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Workability of Hybrid Fiber Reinforced Self-Compacting Concrete

Abstract- *The aim of this work is to evaluate the effect of adding different types of fibers on the fresh properties of the self-compacting concrete, SCC. The used types of fibers were steel (with volume ratios of 0.75, 1.0 and 1.25 %) and polypropylene fibers (0.10 and 0.15 %) and a hybrid system of these fibers (0.65 % steel and 0.10 % polypropylene). The conducted tests in the fresh state were slump flow, T500, V-funnel and L-box. It was noticed that increasing the volume fraction of fibers would lead to decrease in the workability of SCC. According to EFNARC requirements for SCC, many test results were nonconforming. It was also concluded that polypropylene fibers have higher detrimental effect on fresh properties of SCC than steel fibers and that was attributed to the ability of polypropylene to absorb part of mixing water.*

Keywords- *L-box, Polypropylene fibers, Self-compacting concrete, Slump flow, Steel fibers, V-funnel*

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1. Introduction

The basic concept of self –compacting concrete, SCC, was first proposed by Okamura at the University of Tokyo. It was defined that the concrete which can be placed in the formwork and compacted without any consolidation effort. It flows and fills every corner of the formwork by its own weight [1].

Benefits of SCC are reducing the time work of construction, high workability in formworks and filling all porous between the rebar and concrete properties that added to concrete to be SCC (fluidity and segregation resistance) as result as high level of homogeneity, low voids of concrete and consistent concrete strength, providing the potential for a superior level of finish and durability to the structure. Early strength and low water cement ratio are the best way have been found with, earlier demolding and faster using of elements and structures [2].

Due to the highly flowable nature of SCC, it is better to ensure excellent filling ability, passing ability and adequate stability [3].This ability is achieved by ensuring accurate rheological properties of fresh concrete: a low yield stress value associated with suitable plastic viscosity. Merging fibers with SCC in order to produce fiber reinforced self-consolidating concrete (FRSCC) is therefore highly desirable and carries a lot of potential for the concrete industry [4].

2. Fresh Properties of SCC

The workability of SCC is higher than the highest class of consistence and can be described by the following properties:

1. Filling Ability
2. Passing Ability
3. Segregation Resistance

If the requirements for all three characteristics are fulfilled, mix can be classified as SCC as reported by Al-Jabiry [5]. These characteristics were made possible by the development of highly effective water reducing agents (super-plasticizers) those usually based on polycarboxylate ethers [6]. Each of these functional requests; filling ability, passing ability and segregation resistance is affected by the others and it difficult to separate them, for example, inadequate passing ability can be caused by lowly filling ability or lowly segregation resistance [7].

3. Material and Experimental Work

I. Materials

1) Cement

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Ordinary Portland cement had been used in laboratory (IQS 5:1984 – Type 1) [8]. Tables 1 and 2 shown below The chemical and physical properties. It was produced by the United Cement Company (Tasluja-Bazian) in Al -Sulaymaniyah Governate/ Iraq, commercially known as MAS.

2) Fine Aggregate

Ordinary sand from Al-Ukhaidher region, Iraq was usedin this study for concrete mixes. The fine aggregate grading is based on the Iraqi Standard IQS 45-1984 [9] are illustrated in Table 3 and 4 are fit to the specification of the Iraqi Standard IQS 45-1984.

Table 1: Chemical Analysis and Compound Composition for Cement*

Property	%	IQS 5:1984 requirements [8]
CaO	61.27	
SiO_2	21.27	-
Fe_2O_3	3.12	-
Al_2O_3	5.05	-
MgO	2.06	<5
SO_3	2.07	<2.8
L.O.I%	3.21	<4
Insoluble residue	1.32	<1.5
L.S.F	0.88	0.66 – 1.02
Compound Composition (Bogue's equation)		
C_3S	43.42	-
C_2S	28.31	-
C_3A	8.11	-
C_4AF	9.48	-

*: The chemical tests were carried out at the Central Organization for Standardization and Quality Control, COSQC.

Table 2: properties of Physical cement material *

Properties	Cement	IQS 5:1984 requirements [8]
Fineness (Blaine method), m^2/kg	481	≥ 230
Setting time ,hr :min		
Initial	3: 20	≥45 min
Final	4: 40	≤10 hours
F`c , MPa, at		
Three days	33.4	>15
Seven days	42.2	>23
Soundness: autoclave %	0.19	< 0.8

*: The chemical tests were carried out at the Central Organization for Standardization and Quality Control, COSQC.

Table 3: Fine aggregate grading

Sieve size (mm)	% Cumulative Passing	Limitations of the IQS 45-1984 - zone 2 [9]
4.75	100	90-100
2.36	90.4	75-100
1.18	81.9	55-90
0.60	57.9	35-59
0.30	16.9	8-30
0.15	2	0-10

*: These tests were conducted at the NCCLR.

