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Effect of Using Different Supplementary Cementitious Materials in High Strength Self Compacting Concrete

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***ABSTRACT*: *High strength self-compacting concrete (HSSCC) is one of the most significant recent advances in concrete technology. Replacing cement with different supplementary cementitious materials has a good impact on the environment according tothe reducing of the generated amount of carbon dioxide. Supplementary materials can be usednot only as a cement replacement but also as a filler to help in reducing the total voids content in concrete. Replacing cement with supplementary cementitiousmaterialwasaffected the workability and strength of concrete and modify the microstructure of the matrix.An experimental investigation wascarried out to study the effect of replacing cement with different contents of silica-fume, fly ash and marble powder or with mix of two types of these supplementary materials. The rapid chloride penetration test (RCPT) was conducted as an indicator for concrete permeability and durability.Inaddition,the micro-structural analysis using SEM helped in confirming the compressive strength results.*

***Keywords*: *High strength self-compacting concrete, Silica-fume, Fly ash,Marblepowder*.

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I. INTRODUCTION

High strength concrete is defined as "a concrete having a minimum 28-day compressive strength of 60MPa" [1].While, self-consolidating concrete (SCC) as "highly flowable, no segregating concrete that can spread into place, fill the form work, and encapsulate the reinforcement mechanical consolidation"[2]. Cement content reduction could be achieved by replacing with various supplementary cementitious materials [3].For high strength self-compacted concrete (HSSCC),silica fume is an extremely effective material for achieving very high strength and significant decrease in permeability [4]. Silica fume improves both strength and durability of concrete when using silica fume from 10% to 30% of silica fume by replacement [5].The mineral additives as fly ash may increase the workability, durability and long-term properties of concrete [6].Marble powder mainly obtained from the processing plants out of sawing and polishing of marble blocks. In addition, the workability of SCC found to be increasing with increase in waste marble powder percentage from 10-50% by replacement with cement content. It has been observed that, on addition of waste marble powder, the filling ability of SCC by Slump flow and V-Funnel tests found to be increasing with the increase in percentage of waste marble powder [7]. The use of different supplementary cementitious materials such as silica fume, and fly ash reduce both pore sizes and porosity. However, the chemistry, fineness and dosage of the supplementary cementitious material affect the early strength development of concrete [8].Reducing the water-cement ratio and the addition ofpozzolanic admixtures are often used to modify the microstructure of the matrix and to optimize the transition zone. The Reduction of the water-cement ratio results in a decrease in porosity and refinement of capillary pores in matrix [9]. Rapid chloride permeability test (RCPT) has developed as a quick test able to measure the rate of transport of chloride ions in concrete. [10].This study aims to achieve high strength self-compacting concrete while partially replacing cement with different contents of silica-fume, fly ash and marble powder or with mix of two types of these supplementary cementitious materials. Theeffect of adding different types and contents of supplementary cementitious materials on fresh and hardened properties of HSSCC is discussed.

II. EXPERIMENTAL PROGRAM

Twelve high strength self-compacted concrete mixtures compositionswerecast. A series of tests were carried out to investigate the fresh and hardened properties for the concrete mixtures. Flowability, passing-ability and resistance to segregation were measured using slump-flow, J ring, V-funnel, and GTM tests. The compressive strength specimens were cubes (100 x100 x100mm) and tested at 7 and 28 days. Also, the indirect tensile strength were cylinders (100 x 200 mm)and tested at 7 and 28 days, The flexure strength specimens were cast in(100 x 100x 500mm) and tested at 28 and 56 days.

2.1. Materials

Ordinary Portland Cement (OPC) confirming to ASTM C150 [11] standard was used. Coarseaggregateofcrushed dolomite from North Sinai quarry that has a maximum nominal size 12.5 mm and 2.7 specific gravity was used.While, a natural siliceous sand of 2.5 specific gravity used as afine aggregate. Chemical and physical properties of waste marble powder in North Sinai are listed in table1.A high range water reducing admixture which has commercial name of (SikaViscocrerte-3425) complying with the requirement of ASTM C494 Type G[12].

