Journal of Engineering Research

Volume 7 | Issue 3 Article 9

2023

Investigating the Microstructure and Mechanical Properties of Self-Curing Concrete Exposed to Elevated Temperature

Noha Elwakkad

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023

ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

Investigating the Microstructure and Mechanical Properties of Self-Curing Concrete Exposed to Elevated Temperature

Noha Yehia ELWakkad
Civil Engineering Department, Faculty of Engineering, Damahour University, Egypt.
Corresponding Author, E-mail: amatallah_n@hotmail.com

***Abstract*-This experimental study examines the mechanical and microstructure properties of self-curing concrete (SCUC) containing polyethylene glycol (PEG400) when subjected to high temperatures (600°C). The experimental research used two types of concrete mixtures, which were produced to indicate the effects of self-curing concrete using PEG400 that were added in three ratios (i.e., 0.3 %, 0.5% and 1%) by volume of cement. The parameters investigated in this research are heating period (1h and 2h), curing methods (self-curing SCU, and conventional-curing WC), concrete type (self-compact concrete SCC, and ordinary concrete OC), and cooling action (air and water). Compressive, tensile, flexural strengths and microstructural analysis were investigated under elevated temperatures at ambient temperature, and 600°C for 1h and 2 h of exposure time of the two mixtures, namely SCC and OC. Experimental results showed that the increase in heating time and cooling action leads to a decrease in concrete strength from 12% to 41%. Results also indicated that using self-curing concrete containing PEG400 has a more effective impact on resistance to high temperatures than the use of traditional curing, considering the reduction of concrete strength.**

***Keywords*-Self-curing concrete, Microstructure properties, Mechanical properties, Elevated temperature, Water cooling.**

I. INTRODUCTION

One of the most potential critical risks threatening structures and buildings is fire. In contrast to other construction materials, including wood and steel, concrete commonly exhibits agreeable fire resistance. The suitable design of concrete elements ensures adequate fire endurance, and reduces risk of spalling. Thus, high temperature resistance is a key criterion in the selection of an appropriate concrete mix design [1, 2]. Various studies [3-10] tackled the impact of high temperature on the properties of normal strength concrete (NSC), self-compact concrete (SCC) [11], lightweight and heavyweight geopolymer concrete [12,13], and fibre-reinforced lightweight concrete [14]. Nevertheless, internal curing for concrete and the use of concrete incorporated with self-curing agents have recently garnered attention both in the laboratory, and growingly in practice within the field of concrete construction. Several studies confirmed that in order to achieve self-curing of concrete, it is necessary to increase water retention in the mixture, and reduce water evaporation [15-17]. Internal curing for concrete can be achieved via a variety of techniques, including light weight aggregate, and super absorbent polymers. Several researchers studied using light weight aggregate as a source of internal curing [18-20]. Kang et al. [21], Shen et al. [22], and Farzanian et al. [23] examined the impact of internal curing by means of SPA (super absorbent polymers). Some investigators [24-34] also compared conventionally cured concrete to SCUC using polyacrylamide (PAM) and polyethylene glycol (PEG) as self-curing agents. Other researchers tested [35-38] the impact of sustainable materials, such as Recycled fine aggregate (RFA), Crushed Bricks, and Manufactured sand (M-sand), on the properties of SCUC. According to the results, when crushed bricks were used as a self-curing agent, tensile strength reached 169%, and compressive strength reached 87.8%, in comparison with the values achieved by water-cured concrete. While it was found that 40% M sand and 1% PEG 400 as optimum percentage. In addition, using 30% RFA in self-curing method improved its properties.

Vladimir et al. [39] studied the effect of short- and long-term of exposed high temperatures up to 400 °C on the deformations and strength of high-strength concrete (HSC) modified by silica fume, fly ash and superplasticizer. It was demonstrated that after being heated up to 300 °C, the tensile and compressive strength of high-strength concrete had somewhat decreased. The ultimate deformations of HSC after heating have increased. It is important to note that the rise in plastic deformations has been linked to the emergence of micro and large fissures in the concrete's structure.

Alaa et al. [40] investigated how recycled aggregate self-curing concrete (SCUC) performed at high temperatures between 200°C and 600°C, as well as how long it remained stable after cooling using either air or water (for 1 or 28 days). The findings of the trial demonstrated that, despite a strength reduction, the recycled aggregate SCUC could be used in high temperatures. It is effective to use crushed ceramics as a coarse aggregate at a high temperature. As an alternative to using conventionally cured concrete in infrastructure, the use of recycled aggregate self-curing concrete may be taken into consideration.

In 3 hours experiment in an electric furnace, Kizito et al. [41] investigated the physical characteristics and compressive strength of M25 concrete containing Neem Seed Husk Ash (NSHA), which was subjected to and passed through specific temperature ranges (200 °C to 800 °C). NSH were calcined at 800 °C for six hours to create the NSHA, which was subsequently sieved through a 125 m sieve. The experimental findings demonstrate that at 7 and 28 curing days, respectively, the compressive strength of the 5% NSHA concrete exposed to temperatures up to 400 °C is 21.3% and 23.8% better than the standard concrete. At 600 °C and

Doi: 10.21608/ERJENG.2023.224681.1200

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

800 °C, surface cracks and spalling are discernible for all the samples used in this investigation.

Muhammad et al. [42] have been measured the bond strength of concrete at high temperatures (150°, 250°, 350°, and 500°C). To examine the mechanical characteristics of concrete and to learn more about the bond behavior, cylindrical specimens were constructed for pull-out experiments with dimensions 100 mm diameter and 200 mm height contain a 10 mm steel bar at its center Samples were placed in the furnace for 1 hour at the target temperature after being prepared for 3 hours at 100°C. Before being heated, samples were evaluated as controlled specimens. Concrete's mechanical characteristics and bond strength did not significantly change as a result of the elevated temperature of up to 150°C. However, after reaching a temperature of 150°C, the mechanical characteristics and bond strength steadily declined. When compared to the controlled specimens, the maximum bond strength reduction was 52.13% and 49.8% at 500°C for testing after an hour and 24 hours of heating, respectively. Because of the high temperature, it was discovered that bond strength decreased more rapidly than compressive strength.

In order to comprehend the nature of C-S-H gel decomposition and the associated physicomechanical characteristics of thermally damaged cement paste, Amin et al. [13], Tantawy [43] and Golewski et al. [44] studied the compositional and microstructural changes within the cement paste exposed to high temperatures. These changes were monitored by XRD, FTIR, TGA/DTA, and SEM techniques. After being soaked for 28 days, ordinary Portland cement paste (w/c ratio 0.27), was heated to 750°C for 2 hours (heating rate 10°C/min). Calculations based on the TGA values were used to estimate the relative mass percent of calcium hydrates and portlandite. Beyond 450°C, the amount of portlandite rapidly decreases and C-S-H gradually breaks down into C2S and C3S until the calcium hydrate concentration is completely lost at 750°C.There is an increase in overall porosity, a significant loss in mechanical strength, and the spread of damaging fissures. The rehydration of lime and the thermal shock caused by cooling the hot cement paste both contribute to the growth of dangerous fissures.

Using ordinary Portland cement (OPC) and Portland pozzolana cement (PPC) as distinct versions, Mohanadhas et al. [45] examined the flexural strength, compressive strength, and split tensile strength of recycled fine aggregate self-curing concrete (RFA-SCRC) for various replacement proportions of RFAs. The study takes into account RFA replacement proportions of 0%, 10%, 20%, 30%, 40%, and 50% of produced sand weight. Using the Minitab software programme, the Taguchi optimization approach was used to optimize strength. The replacement proportion of RFA, type of cement, and kind of curing are the factors taken into account in this study. The optimization results show that 40% RFA, OPC, and self-curing RFA concrete is found to be optimal when considering compressive and split tensile strength properties, while in flexural strength properties 30% RFA, OPC, and self-curing have been found to be optimum.

Based on the aforementioned, the tested samples in this present research were exposed to the elevated temperature of 600°C, in order to study the extent of deterioration to their mechanical properties, specifically the compressive and tensile strengths. Studying self-curing concrete is of special significance, as the world presently faces a shortage of suitable water resources for treating concrete, besides the pressing need for selecting an appropriate concrete mix that resists fire. Thus, the current investigation examines the performance of self-curing concrete containing polyethylene glycol (PEG400 0.3%, 0.5%, and 1% weight of cement), under the influence of high temperature (600°C). The main variables investigated in this study are concrete type, heating duration, cooling method, and curing method. This research provides data on the effect of utilizing self-curing concrete on the main mechanical properties in elevated temperatures and cooling systems.

