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Mechanical Properties of Ultra High Performance Fiber Reinforced Self Compacted Concrete

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***Abstract* — The main goal of this research is to produce Ultra High Performance Fiber Reinforced Self Compacting Concrete (UHPFRSCC) in Gaza Strip, using materials that are available at the local markets. To meet this purpose, twelve trial mixes are used to obtain acceptable fresh and hardened properties of self-compacting concrete with a compressive strength exceeding 170 MPa. The fresh and hardened mechanical properties of UHPFRSCC like, workability, self-compacting properties, compressive strength, split cylinder strength and flexural strength are studied. The effects of using different amounts of steel fiber and silica fume contents on these properties are also investigated.**

Results show that it is possible to produce UHPFRSCC in Gaza Strip using materials that are available at the local markets if they are carefully selected and they will achieve a minimum compressive strength of 170 MPa at 28 days. This is expected to provide the local construction industry with a feasible new type of concrete which can be used for rehabilitation and strengthening purposes.

***Index Terms*—Ultra High Performance Concrete, Steel Fibers, Self-Compacting, V-funnel.**

I. INTRODUCTION

Ultra-High Performance Fiber Reinforced Concretes (UHPFRC) are cementitious composites with outstanding material properties. They have very high strengths (compressive strength greater than 150 MPa and tensile strength greater than 8 MPa). The extremely low permeability of the dense matrix allows the use of UHPFRC, for example, as a waterproofing layer in bridge decks [1]. In comparison with the normal steel reinforced concrete, the application of UHPFRC is expected to improve the resistance of buildings and infrastructure under extreme mechanical and environmental loads [2].

Self-compacting concrete (SCC) is defined by Okamura as concrete that is able to flow in the interior of the formwork, filling it in a natural manner and passing through the reinforcing bars and other obstacles, flowing and consolidating under the action of its own weight with no mechanical vibration [3]. It is also cohesive enough to be handled without segregation or bleeding. It can be used to facilitate and ensure proper filling of complex and multipart formworks and consequently offers a good structural performance in heavily reinforced structural members. Modification in the mix design of self-compacting concrete may significantly influence the material's mechanical properties. Therefore, it is vital to investigate whether all the assumed hypotheses about conventional concrete are also valid for self-compacting concrete structures [4].

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The addition of steel fibers improves the mechanical properties and the ductility of self-compacting concrete (SCC) in the same manner as in vibrated concrete. However, the fibers greatly impair the workability of SCC because of their elongated shape and large surface area. The amount of fiber that can be added to a SCC mix is, therefore, limited and depends on the fiber type used as well as the composition of the SCC mix. The maximum amount of fiber needs to be determined in such a way as to cause the least decrease in the workability, while maintaining a good flow and passing ability. In order to make the best use of the fibers, they need to be homogeneously distributed in the mix without clustering [5].

The use of Fiber-Reinforced Self-Compacting Concrete (FR-SCC) has received a tremendous impulse in the last years in an attempt to push forward the boundaries of high end structural applications of both Fiber-Reinforced Concrete (FRC) and Self-Compacting Concrete (SCC) [6].

Reinforced concrete is generally considered a good durable material when compared to other competing construction materials. Nevertheless, a large number of concrete structures deteriorate due to inadequacy of design, overloading due to change in use, chloride attack, corrosion, exposure to elevated temperatures, bombardment, etc. [7,8]. In the European Union about 84,000 reinforced and pre-stressed concrete bridges need to be maintained, repaired and strengthened at an annual cost of £215 M, while in the USA, about 27% of highway bridges require repair or replacement [9]. Due to the high cost associated with reconstruction of the damaged elements, repair and strengthening techniques have become a priority in recent years due to its lower cost.

However, the main goal of this research is to produce Ultra High Performance Fiber Reinforced Self Compacting Concrete (UHPFR-SCC) in Gaza Strip, using materials that are available at the local markets. This is expected to provide the local construction market with a feasible new concrete type which can be used mainly for rehabilitation and strengthening purposes.

II. EXPERIMENTAL PROGRAM

The main objective of the testing program is to investigate the fresh and hardened properties of ultra-high performance fiber reinforced self-compacting concrete. Fresh concrete is tested for slump and V-funnel to ensure a reasonable workability and self-compacting ability in the plastic state. Hardened concrete is tested for compression and tension. In addition to this, the influence of steel fiber and silica fume contents is also studied.

