Indian Journal of Engineering & Materials Sciences
Vol. 22, February 2015, pp. 93-104

Performance of self-curing concrete at elevated temperatures

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Received 3 April 2014; accepted 27 August 2015

Self-curing concrete (SCC) can cure without using any external curing methods. Polyethylene glycol (PEG) is one of the chemical agents which minimizes the loss of water and also attracts moisture from the atmosphere and helps in continuous curing of concrete. In this investigation, the effects of the coupled effect of elevated temperature levels of 200°C, 400°C and 600°C and heating periods of 2 h and 4 h as well as air and water cooling action on the compressive strength and splitting tensile strength of conventional-curing concrete and SCC are studied, respectively. Results show that self-curing concrete can be used at elevated temperatures considering its loss of strength. Air cooling is better for ordinary concrete but that may differ for SCC which may cool using water-cooling up to 400°C. Increasing elevated temperature and heating time decreases the values of residual strengths.

Keywords: Self-curing concrete, Polyethylene glycol, Elevated temperature, Cooling, Storage time

The fire effect may be defined in terms of elevated temperature in the case of indirect fire effect. Elevated temperature conditions may affect concrete structures such as concrete foundations for launching rockets carrying spaceships, concrete structures in nuclear power stations or those accidentally exposed to fire[1].

The behaviors of concrete types were different when exposed to high temperature. Self-curing concrete (SCC), as a type of special concretes, is not need external curing[2]. SCC can be self-cured without the need of applying extra water or external curing. The internal curing can be performed using different methods such as lightweight aggregate (LWS natural sand or LWA coarse aggregate), wood powder, chemical additives (super-absorbent polymers (SAP) and shrinkage reducing admixture (SRA)). SRA, based on the use of poly-glycol products, has been suggested to reduce the risk of cracking in concrete caused by drying shrinkage. The mechanism of this admixture is based on a physical change due to reduction of the surface tension of the mixing water rather than on a reduction of water evaporation. The compressive strength will be enhanced with the reduced shrinkage arising from water evaporation, making it ideal for concrete placing without any external curing[3-11]. In comparison with the control mix due to the presence of SRA, there is reduction in the shrinkage. However, the risk of cracking related to drying shrinkage can be mitigated but not completely eliminated[12].

At elevated temperatures, there is a deterioration in concrete properties such as losses in compressive strength, the cracking and spalling of concrete, the destruction of the bonding behavior between the cement paste and the aggregates. Several researchers[13-20] have studied normal strength concrete (NSC) structures subject to fire. Various experimental parameters have been examined such as maximum temperature, heating rate, cooling rate and material, storage time after test, types of aggregates used and various binding materials.

As the temperature elevated, the strength of concrete decreased up to failure depending on the temperature and heating time. The first effects of a slow temperature rise in concrete will occur between 100°C and 200°C when evaporation of the free moisture, contained in the concrete mass, occurs. Instant exposure can results in spalling because of generation of high internal steam pressures. As the temperature approaches 250°C dehydration or loss of the hydration non-evaporable water, begins to take place. At 300°C strength reduction would be in the range of 15-40%. At 550°C reduction in compressive strength is about 55-70% of its original value [13,14]. The range between 400°C and 800°C is critical to the strength loss[21]. At a temperature over 600°C, all tested concretes suffered deterioration and only a small part of the initial strength is left, ranging from 7% to

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25%[15]. Two main types of spalling occur during fire; explosive spalling and sloughing off of concrete surface layers. Explosive spalling as a series of pop outs usually occurs within the first 30 min of fire-exposure. Sloughing off is a gradual non-violent separation of the concrete that occurs primarily at the edges of columns and beams[22]. Therefore, the effects of elevated temperatures are generally visible in the form of surface cracking. To decrease the explosive spalling of high strength concrete (HSC) at high temperatures, the application of polypropylene fibers in concrete may considerably reduce the amount of spalling especially for HSC at high temperatures[16,23,24].