Table1: Chemical and physical properties of North Sinai marble powder

Chemical properties	Values (%)	Physical properties	Values (%)
Sio_2	13.8	Specific gravity	2.5
CaO	43.2	Fineness (kg/m^2)	350
MgO	2.7	Water absorption	0.97
Al_2O_3	2.5		
Fe_2O_3	1.9		
So_3	0.07		

2.2. Concrete mixes proportions

A total of 12 concrete mixes were selected and summarizes in table.2. A total cementitious material of content (600 kg/m^3) was used. The partially replacing of cement with silica fume, fly ash and waste marble powder with different contents. The mixtures included a control mix without any supplementary materials.While,a set of mixtures werereplaced by 10%, 12.5%, 15% and 25% of silica fume, 10%, and30% of Fly ash and 30% of waste marble powder. In addition, combinations of SFandFAwere replaced as (8.5%+12.5%), and (12.5%+8.5%) respectively. while, combinationsFAwithMP were replaced as (7.5%+16.5%), and (15%+16.5%)respectivelywere replaced. The volume ratio of fine aggregate to total aggregates in SCC mix was ranging between 50–57%. Water and superplasticizer contents were chosen to satisfy the self-compacted concrete flowability requirements.

Table2: Mix proportions of modified reference mixture by weight

Quantity of material by weight (Kg/m^3)								
Mix No	Cement content	Coarse aggregate	Fine aggregate	Mineral Admixture			Water	SP
				Silica fume	Fly ash	Marble powder		
Mix1	600	700	900	0	0	0	190	14
Mix2	540	700	850	60	0	0	165	15
Mix3	525	722	867	75	0	0	158.3	16
Mix4	500	800	800	100	0	0	186	13.5
Mix5	450	927	1048	150	0	0	172	14
Mix6	540	780	850	0	60	0	182	14.5
Mix7	420	700	900	0	180	0	179	12
Mix8	420	700	853	0	0	180	165	8
Mix9	475	850	850	50	75	0	167	13
Mix10	475	850	850	75	50	0	171	11
Mix11	455	708	760	0	45	100	169	8.5
Mix12	410	1020	766	0	90	100	169	9

III. RESULTS AND DISCUSSION

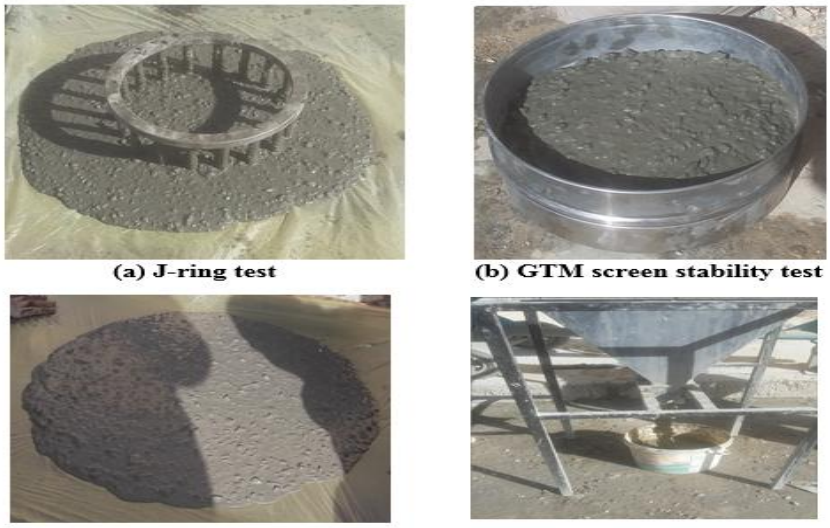
31. Fresh concrete tests results

Table (3) showed the results of the slump flow test as an indicator for the concrete flowability,J-ring and V-funnel as an indicator to passing-ability and finally GTM test to check the concrete segregation resistance.