A. Material Properties

Materials used in this study include ordinary Portland cement, fine aggregate, silica fume, superplasticizer, steel fibers and mixing water.

Ordinary Portland cement CEM I 42.5R which meets the requirements of ASTM C150 is used in preparing all of the test specimens.

Local fine sand with a nominal size ranging from 0.15 mm to 0.60 mm is used. The average SSD specific gravity is 2.67 kg/m^3 and water absorption is 0.63 %, based on ASTM C 128, see Figure (1).

Figure (1): Fine sand used

Silica fume, used in the study is supplied by Sika company. It is a non-toxic material with and a specific gravity of 2.2 kg/m^3 and conforms to ACI 548.6R-96.

Straight steel fibers, with an aspect ratio of 60 and a tensile strength of 650 MPa, are used, see Figure (2).

Figure (2): Steel fibers used

B. Mix Proportions

Twelve trial mixes are prepared using several steel fiber and silica fume contents as shown in Figure (3) and Table (1). Silica fume contents of 10%, 15% and 20%, by weight of cement, are used. In addition, steel fiber contents of 0.5%, 1%, 1.5% and 2%, by total volume, are used.

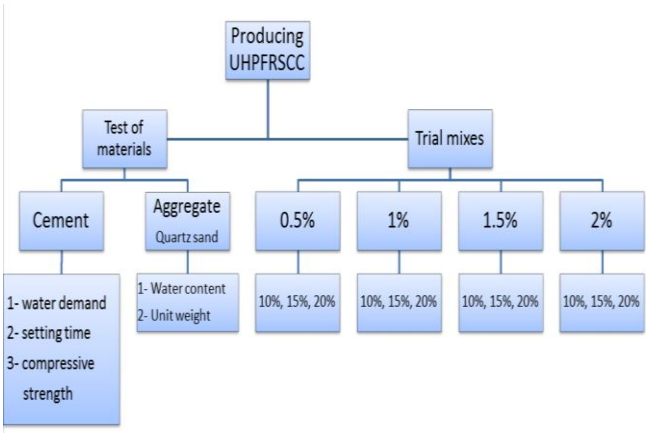

Figure (3): Trial concrete mixes

Table (1): Mix proportions

Mix	Cement	W/C ratio	Silica fume /Cement	Quartz sand /Cement	Steel fibers /Cement
1	1	0.24	10%	125%	4%
2	1	0.24	15%	125%	4%
3	1	0.24	20%	125%	4%
4	1	0.24	10%	125%	8%
5	1	0.24	15%	125%	8%
6	1	0.24	20%	125%	8%
7	1	0.24	10%	125%	12%
8	1	0.24	15%	125%	12%
9	1	0.24	20%	125%	12%
10	1	0.24	10%	125%	16%
11	1	0.24	15%	125%	16%
12	1	0.24	20%	125%	16%

C. Conducted Tests

Fresh Concrete Tests

Slump flow test

It assesses the flowability of self-compacting concrete, based on EFNARC, 2005.

V-funnel test

It assesses the viscosity and filling ability of self-compacting concrete, based on EFNARC, 2005.

Hardened Concrete Tests

Compression test

It tests cube concrete specimens of 100mmx100mmx100mm in dimension, based on ASTM C109- 2012, in compression.

Splitting cylinder test

It tests the tensile strength of cylindrical concrete specimens 6 inches in diameter and 12 inches in height, based on ASTM C496-2011.

Flexural prism test

It tests the flexural strength of concrete prisms of 100mmx100mmx500mm in dimension, based on ASTM C293-2010, under center-point loading.

III. RESULTS AND DISCUSSION

A. Fresh Concrete

Table (2) shows slump and V-funnel test results of the twelve concrete mixes considered in this study. The results also indicate that eight mixtures out of the twelve satisfy the self-compactness properties based on the standards developed by the EFNARC-2005, as well as the concrete strength classification of Ultra High Strength Concrete. These mixtures are, thus, classified as UHPFRSCC. On the other hand, two mixtures do not satisfy the fresh properties standards but satisfy the concrete strength classification of Ultra High Strength Concrete and are, hence, called UHPFRC. The remaining two mixtures do not satisfy the fresh properties standards but satisfy the concrete strength classification of High Strength Concrete and these mixtures are classified as HPFRC.

