Estimation of Shear Strength of High Strength Hybrid Fiber Reinforced Concrete

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Abstract: ***Concrete is one of the principle material for structures and it is widely used all over the world, which possesses high compressive strength and durability, such concrete shows extremely brittle failure. To improve such a poor property, Fiber Reinforced Cementitious Composites (FRCC) have been developed. Tensile and shear properties of fiber reinforced concrete (FRC) depended mostly on the type, content and selected FRC system. Fibres are added to the concrete merely not to increase the tensile strength itself but mainly to control the cracking. A composite is termed as hybrid, if two or more types of fibers are rationally combined. Steel fibres are believed to contribute more to strength while polymeric fibres are believed to contribute to the ductility (i.e., toughness). In the case of hybrid systems (Hy-FRC), the review of literature concluded that the behavior of Hy-FRC was, in fact, the combined behavior of steel and polymeric fibres are more balanced in terms of strength and post-peak ductility.***

Keywords: Fiber reinforced cementitious composites (FRCC), control the cracking, strength, contribute to the ductility, toughness, combined behavior of steel and polymer fibers

1. Introduction

1.1 General

Concrete is a construction material composed of cement (commonly Portland cement) as well as other cementations materials such as fly ash and slag cement, aggregate (generally a coarse aggregate made of crushed rocks such as limestone, or granite, plus a fine aggregate such as sand), water, and chemical admixtures.

1.2 Structural Properties of Concrete

The studies have been conducted largely based on the structural properties of concrete and have been discussed below.

- Compressive strength
- Tensile strength
- Shear strength
- Bond Strength
- Impact Strength

1.3 Types of Concrete

The mechanical properties of concrete can be improved by adding admixtures, plasticizers and super plasticizers. The different types of concrete are;

- Normal Strength Concrete,
- High Strength Concrete,
- Fiber Reinforced Concrete,
- High Performance Concrete,
- Self-consolidating Concrete,

1.4 Benefits

- Improve mix cohesion, improving pumpability over long distances,
- Improve freeze-thaw resistance,
- Improve resistance to explosive spalling in case of a severe fire,
- Improve impact resistance,
- Increase resistance to plastic,

1.5 Objective

The aim of the project is to estimate the shear strength of high strength hybrid fiber reinforced concrete using double notched specimen.

1.6 1.6 SCOPE

The scope of the present investigation is;

1. To estimate the shear strength of concrete, using the notched cylindrical specimen for three different grades of concrete viz. M_{60}, M_{80} and $M_{100.}$
2. The experimental investigation has to be conducted on notched cylindrical specimens.
3. The different types of fibers to be used in the experimental investigation are polyethylene fiber (toyobo) and micro-steel fiber (dramixBekaert).

2. Literature Review

2.1 Literature Review

William Suaris et al (1983) have identified the requirement for the rational design of concrete structures subjected to impact and impulsive loading, the constituent properties of concrete over a wide range of strain rates. With this as objective, concrete and fiber reinforced concrete beams were tested in a drop-weight, instrumented impact-testing machine. The influence of different types of fibers such as steel, polypropylene and glass on impact test was studied. The energy absorbed by fiber reinforced concrete beams was as much as 100 times that for unreinforced beams.

V.Yogendran et al (1987), has studied extensively on High Strength Concrete using Silica Fume with no air entrainment to achieve compressive strength in the range of 50 to 70 Mpa in which cement was replaced by silica fume (0 to 30% by weight). The efficiency of silica fume in improving the properties of concrete was compared at medium and very low water cementitious ratios.

R.Narayanan et al (1987) has done investigations on the behaviour of steel fiber reinforced concrete beams subjected to predominant shear. The report establishes that the inclusion of steel fibers in reinforced concrete beams results in a substantial increase in shear strengths. When 1% volume fraction of fibers was used, increases of up to 170% in ultimate shear strength were observed.

B. Barr (1987), have studied the shear performance of fiber-reinforced concrete (FRC) materials. Three types of fibers (steel, polypropylene and glass fiber) have been used to study the shear performance of fiber-reinforced concrete specimens using double-notched specimens. It has been concluded that the shear strength of steel FRC has been increased by the addition of fibers (by weight).

P.C.Aitcin et al (1990), has investigated the influence of four coarse aggregate types available in Northern California on the compressive strength and elastic behaviour of a very high strength concrete mixture and said that compressive strength and elastic modulus of concrete were shown to be significantly influenced by the mineralogical characteristics of aggregates.

