Durability performance of silica fume Self-Compacting Concrete

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ABSTRACT: The main objective of this research is to investigate the influence of silica fume on the characteristics of SCC in fresh, hardened states and durability performance. Five mixes produced: four of them contain different percentages of SF and the last one is control mixture without SF. Fresh properties were measured by three tests: - slump flow cone to measure flowability for concrete, L-box test to measure the concrete ability for passing and Screen stability to measure segregation resistance. The mechanical property was determined by measuring compressive strength, tensile and flexural strengths. Durability performance was determined by measuring sulfate resistance, chloride resistance, RCPT and permeability of specimens. The microstructural analysisfor the consolidated concrete was determined by SEM. The results of the tests indicate that there is a noticeable improvement on the mechanical and durability performance of SCC by increasing the percent of SF to about 16% as a percent ofcement weight.Furthermore, the enhancement inpermeation properties was more significant when SF percent increased to 20% of cement weight.

KEYWORDS: -Self Compacting Concrete -Silica Fume -Hardened Properties -Durability performance-Scanning Electron Microscopy (SEM)-rapid chloride penetration test (RCPT)

I. INTRODUCTION

The beginning of the development of Self-compacting concrete was in 1998 in Japan to create sustainable concrete structures [1]. Self-compacting concrete (SCC) is defined as the concrete which has the ability to consolidate related to its own weight. The very high fluid nature of SCC makes it appropriate for placing in hard conditions and in sections with engorged reinforcement. The use of SCC also can decrease the rate of hearing-related damages on the worksite that produced by the vibration of concrete, another advantage of SCC is that the time needed to place huge sections is significantly reduced [2]. Sistonen and Fahim [3] concluded that SCC must have the subsequent characteristics to achieve self-compatibility: Filling ability, passing ability and high resistance to segregation.

Mechanical properties of SCC increased by the addition of Silica fume, mechanical properties investigated including compressive strength, split and flexural strengths. Turk et al. [4] reported that the highest value of compressive strength was 73.87 MPa for 130 days when SF replaces 15% of cement weight.

Bhanja and Sengupta [5] reported that inclusion of silica fume within the range of 5 - 25% will increase compressive strength from 6% to30% for water cement ratio from 0.26 to 0.42. the replacement of cement by silica fume (up to18%) and also the addition of superplasticizer increased the strength of cement paste [6].At 15% silica fume content, the tensile strength was found to be within the range of 4.79-5.34% of its compressive strength [7].Sakr [8] concluded that at 15% replacement level, the tensile strength of silica fume concrete improved within the range of 27 -34% compared to concrete manufactured without silica fume. The tensile strength and elasticity modulus of concrete at the age of 3 days improved gradually with the increasing of silica fume ratio from (5% to 15%) by weight of cement[9]. silica fume has a pronounced influence on flexural strength compared with split tensile strength[10].
For flexural strengths, even very much substitution of silica fume considerably improved the strength. In addition, it had been found that there was a steady increase within the flexural strength with an increase within the replacement percentage of silica fume. Self -compacting concrete durability problem still exists, especially in terms of physicochemical characteristics.
Durability properties investigated by studying chloride resistance, sulfate resistance, and water permeability. When chloride ions ingress from the surface, Chloride attack to concrete commonly happens, Chloride ions exist in salts, ocean water, and contaminated water. Petron et al. [11] concluded that the chloride penetrability in SCC is somewhat reduced compared to corresponding traditional vibrated concretes; this reduction takes place when supplementary materials are included into the mixtures. At 100 and 300 days of contact, the result of a solution of Na_2SO_4 on SCC was small however accelerated from 300 to 900 days of experiment because of increasing porosity parallel to the increased air content [12]. The concrete Water permeability is thought to be essential for the preservation of the inner quality of the structure, at later ages and when the hydration reactions is in its later stages, it causes remarkable deterioration of the concrete and reinforcements. The addition of silica fume causes big pore refinement transformation of larger pores into smaller ones related to their pozzolanic reaction and cement hydration, this promotes the durability performance of self-compacting concrete. Subramanian et al. [14] concluded that a blend of micro silica and Nano silica with 15% of micro silica and 3 liters of Nano silica enhance the compressive strength, splitting tensile and flexural strength by 25.61%, 25%,and 19% respectively and increased fresh properties with the help of VMA and improved Saturated Water absorption, sulfate Resistance and Acid Resistance.
The influence of mineral additives on the durability performance of self-compacting concrete with different partial replacements of fly ash, silica fume and combination of fly ash and silica fume as well were presented and it

was concluded that 15% replacement of silica fume shows the ultimate durability factor and lower Sorptivity [16]. Sabet et al. [17] examined the variation in durability performance of self-compacting concrete including different mineral additives and found out that the most effective mineral additive in enhancing durability characteristics is silica fume, including of silica fume with 10% and 20% improved the compressive strength, at the age of 28 days to 75.5 and 79.5 MPa and reduced final absorption from 4.5% to 2.76% and 2.57% respectively. The most important result of SF on the pore structure of concrete is that the reduction of big pores via block them with hydration products. The transformation of continuous pores into discontinuous pores includes a profound result on the permeability of concrete [15].Sellevold and Nilsen [27] concluded that SF is helpful in reducing permeability than it's in enhancing strength and said that it's the improved quality of the cement paste mixture transition zone that is essentially responsible for this behavior. Byfors [28] suggested that the addition of SF up to 20% by cement weight significantly minimizes the diffusion rate of chloride particle compared to the performance of standard PC paste. During a study performed by Poon et al. [29], it had been declared that, compared to that of the control mixture, including 20% MK and10%
SF minimized chloride particle ingress by 79% and 65% after 28 days respectively. du ring a more modern study by Hassan et al. [25] investigated the chloride particle permeability of SCC incorporating MK and SF, They concluded that chloride particle permeability of mixtures containing 11% SF and 20% MK reduced by 54% and 88%, respectively in comparison with the control mixture. Cabrera and Claisse [30] studied the effect of using silica fume in reducing chloride penetration depth by increasing the replacement amount of silica fume to 20% by cement weight. It was verified that for mixes cured in water at 6oc with 20 % SF replacement the chloride particle penetrability minimized by 60 % and 24% rather than control mix for W/cm equal to 0.3 and 0.46 respectively.

Amirreza et al. [31] appraised and compared the performance of four tests for estimating the chloride penetration of concrete; Rapid Chloride Migration Test (RCMT), Rapid Chloride Permeability Test (RCPT), Modified Rapid Chloride permeability test (MRCPT) and Surface Electrical resistance (SR).He ended that for W/cm equal to 0.35 the chloride particle penetrability reduced by 67% and 79% for partial replacement of silica fume 7.5 % and 15% by cement weight respectively. Yunfeng et al. [32] reported that increasing SF from 3% to 12% by weight of cement significantly minimized the diffusion rate of chloride particle compared to the normal pc paste. This research focuses on producing sustainable self-compacting concrete by using by- product waste material from Ferro silicon alloys factory in Egypt (Silica fume).

