CONCRETE
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LETTERS

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Vol. 3(2)- June 2012

Performance of Self-Compacted Concrete Exposed to Fire or Aggressive Media

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Abstract

Fires and aggressive environment affect the durability of different types of concretes, so experimental investigation of concrete deterioration is very essential. The production of self – compacted concrete (SCC) mixes with two different types of mineral admixtures (silica fume and fly ash) are included in this research. The workability of fresh concrete mixes was investigated using five different international specified techniques. The properties of hardened concrete samples were determined under the exposure of different temperatures, which ranges between 25ºC and 600ºC. The effects of the methods of treatment for concrete samples after being exposed to fire on there, physical and mechanical properties were investigated. On the other hand the effects of some aggressive and corrosive mediums on the hardened mechanical properties and deterioration of the different mixes of (SCC) in comparison with normal concrete (NC) was also investigated. Both ($MgSo4$) and ($MgCl2$) were used to investigate the corrosion of reinforcing steel bars and deterioration of SCC mixes. Self-compacted concrete containing fly ashes has a good durability performance rather than self compacting concrete containing silica fume.

Keywords: Corrosion; Media; Self-compacting; Strength; Deterioration; Weight loss, fire resistance.

1. Introduction

Self-compacted concrete (SCC) is a type of concrete which flows without the influence of additional compaction energy, and completely fills the whole volume of the concrete form work under the influence of its own weight and gravity [1], suggested criterion for the fresh properties of self-compacted concrete that reported by [2]. Durability of concrete was defined as the ability to resist fire, weathering action, chemical attack, abrasion, or any other process of deterioration; that durable concrete will retain its original form, quality, and serviceability when exposed to the surrounding environment [3]. Damage of concrete structures may occur due to fires with respect to building integrity and human safety [4]. Since the 1920s, many investigations have been carried out on the residual mechanical properties of concrete subjected to elevated temperatures [5]. Fire is a chemical reaction between flammable material and oxygen in air [6]. The effects of high temperature can be visually seen in the form of discoloring surface, cracking, spalling and disintegration that render the concrete structure unserviceable [7].

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When concrete exposed to high temperatures, such as fire, chemical reactions and physical changes are occurred which affect the mechanical properties of concrete such as reducing strength, modulus of elasticity, increasing mass loss reduction, splitting tensile strength and bending strength [7- 14]. Deterioration of concrete was defined as the destructive interaction for the concrete by the surrounding aggressive environments [15-16]. The influence of aggressive chemicals on the behavior of building materials was a topic of significant practical interest, as it affects the safety and durability of structures [16]. Concrete provided both physical and chemical protection to reinforced steel. The physical protection was provided by its impermeable structure which retards the ingress of aggressive agents like moisture, oxygen, carbon dioxide and other fluids into the interior. The chemical protection was provided by the high PH (13-13.5) of the pore solution which forms passive protective oxide film over the steel surface. If the passivation of steel was broken down, corrosion of reinforcement occurs [17]. Extensive research work was carried out regarding the production and properties of self-compacted concrete however, very limited research work was available regarding the durability of new and desirable materials.

Günegisi, and Gesoglm used lime stone, blended cement portland pozzolana and slag to produce SCC. They concluded that SCC can be manufacture using PPC or PLC cements [18]. SCC produced with portland pozzolana cement had the lowest compressive strength values than those of the concrete produced with normal portland cement and portland lime stone cement at 28 days. Annerel, and Taerwe compared the strain behaviour of both normal and self-compacting concrete during and after fire [19]. The effect of load during heating and cooling results in an increase of the compressive strain with different values for both normal and SCC, Loser, and Leemann studied the shrinkage of both normal and SCC, self-compacting concrete has more higher shrinkage than normal concrete owing to shrinkage was mainly affected by volume of paste [20]. Faris et al. studied the effect of fire on the spalling behaviour of concrete slabs; it was found that all the normal strength reinforced concrete slabs exhibited a larger thermal gradient between the slab surface, the steel reinforcement and the slab case under hydrocarbon fire [21]. Caroline and Farid studied the nonlinear mechanical behaviour of concrete at high temperature, using of mechanical analysis and comparison to experimental results, on relevance's and performance of their different mechanical models [22]. Sahmardn et al. used the spent foundry sand and fly ash for the development of self-consolidation concrete owing to large quantities of spent foundry sand which used successfully in producing self consolidation concrete as a sand replacement material [23]. They concluded that SCC mixes with low stress and adequate fresh properties by replacing sand with SFS. Wong et al. studied the effect of thermal loads on the concrete cover of concrete elements effect reinforced by fiber reinforced polymers [24]. The concrete cover and the horizontal bar spacing have more influence than vertical bar spacing on the determination of the critical temperature increments. Gencel et al. studied the fresh and hardened properties of self-compacting concrete with fly ash and steel fiber [25]. They concluded that mechanical properties of concrete can be improved by the addition of steel fiber and increasing the fiber content, the greater the toughness. Zhang et al. studied the effect of corrosion on concrete structures and their serviceability limit state criteria [26]. It was clear for high sensibility of the bending stiffness, a serviceability limit state criteria based on excessive deflection on structural members in an adequate factor for SLS assessment. Oslakoric et al. and Pathak et al. [27 and 28] studied the service life of concrete structures exposed to marine environment, high concentrations of chlorides on the concrete surface were found above sea level which mainly influenced by strong wind blowing at this location [27 and 28].

The research work reported in this paper was carried out to determine the effect of exposure to fire or chemical attach on the deterioration and corrosion behaviour of self compacted concretes behaviour with special attraction to the compressive, tensile, flexural, bond, strengths and weight loss of the reinforcing bars.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The coarse aggregate was natural dolomite, with a nominal maximum size ½ inches (12.5 mm), and meeting the requirements of ASTM C33-90. However the fine aggregate was natural siliceous sand, with fineness modulus of 2.61, and suitable to the requirements of ASTM C33-90 .The cement was ordinary portland cement (OPC) suitable to the requirements of E.S. 373/1991. Clean drinking fresh water free from impurities was used in mixing and curing the concrete samples. The admixtures used were fly ash, silica fume and viscosity enhancing agent (Viscocrete 5-400) 6th generation carpoxilate super-plasticizer from SIKA Company according to ASTM C-494 type G and F. The chemical and physical characteristics of both fly ash and silica fume as provided by the dealer are given in Table 1.The reinforcing steel bars, mild steel bars of 8 mm diameter and 22.5 cm length with yield stress (200 N\mm^2), tensile strength (360 N\mm^2), and elongation % (22). The concrete cylinder specimens containing steel bars exposed to two aggressive media including magnesium sulfates and magnesium chlorides in crystal shape. Magnesium sulfates ($Mgso_4$) are salts with 99% purity. Magnesium Chlorides ($Mgcl_2$) are salts with 99% purity. A solution was prepared by adding of water to each salt to become 3% concentrations for $Mgso_4$ and of 5% for $Mgcl_2$ from the water weight.

Table 1: Chemical composition of fly ash and silica fume [14 and 15].

