CONCRETE RESEARCH LETTERS
www.crl.issres.net
Vol. 2(2) – June 2011

Comparative Study Between Flowable High Strength Mortar and Flowing High Strength Concrete

Mahyuddin Ramli [1] and Eethar Thanon Dawood [2*]
[1] Professor in Building Technology, *School of Housing, Building & Planning, Universiti Sains Malaysia MALAYSIA*
[2] Assistant Professor in Building Technology, *School of Housing, Building & Planning, Universiti Sains Malaysia MALAYSIA*

Abstract

This paper presents the results of an investigation aimed to evaluate the comparison between high strength flowing concrete (HSFC) and high strength flowable mortar (HSFM) from the view of density, compressive strength and flexural strength at the age of 7 and 28 days. The results illustrate that the use of Silica Fume (10 % as a partial replacement of cement) and superplasticizer (1.6- 2.2% of cementitious materials) gives the properties of high flowability with the high strength for each of concrete and mortar mixes. Besides, the compressive strength and flexural strength for each of mortar and concrete have been enhanced by the inclusion of silica fume.

Keywords: Flowing concrete; flowable mortar; high strength; silica fume; superplasticizer.

1. Introduction

Flowing concrete is a highly fluid but workable concrete that can be placed with little or no vibration or compaction while still remaining essentially free of excessive bleeding or segregation. The Following are a few of the applications where flowing concrete is used:(1) thin-section placements, (2) areas of closely spaced and congested reinforcing steel, (3) tremie pipe (underwater) placements, (4) pumped concrete to reduce pump pressure, thereby increasing lift and distance capacity, (5) areas where conventional consolidation methods are impractical or cannot be used, and (6) for reducing handling costs [1].

* Corresponding Author: E.T. Dawood
Email: Eathar2005@yahoo.com,

The addition of superplasticizer to a 75-mm slump concrete can easily produce a concrete with a 230-mm slump. Flowing concrete is defined by ASTM C 1017 [2] as a concrete having a slump greater than 190 mm, yet maintaining cohesive properties. The high workability (i.e., easy placing and consolidation) is one of the most representative characteristics. For this reason, the use of such concrete is spreading worldwide quickly. Nowadays the workability of flowing concrete is mainly evaluated by the slump test or the Flow test, an alternative test method adopted in Japan and Taiwan is the slump-Flow test JSCE-F503 [3], which is simply a measurement of the diameter of the concrete after it has collapsed in a standard slump test.

Besides that, the use of silica fume in the production of high strength concrete (HSC) has become a compulsory case, because of a significant improvements attained on interfacial zone of cement paste –aggregate. Silica fume consists of ultra fine (<1µm) particles and increases the bond strength between cement paste and aggregate by making the interfacial zone more dense, it also plays an important role on increasing of mechanical strengths of concrete because of having a pozzolanic activity [4] another contributing factor is the fact that silica fume, because its high fineness, reduce bleeding so that no bleed water is trapped beneath coarse aggregate particles. In consequence, the porosity in the interface zone is reduced, compared with a mix not containing silica fume. Subsequent chemical reaction of silica fume results in a still lower porosity in the interface zone which, in consequence, is no longer particularly weak, either in terms of strength or permeability [5].

One of the other most important matters for the use of the flowable high strength mortar or flowing high strength concrete is the repairing, retrofitting and strengthening the damaged structural members .As the repair material is contributed to the mechanical strength of the concrete, so the high fluidity is required to complete filling the cracks and pores and higher compressive strength compared to the concrete substrate is needed [6].

The main objective of the present study is to investigate the comparison for some of mechanical properties for each of the of Flowing high strength concrete and flowable high strength mortar and by maintaining the w/c ratio and adjusting superplasticizer percentage content to denote the properties of flowability. The results of this study can provide a guideline to determine the suitable mix proportions necessary to impart adequate fresh properties of a superplasticized mortar and Concrete.

2. Manufacture and Specimens

The cement used in mortar mixtures was ordinary Portland cement a product of (Tasek corporation berhad). Silica fume product of (Scancem materials Sdn. Bhd.) was used as partial replacement of cement in different percentages in this study to determine the optimum percentage of replacement. The chemical composition of Ordinary Portland and silica fume are given in Table 1.

The superplasticizer (SP.) (Conplast SP1000) was adjusted to give the properties of the required flowability for each of mortar and concrete mixes. The fine aggregate used is natural sand, whose fineness modulus is 2.86 and the maximum size is less than 5 mm. The coarse aggregate is the crushed gravel with maximum size 10 mm.

Four types of mortar mixtures and four types of concrete mixes were prepared by replacing cement with Silica fume at different ratios of 0%, 6%, 8%, and 10%. The material compositions of Mortar mixtures are presented in Table 2, while the material compositions of the four concrete mixtures are presented in Table 3. All batches were prepared by using a mechanical mixer confirming to the requirements of ASTM C305.

The flow test for mortar mixes was performed according to ASTM C230 [7], while the slump test of concrete mixes was performed according to ASTM C143 [8]. Fresh mortar mixtures were cast into 50 mm cube molds and prismatic (40 × 40 × 160 mm) steel molds, from the other side, 100 mm cube molds and prismatic (100 × 100 × 500 mm) steel molds were used for concrete casting. The specimens were left in the molds for 24 h at room temperature of 20 °C. After demolding, the specimens were kept in a curing room till the age of test. After the curing period the cube specimens mortar 50 mm were subjected to compressive strength test according to ASTM C109 [9], whereas the cube specimens concrete 100mm subjected to compressive strength according to BS 1881:Part 116 [10].

