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Effect of w/b ratio and binder content on the properties of self-compacting high performance concrete (SCHPC)

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Silica fume is most commonly used mineral admixture both in high performance concrete (HPC) and self-compacting concrete (SCC). While the incorporation of silica fume in concrete has been extensively investigated in HPC and SCC, further researches are needed to optimize the dosage of silica fume and cement content in self-compacting high performance concrete (SCHPC). This paper presents the results of tests carried out to study the effect of w/b ratio and binder content (cement and silica fume content) on properties of SCHPC. Eighteen batches of concrete with binder content ranging from 500-600 kg/m^3 were produced at two w/b ratios (0.23 and 0.25); with silica fume amount varying from 0 to 20 percent by weight of cement. Super Plasticizer (SP) dosage, porosity, water absorption, compressive strength, modulus of elasticity, splitting tensile strength, autogenous shrinkage (AS) and hydration characteristics were evaluated for all SCHPC mixes. The results indicate that optimum w/b ratio and binder content (cement and silica fume content) is required to get better performance from SCHPC, as high cement content and silica fume dosage tend to deteriorate the overall performance owing to reduced mechanical performances, high degree of hydration and greater autogenous shrinkage in SCHPC mixes incorporating silica fume.

Key words: self-compacting, high performance, silica fume, hydration, mechanical, binder content, shrinkage.

Introduction

Self-compacting concrete (SCC) is regarded as the most important development in the field of construction materials owing to their better performance both in the fresh and hardened state of concrete [1]. SCC is distinguished from conventional concrete by the ability to flow and fill under its own weight all the corners of the framework without segregation [2]. On the other hand, high performance concrete (HPC) is characterized by its high strength, durability, and better fluidity. HPC is a class of concrete which is distinguished from normal concrete on the basis of high fluidity, strength, and durability [3]. ACI defines HPC as the class of concrete which has a compressive strength of 41 MPa or more after 28 days of curing time [4]. SCC and HPC consist essentially of the same components but the proportions are so adjusted that it provides desired class of concrete. In order to benefit from both types of concrete i.e. SCC and HPC, a new class of concrete is being investigated that possess the features of both SCC and HPC and is called self-compacting high performance concrete (SCHPC). SCHPC consolidates under its own weight like SCC and provides high strength and better durability like HPC.

In order to achieve features of both SCC and HPC, SCHPC is usually produced from reduced coarse aggregate content and high binder content which incorporate suitable mineral admixtures. Cement is a major concern for environment owing high CO_2 production involved in its production. Replacing cement by suitable admixtures is a common practice to reduce the cost of SCHPC. Usually, silica fume, fly ash and GGBS are incorporated not only to improve the strength of concrete but also the durability of concrete [5-6]. In addition, mineral admixtures also increase the paste volume of concrete mix, which in turn helps in achieving high workability of concrete mix [7]. These admixtures act as micro fillers between aggregates and cement in a cement matrix and owing to their high pozzolanic activity accelerate the process of hydration. HPC mix is made from silica fume and usually incorporates high binder content. It is well known that use of silica fume reduces porosity and enhances the strength of conventional concrete [8]. According to Chan et al. [9] silica fume is much more effective than other mineral admixtures, in terms of imparting high strength to concrete. Mazloom etal. [10] in his study on HPC reported the efficacy of silica fume in achieving high 90-day compressive strength compared to control

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specimens. It is also an established fact that water to binder ratio is the basic parameter that affects the strength of concrete. The water to binder ratio in HPC is kept below 0.3 to ensure attainment of high strength [11]. However, limited literature is available regarding maximum desirable binder content and w/b ratio in SCHPC incorporating silica fume. Building codes worldwide emphasize the use of minimum cement for environmental sustainability and to prevent microcracking in concrete developed due to thermal stresses in higher cement content [12].

The main hypothesis in the production of SCHPC is using the large amount of cement and fine aggregate, reduced coarse aggregate, and high amount of suitable high range water reducing admixture. In addition to environmental sustainability concerns, use of high cement content generates high heat of hydration and results in high autogenous shrinkage [13]. In order to achieve the required performances from SCHPC low water to binder ratio and larger binder quantity is used. In concrete with w/b ratio less than 0.5, water remains bonded with a binder, which results in a decrease in cement paste volume. The restrained volumetric shrinkage in absence of water results in the development of small pores in cement paste, which induces AS in concrete [14]. Autogenous shrinkage is thus the result of chemical volume contraction and low water to binder ratio during hydration phase of concrete [15]. Polycarboxlic type superplasticizers which are most commonly used admixture in SCHPC might affect the hydration process of SCHPC due to its molecular variability [16].