Constituent	Content %	
	Fly ash	Silica fume
Silicon (SiO_2)	(47 – 55)	95
Aluminum (Al_2O_3)	(25 – 35)	0.2
Iron (Fe_2O_3)	(3 – 4)	0.5
Manganese (Mn_2O_3)	(0.1 – 0.2)	–
Calcium (CaO)	(4 – 10)	0.2
Magnesium (MgO)	(1 – 2.5)	0.5
Phosphorus (P_2O_5)	(0.5 –1)	–
Potassium (K_2O)	(0.5 – 1)	–
Sodium (NA_2O)	(0.2 – 0.8)	–
Titanium (TiO_2)	(1 – 2)	–
Sulphur (SO_3)	(0.1 – 0.5)	–
H_2O	–	0.5
pH	–	6.5
Loss on Ignition (Loi)	(0.5 – 2)	0.5
Color	–	Light Gray
Specific Gravity	–	2.1
Specific surface area	–	16.7 m^2/g

2.2 Concrete Mix Design

The Swedish cement and concrete institute (CBI) mix design method [1] were used to design three different mixes of self-compacted concrete. With regard to the three mixes of SCC, design parameters were kept constant except the percentages of fly ash and silica fume. SCC1 mix incorporated silica fume as a 10% replacement of cement content, SCC2 mix incorporated fly ash as a 10% replacement of cement content where SCC3 mix incorporated both 5% silica fume and 5% fly ash as replacement of cement content as shown in table 2. Table 2 shows the mix constituents of the investigated normal and self-compacted concrete mixes. The absolute volume design method recommended by ACI code was used to design the normal concrete (control mix).

Table 2: The mix constituents of both normal and self-compacted concrete mixes.

Mix Code	Cement (KN)	Dolomite (KN)	Sand (KN)	W/C	F.A %*	S.F %**	VEA %***
Nc	3.5	12.61	6.30	0.40	—	—	—
Scc1	4.0	7.155	8.745	0.35	—	10	2.5
Scc2	4.0	7.155	8.745	0.35	10	—	2.5
Scc3	4.0	7.155	8.745	0.35	5	5	2.5

*: Fly ash replacement from cement by weight, **: Silica fume replacement from cement by weight, ***: Viscosity enhancing agent addition to cement by weight

2.3 Fresh concrete Testes

Table 3 shows the suggested criteria and test results for fresh properties of self-compacted concrete mixes [1, 2, 14 and 15].

The tests of fresh self-compacted concrete investigated within this study were slump flow and T50cm tests, J-ring test, V-funnel and V-funnel at T5minutes tests. Fig. 1 shows slump test rig, Fig. 2 shows J-ring test rig, where Fig. 3 shows V-funnel test apparatus as mentioned in [1, 2, 14 and 15].

2.3.1 Slump flow test

This test is used to assess the horizontal free flow of SCC mixes in the absence of abstractions as shown in Fig. 1. The test is used to determine the mean diameter of the concrete sample spread on base plate after performing a slump test without any compaction (D). The test Judges the capability of concrete to deform under its own weight against the friction on the surface of the base plate without any external restraint present Fig. 1.

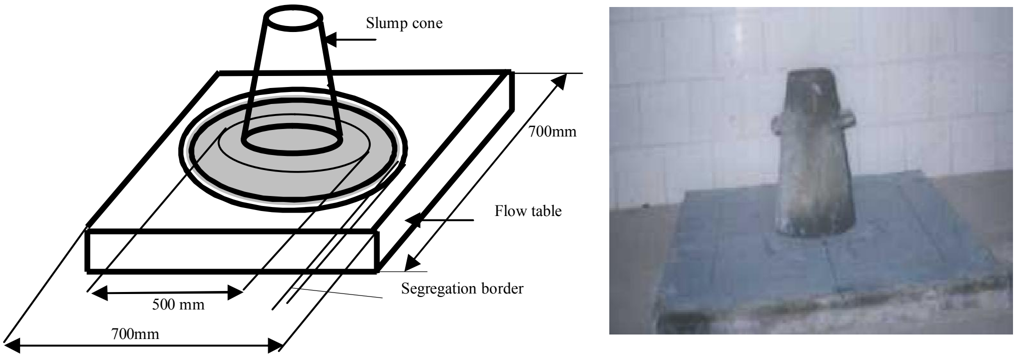

Fig. 1: Slump flow test.

2.3.2 J-ring test

This test is used to determine the passing ability and the flow ability of SCC mixes. The test shown in Fig. 2 consists of an open steel ring drilled vertically with holes that accept threaded sections reinforcement bar. The diameter of the ring of vertical bars is 300 mm and height 100 mm. The ring is generally used in conjunction with the slump flow test or the V-funnel test. In the J-ring in conjunction with the slump flow test, the J-ring is placed in the middle of the base plate and the slump cone centrally inside it and holds down firmly. The slump cone is filled with concrete as in the slump flow test. The concrete flows through the vertical bars as the cone is lifted. Measure the difference in the height (H1-H2) between the concrete just inside the bars H1 and just outside the bars H2. Calculate the average of the difference height at four locations in mm. And also, T50cm and final spread diameter in two orthogonal directions are measured Fig. 2.

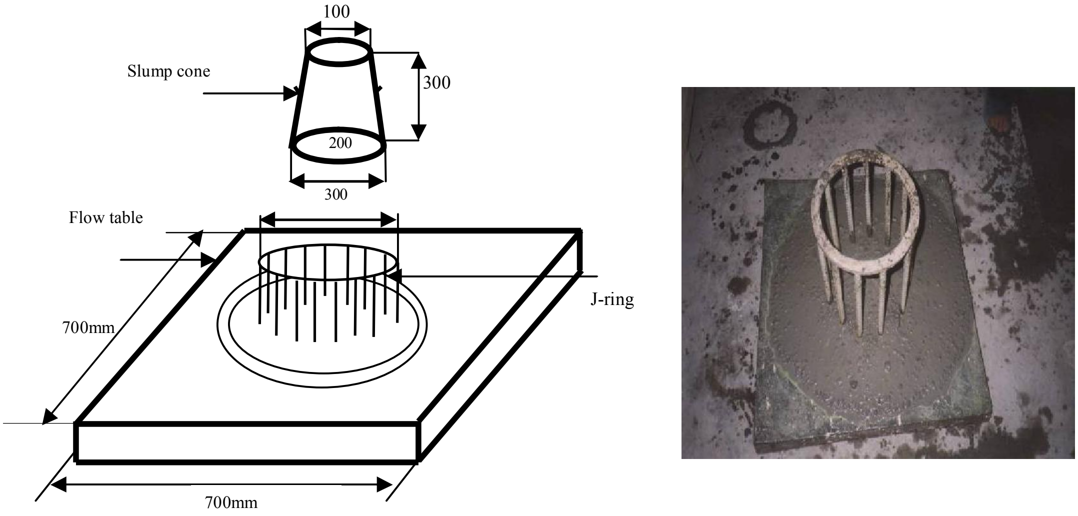

Fig. 2: J-ring test.

2.3.3 V-funnel flow test

This test is used to determine the filling ability (flow ability) of SCC mixes as shown in Fig. 3 .The funnel is completely filled with concrete (about 12 liter) without compaction. Open for (10 sec). After filling, the trap door is opened and allows the concrete to flow under gravity. Start the stopwatch when the trap door is opened and record the time for discharge (the flow time). Then, place a bucket under its own weight; Fill the apparatus completely with concrete without compacting. Open the trap door. After 5 min fill the funnel for a second time and allow the concrete to flow under gravity simultaneously. Start the stopwatch when the trap door is opened and record the time for the discharge (the flow time at T 5 min) Fig. 3.