The results showed that slump flow test results for the experimented mixtures as shown in fig (1) were between 600 to 720 mm. For the T-50 tests results values ranges between 3.2 and7 sec, it is observed the lower time results for Mix8 and Mix4 were 3.2, and 3.9 sec.For the V-Funnel tests results values ranges between from 9 to16 sec, it is observed the lower time results for Mix4 were 6 sec, while, the higher time was 16 sec for Mix5 Segregation was happened when 30% MP for Mix8 at GTM sieve test applied. All results have good results complying with the limits of (EFNARC2005)[13].

Table3: Tests results of Fresh concrete samples

Mix No.	Slump Flow (mm)	T-50 (mm)	J-Ring (mm)	V-funnel (sec)	GTM (%)	Note
Mix1	660	4.3	1.5	10	9.8	No Segregation
Mix2	670	4.1	2.5	11	7.4	No Segregation
Mix3	680	5	2	10	6.3	No Segregation
Mix4	660	3.9	1.5	6	8.7	No Segregation
Mix5	600	7	2.5	16	13.8	No Segregation
Mix6	640	5	2.5	11	13.5	No Segregation
Mix7	640	4.5	2	10	14.2	No Segregation
Mix8	700	3.2	-	9	22	Segregation
Mix9	640	4.5	1.5	9	14.5	No Segregation
Mix10	720	5	2	12	25	No Segregation
Mix11	650	4.1	1.5	11	14.3	No Segregation
Mix12	620	4.7	2	12	15	No Segregation
ESS limits/2007	600-800	2-5		6-12	5-15	



(a) J-ring test (b) GTM screen stability test (c) slump flow test (d) Vfunnel test

Figure 1: Experimented workability tests

3.2. Hardened concrete tests results

The results of hardened concrete were shown in table (4). For compressive strength, it can be seen that the higher compressive strength that equal or more than 70 MPa after 28 days curing age were shown in mixes (Mix1, Mix2, Mix4, Mix6 and Mix12). On the other hand, the compressive strength for mixes Mix3, Mix5, Mix7, Mix9, Mix10 and Mix11 are between 60 and 70 MPa after 28 days curing age. However, for Mix8 have compressive strength of less than 60 MPa after 28 days curing age.

The difference between the higher and lower compressive strength at 7 and 28 days curing ages are between 9 to 19%.the highest compressive strength compared to other investigated mixtures was in Mix2. The result of compressive strength was 64 MPa in 7 days and increased to 74 MPa in 28 days about 14%. While, the lowest compressive strength compared to other investigated mixtures was in Mix8, it was 50 MPa in 7 days and increased to 55 MPa in 28 days about 9%.

Table4: Tests results of hardened concrete mixtures

Mix No.	Compressive strength (MPa)		Indirect Tensile Strength (MPa)		Flexure Strength (MPa)	
	7 days	28 days	7 days	28 days	28 days	56 days
Mix1	61	70	4.9	6.2	8.2	8.8
Mix2	64	74	5.7	6.9	8.7	10
Mix3	58	68	5.1	5.4	8.5	8.5
Mix4	63	71	5.5	6.1	8.7	9.6
Mix5	55	66	5.1	5.8	7.6	8.2
Mix6	59	70	5.4	6.3	8.4	9.1
Mix7	56	69	5.1	5.7	8.1	8.1
Mix8	50	55	3.6	4.1	5.8	6.9
Mix9	60	67	5.5	5.8	8.1	8.7
Mix10	60	68	5.5	6.3	8.8	9.7
Mix11	55	62	4.6	5.4	8.0	7.6
Mix12	61	72	5.7	6.2	6.6	9.3

As shown in Fig (2), the relationship was constructed between the compressive, strength splitting tensile strength and flexure strength in (MPa), for HS-SCC at 28 days curing ages. All mixtures data were available for a graphical representation to check the relation between high strength self-compacted hardened concrete mixtures.A good correlation coefficient is obtained for the Co-relation curves about $R^2 = 0.90$.

