The behavior of self-compacting concrete incorporating slag and natural zeolite as admixtures

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ABSTRACT:

In recent years, self-compacting concrete has been seen as a step forward in the development of concrete technology. Concrete mixtures that self-compact can be used without bleeding or segregating in a variety of heavily reinforced structures, including walls, foundations, and bridges. The primary objective of this study is to explore the potential of using new materials, such as natural and by-product materials, to reduce cement factories' carbon dioxide emissions. In this study, Portland cement was substituted in the binary mixtures with (20%, 30%, and 40%) slag and (5%, 10%, and 15%) natural zeolite in order to assess the results of the hardened and fresh properties of self- compacting concrete. The ternary cementitious blends (ZS20, ZS30, and ZS40) were combined with 10% zeolite and 20%, 30%, and 40% slag to create the mixtures.In self-compacting concrete, these substances function as both fine filler and cementitious admixtures. The fresh properties of self- compacting concrete mixtures were assessed through the investigation of properties like slump flow, J- ring, V-funnel, and T50. Additionally, mechanical tests were performed to determine the hardened concrete's compressive strength. The addition of new cementitious materials increased the mixtures' compressive strength, particularly as they aged. The mixtures containing zeolite, slag, and ternary mixtures with the highest compressive strength at 180 days were Z10, S30, and ZS30, with 58.5, 58, and 58.7 MPa, respectively.

1. INTRODUCTION

Japan developed self-compacting concrete (SCC) in the 1980s. SCC is a flowing mix with a high deformability and low yield stress. It can fill the formwork without bleeding or segregation and doesn't require vibration. Self-compacting concrete uses stabilizer A and superplasticizers, which greatly boost the flow rate [1,2]. Three key characteristics flowability, passing ability, and segregation resistance make flowable concrete suitable for placement in crowded reinforcement frameworks [3]. The benefits of SCC over conventional concrete include vibration elimination, labor cost and time savings during construction, and improved strength properties [4–11]. On the other hand, the use of chemical admixtures like viscosity-modifying admixtures (VMA) and high range water reducers (HRWR) along with a higher cement content raises the cost..

There are certain detrimental effects on the environment from SCC's increased use of ordinary Portland cement (OPC) . Approximately 7% of the world's CO2 emissions are released during the manufacturing of OPC [1,12]. Among the most efficient ways to resolve The solution to these environmental issues is to replace OPC in SCC with supplementary cementitious materials (SCM) [3, 12– 15]. Therefore, increasing the use of mineral admixtures in concrete is a considerable and necessary step to provide sustainable development in the construction industry [16,17]. These supplementary cementitious materials, when used in composite mixture, enhance the fresh properties, mechanical performance, and durability of concrete, especially when used in binary and ternary blends [13,18]. Pozzolanic reaction takes place when enough calcium hydroxide which is a by-product of hydration reactions, exist. So, careful balance is required between the cement content and volume of pozzolanic admixture to both reaction completely lead to gaining strength [13].

Ground granulated blast furnace slag (GGBFS) is one of the supplementary cementitious materials which can be used in SCC as mineral admixtures. Many investigations have been done that showed that utilization of slag could improve rheological properties of SCC. The influence of slag on mechanical properties were significant at later ages. The fresh properties of an investigation showed that replacement of 20%,30%,40% slag increased the initial slump flow and reduced the slump flow loss rate and elongated the setting

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times of cement paste. At early curing period, replacement of cement with GGBFS indicated worse outcomes with respect to mechanical properties. Compressive strength has reduced at the curing period of 7 days. After 90 days curing, these values with respect to the control SCC were insignificant [19]. The results of SCC incorporated with high volume of slag and fly ash showed that high volume replacement SCC had better workability and ease of construction benefits compared with conventional SCC. The lowest amount of superplasticizer to reach the goal slump flow belonged to the binary mixtures containing slag and fly ash. The results indicated that compressive strength of binary and ternary mixtures was lower than conventional concrete specially at early-ages [20].

