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Survey on the Impact of Steel Fiber and Silica Fume on the Properties of Self-Compacting Concrete

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Abstract

Utilizing the massive advantages provide by self-compacting concrete (SCC), there's negative aspects of SCC such as ductility problem as well as the high cost of its constituted materials. Steel fiber with silica fume can solve this problem by increase their ductility besides that will decrease the cost of SCC by replacing cement contents. Many researches find that a few similar studies ended round the characteristics of steel fiber self-compacting concrete (SFRSCC) that consists of silica fume. This paper checks both fresh and mechanical characteristics of SFRSCC with silica fume ; a fresh characteristics where slump flow , slump T50 and V-funnel while the mechanical characteristics were compressive strength , ultrasonic pulse velocity (UPV) and elastic modulus of concrete samples. The experimental results prove that steel fiber can improve the mechanical characteristics since the silica fume in the entire hybrids may possibly adapt the fiber dispersion and strength losses attributable to fibers, and improve strength and the bond between fiber and matrix with dense calcium silicate-hydrate gel in SFRSCC. The result forecasts by linear mathematical models are found in great agreement with experimental results.

Keyword: *self-compacting concrete, silica fume, steel fiber and fresh state.*

1. Introduction

Self –compacting concrete (SCC) is the rapid revolution in concrete production which provide high fresh quality as well as the hardened characteristic , SCC mix has ability to resist the segregation and to flow easily by it is own weight [1,2].The properties of SCC have been studied in many research due to it is important and ability to solve the problems of concrete mix [2].To develop the SCC-mix required to reduce the aggregate content with high binder content as possible , to maintain excellent fresh properties it is recommended that to minimize the water content and using a chemical admixture such as superplasticizer and Glenium [3,4]. The increase in cement content will lead to cause brittleness of concrete and increase the total cost , to avoid these two problem the steel fiber with cement replacement material (CRM) can be used because the fiber can bridge the crack and enhance the ductility of the concrete while the CRM can replace the part of cement and hence reduce the total cost[5]. Much research has been conducted to investigate the properties of fiber reinforced self-compacting concrete (FRSCC) [6,7,8] .The disadvantages of fibers in concrete mix are the clumping because the fibers may climb together before they are added to the mix , normal mixing action will not break down these clumps[9,10]. Silica fume is the type of CRM can apply to replace the cement content in the concrete and can be increase the workability properties of SCC mix [11, 12] . Silica fume with different level of replacement in SCC mix have been studied to ensure the effectiveness and optimum degree of replacement can be used [13]. The ultrasonic pulse velocity can be used being an indicator as a result of the concrete strength with 95% confidence limits of ±20% on predicted strength [14], Now, the method to measure the None Destructive Test (NDT) parameters is based on the years-old ultrasonic method. Similar combinations include other quality of the ultrasonic measurement, such as UPV and damping constant [15]. Assessment of concrete quality by UPV test was found in literature as hardened properties of concrete sample at different curing time [16]. The objectives of this work are that to study the effect of steel fiber and silica fume on the properties of SFSCC and to find out the relationship between the compressive strength with ultrasonic pulse velocity (UPV) and elastic modulus of SFSCC.

2. Experimental Program

2.1 Materials of experimental

ASTM, type-1 ordinary Portland cement (OPC) is applied into the experiment; its chemical composition was tabulated in table (1). Silica fume was provided with Elkem materials in dry densified form with Grade 920E with LOI fewer than 4% and particular area (Bet) of 15-35 m^2/gram verifying with the mandatory needs of ASTM C-1240. Chemical composition of silica fume is proven in Table (1). The fine aggregate in the experiment were clean natural sand with specific gravity of 2.61 and fineness modulus of 2.76, largest size only 3. 35mm. Since the coarse aggregate is applied as (10 -5) mm crushed granite stone of BS: 812-103.2-1989 getting a particular gravity of 2.66 in SSD. HRWR superplasticiser from SIKA-KIMIA, Malaysia is tried for enhancing the workability of concrete; it is a highly effective liquid based superplasticiser for the production of free-flowing concrete that complied with the requirements of BS 5075. WSF0220 high-strength steel wire of diameter 0.2 mm and 20 mm in length with an aspect ratio of 100 was used in this experiment to replace the cement by weight, its tensile strength more than 2300 MPa confirm the ASTM A820 and EN 14889 . Steel fibers coated with brass and possess very smooth surfaces, which reduces the energy loss during the movement of particles.

