STRENGTH AND WORKABILITY OF HYBRID FIBER REINFORCED SELF COMPACTING CONCRETE

Hawraa A.Al-Shibani

Email: hawraa09537@cceoman.net

Abstract. In this project, an experimental investigation is carried out on Hybrid Fiber Reinforced Self Compacting Concrete (HFR-SCC) containing macro steel and micro polypropylene fibers, in volume proportions of 0.316% and 0.451%, respectively. Standard cube, beam and cylindrical specimens were cast and tested for strength properties and compared with C40 grade control mix. Specimens were subjected to high temperature of 110^0C for durability property and tested. Slump flow, V-funnel and L-Box tests were also conducted on (HFR -SCC). The study indicate (HFR-SCC) mix with the highest volume fraction of 0.451% showed high characteristic compressive, split tensile and flexure strengths. Workability of HFR-SCC also showed satisfactory results except L-box test.

Keyword. Strength, Workability, Self Compacting Concrete, Hybrid Fibre Reinforced Self Compacting Concrete, Macro steel fibres, Micro polypropylene fibres.

INTRODUCTION

SCC was initially developed in Japan by Okamura in late 1980's, referred to as the Japanese method. SCC has been used widely in the construction industry worldwide for a long duration of time. Recently many research works has been carried out on developing self-compacting concrete including the addition of hybrid fiber in SCC, (HFR-SCC).

Hybrid Fiber Reinforced Self Compacting Concrete (HFR-SCC) is defined as the addition of combination of two fibers either from different materials or from the same material with different geometry (aspect ratio) and shapes. HFR-SCC offer the application of hybridized fibers in SCC has been presented by many research studies, "The combination of hybrid fiber reinforced concrete HFRC and SCC together can provide a way of producing a HFR-SCC with superior properties in not only hardened state but also fresh state" [1]. The addition of hybridized fibers results mainly toward increasing the strength and toughness properties of SCC and the workability properties may face slightly reduction mainly in flow rate [1, 2]. Finally, the main factors to be considered for the workability of the SCC with the addition of hybrid fibers are: the flow-ability, passing ability, flow rate and segregation resistance [3].

Macro steel (S-F) and micro polypropylene fiber (PP-F) reinforced acts as reinforcement in SCC, where micro polypropylene fibers functions as reinforcement, towards minimizing and eliminating the formation and propagation of micro cracks, and reduces the plastic shrinkage and sedimentation, whereas macro steel fibers functions as reinforcement, towards minimizing and eliminating the formation and propagation of macro cracks, and increases ductility of the concrete. The properties of fibers that are of main concern to the SCC properties are the geometry, concentration, distribution and orientation of the fiber [1]. The study investigates the strength and workability characteristics of SCC with the inclusion of two different volume of fraction of steel and polypropylene fiber reinforced.

In addition, the effects of high temperature on the characteristics strength properties of self compacting concrete with the addition of fibers are investigated. The addition of steel fibers improves the heated concrete mechanical properties and may delay the occurrence of spalling. However, the addition of polypropylene fibers results in the heated concrete towards reducing the possibility of spalling, and since the polypropylene fibers melt at 160 ^{o}C or 170 ^{o}C causes porosity, which may lead toward decreasing the mechanical properties of the concrete [4].

METHODOLOGY

The methodology and experimental setup in this study to achieve the objectives set of the study is presented in this chapter.

Materials Properties

The materials properties adapted in the production of HFR-SCC are as follows:

- Cement, the type of cement introduced within this study for casting C40 grade concrete for all the mixes are Ordinary Portland Cement (OPC) and the addition of type 2 pozzolanic Flyash cement. The specification of OPC is in accordance to BS EN 197-1:2000, and the specification of Flyash cement is in accordance to BS 3892 Part 1:1997.
- Fine aggregate, two types of fine aggregate were presented within the mix design of this study, Natural washed sand and Dune sand, with relative density of 2.76 Mg/m^3 and 2.70 Mg/m^3, respectively.
- Coarse aggregate, two types of coarse aggregate were presented within the mix design of this study. Crushed aggregate of 20 mm and 10 mm diameter with relative density of 2.81 Mg/m^3 and 2.80 Mg/m^3, respectively.
- Admixture, the super-plasticiser introduced in the mix design is Glenium 110M, with density of 1.1 g/m^3.
- Macro Steel fibers, in this study only one type of steel fibers are presented. The macro steel fibers Dramix RC-65/60-BN are cold drawn wire fiber of hooked ends with 60 mm length and 0.9 mm diameter and the aspect ratio (l/d) of the fiber is 67, the density of the fiber is 7.8 g/m^3.
- Micro Polypropylene Fibers, the study also presents another type of fiber micro polypropylene fibers. Micro polypropylene fibers presented in this study are a RHEOFIBRE which is a fiber of a high performance monofiliment polypropylene with a 12 mm length and 18 microns diameter and the aspect ratio of the fiber (l/d) 666.67, the density of the fiber is 0.91 g/m^3.

Table 1. HFRC properties.

Fibres	Length	Diameter	Aspect Ratio L/d
Macro S-F (hooked end)	60 mm	0.90 mm	67
Micro PP-F	12 mm	18 micron	666.67

Mix Design

- Volume Fraction of Fibers: the study included two different volume of fraction of 0.316% and 0.451%. The volume of micro polypropylene fibers are kept constant throughout all the mixes and the volume of macro steel fibers are changed.
  Three mixes were prepared in this study, one control mix and the rest Hybrid Fiber Reinforced Self Compacting Concrete (HFR-SCC) mixes. The following table 2 presents the different mixes with the different fibers volume percentage of the study.
- Mix Design: Three mix designs are presented in this study which results with compressive strength of 40 N/mm^3 based on a reference mix from “Al Turki Cement Product LLC”.

Table 2. Volume Fraction of Fibers in each mix.

Mix Designs	Macro Steel fibres By %volume	Micro polypropylene fibres By %volume	Total Fibres By % volume
Mix 1 (control mix)	-	-	-
Mix 2	0.25%	0.066%	0.316%
Mix 3	0.385%	0.066%	0.451%

Table 3. Mixture proportion.

Mixture no.	Cement OPC (Kg/m^3)	Flyash (Kg/m^3)	Washed Wadi Sand (Kg/m^3)	Fine Sand (Dune Sand) (Kg/m^3)	10 mm Crushed Agg. (Kg/m^3)	20 mm Crushed Agg. (Kg/m^3)	Macro Steel Fibers (Kg/m^3)	Micro Polypropylene Fibers (Kg/m^3)	Water (Kg/m^3)	Glenuim 110M (Kg/m^3)
1	375	125	650	260	460	380	-	-	170	4.8
2	375	125	650	255	460	380	20	0.6	170	5.20
3	375	125	660	260	450	370	30	0.6	170	5.30

Note:
1 *– Control mix 0% fiber.*
2 *- 0.25% macro steel + 0.066% micro polypropylene fibers*
3 *- 0.385% macro steel + 0.066% micro polypropylene fibers*

Table 3 demonstrates the trail mix details mentioned above, where all the trail mixes comprised of water cement (w/c) ratio of 0.34 and the mix design ratio of 1: 1.82: 1.7.

The mixing and casting of the samples for this study included a pan mixer with a capacity of 0.035 m^3. The following mixing and casting procedure steps were adapted in this study:

- The mixing and casting of specimens is executed in an open atmosphere at a temperature varying from 32^oC to 40^oC.
- The duration of mixing process is approximately 5 minutes.
- Coarse and fine aggregates are initially added to the pan mixer vessel, were its mixed for approximately 10 seconds for homogeneity.
- OPC and Flyash cement are then added to the vessel, it's mixed for approximately 10 seconds.
- Only for Mix 2 and Mix 3 Macro Steel Fibers and Micro Polypropylene Fibers are then added to the vessel, were it is mixed for approximately 30 seconds to assure the homogeneity of fibers in the mix.
- Cold water of a temperature 20^oC is added to the mixing vessel.
- Super-plasticizer Glenium 110M is finally added to the vessel.
- Finally the placing of fresh concrete mix into the cube, beam and cylindrical specimen moulds.