II. EXPERIMENTAL PROGRAM

2.1. Materials

Cement

In this study, Portland cement (CEM I 42.5 N) was used. The physical and mechanical properties are satisfied with the Egyptian standard [18] and also the European standard [19]. The mechanical properties and physical properties are given below in Table 1.

Table1: mechanical and physical properties of Portland cement (CEM I 42.5 N)

Property			Result of test	ES 4756-1/2013
Specific surface area (m2/kg)			360	Not less than 2750
Setting Time (min)		Initial	75	Not less than 60 min
		Final	210	--
Compressive strength (MPa)		2 days	24	Not less than 10
		28 days	54	Not less than 42.5

Silica Fume

The Silica Fume used was produced by the Ferro Silicon Alloys factory in Edfu, Aswan, as a waste material with a specific gravity Equal to 2.25 and specific surface area of 17×10^3m2/kg. Silica fume was mixed in a percentage of 8%, 12%, 16% and 20% by cement weight. The physical characteristics of silica fume are shown in Table2 below.

Table 2: Physical properties of silica fume used

Property	Value
Specific surface area(m^2/kg)	17,000
Mean Particle size (µm)	0.15
Specific gravity	2.25

Aggregate

The coarse aggregate used in the experimental work was a crushed dolomite type 4/12.5 with a maximum nominal size of 12.5 mm. Natural sand type 0/4 was used as fine aggregates. The properties of crushed dolomite and sand used were carried out according to the Egyptian Standard [20] as shown in Tables 3 and 4.

Table 3: The physical properties of the used crushed dolomite

Property	Test results	ES 1109/2008
Specific weight	2.6	-
Bulk density (t/m3)	1.67	-
Coefficient of abrasion (Loss Anglos) %	17	Less than 30
Coefficient of Impact %	12.2	Less than 30
Absorption %	1.6	Less than 2.5
Clay and fine dust content %	0.8	Less than 3.0

Table 4: The physical properties of the used fine aggregate

Test	Test Result	ES 1109/2008
Specific weight	2.55	-
Bulk density (t/m3)	1.70	-
Fineness modulus	2.8	-
Material finer than No 200 sieve %	2.6	Less than 3%

Superplasticizer

In this study a high range water reducer (Visco Crete 3425) type F used according to ASTM C494 [21].

Water

Drinking water was used in all concrete mixes. The same water used for curing the specimens. Water added in the percentage of 0.38 by weight of cementitious materials (W/cm), where: cm= (cement + silica fume).

2.2. Mix proportions

Five Self Compacting Concrete (SCC) mixtures were designed M0, M8, M12, M16, and M20 where: The number of mixes indicates the percent of silica fume used in the mixture. For all mixes cement content, 450 kg/m3 was used. The control mixture (M0) was made without adding silica fume. The other four mixes were made by adding a different percentage of silica fume 8%, 12%, 16% and 20% by weight of cement. The mix components of concrete mixtures are listed in Table 5.

Table 5: The components of the mixes by kg/m3

Mix	C	SF	FA	CA	W	W/cm	SP
M0	450	0	865	865	171	0.38	9
M8	414	36	865	865	171	0.38	9
M12	396	54	865	865	171	0.38	9
M16	378	72	865	865	171	0.38	9
M20	360	90	865	865	171	0.38	9

C: cement, SF: Silica *fume, SP: superplasticizer, W: water, FA: fine aggregate, CA: coarse aggregate.*

2.3 Mixing, Casting, and Curing

For each mixture, the components were placed into the laboratory mixer in the following sequence: coarse aggregate, and fine aggregate for a period thirty seconds, then cement was combined, silica fume in dry condition and blended. After sixty seconds from the beginning of the mixing process, 75% of water added to the mix. Then the remainder of the water and superplasticizer were added into the mix gradually to provide uniformity to the mixture.

The total mixing time was 4 minutes to ensure uniformity. Cubes with dimensions of 100x100x100 mm for compressive strength tests, cylinder 150 mm diameter and 300 mm height for tensile strength tests, and beams100x100x500 mm for flexural strength was used. To determine the fresh properties (filling ability, passing ability, and segregation resistance), the slump-flow test, T50 flowing time test, L-box and GTM screen stabilities were evaluated. Specimens were then cast without compaction and vibration. The specimens were preserved at room temperature for 24 hours. The specimens kept in water till 28 days then the specimens were removed from the water at room temperature for 24 hours.

2.4 Testing procedure

The Compressive Strength was evaluated after 7, 28 and 90 days. Splitting tensile and flexural strengths were measured after 28 days. Chemical resistance including chloride resistance and sulfate attack resistance were measured after 28, 90 days from exposure in NaCl (0.4M and 0.8M) and $MgSO_4$ (3% and 6%) respectively by determining the loss on weight and strength. Water permeability was measured by evaluating water absorption and Sorptivity after 90 days of curing in water. A rapid Chloride Penetration test (RCPT) and Scanning Electron Microscopy (SEM) were measured after 28 days.

3. TEST RESULTS AND DISCUSSIONS

3.1 Fresh properties

There were many tests done in the experimental program to express the fresh properties of self-compacting concrete as follows: The slump flow, T500 slump flow time to measure flowability. V-funnel test to measure passing ability. Screen stability (GTM) to measure the segregation resistance of concrete as shown in Table 6 and Figure 1.

Table 6: Workability of all mixture

Mix No.	Mo	M8	M12	M16	M20
Slump-flow (mm)	730	715	695	680	650
T_{500} (second)	2.5	2.8	2.8	3.0	3.5
L-box (h2/h1)	0.82	0.85	0.88	0.90	0.95
GTM (%)	14.3	12.6	10.8	9.2	8.8

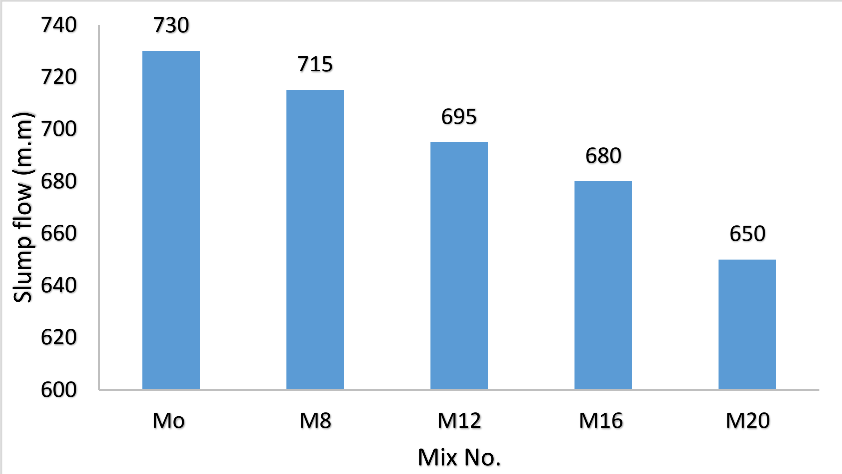


Figure 1: Relationship between SF content and slump flow

From Figure 1 it's discovered that the increase of silica fume replacement causes a decrease in slump flow, this has been because of the higher specific surface of silica fume that desires a lot of water to finish hydration and for workability. Because of increasing within the number of contact points between solid particles, the cohesiveness of mortar mixture greatly enhances once silica fume is added, and this can be clear from Figure 1 once silica fume added with 20% by weight of cement, the slump flow reduced with percent 10.95%, the previous results were coincident with conclusions of the analysis that was applied by Rao [22]. Blocking ratio (H_2/H_1) increased with a higher volume of silica fume, it means that silica fume enhances passing ability [23].