Table 4: General fine aggregate Properties *

Properties	Test Results	Limitations of the IQS 45-1984 [9]
Specific gravity	2.62	-
Sulfate ontent %	0.08	≤ 0.50 %
Absorption%	0.9	-
Materials finer than 75 µm sieve, %	1	< 5%
Fineness Modulus	2.51	-

*: These tests were conducted at the NCCLR.

Table 5: Grading of coarse aggregate*

Sieve size (mm)	% Cumulative Passing	Limitations of the IQS 45-1984 [9]
20	100	-
14	100	100
10	93	85-100
5	10	0-25
2.36	0	0-5

*: These tests were conducted at the, NCCLR.

Table 6: General properties of coarse aggregate*

Properties	Test results	IQS Limits No.45/1984 [9]
Specific gravity	2.6	-
Sulfate content	0.08	≤0.1
Absorption %	0.52%	-

*: These tests were conducted at the NCCLR.

Table 7: Chemical Analysis and Compound Composition for limestone dust*

Oxides	Percent
SiO_2	1.38
Fe_2O_3	0.12
Al_2O_3	0.72
CaO	56.1
MgO	0.13
SO_3	0.21
L.O.I	40.56

*: The chemical analysis was conducted at the National Center for Geological Survey and Mines.

Table 8: Specifications of fibers used in the SCC mixes*

Fiber type	steel	Polypropylene
Length, mm	15	12
Diameter, mm	0.2	0.15
Aspect ratio	75	80
Geometry	straight	Straight
E modulus,Epa	212	3.5
Tensile strength mpa	2850	1300
Density, kg/m3	7850	900
Cross-section	circular	circular

*: According to the manufacturer.

3) Coarse Aggregate

Crushed gravel passing sieve 12 mm had been used from Al-Niba'ee region. The grading and general properties are listed in Tables 5 and 6 respectively are fit to the specification of the Iraqi Standard IQS 45-1984 [9].

4) Limestone Dust, LS

"Al-Gubra" is material that commonly used as unenhance material for self-compacting concrete. The limestone, LS, powder-passing sieve 1.18 mm is used in this study. The surface area of limestone powder can influence the rheological behavior of the SCC mix. Limestone powder with very fine particles increases the yield stress of fresh SCC and decreases its slump flow. Hence, more superplasticizer is needed to offset the reduction in SCC flowability [11].The chemical analysis and compound composition for limestone dust LS is listed in Table 7.

5) Fibers

The fibers used in this research work were steel and polypropylene fibers. The properties of the used fibers are tabulated in Table 8.

6) Mixing water:

It was drinkable water.

7) High-Range Water Reducer (Superplasticizer):

Glenium 54 a chemical composition was used im self-compacting concrete and this product is conforming to the ASTM C 494 [12].

Table 9: Details of the reference SCC mix

Mix	M0
Cement, Kg/m3	425
Silica fume, kg/m3	75
Limestone dust,Kg/m3	120
Fine aggregate, kg/m3	780
Coarse aggregate,kg/m3	830
Water,kg/m3	170
Glenium 54,l/m3	12

II. Experimental Program

A reference SCC mix, M0, is designed to give us a 28-day characteristic cube compressive strength of 60 MPa. The design of mixing concrete method used in this study is done according to EFNARC [13, 14]. Weights of used materials are listed in Table 9.

Another seven fiber-reinforced SCC mixes were produced by adding different types and contents of fibers to the mix M0 as shown in Table 10.

III. Mixing Procedure for SCC

The mixing procedure had been used in this study was recommended by Emborg [15] and adjusted by Al-Jabri [5]. The procedure is as following:

1) First add fine aggregate to the mixer with 1/3 of mixing water and start to mix for 1 minute.

2) Add the cement with the Silica fume with another 1/3 quantity of water.

3) After that add the coarse aggregate with the remaining quantity of water and 1/3 dosage of Glenium 54, and mix for one and half minutes.

4) The remaining quantity of Glenium 54 is added to the mix and mixed for one and half minutes.

5) Take a sample of concrete and test.

6) If the mix contains fibers, they were added before step 4.

Table 10: Details of the fiber-reinforced SCC mixes

mix	Type of combination	Steel Vf%	Poly-Propylene Vf%	Total Vf%
M0	No fibers	0.00	0.00	0.00
MSF75	Single fiber	0.75	0.00	0.75
MSF100		1.00	0.00	1.00
MSF125		1.25	0.00	1.25
MPF10		0.00	0.1	0.10
MPF15		0.00	0.15	0.15
MPF25		0.00	0.25	0.25
MHF75	Double fibers	.65	0.1	0.75

4. **Test Result and Discussion**

Flowability level measurements as well as fresh properties and L-box. Table 11 shows the results of the aforementioned tests for SCC mixes. Results of the selected SCC mixes were proved by follow the applicable standards. The fresh SCC tests were slump flow, T500, V-Funnel and L-box.

