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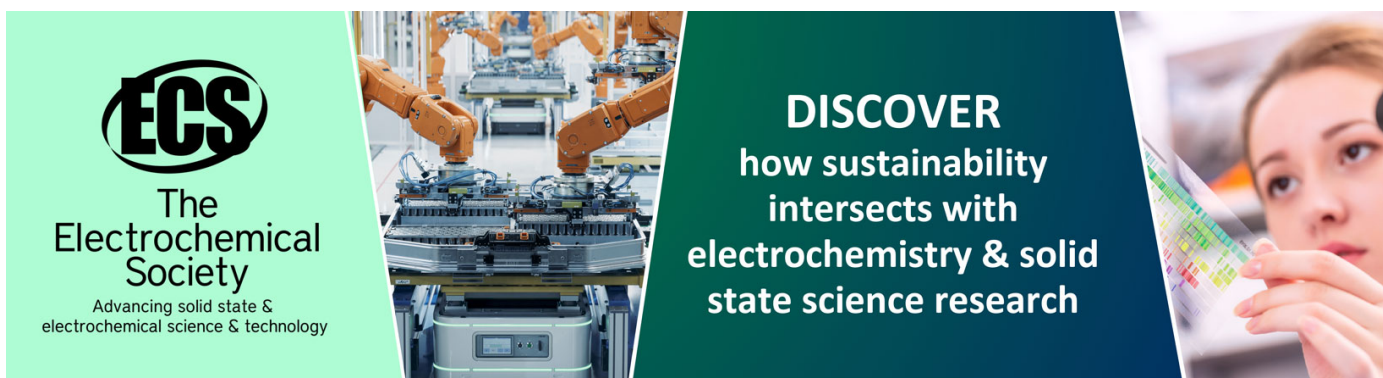
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Effect of Hybrid Discrete Fibers on Mechanical Properties of FRC

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Abstract. Combining micro and macro fibers provide high performance of fiber reinforced concrete before and after concrete matrix cracks. Concretes including different volume content of hybrid discrete fibers were evaluated regarding compressive, elastic modulus, and tensile splitting strength. Eight cases include seven types of hybrid composites that were constructed using fiber combinations of PVA and Polyolefin fibers. Test results showed that the PVA, Polyolefin, hybrid fibers reduce the compressive strength properties of concrete, especially with high volume content (2%). On the other hand, hybrid fibers improve significantly the tensile strength of concrete that leads to change the concrete behavior from brittle materials to ductile.

1. Introduction

Using discrete fibers in concrete applications improve flexural capacity, tensile strength, toughness, fatigue resistance, ultimate strain, and impact strength and reduced the crack width and required thickness. The properties of fiber reinforced concrete (FRC) depend on three factors; discrete fiber properties (i.e. length, diameter, strength, and shape), concrete matrix property, and bond property between fibers and concrete [1-13]. The concrete tensile and compressive strength are significant properties that used in the design and analysis of concrete applications although concrete behavior mostly governs compressive strength. The concrete tensile strength approximately presents 10% of compressive strength [14-15]. There are three of tests types have been utilized to determine concrete tensile strength; the flexural test, the direct tension test, and the splitting tensile test. The direct tension test is a complex to hold the sample and difficult to ensure the applied load is axial without any eccentricities. The flexural test gives flexural strength that is approximately 1.3 times of concrete tensile strength. While, the splitting tensile test is a rapid and easy to do for casted samples or drilled from the field [16-19]. According to ASTM C496 [20], the splitting test includes testing a cylindrical sample by compression diametrically load that create uniform tensile stresses along the sample diameter.

Discrete fibers have been classified into two types; macro and micro fibers that depend on length and diameter of the fibers. Macro FRC improves toughness, strain capacity, and ductility by bridge cracks after concrete matrix crack, while micro FRC delay appears the first crack by hold micro crack within



concrete matrix. Hybrid FRC contents two or more different kinds of discrete fibers to provide attractive engineering properties that derive from each of the individual fibers. The properties of hybrid FRC depend on the type, volume and combinations of fiber types and the interaction between them and concrete matrix [21-24]. Hybrid FRC has been divided into three composite categories; different fibers size with same properties, different fibers properties with same sizes, and different sizes and properties of fibers.