II. Experimental Procedure

A. Materials

In order to comply with Egyptian Standard Specifications ES. 4756-1/2013 [46], the EL-Suez Cement Company in Egypt produced the ordinary Portland cement (OPC) CEM I 42.5 N which has been used in this study. Tests on cement were conducted in accordance with ASTM C-150 3 [47]. A by-product of coal-fired power plants is fly ash (FA). According to the specifications of ASTM C618 Class F [48], fly ash in this study is classed as class F fly ash. The chemical compositions of OPC and FA are shown in Table 1. Natural siliceous sand that is clean and rounded with a particle size range of 0.15 to 5 mm, a specific gravity of 2.6, a bulk unit weight of 1730 kg/m3, and a fineness modulus of 2.75 is the fine aggregate have been employed in this experimental work. The coarse materials used in this work are local dolomite from (Attaka area-Egypt). Which has a specific gravity of 2.64 and a bulk unit weight of 1740 kg/m^3. The study utilized a super plasticizer to improve the workability of concrete mixtures, under the commercial denomination of Sika-Viscocrete 3425 [49], from Sika Egypt. Which is classified as a high range water reducer (HRWR) meeting the requirements of superplasticizers, as per ASTM C494/C494M-17 [50], with a specific gravity of 1.08. The dosage of the superplasticizer was approximately 7.7% by weight of cement. For the present investigation, Polyethylene Glycol-400 (PEG400) was utilized in the internal curing of concrete as a self-curing agent in a liquid form, in order to prevent water evaporation from fresh concrete. The properties of PEG400 are listed in Table 2, as per the manufacturer. The agent is manufactured by Morgan chemicals Pvt. Ltd in Egypt [51]. PEG400 was used at ratios of 0.3 %, 0.5% and 1 % by the weight of cement. Clean potable water was utilized in the mixing and curing.

Doi: 10.21608/ERJENG.2023.224681.1200

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

Table 1. Chemical Compositions of Ordinary Portland Cement and Fly Ash

Chemical Composition (%)	Cement [43]	Fly Ash
SiO_2	20.90	53.00
Al_2O_3	6.20	34.00
Fe_2O_3	3.00	3.50
Mn_2O_3	-	0.2
CaO	62.90	4.5
MgO	3.80	1.50
K_2O	0.3	0.60
SO_3	2.50	0.30
Na_2O	0.40	-

Table 2. Properties of Polyethylene Glycol-400 (PEG400) [51]

PEG Type	PEG 400
Average Molecular Weight	380 to 420
Hydroxyl Number, Mg KOH/g	264 to 300
20 °C	1.1255
Liquid Density, g/cc 60 °C	1.0931
80 °C	1.0769
Melting or Freezing Range, °C	4 to 8
Solubility in Water at 20°C, % by wt	complete
Viscosity 100°C	7.3

B. Experimental Program

All the tests in this investigation were conducted in the Reinforced Concrete Laboratory, at the Faculty of Engineering, Menoufia University. Fig. 1 demonstrates the experimental program.

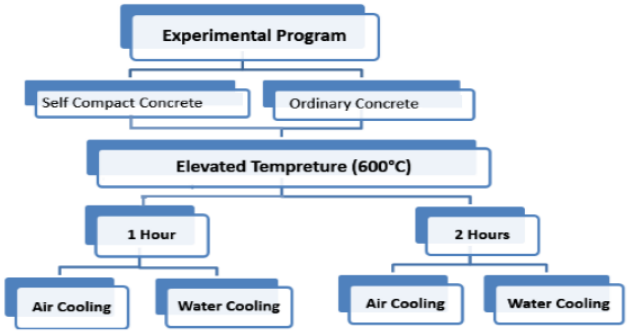


Figure 1. Experimental program.

C. Concrete and Mix Design

Two concrete mixtures were used in the present investigation, as shown in Table 3: the first concrete mix was self-compact concrete (SCC); and the second concrete mix was ordinary concrete (OC). The steps for mixing are as follows: For the first two minutes, coarse and fine particles were mixed. Second, fly ash and cement were mixed into the dry mixture for about one minute. The third step is to mix water, polyethylene glycol 400 and a superplasticizer together. Fourth, the dry mixture was combined for 3 minutes with 60% liquids (Sika-Viscocrete 3425, PEG 400, and water). Finally, residual liquids were used to stir the mixture for 5 minutes. The experimental program was carried out in two phases. During Phase One, the tests for mix SCC examined the fresh workability properties of concrete (Slump flow, V-funnel time, J-ring, and L-box test). During Phase Two, fresh concrete was cast into cubes and cylinders. Specimens were cured as self-curing until testing at ages 7, 14, and 28 days. Testing determined the mechanical properties, namely compressive, split tensile, and flexural strengths. Results showed that all the five mixes were good and workable. Table 4 demonstrates that these findings were well within the EFNARC limits (Specification and Guidelines for Self-Compacting Concrete 2002).

Table 3. Material Required per Cubic Meter of Concrete

Mix	Specimens	Cement	Sand	Gravel	Fly Ash
SCC	SCC1	366	817	1128	19
	SCC2	366	817	1128	19
	SCC3	366	817	1128	19
	SCC4	366	817	1128	19
	SCC5	366	817	1128	19
OC	OC1	440	520	1220	-
	OC2	440	520	1220	-
	OC3	440	520	1220	-
	OC4	440	520	1220	-
	OC5	440	520	1220	-
Mix	**Specimens**	**Superplastizer**	**Water**	**PEG %**	**Curing**
SCC	SCC1	7.7	140	-	WC
	SCC2	7.7	140	-	SCU
	SCC3	7.7	140	0.3	SCU
	SCC4	7.7	140	0.5	SCU
	SCC5	7.7	140	1	SCU
OC	OC1	-	154	-	WC
	OC2	-	154	-	SCU
	OC3	-	154	0.3	SCU
	OC4	-	154	0.5	SCU
	OC5	-	154	1	SCU

Where **PEG**: Polyethylene Glycol-400, **WC**: Water Curing, **SCU**: Self-Curing.

D. Test Samples

Samples were cast using both concrete mixtures, SCC and OC. For each mixture, 180 cubes with dimensions of 150 x 150 x 150 mm, 180 cylinders with dimensions of 150 x 300 mm, and 180 beams with dimensions 100 x 100 x 500 mm were cast were cast. In addition, after 28 days, three samples of each mixture were tested, in order to assess the mechanical properties (compressive, tensile and flexural strengths).

E. Testing Methodology

A control set was tested at 28 days for compressive, tensile and flexural strengths. The specimens' microstructure interfacial transition zone (ITZ) has been examined by SEM. The furnace chamber was used to heat up the other specimens. Upon reaching the target temperature (600°C), temperature was continuously measured using a digital temperature controller. The thermocouple used was positioned in the furnace room in contact with the flame to measure the temperature. The tested specimens were kept at target temperature for a duration of 1 hour and 2 hours. For the two groups of specimens, the first was left for 24 hours to cool at the laboratory room temperature of 25°C, as a slow cooling method, whereas the second was cooled by water immersion, as a fast-cooling method. Then, both groups were tested to estimate residual strength.

Doi: 10.21608/ERJENG.2023.224681.1200

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

III. Experimental Results and Discussions

A. Results of mixtures properties under ambient temperatures

Researchers have examined the properties of mixes in both their fresh and hardened states. Table 4 displays the experiment's findings in accordance with ASTM C143 [52], including the results of the slump, V-Funnel, J-Ring, and L-Box tests and Tables (5, 7&9) lists the main mechanical properties (compressive strength according to BS-1881: part-116 [53], and tensile strength according to ASTM C496/C496M-17 [54] and flexural strength according to ASTM C78 / C78M-18 [55]) of the control set of mixtures SCC and OC.