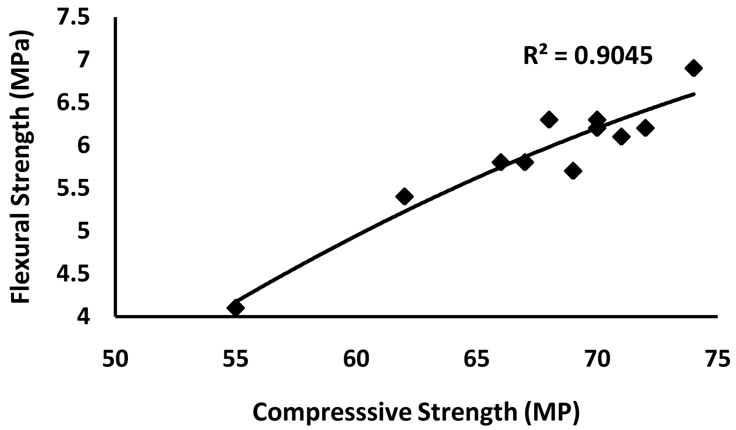


Fig (4.17) Relation between indirect tensile and flexure strength with compressive strength after 28 days curing age for (HS-SCC) mixes.

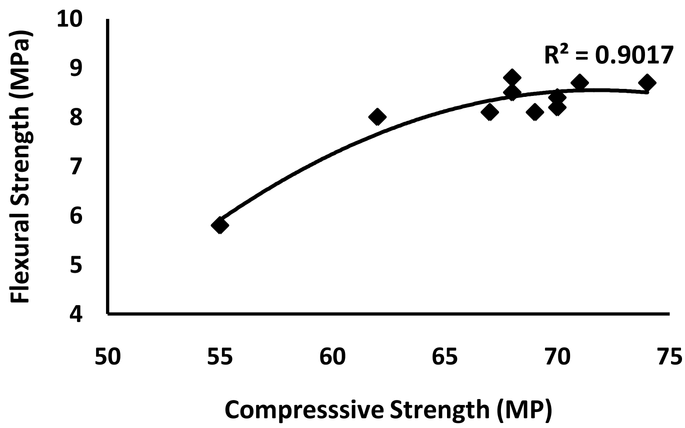


Fig (4.18) Relation flexural strength with compressive strength after 28 days curing age for (HS-SCC) mixes.

A proposed equation between compressive strength and indirect tensile strength was presented in equation (1), whilea proposed equation between compressive strength and flexure strength was presented in equation (2) as follow:

$$f_t = +0.375\,(f_c) - 0.0019\,(f_c)^2 - 10.65 \qquad (1)$$

$$f_b = 1.3\,(f_c) - 0.094\,(f_c)^2 - 40 \qquad (2)$$

Where: (f_c) is the cube compressive strength at 28 days age in (MPa), (f_t) is the splitting tensile strength at 28 days age in (MPa) and (f_b) is the flexure strength at 28 days age in (MPa). The above equations are valid only for $\boldsymbol{f_c}$from (50-80)MPa.

3.3Chloride Permeability test results

The object of the test was to evaluate the performance of high strength self-compacting concrete mixes. The interpretation of the RCPT results is that the larger the Coulomb number or the charge transferred during the test, the greater the permeability of the sample, in other words the more permeable the concrete, the higher the coulombs. The procedure of this test method performed in housing and building national research center (CHBR) in Dokki, Egypt as shown in Fig 3.The results of chloride permeability in coulombs for different grades at the age 28 days were shown in table 3.