Table 1: Chemical Composition of Binder

Chemical Composition	Percentage %	
	OPC[1]	SILICA FUME[2]
SiO2	20.3	96.36
Al2O3	4.2	0.21
Fe2O3	3	0.77
CaO	62	0.24
MgO	2.8	0.52
SO3	3.5	0.55
K2O	0.9	0.102
Na2O	0.2	0.12

[1]OPC , the data provide by Shafiq , et al. [17], [2]Silica fume, the data provides by M.F. Nuruddin , et al. [18]

2.2 Test setup of experimental

One of the main characteristics of SCC is the workability; the experimental test was started by conducting the fresh properties which consist of slump flow, slump T50 and V-funnel. Fresh test result governs by Specification of European Federation of Producers and Applicators of Specialist Products for Structures – EFNARC [19]. The methodology of the experiment was examined the new qualities after which hardened qualities for example compressive strength, ultrasonic pulse velocity (UPV) and elastic modulus. The SCC mixes were prepared using drum mixer, the mixer was first of all cleaned with water to make sure that there's no absorption inside and next the two aggregate were combined with the half of water and left it for just two minutes to allow water completely absorbed with aggregate, then third the cement and mineral admixture (as needed) is added with mixture of remaining water and superplasticizer for 4-minutes to permit the result of chemical admixture to completed , and lastly the mixer left for 4-minutes to permit the elements to distribute evenly within the concrete mixer . Each sample was examined to look for the compressive strength at various stages after going through water curing. Cube individuals were stored at 23 °c for 24 h after casting. After remolding, the individuals were moved towards the water tank for more curing until age the exam. The compressive strength examined at 7, 28, and 90 days with the cube of 100 mm3 immediately after acquiring their densities based on BS1881: Part 116 for every test age. The axial compressive load was put on 100 mm3 cube samples using a universal testing machine (UTM) having a capacity of 1000 KN.

2.3 Mix proportions

There are twelve mix of SFSCC was developed based on three groups which are 100% OPC in group one and 5% with 10% of silica fume was used to replace the cement in group two and three respectively .Each group contains 4-mix according to the volume ratio of steel fiber which are 0%, 1%, 1.5% and 2% by weight of cement .The group one was kept as the control to compare it with the other groups to highlight the effect of steel fiber associated with silica fume. Mix proportioning is tabulated in table (2) which show the arrangement of mixing according the silica fume content.

Table 2: Mix Proportion

GROUPS	CODE	OPC	Silica fume	Water	Steel fiber
	MIX	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3
GROUP 1	G1- 0. 0%	600	0	200	0
	G1- 1. 0%	600	0	200	6
	G1- 1. 5%	600	0	200	9
	G1- 2. 0%	600	0	200	12
GROUP 2	G2- 0. 0%	570	30	196	0
	G2- 1.0%	570	30	196	6
	G2- 1. 5%	570	30	196	9
	G2- 2. 0%	570	30	196	12
GROUP 3	G3- 0. 0%	540	60	192	0
	G3- 1.0%	540	60	192	6
	G3- 1.5%	540	60	192	9
	G3- 2. 0%	540	60	192	12

Note: *For all concrete mixtures, coarse aggregate=750 kg/m^3, fine aggregate=900 kg/m^3 and Superplasticizer = 12 kg/m^3*

4. Experimental Test Result

4.1 Fresh properties

Table (3) shows the result of experimental test on fresh stage which includes slump flow, slump T50 and V-funnel. The trend of the result proved that the addition of steel fiber will cause a reduction in the workability of SCC as in movement and time of slump; in group one the slump flow was high because the binder is totally cemented, but with increase in steel fiber the slump was decreased gradually; the replacement of cement by 5% and 10% of silica fume in groups two and three respectively prevent the SCC mix to loss their slump flow due to the graphical behavior of silica fume particles. The slump T50 which represents the time of fresh mix to reach their 500 mm diameter, the all groups show time of discharge within the specification of EFNARC between 2 to 5 second . V-funnel test was performed to assess the viscosity of SCC mix which can be done through the V-funnel shape staring by keeping the fresh mix of SCC inside the funnel and finishing by calculating the time required for mix to come out through the outlet, the result of V-funnel was located within the range of EFNARC.