TABLE1: CHEMICAL COMPOSITION OF ORDINARY PORTLAND CEMENT AND SILICA FUME

Constituent	Ordinary Portland Cement	Silica fume
	% by weight	% by weight
Lime (CaO)	64.64	1.0% (max)
Silica (SiO_2)	21.28	90% (max)
Alumina(Al_2O_3)	5.60	1.2 % (max)
Iron Oxide(Fe_2O_3)	3.36	2.0% (max)
Magnesia(MgO)	2.06	0.6%(max)
Sulphur Trioxode (SO_3)	2.14	0.5%(max)
N_2O	0.05	0.8%(max)
Loss of Ignition	0.64	6% (max)
Lime saturation factor	0.92	-----
C_3S	52.82	-----
C_2S	21.45	-----
C_3A	9.16	-----
C_4AF	10.2	-----

TABLE 2: MORTAR MIXES

Index	Cement Kg./m^3	Silica fume Kg./m^3	Water Kg./m^3	Sp. %	Sand Kg./m^3	W+SP/B	Flow mm
M1	600	-------	240	1.6	1400	0.40	160
M2	564	36	240	1.8	1400	0.40	150
M3	552	48	240	2.0	1400	0.40	150
M4	540	60	240	2.2	1400	0.40	140

TABLE 3: CONCRETE MIXES

Index	Cement Kg./m^3	Silica fume Kg./m^3	Water Kg./m^3	Sp %	W+SP /B	Sand Kg./m^3	Gravel Kg./m^3	Flow Slump mm

C1	550	-----	220	1.6	0.40	880	715	590
C2	520	30	220	1.8	0.40	880	715	560
C3	505	45	220	2.0	0.40	880	715	550
C4	495	55	220	2.2	0.40	880	715	535

The prismatic mortar specimens were subjected to flexural strength test according to ASTM C348 [11] where the specimens were loaded from their mid span and the clear distance between simple supports was 120 mm. The prismatic concrete specimens were subjected to flexural strength test according to BS 1881: Part 118 [12]. The all specimens were tested for each stage and average values were recorded. The density test for all concrete and mortar specimens have achieved according to BS 1881: Part 114 [13], where the saturated densities have been determined.

3. Results and discussion

3.1. Mortar Mixes

Table 4 reports the mean value of density, compressive strength and flexural strength for cement Mortar used at 7 and 28 days. Proportions of Silica fume used as partial replacement of cement have been used.

TABLE 4: MORTAR MIXES RESULTS

Index	Density Kg./m^3 (7days)	Compressive strength (MPa) (7days)	Density Kg./m^3 (28days)	Compressive strength (MPa) (28days)	Flexural strength (MPa)7 days	Flexural strength (MPa) 28 days
M1	2250	38.5	2270	48.4	6.72	7.56
M2	2275	41.3	2290	52.6	7.12	8.06
M3	2290	44.0	2310	53.8	7.40	8.25
M4	2300	45.1	2315	55.6	7.65	8.44

From these results, it can be concluded that the adding of silica fume to the mix gives a slight raise to the density of mortar for each of 7 & 28 days. Figure 1 illustrates the relation between silica fume with density of HSFM. The compressive strength results at 7 and 28 days show that there is an increase with adding silica fume. The percentages of that increase in the compressive strength at age of 28 days were 8.7 %, 11.1% and 14.9 % by silica fume incorporation of 6%, 8% and 10% respectively.

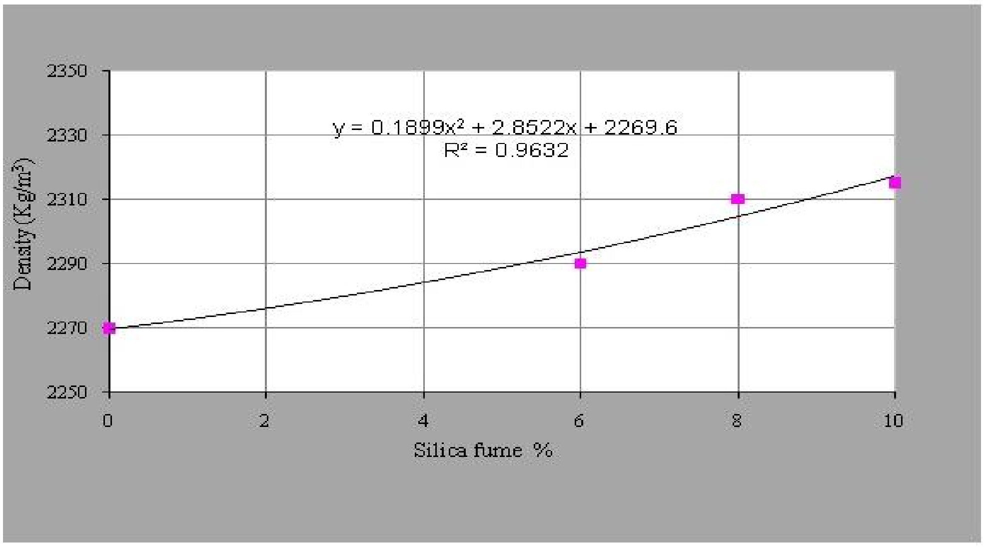

Figure 1: Relation between silica fume and density for Mortar mixes.

Figure 2 shows the relation of silica fume content with compressive strength at 28 days, from these results, it can be concluded that there is an increase of compressive strength using silica fume as partial replacement of cement till the range of 10%. The increase of compressive strength is accompanied with an increase of density but in a slow rate.