Mariano Valle et al (1993), have studied shear strength and ductility properties of fiber reinforced high strength on double-notched specimen's concrete under direct shear. Steel fibbers to High Strength Concrete produced a relative toughness, which was greater (5%) than that for the plain high strength concrete specimens.

3. Steel, Polypropylene and Hybrid Fiber Reinforced Concrete

3.1 General

The early theoretical studies, initiated by Romualdi, Batson, and Mandel, in the 1950's and 1960 are focused mainly on the characteristics of steel fiber reinforced concrete (SFRC). Only straight steel fibers were used in the beginning. The various types of steel fibers are shown in figure 3.1.

3.2 Mechanical Properties of SFRC

Flexural Tensile Strength: Steel fibers are more efficient in increasing flexural strength of concrete.

Toughness and Ductility: The primary purpose of fiber inclusion to concrete is not to increase strength but to provide toughness and ductility.

Fatigue Behavior: Data on fatigue behavior of SFRC is rare and mixed. Various researchers concluded that steel fiber inclusion does not affect the uniaxial compressive fatigue strength.

Creep Behavior: Steel fiber inclusion does not significantly affect the creep behavior since the fiber content as a volume percentage is very small when compared with the aggregate content.

Behavior under High Strain Rates:
Like plain concrete, SFRC is also very strain rate sensitive. Both the compressive and tensile strengths and corresponding ultimate strain values, and therefore fracture energy values are increased as the applied strain rate isincreased.
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3.3 Mix Design Considerations ForSfrc

By making certain adjustments to conventional concrete practice, it is possible to produce SFRC. The primary concern is to introduce sufficient amount of uniformly distributed fibers in concrete to achieve improvements in mechanical properties, keeping the concrete workable to permit proper mixing, placing, and finishing. There are various procedures available for the mix design of SFRC. Typical recommended proportions are shown in Table1

Table 1: Range of Proportions for normal weight SFRC

Property		*9.5mm maximum size aggregate*	*19 mm maximum size aggregate*
Cement kg/m^3		355 - 590	300 -535
w/c ratio		0.35 – 0.45	0.4-0.5
Fine/coarse aggregate (%)		45-60	45-55
Entrained air		4-7	4-6
a.	Smooth steel	0.9-1.8	0.8-1.6
b.	Deformed Steel	0.4-0.9	0.3-0.8

3.4 Polypropylene Fiber Reinforced Concrete (PPFRC)

3.4.1 General

Synthetic fibers have attracted more attention for reinforcing cementitious materials in the recent years. In this part emphasis is given on polypropylene fibers, as they were used throughout the experimental program. Polypropylene fibers were suggested as an admixture to concrete in 1965 for construction of blast-resistant buildings for the U.S Corps of Engineers [3]. Results of this research work showed that polypropylene fibers could be practical for reinforcing concrete, since polypropylene is cheap, abundantly available, and possess a consistent quality. Considerable improvements in strain capacity, toughness, impact resistance, and crack control of concrete can be obtained through the use of polypropylene fibers. Polypropylene fibers are manufactured in various shapes and different properties.

3.4.2 Mechanical Properties of PPFRC

Conventionally polypropylene fibers are used in concrete at relatively low contents, 0.1 to 0.3% by volume, as a secondary reinforcement to control and reduce the plastic shrinkage cracking of concrete. Polypropylene is hydrophobic due to its chemical structure, which leads to reduced bonding with the cement, and negatively affecting its dispersion in the matrix.

3.4.3 Mix Design Considerations for PPFRC

Mix design for PPFRC should take into account the properties of polypropylene fiber that best suits the aggregate, the required workability, and the equipment to be used in making the product. For thin sheet products, more flexible polypropylene fibers should be accommodated as stiffer ones may protrude after demolding, whereas use of stiffer polypropylene fibers would be more beneficial in applications where toughness is of concern.

3.5 Hybrid Fiber Reinforced Concrete (HFRC)

A composite can be termed as hybrid, if two or more types of fibers are rationally combined in a common matrix to produce a composite that derives benefits from each of the individual fibers and exhibits a synergetic response. According to Benthur and Mindess the advantages of hybrid fiber systems can be listed as follows.

1. To provide a system in which one type of fiber, which is stronger and stiffer, improves the first crack stress and the ultimate strength, and the second type of fiber, which is more flexible, and ductile leads to improved toughness and strain in the post-cracking zone.

2. To provide hybrid reinforcement in which one type of fiber is smaller, so that it bridges the micro cracks of which growth can be controlled. This leads to a higher tensile strength of the composite. The second type of fiber is larger, so that it arrests the propagating macro cracks and can substantially improve the toughness of the composite.