Table 4. Workability Results of SCC mixtures

		Mix Proportions				
		SCC1	SCC2	SCC3	SCC4	SCC5
Slump Flow Test Dia (mm) (650-800)		650	650	670	685	710
V-Funnel	T0 (sec) (2-5)	5	5	4.2	8	3.6
	T5 (sec) (6-12)	12	12	11.5	9	10
J-Ring Test H2-H1 (mm) (0-10)		10	10	6	4	8.5
L-Box Test H2-H1 (mm) (0.8-1)		0.8	0.8	8.5	0.86	0.9

1- Compressive strength

The results of the compressive strength of the control mixes (SCC & OC) were shown using water and internal curing at 28 days in Table 5. SCC self-curing mixtures using 0.3%, 0.5% and 1% of PEG400 attained more compressive strength than OC mixtures. The mixtures that content 0.5% PEG400 were recorded the maximum values of compressive strength. The values were increased by 17.17%, and 10.66% for SCC4, and OC4 respectively, comparing by SCC2, and OC2. While the values of the compressive strength decreased for the mixtures that content 1% PEG400.

2- Splitting tensile strength

The results of the splitting tensile strength of the control mixes (SCC & OC) were shown using water and internal curing at 28 days in Table 7. SCC self-curing mixtures using 0.3%, 0.5% and 1% of PEG400 attained more splitting tensile strength than OC mixtures. The mixtures that content 0.5% PEG400 were recorded as the maximum values of splitting tensile strength. The values were increased by 25.6%, and 3.08% for SCC4, and OC4 respectively, comparing by SCC2, and OC2. While the values of the splitting tensile strength decreased for the mixtures that content 1% PEG400.

3- Flexural strength

The values of flexural strength are determined using beams with dimension 100 x100 x 500 mm. where, the load has been applied on the beam and has been increased till beams get failure. The results of the flexural strength at 28 days for the different mixes showed in Table 9. The results have been showed increases in the values of flexural strength with increases in the percentages of PEG compared with those in the control mixtures. The flexural strength of SCC was higher than that of OC. The flexural strength increased by 17.7% when the percentage of PEG in the SCC mixtures was 0.5%, and it becomes 21.4% for OC mixtures. Because using PEG slow down the unstable fracture formation that typically happens in flexure, they have a considerable impact on the improvement of flexural strength [55]. As a result, both strength and pre-peak and post-peak behavior are enhanced. While the rest of the mixtures witnessed a noticeable decrease in the bending strength, this decrease ranges between 7-17%. This confirms to us the importance of choosing the optimal ratio of using PEG that based on the concrete type (normal concrete, high strength concrete, etc.).

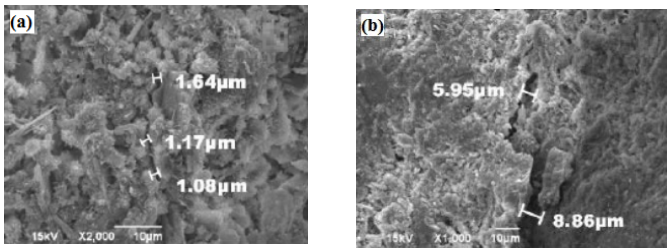
4- Microstructural Characteristics

Microstructure characteristics investigation have conducted for the specimens of age 28 days. Microstructure investigation was conducted on the control concrete mixtures exposed to air curing, 28 days water curing, and for the concrete mixtures using polyethylene glycol (PEG 400) as self-curing agents to produce SCUC. Figs. 2 show SEM micrographs of the control set mixtures. When compared to the identical mixture exposed to air curing, the control set mixtures that were subjected to 28 days of water curing had denser microstructure. The improved cement hydration may be related to microstructure densification. In comparison to the control mixtures that underwent 28 days of water curing, the air-cured control mixture showed more voids. Additionally, the 28-day water-cured control mixtures (SCC1 & OC1) had microcracks up to 2.0 m wide, whereas the air-cured control mixture had few microcracks up to 9.0 m wide (SCC2 & OC2). The control mixtures' narrower microcracks and denser microstructure, which were water cured for 28 days, contributed to the better performance seen across all investigated characteristics. As well, the air cured control mixture's large pores and wide microcracks substantiated its weak performance in each of the evaluated characteristics. Fig. 3 shows the SEM micrographs of self-curing mixtures using polyethylene glycol (PEG 400) as self-curing agents. All SCUC mixtures had a less thick microstructure than the 28-day water-cured control mixtures. But in the other hand, compared to the air-cured control mixture, the microstructure of all self-curing mixtures exposed to air curing was denser. The conclusions of the measured characteristics were supported by all of this. The lack of sharp edges and corners in crystalline hydration products like Ca (OH)2 in all self-curing combinations was noticed, and this may be explained by the lack of room for crystal growth and development due to the dense microstructure brought on by the continued hydration. Similar observations have been reported in previously studies [14, 28]. Additionally, all SCUC mixtures with 1% PEG400 had microcracks with a width between (2.0-5.0 µm), which was less than the microcracks seen in the control mixture that underwent air curing. The interfacial

Doi: 10.21608/ERJENG.2023.224681.1200

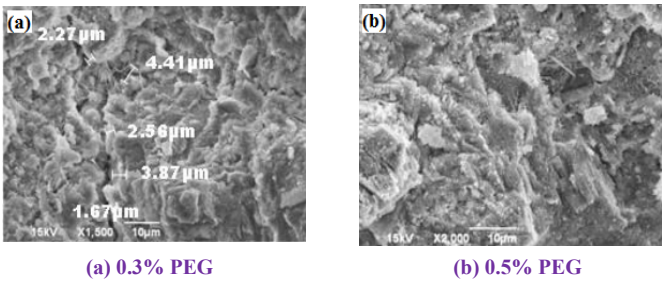
Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

transition zone (ITZ) for the control and SCUC mixtures exposed to air curing is shown in Fig. 4. Fig. 4(a), the air-cured control combination, showed a more porous ITZ with well-formed, sizable crystalline hydration products. As illustrated in Fig. 4, the ITZ zone of the SCUC combinations exposed to air curing was dense and comprised less-sized and poorly-formed crystalline hydration products.

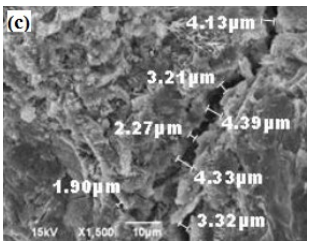


(a) 28 days water-curing, (b) air curing

Figure 2. Microstructure of control concrete mixture.

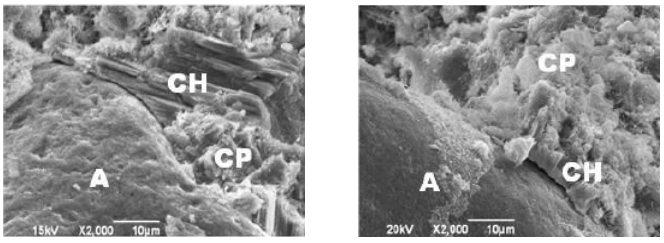


(a) 0.3% PEG (b) 0.5% PEG



(c) 1% PEG

Figure 3. Microstructure of self-curing concrete mixtures exposed to air curing.



(a) 0% PEG (b) 0.5% PEG 100

Figure 4. Microstructure of aggregate matrix interfacial transition zone (ITZ), A = aggregate, CH = calcium hydroxide, CP = cement paste4.

B. Exposure to elevated temperatures

1- Compressive strength test

Figures (5-8) illustrate the values of compressive strength obtained at the different heating time and cooling systems. Table 5 lists the values of compressive strength at target heating temperature (600°C), and the reduction percentage of compressive strength. These values indicated that subjecting specimens of self-curing ordinary concrete and self-curing self-compact concrete to high temperature (600°C) decreased compressive strength by 12% to 41%.

1.1. Effect heating time

Figures (5&6) illustrate that the increase in the heating time from 1 hour to 2 hours further decreased the values of compressive strength by about 2%-7.2%, as listed in Table 5. These results are consistent with previous studies [4, 56-60]. Results also indicated that when the target temperature was reached (600°C) in a 1-hour heating time, compressive strength loss was about 19.2%-29.7% for self-curing self-compact concrete (SCUSCC), and 26%-34.5% for self-curing ordinary concrete (SCUOC). In the case of 2 hours of heating time, compressive strength loss was about 21.24%-37.6% for self-curing self-compact concrete (SCUSCC), and 19.4%-41.2% for self-curing ordinary concrete (SCUOC). Table 5 shows that all the tested specimens exhibited compressive strength loss at the heating times of 1 hour and 2 hours at a temperature of 600°C. Nevertheless, the highest values of compressive strength loss were recorded by specimens subjected to elevated temperature (600°C) for 2 hours. When specimens were exposed to air cooling, these values were 24.28% for self-curing self-compact concrete (SCUSCC) containing 0.5% PEG400, and 31.4% for self-curing ordinary concrete (SCUOC), containing 0.3% PEG400. For specimens subjected to water cooling, these values became 30.99% for SCUSCC, and 38.41% for SCUOC.