So, once silica fume percent increased from 8% to 20% by weight of cement, the blocking ratio increased as well shown in Table 6. Concrete with silica fume presents substantially reduced bleeding. In addition, silica fume reduces bleeding by physical obstruction the pores within the fresh concrete due to its fines particles [23]. So, when silica fume percent increased from 0% to 20% by cement weight, the segregation resistance of SCC enhanced by 38.46 % as illustrated in Table 6.

3.2 Hardened properties Test Results and Discussion

Compressive Strength

Compressive strength is the most important mechanical property of concrete. The compressive strength of concrete primarily depends on the W/B ratio, binder/aggregate (B/A) ratio, mixture composition, and degree of consolidation. Table 7 shows the mechanical properties results for different mixes.

Table 7: Mechanical Properties for Different SCC Mixes

Mix No.	*Compressive strength F_{cu} (MPa)*			f_t (MPa)at 28 days	f_{fl} (MPa) at 28 days
	7 days	*28 days*	*90 days*		
Mo	27	36	45	3.07	4.56
M8	29	39	50	3.17	4.76
M12	29	41	52	3.27	5.10
M16	34	46	60	3.71	5.54
M20	32	43	56	3.54	5.32

(Fcu: compressive strength, f_t: tensile strength, and f_{fl}: flexural strength)

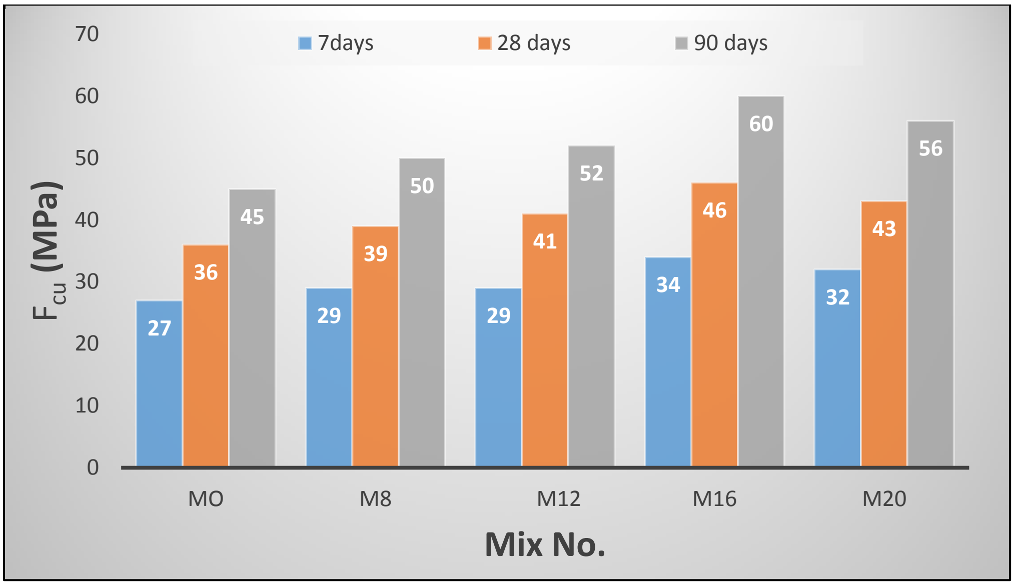


Figure 2: Relationship between SF content and compressive strength at different ages

Table 7 and Figure 2 show that there's an excellent positive impact of increasing silica fume replacement on the compressive strength of SCC at 7, 28 and 90 days tests of specimens. Increasing silica fume content to 16 % by cement weight improves the compressive strength at the age of 7, 28 and 90 days by approximately 20.59 %, 21.74% and 25% respectively, our results coincide with Bhanja and Senjupta [5]. Concrete containing silica fume as a mineral replacement exhibited an enhanced compressive strength mostly as a result of the improved strength of the cement paste matrix.

Tensile Strength

The tensile strength of concrete is much lower than the compressive strength, as a result of the principle that cracks propagate under tensile loads. The tensile strength of concrete is measured using the Brazilian test using standard cylinder. The indirect tensile strength test results are clarified in Table 7 and Figure 3.

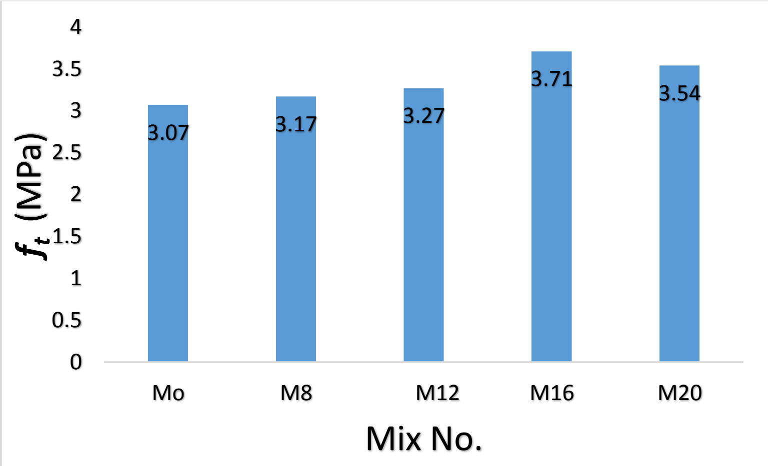


Figure 3: Relationship between SF content and split tensile strength

Figure 3 shows that at 16% silica fume content, tensile strength was 6.6 % of compressive strength, this is slightly coincident with Paillere [7] results. From Figure 3 for M16 (16% SF), tensile strength increased to 20.84% compared to control mixture, these results were slightly agreed with the results of Sakr [8].

Flexural Strength

The flexural strength test results are mentioned in Table 7 and Figure 4.