The aim of this investigation is to systematically investigate the effect of w/b ration and total binder content and partial replacement of PC (Portland cement) with silica fume on the physical, mechanical, shrinkage and hydration characteristics of SCHPC mixes. The total binder content in SCHPC incorporating silica fume needs to be optimized in controlling its overall performance and to improve its impact on the environment. In this study binder content in the range of 500-600 kg/m^3 and two w/b ratios (0.23 and 0.25) have been selected and silica fume is incorporated. The effect of w/b ratio and binder content on SCHPC performance is studied by evaluating SP dosage, compressive and splitting tensile strength, modulus of elasticity, water absorption, and porosity. Autogenous shrinkage has been determined due to use of high cement content in SCHPC mixes. The hydration studies have been carried out to investigate the heat evolution during hydration phase in these SCHPC mixes.

Experimental

Materials

Portland cement (PC) Type-1 conforming to ASTM C-150 specification having a specific gravity of 3.15 and specific surface area of 311 m^2/kg was used throughout the experimental work to produce concrete specimens. Commercially available silica fume with the SiO_2 content of 92% having specific gravity 2.33 and specific surface area of 20,470 m^2/kg was used. Table 1 gives the physical properties and composition of OPC and silica fume used. A polycarboxylic ether type super plasticizer (SP) manufactured by Econex having a specific gravity of 1.06 was used to acquire the desired workability for all mixes. Locally available natural river sand having fineness modulus of 2.66, water absorption of 1.83% and specific gravity of 2.60

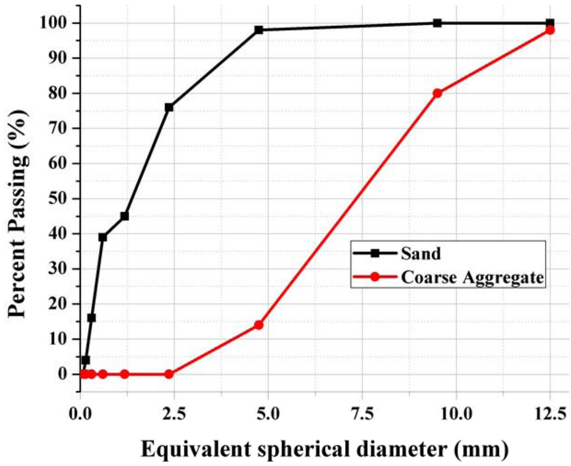

Fig. 1. Fine and coarse aggregate gradation curves.

Table 1. Chemical composition and physical properties of OPC and silica fume.

Component	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	SO_3 (%)	LOI	Specific gravity	Specfic surface (m^2/kg)
OPC	21.95	6.59	2.81	60.12	3.32	2.11	2.58	3.15	3.11
SF	92.24	0.94	0.61	0.25	1.32	0.50	30.02	2.33	204.11

Table 2. Properties of coarse and fine aggregates.

Aggregate type	Specific gravity	Absorption (%)	Fineness modulus	Unit weight (kg/m^3)	Voids ratio (%)
Fine	2.60	1.83	2.66	1584	61
Coarse	2.62	1.21	6.83	1586	61

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was used. Coarse aggregate used was a blend of crushed stone and round aggregates with a maximum size of 12 mm, water absorption of 1.21% and specific gravity of 2.62. Table 2 gives the properties of coarse and sand used. Fig. 1 shows the sand gradation curve for coarse and fine sands used in this study. Water for producing mortars was clean and free of acids, alkalis, and organic materials.

Mix proportions

A total of 18 mixtures were designed having a water-binder ratio of 0.23 and 0.25 and a total binder content of 500,550 and 600 kg/m^3. The control concrete mix included only OPC while other mixes incorporated silica fume along with OPC. The replacement levels of silica fume were 10 and 20% by the weight of cement. The coarse to fine aggregate ratio is kept as 1.18 for all mixes. These values were chosen after testing numerous mix designs to achieve high performance with adequate flowability. All the mix proportions produced in this study are summarized in Table 3. The mixes are given names on the basis of binder and silica fume content. For example, SCHPC500SF10 means self-compacting high performance concrete having binder content of 500 kg/m^3 and silica fume content of 10%.

Mixing and fabrication of specimens

All mixtures were prepared in accordance with ASTM C-192 using a power-driven pan mixer. Dry material was mixed first. SP was first mixed with water and then the water was mixed with dry materials. Immediately, after mixing slump flow diameter was calculated. For compressive strength test ϕ 150×300 mm concrete cylinders, ϕ 150 × 300 mm cylinders for splitting tensile strength and modulus of elasticity measurement, and additional ϕ 150 × 300 mm cylinder specimens for porosity and absorption determination were fabricated. All the specimens were first kept covered with plastic sheets for 24 hrs. After 24 hrs the specimens were removed from the moulds and were place in curing tank at the tank at the temperature of 20 ± 2 ºC.