1.2. Effect of cooling methods

Figures (7&8) demonstrate that when the heating duration was 1 hour, water cooling (i.e., fast cooling) caused higher loss of compressive strength by about 5%-11% than that caused by air cooling (i.e., slow cooling). However, a heating duration of 2 hours resulted in loss percentages of about 3%-8.6%. The results correspond to the study findings of Emmanuel Annerel et al. [61].

1.3. Effect concrete type

Figures (5-8) illustrate that most of the self-compact concrete (SCC) mixes recorded a reduction in compressive strength, compared to ordinary concrete (OC) mixes, with the exception of mix OC5 which recorded the lowest value of strength loss, compared to the other mixes. For SCC mixes, it is clear that; decreasing the compressive strength from (17.5% to 36.5%) comparing with the control set before fire. while the compressive strength for OC have been decreased from (12.2% to 41.2%).

1.4. Effect of curing method

Table 6 shows that using shrinkage reducing admixture PEG400, as a curing agent to produce self-curing concrete, increased concrete resistance to high temperature (600°C) by

Doi: 10.21608/ERJENG.2023.224681.1200

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

about 1% -28%, compared to ordinary curing with water. These results do not coincide with the findings obtained by Bashandi [4], where the percentage of PEG400 used in the concrete mix was 2% of the weight of cement, causing a 20% reduction of compressive strength. Therefore, the lack of agreement can be attributed to percentage selection, since using high doses of PEG400 leads to the substantial reduction of concrete compressive strength. Various other researchers who studied self-curing concrete [24- 27, 29, 62-65] recommended the use of PEG400 in doses ranging from 0.1% to 1%, based on the concrete type (normal concrete, high strength concrete, etc.) It is noteworthy that the lowest percentage of loss in compressive strength was recorded when polyethylene glycol (PEG400) was used at 1% of cement weight, in comparison with other ratios (0%, 0.3%, and 0.5%).

Table 5. Percentage of Reduction Compressive Strength as Function of Heating Time and Cooling System

Mix No.	Normal Strength (Control Set)	Elevated Temperature 600ºC Air Cooling			
		1h		2h	
		Air	(Reduction strength%)	Air	(Reduction strength%)
SCC1	43.30	31.87	-26.41	30.93	-28.57
SCC2	43.14	31.05	-28.04	30.15	-30.10
SCC3	40.65	33.03	-18.73	31.57	-22.33
SCC4	50.55	40.86	-19.18	38.27	-24.28
SCC5	39.34	32.44	-17.54	30.98	-21.25
OC1	33.42	23.78	-28.85	22.95	-31.33
OC2	33.75	22.95	-31.99	22.14	-34.41
OC3	36.30	26.85	-26.03	24.89	-31.43
OC4	37.35	29.53	-20.93	28.16	-24.59
OC5	28.75	25.23	-12.23	23.17	-19.40
Mix No.	Normal Strength (Control Set)	Water Cooling			
		1h		2h	
		Water	(Reduction strength%)	Water	(Reduction strength%)
SCC1	43.30	28.26	-34.73	27.49	-36.52
SCC2	43.14	27.73	-35.72	26.91	-37.62
SCC3	40.65	28.55	-29.76	28.05	-31.00
SCC4	50.55	36.61	-27.57	35.28	-30.21
SCC5	39.34	30.43	-22.66	29.61	-24.73
OC1	33.42	22.39	-33.00	21.46	-35.78
OC2	33.75	21.46	-36.41	19.84	-41.21
OC3	36.30	23.75	-34.57	22.36	-38.41
OC4	37.35	26.36	-29.41	25.17	-32.61
OC5	28.75	22.87	-20.45	22.15	-22.95

Table 6. Percentage of Increasing Compressive Strength as Function of using PEG400

Mix No.	%PEG400	% Increasing Compressive Strength			
		Air cooling		Water cooling	
		1h	2h	1h	2h
SCC1	Ordinary Curing (water)	-	-	-	-
SCC2	Self-Curing 0%	-2.6	-2.5	-1.9	-2.1
SCC3	Self-Curing 0.3%	3.7	2.1	1.0	2.1
SCC4	Self-Curing 0.5%	28.2	23.7	29.5	28.3
SCC5	Self-Curing 1%	1.8	0.2	7.6	7.7
OC1	Ordinary Curing (water)	-	-	-	-
OC2	Self-Curing 0%	-3.5	-3.5	-4.2	-7.5
OC3	Self-Curing 0.3%	12.9	8.4	6.1	4.2
OC4	Self-Curing 0.5%	24.2	22.7	17.7	17.3
OC5	Self-Curing 1%	6.1	0.96	2.1	3.2

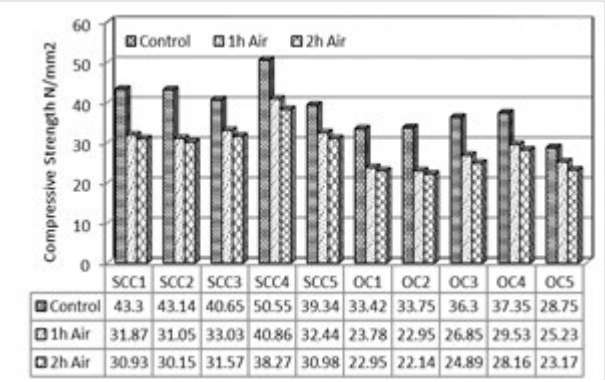


Figure 5. The effect of heating time on the compressive strength for mixes SCC & OC when using air cooling.

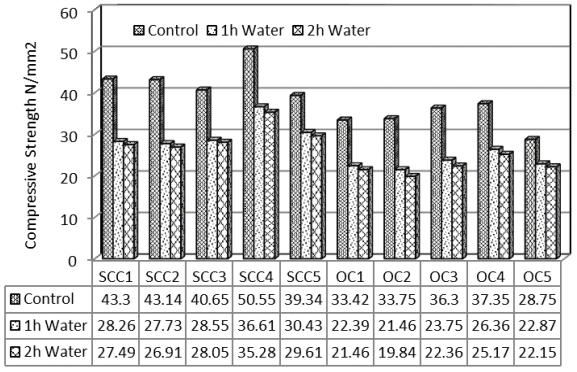


Figure 6. The effect of heating time on the compressive strength for mixes SCC & OC when using water cooling.

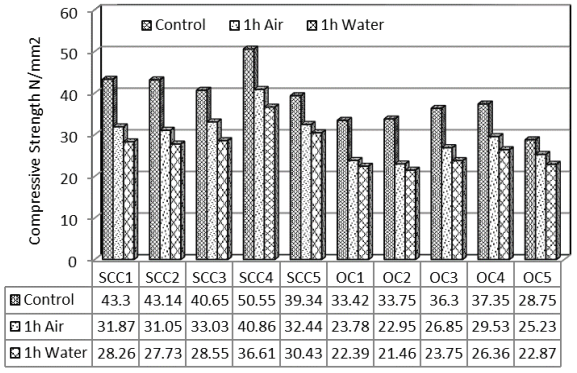
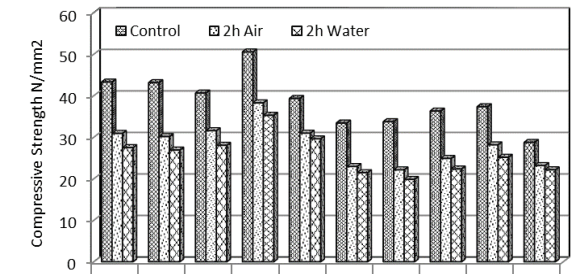


Figure 7. The effect of cooling system on the compressive strength for mixes SCC&OC when exposed to elevated temperature (600°C) for 1 hour.

Doi: 10.21608/ERJENG.2023.224681.1200

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873



	SCC1	SCC2	SCC3	SCC4	SCC5	OC1	OC2	OC3	OC4	OC5
Control	43.3	43.14	40.65	50.55	39.34	33.42	33.75	36.3	37.35	28.75
2h Air	30.93	30.15	31.57	38.27	30.98	22.95	22.14	24.89	28.16	23.17
2h Water	27.49	26.91	28.05	35.28	29.61	21.46	19.84	22.36	25.17	22.15

Figure 8. The effect of cooling system on the compressive strength for mixes SCC & OC when exposed to elevated temperature (600°C) for 2 hours.