Figure3:RCPT apparatus in CHBR

Table5: Chloride permeability for Experimented (HS-SCC) concrete mixtures

Mix No.	Compressive strength after 28 days (MPa)	Charge passing (Q) (Coulombs)	Classify according to (1202) ASTM limits
Mix1	70	51	negligible
Mix2	74	63	negligible
Mix3	68	163	Very low
Mix4	71	76	negligible
Mix5	66	182	Very low
Mix6	70	79	negligible
Mix7	69	730	Very low
Mix8	55	804	Very low
Mix9	67	227	Very low
Mix10	68	46	negligible
Mix11	62	85	negligible
Mix12	72	628	Very low

The result showed that, the average charge passed (Q) for Mix1 and Mix10 were 51 and 46 (coulombs) respectively considered the lowest charge passed compared with the other mixtures. While, the average charge passed for Mix 8 was 804 (coulombs) considered the highest charge passed compared with the other mixtures.

When silica fume was used with 10%, 12.5%, 15% and 25% as replacement with cement content for Mix2, Mix3, Mix4 and Mix5. The highest compressive strength with lowest charge passed was investigatedwhen 10% and 15% silica fumewere used. They were increased about 6% when compare to control Mix1. While for 12.5% and 15% silica fume the compressive strength decreased about 5% compare to control Mix1, the charge passed was increased.

When fly ash was used with 10% and 30% as replacement with cement content for, Mix6 and Mix7. The compressive strength was 70 MPa the same as control mix. Fly ash,had negative impact because the high values of charge passed compared to the mixes contain silica fume and the control mix. This indicates that effect of silica gel of silica fume have a great effect on the compressive strength and contribute to eliminate voids in the mix. On the other hand, marble powder had bad effect on both compressive strength and permeability as shown in Mix8.

When combinations of SF and FA were replaced as (8.5%+12.5%), and (12.5%+8.5%) respectively for Mix9 and Mix10,the compressive strength compared to control Mix1was decreased about 2%.However, it was noted when silica fume was predominant in the mixture as in Mix10, the charge passed was very low as shown in table 5.

The effect of combinations of FA with MP as a replacement by cement content will discussed that, when FA with MP replaced as (7.5%+16.5%) for Mix11, the compressive strength was decreased about 11%compared to control Mix1. While, when FA with MP replacedas(15%+16.5%) for Mix12, the compressive strength was increased about 2% compared to control Mix1and the charge passed was very low. The results showed that, silica fume has a great effect than fly ash and marble powder. Itwas observed that, when the average charge passé for rabid chloride penetration decreased indicate to decreaseof voids in the concrete mixthus, the compressive strength was increased. The good results refer to low pore structure porosity. Forcontrol mixture without used any supplementary materials and with used silica fume or fly ash only had results better than the combinations mixtures. The results showed that all the experimented mixtures concrete are good results and acceptable of permeability for rapid chloride penetration test according to ASTM 1202.On durability level, the values for resistivity all show a clear increase.

These results are agreement with a good correlation coefficient, obtained for the Co-relation curves with a bout $R^2 = 0.93$, the results depicts the average values of rapid chloride penetration in Fig (4). While a proposed equation between charge passedin(coulombs) and the compressive strength was presented in equation (4), thisequationis valid only for $\boldsymbol{f_c}$from (50-80)MPa.