Testing Methods

Physical Performances were evaluated by estimating 28-day porosity and absorption values for each mix in accordance with ASTM C-642.Three specimens each for every mix was evaluated for porosity and water absorption and average is reported.

Tests performed on hardened concrete specimens were aimed to evaluate compressive strength, modulus of elasticity measurement and splitting tensile strength of SCHPC. The compressive strength test was performed on specimens cured for 3,7,28 and 91 days in accordance with ASTM C-39. Whilst, splitting tensile strength test was performed on 28-day cured specimens according to ASTM C-496. Modulus of elasticity in compression was determined on 28-day cured specimens according to ASTM-C469.

For measurement of autogenous shrinkage, concrete prismatic beams of dimensions 100 × 100 × 400 were cast. Mituyoto IDC digital indicator was used to measure the autogenous shrinkage in concrete specimens for 28 days. The specimens were kept covered under polythene sheet, to prevent transport of moisture in and out of the

Table 3. Mix proportions for SCHPC mixes.

	Concrete Id	w/b	sf/c+sf (%)	Batch quantities (kg/m^3)					
				Water	Cement	Silica fume	Sand	Coarse aggregate	SP (%)
1	SCHPC500SF0	0.25	0	125	500	0	857	1018	1.32
2	SCHPC500SF10	0.25	10	125	450	50	857	1018	1.30
3	SCHPC500SF20	0.25	20	125	400	100	857	1018	1.68
4	SCHPC500SF0	0.23	0	115	500	0	862	1023	1.52
5	SCHPC500SF10	0.23	10	115	450	50	862	1023	1.38
6	SCHPC500SF20	0.23	20	115	400	100	862	1023	1.60
7	SCHPC550SF0	0.25	0	137	550	0	829	983	1.32
8	SCHPC550SF10	0.25	10	137	495	55	829	983	1.30
9	SCHPC550SF20	0.25	20	137	440	110	829	983	1.68
10	SCHPC550SF0	0.23	0	126	550	0	833	990	1.52
11	SCHPC550SF10	0.23	10	126	495	55	833	990	1.43
12	SCHPC550SF20	0.23	20	126	440	110	833	990	1.80
13	SCHPC600SF0	0.25	0	150	600	0	800	950	1.32
14	SCHPC600SF10	0.25	10	150	540	55	800	950	1.60
15	SCHPC600SF20	0.25	20	150	480	110	800	950	1.87
16	SCHPC600SF0	0.23	0	138	600	0	795	943	1.58
17	SCHPC600SF10	0.23	10	138	540	55	795	943	2.17
18	SCHPC600SF20	0.23	20	138	480	110	795	943	2.48

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mould. For hydration studies, each SCHPC mix was cast into 100 × 200 cylindrical container, thermo couples were immersed in container having SCHPC mix, the container was placed in styrofoam to simulate semi adiabatic conditions. The temperature was recorded at every 20 minutes interval for first 3 hrs and at every one-hour interval for remaining 69 hrs.

Results and Discussions

Physical performances

Fresh properties

All mixes were designed to have a slump flow diameter of 600 ± 25 mm by optimizing the dosage of SP used. All the SCHPC mixes demonstrated the slump flow diameter in the range of 550-650 mm. The dosage of SP required to achieve target slump flow diameter for each mix is shown in Fig. 2. It is ascertained from the figure that increase in silica fume content at each binder content level increases the SP demand for all mixes; this phenomenon was probably due to high adsorption capacity of fine silica particles owing to the high specific surface area of silica particles. Another reason for this phenomenon may be due to increased paste volume due to the low specific gravity of silica fume. Similar researches on a conventional concrete support these findings [17, 18]. For all three binder contents, the SP demand for mixtures with 10 % and 20% replacement of OPC with silica fume is substantially higher than their control counterparts. The SP demand at w/b ratio of 0.25 with 0, 10 and 20% replacement of cement by silica fume for binder content of 500 (1.32, 1.42 and 1.68%), 550(1.68, 1.78, and 1.92%) and 600 kg/m^3(1.91, 1.97 and 2.09%) increases substantially when w/b is lowered to 0.23. The high SP dosage to maintain target slump at w/b of 0.23 with 0,10 and 20% replacement of cement with silica fume for 500(1.39, 1.48 and 1.72%), 550 (1.75, 1.82,1.96%) and 600 kg/m^3(1.96, 2.01 and 2.22%) is observed. The results further reveal that SP dosage is increased with the increase in binder content. This phenomenon could be due to the fact that the SP is absorbed by the high amount of cementitious materials to achieve target slump flow diameter.