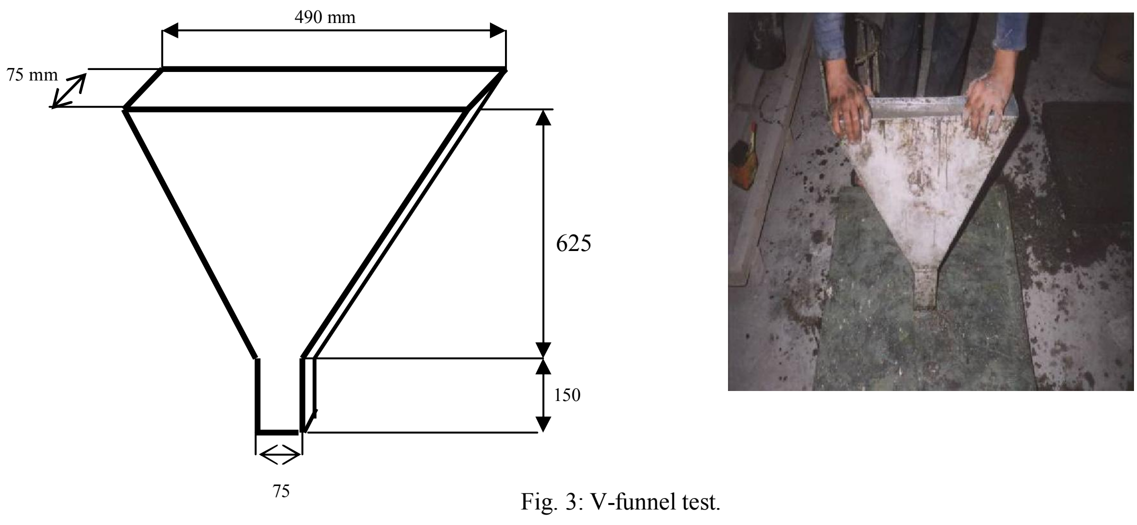

Fig. 3: V-funnel test.

2.4 Hardened concrete testes

The compression test was carried out on a concrete specimens, cubes (15×15×15 cm) and cylinders φ (10×20 cm) according to ASTM C39-86 (standard test method for compressive strength of cube and cylinder concrete specimens) to determine cube and cylinder compressive strength f_{cu} and f_{cy}.

Cube compressive strength (f_{cu}) was performed according to ASTM C 39-86, equation (1).

$$f_{cu} = \frac{Pc}{Ac} \tag{1}$$

where:
Pc : Crushing load in KN,
Ac: Cube cross-sectional area in cm^2

Cylinder compressive strength (f_{cy}) was performed according to ASTM C 39-86, equation (2).

$$f_{cy} = \frac{Pc}{Ac} \tag{2}$$

where:
Pc: Crushing load in KN,
Ac: Cylinder cross-sectional area in cm^2

The indirect tension test was carried out on concrete cylinders 10×20 cm according to ASTM C496-96 to determine splitting tensile strength f_{sp}.

Splitting tensile strength (fsp) was performed According to ASTM C 496-96 standard test method for splitting tensile strength of cylindrical concrete specimens, equation (3).

$$f_{sp} = \frac{P_u}{2\pi RL} \tag{3}$$

where:
P_u: Ultimate load in KN,
R: Radius of the specimen in cm,
L: Length of the Specimen in cm.

The flexural test was carried out on a concrete beams 10×10×50 cm with a span of 45 cm according to ASTM C78-02 to determine flexural strength f_f.

Flexural strength (f_f) was performed according to ASTM C78-02 standard test method for flexural strength of concrete specimens (using simple beam with third point loading), equation (4).

$$f_f = \frac{M.Y}{I} \tag{4}$$

where:
M: Maximum bending moment of the specimens in m.KN,
I: Moment of inertia of the cross-section in cm^4,
Y: Section modulus or distance from the upper face from the material axis.

The push out test was carried out on a concrete cylinders (10×20 cm) reinforced with a central mild steel bars of 0.8 cm diameter and 22.5 cm height to determine bond strength f_b.

Bond strength (f_b) was performed, according to equation (5).

$$f_b = \frac{p_b}{2\pi D_b Le} \tag{5}$$

where:
P_b: Applied Load in KN,
D_b: Diameter of steel bar in cm,
L_e: Embedded length of the steel bar in concrete specimen in cm.

The loss weight of reinforced steel bars was carried out on bars of 0.8 cm diameter and 22.5 cm height through reinforced cylinders of 10×20 cm.

Weight Loss of reinforcing Steel bars was performed, according to the equation (6).

$$W\% = \frac{W1 - W2}{W1}\% \qquad (6)$$

where:
W1: steel bar weight before corrosion process in N,
W2: steel bar weight after corrosion process in N.

2.5 Methodologies of Fire Process and Treatment Techniques

For fire tests, specimens were cured in water for 28 days after remolded. Test specimens were exposed to fire with temperatures 200, 400 and 600ºC for two hours according to ASTM E-119 standard test methods for fire tests of building construction and materials. After that, the specimens were classified into two groups. The first group was cooled down immediately after fire in laboratory atmosphere (air treated) then was left for about 24 hours in laboratory atmosphere before testing. And; the second group was cooled down immediately after fire by immersion in water with 20ºC (water treated) then was left for about 24 hours in laboratory atmosphere before testing. Fig. 4 shows the fire chamber which was especially constructed for this research. The mechanical properties were investigated after exposing the specimens to fire and their treatment included compressive strength, indirect tensile strength, flexural strength and bond strength.

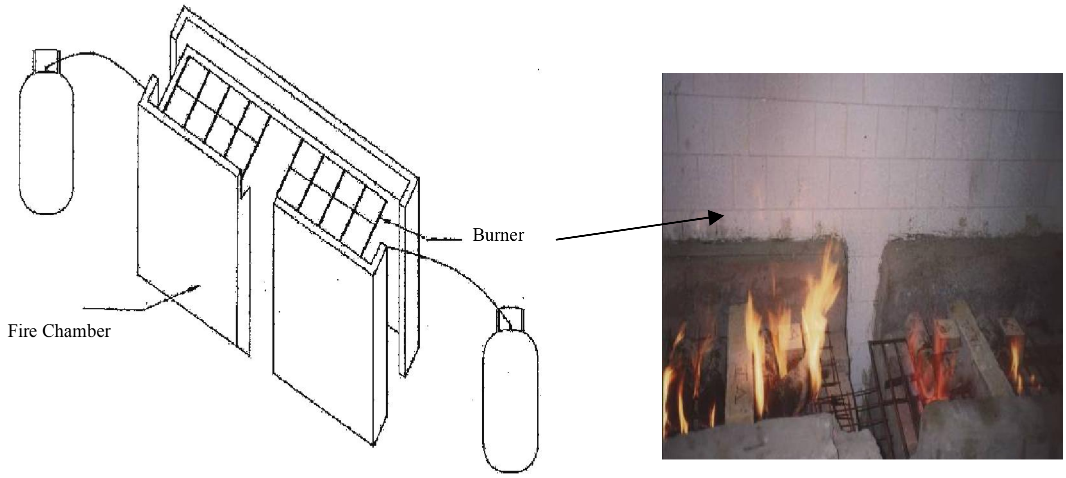

Fig. 4: Fire chamber.