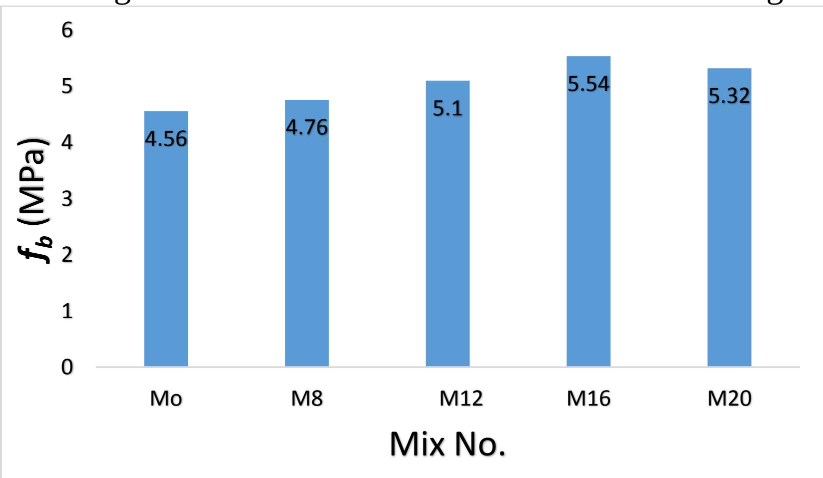


Figure 4: Relationship between SF content and flexural strength.

The flexural strength test results show that the increase in silica fume content incorporates a valuable positive impact on the flexural strength of SCC at 28 days. It's shown that increasing silica fume content to 16 % by weight of cement improves the flexural strength at the age of 28 days by about 21.49 %. Silica fume has a pronounced impact on flexural strength as compared with splitting tensile strength. For flexural strengths, even very high substitution of silica fume considerably improved the strength. In addition, there was a gradual increase within flexural strength with the increase within the silica fume replacement percentage in a steady way[10].

3.3 Durability Test results and Discussion

Chloride resistance

In order to study the durability characteristics, chloride attack was studied, the SCC cubes were immersed in sodium chloride solution (NaCl) with a concentration of 0.4M and 0.8M. The cubes were demolded and dipped in the solution. Then the cubes were taken from the solutions after 28 and 90 days and their corresponding compressive strengths and loss on weight were noted. Table 8 and Figures 5, 6 clarify the effect of sodium chloride in compressive strength.

Table 8: Compressive strength of cubes immersed in NaCl solution for Different SCC Mixes

Curing solution	Compressive strength F_{cu} (MPa)									
	Mo		M8		M12		M16		M20	
	28d	90d	28d	90d	28d	90d	28d	90d	28d	90d
Water curing	36	45	39	50	41	52	46	60	43	56
0.4M NaCl	32	38	35	45	37	47	43	55	40	51
0.8M NaCl	30	34	33	40	35	43	41	53	39	49

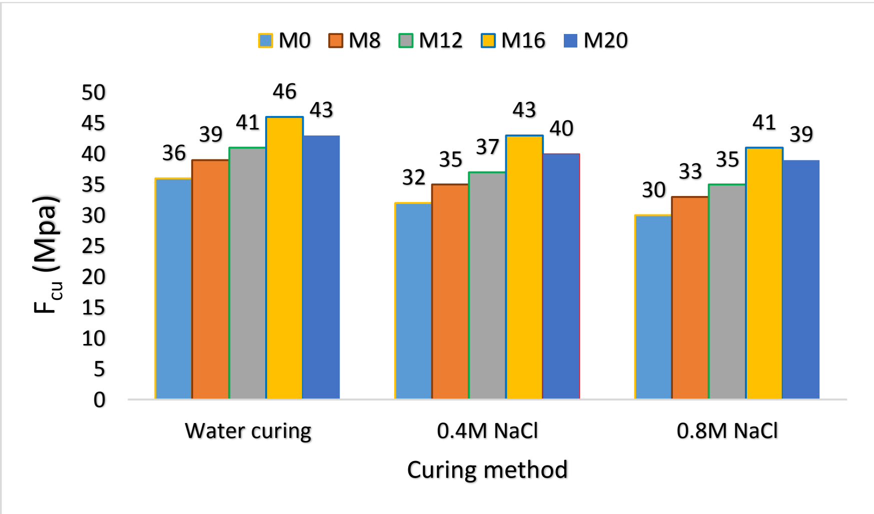


Figure 5: The effect of NaCl solution on compressive strength after 28 days

Figure 5 describes the effect on compressive strength after 28 days immersion of the specimens in NaCl solution and it's obvious that increasing the concentration of the NaCl solution causes decreasing in compressive strength.

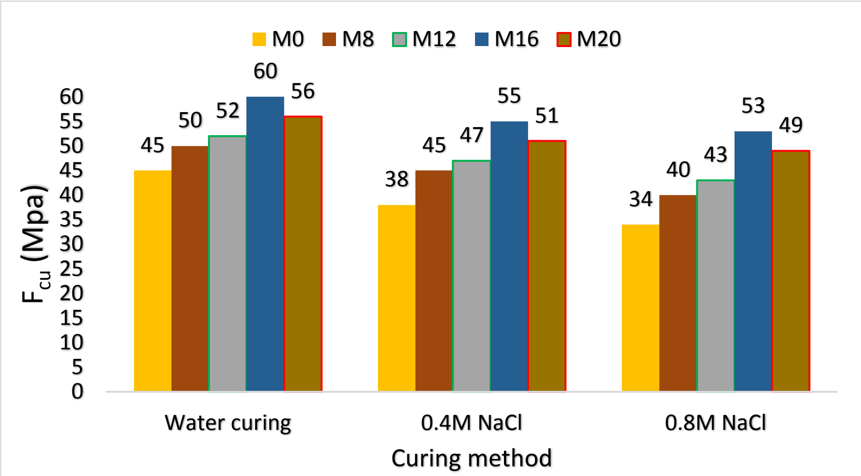


Figure 6: The effect of NaCl solution on compressive strength after 90 days

Figure 6 describes the effect on compressive strength after 90 days immersion of the specimens in NaCl solution and it's obvious that increasing the concentration of the NaCl solution causes decreasing in compressive strength. Adding silica fume with 16% by weight of cement enhances the strength than control mix at 28 and 90 days for 0.4M NaCl as follow: The strength increased by 4.59 % after 28 days and 7.23% after 90 days, the rate of decrease on strength increased with increasing the duration of immersing in the chlorides solution, this is due to the deterioration of concrete. From Figure 5, 6 the decrease in strength due to 0.8M of NaCl is higher than the decrease in strength due to 0.4M of NaCl as while the concentration of the solution increased, the strength of concrete decreased.

Table 9: The effect of NaCl solution on the loss of weight for SCC Mixtures after 28 and 90 days

Mix No.	**Loss of weight after 28 days**		**Loss of weight after 90days**	
	0.4M NaCl	0.8M NaCl	0.4M NaCl	0.8 NaCl
M0	1.2911	1.4286	1.7964	1.9688
M8	1.1598	1.2658	1.3977	1.3617
M12	1.0169	1.0832	1.1745	1.268
M16	0.818	1	1.0148	1.1297
M20	0.682	0.92	0.93	1.02

It's shown from Table 9 that loss on weight decreases as silica fume replacement percentage increases, as silica fume enhances the pores of the concrete and makes it denser and resistant to chloride attack. This results coincident with the results of many researchers as follow: replacing 20% of silica fume by weight of cement shows very good resistance to chloride attack rather than traditional concrete, this is because of the enhancement of microstructure, the filler effects of silica fume causing fine and discontinuous pore structure [24]. Silica Fume presented a decrease in total charges as Silica Fume content changed from 0% to 11% [25].