Three test methods are used to obtain the residual strength after fire exposure namely; stressed, unstressed and unstressed residual strength[25]. More and more attention is paid to the unstressed residual properties of concrete after exposure to elevated temperatures[24]. It represents the lowest limit of residual strength. When concrete is subjected to elevated temperatures, various physical (e.g., evaporation, condensation, water and vapor advection, vapor diffusion, heat conduction and advection, phase expansion), chemical (e.g., dehydration, thermo-chemical damage) and mechanical (e.g., thermo-mechanical damage, cracking, spalling) processes take place, leading to the deterioration of the concrete[16,26]. Increasing heating time and heating temperature decreases the residual concrete strength. Cooling system and storing time after heating are important factors affecting strength loss of concrete despite of its type[16]. The results of compressive test show that the concrete's fire residual compressive strengths are very low. Their reduction has reached the 70%. This fact indicates that the temperature exposure exceeds 700°C is not recommended for conventional concrete[17]. The surface cracks become visible when the temperature reaches 600°C. The cracks are very pronounced at 800°C and increase extremely when the temperature is increased to 1000°C[18].

Previous experimental studies on concrete under high temperatures have mainly concentrated on the reduction of stiffness and strength properties. Only few studies are concerned with the combined effect of high temperature and heating time on residual strength of concrete[19,20]. This subject needs more investigation that will be beneficial in engineering practice especially in SCC. Although the assessment of the degree of deterioration of the concrete structure after exposure to high temperatures can help engineers to decide how a structure can be repaired.

In the present investigation, the effect of elevated temperature as well as the exposure time on SCC compared to ordinary concrete (OC) with the same material proportions but without the curing agent are studied. The effects of the cooling system and storage time are considered on the compressive and tensile strength of tested specimens.

This study aims to investigate the performance of SCC under the effect of elevated temperature for different periods. The main variables in this investigation are: concrete type, heating temperature, heating duration, cooling method and storage time. The importance of this work is based on the need to know the data available addressing the behavior of SCC under the effect of elevated temperature. This study provides data concerning the influence of using SCC in high temperature and cooling systems on the main mechanical properties.

Experimental Procedure

All tests in this study are carried out in the Construction Materials Laboratory in Civil Engineering Department, Faculty of Engineering Science, Sinai University. The concrete samples and electrical heating furnace used are shown in Fig. 1 and the experimental program is shown in Fig. 2.

Materials

The cement used is the ordinary Portland cement CEM I 32.5 N from the Suez Cement Factory. It satisfies the Egyptian Standard specification (E.S.S. 4756-1/2009). The fine aggregate used is the natural siliceous sand that satisfies the Egyptian Code (E.S.S 1109/2008). It is clean and nearly free from impurities with a specific gravity 2.6 t/m^3 and a fineness modulus of 2.52. Its mechanical properties

Fig. 1—Concrete samples and electric heating furnace used

are given in Table 1 while its grading is given in Table 2.

The coarse aggregate used is crushed dolomite, which satisfies the (E.S.S 1109/2008) given in Tables 3 and 4. The shape of these particles is irregular and angular with a very low percentage of flat particles.

Drinkable clean water, fresh and free from impurities is used for mixing and curing the tested samples according to the Egyptian code of practice 203/2007.

Silica fume is a by-product of silicon and silicon alloys industry consisting mainly of non-combustible amorphous silica (SiO_2) particles. It is produced by the Egyptian Ferro Alloys Corporation (EFACO). The chemical components are given in Table 5 and main properties are given in Table 6. The silica fume used is met the main requirements of ASTM C 1240.

A high-range water-reducing admixture (HRWR) is often referred to as super-plasticizers to help in increasing the workability of concrete without additional amount of water. A naphthalene sulphonate group based super-plasticizer, supplied by Chemicals for Modern Buildings Company (CMB) under the brand name of Addicrete BVF is chosen to be used in this study. Its main properties are given in Table 7. The used super-plasticizer complies with (ASTM C494-Type F) and (ESS 1899-1).