2.6 Accelerated Corrosion Setup and Chemical Attack Techniques

For chemical attack, the tested specimens were concrete cylinders of 10 cm diameter by 20 cm height. Each specimen was reinforced with central mild steel bar of 8 mm diameter and 22.5 cm height. The concrete specimens were cast in special designed plastic molds that had two sockets fixed to the top and the bottom to allow steel bars to pass through it and to insure a uniform concrete cover thickness. The reinforcing bar extended 0.3 cm from the bottom of the specimen and 2.2 cm from the top of the specimen. Just outside the concrete specimen, the extensions of the bars were covered with two layers of tape in an attempt to protect these parts of steel from corrosion during acceleration process. After the cylinder specimens were remolded and the apparent steel parts were covered with tape, the specimens were submerged in a plastic tank aggressive media (3% $Mgso_4$ or 5% $MgCl_2$ by weight of water), duration of corrosion were 2 days, 4 days, and 7 days. The samples are connecting in series with the positive pole of a DC power supply (13.8V/3A) as anode and the negative pole of a DC power supply was connected to the stainless steel bar of 1 cm diameter and 50 cm height as cathode as shown in Fig. 5 The distance between any cylinder (as anode) and the stainless steel bar (as cathode) was 14 cm. This setup contains 8 cylinder specimens, were tested after 2 days, 4 days and finally 7 days from their exposure to each aggressive media.

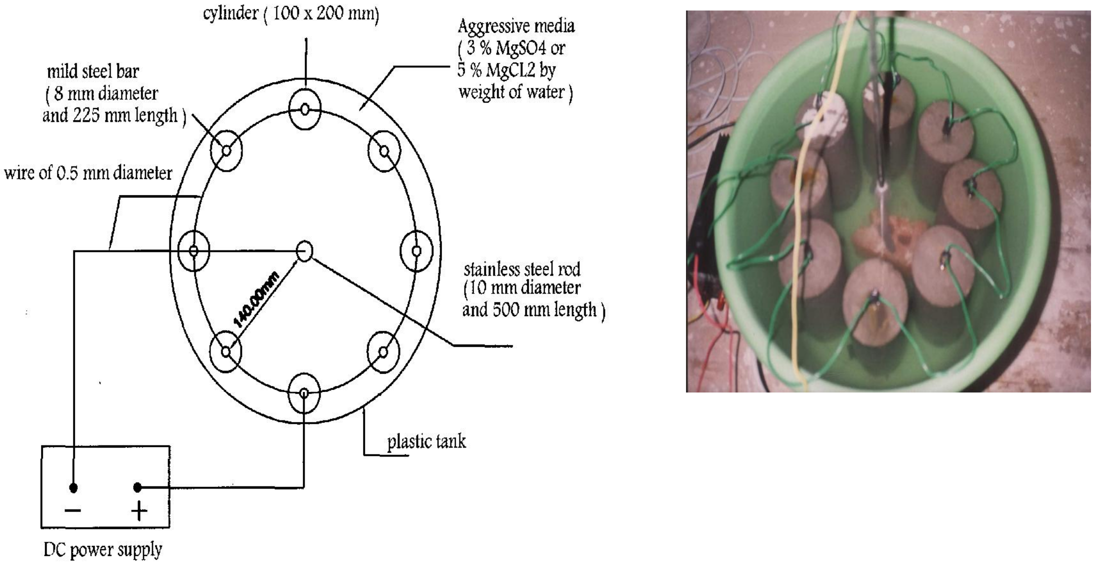

Fig. 5: Accelerated corrosion setup.

3. ANALYSIS AND DISSICIONS OF TEST RESULTS

3.1 Properties of Fresh Self-Compacted Concrete Mixes

3.1.1. Effect of silica fume and fly ash

Referring to slump flow results test in table 3, it is clear that self-compacted concrete mix SCC2 and mix SCC3 achieved the best results for fresh self-compacted concrete tests results in comparison with mix SCC1. Table 3 shows the results of fresh self-compacted concrete tests. SCC3 have the max spread diameter (D) for slump flow test that reached 695 mm whereas for SCC2 was 690 mm and for SCC1 was 675 mm. Referring to slump flow test, SCC3 mix has the minimum time of flow 2.28 sec. Where for SCC2 were 4.59 sec. and for SCC 1 were 2.4 sec. Referring to J-RING test results table 3, self-compacted concrete mix SCC3 have (H1-H2) values equals 2 sec where for mix SCC 2 (H1-H2) equals 3 sec; finally (H1-H2) equals 5 sec for mix SCC1. Referring to V-FUNNEL test results table 3, the flow time was 6.62 sec for self-compacted concrete mix SCC 3 and 6.82 sec for self-compacted concrete mix SCC2 and 8.42 sec for self-compacted concrete mix SCC1. Referring to V-FUNNEL test results Table 3, also the T5 min. T5 was 7.62 sec for SCC3 mix and 8.32 sec for SCC2 mix and 10.4 sec for SCC1. From the above discussions and analysis of the fresh results of self –compacted concrete mixes, it can be concluded that, all self –compacted concrete mixes achieve the requirements of all suggested testes, and SCC3 mix was the best one from the fresh point of view.

Table 3: Typical range of values and test results for fresh properties of self-compacted concrete

Test method	Unit	Typical range of values [14 - 15]		Expermintal results Mix. Code		
		Minimum	Maximum	SCC1	SCC2	SCC3
Slump flow (D)	mm	650	800	675	690	695
slump flow (T_{50cm})	Sec	2	5	2.40	4.59	2.28
J-ring (H1-H2)	mm	0	10	5	3	2
V-funnel (T)	Sec	6	12	8.47	6.82	6.62
V-funnel at ($T_{5minutes}$)	Sec	0	3	10.47	8.32	7.62

3.2 *Effect of Fire on the Mechanical Properties of NC and SCC*

3.2.1 Compressive Strength

3.2.1.1 Cube compressive strength (f_{cu})

Figs. 6 and 7 indicates the relation between temperatures and cube compressive strength (f_{cu}) using two methods of treatment, air treatment and water treatment for different concrete mixes. Fig. 6 shows that for all concrete mixes air treated after exposed to fire at temperature from 25ºC up to 200ºC, there is an enhancement in f_{cu} by about 10% of its original values. Also it is clear that the f_{cu} decreases dramatically when temperature increase from 200ºC up to 600ºC where there is a severe degradations in f_{cu} for all mixes. The conclusions are that SCC1 mix was more dramatically affected by fire than those containing fly ash. SCC mixes SCC2 and SCC3 have more uniform decrease in f_{cu} with temperature. Fig 7 show that for all concrete mixes water treated after exposed to fire at temperature from 25ºC up to 600ºC, there is a severe degradations and a dramatically decrease in f_{cu} for all mixes. From Fig.7, The conclusions are, SCC1 mix was more dramatically affected by fire than those containing fly ash. SCC mixes SCC2 and SCC3 have more uniform decrease in f_{cu} with temperature after water treatment. The conclusions are the putting off fires by air is more recommended than by water. Water treatment of concretes after fire at 600ºC cause a reduction in its f_{cu} by about 40 to 60 % of its original strength value, this can be attributed to when concrete is exposed to fire, it undergoes a series of changes in its chemical composition and physical structure which affects the mechanical properties of concrete such as reducing strength and modulus of elasticity increasing mass loss reducing, splitting tensile strength and bending strength. By comparing Figs. 6 and 7 it is clear that normal concrete has a clear and obvious trend when treated by air or water also SCC2 and SCC3 mixes have nearly the same trend of reduction in f_{cu}.