Table (2): Fresh concrete test results

Mix	Slump test (mm)		V-funnel test		Compressive strength at 28 days (MPa)		Class
1	770	OK	9.7	**OK**	120.7	OK	UHPFRSCC
2	754	OK	10.2	**OK**	134.9	OK	UHPFRSCC
3	745	OK	13.15	**N.OK**	116.2	N.OK	HPFRC
4	768	OK	9.85	**OK**	143.2	OK	UHPFRSCC
5	756	OK	10.4	**OK**	156.7	OK	UHPFRSCC
6	743	OK	13.2	**N.OK**	130.4	N.OK	HPFRC
7	760	OK	10.1	**OK**	149.7	OK	UHPFRSCC
8	748	OK	10.8	**OK**	162.1	OK	UHPFRSCC
9	739	OK	13.35	**N.OK**	141.3	OK	UHPFRC
10	757	OK	10.55	**OK**	159.4	OK	UHPFRSCC
11	742	OK	11.4	**OK**	177.5	OK	UHPFRSCC
12	733	OK	14.9	**N.OK**	148.4	OK	UHPFRC

Figure (4) shows that the slump values decrease as the silica fume or the steel fiber content increases.

In addition, Figure (5) indicates that the larger the amounts of the silica fume and steel fibers, the lower is the viscosity of mixture. When the silica fume content is above 20%, the mixtures cannot be considered as self-compacting concrete since silica fume is a fine Pozzolanic material that fills all the spaces between cement particles and, therefore, needs higher range of water reducers to make the concrete self-compacted.

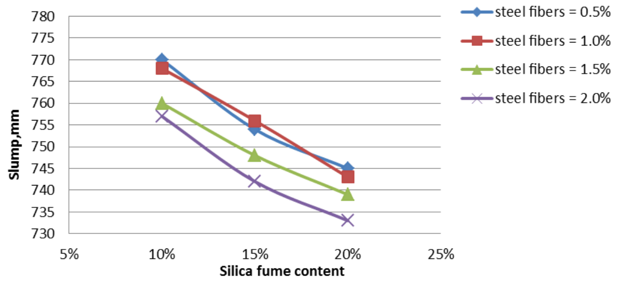

Figure (4): Slump vs. silica fume content

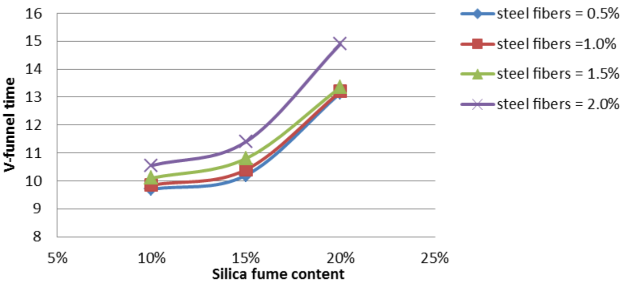

Figure (5): V-funnel time vs. silica fume content

B. Hardened Concrete

Table (3) shows compressive strength, splitting cylinder strength and flexural strength results, at 28 days, for the 12 mixes considered in the study.

Table (3): Compressive and tensile strength test results

Mix #	compressive strength at 28 days (MPa)	Splitting cylinder strength at 28 days (MPa)	Flexural strength at 28 days (MPa)
1	120.7	12.5	15.4
2	134.9	14.2	16.9
3	116.2	12.1	15.2
4	143.2	15.1	16.7
5	156.7	16.4	18.1
6	130.4	13.7	15.8
7	149.7	15.7	17.1
8	162.1	17.1	18.9
9	141.3	14.8	16.7
10	159.4	16.1	17.4
11	177.5	18.7	22.1
12	148.4	15.6	16.9

(1) Compressive Strength

Figure (6) portrays that the compressive strengths of the tested cubes increase with increasing the silica fume contents up to 15%. On the other hand, increasing silica fume contents which range from 15% to 20 % decreases the compressive strength. This may be caused by the chemical reaction of the silica fume with the CH producing an additional C-S-H that improves the bond between the cement, where the aggregate and the silica fume particles can fill the voids created by the free water in the matrix. But when silica fume content increases significantly, the strength decreases. This may be attributed to the silica fume particles that do not participate in the hydration process and remain inert.

When the amount of steel fibers increases, the compressive strength also increases. Out of all the tested specimens, a maximum compressive strength of 177.5 MPa is obtained using 15 % silica fume content, 2% of steel fibers (mix # 11) and can be named UHPFRSCC.