2- Splitting tensile strength test

Figures (9-12) show the splitting tensile strength values recorded at the different heating time and cooling systems. Table 7 lists the tensile strength values at the target heating temperature (600°C), and the reduction percentage of splitting tensile strength. Based on these values, subjecting specimens of self-curing ordinary concrete and self-curing self-compact concrete to high temperature (600°C) reduced tensile strength by 8% to 61%.

2.1- Splitting tensile strength test

Figures (9&10) demonstrate that increasing the heating time from 1 hour to 2 hours further decreased splitting tensile strength values by about 2.7%-10.5%, as listed in Table 7. These findings coincide with studies [4, 56-60]. Results also determined that reaching the target temperature (600°C) in a 1-hour heating time caused a loss in splitting tensile strength by about 19.3%-37.95% for self-curing self-compact concrete (SCUSCC), and 8.22%-39.25% for self-curing ordinary concrete (SCUOC). The specimens subjected to 2 hours of heating time showed a splitting tensile strength loss by about 20.15%-41.28% for self-curing self-compact concrete (SCUSCC), and 13.83%-43.34% for self-curing ordinary concrete (SCUOC). Table 7 shows that all the tested specimen exhibited splitting tensile strength loss at 600°C for the heating times of 1 hour and 2 hours. The highest values of splitting tensile strength loss were recorded by specimens exposed to elevated temperature (600°C) for 2 hours. When specimens were exposed to air cooling, these values were 24.56% for self-curing self-compact concrete (SCUSCC) containing 1% PEG400, and 28.06% for self-curing ordinary concrete (SCUOC) containing 0.3% PEG400. For specimens subjected to water cooling, these values became 39.72% for SCUSCC, and 37.12% for SCUOC.

2.2- Effect of cooling methods

Figures (11&12) demonstrate that when the heating duration was 1 hour, water cooling (i.e., fast cooling) caused a higher loss of splitting tensile strength by about 5%-19.9% than that caused by air cooling (i.e., slow cooling). However, when the heating duration was 2 hours, losses were recorded at about 5%-18.8%. These results correspond to the study by Emmanuel Annerel et al. [61].

2.3- Effect of concrete type

Figures (9-12) illustrate that most of the self-compact concrete (SCC) mixes recorded a decrease in splitting tensile strength, in comparison with ordinary concrete (OC) mixtures, with the exception of mix OC5 which recorded the lowest value of strength loss, compared to the other mixes. For SCC mixes, it is clear that; decreasing the tensile strength from (15.5% to 61.2%) comparing with the control set before fire. while the tensile strength for OC have been decreased from (8.2% to 47.5%).

2.4- Effect of curing method

Table 8 shows that using shrinkage reducing admixture PEG400, as a curing agent to produce self-curing concrete, increased concrete resistance to high temperature (600°C) by about 5%-64%, compared to ordinary curing using water. These findings do not correspond with Bashandi [4], due to the reasons aforementioned in section (3.2.1.4).

Table 7. Percentage of Residual Tensile Strength as Function of Heating Time and Cooling System

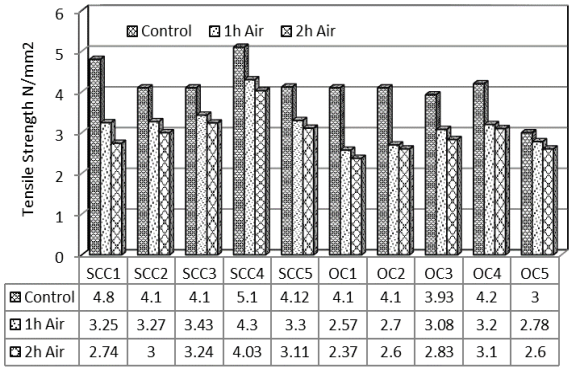
Mix No.	Normal Strength	Elevated Temperature 600ºC			
		Air Cooling			
		1h		2h	
		Air	(Reduction strength%)	Air	(Reduction strength%)
SCC1	4.81	3.25	-32.53	2.74	-42.99
SCC2	4.06	3.27	-19.33	3.00	-26.02
SCC3	4.06	3.43	-15.57	3.24	-20.15
SCC4	5.09	4.29	-15.70	4.03	-20.92
SCC5	4.12	3.30	-19.95	3.11	-24.56
OC1	4.08	2.57	-36.91	2.37	-41.88
OC2	4.08	2.70	-33.86	2.59	-36.53
OC3	3.93	3.08	-21.68	2.83	-28.06
OC4	4.21	3.21	-23.73	3.08	-26.88
OC5	3.03	2.78	-8.22	2.61	-13.83
Mix No.	Normal Strength	Water Cooling			
		1h		2h	
		Water	(Reduction strength%)	Water	(Reduction strength%)
SCC1	4.81	2.29	-52.47	1.86	-61.25
SCC2	4.06	2.52	-37.95	2.38	-41.28
SCC3	4.06	2.85	-29.86	2.63	-35.18
SCC4	5.09	3.55	-30.23	3.07	-39.72
SCC5	4.12	2.75	-33.16	2.49	-39.68
OC1	4.08	2.25	-44.97	2.14	-47.52
OC2	4.08	2.48	-39.25	2.31	-43.34
OC3	3.93	2.69	-31.60	2.47	-37.12
OC4	4.21	2.85	-32.28	2.69	-36.00
OC5	3.03	2.52	-16.79	2.34	-22.74

Doi: 10.21608/ERJENG.2023.224681.1200

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

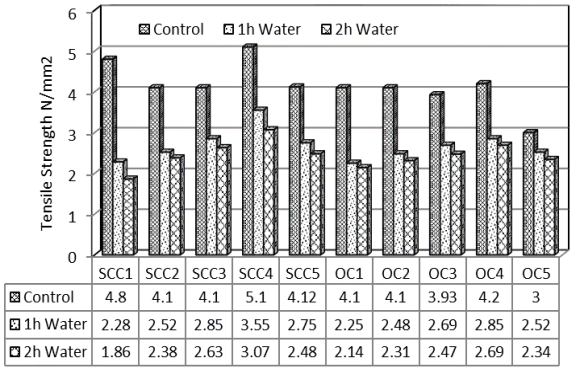
Table 8. Percentage of Increasing Tensile Strength as Function of using PEG400

Mix No.	%PEG400	% Increasing Compressive Strength			
		Air cooling		Water cooling	
		1h	2h	1h	2h
SCC1	Ordinary Curing (water)	-	-	-	-
SCC2	Self-Curing 0%	0.8	9.4	10.1	27.7
SCC3	Self-Curing 0.3%	5.6	18.2	24.5	41.1
SCC4	Self-Curing 0.5%	32.3	46.9	55.5	64.7
SCC5	Self-Curing 1%	1.6	13.3	20.4	33.3
OC1	Ordinary Curing (water)	-	-	-	-
OC2	Self-Curing 0%	4.9	9.3	10.5	8.1
OC3	Self-Curing 0.3%	19.6	19.2	19.7	15.4
OC4	Self-Curing 0.5%	24.7	29.8	27	25.8
OC5	Self-Curing 1%	8.0	10.1	12.3	9.3



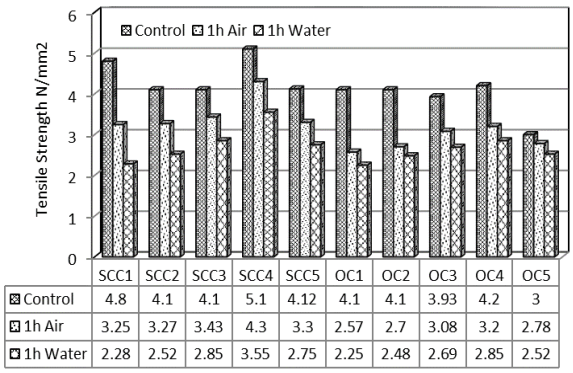
	SCC1	SCC2	SCC3	SCC4	SCC5	OC1	OC2	OC3	OC4	OC5
Control	4.8	4.1	4.1	5.1	4.12	4.1	4.1	3.93	4.2	3
1h Air	3.25	3.27	3.43	4.3	3.3	2.57	2.7	3.08	3.2	2.78
2h Air	2.74	3	3.24	4.03	3.11	2.37	2.6	2.83	3.1	2.6

Figure 9. The effect of heating time on the tensile strength for mixes SCC&OC when using air cooling.