3. To provide a hybrid reinforcement, in which the durability of fiber types is different. The presence of the durable fiber can increase the strength and/or toughness relation after age while the other type is to guarantee the short-term performance during transportation and installation of the composite elements. In the present approach the strengthening and toughening mechanisms for cement based composites are viewed on two different scales. To strengthen the matrix, the specific fiber spacing must be decreased in order to reduce the allowable flaw size.

4. Experimental Study

4.1 Experimental Program

Aim of this study was to produce HFRC and then to characterize its properties, especially the mechanical properties such as tensile strength in the hardened state. Three different types of fibers were used in combination, two of which were steel fibers, and the other was polyethylene fibers. For this purpose three mixes were cast and in each mix there were five batches and in each batch, one plain control mix and four fiber reinforced mixes were prepared. In three of the fiber-reinforced mixes, a hybrid form of reinforcement was used.

The volume percentage of fibers is shown in table 4.1. These values were chosen after a careful examination of available literature considering the capability of compaction equipment in the laboratory. Steel fibers constituted half of the total fiber content whereas the remaining part was composed of micro fibers in hybrid fiber reinforced mixes.

Slump test was performed for each mix in the fresh state. Compressive strength and shear strength tests were carried out for each mix in the hardened state. The sectional detail of the notched specimen is shown in figure 1.

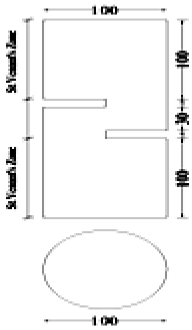

Figure 1: Sectional details of Notched specimen

4.2 Material

Cement used was Type I Portland cement conforming to ASTM C150. The fly ash was Class F fly ash. The physical properties and chemical analysis of cement, fly ash and silica fume are given in Table2

Table 2: Physical properties and chemical analysis of cement, fly ash and silica fume

Properties	*OPC*	*Fly Ash*	*Silica Fume*
Type/Class	ASTM Type I	ASTM Class F	-
Physical Properties			
Specific Gravity	3.08	2.16	2.22
Fineness			
Passing 45µm sieve (%)	-	90%	-
Retained on 150µm sieve (%)	-	1%	-
Surface Area, Blaine's (cm^2/gm)	2746	3683	-
Chemical Analysis			
SiO_2	22.38	61.85	87.13
Al_2O_3	6.73	28.03	1.96
Fe_2O_3	4.72	5.03	1.13
CaO	59.46	1.06	7.16
MgO	1.02	1.05	0.33
SO_3	2.33	0.07	0.12
Na_2O	0.021	0.21	0.09
K_2O	0.36	1.34	0.33
Cl	0	0.001	0
LOI	2.31	0.95	1.52

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Table 3: Concrete Mix Proportions

Materials	*Quantity (M_{60})*	*Quantity (M_{80})*	*Quantity (M_{100})*
Binder Content, kg/m^3	550	590	650
Type I Cement, kg/m^3	412	471	552
Silica Fume, kg/m^3	55	42	98
Fly Ash, kg/m^3	83	77	-
Fine Aggregate, kg/m^3	640	610	600
Coarse Aggregate, kg/m^3	1075	1060	1050
Water, kg/m^3	145	141.6	140
Superplasticizer, liters/ m^3	8.25	8.25	10.1
Water/Cement Ratio	0.26	0.24	0.22

Table 4: Properties of fibers

Properties	*Fibers*		
	Polyethylene Fiber	*Micro Steel Fiber*	*Dramix Steel Fiber*
Tensile strength	2.6GPA	2.6GPA	-
Tensile modulus	79GPA	-	-
Elongation	3-5%	-	-
Diameter	0.012mm	0.16mm	0.55mm
Density	0.97g/cm3	7850 kg/m^3	7850 kg/m^3
Length	12mm	13mm	35mm
Specific gravity	-	7.17	7.6
Aspect Ratio	1000	81.25	64

Table 5: Fiber Mix Proportion

Designation	*Percentage of Fiber*		
	MSF	*SF*	*PE*
M1	-	-	-
M1SF1	0.25	-	-
M1SF2	-	0.75	-
M1SF3	-	-	0.5
M1TF	0.15	0.25	0.4
M2	-	-	-
M2SF1	0.25	-	-
M2SF2	-	0.75	-
M2SF3	-	-	0.5
M2TF	0.15	0.25	0.4
M3	-	-	-
M3SF1	0.25	-	-
M3SF2	-	0.75	-
M3SF3	-	-	0.5
M3TF	0.15	0.25	0.4

MSF – Micro steel Fiber
SF – Steel Fiber
PE – Polyethylene Fiber

4.3 Notched Cylinder

Concrete has been poured until the bottom of the notch and horizontal plank to cover the slit has been provided and vibrated. Then the concrete has been placed till the top level of the notch and the next horizontal plank to cover the second slit has been provided and vibrated. Then the concrete has been filled up to the top level of the cylinder and compacted finally. The top level of concrete in the mould has been capped as per standards. The cast specimen is shown in Figure 1.