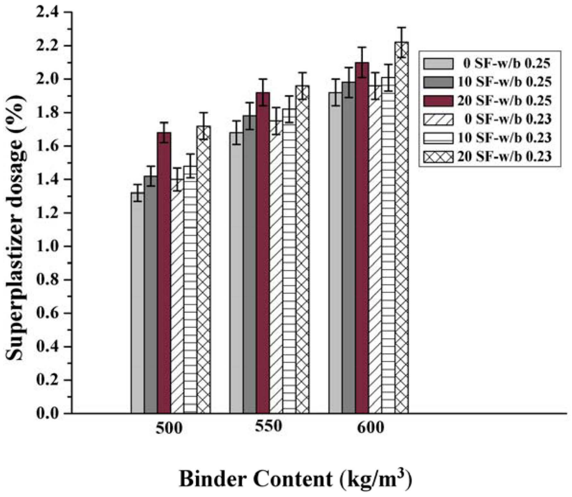

Fig. 2. Superplasticizer dosage to maintain target slump flow diameter.

Porosity and water absorption

Water absorption and porosity are two most important factors that control the strength of concrete [19]. Low w/b ratio generally facilitates HPC in achieving high strength. Thus, SCHPC mixes should demonstrate low transport properties (water absorption and porosity) in order to achieve high early and later strength. Results for 28-day porosities and water absorption are summarized in Table 4. It can be observed from the Table 4 that the porosity and absorption for higher binder content were much higher than for lower binder contents. The total porosities were found less for binder content of 550 kg/m^3 than for 500 and 600 kg/m^3. The 500 kg/m^3 binder content HPC contained less binder to enable all coarse and fine aggregates, whilst the mixes of 600 binder content might have developed microcracking due to the high heat of hydration, which resulted in increased porosity and water absorption (Table 4). The variation of absorption and porosity as function binder content shows strong agreement with mechanical properties discussed in coming section of this paper. Based on results of porosity and water absorption, it is assessed that lower binder contents have strong durability than binder content of 600 kg/m^3 due to less porosity and water absorption. The ability of silica fume to fill pores is evident at all three binder contents. With the incorporation of silica fume at every level of binder content, the porosity and water absorption decreased and these findings are in agreement with studies carried out by earlier researchers on HPC. [20, 21]. All the SCHPC mixes were found to be high-quality concrete in terms of water absorption, as high-quality concrete tends to have water absorption below 5% [22].

Table 4. Porosity and water absorption values of SCHPC after 28- days.

Concrete ID	Water Absorption (%)		Porosity (%)	
w/b	0.25	0.23	0.25	0.23
SCHPC500SF0	4.81	5.11	10.78	10.12
SCHPC500SF10	4.10	4.61	9.78	9.11
SCHPC500SF20	3.81	4.21	8.54	8.16
SCHPC550SF0	3.91	4.02	8.15	8.06
SCHPC550SF10	3.71	3.91	8.10	7.94
SCHPC550SF20	3.23	3.61	8.01	7.09
SCHPC600SF0	5.12	5.21	11.70	11.15
SCHPC600SF10	4.61	4.80	11.19	11.08
SCHPC600SF20	4.32	4.50	10.56	10.08

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Mechanical performances

Compressive strength development

The average compressive strength of all the concrete mixes during the entire curing age is shown in Fig. 3. The 28-day strength of all mixes was in the range of 70-104 MPa. High compressive strength is achieved for all control and silica fume concrete at all three binder contents. Comparing the compressive strength of control specimens for each binder content revealed that insignificant variation in the strength was found for all binder contents. This result is in agreement with the findings of who found that compressive strength of concrete at constant w/b is independent of binder content. However, greater strength is achieved for silica fume concrete for lower binder contents at all replacement levels. For example, at w/b ratio 0.25, the replacement of OPC with 10 and 20% silica fume increased the 28-day strength of concrete mixes with respect to respective control specimens by 18, 18.44; 23.81, 31.11 and 7.30, 19.38% for binder contents of 500,550 and 600 kg/m^3 respectively. At w/b ratio of 0.23 this increase was found to be 22.42, 24.45; 22.22, 8.06; and 7.48, 16.73%. It was found that the inclusion of silica fume showed a significant increase in strength as the binder content of SCHPC was increased from 500 to 550 kg/m^3. However, compressive strength decreased as the binder content is increased beyond 550 kg/m^3 for SCHPC with or without silica fume. This trend continued till 90 days of curing.

From the figure, it can be further observed that at all binder contents the compressive strength is greater at the w/b ratio of 0.23 as compared to 0.25. Effect of w/b ratio was found more pronounced at lower binder contents for silica fume replacement. Lowering w/b ratio and increasing silica fume content increased the compressive strength for all mixes. For 500 kg/m^3 of binder content, the average increase is observed as 1.94, 5.72 and 7.12% for 0, 10 and 20% replacement of PC with silica fume as w/b ratio was lowered to 0.23 from 0.25. For binder content of 550 kg/m^3, this increase was 2.56, 1.24 and 8.29%. For binder content of 600 kg/m^3, the increase is found as 3.23, 3.40 and 0.94%. It has been ascertained that compressive strength is also increased for every mix with an increase in silica fume content and the role of binder content is also important in strength gain of SCHPC.