Natural zeolite is one of pozzolanic materials which can be used in SCC as mineral admixture. Different amounts of zeolite at different water/ binder ratios have been investigated on rheological, mechanical and durability of SCC mixtures. The result of an investigation showed that higher amount of zeolite led to higher reduction in rate of slump flow with haulingtime. [21].Replacingcement bypozzolans is a practical solution to reduce the cost of manufacturing SCC. The result of an investigation showed the effect of zeolite, silica fume and fly ash on properties of hardened and fresh concrete. The results represented that durability and mechanical properties of the mixtures were improved by incorporating of pozzolans in to the mix. To improve the durability characteristic, silica fume was slightly more efficient than fly ash and natural zeolite. While zeolite was much more economic and cost effective. It is reported that, superplasricizer demand of SCC mixtures containing zoelite was higher than control mixture due to high surface area of its structure. The result of compressive strength indicated that the optimum percentage of replacement of zeolite was 10%. At 28 days, the mixtures containing 10% zeolite had higher compressive strength than control mixture while 20% replacement of zeolite by cement reduced the compressive strength compared to control mix [22]. Natural pozzolans such as volcanic pumice have been studied in order to measure the effect of mineral admixtures in hardened and fresh properties of SCC. In fresh properties of mixtures, binary mixes containing pumice showed a slight reduction in flow diameter, whereas incorporation of pumice and silica fume in ternary mixes showed a gradual fall in slump diameter. Volcanic pumice increased the later age compressive strength while the result was converse in early ages. Durability properties such as chloride ion and water penetration enhanced significantly compared to ordinary SCCs [23].

Fresh and hardened properties of SCC`s mixtures containing different types of supplementary cementitious materials (silica fume, metakaolin, fly ash, slag) with various amount of pozzolans were investigated. Results showed that replacing cement by mineral admixtures, increased compressive strength of mixes in later times and durability parameters like water and chloride penetration decreased considerably according to type and amount of replacement [18]. Self-consolidating lightweight concrete containing natural zeolite was studied in order to determine the effect of pozzolanic reaction on gaining compressive strength and assessing segregation resistance of lightweight aggregates in fresh and hardened samples. By increasing zeolite, compressive strength increased up to 25% at 28 days. Segregation resistance enhanced by increasing zeolite, 12% natural zeolite as a partial replacement of cement prevented segregation of lightweight aggregate in the mixture [24].

Table 1. Chemical composition of powder materials.

Chemical composition (%)	PC	S	Z	L
CaO	62.4	36	3.1	54.78
SiO_2	20.4	35.05	66.5	0.8
Al_2O_3	2.56	10.36	11.8	0.23
Fe_2O_3	4.5	0.9	1.3	-
MgO	3.7	10.4	0.8	0.41
K_2O	0.85	0.68	2.1	-
MnO	0.25	1.58	0.04	-
Na_2O	0.2	0.6	2	-
TiO_2	0.38	-	-	-
SO_3	2.56	-	-	0.25
L.O.I	1.89	1.3	12	42.86

The above literature review showed that the utilization of GGBFS in SCC led to increment of slump flow rate and rheology of concrete, while, the opposite tendency was seen when Portland cement (PC) was replaced by zeolite. In addition, no research has been investigated on combination of slag and zeolite in manufacturing of SCC mixtures. Therefore, in this study, the possibility of using slag, zeolite and their combination in order to determine rheological and mechanical properties of mixtures were conducted. The fresh concrete tests include slump flow diameter, T50, V-funnel and J-ring while hardened concrete tests consist of compressive strength.

2. EXPERIMENTAL PLAN

2-1- Materials

An ASTM C 150 [25] type 1-425 Portland cement was used to prepare the SCC mixtures. The chemical composition of raw materials was determined by X-ray fluorescence (XRF). The XRF results of industrial slag, a clinoptilolite type of zeolite, type 1 ordinary PC and lime stone powder (L) utilized in this research are presented in Table 1. The blast-furnace slag was obtained from Madaen Cement Company with a specific gravity of 2.94 gr/cm^3[26]. The PC and zeolite were provided from Tehran cement and Afrand Tusca Company respectively. The specific gravity of zeolite and PC used in this study was 2.23 and 3.1 gr/cm^3 respectively. For natural pozzolans, the total content of SiO_2, Al_2O_3, and Fe_2O_3 for zeolite was about 79.6%. This value satisfied the minimum requirement for the standard (70%) [27]. In addition, the compressive strength of cement mortars, which were produced according to ASTM C 109 [28], were 27 and 34 MPa at 3 and 7 days. The specific gravity of lime stone powder (L) was 2.67 gr/cm^3. Local natural river sand was used as fine aggregate, and coarse aggregate with a maximum size of 12.5 mm was utilized. The grading of