Table 1—Physical properties of the sand

Property	Value
Specific gravity (t/m^3)	2.58
Volumetric weight (t/m^3)	1.7
Voids ratio (%)	33.8%
Percent of clay, silt and dust (by weight)	0.75%

Table 2—Grading of the sand

Sieve size (mm)	4.5mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm
% Passing ASTMC 33- 82	100-90	100-80	85-50	60-25	30-10	10-2
% Passing	92,8	84	63,4	34,7	17,5	8

Table 3—Physical properties of the dolomite

Property	Value
Specific gravity (t/m^3)	2.62
Volumetric weight (t/m^3)	1.84
Voids ratio (%)	31%
Percent of sulfate (by weight)	0.08%
Percent of chloride (by weight)	0.025%

Table 4—Grading of the dolomite

Sieve size (mm)	12.5 mm	9.51 mm	4.67 mm	2.38 mm
% Passing ASTMC 33- 82	90-100	40-70	0-15	0-5
% Passing	96	49,3	8	3

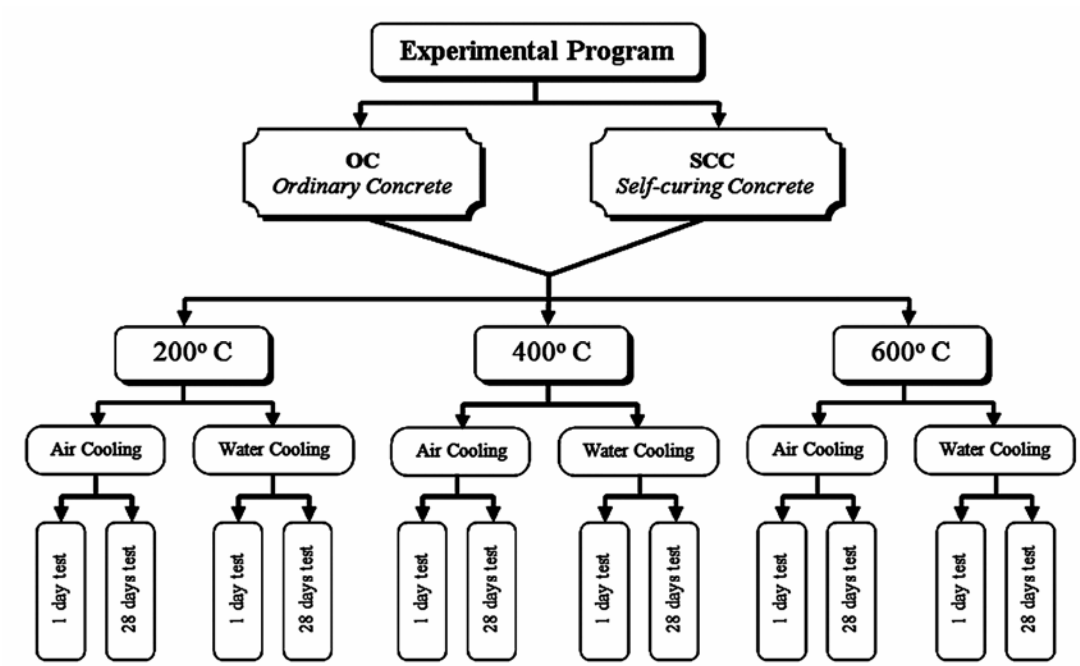

Fig. 2—Experimental program

The self-curing agent used in this study is polyethylene glycol (PEG400) in a liquid form for internal curing of concrete. It is free of chlorides and produces an internal membrane, which protects and prevents fresh concrete from over-rapid water evaporation. Table 8 shows the characteristics of polyethylene-glycol PEG400 as produced by manufacturer. The agent is produced by Morgan Chemicals Pvt. Ltd in Egypt.