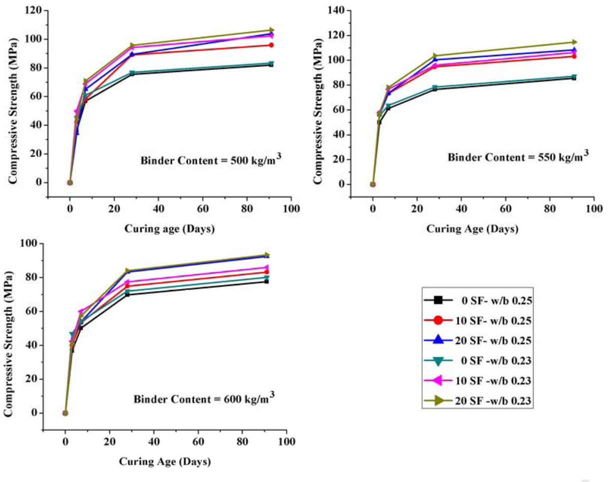

Fig. 3. Compressive strength development with age.

The highest 28-day compressive is achieved for SCHPC having 20% silica fume and binder content of 550 kg/m^3, conversely, lowest compressive strength is achieved by control SCHPC mix with binder content of 600 kg/m^3, which shows that w/b ratio, silica fume content, and binder content plays crucial role in strength development. The highest strength development was achieved for binder content of 550 kg/m^3 which shows replacement of silica fume is most desirable at lower binder content. It is presumed that silica fume utilized the portlandite a hydration product which results in more compact and dense CSH product formation [23]. It is ascertained that increasing the binder content increases the quantity of fine particles in SCHPC mixes, which draws the increment in porosity and heat of hydration, bringing along shrinkage cracks, which leads to lower compressive strength.

Splitting tensile strength and modulus of elasticity

The results for 28-day splitting tensile strength for all SCHPC mixes are shown in Fig. 4. It can be observed that as the compressive strength is increased, the tensile strength also increased slowly and proportionally. Previous studies [24-26] on conventional, HPC and SCC incorporating silica fume also confirm the improvement in split tensile strength with the inclusion of silica fume. There was an overall systematic increase in tensile strength with increase in silica fume content. The maximum splitting tensile strength (5.65 MPa) was obtained for SCHPC having 20% silica fume and a total binder content of 550 kg/m^3 at w/b ratio of 0.23. Compared to control specimens the 10% and 20% replacement by weight with silica fume for w/b ratio 0.23 increased the strength by 1.69, 3.75; 1.84, 4.43 and 1.58, 3.76% for binder content of 500,550 and 600 kg/m^3 respectively. At w/b ratio 0.25 this increase was found to be 1.6, 3.10; 1.74, 4.25 and 1.41, 3.64%. Conversely, the minimum splitting tensile strength (4.94 MPa) was obtained for control specimens at w/b ratio of 0.25 for binder content of 600 kg/m^3. It was ascertained that 550 kg/m^3 is the maximum desirable content as far as mechanical performances are concerned.

Results for 28-day modulus of elasticity in compression are shown in Fig. 5. It can be observed that modulus of elasticity for each group of SCHPC mix increased with the increase in silica fume content. The modulus of elasticity of SCHPC mixes having binder content of 550 kg/m^3 performed better than 500 and 600 kg/m^3.There was observed a decrease in modulus of elasticity for SCHPC with binder content beyond 550 kg/m^3.

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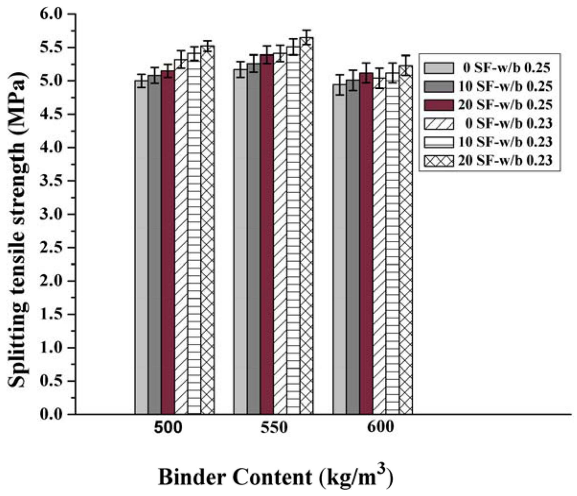

Fig. 4. Splitting Tensile strength of SCHPC after 28 days.