Table 3: Fresh Test Result

GROUPS	Code Mix	Slump flow	Slump T_{50}	V-Funnel
		mm	Second	Second
GROUP 1	G1- 0. 0%	760	5	10
	G1- 1. 0%	750	5	11
	G1- 1. 5%	720	4	12
	G1- 2. 0%	670	5	12
GROUP 2	G2- 0. 0%	690	4	7
	G2- 1.0%	680	2	6
	G2- 1. 5%	650	4	11
	G2- 2. 0%	600	4	12
GROUP 3	G3- 0. 0%	695	3	7
	G3- 1.0%	670	5	6
	G3- 1.5%	650	4	6
	G3- 2. 0%	630	4	12
Guidelines	EFNARC	650-800	02-05	06-12

Table 4: Hardened Test Result

Code	Compressive Strength			UPV	Elastic Modulus
Mix	KN/m^3			m/sec	KN/m^3
	7-Day	28-Day	90-Day	28-Day	28- Day
G1- 0. 0%	71.1	89.8	94.62	4166	22.15
G1- 1. 0%	73.82	91.92	105.7	4760	28.36
G1- 1. 5%	77.7	94.04	108.15	5020	35.5
G1- 2. 0%	80.63	101.48	110.55	5250	37.13
G2- 0. 0%	60.36	77.42	89.76	3800	28.6
G2- 1.0%	71.88	82.78	97.05	4600	43.3
G2- 1. 5%	70.07	80.37	94.52	4358	37.7
G2- 2. 0%	67.67	79.92	90.68	3936	34.6
G3- 0. 0%	57.81	75.09	83.19	3780	30.5
G3- 1.0%	59.13	85.73	88.28	4470	35.3
G3- 1.5%	62.17	89.25	93.38	4918	39.1
G3- 2. 0%	60.91	86.81	90.47	4827	3.6

4.2 Compressive Strength

The compressive strength test had been conducted for 7, 28 and 90 days, three molds were cast for each one and the average was calculated. The results are tabulated in table (4).The result table indicates that the steel fiber increases the compressive strength per each group at different curing time. According to the result the 2.0% of steel fiber was found as the optimum steel fiber for group one while the 1.0% and 1.5% was the optimum values for groups two and three respectively .

4.3 Ultrasonic Pulse Velocity

The ultrasonic pulse velocity (UPV) test is a non-destructive test which actually is carried out by delivering high-frequency wave (over 20 kHz) throughout the media. Utilizing the theory that a wave moves quicker in denser media than in the looser one, manufacture can figure out the level of quality of material by the velocity of the wave this could be applied to numerous types of materials like concrete, wood, etc. The objective of the UPV test is that to study the effect of steel fiber and silica fume on the relationship between compressive strength and UPV as well as produce a general equation which relates the UPV and compressive strength. The test was done on PUNDIT instrument according to BS-1881: Part 203: 1986 while the methodology of the test was done by the direct method of UPV test. The test result is shown in table (4) and figures (1), the result of group (1) record high values of UPV compared with the other groups, nevertheless, the result proved that the combination of silica fume with steel fiber can enhance the UPV properties of SCC.