Concrete and test samples

Two concrete mixtures (Table 9) are proportioned. The first concrete mix SCC is cast using ordinary Portland cement, crushed dolomite with a maximum nominal size of 12.5 mm, graded sand with a fineness modulus of 2.40, silica fume as 15% of cement content[27,28], super-plasticizer "Addicrete BVF" as 0.06% of cement content (chosen mix proportions referred to previous studies)[27], chemical curing agent "Polyethylene glycol PEG400" as 2% of cement content[27] and tap water for the first concrete mix. The second concrete mix ordinary concrete (OC) is a normally cured concrete mix with the same proportions of the SCC mixure but without using chemical curing agent to produce the possibility to compare between the both mixtures.

Samples are cast using the both concrete mixtures SCC and OC then the OC mixture is cured for 28 days at room temperature and relative humidity of about 72%. For each mixture, 30 cubes having the dimensions of 100×100×100 mm and 30 cylinders having the dimensions of 100×200 mm are cast. Three samples of each mixture are tested after 28 and 56 days to determine mechanical properties including compressive strength (f_{cu}) and tensile strength (f_t). Table 10 shows the main mechanical properties of the two mixtures at 28 and 56 days tests.

Elevated temperature and testing methodology

At 28 days, a control set of unheated samples is tested for compressive, splitting tensile and flexural strength. Other specimens are heated in an electric furnace of 1200°C capacity at a heating rate of 10ºC/min to target temperature as shown in Fig. 1. Three target temperatures; namely, 200°C, 400°C and 600°C are used. At each target temperature, the specimens are maintained for the duration of 2 and 4 h. After each exposure cycle, the first group in two

Table 5—The chemical components of silica fume.

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	L.O.I.
Average (%)	95.93	0.52	0.05	0.2	0.18	0.1	0.4	2.9

Table 6—Physical properties of the silica fume

Property	Value
Specific gravity (t/m^3)	2.21
Bulk density [uncompacted unit weight] (t/m^3)	0.3
Fineness (m^2/gm)	23.52

Table 7—Technical information of Addicrete BVF*(As Provided by Manufacturer)*

Base	Appearance	Density	Chloride content	Air entrainment	Compatibility
Naphthalene sulphonate	Brown liquid	1.18±0.01 kg/L	Nil	Nil	All types of Portland cement

Table 8—Technical information of Polyethylene Glycol 400 "PEG400" *(as provided by manufacturer)*

PEG type	Average molecular weight	HydroxylNumber, Mg KOH/g	Liquid Density, g/cc			Melting or Freezing range, °C	Solubility in Water at 20°C,% by wt	Viscositya, 100°C
			20°C	60°C	80°C			
PEG 400	380 to 420	264 to 300	1.1255	1.0931	1.0769	4 to 8	Complete	7.3

Table 9—Concrete mixtures

Mix.	Cement (kg/m^3)	W/C	Sand (kg/m^3)	Dolomite (kg/m^3)	Silica fume (kg/m^3)	Super-plasticizer	Chemical agent PEG400 (kg/m^3)
OC	300	0.5	643	1193	45 *(15% C)*	2.1 *(7%)*	--
SCC							6 *(2% C)*

W/C = Water to cement ratio.
OC = Ordinary concrete.
SCC = Self-curing concrete.

groups of specimens is allowed to cool at laboratory room temperature of 25°C for 24 h (as slow cooling method) while the other group is cooled by immersing in water of 25°C (as fast cooling method). Both are then tested to assess the residual strength after storage time of 1 and 28 days. For each data point of test, three identical specimens are used to guarantee repeatability in all tests. The abbreviations for the samples are given in Table 11.

Results and Discussion

Compressive strength test results

The percentages of compressive strength loss for OC and SCC are given in Table 12. The compressive strength values at different heating temperatures are shown in Figs 3-14.