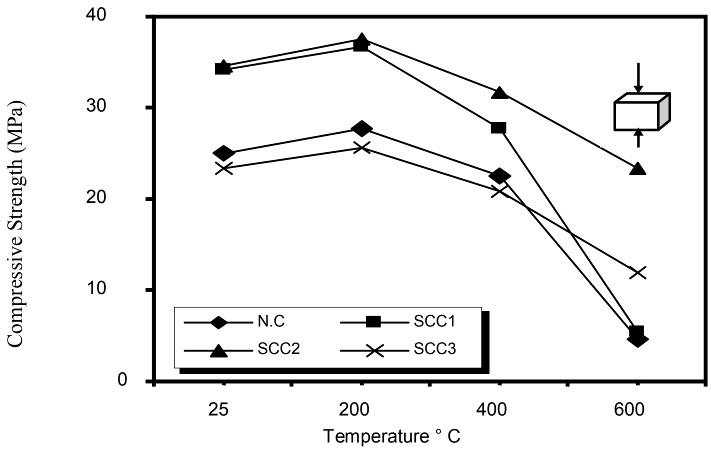

Fig. 6: Relationship Between Temperatures and Cube Compressive Strength (f_{cu}) for NC and SCC mixes treated by air

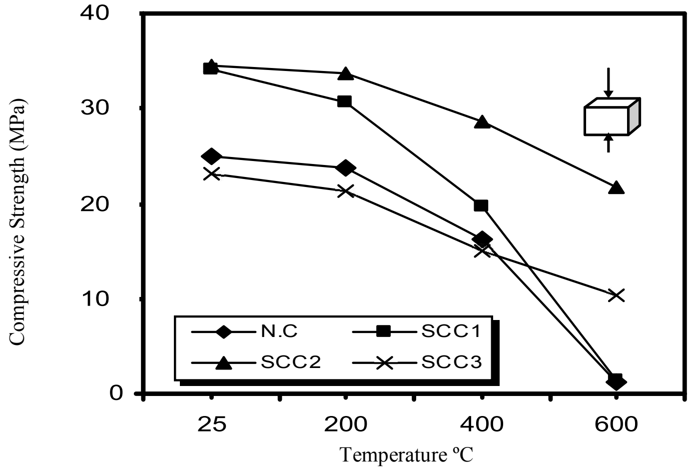

Fig. 7: Relationship Between Temperatures and Cube Compressive Strength (f_{cu}) for NC and SCC mixes treated by water

3.2.1.2 *Cylinder compressive strength (f_{cy})*

Figs. 8 and 9 indicate the relation between temperature and cylinder compressive strength f_{cy} using two methods of treatment, air treatment and water treatment for different concrete mixes .The results in Fig.8 show that for all mixes ,the compressive strength of cylinders f_{cy} increased with increasing temperatures up to 200ºC. When temperature rose from 200ºC through 400ºC up to 600ºC there is a clear reduction in compressive strength of f_{cy} for all tested samples. SCC2 mix containing fly ash was the best mix compared to other mixes within the range of study. Fig. 9 shows that for all concrete mixes treated by water after exposed to fire at temperature range from 25ºC up to 600ºC, there is a severe degradations and a dramatically decrease in f_{cy} for all mixes by comparing Figs. 8 and 9 it is clear that normal concrete have a clear and linear behaviour of degradation in f_{cy} when the treating by air or water. SCC2 mix gives the highest values of f_{cy} and also the lowest reduction rate during water treatment. It is concluded that both cube and cylinder compressive strengths can be used to express the quality and durability behaviour of normal and self-compacted concretes. Both f_{cy} and f_{cy} have same trend of increase or reduction when treating by air or water. By comparing Fig. 6 and 8 it is clear that both f_{cu} and f_{cy} have the trend of increase or loss with the same treatment system but f_{cy} has greater values for residual strengths after treatment rather than f_{cu}, this can be attributed to the uniform distribution of internal stresses in the cylinder rather than in the cube.

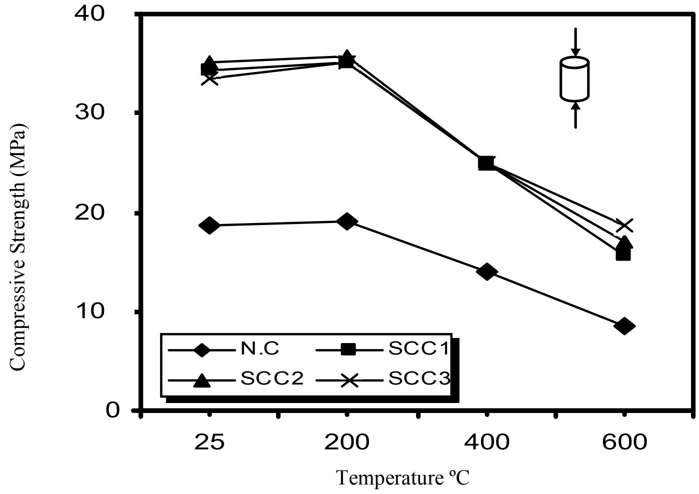

Fig. 8: Relationship Between Temperatures and Cylinder Compressive Strength (f_{cy}) for NC and SCC mixes treated by air

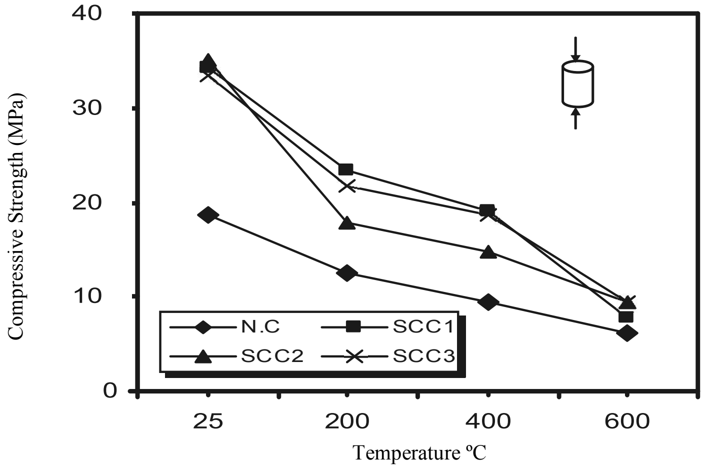

Fig. 9: Relationship Between Temperatures and Cylinder Compressive Strength (f_{cy}) for NC and SCC mixes treated by water