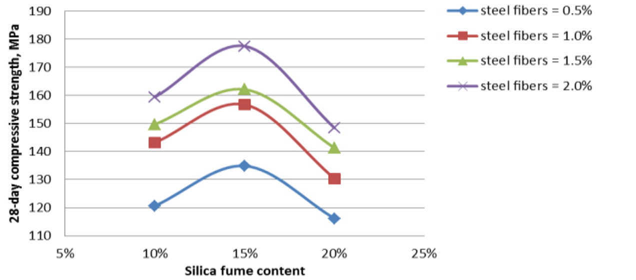

Figure (6): 28-day compressive strength vs. silica fume content

(2) Splitting Cylinder Strength

Figure (7) shows that the splitting tensile strengths of the tested cylinders increase with increasing the silica fume contents up to 15%. On the other hand, increasing silica fume contents from 15% to 20 % decreases the strength. When the amount of steel fibers increases, the splitting tensile strength increases. Out of all the tested specimens, a maximum tensile strength of 18.7 MPa is obtained using 15 % silica fume content and 2% of steel fibers (mix # 11).

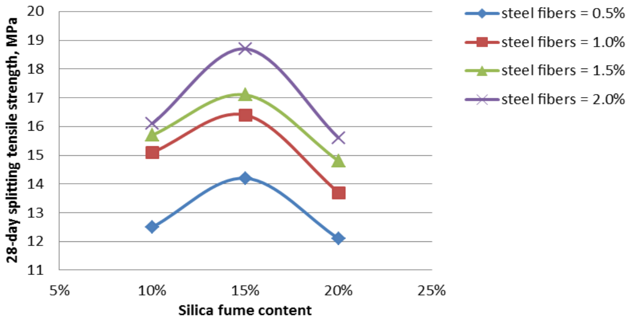

Figure (7): 28-day splitting cylinder strength vs. silica fume content

(3) Flexural Strength

Figure (8) shows that the flexural tensile strengths of the tested prisms increase with increasing the silica fume contents up to 15%. On the other hand, increasing silica fume contents from 15% to 20 % decreases the strength. When the amount of steel fibers increases, the flexural tensile strength increases. Out of all the tested specimens, a maximum tensile strength of 22.1 MPa is obtained using 15 % silica fume content and 2% of steel fibers (mix # 11).

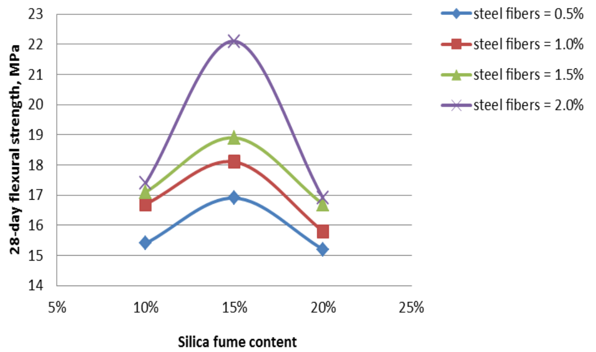

Figure (8): 28-day Flexural tensile strength vs. silica fume content

IV. CONCLUSIONS

Based on the results of the executed experimental program, the following may be drawn out

- It is possible to produce UHPFRSCC in Gaza Strip using materials which are available at the local markets, if they are carefully selected, and will achieve a minimum compressive strength of 177 MPa at the age of 28 days.
- Increasing silica fume and steel fiber contents tend to decrease the slump values and increases the V-funnel time.
- When silica fume content is increased up to 15% the compressive strength increases, but when the content is increased beyond the 15%, the strength decreases.
- When silica fume content is increased up to 15% the splitting and flexural tensile strengths increase, but when the content is increased beyond the 15%, the strengths tend to decrease.
- The compressive and tensile strengths increase with increasing the steel fiber contents.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

UHPFRSCC: Ultra high performance fiber reinforced self compacting concrete
UHPFRC: Ultra high performance fiber reinforced concrete
SCC: Self compacting concrete
FRC: Fiber reinforced concrete
FR-SCC: Fiber-reinforced self-compacting concrete
ASTM: American Society for Testing and Materials
ACI: American Concrete Institute
EFNARC: European Federation of National Associations Representing for Concrete

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