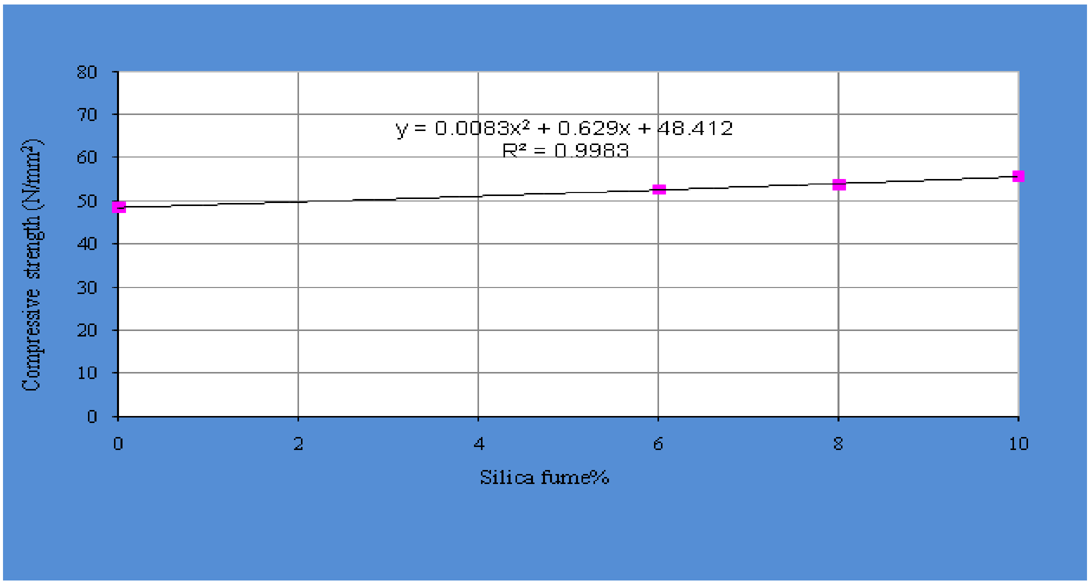

Figure 2: Relation between silica fume and compressive strength at age of 28 days for mortar mixes.

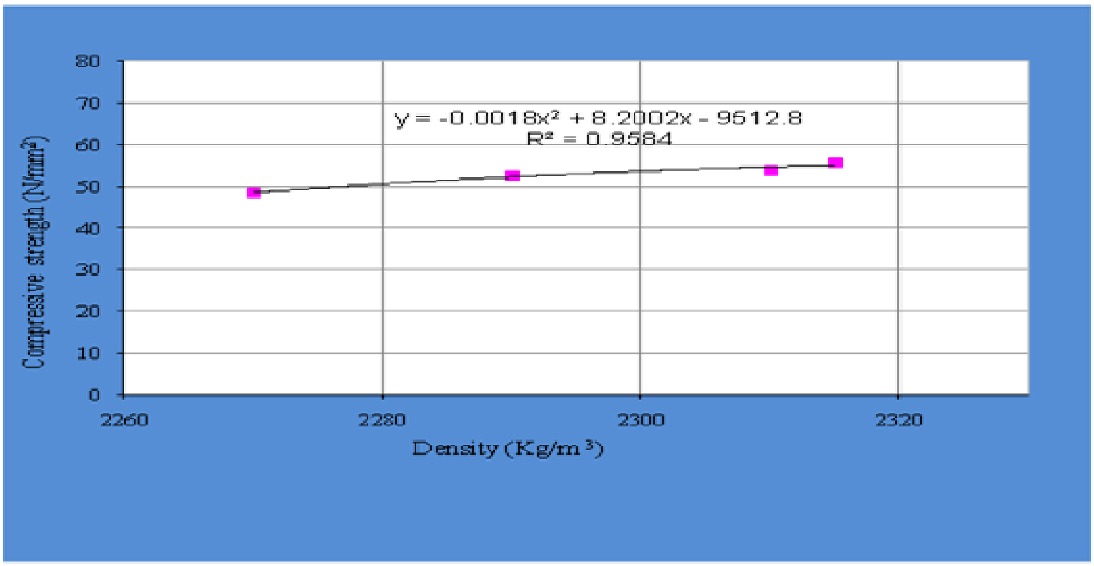

Figure 3: Relation between Density and compressive strength at age of 28 days for mortar mixes

Figure 3 represents this relation between the density and compressive strength at 28 days. The flexural strength results at the same age have improved also by the adding of silica fume as its shown in Figure 4 and the percentages of this increase were 6.6%, 9.1% and 11.6 % for the silica fume adding of 6%, 8% and 10% respectively. It's clear that the percentage of 10% of silica fume as a partial replacement of cement gives the best results due to the pozzolanic reaction between the amorphous silica in silica fume and calcium hydroxide produced by the hydration of Portland cement, silica fume contributes to the progress of hydration of latter material [14, 15].

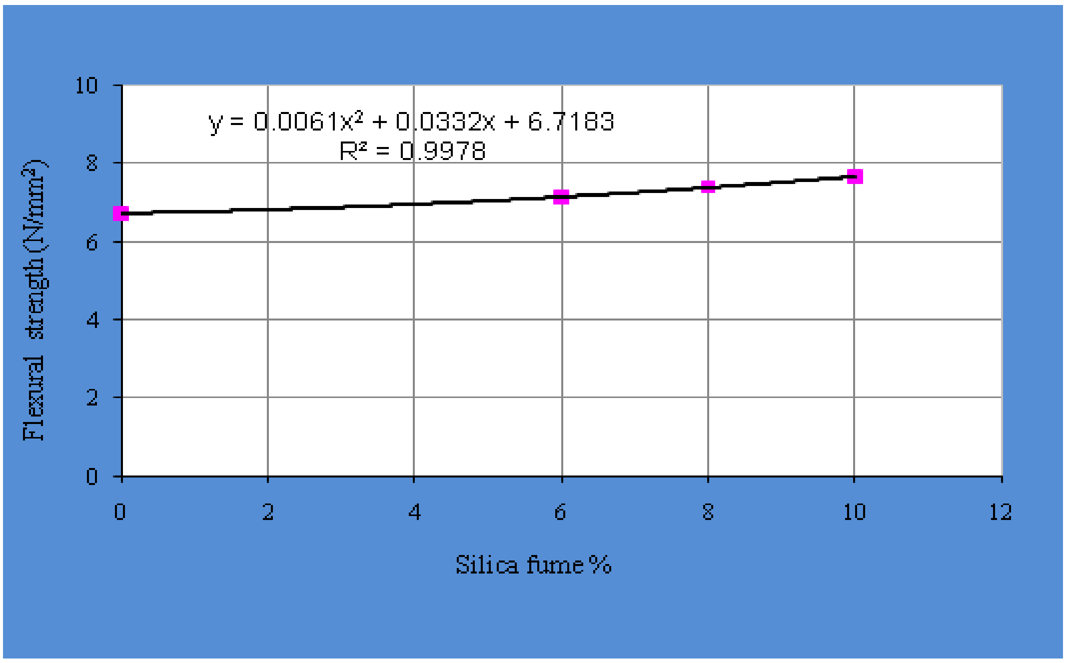

Figure 4: Relation between silica fume and flexural strength for mortar mixes at 28 days.