The study includes 36 test specimens.

Test procedures

The study examines the workability and strength of SCC with the inclusion of hybridized fibers. The workability properties of the mixes were investigated through several tests conducted as per The European Guidelines for Self-Compacting Concrete [5]. The following points describe briefly the workability test procedures adapted through the study:

- Flow Test, is used to evaluate the flow-ability of the SCC. The test classifies the flow-ability of the mix, from the recorded slump flow, through measuring the spread concrete in two perpendicular directions, and also it evaluates the viscosity of the mix, through recording T500, the time in which it requires the concrete to reach 500 mm diameter.

- V-Funnel Test is used to evaluate the viscosity, segregation resistance and filling-ability of the mixes. The V-funnel is filled with the concrete and the V-funnel time is recorded, the time in which it requires the concrete to flow through the apparatus.
- L-Box Test is used to verify the flow-ability and passing ability through obstacles of the mixes. The concrete is filled in the L-Box and the gate is opened, allowing the concrete to flow through the rebars, and the passing ability is recorded.

For each mix design, 6 cube specimens of size (150 mm X 150 mm X 150 mm), 3 beam specimens of size (750 mm X 150 mm X 150 mm) and 3 cylindrical specimens of size 300 mm height and 150 mm diameter were prepared. The specimens were cured for 28 days in water at (20±2) ^{o} C. The strength properties of the mixes were investigated through compressive strength, flexural strength and split tensile strength tests conducted as per BS EN 12390, at the age of 28 days. Moreover, durability characteristics of high temperature of 110^{o}C on the compressive strength have been studied.

RESULTS AND DISCUSSION

Workability properties test results.

<u>Flow Test</u>

Table 4. Flow test results

Mixture	Fiber Vol.%	Slump (mm)	Slump classes	T500 (s)	Viscosity classes
1	0%	750	SF3	5	VS2
2	0.316%	725	SF2	3	VS2
3	0.451%	625	SF1	4	VS2

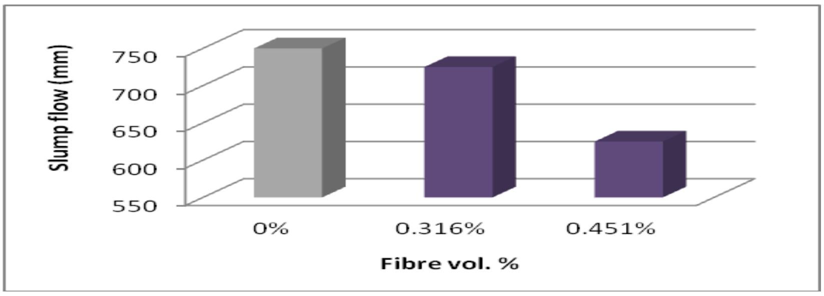

Figure. 1. Slump Flow (mm)

Table 4 and fig. 1 shows that the slump of Mix 2 and Mix 3 decreased from Mix 1 (control mix) due to the addition of fibers, but as per the classification the slump results were sufficient for both Self Compacting Concrete (SCC) Mix 1 (control mix) and the Hybrid Fiber Reinforced Self Compacting Concrete (HFR-SCC) Mix 2 and Mix 3. Table 4 and fig. 2 presents the viscosity classes of the resulted T500, where the viscosity of Mix 2 and Mix 3 resulted slightly higher than Mix 1, due to the addition of Glenium 110M super-plasticizer and the high paste content the viscosity of (HFR-SCC) was not affected by the addition of fibers as it increased the flow-ability of the mixes.