Figure 1: Notched specimen

4.4 Curing

Curing can be described as keeping the concrete moist and warm enough so that the hydration of cement can continue. More elaborately, it can be described as the process of maintaining a satisfactory moisture content and a favorable temperature in concrete during the period immediately following placement, so that hydration of cement may continue until the desired properties are developed to a sufficient degree tom meet the requirements of service. Curing is being given a place of increasing importance as the demand for high quality concrete increases. It has been recognized that the quality of concrete shows all round improvement with efficient uninterrupted curing. If curing is neglected in the early period of hydration, the quality of concrete will experience a sort of irreparable loss. An efficient curing in the early period of hydration can be compared to a good and wholesome feeding given to a new born baby. So curing of concrete is very important and the specimens are placed in the curing tank after 24 hours of casting of concrete and taken out before testing.

4.5 Testing Procedure

The micro crack initiated stress for the various grades of concrete is shown in table6, 7 and 8 the graph has been plotted for stress along X axis and UPV values along Y axis as shown in fig2, 3 and 4. The failure pattern and failed specimen are shown in fig5 and6.

Table 6: UPV values for grade M1

Stress (N/mm^2)	*Velocity (m/sec)*				
	M1	*M1SF1*	*M1SF2*	*M1SF3*	*M1TF*
0	4740	4510	4610	4620	4720
5	4790	4720	4650	4680	4770
10	4790	4760	4650	4680	4770
15	4790	4760	4650	4680	4770
20	4790	4760	4650	4680	4770
25	4740	4760	4610	4680	4770
30	4740	4760	4610	4680	4770
35	4740	4670	4610	4610	4770
40	4740	4670	4610	4610	4770
45	4740	4670	4610	4610	4600
50	4740	4650	4610	4610	4600
55	4740	4650	4550	4550	4600
60	4700	4650	4550	4530	4520
65	4690	4650	4550	4530	4520

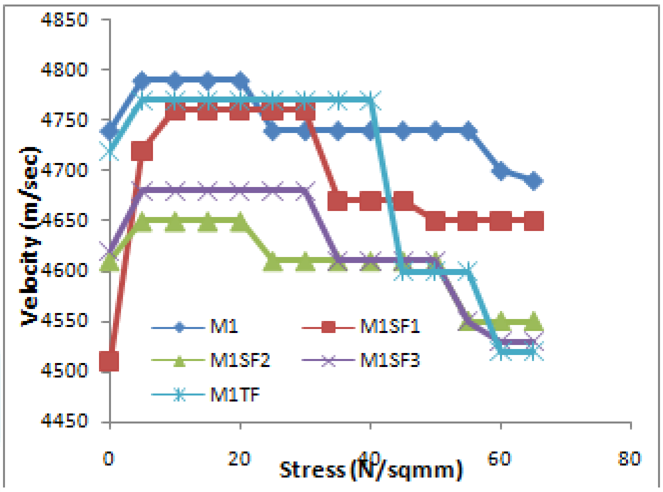

Figure 2: Micro crack initiated stress for grade M1

Table 7: UPV values for grade M2

Stress (N/mm²)	*Velocity (m/sec)*				
	M2	*M2SF1*	*M2SF2*	*M2SF3*	*M2TF*
0	4720	4740	4730	4740	4830
5	4760	4780	4735	4750	4880
10	4760	4790	4735	4750	4880
15	4760	4790	4740	4750	4880
20	4760	4790	4820	4750	4880
25	4760	4790	4820	4750	4880
30	4760	4790	4820	4750	4880
35	4630	4790	4820	4750	4880
40	4550	4790	4820	4750	4880
45	4510	4710	4820	4750	4880
50	4460	4710	4820	4630	4880
55	4330	4710	4700	4630	4730
60	4330	4710	4700	4630	4730
65	4320	4510	4500	4610	4730