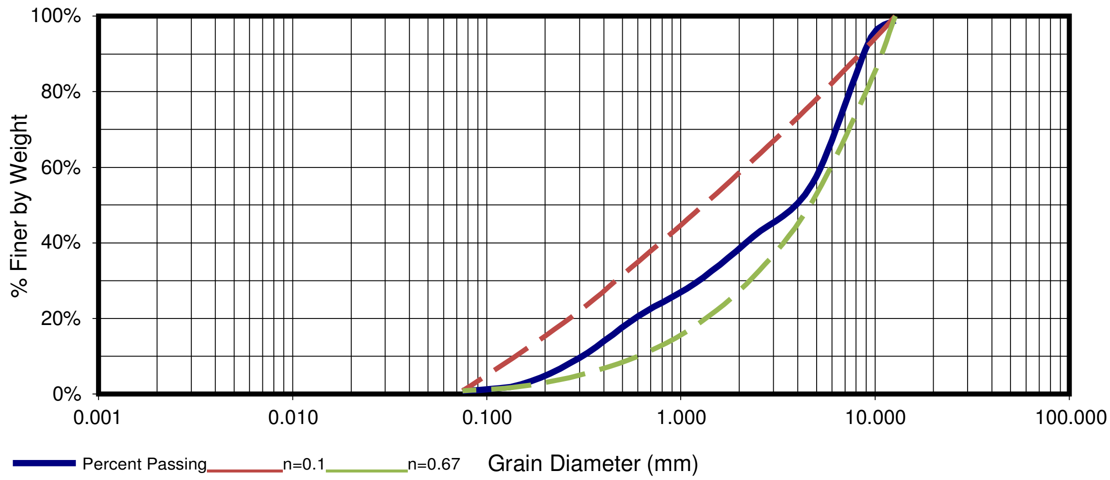


Fig. 1. Particle size distribution of aggregates

Table 2. Mix proportions of SCC mixtures substituted with SCM (kg/m³).

NO	MIX ID	Description	W/b	Cement	Zeolite	Slag	Filler	Water	gravel	sand	SP (%)
1	R	Reference	0.4	450	0	0	150	180	686.5	839.5	1.2
2	Z5	5% Zeolite	0.4	427.5	22.5	0	150	180	683.3	835.6	1.2
3	Z10	10% Zeolite	0.4	405	45	0	150	180	680.1	831.8	1.8
4	Z15	15% Zeolite	0.4	382.5	67.5	0	150	180	676.9	827.9	2.3
5	S20	20% Slag	0.4	360	0	90	150	180	684.7	837.3	0.9
6	S30	30% Slag	0.4	315	0	135	150	180	683.8	836.2	0.85
7	S40	40% slag	0.4	270	0	180	150	180	682.9	835.1	0.85
8	ZS20	10%Z+20%S	0.4	315	45	90	150	180	678.3	829.6	1.7
9	ZS30	10%Z+30%S	0.4	270	45	135	150	180	677.4	828.5	1.9
10	ZS40	10%Z+40%S	0.4	225	45	180	150	180	676.5	827.4	1.7

aggregates is presented in Fig 1. The specific gravity and water absorption of coarse aggregates were 2.54 gr/cm^3 and 2.49% respectively [29]. The specific gravity and water absorption of fine aggregates were 2.508 gr/cm^3 and 2.56% respectively [30]. To achieve accepTable workability, a polycarboxylic-ether type super plasticizer was applied according to ASTM C494 standard [31] with specific gravity of 1.1 gr/cm^3.

2-2- Mix proportions

As presented in Table 2, a total of ten SCC mixtures were designed with a total binder content of 450 kg/m^3 and constant w/b ratio of 0.4. The control mixture was only made with PC as binder materials and 9 SCC mixtures with slag and zeolite as binary and ternary concrete mixes were prepared. The fine aggregate to total aggregate ratio was set constant for all SCC mixes at 55%. These factors were not changed in all mixture proportions in order eliminate their effects on the results of SCMs performance. The superplastisizer dosage used in this research was adjusted to secure an initial slump flow of 750±30mm. In the binary mixtures, PC was replaced by (5%, 10%, and 15%) zeolite and (20%, 30% and 40%) slag. The mixtures incorporating ternary cementitious blends (ZS20, ZS30 and ZS40) were made with 10% zeolite and (20%, 30% and 40%) slag. All replacements of PC by SCMs were made on the total mass basis of the binder. In order to supply a similar homogeneity and uniformity in all mixtures, the same procedure for batching and mixing according to khayat et al [32], was used. The natural coarse and fine aggregates were homogenized for 30 s at normal mixing speed. Afterward, half of the mixing water was added into the mixer while mixing continued for 1 min. The mixture was rested for one min in order to the aggregates could absorb the water. Then, powder materials were added and mixed for 1 minute. The remaining water and superplasticizer were added to the wet mixture, while mixing was going on for 3 min. Finally, after 2 mins resting, mixing sequence resumed for additional 2 min.