Table 11: Test results of fiber-reinforcement scc mixes

mix	Slump flow, mm	T 500, sec	v-funnel ,sec	v-funnel after 5 min	l-box H2/ H1
M0	770	2.0	6.5	9	.92
Msf75	660	3.0	9	13	.85
Msf100	610	4.0	11	14	.82
Msf125	480	9.0	18	22	.4
Mpf10	630	4.0	8	11	.84
Mpf15	580	4.7	10	12	.87
Mhf75	600	4.2	11.5	13.5	.85

I. Slump Flow and T500 Tests

According to Table 11 and Figures 1 and 2, all SCC mixes, except for MSF125 and MPF25, have showed an acceptable fluidity and consistency requirements from the filling ability point of view. The slump flow values lie between 580 and 770 mm. Furthermore, T500 values are in the range of 2 to 4.7 sec. These results are similar to those of acceptable limits for these results are similar to those of acceptable limits for SCC [13, 14]. Only the mix MSF125, with 1.25 percent steel fibers, and mix MPF25, with 0.25 polypropylene fibers, are not acceptable according to the requirements of governing specifications [13, 14]. Therefore, mixes MSF125 and MPF25 were discarded from the next testing program.

Figures 1 and 2 indicate that a dropped in the slump flow and a raised in T500 values were caused by the inclusion of fibers in mix M0. The slump flow reduced by 3.6, 6.3 and 6.9 % and increase in the T500 by 10, 20 and 30 percent for mixes MSF, MPF and MHF respectively compared with reference mix, M0. It seems that hybrid fibers have the most negative effect on the flowability than polypropylene and steel fibers alone. This effect could be due to the network action and large surface area of polypropylene than steel which reduces the flow significantly and hence increases the flow time. These findings are in agreement with Johnsirani and Than [16].

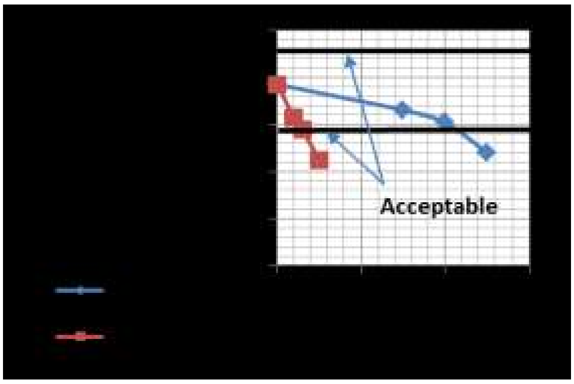

Figure 1: Slump flow variation for different SCC mixes

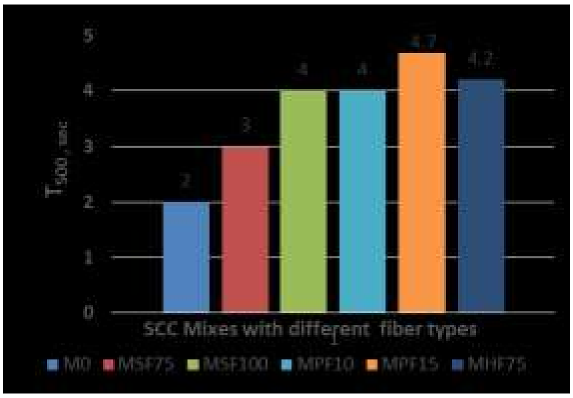

Figure 2: T500 variation for different SCC mixes

II. Funnel Test

The V-Funnel test used to investigate the filling ability and SCC stability. According to the part regarding with SCC filling ability, test results lie between 6.5 and 11.5 sec, where no segregation appearance is observed for all mixes. These results are within the acceptable criteria for SCC [13, 14], Figures 3 and 4 show V-funnel test results and V-funnel test after 5 minutes.