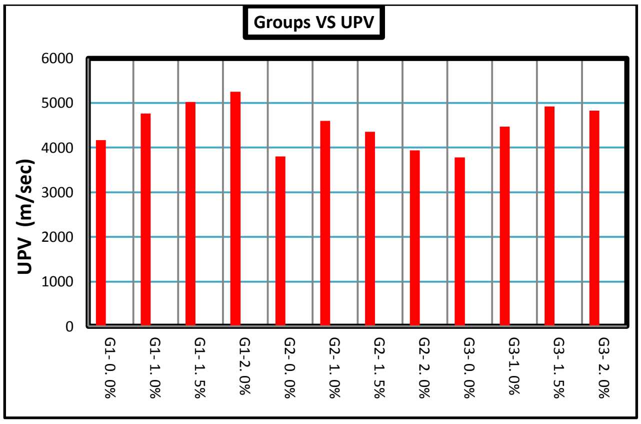

Fig. 1: Groups VS UPV

4.4 Stress – Strain relationship

The main objective to use the fibers in concrete mixes is to enhance the ductility characteristics of the mix [20], ductility can be evaluated by the value of the modulus of elasticity which can be derived from the stress – strain curve. The axial compressive load was applied to 100mm cube sample by using a universal testing machine (UTM) with a capacity of 100 KN, the strain gauge was fixed at the center of the cube surface while it is connected with data logger and software called Excute UCS-60A MEAS.Table (4) and figure (2) explained the result of elastic modulus per each mix group. From the result it found out that the ductility of SCC mix according to their elastic modulus was improved at additional steel fiber content ,the concrete sample after reach to their cracking load did not crash totally but locking similar as at the beginning of the test. Silica fume also can improve the elastic Properties of concrete at long term because their latest activity to replace the cement content.

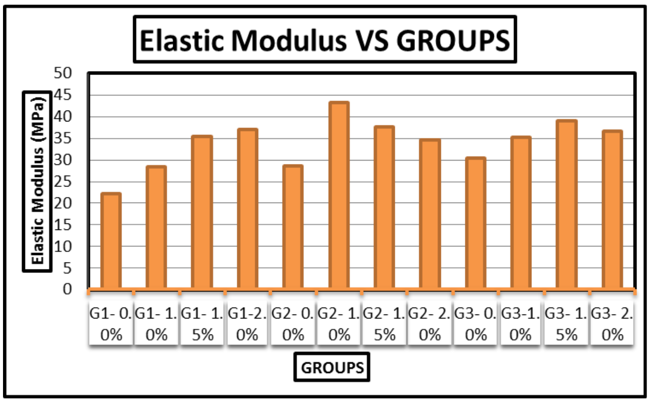

Fig. 2: Groups VS Elastic Modulus

5. Analysis of the Result

5.1 Relative change in compressive strength

Table (5) referred to the relative change in compressive strength result ; the highest increase value was occurred in 7-day of 1.0% steel fiber for group two while the lowest value was found in group two at 90 days of 2.0% of steel fiber.

Table 5: Relative change of compressive strength

Code Mix	7-Day	28-Day	90-Day
G1- 0. 0%	0	0	0
G1- 1. 0%	3.83	2.25	11.71
G1- 1. 5%	9.28	4.61	14.3
G1- 2. 0%	13.4	12.99	16.84
G2- 0. 0%	0	0	0
G2- 1.0%	19.08	6.92	8.12
G2- 1. 5%	15.57	3.81	5.3
G2- 2. 0%	12.11	3.23	1.03
G3- 0. 0%	0	0	0
G3- 1.0%	2.28	14.17	6.12
G3- 1.5%	7.54	18.86	12.25
G3- 2. 0%	5.36	15.61	8.75

5.2 Correlation between compressive strength and UPV

The figures (3) conclude the correlations between compressive strength and UPV, three statistical models was proposed to predict the compressive strength of concrete based on the groups. Group (3) possess higher correlation than the other groups while the UPV value was increased by the combination of steel fiber and silica fume.