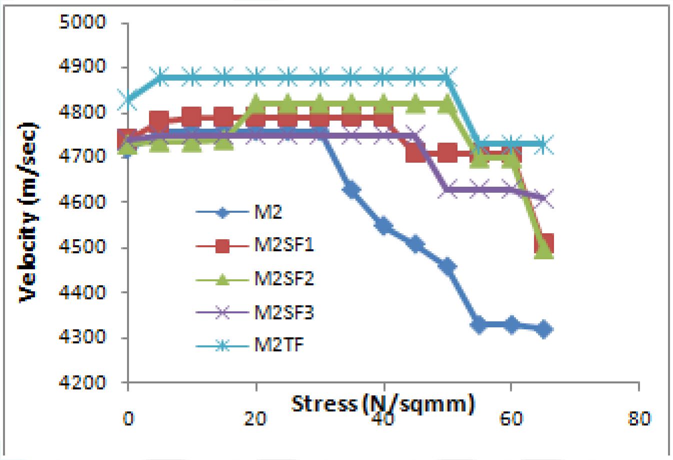

Figure 3: Micro crack initiated stress for grade M2

Table 8: UPV values for grade M3

Stress (N/mm²)	*Velocity (m/sec)*				
	M3	*M3SF1*	*M3SF2*	*M3SF3*	*M3TF*
0	4550	4750	4840	4690	4870
5	4570	4790	4880	4760	4890
10	4670	4790	4880	4760	4890
15	4670	4790	4880	4760	4890
20	4670	4790	4880	4760	4890
25	4670	4790	4880	4760	4890
30	4670	4790	4880	4760	4890
35	4670	4790	4620	4760	4890
40	4670	4670	4620	4620	4890
45	4410	4670	4620	4620	4860
50	4410	4670	4600	4620	4860
55	4410	4670	4580	4440	4860
60	4410	4550	4580	4440	4860
65	4400	4550	4580	4440	4810

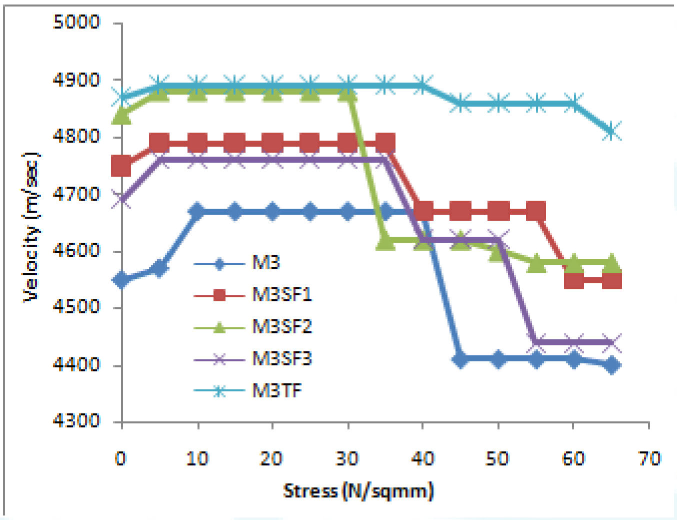

Figure 4: Micro crack initiated stress for grade M3

Table 9: Results of Compressive Strength and Shear Strength

Grade of Mix	*Compressive strength after 28 days (N/mm²)*	*Designation*	*Gradually applied load*			
			Ultimate Load (P) kN	*Shear Area * (mm²)*	*Shear Stress (τ_c) (N/mm²)*	*Failure observed*
M1 M60	68.4	M1	32	3000	10.67	Shear
		M1SF1	36	3000	12	Shear
		M1SF2	37	3000	12.33	Shear
		M1SF3	39	3000	13	Shear
		M1TF	44	3000	14.67	Shear
M2 M80	84	M2	34	3000	11.33	Shear
		M2SF1	39	3000	13	Shear
		M2SF2	40	3000	13.33	Shear
		M2SF3	41	3000	13.67	Shear
		M2TF	47	3000	15.67	Shear
M3 M100	101	M3	39	3000	13	Shear
		M3SF1	42	3000	14	Shear
		M3SF2	44	3000	14.67	Shear
		M3SF3	45	3000	15	Shear
		M3TF	48	3000	16	Shear

Figure 5: Failure Pattern

Figure 6: Failed Specimen

5. Results and Conclusions

5.1 General

The results show that the shear strength of triple fibers used in concrete gives higher strength compared to other mixes.

5.2 Experimental Results

The compressive strength and shear strength results are shown in Table 9.

5.3 Conclusions

1. The shear stress is critical in the common vertical plane available between the top and bottom notches and hence the sudden failure is witnessed during experiment with a “THUD“ noise.
2. When the overlap of notches is greater than 10mm in specimens the failure is initiated due to flexure followed by shear.
3. For the distance between the notches 30 mm the specimen failed in pure shear.

The overlap of the notches plays an vital role and hence it should to be taken into consideration.

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