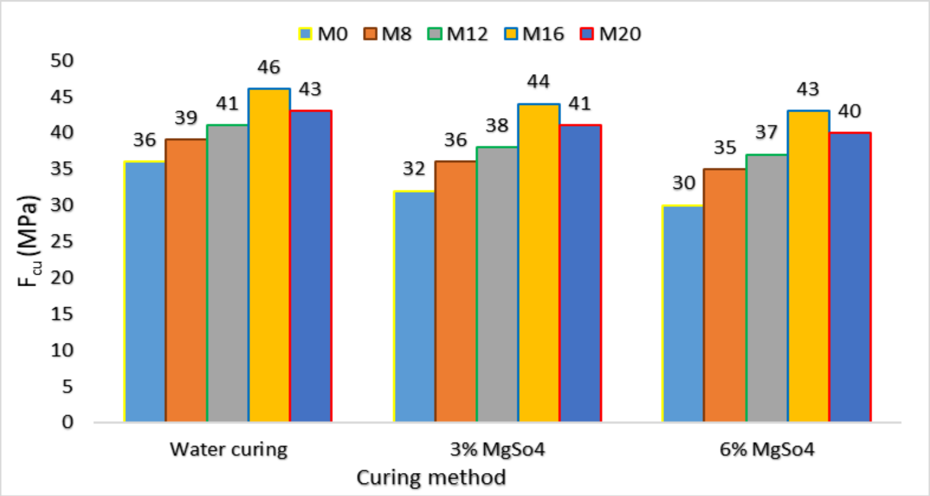


Figure 7: The effect of $MgSO_4$ solution on compressive strength after 28 days

Sulfate resistance

In order to study the durability characteristics, sulfate attack was studied, the SCC cubes were immersed in Magnesium sulfate solution. The cubes were demolded and dipped in the solution. Then the cubes were taken from the solutions after 28 and 90 days and their corresponding compressive strengths and loss on weight were noted. Magnesium sulfate solution of two different concentrations was used. Magnesium sulfate of percent 3% and 6% were used. Table 10 and Figures 7, 8 clarify the effect of Magnesium sulfate in compressive strength.

Table 10: Compressive strength of cubes immersed in MgSO4 solution for Different SCC Mixes

Curing solution	Compressive strength F_{cu} (MPa)									
	Mo		**M8**		**M12**		**M16**		**M20**	
	28d	90d	28d	90d	28d	90d	28d	90d	28d	90d
Water curing	36	45	39	50	41	52	46	60	43	56
3% MgSO4	32	37	36	45	38	48	44	57	41	53
6% MgSO4	30	33	35	43	37	45	43	55	40	51

Figure 7 describes the effect on compressive strength after 28 days immersion of the specimens in MgSO4 solution and it's obvious that increasing the concentration of the MgSO4 solution causes decreasing in compressive strength.

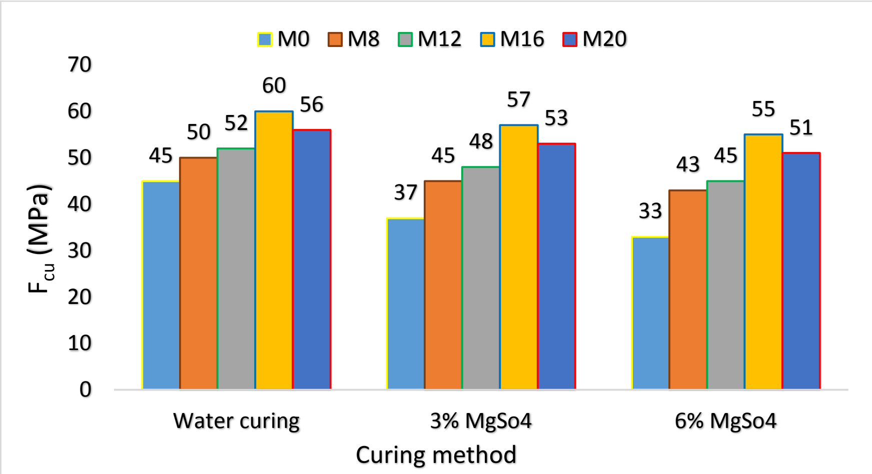


Figure 8: The effect of MgSO4 solution on compressive strength after 90 days

Figure 8 describes the effect on compressive strength after 90 days immersion of the specimens in MgSO4 solution and it's obvious that increasing the concentration of the MgSO4 solution causes decreasing in compressive strength. Adding silica fume as a mineral additive of 16% by weight of cement enhances the strength than control mix at 28 and 90 days for 3% MgSO4 as follow : the strength increased by 6.76% after 28 days and 12.78% after 90 days respectively, the rate of decrease in strength increased with increasing the duration of immersing in the sulfate solution, this is due to the deterioration of concrete. From Figure 7, 8 the decrease in strength due to 6% of MgSO4 is higher than the decrease in strength due to 3% of MgSO4 as while the concentration of the solution increased, the strength of concrete decreased. Sulfates react with calcium hydroxide and forming gypsum then reacts with the tricalciumaluminate to form ettringite and monosulphoaluminate. This reaction results in a substantial increase in volume and led to more loss on weight as presented in Table 11but it still noted that loss on weight decreases as silica fume replacement percentage increases. It is suitable to use SCC instead of conventional concrete as it has better resistance to sulfuric acids [12]. Partial replacing 20% of silica fume by weight of cement shows very good resistance to sulfate attack than traditional concrete, this is because of the enhancement of microstructure and this slightly coincides with our results due to using 16% SF [24]. The filler effects of silica fume producing fine and discontinuous pore structure.

Table 11: The effect of $MgSO_4$ solution on the loss of weight for SCC Mixtures after 28 and 90 days

Mix No.	Loss of weight after 28 days		Loss of weight after 90days	
	3% $MgSO_4$	6% $MgSO_4$	3% $MgSO_4$	6% $MgSO_4$
M0	0.8065	1.25	1.0946	1.9646
M8	0.6061	1.1694	1.0212	1.4658
M12	0.553	1.0788	0.9411	1.2097
M16	0.4825	0.7243	0.8839	1.0089
M20	0.423	0.652	0.785	0.932

Water permeability

Water absorption

Water absorption is measured using cylinder of height 100mm and diameter 100mm after 90 days of water curing as illustrated in Table 12 and Figure 9 as listed below.