Relation between Flexural strength and compressive strength can be established for this type of mortar (Flowable high strength mortar) (FHSM) where Figure 5 clarifies this relation.

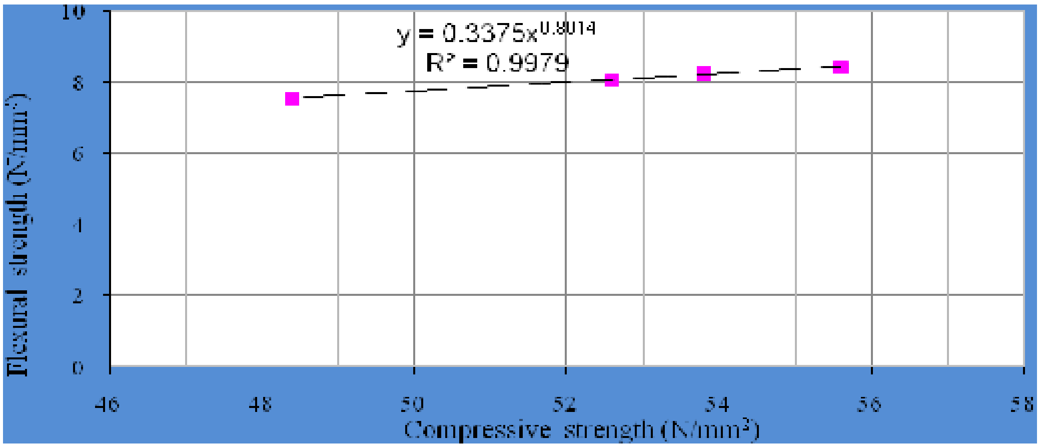

Figure 5: Relation between silica fume and Flexural strength for concrete mixes at age of 28 days.

Figures 6 and 7 show the effect of different portions of silica fume on the properties of mortar mixes at the age of 7 & 28 days.

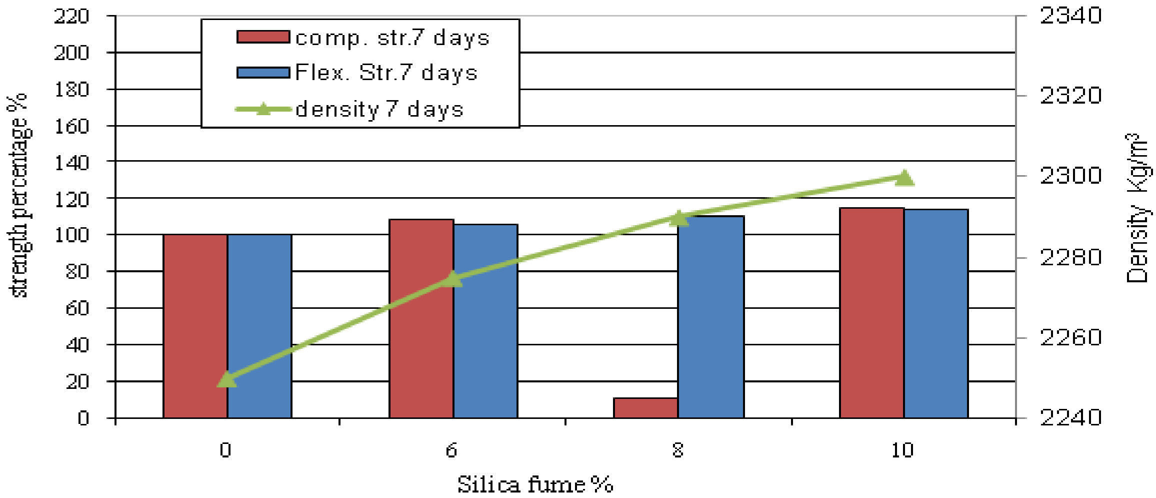

Figure 6: Relation between silica fume with strength percentage and density for mortar mixes at age of 7 days.

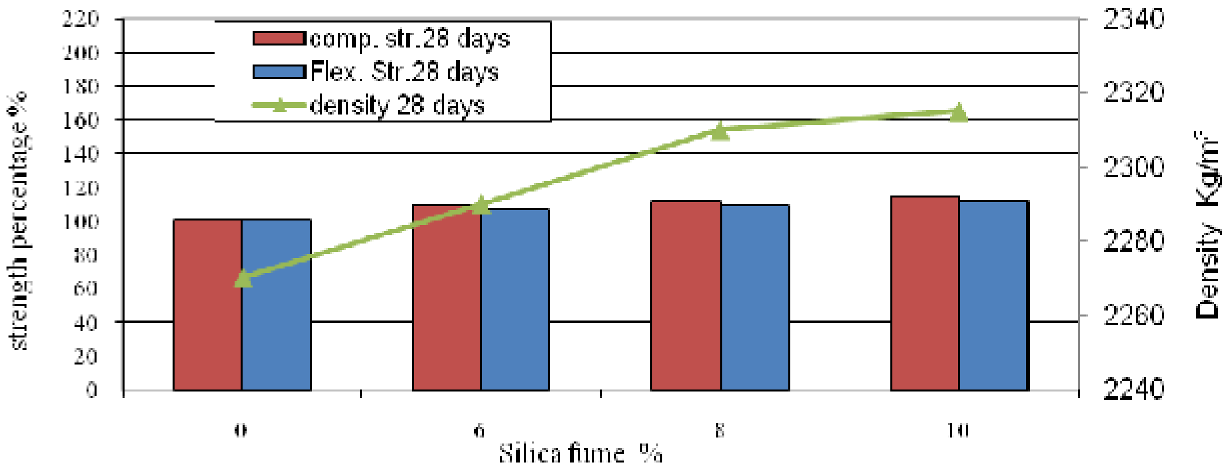

Figure 7: Relation between silica fume with strength percentage and density for mortar mixes at age of 28 days.