2-3- Test procedure

2-3-1- Rheological tests on fresh concrete

In the laboratory some relative measures of viscosity are needed to obtain the desired flow rate of a SCC mixture. In this research, some tests were employed to determine rheological properties of SCC mixtures (Fig 2) such as: slump flow diameter, V-funnel flow time, slump flow time (T50) and J-Ring test to measure the flowability and passing ability of SCC`s mixtures according to the guidelines and specifications for SCC that provided by European Federation of National Associations Representing for Concrete (EFNARC) [33].

Fig. 2. Rheological tests set up for determining the flow ability and passing ability of mixtures.

Table 3. Results of fresh SCC mixtures.

NO	MIX ID	Slump flow		J-ring		D_1-D_2(cm)	V-funnel(s)	Sp(%)
		T50 (s)	D_1(cm)	Δh(cm)	D_2(cm)			
1	R	2.1	73	0.5	72	1	3.6	1.2
2	Z5	2.3	75	0.5	74	1	4.9	1.2
3	Z10	2.3	74	1	73	1	4.6	1.8
4	Z15	2.5	74.5	0.5	73	1.5	5.3	2.3
5	S20	1.7	77	0.5	72	5	3.7	0.9
6	S30	1.7	76	0.5	74	2	3.5	0.85
7	S40	1.5	75	0.5	70	5	3.1	0.85
8	ZS20	2.2	72	1	67	5	4.8	1.7
9	ZS30	2.2	77	1	74	3	4.9	1.9
10	ZS40	2.2	77	0.5	75	2	4.7	1.7

In the slump flow test, the SCC mixture is poured into the truncated cone mold. After lifting the mold, the diameter of spread concrete is measured in two vertical directions, and the mean is measured. The time (T50) is calculated to assess a relative measure of the unconfined flow rate of the concrete mixture, it takes from the mold is first raised to spread and reach the mixture a diameter of 500mm [33]. SCC mixtures were generally designed to attain satisfactory Visual Stability Index (VSI) within the targeted range of 0-1, which this property was visually inspected during the slump flow test. Thus, all of the mixtures were homogeneous with proper stability and no evidence of bleeding or segregation. To select an appropriate water-powder ratio in the mix design and to realize the alteration with mix proportions, the V-funnel flow time was proposed by Okamura [11]. In this test the flow time is between opening the orifice and full discharge of mixture. Eventually, J-Ring test was done as further workability measure of the passing ability of fresh mixture of concrete.

2-3-2- Mechanical test

Compressive strength as mechanical test was carried out on the specimens at the age of 7, 28 and 90 days of curing. The dimension of the specimens was 100×100×100 mm cube. The specimens were remolded after 24 h then cured in water at temperature of 20°c in the ambient condition. The compressive strength test was performed in accordance with BS EN 12390-3.