Table 12: Water absorption test results

Mix	M0	M8	M12	M16	M20
W.A%	2.075	1.26	0.836	0.467	0.385

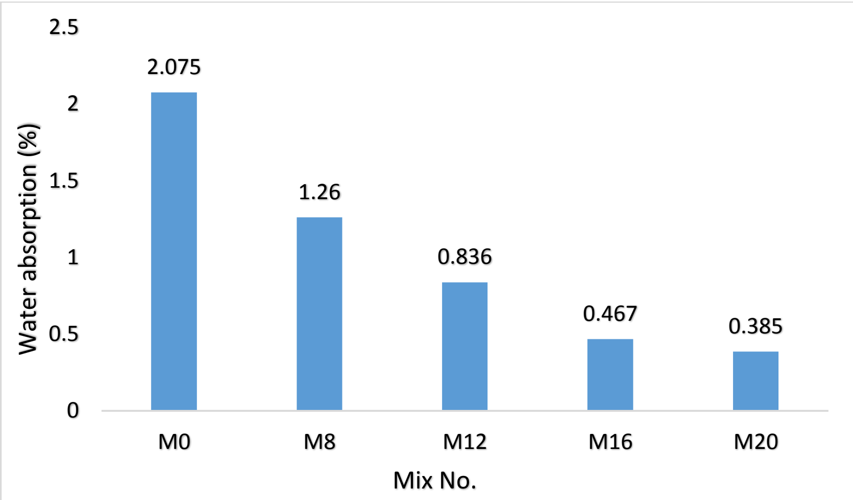


Figure 9: The relationship between SCC mixtures and water absorption after 90days

Figure 9 describes the ability of water to a path through the concrete from voids with different silica fume replacement contents. It was noted that the presence of silica fume significantly reduces the surface water absorption of self-compacting concrete as the addition of silica fume increases the 28-day cube strength and enhances the structure of concrete by decreasing the porosity [26].

Sorptivity

Sorptivity is measured for a cylinder of height 50mm and diameter 100mm after 90 days of water curing as illustrated in Table 13 and Figure 11 as listed below.

Table 13: Sorptivity test results

Mix	M0	M8	M12	M16	M20
S %	1.743	1.162	0.77	0.77	0.68

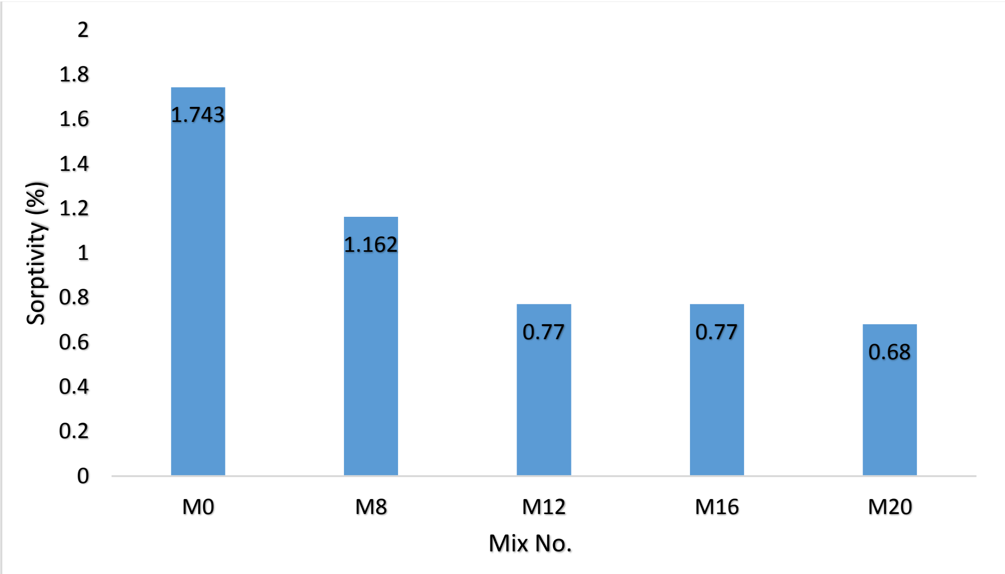
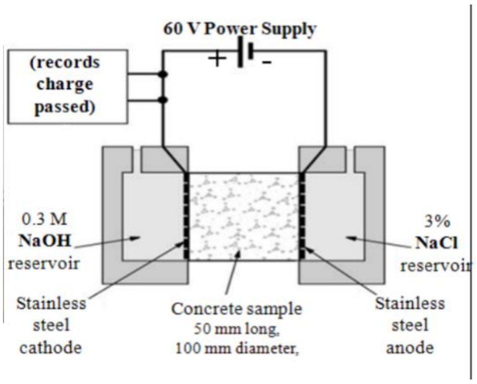


Figure 10: The relationship between SCC mixtures and Sorptivity after 90days

Figure 10 describes the ability of SCC concrete for suction of water by capillary with different silica fume replacement contents. Silica fume has a great effect on decreasing the Sorptivity and water absorption for SCC due to its fine particles. It's shown from Tables 12 and 13 that improvement in water absorption and Sorptivity were 81.45% and 59.71% compared to control mixture because of increasing silica fume percent to 20 % by cement weight. Many and several researches were in agreement with our results such as: Leung et al. [26] who reported that silica fume considerably decrease the surface water absorption of self-compacting concrete at the water-binder ratio of 0.38, Turk et al. [4] who found that SCC mixtures with SF had the lowest Sorptivity values followed by VTC, SCC with only PC and SCC with FA. Moreover, the values of water Sorptivity of SCC specimens with SF reduced with an increase within the replacement level of SF from 5 to 20%.

Rapid Chloride Penetration Test

Figure 11 shows the setup of the RCPT test and Figure 12 shows the current passed through different concrete samples along the test period. To obtain the results of the test, the area under the curve was integrated to obtain the ampere-seconds, or coulombs, of charge, passed throughout the 6-h period. Table 14 shows the results of integration and therefore the chloride particle penetrability of concrete according to ASTM C1202-12 classification. It may be obtained from the test results that, usually chloride particle penetrability of concrete samples had been decreased significantly by partially replacing ordinary cement with silica fume, which leads to a decrease in the rate of reinforcement corrosion.