3.2. Concrete Mixes

Table 5 reports the mean value of density, compressive strength and flexural strength for concrete used at 7 and 28 days. Proportions of Silica fume used as partial replacement of cement) have been used.

TABLE 5: CONCRETE MIXES RESULTS

Index	Density Kg./m^3 (7days)	Compressive Strength (MPa) (7days)	Density Kg./m^3 (28days)	Compressive Strength (MPa) (28days)	Flexural Strength. (MPa) (7 days)	Flexural Strength (MPa) (28 days)
C1	2270	43.7	2280	56.3	5.92	7.05
C2	2275	47.2	2290	60.1	6.18	7.20
C3	2290	49.1	2300	61.4	6.34	7.38
C4	2300	49.8	2310	63.6	6.55	7.65

From these results, it can be concluded that the adding of silica fume gives a slight increase to the density of concrete for each of 7 & 28 days. Figure 8 illustrates the relation between silica fume with density of HSFC. The silica fume adding to the mix also improves the compressive strength at 7 and 28 days.

Figure 9 shows the relation of silica fume percentage with compressive strength at 28 days. The percentages of increase in the compressive strength at age of 28 days were 6.7%, 9 % and 13% for the silica fume adding of 6%, 8% & 10 % respectively.

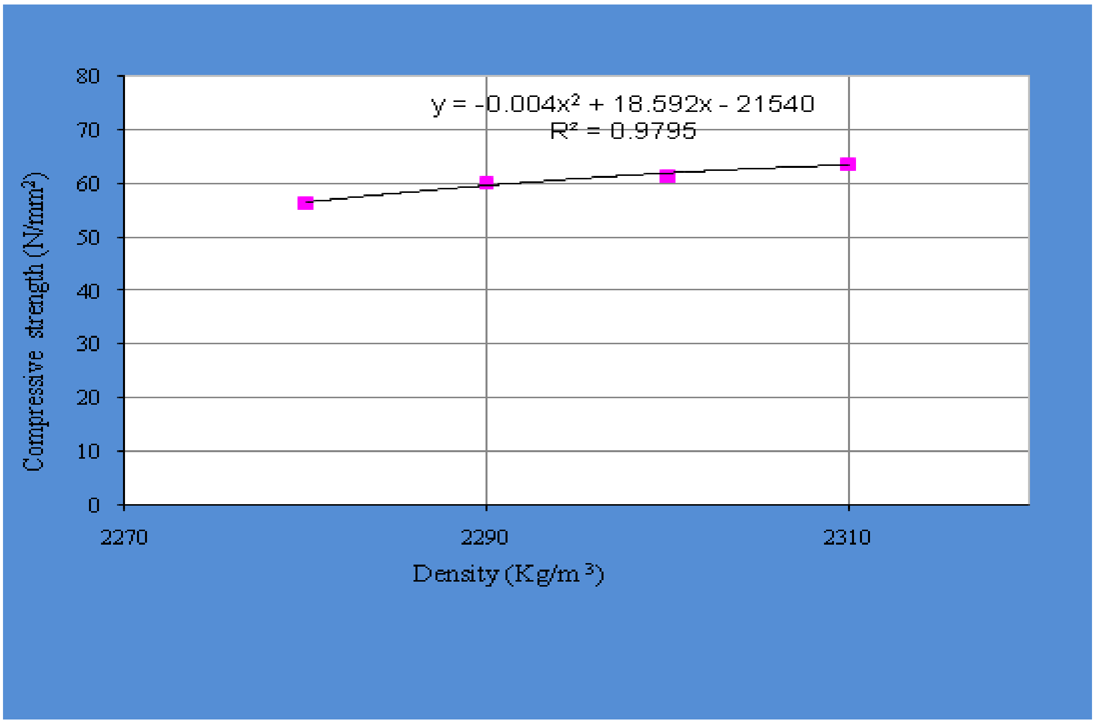

Figure 8: Relation between silica fume and density for concrete mixes.