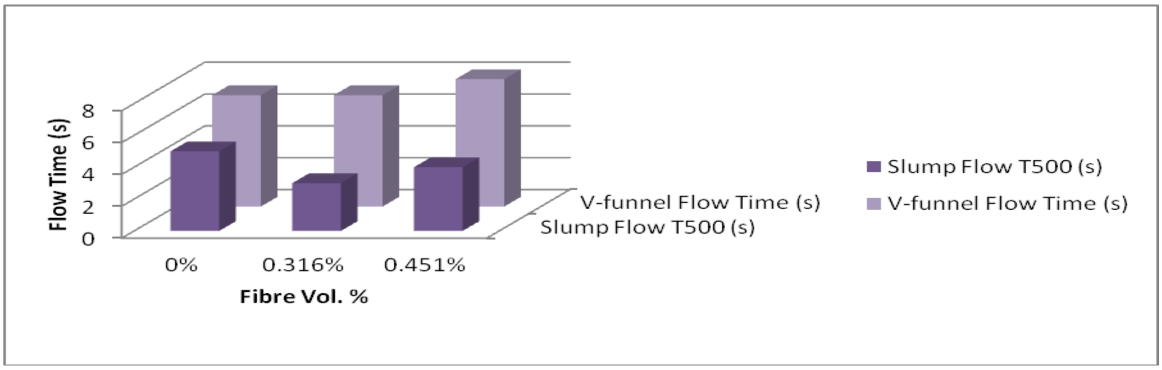

Figure. 2. Slump Flow T500 (s) & V-Funnel Flow Time (s)

V-funnel Test

Table 5 and fig. 2 presents the viscosity classes of V-Funnel Flow time. The results indicate that Mix 1 (Control mix) with 0% fibers and Mix 2 with 0.316% volume of fraction resulted equally, where Mix 3 with 0.451% volume of fraction resulted slightly higher than Mix 1 and Mix 2 due to a high dosage of fibers.

Table 5. V-funnel and L-Box test results

Mixture	Fiber Vol.%	V-funnel Flow Time (s) .	Viscosity Classes	Passing Ability (cm)	PA Classes 3 rebars
1	0%	7	VF1	0.875	PA2
2	0.316%	7	VF1	0.14	<0.8
3	0.451%	8	VF2	0.0896	<0/8

L-Box Test

Table 5 and fig. 3 shows the passing ability of the mix designs. Mix 1 (Control mix) SCC with 0% fibers resulted adequately as per the European Guidelines for Self-Compacting Concrete. However, the passing ability of Mix 2 and Mix3 of HFR-SCC resulted with a failure, as per the code for a 3 rebars L-Box test the passing ability should exceed 0.8 cm where Mix 2 and Mix 3 resulted less than 0.8 cm, due to the length of Macro Steel Fibers. Due to the fact that the L-Box rebars spacing is of 50 mm and the length of Macro Steel Fibers is 60 mm, the fibers could not pass through the rebars spacing, which as a result blocked the aggregate and fibers. Segregation case was observed during the experiment procedure. However, the HFR-SCC mixes can be safely utilized in case of any rebars of spacing 100 mm or more.

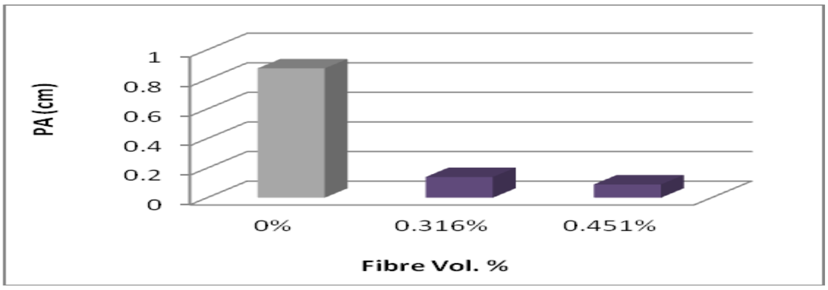

Figure. 3. L-Box Passing Ability (cm)

Strength properties test results.

Table 6. Strength Properties Test Results.