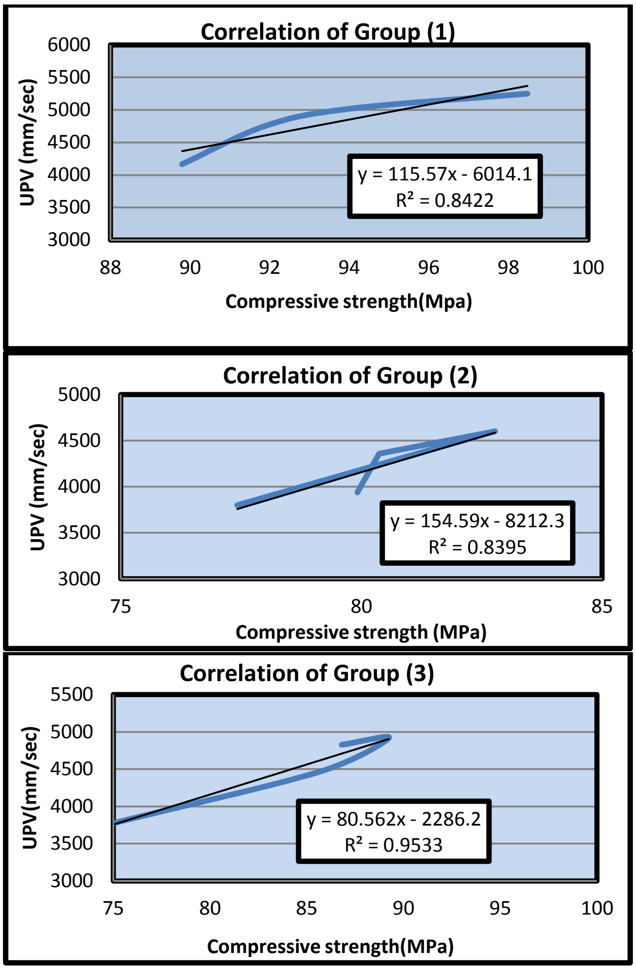

Fig.3: Correlation between compressive and UPV for each groups

5.3 Correlation between compressive strength and Elastic modulus

Different research was done to develop the relationship of compressive strength and elastic modulus of steel fiber reinforced concrete [21] , some of it concludes that the elastic modulus did not correlate well with compressive strength and that according to their constitute materials while the other research proved the trend of good correlation because they applied different condition and due to the combination of fiber with the cement replacement material (CRM) [22]. The correlation of this experimental shown in figure (4) and can be classified as good between the compressive strength and elastic modulus and this attributed to the steel fiber which increase the ductility of SCC mix.

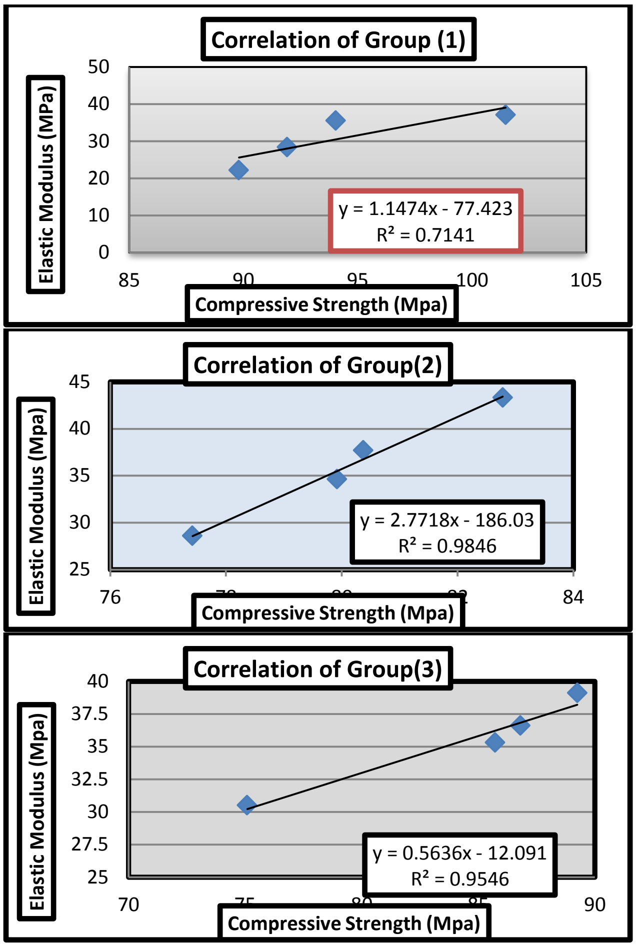

Fig.4: Correlation between compressive and elastic modulus for each

6. Conclusion and Discussion

Based on the experimental work of steel fiber reinforced self-compacting concrete containing silica fume, the following conclusions are arrived:

The composition of steel fiber and silica fume can be used to produce SCC with high fresh and hardened properties. Steel fiber addition reduced the workability properties of SCC but silica fume may adjust the dispersion of steel fiber and hence improve the strength between the steel fiber and matrix.

2.0% of steel fiber by weight of cement was found as the optimum steel fiber for group one while the 1.0% and 1.5% was the optimum values for groups two and three respectively regarding to the compressive strength result, SCC sample of the experimental work show that the steel fiber increase the compressive strength slightly. Result have been an analysis by the correlation between the compressive strength and UPV as well as the elastic modulus , the correlation was agreement with the experimental result.

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