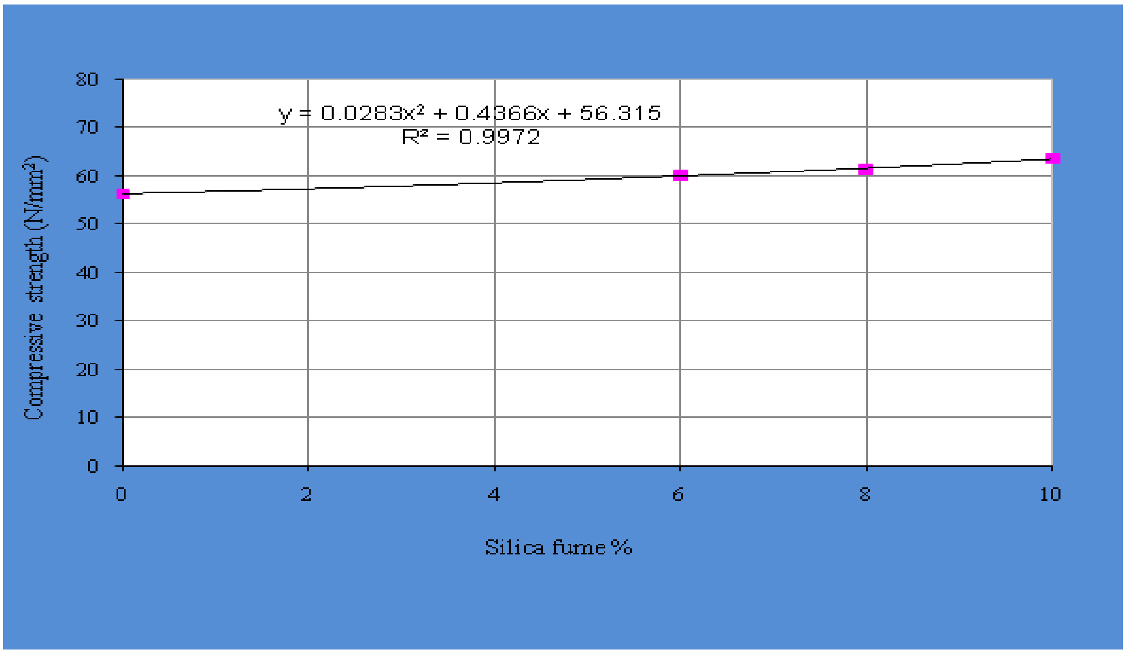

Figure 9: Relation between silica fume and compressive strength at age of 28 days for concrete mixes.

The increase of compressive strength is accompanied with an increase of density but in a slow rate. Figure 10 represents this relation between the density and compressive strength at 28 days.

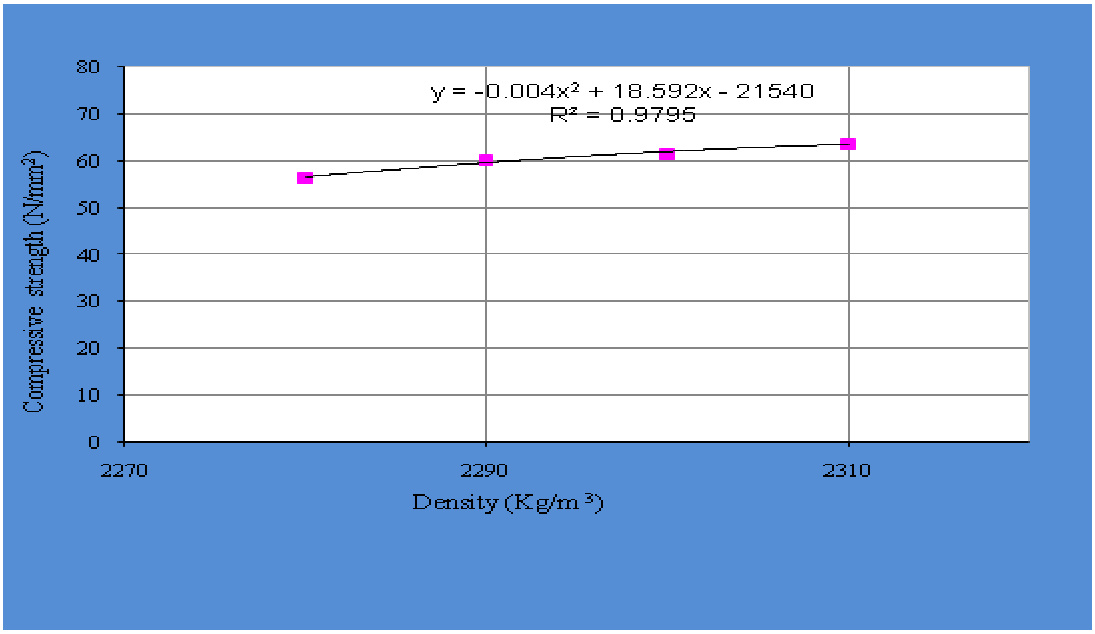

Figure 10: Relation between density and compressive strength at age of 28 days for concrete mixes.

The flexural strength results at the same age have improved also by the adding of silica fume as it's shown in Figure 11 and the percentages of this increase were 2.1%, 4.7% and 8.5% for the silica fume adding of 6%, 8% and 10% respectively. It's clear that the percentage of 10% of silica fume as a partial replacement of cement gives the best results due to the pozzolanic reaction between the amorphous silica in silica fume and calcium hydroxide produced by the hydration of Portland cement, silica fume contributes to the progress of hydration of latter material [14, 15].