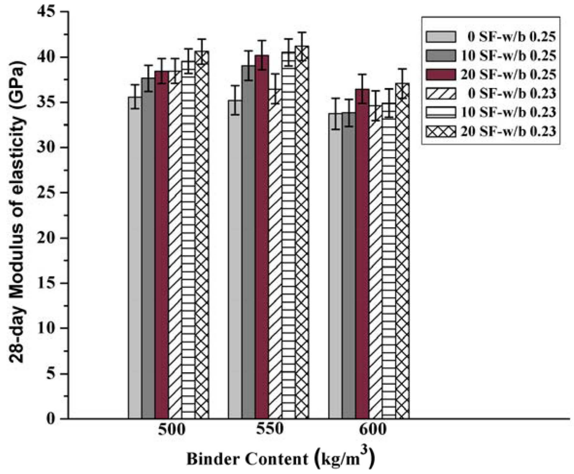

Fig. 5. Modulus of elasticity of SCHPC after 28 days.

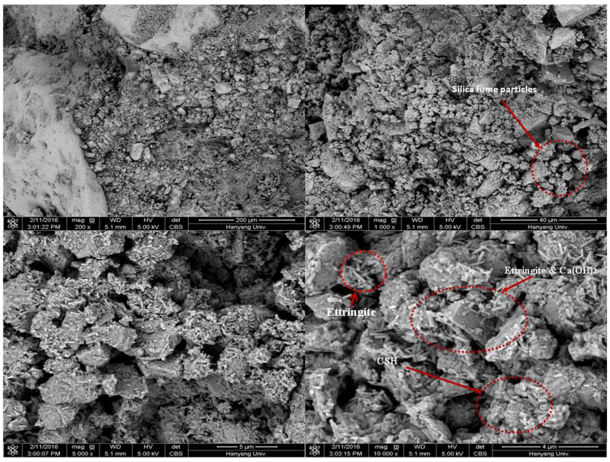

Fig. 6. Back scattering mode SEM images at different magnification levels of 3 day hydrated 20 SF SCHPC at w/b 0.23.

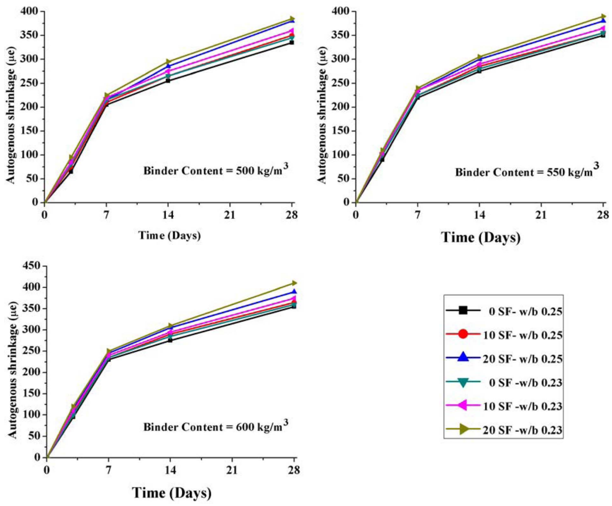

Fig. 7. Autogenous shrikange of SCHPC mixes upto 28 days.

SEM images of silica fume SCHPC at different magnification levels is shown in Fig. 6. The high enhancement in mechanical performances of SCHPC having silica fume is due to rapid consumption of $Ca(OH)_2$ formed at the early age of hydration. As a result, hydration of cement increases, and more compact and dense microstructure is obtained. Furthermore, silica fume particles tend to improve the packing density of concrete which tends to reduce transport properties.

Autogenous shrinkage

The results for autogenous shrinkage strain up to 28 days for all SCHPC mixes are given in Fig. 7. It is envisaged from the figure that, the autogenous shrinkage increased with the increase in total binder content for all SCHPC mixes. It was observed that at SCHPC mix at w/b = 0.23 with a binder content of 600 having 20 percent silica fume underwent the greatest shrinkage, with peak strain value of 410 microstrains. For all binder contents, shrinkage increased with the increase in silica fume content and decrease in w/b ratio. This finding was in agreement with earlier researchers on HPC [27-29]. It is presumed that high specific surface area of silica fume allows it to precipitate hydration product CSH by consumption of Ca $(OH)_2$ crystal lattices, which results in rapid hydration of concrete and self-drying phenomenon within the concrete, which consequently leads to high degree of autogenous shrinkage [30, 31]. Seventy percent or more of total autogenous shrinkage occurred in first two weeks for all SCHPC mixes.

Hydration study

The hydration test was performed in order to evaluate the temperature rise due to hydration reactions in SCHPC mixes at higher binder contents. The results of the heat of hydration development versus time for each SCHPC mix are given in Fig. 8. According to one previous study [30] on HPC, w/b ratio along with silica fume content influences the hydration mechanism of concrete with silica fume.