3.2.2 Splitting tensile strength (f_{sp})

Figs. 10 and 11 indicates the relation between temperatures and the splitting tensile strength f_{sp} using two methods of treatment, air treated and water treated for different concrete mixes. Fig. 10 shows, the splitting tensile strength f_{sp} of the concrete cylinders increases with increasing the temperature up to 200ºC for all mixes by about 5 to 10 % of its original value. For temperature increased from 200ºC through 400ºC up to 600ºC the splitting tensile strength f_{sp} is for all tested samples. SCC 1 mix containing silica fume has the largest values of f_{sp}. Degradation of f_{sp} due to treated air after fire is clear and harmony in SCC2 and SCC3 mixes containing fly ash rather than normal and SCC1 mixes. Fig. 11 shows that for all concrete mixes treated by water after exposed to fire at temperature range from 25ºC up to 600ºC, there is a severe degradations and a dramatically decrease in f_{sp} for all mixes. SCC1 mix give, the highest values of f_{sp} during water treatment compared to other mixes within the range of study. SCC3 containing both silica fume and fly ash has the most harmonic trend of degradation and reduction in splitting tensile strength f_{sp} during water treatment. By comparing Figs. 10 and 11 it is clear that values of f_{sp} was greater in treated mixes by air than in treated mixes by water for both normal and self –compacted concrete cylinders. SCC3 mix gives the harmonic values of f_{sp} for both air and water treated so it may consider the most suitable mix It can be concluded that air treatment leads to some higher values of f_{sp} at temperature ranges from 25ºC up to 200ºC, where noticed degradation in f_{sp} values for all treated mixes by water at any temperature.

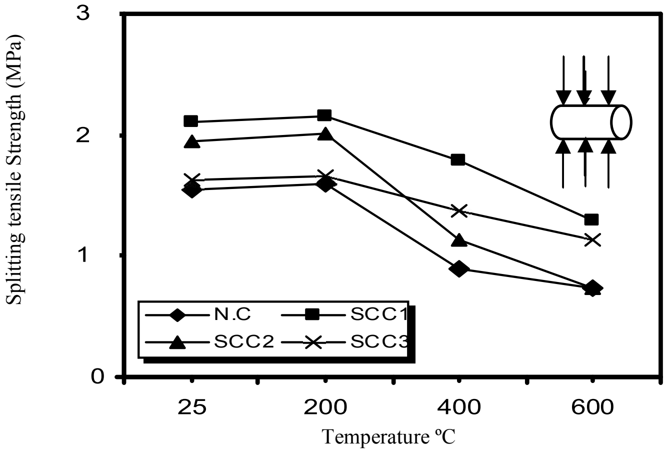

Fig. 10: Relationship between Temperatures and Splitting Tensile Strength (f_{sp}) for NC and SCC mixes treated by air

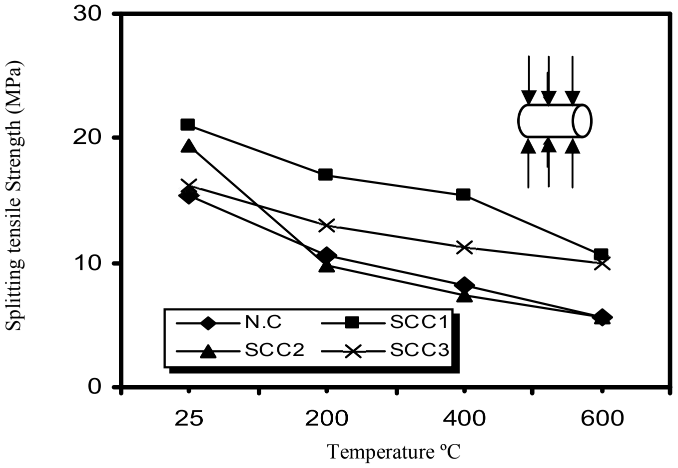

Fig. 11: Relationship between Temperatures and Splitting Tensile Strength (f_{sp}) for NC and SCC mixes treated by water

3.2.3 Flexural strength (f_f)

Figs. 12 and 13 indicate the relation between temperatures and the flexural strength f_f using two methods of treatment, air to treated and water treated for different concrete mixes. Form Fig. 12 the results show that, the flexural strength f_f of concrete tested samples increases with increasing the temperatures up to 200 °C for all mixes by about 5 to 10 % of its original values. A clear reduction in flexural strength f_f for concrete samples for all mixes is observed when temperature raises from 200°C up to 600°C. The rate of decreasing was vastly at temperatures raise from 200°C to 400°C and slowly at temperatures raises from 400°C to 600°C.At 600°C all normal and self –compacted concrete mixes nearly losses 90% of its original values of f_f. SCC2 mix containing fly ash has the highest value of f_f where SCC1 containing silica fume and NC mixes have the lowest values of f_f. Fig. 13 shows that for all concrete mixes treated by water after being exposed to fire at temperature ranges from 25°C up to 600°C, there are severe degradations and a dramatically decrease in f_f for all mixes. At 600°C all normal and self –compacted concrete mixes nearly losses 95% of its original values of f_f at RT, SCC2 mix containing fly ash has the highest values of f_f whereas SCC1containing silica fume and NC mixes has the lowest values of f_f. By comparison between Fig. 12 and 13 it is clear that the treating system has a clear effect on f_f for all mixes. It can be concluded that air treatment is recommended than water treatment for normal and self compacted concrete mixes.

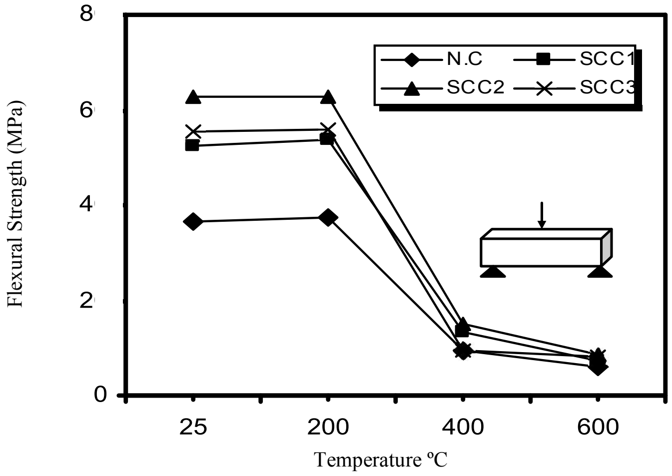

Fig. 12: Relationship between Temperatures and Flexural Strength (f_f) for NC and SCC mixes treated by air

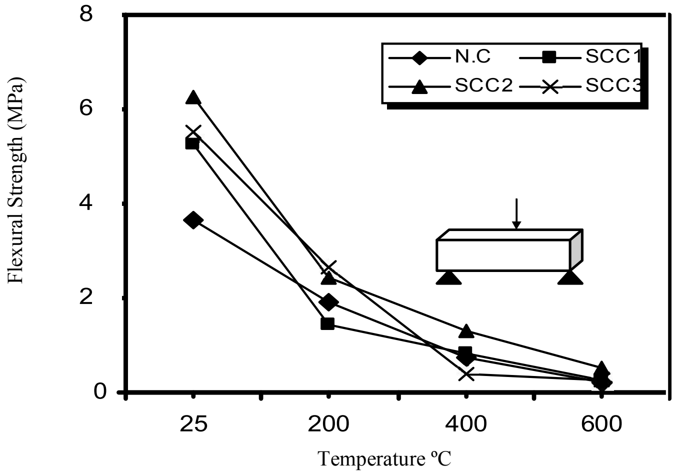

Fig. 13: Relationship between Temperatures and
Flexural Strength (f_f) for NC and SCC mixes treated by water