Using two different fibers types offer gain combined optimum properties of FRC. For example, strong and stiff discrete fiber improve ultimate capacity and first crack strength, while flexible discrete fiber increase toughness and ductility of FRC [25]. Steel fibers have been used several decades, but recently synthetic fibers have become predominant due to their ease of handling and resistance to rust damage⁹. Polyvinyl alcohol (PVA) synthetic micro fiber is typically has a tensile strength (250-350) ksi, and the cost of PVA is about 70% of steel fibers [26]. Polyolefin macro fibers are chemically stable and possess improved mechanical properties and have little effect on the workability of fresh concrete state. The weak point of polyolefin is the low modulus of elasticity and frictional adhesion with concrete matrix [2-29]. This paper investigates the effect of hybrid discrete fibers (PVA and Polyolefin) on the compression and tensile properties of fiber-reinforced concrete (FRC) tensile bond test.

2. Experimental Program

An extensive experimental study had been conducted to calculate the mechanical properties of hybrid FRC under splitting tensile strength of cylindrical concrete specimens using ASTM C496 [20]. In splitting tensile strength test record the longitudinal direction deformation of the specimens during the tests. Two Linear Variable Displacement Transducers (LVDTs) were placed longitudinally from face to face of the base plate that distribution the load on the specimens as shown in Figure 1. The Addition to that it was used the compressive strength of cylindrical Concrete Specimens ASTM C39 [30]. All mixtures had the same water-to-cement (w/c) ratio of 0.45. The ordinary concrete mixture was used as a control mixture without any discrete fibers added. All mixtures proportion of different cases shown in Table (1). The concrete was mixed by ASTM C192 [31]. Two different volume fraction is consisting of FRC that PVA and Polyolefin used to investigate their effects on mechanical properties of FRC. Their physical properties are summarized in Table (2). ASTM C150 [32] type I/II Portland cement with a specific gravity of 3.15 was used in all mixtures. The coarse aggregate used was crushed limestone with a maximum size of 0.5 in (12.7 mm), and relative density of 2.48. While the fine aggregate used was natural sand with a relative density of 2.63. Both coarse and fine aggregates conformed to the ASTM C33 [33] specification.

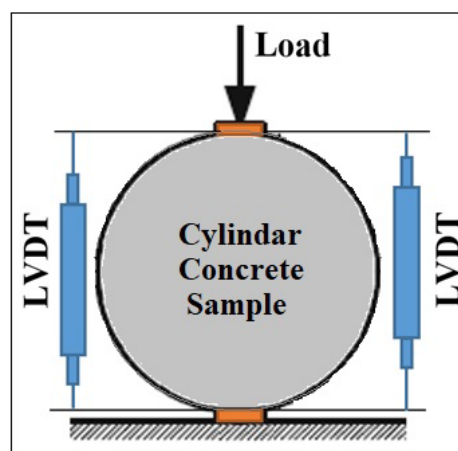


Figure 1. Splitting Tensile Test with Longitudinal Direction Deformation Setup.

Table 1. Proportion of Cases Mixtures.

Case #	V_f , %	PVA, %	Polyolefin, %
1	0	0	0
2	1	1	0
3	1	0.75	0.25
4	1	0.5	0.5
5	1	0.25	0.75
6	1	0	1
7	2	0.5	0.5
8	2	0.25	0.75

Table 2. The physical properties of used fibers.

Properties	Types of Fibers	
	Polyolefin 	PVA 
Specific Gravity	0.91	1.3
Cut Lengths, in.	1.9	0.75
Diameter, in.	0.1	0.0079
Tensile Strength, ksi	80	150
Flexural Strength, ksi	1160	4200

3. Results and Discussion

3.1. Effect of Hybrid Discrete on Compressive Strength

Table (3) illustrates the compressive strength versus fiber volume fraction for mixtures with FRC and hybrid FRC. It is observed that in general for the mixtures with hybrid FRC, there was little effect on compressive strengths, but it had small effect by volume fraction. However, for the FRC mixtures with volume fraction 1% the compressive strength decreased by roughly 10% and 22% for PVA and Polyolefin fiber, respectively. This could be attributed to the fiber acting as voids in the concrete matrix as the discrete fiber cannot provide any resistance to compression.

3.2. Effect of Hybrid Discrete on Elastic Modulus

Similarly, the same effects were also observed in elastic modulus. Table (3) shows the hybrid fiber did not influence its elastic properties, but it had small effect by volume fraction. However, for the FRC mixtures with volume fraction 1%, the elastic modulus did not influence its elastic for PVA, while for Polyolefin it was decreased roughly 15%. This could also be attributed to the possible extra voids brought on by the addition of fiber as revealed by the results.

Table 3. The Compression Properties of Hybrid FRC.