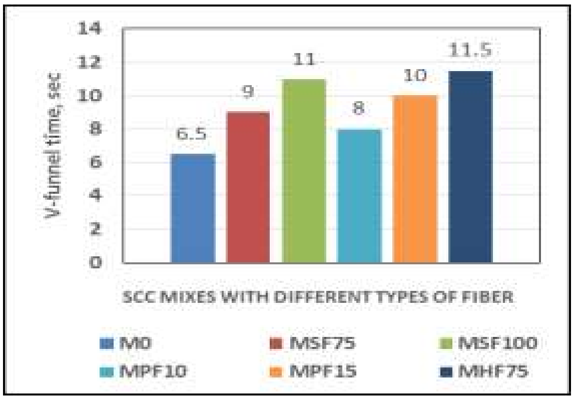

Figure 3: V-funnel time variation for different SCC mixes

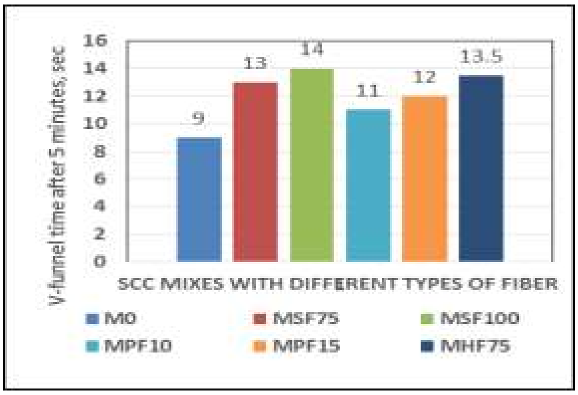

Figure 4: V-funnel time after 5 minutes variation for different SCC mixes

All the mixes indicated that there was an increase in the V-funnel time with increasing of the fibers contained in the mix. Whereas, the incorporation of steel, polypropylene and hybrid fibers caused an increase in the time by 27, 40, 18, 35 and 43 percent for the mixes MSF75, MSF100, MPF10, MPF15 and MHF75 respectively if compared with reference mix, M0. The higher elapsed time of steel fibers that try to avoid fiber passage through the openings as compared with polypropylene fibers is due to the higher aspect ratio of the former. In hybrid mode, the time becomes higher due to the difficulty of passing of the combination. These findings are compatible with the results of Tarun et al. [17] and Tamrakar [18].

According to SCC stability test (segregation resistance test), it was done after 5 minutes from the first mentioned test. Results indicated that the incorporation of single and hybrid fibers as volume fraction leads to a raised in the V-funnel time, (i.e. an increase in the time by 30.7, 35.7, 18.2, 25 and 33.3percent for mixes MSF75, MSF100, MPF10, MPF15 and MHF75 respectively).

III. Box Test

The L-Box test is used to assess SCC passing ability. The present test results lie between 0.8 and 0.94. These values are acceptable according to EFNARC requirements [13], as illustrated in Figure 5. The tested mixes indicated that there was a drop in the L-Box (H1/H2) ratios with the increase in the fiber content. Results indicated that the incorporation of single and hybrid fibers leads to a decrease in these ratios by 7.6, 10.8, 8.6, 5.4 and 7.6 percent for the mixes MSF75, MSF100, MPF10, MPF15 and MHF75 respectively if compared with reference mix, M0. These observations are in good agreement with Tarun et al. [17] and Tamrakar [18].

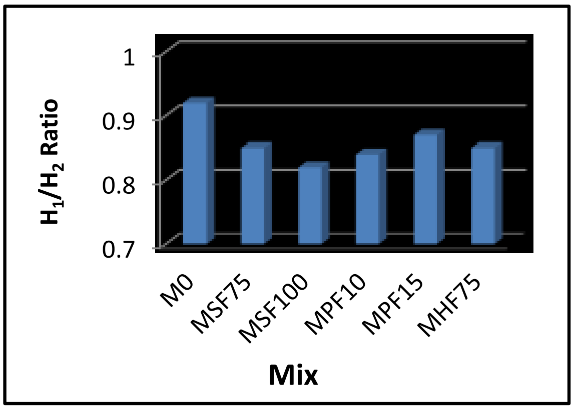

Figure 5: H1/H2 ratio variation for different SCC mixes

IV-Effect of Fiber Type and Content on the Fresh Properties of HFR-SCC

The inclusion of fibers had always negative effect on the workability of SCC. This statement was in agreement with Al-Qaisy [19]. According to the present study results, the volume fraction of 1 % for steel fiber and of 0.15 % for polypropylene fiber were the maximum values that can be used to attain a slump more than 550 mm. The slump flow test was adopted as a guide to make a decision about the highest volume fraction of fibers that make the studied mixes self-compacting. Therefore, mixes MSF125 and MPF25 were not tested for V-funnel and L-box tests.

5. Conclusions

The following conclusions could be extracted from the present study:

1. To meet the requirements of international standards for SCC, there were upper limits for the volume fraction of added fibers. These limits were 1.0, 0.15 and 0.75 % for steel, polypropylene and hybrid fibers respectively.
2. The inclusion of fibers had always negative effect on the workability of SCC. The inclusion of fibers had always negative effect on the workability of SCC The addition of fibers (irrespective of their type) caused the decrease of slump flow, the increase of T500 time, the increase of V-funnel time and the decrease of H1/H2 ratio of L-box.
3. Polypropylene fibers showed higher negative effect than steel fibers on the flowability of SCC mixes due to the network action and large surface area of these fibers.

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