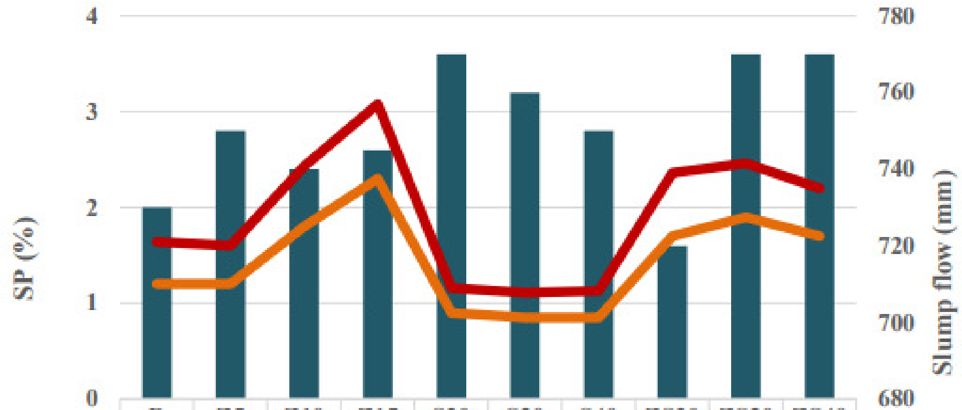
3. RESULTS AND DISSCUSION

3-1- Fresh properties

The properties of fresh SCC mixtures containing zeolite and slag were assessed immediately after producing process by slump flow test, T50, V-funnel and j-ring test which is presented in Table 3.

3-1-1- Slump flow diameter and superplasticizer demand

The superplastisizer demand to produce a 750±30 mm slump-flow diameter for all binary, ternary and control mixtures are demonstrated in Table 3 and Fig 3. As can be seen, SCC`s mixtures have reached the target slump-flow diameter by adding superplasticizer range between 0.85%-2.3% of cement weight. Most of the mixtures were categorized in SF2 (660-750 mm) class which is suiTable for many normal applications (e.g. walls, columns). The mixtures S20, S30, ZS30 and ZS40 were categorized in SF3 (760-850) class which is appropriate for vertical applications in very congested structures, structures with complex shapes, or filling under formwork [33]. The highest and lowest high range water reducer (HRWR) demand of mixtures belonged to Z15 and S30, S40 respectively. The results of binary mixtures showed that HRWR content of mixtures increased by increasing the percentage of zeolite, while, the opposite tendency was



	R	Z5	Z10	Z15	S20	S30	S40	ZS20	ZS30	ZS40
D slump(mm)	730	750	740	745	770	760	750	720	770	770
SP(%)	1.2	1.2	1.8	2.3	0.9	0.85	0.85	1.7	1.9	1.7
(SP/D)*1000	1.64	1.6	2.43	3.08	1.16	1.11	1.13	2.36	2.46	2.2

Fig. 3. Slump flow diameter and HRWR demand rate.

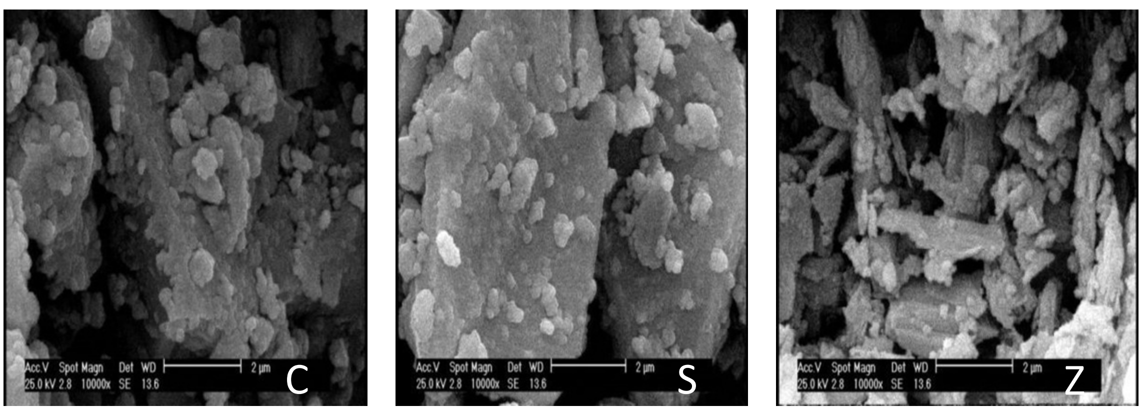


Fig. 4. SEM images of C: cement, S: slag, Z: zeolite particles.