Case #	V_f , %	PVA, %	Polyolefin, %	f_c' , psi	E_c , ksi
1	0	0	0	6200	4488
2	1	1	0	5700	4303
3	1	0.75	0.25	5500	4227
4	1	0.5	0.5	5100	4071
5	1	0.25	0.75	4900	3990
6	1	0	1	4650	3887
7	2	0.5	0.5	4700	3908
8	2	0.25	0.75	4450	3802

3.3. Effect of FRC and Hybrid FRC on Tensile Strength

In this study, two types of fiber; PVA and Polyolefin with different fiber contents and mixing properties were investigated to determine improving concrete tensile strength. For 1% volume fraction of FRC, Figure (2a) shown that PVA and Polyolefin improve significantly tensile strength of more than 70% and 140% of plain concrete. For 1% volume fraction of Hybrid FRC it is clearly with increasing percentage of Polyolefin to PVA fiber tensile strength was improved, see Figure (2b). For 2% volume fraction of Hybrid FRC Figure (2c) shown that add 0.5% volume fraction of PVA and Polyolefin improves significantly tensile strength more than 160% of plain concrete.

3.4. Effect of FRC and Hybrid FRC on Tensile Stress- longitudinal strain

The splitting tensile stress-longitudinal strain curves obtained for the cylinder splitting tests performed are shown in Figure 3. These results explain that the PVA had lower longitudinal strain than Polyolefin fiber. Therefore, by adding Polyolefin fiber to PVA FRC, it was improved the longitudinal strain that improving from the toughness of compression part. In another hand, the PVA fiber had an excellent improvement in the elastic stage that led to prevent the growth and formation of cracks. The results indicate that the material behaves linearly elastically until a first peak is reached then the fiber work to carry the additional load until tensile strength. The load stabilizes at this level before increase deformation and failure.

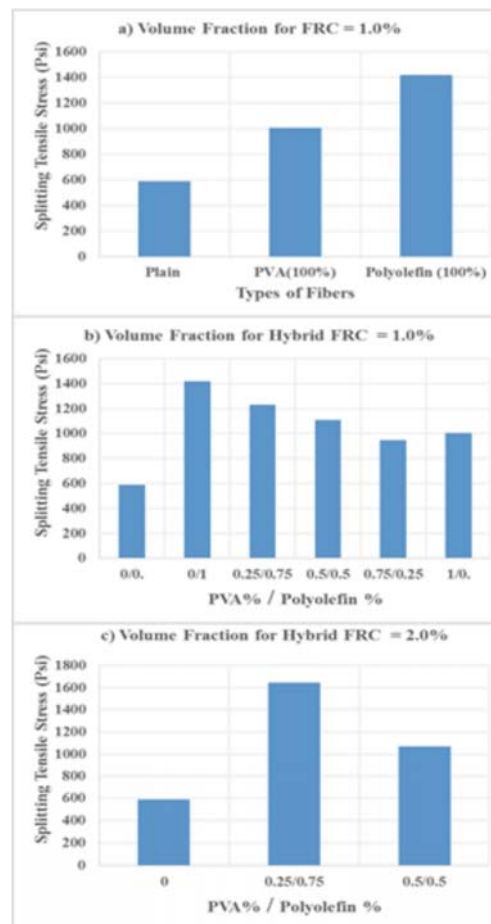


Figure 2. Splitting Tensile Strength for a) FRC, b) hybrid FRC for $vf=1.0\%$, and Hybrid FRC for $vf=2.0\%$.

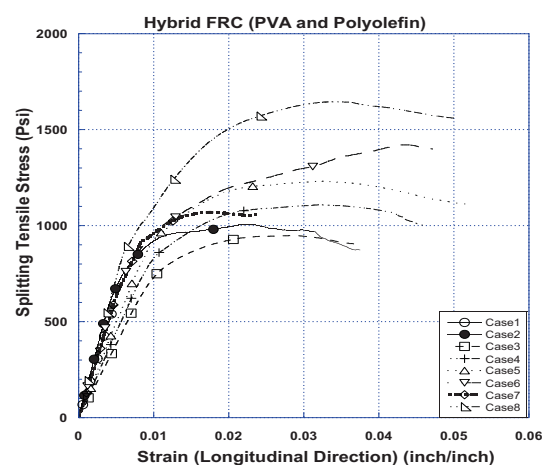


Figure 3. Tensile Stress and the Longitudinal Direction Strain Hybrid FRC.

4. Conclusion

From this study, it could be clearly seen discrete fiber reduce the compression properties and improve the tensile strength of concrete mixtures.

- Adding 1% of PVA and Polyolefin decrease the concrete compressive strength of FRC by 10% and 22%, respectively.
- Using 1% PVA in FRC has little effect on elastic modulus while adding Polyolefin reduced elastic modulus more than 15%.
- PVA and Polyolefin improve the significantly tensile strength of FRC more than 70% and 140% of plain concrete.

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