$$f_c = 2E\text{-}05(Q)^2 - 0.0392(Q) + 74.338 \quad (4)$$

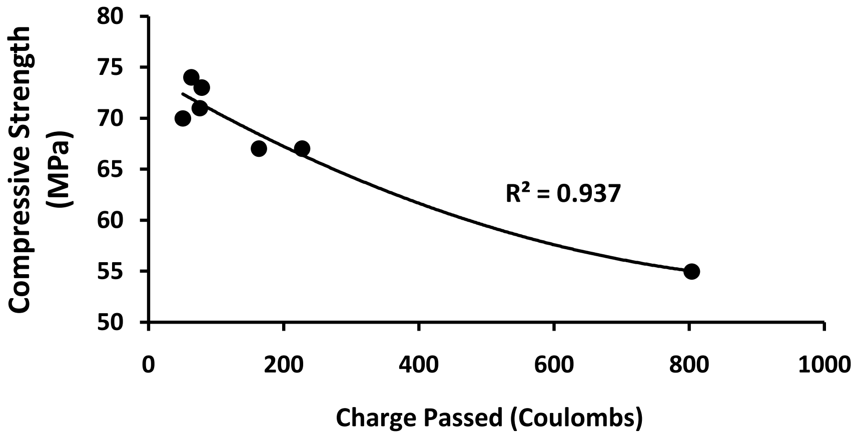


Figure4: Average values of rapid chloride penetration

3.4. Microstructural Characterization and Analysis

The densification of microstructure of the hardened concrete was verified by SEM analyses used. HS-SCC mixes were analyzed in a low vacuum environment (0.6 mbar) using FEG-SEM device. Results shown in Fig 6, showed some morphological characteristics of the microstructure of mixtures. a) Cement matrix and aggregate, b) Cement matrix and c) paste-aggregate interface zone ITZ. As shown in (Fig 5A) to (Fig 9A), the mixtures investigated when water to binder were used from 0.34 to 0.30.It was observed that HS-SCC mix had a high voids structure and relative bad paste-aggregate interface zone (ITZ). But As shown in (Fig 5B) to (Fig 9B), when water to binder improved as shown in table 2, a dense structure and relative good paste-aggregate interface zone (ITZ) were occurred.

This microstructure was characterized by compact the aggregates with used supplementary materials, which contributed to eliminate more small pores, distributed. The fundamental processes that govern the properties of concrete were effected by the performance of the material on mixtures. The mechanical properties and the durability of concrete mainly depend on the refinement of the microstructure of the hardened cement paste and the improvement of the paste aggregate interface zone (ITZ). It was observed that the supplementary materials replacement with cement content increase the compressive strength and reduces the overall permeability of hardened concrete due to its pozzolanic properties, which result in finer hydrated reactions and densified microstructure. These effects may enhance the durability of concrete elements and structures.

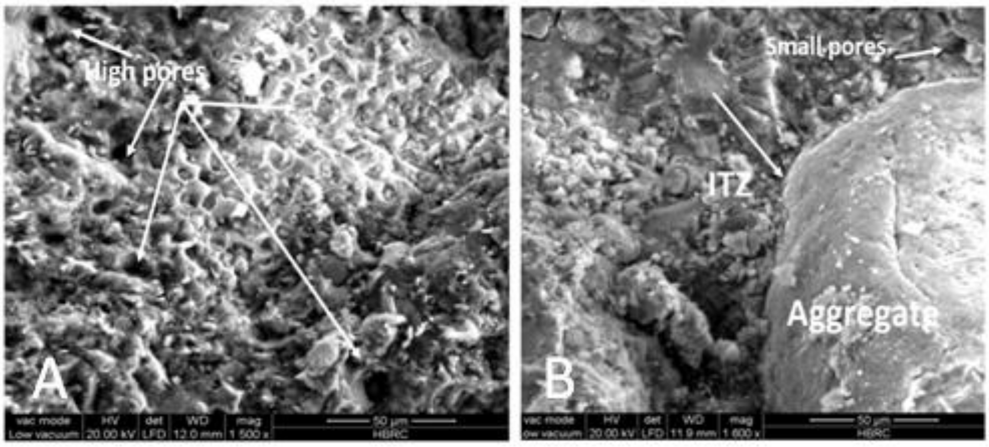


Figure 5: Microstructure low vacuum (0.6 mbar) FEG–SEM photomicrographs of the control mix**.**