seen when PC was replaced by slag. The partial replacement of 20%, 30% and 40 % slag decreased the HRWR content approximately 25%, 29% and 29% in compared to control mixtures. Similar results were reported by other researches [22, 34]. As illustrated in Fig 4, the high HRWR demand of zeolite was probably due to high surface area of zeolite as well as their rough surface while, the morphology of glassy slag particles as well as their smooth surface led to low HRWR demand. Combination of zeolite with porous particles and slag with spherical shape adjusted the HRWR demand of mixtures between the highest and lowest values. For instance, the mixture incorporating 10% zeolite (Z10) had 740 mm slump-flow diameter with consuming 1.8% superplasticizer. While, the mixture containing 10% zeolite and 40% slag had 770 mm Slump-flow diameter with consuming 1.7% superplasticizer. From Fig 3, it can be noticed that the rate of superplasticizer to slump flow diameter (SP/D) was determined to present the HRWR demand of mixtures incorporating different SCMs against slump-flow diameter. This Figure described properly the function of slag and zeolite on the rheology of the mixtures. The slump-flow diameter of all mixtures weren't exactly equal, therefore in constant amount of superplasticizer, a mixture with lower SP/D ratio had a higher rheology. The lowest value of SP/D*1000 ratio appertained to S20, S30 and S40 with the values of 1.16, 1.11 and 1.13. The highest value of SP/D*1000 ratio belonged to Z15 which increased the amount of superplasticizer dosage.

3-1-2- T50 and V-funnel flow time

T50 and V-funnel flow time are tests to measure the flow-ability of self-compacting concrete in absence of obstacles. The effect of SCMs on rheological properties of different mixtures are presented in Table 3. T50 flow time for binary mixtures containing zeolite and slag were in the range of 2.3-2.5 s and 1.5-1.7 s respectively. The ternary mixtures had T50 flow time of 2.2s. With respect to the similar trend that was observed with T50, the V-funnel flow time of binary and ternary mixtures incorporating zeolite, slag, combination of zeolite and slag were respectively in the range of 4.6-5.3 s, 3.1-3.7 s, 4.7-4.9 s. The results showed that the utilization of

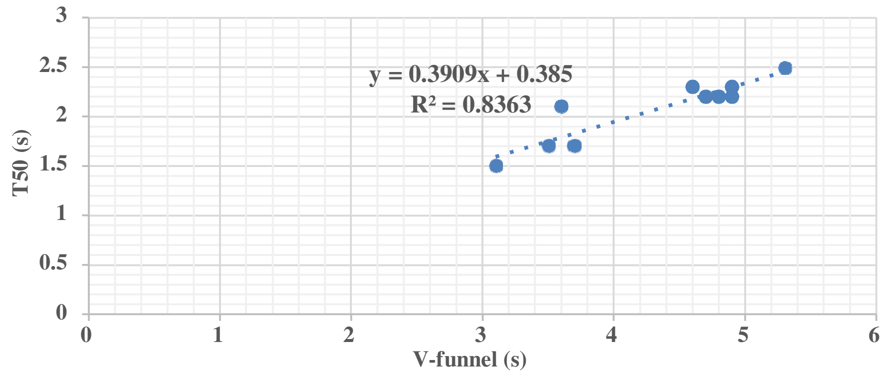


Fig. 5. Relationship between T50 and V-funnel flow times.

various SCMs had considerable diverse effect on rheological properties of mixtures. The flow time of mixtures containing zeolite increased by increasing the zeolite content. While, different physical characteristic and frame structure of slag led to the decrease of flow time by increasing the slag percentage. The greatest flow time values belonged to Z15 due to high surface as well as pores in frame structure of zeolite which is demonstrated in Fig 4. In all ternary mixtures, the utilization of 10% zeolite with 20, 30 and 40% slag resulted in a sensible increment in T50 and V-funnel flow time compared to the binary mixtures containing slag. Viscosity of fresh concrete can be evaluated by T50 and V-funnel flow time tests [33]. The rate of flow of fresh concrete tests could evaluate comparatively the viscosity of mixtures. Quick initial flow of all mixtures especially binary mixtures containing slag showed that they had low viscosity which had proper filing ability even with congested reinforcement. As shown in Fig 5, T50 flow time values were well correlated with V-funnel flow time. The correlation coefficient of this relationship was calculated as 0.836.

3-1-3- J-Ring test

J-ring test results of SCC mixtures containing various SCMs are presented in Table 3. The J-ring results ranged from 5-10 mm without any tendency of blockage. The highest difference between slump flow and j-ring diameter belonged to S20, S40 and ZS20 which was about 50 mm. While, the lowest differences between diameters appertained to control and binary mixtures incorporating Z. Therefore, all binary, ternary mixtures showed adequate ability to flow through the rebar of the J-ring apparatus.