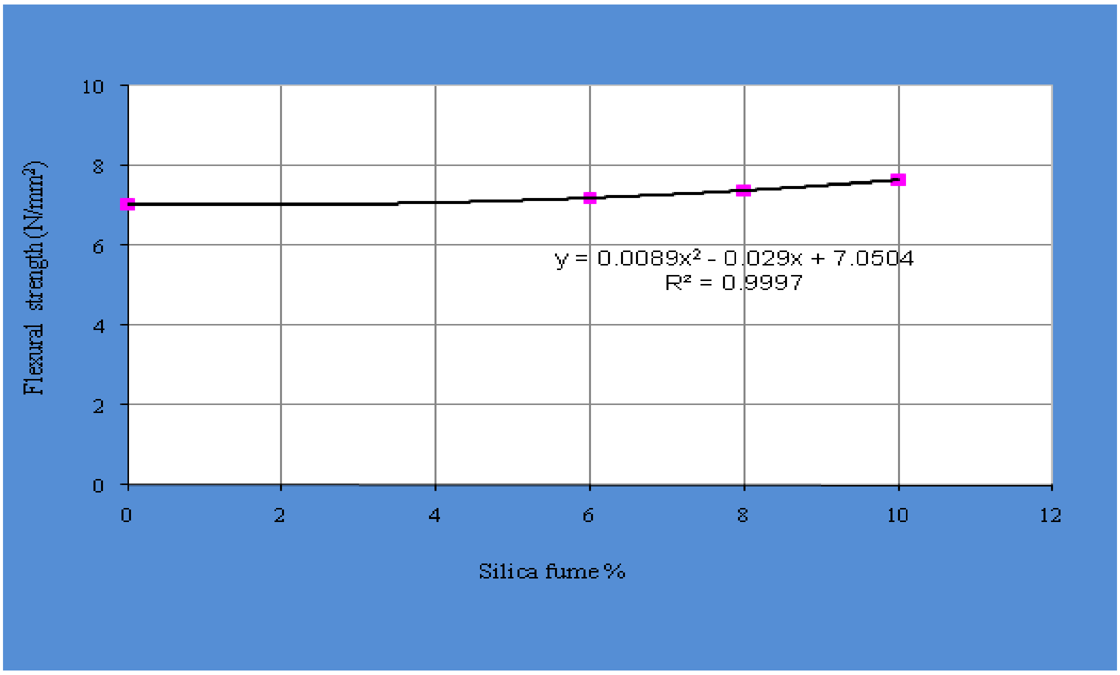

Figure 11: Relation between silica fume and flexural strength for concrete mixes at 28 days.

The relation between compressive strength and flexural strength can be established for this type of concrete (Flowing high strength concrete) (FHSC) where Figure 12 clarifies this relation.

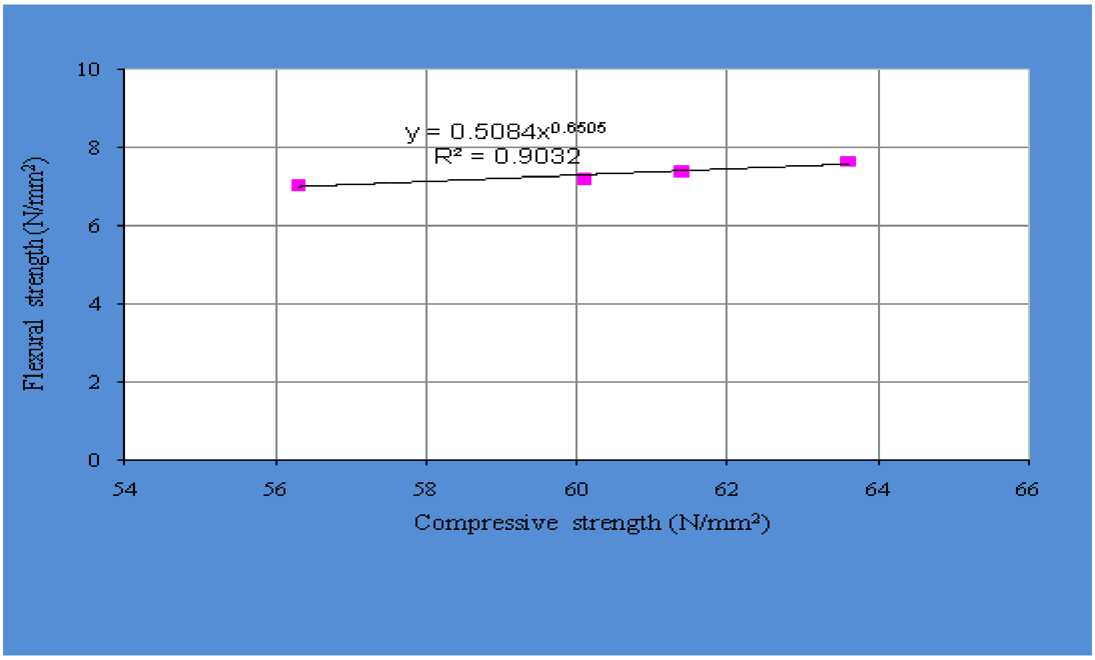

Figure 12: Relation between compressive strength and flexural strength for concrete mixes at age of 28 days.

Figures 13 and 14 show the effect of different portions of silica fume on the properties of mortar mixes at the age of 7 & 28 days.

The comparison between mortar and concrete mixes clarifies that the flexural strength of concrete is lower than the flexural strength mortar, so the presence of the coarse aggregate generally reduce this strength, on the other hand, the compressive strength of concrete is higher than that of mortar and this is because of the mechanical interlocking of the coarse aggregate contributes to the strength of concrete in compression.

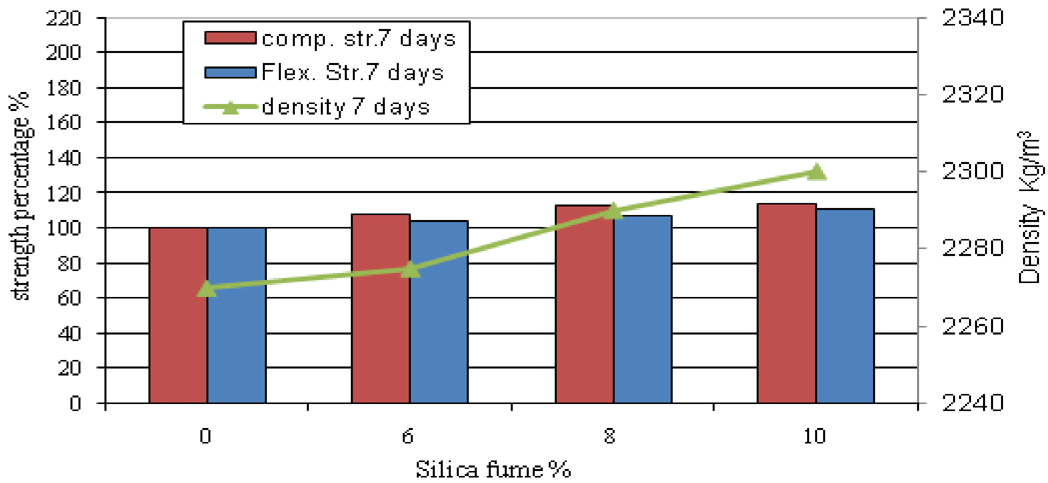

Figure 13: Relation between silica fume with strength percentage and density for concrete mixes at age of 7 days.