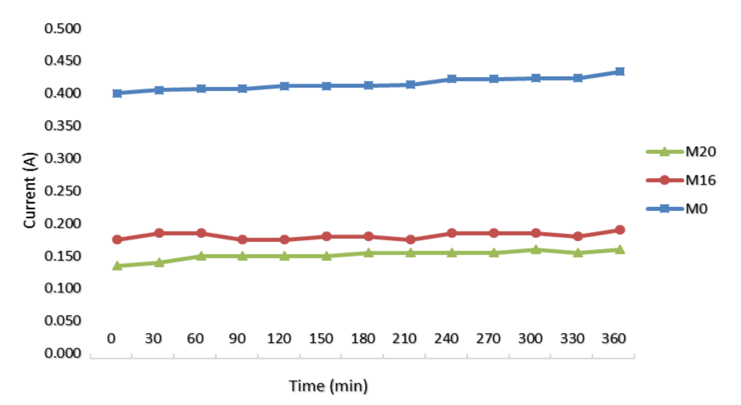


Figure 11: RCPT setup Figure12: The current passed with time for different mixes

Table 14: The chloride ion penetrability of concrete samples

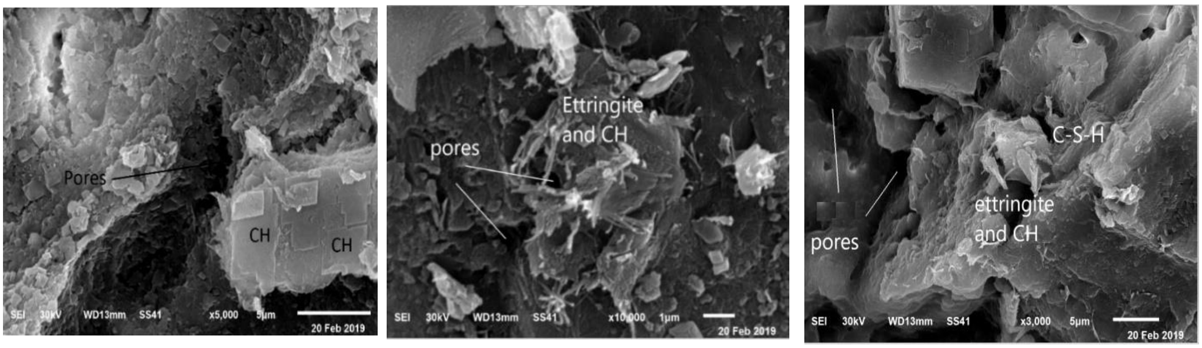
Samples	Charge passed (coulombs)	Chloride ion penetrability (according to ASTM C1202-12)
M0	8951	High >4000
M16	3911	Moderate 2000-4000
M20	3281	Moderate 2000-4000

From the test results, under the condition of determinate low water-binder ratio or age, the penetration resistance to chloride ions of concrete may be improved during the increase of the substitution quantity of silica fume. Using 16 % and 20% SF as partial replacement reduces the chloride particle permeability by 56% and 63% respectively. These results coincide with Cabrera and Claisse [30] results that increasing the substitution quantity of silica fume to 20% by cement weight minimizes the chloride particle permeability by 60 % than the control mix. Byfors [28] told that the addition of SF up to 20% by cement weight significantly decreased the diffusion rate of chloride particle compared to the normal PC paste.

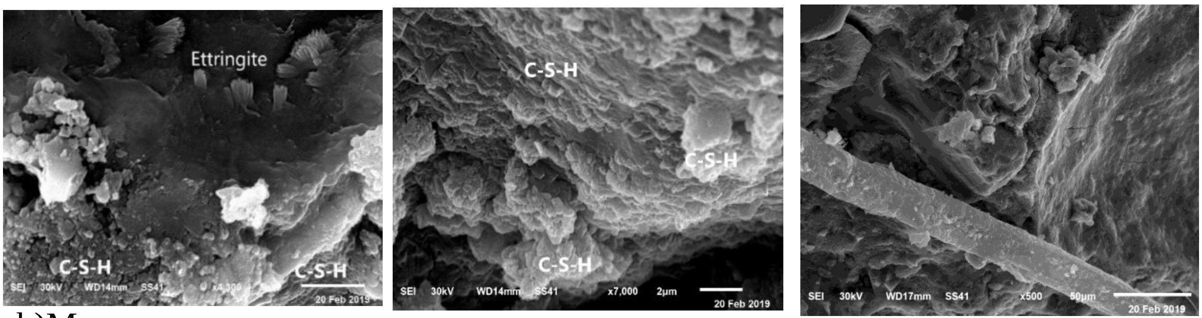
This reduction can be explained as the silica fumes are very fine particles and fill the voids among the particles of cement effectively, thus silica fume will create cement particles nearer and more uniform. On the other hand, the volcanic ash impact of silica fume will transform Ca (OH) 2 crystal that is created by cement hydration into C-S-H gel and additionally improves the densification of concrete.

Scanning Electron Microscopy (SEM)

The dense degree of the microstructure of the consolidated concrete was determined by SEM analyses. SCC mixtures were analyzed in a low vacuum environment (0.6 m bar) using the FEG-SEM device. Results clarified in Figure 13, showed some morphological properties of the microstructure of mixes.



a)M_0



b)M_{16}

Figure 13: SEM image of specimens after 28 days of curing (a) OPC (control group), (b) 16 % SF by weight of cement

As shown in Figure 13, the mixture investigated for the control mix, it was observed that the SCC mix had a high voids structure and relative bad paste-aggregate interface zone (ITZ). But when silica fume replaced with 16% by weight of cement, a dense structure, and relative good paste-aggregate interface zone (ITZ) occurred. This microstructure was characterized by compact the aggregates with used supplementary materials, which contributed to eliminate more small pores, distributed. The major processes that adjust the properties of concrete were affected by the material behavior on mixtures. The mechanical properties and therefore the durability of concrete primarily rely on the refinement of the microstructure of the consolidated cement paste and therefore the refinement of the paste aggregate interface zone (ITZ) [33]. It had been discovered that the replacement of the supplementary material with cement content increases the compressive strength and reduces the porosity of consolidated concrete because of its pozzolanic reactions, which lead to finer hydrated reactions and densification in the microstructure.

These effects could enhance the durability of concrete components and structures. The silica fume particles provide nucleation and crystallization sites for C-S-H phases، the crystallization and further growth of tapered C-S-H phase's result in the densification of the microstructure[34].

Conclusions

The addition of silica fume to SCC improves the durability throughout a reduction within the permeability and refined pore structure which ends up in higher resistance to salt attack. Incorporating of silica fume with different percentage 8, 12 , 16% and 20% by weight of cement decreases slump flow by 2.05% , 4.79% , 6.85% and 10.96% respectively although, passing ability increased by 3.66% , 7.32% , 9.76% and 15.85 % respectively and segregation resistance enhanced by 11.88 % , 24.47% , 35.66% and 38.46 % respectively. Compressive strength enhanced as a result of adding silica fume and it's noticed that 16% replacement of SF by cement weight produces the best results after 7, 28 and 90 days and when SF increased to 20 % by cement weight compressive strength decreased. Silica fume also has a pronounced effect on tensile strength and splitting strength as it's related to compressive strength and 16 % SF enhanced tensile strength by 20.84% and splitting strength by 21.49% after 28 days. Increasing silica fume percent to 16 % by weight of cement led to increasing of compressive strength for 0.4M of NaCl solution by 4.59% after 28 days and 7.23% after 90 days. When solution concentration increased to 0.8M of NaCl the loss in compressive strength increased after 28 and 90 days. Increasing silica fume percent to 16 % by cement weight led to increasing of compressive strength for 3% of MgSO4 solution from by 6.76 % after 28 days and 12.78% after 90 days. When solution concentration increased to 6% of MgSO4 the loss in compressive strength increased after 28 and 90 days. The loss in weight that results from sulfate (MgSO4) and chloride (NaCl) decreased when SF percent increased to 20% by weight of cement. Water permeability enhanced as a result of increasing SF percent to 20% by weight of cement and it was approved in decreasing water absorption and Sorptivity by 81.44% and 59.71% respectively. The results of the chloride penetration test, listed as the total charge passed in Coulombs resulting from current passed with time when charge passed decreases that indicates good resistance to chloride, and it was found that 20% of SF percent was the best percentage for chloride penetration resistance. Scanning electron microscopy shows that silica fume particles provide nucleation and crystallization sites for C-S-H phases as a result, it makes the microstructure denser and enhanced the compressive strength and durability performance.