3.2 Mechanical properties

3-2-1- Compressive strength

The results of the compressive strength of SCC mixtures are shown in Fig 6-a at 7, 28, 90 and 180 days. From the results of the compressive strength an increase of compressive strength with increasing days of curing was obvious. By adding additives (slag, zeolite) the compressive strength of all specimens was decreased at the age of 7 days of curing due to the reduction of hydration process and amount of cement in the mixture. The lowest compressive strength belonged to ZS40 mixture with replacing 50% PC by additives at 7 days. The highest compressive strength was seen in ZS30 whose compressive strength was 58.7 MPa at 180 days. As shown in Fig 6-a, the binary use of zeolite increased the compressive strength of the control mixtures irrespective of the percentage of replacement at 90 days. At 180 days, except for the S40 and ZS40 mixtures, all the binary and ternary mixtures enhanced the compressive strength of the control mixtures.

The compressive strength test results of the binary mixtures containing zeolite are illustrated in Fig 6-b. The results of the present study demonstrated that the contribution of zeolite to concrete strength was considerable up to 10% replacement of cement by zeolite. Therefore, irrespective of the age of concrete, increasing the percentage of zeolite from 10% to 15% did not present a noticeable effect on compressive strength. These test results were in agreement with the findings of the other researchers [22, 35]. As can be shown in Fig 6-b, there is a significant enhancement in the compressive strength of mixtures containing zeolite between the ages of 7and 28 days. For example, the development in strength of Z5, Z10, Z15 were approximately 31%, 46%, 63% respectively between 7 and 28 days while they were 22%, 22%, 23% respectively between 28 and 90 days.

The compressive strength test results of the binary mixtures containing slag are shown in Fig 6-c. The results of present study demonstrated that compressive strength of slag incorporated mixtures were lesser than control mixtures at 90 days. According to present study, Zhao et al. [19] showed that the partial replacement of PC by 20%, 30%, 40% slag decreased the compressive strength of control mixtures at 90 days. The highest compressive strength of mixtures belonged to S30 with 58 MPa at 180 days. The enhancement in strength of S20, S30, S40 were approximately 43%, 54%, 69% respectively between 7 and 28 days while they were 17%, 17%, 33% respectively between 28 and 90 days.

The compressive strength test results of the ternary mixtures incorporating zeolite and slag are demonstrated in Fig 6-d. The results showed that replacement of PC by zeolite and slag in ternary mixtures decreased the compressive strength of control mixtures except ZS30 at 180 days. The increase in strength of ZS20, ZS30, ZS40 were approximately 67%, 78%, 92% respectively between 7 and 28 days while they