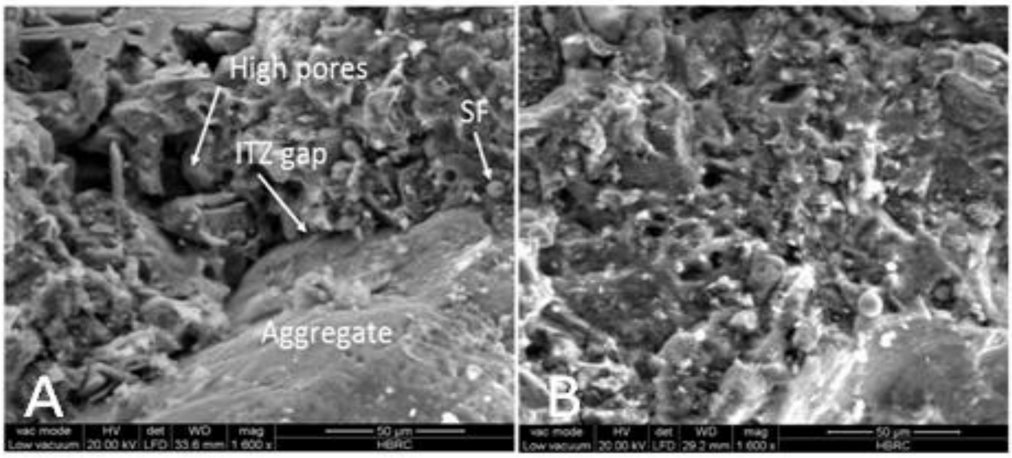


Figure6: Microstructure low vacuum (0.6 mbar) FEG–SEM photomicrographs of the HS-SCC mixtures with silica fume.

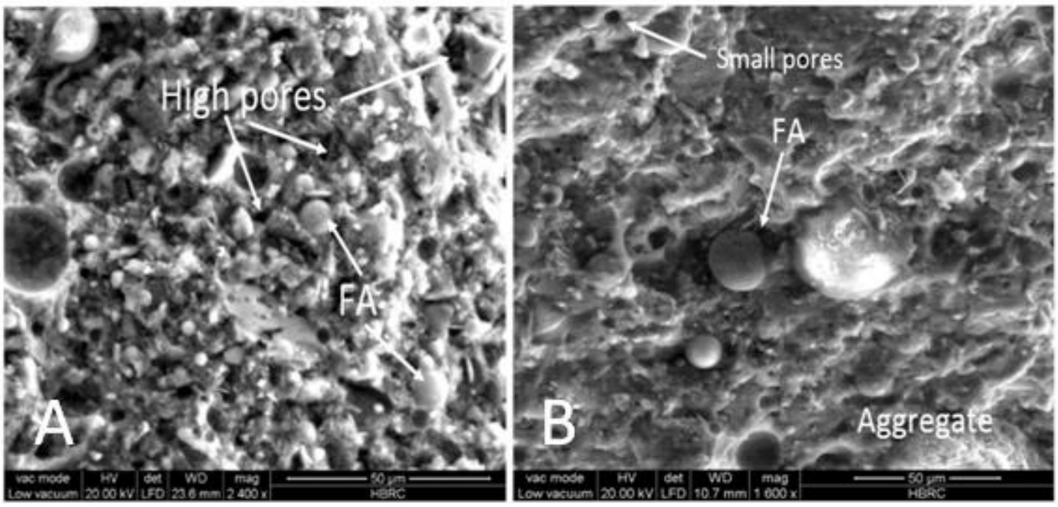


Figure7: Microstructure low vacuum (0.6 mbar) FEG–SEM photomicrographs of the HS-SCC mixtures with fly ash.