.REFERENCES

[1] Okamura, H., Ouchi, M., "Self-Compacting Concrete", Journal of Advanced Concrete Technology, vol 1, pp. 5-15, 2003.

[2] Dinesh, A., Harini, S, Jasmine, J. P., Jincy, J., and Javed, S., "Experimental Study on Self Compacting Concrete", International Journal of Engineering Sciences and Reasearch, vol 6, 2017.

[3] Sistonen, E., Fahim, A. N., "Self Compacting Concrete", 2015.

[4] Turk, K., Karatas, M., and Gonen, T., "Effect of Fly Ash and Silica Fume on Compressive Strength, Sorptivity and Carbonation of SCC", KSCE Journal of Civil Engineering, vo 17, pp. 202-209, 2013.

[5] Bhanja, S., Senjupta, B., "Optimum Silica Fume Content and Its Mode of Action on Concrete", ACI Materials Journal, vol 100, 2003.
[6] Cong, X., Cong, S., Darwin, D., and Mccabe, S. L., "Role of silica fume in compressive strength of cement paste, mortar and concrete", ACI Mater. J, vol 89, pp. 375-387,1992.
[7] Paillere, A. B. " Effect of fiber addition on the autogenous shrinkage of silica fumes concrete", ACI Material Journal, vol 86, pp. 139-144, 1989.
[8] Sakr, K., "Effects of silica fume and rice husk ash on the properties of heavyweight concrete", Journal Material Civil Engineering, vol 18, pp. 367-376, 2006.
[9] Xinjie, W., Pinghua, Z., and Qun, X., "Experimental Research on the effect of Silica Fume on Tensile Basic creep of Early-age concrete", The Open Civil Engineering Journal, vol 9, pp. 997-1001, 2005.
[10] Siddique, R., "Utilization of silica fume in concrete: Review of hardened properties", Construction and Building Materials, 2011.
[11] Kanellopoulos, A., Petrou, M. F., and Ioannou, I., "Durability Performance of Self-compacting Concrete", Construction and Building Materials, vol 37, pp. 320-325, 2012.
[12] Persson, B., "Sulfate resistance of self-compacting concrete", Construction and Building Materials, vol 33, pp. 1933-1938, 2003.
[13] Trezos, G., Sifkas, P. l., Paviou, D. I., "Water Permeability of Self Compacting Concrete", 3rd fib International Congress, Greece, 2010.
[14] Subramanian, E.S., Arunkumar, P., Arul, N., "Strength and Durability Properties of Self-Compacting Concrete with Micro Silica and Nano Silica", International Research Journal of Engineering and Technology (IRJET), vol 4, no 1, 2017.
[15] Tholkapiyan, M., kumar, U. A., "An Experimental Study on Self-Compacting Concrete by Partial Replacement of Cement with Silica Fumes and GGBS", International Journal of Emerging Technology and Advanced Engineering, vol 7, 2017.
[16] Johnsirani, K. S., Jagannathan, A., "Studies on Effect of Mineral Admixtures on Durability of Self Compacting Concrete", European Journal of Advances in Engineering and Technology, vol 2, pp. 87-94, 2015.
[17] Sabet, F.A., Libre, N. A., and Shekarchi, M., "Mechanical and Durability properties of self-consolidating high-performance concrete incorporating natural zeolite silica fume and fly ash", Construction and Building Mat J, vol 44, pp. 175-184, 2013.
[18] ES 4756-1, "Cement-Part 1: Composition, Specifications and Conformity Criteria for Common Cements", Egypt: Egyptian Organization for Standardization, 2013.
[19] BS EN 197-1, "Cement - Part 1: Composition, specifications and conformity criteria for common cements", 2000.
[20] ES 1109,"Aggregates for concrete". Egypt: Egyptian Organization for Standardization, 2008.
[21] ASTM C494, "Standard Specification for Chemical Admixtures for Concrete", ASTM Standards, 2001.

[22] G. A. Rao, "Investigations on the performance of silica fume-incorporated cement pastes and mortars", Cement and Concrete Research, vol 33, pp. 1765-1770, 2003.
[23] Khan, M. I., Siddique, R., "Supplementary Cementing Materials- Chapter 2 Silica Fume", 2011.
[24] Karthick, M., Nirmalkumar, K., "Durability Properties of High Strength Self Compacting Concrete using Silica Fume and Quarry Dust", International Journal of Scientific Engineering and Applied Science (IJSEAS), vol 2, 2016.
[25] Assem, H. A., Lachemi, M., and Hossain, K. M., "Effect of metakaolin and silica fume on the durability of self-consolidating concrete", Cement and Concrete Composites, vol 34, pp. 801-807, 2012.
[26] Leung, H. Y., Kim, J., Nadeem, A., Jagannathan, J., and Anwar, M. P., "Sorptivity of self-compacting concrete containing fly ash and silica fume", Construction and Building Materials, vol 113, pp. 369-375, 2016.
[27] Sellevold Ej, Nilsen T. condensed silica fume in concrete: a world review in Malhotra VM, editor. Supplementary cementing materials for concrete, Ottawa, Canada: canmet : 1987. P.165-243.
[28] Byfors, Kajsa. "Influence of silica fume and fly ash on chloride diffusion and pH values in cement paste." *Cement and Concrete Research* 17.1 (1987): 115-130.
[29] Poon, Chi-Sun, S. C. Kou, and L. Lam. "Compressive strength, chloride diffusivity and pore structure of high-performance metakaolin and silica fume concrete." *Construction and building materials* 20.10 (2006): 858-865.
[30] Cabrera, J. G., and P. A. Claisse. "Measurement of chloride penetration into silica fume concrete." *Cement and Concrete Composites* 12.3 (1990): 157-161.
[31] Pilvar, Amirreza, et al. "Practical evaluation of rapid tests for assessing the chloride resistance of concretes containing silica fume." Computers and Concrete 18.4 (2016): 793-806.
[32] Li, Yun Feng, et al. "Penetration Resistance to Chloride Ions of Silica Fume Concrete." Applied Mechanics and Materials. Vol. 584. Trans Tech Publications, 2014.
[33] Sharobim, Kamal G., et al. "Effect of Using Different Supplementary Cementitious Materials in High Strength Self Compacting Concrete."American Journal of Engineering Research. 6.10 (2017): 2320-0936.
[34] Pfeifer, C., et al. "Investigations of the pozzolanic reaction of silica fume in Ultra-high performance concrete (UHPC)." International RILEM Conference on Material Science. RILEM Publications SARL, 2010.