Mixture	Fiber Vol.%	Compressive Strength MPa.	Flexural Strength MPa.	Split Tensile Strength MPa.	Compressive Strength MPa under high temp.
1	0%	63	7.23	5.07	75.3
2	0.316%	62.8	7.23	6.73	72
3	0.451%	63.13	7.87	7.13	71.73

Compressive Strength

The results of compressive strength of the mixes from table 6 and figure 4, the following can be observed:

- The compressive strength of Mix 1 control mix resulted with 63 MPa, where Mix 2 and Mix 3 of HFR-SCC resulted with 62.8 MPa and 63.13 MPa, respectively.
- The results of compressive strength of the plain SCC and HFR-SCC mixes resulted higher than the proposed mix design C40, due to high paste content and the addition of Glenuim 110M super-plasticizer.
- The compressive strength of the SCC mixes with the inclusion of hybrid fiber reinforced resulted slightly similar to the SCC mix with 0% fibers.
- As the addition of hybrid reinforced fibers increased the compressive strength increased in case of Mix 3.
- Mix 2 of 0.316% fiber volume observed a decrease of 0.32% compared to Mix 1 (control mix) in the compressive strength, where Mix 3 of 0.451% fiber volume observed an increase of 0.21% compared to Mix 1 in the compressive.

Flexural Strength

The following points analyze the results of flexural strength of the mixes from table 6 and figure 5:

- The flexural strength of Mix 1 control mix resulted with 7.23 MPa, where Mix 2 and Mix 3 of HFR-SCC resulted with 7.23 MPa and 7.87 MPa, respectively.
- The flexural strength results shows that there's a slight increase due to the inclusion of hybrid fibers compared to the control mix of 0% fibers.
- Mix 3 with 0.451% fiber volume resulted with highest flexural strength compared to Mix 1 and Mix 2.
- As the fiber volume increases the flexural strength of the mix increases.
- In comparison with the Mix 1 (control mix), Mix 2 resulted equally, where Mix 3 observed an increase of 8.85%.
- As per the crack patterns during the flexural strength tests on the beams samples, an observation of two types of crack patterns were recorded that are bending cracks and shear cracks.

Split Tensile Strength

The results of split tensile strength of the mixes from table 6 and figure 6, the following can be analyzed:

- The flexural strength of Mix 1 control mix resulted with 5.07 MPa, where Mix 2 and Mix 3 of HFR-SCC resulted with 6.73 MPa and 7.13 MPa, respectively.
- The split tensile strength tests result shows an increase due to the inclusion of hybridized fibers.

- As the fiber volume of the mixes is increased, the split tensile strength of the SCC is increased.
- In comparison with the Mix 1 (control mix), Mix 2 observed an increase of 32.7%, where Mix 3 observed an increase of 40.6%.

Effect of high temperature on compressive strength

The results of compressive strength under high temperature of the mixes from table 6 and figure 7, the following can be observed:

- The compressive strength of Mix 2 and Mix 3 of HFR-SCC resulted with 72 MPa and 71.73 MPa, respectively, where Mix 1 control mix resulted with 75.3 MPa.
- The higher the amount of the hybridized fibers, the lower the compressive strength of the concrete mixes.
- As per the results of the compressive strength under high temperature, the decrease of strength in HFR-SCC mixes in comparison to the SCC control mix; is due to the fact that polypropylene fibers melt at high temperature, which leads towards additional expansion channels and porosity, causing a decrease of the mechanical properties of the concrete [4].Moreover, the reduction of the quantity of water as it evaporates due to high temperature causing additional porosity, leading towards reduction of the mechanical properties of the samples.
- Furthermore, the compressive strength results showed an improvement under high temperature compared to the normal temperature SCC samples.

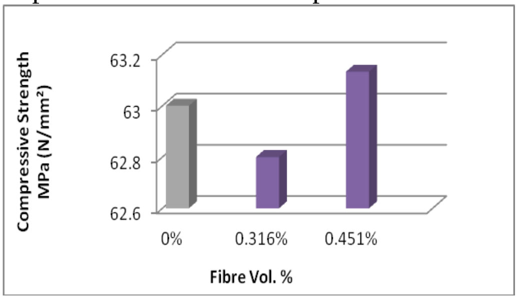

Figure. 4. Compressive Strength Test Results.