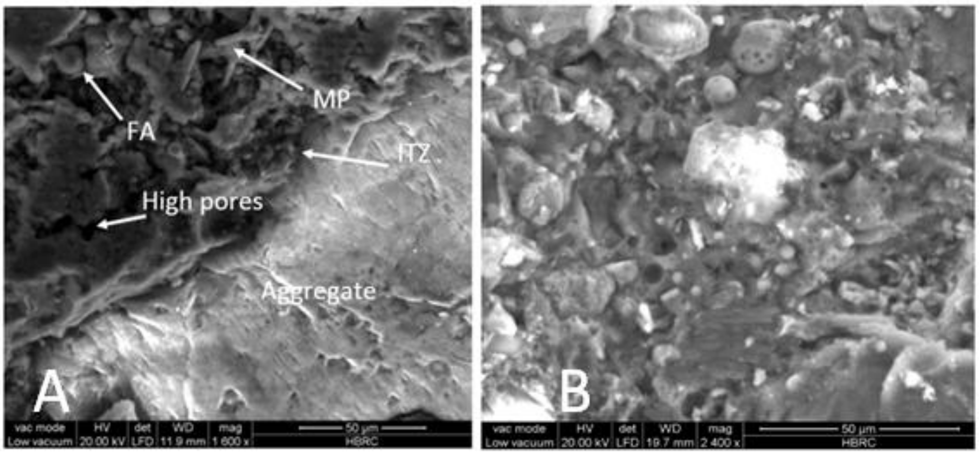


Figure8: Microstructure low vacuum (0.6 mbar) FEG–SEM photomicrographs of the HS-SCC mixtures with fly ash and marble powder.

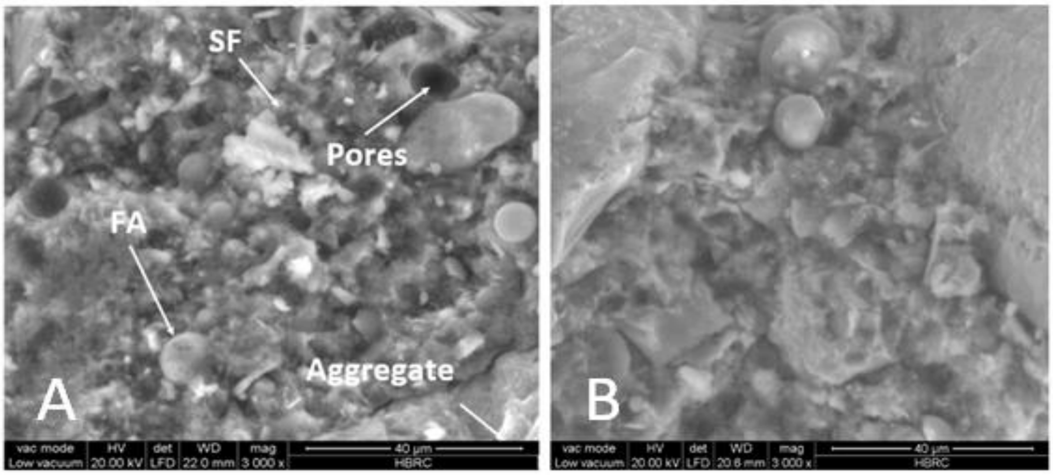


Figure9: Microstructure low vacuum (0.6 mbar) FEG–SEM photomicrographs of the HS-SCC mixtures with silica fume and fly ash

IV. CONCLUSION

From the experimental results, the following conclusion can be drawn;

1. High strength self-compacted concrete can be produced with using the local materials in north Sinai, Egypt, with a compressive strength up to 70 MPa after 28 days can be obtained.
2. The adjustment of supplementary materials as silica fume, fly ash and marble powder contents as a replacement by cement content, the high strength concrete was gained with keep concrete in self-compacted properties.
3. Silica fume has a great effect on compressive strength and permeability when used Individually or collectively with fly ash and marble powder as a replacement with cement content.
4. Equation 4, was concluded to express the relation between compressive strength with charge passed to evaluate permeability for high strength self-compacted concrete mixtures, whichvalid only for $f_c$from (50-80)MPa.

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