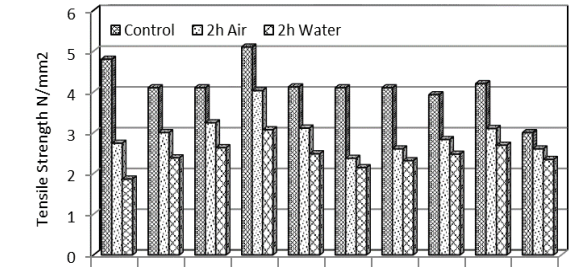
	SCC1	SCC2	SCC3	SCC4	SCC5	OC1	OC2	OC3	OC4	OC5
Control	4.8	4.1	4.1	5.1	4.12	4.1	4.1	3.93	4.2	3
1h Water	2.28	2.52	2.85	3.55	2.75	2.25	2.48	2.69	2.85	2.52
2h Water	1.86	2.38	2.63	3.07	2.48	2.14	2.31	2.47	2.69	2.34

Figure 10. The effect of heating time on the tensile strength for mixes SCC&OC when using water cooling.



	SCC1	SCC2	SCC3	SCC4	SCC5	OC1	OC2	OC3	OC4	OC5
Control	4.8	4.1	4.1	5.1	4.12	4.1	4.1	3.93	4.2	3
1h Air	3.25	3.27	3.43	4.3	3.3	2.57	2.7	3.08	3.2	2.78
1h Water	2.28	2.52	2.85	3.55	2.75	2.25	2.48	2.69	2.85	2.52

Figure 11. The effect of cooling system on the tensile strength for mixes SCC & when exposed to elevated temperature (600°C) for 1 hours.



	SCC1	SCC2	SCC3	SCC4	SCC5	OC1	OC2	OC3	OC4	OC5
Control	4.8	4.1	4.1	5.1	4.12	4.1	4.1	3.93	4.2	3
2h Air	2.74	3	3.24	4.03	3.11	2.37	2.6	2.83	3.1	2.6
2h Water	1.86	2.38	2.63	3.07	2.48	2.14	2.31	2.47	2.69	2.34

Figure 12. The effect of cooling system on the tensile strength for mixes SCC & OC when exposed to elevated temperature (600°C) for 2 hours.

3- Effect of elevated temperature on flexural strength

Table 9 shows how elevated temperature 600°C for 1hour and 2 hours effect on the flexural strength of specimens incorporating PEG content under cooling action (air and water). All specimens' flexural strength decreased at a target temperature 600°C. It has been noticed that, the significant cracks have been caused when using cooling with water and 1% PEG. Flexural strength decreased by around 17%-33% at cooling with air for (1-2hours), while it decreased by around 20%-40% at cooling with water.

Table 9. Percentage of Reduction Flexural Strength as Function of Heating Time and Cooling System

Mix No.	Normal Strength	Elevated Temperature 600ºC			
		Air Cooling			
		1h		2h	
		Air	(Reduction strength%)	Air	(Reduction strength%)
SCC1	6.3	4.7	-25.40	4.5	-28.57
SCC2	6.2	4.6	-25.81	4.4	-29.03
SCC3	5.8	4.8	-17.24	4.6	-20.69
SCC4	7.3	5.9	-19.18	5.6	-23.29
SCC5	5.7	4.7	-17.54	4.5	-21.05
OC1	4.1	3	-26.83	2.9	-29.27
OC2	4.2	2.9	-30.95	2.8	-33.33
OC3	4.5	3.4	-24.44	3.2	-28.89
OC4	5.1	4.1	-19.61	3.9	-23.53
OC5	3.5	3.1	-11.43	2.8	-20.00
Mix No.	Normal Strength	Water Cooling			
		1h		2h	
		Water	(Reduction strength%)	Water	(Reduction strength%)
SCC1	6.3	4.1	-34.92	3.9	-38.10
SCC2	6.2	4.1	-33.87	4	-35.48
SCC3	5.8	4.2	-27.59	4.1	-29.31
SCC4	7.3	5.4	-26.03	5.2	-28.77
SCC5	5.7	4.5	-21.05	4.4	-22.81
OC1	4.1	2.8	-31.71	2.7	-34.15
OC2	4.2	2.7	-35.71	2.5	-40.48
OC3	4.5	3	-33.33	2.8	-37.78
OC4	5.1	3.7	-27.45	3.5	-31.37
OC5	3.5	2.8	-20.00	2.6	-25.71

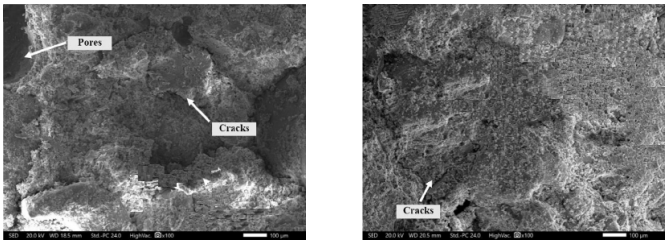
4- Microstructure analysis of elevated temperatures specimens

Fig. 13 shows the SEM microstructure analysis of cementitious materials and the ITZ close to the aggregate

Doi: 10.21608/ERJENG.2023.224681.1200

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

after heating at 600°C. Fig. 13 demonstrates that the aggregate has an internal porous structure at 25 °C (ambient temperature). When PEG 400 was used in the cement paste by ratio 0.5%, the result was a solid structure with few noticeable voids. At room temperature, there was little distinction between cement paste and aggregate. At 600°C exposure, the cement paste of the mixes contracted, microcracks began to show, and ITZ became less durable. Due to the vaporisation of water, these shrinkages and microcracks grew at the same high temperature when the ratio of PEG400 was 0% and 1%, respectively. The surface of cement paste that contain 0.5% PEG had appearence a few tiny cracks that were around 0.1 mm wide. In addition, a significant increase in porosity and severe degradation of the microstructure of the pastes were seen. CSH gel, on the other hand, decamped and lost all of its water, leaving pores at ITZ. At 600°C, there was a noticeable increase in microcracks. The calcium hydroxide (CH) was broken down into lime and water, converted to tiny hydrate needles, and then changed into more CSH gel. The C-S-H gel, which releases water molecules over a wide temperature range, is said to be composed of several microscopic globules with a disordered layered structure, according to [14, 43, 44, 66, 67]. As a result, increasing temperature considerably speeds up the disintegration of C-S-H. The cracks form as a result of the following factors; 1) The internal pore pressure brought on by water vapour that accumulated after the dehydration of calcium hydrates in the case of relatively low permeability cement paste coupled with loss of mechanical strength causes fractures to form. 2) The cooling action caused a higher loss of all mechanical properties. 3) The rehydration of lime that had been accompanied by a significant volume increase. The samples' internal structure reduced the compressive resistance to crack development at high temperatures. This decline coincided with the findings of the compressive, tensile, and flexural strength tests.



(a) 1% PEG **(b) 0.5% PEG**

Figure 13. SEM micrograph of the specimens effects of the elevated temperatures on ITZ.

IV. Conclusions

The experimental program conducted in the present research examined the loss in the mechanical properties of self-curing self-compact concrete, and self-curing ordinary concrete subjected to high temperature (600°C), for a heating duration of 1-2 hours. After exposing the samples to an elevated temperature of 600°C, they were cooled via a slow cooling method, i.e., air-cooling, or fast cooling method, i.e., water-cooling. Samples were then mechanically tested. As per the experimental test results considered in this investigation, the following conclusions can be extracted.

1- The mechanical properties of self-curing self-compact concrete (SCUSCC), and self-curing ordinary concrete (SCUOC) were significantly affected by the exposure to high temperature (600°C) for a period of 1-2 hours.
2- Using slow cooling (i.e., air cooling) exhibited a more favorable impact on the mechanical characteristics of self-curing concrete than using fast cooling (i.e., water cooling). Concrete loses approximately 40% of the original strength when water was used for cooling.
3- Results revealed that self-compact concrete was generally more able to resist high temperature than ordinary concrete.
4- Results asserted that the use of polyethylene glycol (PEG400 0.3%, 0.5%, and 1% weight of cement) in the production of self-curing concrete improved the mechanical characteristics of concrete, and its resistance to the elevated temperature of 600°C, when contrasted with the ordinary curing concrete with water.
5- These microstructural changes can be noted and discovered out of experimental techniques. SEM allows the noticeable of morphological changes, voids, and cracks in the hydrated products.
6- These harmful changes in the composition of cement paste had been accompanied by an increase of the total porosity, propagation of cracks and losses in the mechanical strength.

