compressive strength is not effective but it has marginal improvement in it because of improper compaction the fibers create the unwanted voids.
- Improvement in strength effectiveness of flexural strength & split tensile strength have desired increase in it. Fibers helps in resisting the crack growth elongation and improves the peak strength and toughness in concrete.
- Mono PVA fiber of 12mm shown the desired results of mechanical parameters as compared with the 6mm mono PVA fiber.
- Graded PVA fiber of combination 6mm and 12mm with circular cross-section shows more effectiveness in strengths as compared to the nominal mix &mono PVA fibers of individual lengths.
- Hybridization of fibers with the combination of 30% short fiber + 70% long fiber with the optimum volume fraction of 0.15% shown better results in strength parameters as compared with the other combinations considered in this study.
- Short fibers resist the shrinkage and micro-cracks & long fibers resist the large-scale

cracks and enhance toughness in concrete. So, hybridization of graded PVA fiber is necessary for improving the overall performance of concrete.

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