3.3 Effect of Chemical Attack on the Properties of NC and SCC

3.3.1 Bond strength (f_b)

Figs. 14 and 15 indicate to the relation between age of exposure to aggressive medium and the bond strength f_b with using two aggressive mediums, magnesium chlorides ($Mgcl_2$) with 5% concentration and magnesium sulfates (Mgso4) with 3% concentration for different concrete mixes. The results show that, the bond strength of reinforcing steel bars embedded in concrete cylinders decreased with increasing time of exposure to aggressive mediums. From Fig. 14 It is clear that bond strength f_b decreases by increasing time of exposure to $Mgcl_2$ attack up to 7 days, using accelerated cell for all concrete mixes, where normal and self compacted mixes loss about 75% of their original values of f_b during $Mgcl_2$ attack at 7 days. From Fig. 15 It is clear that the bond strength f_b decreases by increasing time of exposure to $Mgso_4$ attack up to 7 days, using accelerated cell for all concrete mixes, whereas self compacted mix SCC2 losses about 70% of its original values of f_b during $Mgso_4$ attack at 7 days. Self-compacted concrete mix SCC2 incorporating fly ash as a 10% replacement of cement content has a lower reduction in bond strength when it is exposed to $Mgso_4$, where self-compacted concrete mix SCC1 incorporating silica fume as a 10% replacement of cement content has a lower reduction in bond strength when it is exposed to ($MgCl_2$) compared to other mixes Figs. 14 and 15. It can be concluded that ($MgCl_2$) is more aggressive than ($MgSo_4$) on affect f_b for all concrete mixes .Accelerated cell specially designed for this investigation is a very effective method in showing the attack progress of ($MgCl_2$) and Mgso4 on the behaviour of different concrete mixes.

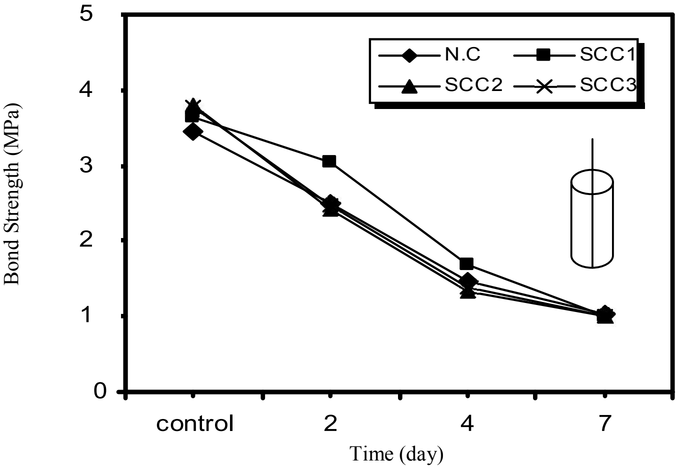

Fig. 14: Relationship Between Temperatures and
Bond Strength (f_b) for NC and SCC mixes Exposed to MgC12

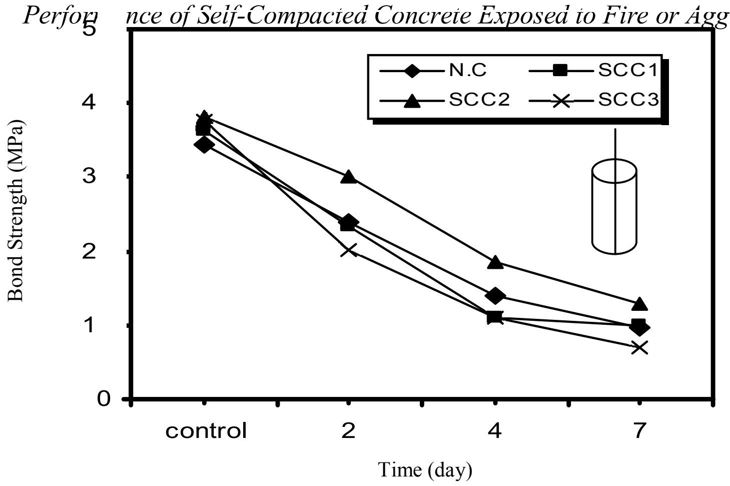

Fig. 15: Relationship Between Temperatures and
Bond Strength (f_b) for NC and SCC mixes Exposed to MgS04

3.3.2 Weight Loss of reinforcing Steel bars (W%)

Figs. 16 and 17 indicate to the relation between age of exposure to aggressive medium and the percentage of loss weight of reinforcing steel bars embedded in concrete cylinders when using two aggressive mediums, magnesium chlorides ($MgCl_2$) with 5% concentration and magnesium sulfates ($MgSo_4$) with 3% concentration for different concrete mixes. Fig. 16 shows the effect of ($MgCl_2$) on the corrosion rate of steel bars at different times for different concrete mixes. It is clear that ($MgCl_2$) has a very severe effect on loss weight of reinforcing steel bars reaches to about 22% of original weight when exposed to ($MgCl_2$) for 7 days. SCC2 mix containing fly ash has the largest values of loss weight compared to other concrete mixes Fig. 17 shows the effect of ($MgSo_4$) on the corrosion rate of steel bars at different times for different concrete mixes. It is clear that ($MgSo_4$) has a clear effect on loss weight of reinforcing steel bars reached to about 22% of original weight when it is exposed to ($MgSo_4$) for 7 days. SCC3 mix containing both silica fume and fly ash has the largest values of loss weight compared to other concrete mixes. Results showed that, the weight of reinforcing steel bars decreases with increasing time of exposure to aggressive mediums. For all mixes, the reduction in weight of reinforcing steel bars increases when being exposed to ($MgCl_2$) than being exposed to ($MgSo_4$). By comparison Figs. 16 and 17 it is clear that ($MgCl_2$) has a clear effect on both bond strength and weight loss % values of different concrete mixes rather than ($MgSo_4$), this can be analyzed as follows: chemical corrosion occurs due to the penetration of free chloride ions to the concrete cover layers, the chloride ions break down the passive film locally in these areas where as the chloride-based premature corrosion of steel bar in reinforced concrete structures currently constitutes a concentration is in high or passive film weak. Then, as soon as the corrosion is initiated a corrosion cell is formed with an adjacent area of passive steel acting as a cathode, where oxygen is reduced and the dissolution of a node iron taking place only at the small, central anode causing pitting corrosion. Sulfate corrosion of cement and concrete is a very serious problem caused by aggressive influence of sulfate solutions. Mechanisms of sulfate solution attack on concrete can be described as follows, the calcium hydroxide from concrete reacts with the aggressive SO4-2 ions to form gypsum, which reacts with the C3A constituent of cement to form ettringite whose volume is few times greater than the volume of initial compounds there by causing internal stresses and cracking into concrete which allow the ingress of oxygen and moisture through concrete to reach steel surface causing corrosion.