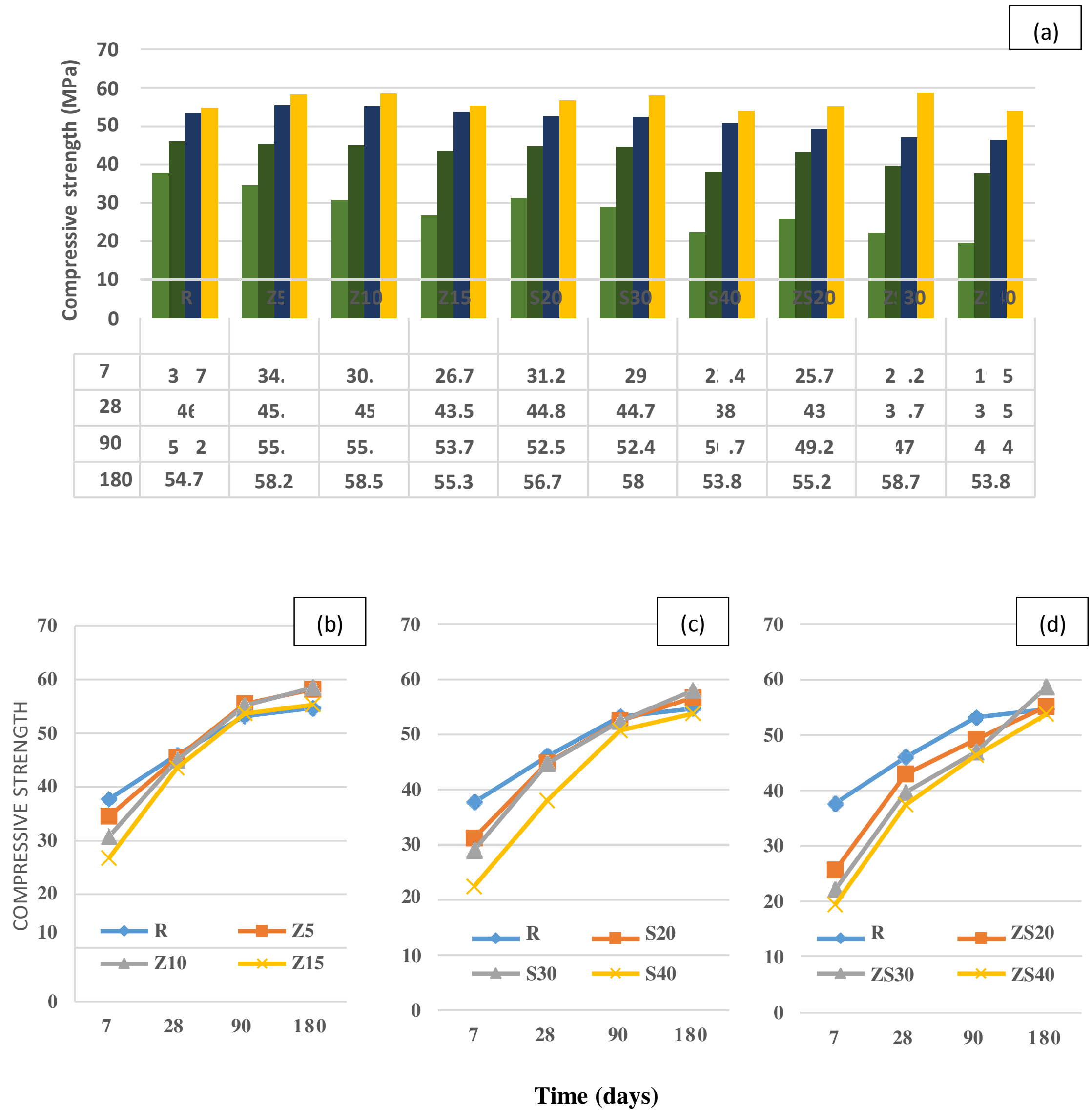


Fig. 6. Compressive strength of SCC mixtures made with various SCMs (MPa).

were 14%, 18%, 23% respectively between 28 and 90 days. According to the enhancement in strength in all mixtures, generally by adding more percentage of additives in cement matrix, regardless to the type of them, the increase in strength was significant between 7 and 28 days.

At 180 days, the highest compressive strength of mixtures incorporating zeolite, slag and combination of zeolite and slag belonged to Z10, S30, ZS30 with 58.5, 58, 58.7 MPa respectively. The results showed that replacement of PC by 10% zeolite and 30% slag increased compressive strength of control mixtures at later ages. Therefore, the highest compressive strength among all mixtures was seen in ZS30.

4. CONCLUSIONS

According to the results obtained from this study, the main conclusions can be summarized as follows:

1) The lowest value of superplasticizer to slump flow diameter (SP/D*1000) belonged to S20, S30 and S40 with the values of 1.16, 1.11 and 1.13. The highest value of SP/D*1000 ratio belonged to Z15 which increased the amount of superplasticizer dosage.

2) The enhancement in strength of all binary and ternary mixtures were more sensible between 7 and 28 days than the increase between 28 and 90 days. The ternary mixture containing 10% Z and 40% S had the highest increase (92%) between 7-28 days while it was only 23% between 28-90 days.

3) The compressive strength of mixtures containing natural zeolite was greater than control mixture at the age of 90 days. From the results it could be concluded that 5% and 10% replacement of cement by zeolite improved the compressive strength more than that for 15% replacement. Replacing cement with slag decreased compressive strength of mixtures at all ages but with more curing time, the reduction of values of compressive strength diminished. At the age of

90 days, replacement of 20%, 30% and 40% slag decreased strength of mixture for 0.7, 0.8, 2.5 MPa respectively when compared with the control mix.

4) At 180 days, except for the S40 and ZS40 mixtures, all the binary and ternary mixtures enhanced the compressive strength of the control mixtures. Therefore, the highest compressive strength of mixtures incorporating zeolite, slag and combination of slag and zeolite belonged to Z10, S30, ZS30 with 58.5, 58, 58.7 MPa respectively. The results showed that replacement of PC by 10% zeolite and 30% slag increased compressive strength of control mixtures at later ages. Therefore, the highest compressive strength among all mixtures was seen in ZS30.

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