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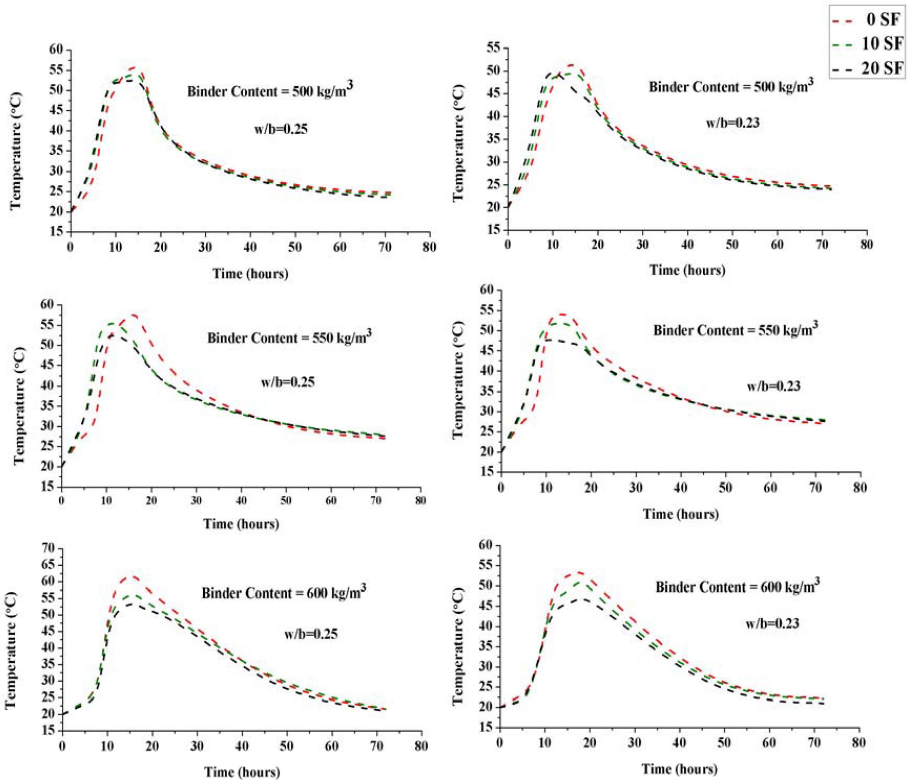

Fig. 8. Hydration curves for SCHPC mixes.

From the figure, it is observed that at a particular w/b ratio, compared to concrete mixtures having binder content of 600 kg/m^3, peaks for temperature occur earlier for SCHPC mixes having 500 and 550 kg/m^3 binder content. This phenomenon might be due to retarded hydration effect due to the addition of high dosage of SP [31].

In addition, silica fume concrete at lower binder contents underwent high heat liberation in the first hour of hydration. The early hydration of silica fume concrete at lower binder contents may be due to the fact that silica fume dissolute rapidly by utilizing available water in the presence of portlandite to form silica-rich phase, the silica-rich phase forms a layer on silica fume particles which provides a nucleation sites for CSH to precipitate, which tends to demonstrate the pozzolonic activity of silica fume [32]. However, at higher binder content this effect is diminished i.e. the peaks for control as well as silica fume concrete are demonstrated at the same time and dormant period is prolonged. In addition, the high temperature is achieved for plain concrete compared to silica fume concrete. It can be concluded that at higher binder content the degree of hydration of concrete mixes have retarded due to high dosage of SP and effect of the pozzolanic behavior of silica fume becomes relatively ineffective.

At lower binder content, the silica fume concrete achieves high temperature than a plain concrete mix, in first few hours of hydration. This phenomenon is found more pronounced at higher w/b ratio, it can be seen that for all binder contents the temperature rise is lower for 0.23 than for 0.25, this phenomenon is probably due to the fact that more water is available to hydrate binder grains, which leads to high hydration rate of concrete mix. This phenomenon seems to be more pronounced for silica fume concrete where fine grain particles rapidly consume water available compared to cement grains [32].

Conclusions

In order to evaluate the overall performance SCHPCs in terms of total binder content, an experimental study was carried out. In the light of results presented, following conclusions were made.