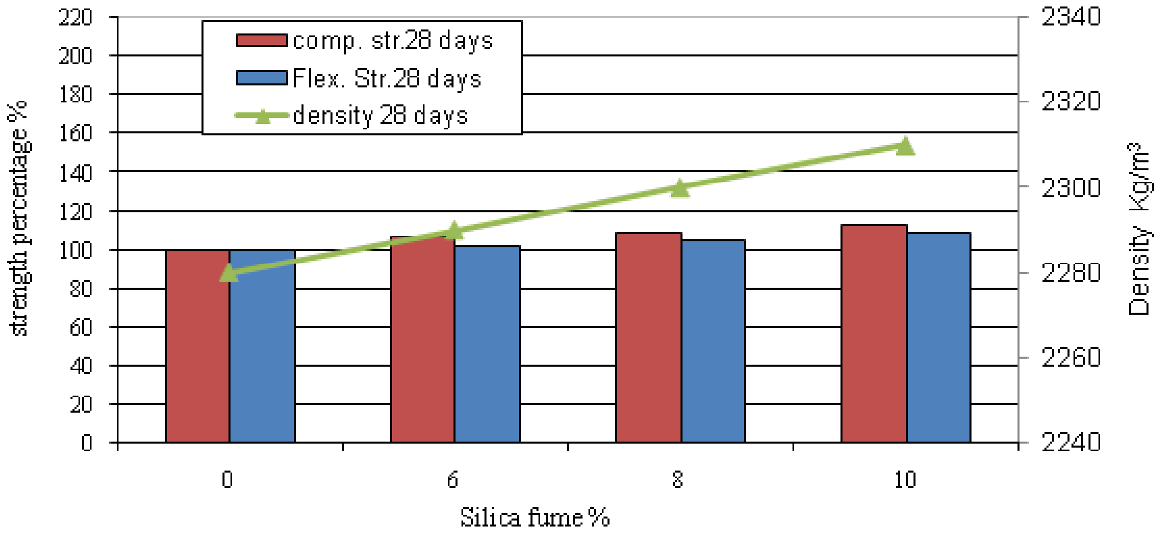

Figure 14: Relation between silica fume with strength percentage and density for concrete mixes at age of 28 days.

4. Conclusions

This study was conducted to assess the properties of HSFC and HSFM produced by adjusting the percentage of superplasticizer with different percentages of silica fume as partial replacement of cement (0%, 6%, 8% and 10%). The following conclusions can be drawn from the present study:

1. Using the appropriate mix proportions make it possible to get mortar and concrete mixes with high strength and high flowability.
2. Incorporation of silica fume in concrete and mortar mixes of 10 % as partial replacement of cement has increased the compressive strength and flexural strength and this is due to the pozzolanic activity of silica fume.
3. The relations between density with compressive & flexural strength for the mortar and concrete mixes illustrate that the silica fume affects on the density of cement paste leading to increments in compressive and flexural strength for all concrete and mortar mixes.
4. There is clear relations between compressive strength and flexural strength for each of mortar and concrete mixes, and it is observed that the flexural strength of concrete is lower than the flexural strength mortar ,so the presence of the coarse aggregate generally reduce this strength .On the other hand, the compressive strength of concrete is higher than that of mortar and this is because of the mechanical interlocking of the coarse aggregate contributes to the strength of concrete in compression.
5. The properties of concrete and mortar with high strength and high flowability encourage the use of them in repairing and rehabilitation of damage structures.

References

[1] Steven, H.K, Kerkhoff, B. and William, C. Design and Control of Concrete Mixture. Portland cement association, 2003, Fourth edition.

[2] ASTM C1017. Standards Specification for Chemical Admixtures for Use in Producing Flowing Concrete. Annual book of ASTM, 2000, Standards, Vol.04.02.

[3] JSCE-F503. Method of Test for the Slump Flow of Concrete. Standards of Japan Society of Civil Engineers, 1990.

[4] Koksal, F., Altun, F., Yigit, I. and Sahin, Y. Combined Effect of Silica Fume and Steel Fiber on the Mechanical Properties of High Strength Concretes. Construction and Building Materials, 2007. 22(8): pp.1874-80.

[5] Neville, A.M. Properties of Concrete, Longman limited, UK, Fourth and Final edition, 1995.

[6] Liu, C. T. and Huang, J. S. Highly Reactive Powder Mortar as a Repair Material. Construction and Building Materials, 2008. 22(6): pp. 1043-50.

[7] ASTM C230. Standards Specification for Flow Table for Use in Tests of Hydraulic Cement. Annual book of ASTM, 2000, Standards, vol.04.01.

[8] ASTM C143. Standards Specification for Slump of Hydraulic–Cement Concrete. Annual book of ASTM, 2000 Standards, vol.04.02.

[9] ASTM C109. Standards Test Method for Compressive Strength of Hydraulic Cement Mortar. Annual book of ASTM, 2000, Standards, vol.04.01.

[10] BS 1881: Part 116. Methods for Determination of Compressive Strength of Concrete Cubes. British Standard, 1983.

[11] ASTM C348. Standards Test Method for Flexural Strength of Hydraulic Cement Mortar. Annual book of ASTM, 2000, Standards, vol.04.01.

[12] BS 1881: Part 114. Methods for Determination of Density of Hardened Concrete. British Standard. 1983.

[13] BS 1881: Part 118. Methods for Determination of Flexural Strength. British Standard. 1983.

[14] Roy, D. M. Hydration of Blended Cement Containing Slag, Fly Ash or Silica Fume. Proc. of meeting institute of concrete Technology. Coventry, 29 UK, 2002.

[15] Hooton, R. D. Influence of Silica Fume Replacement of Cement on Physical Properties and Resistance to Sulfate Attack. Freezing and Thawing and Alkali– Silica reactivity. ACI Materials Journal, 1993. 90(2): pp. 143-51.