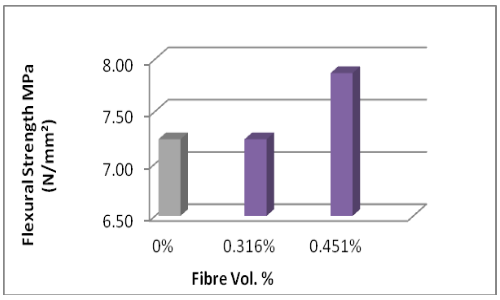

Figure. 5. Flexural Strength Test Reults.

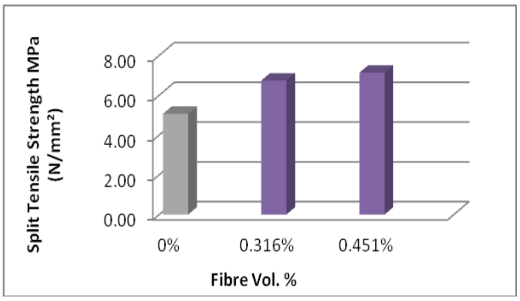

Figure. 6. Split Tensile Strength Test Results

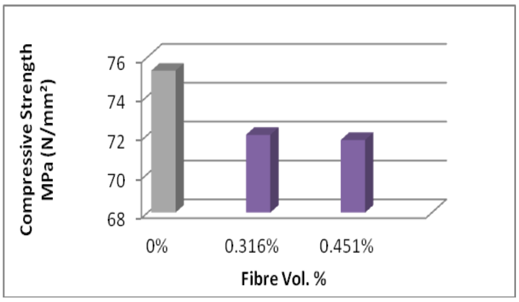

Figure. 7. Compressive strength under high temperature test results.

CONCLUSION

Based on the experimental investigation and analysis the following conclusions are derived:

– **Workability Properties:**

- Flowability of Hybrid Fibre Reinforced Self Compacting Concrete (HFR-SCC) of Mix 2 and Mix 1 in Slump Flow test reduced comparing to the control mix of SCC Mix 1, due to the addition of fibres, but the flowability and viscosity of T500 results were sufficient as per the European Guidelines of Self-Compacting Concrete.
- The viscosity and filling ability of HFR-SCC Mix 2 and Mix 3 in V-Funnel test, resulted with extremely sufficient viscosity compared to the control mix SCC Mix 1, due to the high paste

content and Glenium 110M super-plasticizer which produced a flowable HFR-SCC despite the inclusion of fibres.
- Passing ability through reinforcement in L-Box test, the HFR-SCC Mix 2 and Mix 3 resulted with failure, due to blocking case causing segregation, due to the length of macro steel fibres of 60 mm and the rebars spacing of 50 mm, whereas the control mix SCC Mix1 resulted with sufficient passing ability.

– **Mechanical Properties:**

- Compressive strength tests results indicate that as the volume fraction of fibre is increased, the compressive strength of the HFR-SCC is increased.
- The flexural strength results shows that there's a slight increase due to the inclusion of hybrid fibres compared to the control mix of 0% fibres.
- The split tensile strength tests result shows an increase due to the inclusion of hybridized fibres, in-comparison to the control mix of 0% fibres.
- HFR-SCC (Mix 3) with volume of fraction of 0.451% resulted with the highest mechanical properties in compressive strength, flexural strength and split tensile strength tests.
- Durability characteristics of high temperature of 110^{o}C resulted with reduction in the compressive strength of the HFR-SCC mixes in comparison to the control mix of 0% fibers, due to evaporation of water and the inclusion of polypropylene fibers which melt at high temperature causing additional porosity.
- Finally, as per the split tensile strength test the samples shows an even homogenous distribution of fibers in the samples.

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