Finally, this study concludes that self-curing concrete could withstand the elevated temperature (600°C), and is thus considered an alternative to ordinary curing concrete.

Acknowledgment

It is with great appreciation that author acknowledge the specialized assistance of Prof. Dr. Sayed Shebl Mohamed Shebl, Professor at National Center for Housing and Building Research and Chairman of the Standing Committee for the Standards of Implementation, Testing and Receipt of Fire-Resistant Materials Systems in Buildings. For helping me complete the microstructural test in the national center.

Funding: No funds were used to perform the research.

Conflicts of Interest: There is no conflict of interest, according to the Author understanding.

References

[1] KH. Heiza, Design of reinforced concrete structures subjected to fire, According to NFPA-5000, Building Construction and Safety Code, Third Edition, 2016.
[2] EN 1992-1-2, Euro Code 2: Design of concrete structures, Part 1-2 General Rules-Structural Fire Design, Authority: The European Union

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

Per Regulation, 305/2011, Directive 98/34/EC, Directive 2004/18/EC, 2004.
[3] A. N. S. Al Qadi, and S. M. Al-Zaidyeen, "Effect of fibre content and specimen shape on residual strength of polypropylene fibre self-compacting concrete exposed to elevated temperatures", Journal of King Saud University-Engineering Sciences, vol. 26, pp. 33-39, 2014.
[4] A. A. Bashandy, "Performance of self-curing concrete at elevated temperatures," Indian Journal of Engineering & Material Sciences, vol. 22, pp. 93-104, 2015.
[5] K. K. Sideris, and P. Manita, "Residual mechanical characteristics and spalling resistance of fiber reinforced self-compacting concretes exposed to elevated temperatures," Construction and Building Materials, vol. 41, pp. 396-302, 2013.
[6] N. Pathak, and R. Siddique, "Effects of elevated temperatures on properties of self-compacting-concrete containing fly ash and spent foundry sand," Construction and Building Materials, vol. 34, pp. 512-521, 2012.
[7] Ö. Çakır, and S. Hızal, "Influence of elevated temperatures on the mechanical properties and microstructure of self-consolidating lightweight aggregate concrete," Construction and Building Materials, vol. 34, pp. 575-583, 2012.
[8] T. Uygunoğlu, and İ. B. Topçu, "Thermal expansion of self-consolidating normal and lightweight aggregate concrete at elevated temperature," Construction and Building Materials, vol. 23 pp. 3063-3069, 2009.
[9] A. Al-Sibahy, and R. Edwards, "Thermal behaviour of novel lightweight concrete at ambient and elevated temperatures: experimental, modelling and parametric studies," Construction and Building Materials, vol. 31, pp. 174-187, 2012.
[10] M. A. Othuman, and Y. C. Wang, "Elevated-temperature thermal properties of lightweight foamed concrete," Construction and building materials, vol. 25, pp. 705-716, 2011.
[11] Kh. M. Heiza., N. N. Meleka, and N. Y. Elwkad, "Behavior and Analysis of Self-Consolidated Reinforced Concrete Deep Beams Strengthened in Shear." ISRN Civil Engineering, 2012. DOI:10.5402/2012/202171.
[12] B. A. Tayeh, A. M. Zeyad, and I. S. "Agwa, Mohamed Amin, Effect of elevated temperatures on mechanical properties of lightweight geopolymer concrete," Case Studies in Construction Materials, vol. 15, 2021.
[13] M. Amin, A. M. Zeyad, B. A. Tayeh, and I. S. Agwa, "Effect of high temperatures on mechanical, radiation attenuation and microstructure properties of heavyweight geopolymer concrete," Structural Engineering and Mechanics, vol. 80, issue 2, pp. 181 -199, 2021.
[14] M. Amin, B. A. Tayeh, and I. S. Agwa, "Investigating the mechanical and microstructure properties of fibre-reinforced lightweight concrete under elevated temperatures," Case Studies in Construction Materials, vol. 13, 2020.
[15] M. O. Younis, M. Amin, and A. M. Tahwia, "Case study:Durability and mechanical characteristics of sustainable self-curing concrete utilizing crushed ceramic and brick wastes," Case Studies in Construction Materials, vol. 17, December 2022.
[16] G. S. Teja, D. P. Ravella, V. C. Sekhara, and P. Rao, "Studies on self-curing self-compacting concretes containing zeolite admixture," Materialstoday: Proceedings, vol. 43, Part 2, pp. 2355-2360, 2021.
[17] B. Han, L. Zhang, and J. Ou, "Smart and multifunctional concrete toward sustainable infrastructures," Springer Nature Singapore, 2017.
[18] D. Zou, H. Zhang, Y. Wang, J. Zhu, and X. "Guan, Internal curing of mortar with low water to cementitious materials ratio using a normal weight porous aggregate," Construction and Building Materials, vol. 96, pp. 209-216, 2015. https://doi.org/10.1016/j.conbuildmat. 2015.08.025.
[19] C. W. Tang, "Effect of pre-soaking degree of lightweight aggregate on the properties of lightweight aggregate concrete," Computers and Concrete, vol. 19, no. 1, pp. 69-78, 2017. https://doi.org/10.12989/cac.2017.19.1.069.
[20] X. F. Wang, C. Fang, W. Q. Kuang, D. W. Li, N. X. Han, and F. Xing, "Experimental investigation on the compressive strength and shrinkage of concrete with pre-wetted lightweight aggregates," Construction and Building Materials, vol. 155, pp. 867-879, 2017. https://doi.org/10.1016/j.conbuildmat.2017.07.224.
[21] S. H. Kang, S. G. Hong, and J. Moon, "The effect of superabsorbent polymer on various scale of pore structure in ultra-high performance concrete," Construction and Building Materials, vol. 172, pp. 29-40, 2018. https://doi.org/10.1016/j.conbuildmat.2018.03.193.
[22] D. Shen, X. Wang, D. Cheng, J. Zhang, and G. Jiang, "Effect of internal curing with super absorbent polymers on autogenous shrinkage of concrete at early age," Construction and Building Materials, vol. 106, pp. 512-522, 2016. https://doi.org/10.1016/ j.conbuildmat.2015.12.115.
[23] K. Farzanian, K. P. Teixeira, I. Perdigão Rocha, L. D. S. Carneiro, and A. Ghahremaninezhad, "The mechanical strength, degree of hydration, and electrical resistivity of cement pastes modified with superabsorbent polymers," Construction and Building Materials, vol. 109, pp. 156-165, 2016. https://doi.org/10.1016/j.conbuildmat. 2015.12.082.
[24] N. Elwakkad, and Kh. Heiza, "Mechanical properties of self-curing concrete (SCUC)," Challenge Journal of Concrete Research Letters, vol. 1, pp. 2548-0928, 2019. /DOI: https://doi.org/10.20528/cjcrl.2019.01.001
[25] N. Elwakkad, and Kh. Heiza, "Mechanical Properties of Self Curing Concrete Incorporating PEG400", 2nd International Conference in Innovative Building Materials, Housing and Building national Research Center (HBRC), 2 -4 December 2018, Cairo, Egypt.
[26] S. M. Junaid, S. Saddam, M. Junaid, K. Yusuf, and S. A. Huzaifa, "Self-curing concrete," International Journal of Advance Foundation and Research in Science & Engineering (IJAFRSE), vol. 1, 2015.
[27] NY ELWakkad, Kh Heiza," Structural Behavior Of Self Curing Reinforced Concrete Flat Slabs With Openings", ERJ. Engineering Research Journal, vol. 42, pp. 125-131,2019.
[28] A. S. El-Dieb, and T. A. El-Maaddawy, "Performance of self-curing concrete as affected by different curing regimes," Advances in Concrete Construction, vol. 9, pp. 33-41, 2020. DOI:https://doi.org/10.12989/acc.2020.9.1.033
[29] N. Y. Elwakkad, and Kh. M. Heiza, "State of the Art Review on-Self-Curing Concrete," Menoufia University, Faculty of Engineering, Second International Conference, March 2019 [10th Conference of Sustainable Environmental Development], Sharm El Sheikh, Egypt.
[30] B. N. Reddy, and M. V. Kumar, "Comparative review on mechanical properties of concrete with replacing curing water by self-curing compounds," IOP Conf. Series: Materials Science and Engineering, vol. 925, 2020. doi:10.1088/1757-899X/925/1/012008.
[31] N. Elwakkad, and Kh Heiza,"Mechanical Properties of Self Curing Concrete Incorporating PEG400", Engineering Research Journal (ERJ), Menoufia University, Faculty of Engineering, October 2018.
[32] P. V. Chavan, and P. O. Modani, "An Experimental Investigation on Self Curing Self-Compacted Concrete: A Review," International Journal of Advanced Research in Science, Communication and Technology (IJARSCT), vol. 2, Issue 1, 2022.
[33] C. Bhojaraju, M. Balasubramanya, S. S. Mousavi, and Y. Bhagithimar, "On sustainable self-curing self-compacting concrete using polyethylene glycol and manufactured sand," Research Square, 2022. DOI: https://doi.org/10.21203/rs.3.rs-1583235/v1.
[34] N. Hamzah, H. M. Saman, M. H. Baghban, A. R. M. Sam, I. Faridmehr, M. N. M. Sidek, O. Benjeddou, and Gh. F. Huseien, A review on the use of self-curing agents and its mechanism in high-performance cementitious materials," Buildings, vol. 12, no. 152, 2022. https://doi.org/10.3390/buildings12020152.
[35] N. Dharani, and J. G. Rajan, "Experimental study on strength properties of self curing concrete using polyethylene glycol with partial replacement of river sand by M sand," International Journal of Mechanical Engineering, vol. 6, no. 3, 2021.
[36] S. T. Abdulhussain, "Evaluation of compressive and tensile strength of self-curing concrete by adding crushed bricks as additive material," Journal of Engineering, 2022.
[37] M. C. Ravathi, and R. Chithra, "Strength optimization of recycled fine aggregate self-curing concrete using Taguchi design," Structural Concrete, 2022. DOI:10.1002/suco.202100339.
[38] Z. Awadh, D. Dashti, S. Al-Bahar, and J. Chakkamalayath, "Using the moisture retention property of recycled coarse aggregates for self-curing of high performance concrete," International Journal of Structural and Civil Engineering Research, vol. 11, no. 1, 2022.
[39] V. Korsun, and A. Baranov, "Mechanical properties of high-strength concrete after heating at temperatures up to 400 °C," In book: Proceedings of EECE, pp.454-463, 2020. DOI:10.1007/978-3-030-72404-7_44.
[40] A. Bashandy, N. M. Soliman, and M. I. El-Nemr, "Recycled aggregate self-curing concrete under elevated temperatures," Engineering Research Journal ERJ, PART4, Civil. Eng., vol. 45, no. 1, pp. 77- 88, 2022.
[41] K. P. Mwilongo, R. L. Machunda, and Y. A. C. Jande, "Effect of elevated temperature on compressive strength and physical properties of neem seed husk ash concrete," Materials (Basel), vol. 13, no. 5, 2020.