The SP demand increased with the increase in binder content. The SP dosage also increased with the increase in silica fume content, due to high adsorption of SP by fine silica fume particles. All mechanical properties improved when binder content was increased from 500 to 550 kg/m^3, however, the overall reduction in mechanical performances was found for SCHPC mixes when binder content was increased beyond 550 kg/m^3. At all binder content levels, silica fume improved the mechanical properties of all SCHPC mixes. In general, mechanical properties were found to be a function of w/b ratio, silica fume, and cement content. Highest mechanical strength was achieved for 20 percent replacement of PC with silica fume for the total binder content of 650 kg/m^3.With the increase in binder content and silica fume the

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dosage of SP required to achieve target slump increases, possibly due to high adsorption of admixture on larger amounts of binder grains. For all binder contents, shrinkage increased with the increase in silica fume content and decrease in w/b ratio. High autogenous shrinkage was observed for higher binder content and silica fume content. Silica fume, w/b ratio, SP and binder content have influenced the hydration characteristics of SCHPC. For lower binder contents, the temperature rise is more in first 3 hrs of hydration for silica fume concrete; however, this effect is diminished at higher binder contents due to high dosage of SP. In general, high cement content results in the high heat of hydration during 18-72 hrs.

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References

1. P. Dinakar, S.N. Manu, Mater. and Des. 60 (2014) 661-668.
2. B.H. Nagaratnam , M.E. Rahman , A.K Mirasa, M.A. Mannan, S.O. Lame , J. Clnr. Prod. 112 (2016) 882-894.
3. CT-13: ACI Concrete Terminology - An ACI Standard. 4. ACI Committee 363 R, Amer. Concr. Inst. (1997).
4. A. Bilodeau, V. Sivasundaram, K.E. Painter, V.M. Malhotra, ACI Mater. J. 91 (1994) 3-12.
5. C. Shi, J. Qian, Resour. Conserv. Recycl. 29 (2000) 195-207.
6. H.T. Le, H.M Ludwig, Mater. and Des. 89 (2016) 156-166.
7. E. Guneyisi, M. Gesoglu, S. Keraoglu, K. Mermerdas, Constr. Build. Mater. 34 (2012) 120-130.
8. S. Chan, X. Ji, Cem. Concr. Compos. 21 (1999) 293-300.
9. M. Mazloom, A.A. Ramezanianpour, J.J Brooks, Cem. Concr. Compos 26[4] (2004) 347-357.
10. P. Xincheng, in 'Super-High-Strength High Performance Concrete" (CRC Press Reference, 2012).
11. K.O. Kjellsen, O.H. Wallevik and M. Hallgren, Structures/ Matdriaux et Construct. 32 (1999) 63-69.
12. B.S. Thomas, R.C. Gupta, J. Clean. Prod (2013) 1-6.
13. S.W. Yoo, S.J. Kwon, S.H. Jung, Constr. Build. Mater. 34 (2012) 1-10.
14. M.S. Habashi, in the proceedings of 36th Conference on Our world in concrete & structures, August 2011.
15. F.R. Kong, L.S. Pan, C. Wang, D. Zhang, N. Xu, Constr. Build. Mater. 105 (2016) 545-553.
16. M. Mazloom, A.A. Ramezanianpour, J.J. Brooks, Cem. Concr. Compos. 26[4] (2004) 347-357
17. F.A.Sabet, N.A. Libre, M. Shekarchi, Constr. Build. Mater. 44 (2013) 175-184.
18. T. Deboodt, T. Fu, J.H. Ideker, Cem. Concr. Compos 57 (2015) 94-101.
19. M.I. Khan, Build. Environ. 38[8] (2003) 1051-1056.
20. C.S. Poon, S.C Kou, L. Lam, Constr. Build. Mater. 20[10] (2006) 858-865.
21. M.S. Shetty, in "Concrete technology: theory and practice" (S. Chand and Company Ltd., 2001).
22. G. Fonteboa, B.F. Martinez-Abella, Build. Environ. 43[4] (2008) 429-437.
23. R.D. Hooton, ACI Mater. J. 90[2] (1993) 143-152.
24. S. Bhanja, B. Sengupta, Cem. Concr. Res. 35[4] (2005) 743-747.
25. H. Yazıcı, Constr. Build. Mater. 22[4] (2008) 456-462.
26. E. Tazawa, S. Miyazawa, in the Proceedings of the 5th International RILEM Symposium, April, 1993 (E & FN Spon, London, 1993) pp. 159-168.
27. J.J. Brooks, J.G. Cabrera, M.A. Megat Johari, in: E. Tazawa (Ed.), Proceedings of International Workshop on Autogenous Shrinkage of Concrete, March 1998, p.195-201.
28. M.H. Zhang, C.T. Tam, M.P. Leow, Cem. Concr. Res. 33[10] (2003) 1687-1694.
29. E.H. Kadri, R. Duval, Constr. Build. Mater. 23 (2009) 338-3392.
30. H. Uchikawa, in the proceedings of 8th International Congress on the Chemistry of Cement, April 1986, p. 249-280.
31. M. Grutzeck, S. Atkinson, D.M Roy, ACI Special Publications SP-79 [2] (1983) 643-664.

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