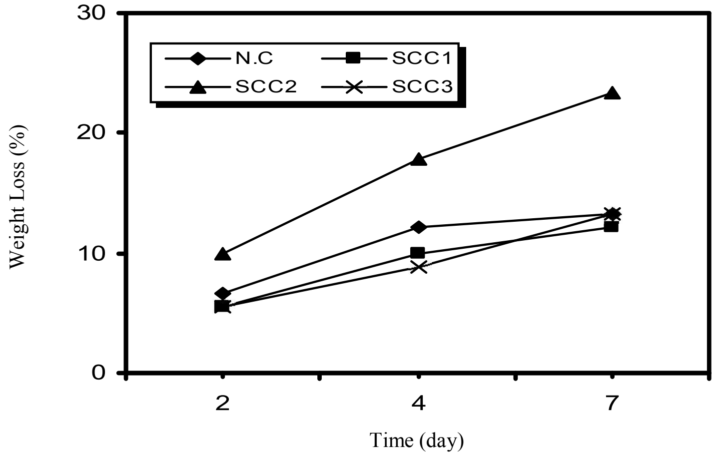

Fig. 16: Relationship between Temperatures and Weight Loss (%) for Steel Bars in NC and SCC mixes Subjected to MgC12

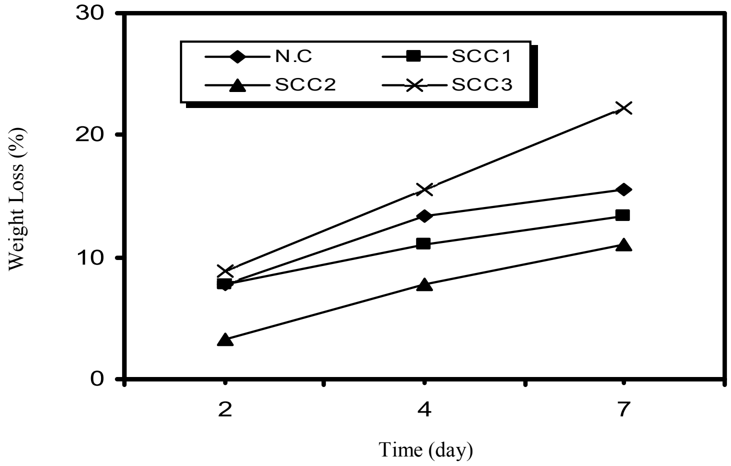

Fig. 17: Relationship between Temperatures and Weight Loss (%) for Steel Bars in NC and SCC mixes Subjected to MgSO4

4. MODES OF FAILURE

Figs. 18 to 22 show the modes of failure, cracking and spalling occurred in different concrete mixes subjected to aggressive media. Fig. 18 shows the modes of failure results in normal concrete cylinders exposed to ($MgSo_4$) for 2, 4, and 7 days, it is clear that the rate of corrosion increases with increasing time of exposure for normal concrete cylinders Fig. 18. Figs. 19 and 20 show the modes of failure results in self-compacted concrete cylinders SCC2 and SCC3 exposed to ($MgSo_4$). For 2,4, and 7 days of exposure, the rate of corrosion increases with increasing the time of exposure to chemical attack of self –compacted concrete mixes Fig. 19 and (20). Fig. (21) shows the cracks and spalling occurred in self-compacted concrete cylinders SCC1 exposed to ($MgCl_2$). For 2, 4, and 7 days of exposure, the number and width of cracks increase with increasing time of exposure to chemical attack Fig. 21. Fig. 21 shows the effect of ($MgCl_2$) on the rate of corrosion SCC2 mix cylinders. After 2, 4, and 7 days of exposure, the rate of corrosion increases with increasing the time of exposure to ($MgCl_2$) Fig. 18. Also by comparison Fig. 19 and Fig. 22, $Mgcl_2$ has a serious effect on corrosion rate than Mgso4 for the same time of exposure and the same mix.

Fig. (18): Modes of Failure in NC Cylinders after 2, 4 and 7 days of Exposure to ($MgSO_4$).

Fig. 19: Modes of Failure in SCC2 Cylinders after 2, 4 and 7 days of Exposure to ($MgSO_4$).

Fig. 20: Modes of Failure in SCC3 Cylinders after 2, 4 and 7 days of Exposure to ($MgSO_4$).

Fig. 21: Modes of Failure in SCC1 Cylinders after 2, 4 and 7 days of Exposure to ($MgCl_2$).

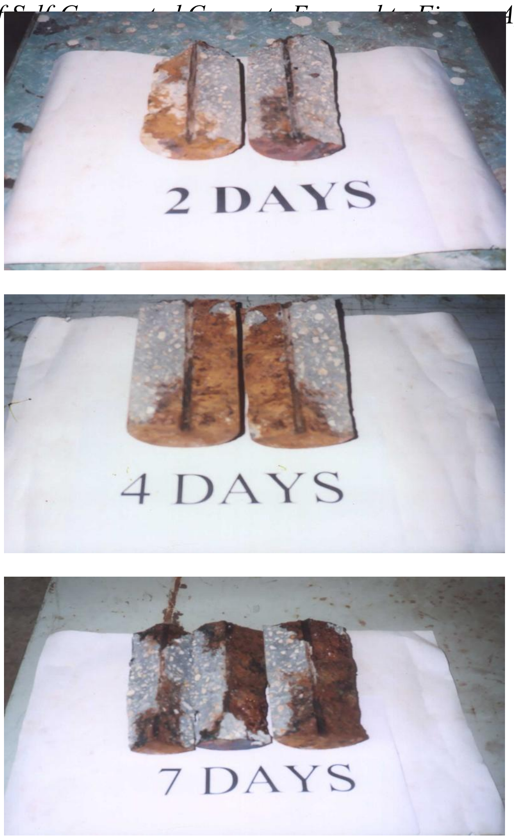

Fig. 22: Modes of Failure of SCC2 Cylinders after
2, 4 and 7 days of exposure to (Mgcl2)

5. CONCLUSIONS

1- Self –compacted concrete could be produced using local materials, coarse aggregate, fine aggregate, silica fume, fly ash and viscosity enhancing agent.
2- The higher and better workability was recorded for mixes which contained a mixture of 5% silica fume plus 5% fly ash as a replacement of the cement content, where the best workability was recorded for mixes which contained fly ash in comparison with mixes contained silica fume.
3- The enhancement in the mechanical properties including the compressive, tensile flexural strengths and bond strength of concrete mixes were recorded for mixes including fly ash followed by that including silica fume.
4- The enhancement of resistance to the fire damage was recorded for mixes which contained a mixture of 5% silica fume plus 5% fly ash as a replacement of the cement content however, mixes contained silica fume showed the highest destruction effect when exposed to fire.
5- Higher destruction effect was recorded for samples treated with water after fire than those left to cool down in the ambient atmosphere air treated.
6- Self-compacted concrete incorporating silica fume as a 10% replacement of cement content has a higher percentage of cracking and spalling, self-compacted concrete incorporating fly ash as a 10% replacement of cement content has a lower percentage of cracking and spalling when exposed to fire.
7- Using an accelerated corrosion setup was necessary in accelerating the effect of magnesium sulfates ($MgSo_4$) and magnesium chlorides ($MgCl_2$) for different concrete mix.
8- Corrosion of reinforcing steel bars in concrete cylinders increased with increasing the age of exposure to magnesium sulfates ($MgSo_4$) and magnesium chlorides ($MgCl_2$), the reduction in bond strength of reinforcing steel bars and the percentage of reduction in weight loss of reinforcing steel bars increased when samples exposed to ($MgCl_2$) than ($MgSo_4$) for all mixes.

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