Journal of Engineering Research (ERJ)
Vol. 7 – No. 3, 2023
©Tanta University, Faculty of Engineering
ISSN: 2356-9441 https://erjeng.journals.ekb.eg/ e ISSN: 2735-4873

[42] M. H. Rashid, Md. M. Molla, and I. M. Taki, "Effect of elevated temperature on bond strength of concrete," Materials Science Forum, vol. 972, 2019.
[43] M. A. Tantawy, "Effect of high temperatures on the microstructure of cement paste," Journal of Materials Science and Chemical Engineering, vol. 5, no. 11, 2017.
[44] G. L. Golewski, and B. Szostak, "Strength and microstructure of composites with cement matrixes modified by fly ash and active seeds of C-S-H phase," Structural Engineering and Mechanics, vol. 82, issue 4, pp. 543-556, 2022.
[45] M. C. Ravathi, and R. Chithra, "Strength optimization of recycled fine aggregate self-curingconcrete using Taguchi design," Structural Concrete, 2022.
[46] ES 4756-1/2013, "Specification for Ordinary Portland cement," Egyptian Standards.
[47] ASTM C150 / C150M-20, "Standard Specification for Portland Cement," ASTM International, West Conshohocken, PA, 2020, doi: http://dx. doi.org/10.1520/ C0150_C0150M-20.
[48] ASTM, "Standard Specification for Fly Ash or Raw or Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete," ASTM C618, Barr Harbor Drive, West Conshohocken, p. 4, 2005.
[49] Sika-Viscocrete 3425, Sika Egypt for Construction Chemicals S. A. E. International.
[50] ASTM C494 / C494M-17, "Standard Specification for Chemical Admixtures for Concrete," ASTM International, West Conshohocken, PA, 2017, doi:http:// dx.doi.org/10.1520/C0494_C0494M-17.
[51] Morgan Chemical Pvt. Ltd Industries Co. in Egypt. https://www. findinegypt.com/c/morgan-chemical-industries-co-263265.
[52] ASTM, "Standard Test Method for Slump of Hydraulic-Cement Concrete," ASTM C 143/C 143M, 100 Barr Harbor, West Conshohocken, p. 3, 2015.
[53] BS, "Method for Determination of Compressive Strength of Concrete Cubes," in BS 1881-116:1983, BSI, London, UK, p. 11, 1998.
[54] ASTM, "Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens," in ASTM C496/C496M, ASTM International, West Conshohocken, USA, p. 5, 2017.
[55] ASTM C78 / C78M-18, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Third-point Loading)," ASTM International, West Conshohocken, PA, 2018, doi: http://dx.doi.org/ 10.1520/C0078_C0078M-18.
[56] N. Elwakkad," Behavior of reinforced self-curing concrete slabs exposed to fire", Journal of Engineering Sciences (JES), Faculty of engineering- Assuit university, part A-civil engineer, July 2023.
[57] O. Arioz, "Effects of elevated temperatures on properties of concrete," Fire Safety Journal, vol. 42. pp. 516-522, 2007.
[58] B. Georgali, and P. E. Tsakiridis, "Microstructure of fire-damaged concrete, A case study," Cement and Concrete Composites, vol. 27, pp. 255-259, 2005.
[59] B. Toumi, M. Resheidat, Z. Guemmadi, and H. Chabil, "Coupled effect of high temperature and heating time on the residual strength of normal and high-strength concretes," Jordan Journal Civil Engineer, vol. 3, no. 4, pp. 322-330, 2009.
[60] T. P. Long, and J. C. Nicholas, "Fire performance of high strength concrete: research needs, In: Proceedings of the ASCE 2000 Structures Congress, ASCE World Structural Engineering Conference, May 2000. https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=860213.
[61] E. Annerel, and L. Taerwe, "Approaches for the assessment of the residual strength of concrete exposed to fire," International Workshop, Fire Design of Concrete Structures-From Materials Modelling to Structural Performance, pp. 489-500, 2007.
[62] N. Y. Elwakkad, B. Tayeh, Gh. Mousa Hekal, and Kh. Heiza," Experimental and numerical investigation of the behavior of self-curing R.C. flat slabs", Case Studies in Construction Materials Volume 17, December-2022.
[63] E. Común, A. Sanabria, L. Mosquera, and A. Torre, "Application of Self-Curing Concrete Method Using Polyethylene Glycol," Engineering, Integration, and Alliances for a Sustainable Development, Hemispheric Cooperation for Competitiveness and Prosperity on a Knowledge-Based Economy [18th LACCEI International Multi-Conference for Engineering, Education, and Technology], pp. 27-31, July 2020.
[64] D. Allam, S. R. Rao, B. Manideep, V. Hemanth, and J. L. Sudha, "Strength performance of self curing concrete in comparison with conventional concrete," Journal of Emerging Technologies and Innovative Research (JETIR), vol. 6, no. 4, 2019.
[65] S. Karthiga, and T. D. Ramadsan, "Durability properties of high strength self curing concrete using Polyethylene Glycol," International Journal of Engineering Science and Computing, 2019.
[66] H. M. Jennings, "Refinements to Colloid Model of C-S-H in ement: CM-II," Cement and Concrete Research, vol. 38, p. 275, 2008.
[67] G. F. Peng, Z. S. Huang, "Change in microstructure of hardened cement paste subjected to elevated temperatures," Construction and Building Materials, vol. 22, no. 4, pp. 593-599, 2008.

Doi: 10.21608/ERJENG.2023.224681.1200