Table 10—Mechanical properties of the concrete

Mix.		Compressive strength f_{cu} (MPa)	Splitting tensile strength f_t (MPa)
OC	28 days	46.3	3.82
	56 days	50	4.3
SCC	28 days	35.8	2.87
	56 days	38	3.18

Table 11—Abbreviations for the samples

Sample code	Heating time (h)	Cooling system (Air-water)	Storage time (1-28 days)
2-A-1	2	Air	1
4-A-1	4	Air	1
2-W-1	2	Water	1
4-W-1	4	Water	1
2-A-28	2	Air	28
4-A-28	4	Air	28
2-W-28	2	Water	28
4-W-28	4	Water	28

Effect of elevated temperature and heating time

Figures 3-6 show that the compressive strength of OC increases up to 200°C then drops with target temperature and heating time starting from 200°C as per the reported studies[20,29], while SCC drops with

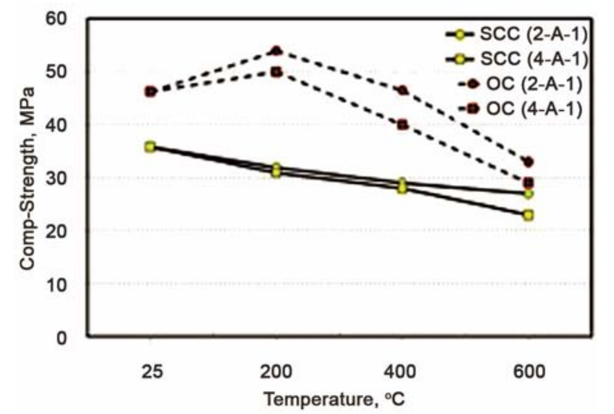

Fig. 3—The effect of heating time (2 h and 4 h) on the compressive strength of OC and SCC samples when using air cooling (after 1-day storage time)

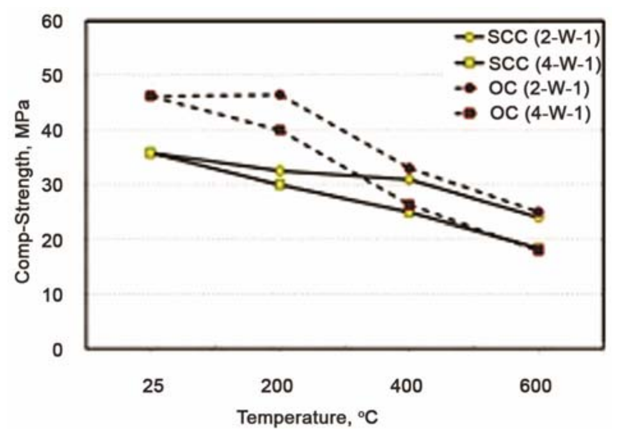

Fig. 4—The effect of heating time (2 h and 4 h) on the compressive strength of OC and SCC samples when using water cooling (after 1-day storage time)

Table 12—Percentage of compressive strength loss as functions of temperature, heating time and storage time

Type of Concrete	Heating time (h)	Storage time (days)	% Loss of compressive strength values 200°C A.C.	200°C W.C.	400°C A.C.	400°C W.C.	600°C A.C.	600°C W.C.
OC	2	1	+16.6	+3.7	+0.4	-28.7	-28.7	-46.0
		28	+5.8	+1.5	-12.5	-20.1	-30.9	-36.3
	4	1	+8.0	-13.6	-13.6	-43.2	-37.4	-61.1
		28	+8.0	-13.6	-13.6	-43.2	-37.4	-61.1
SCC	2	1	-10.6	-9.2	-19.0	-13.4	-24.6	-33.0
		28	-10.6	-1.7	-16.2	-2.2	-38.5	-35.8
	4	1	-13.4	-16.2	-21.8	-30.2	-35.8	-48.3
		28	-16.2	-14.8	-27.4	-21.8	-42.7	-48.3

A.C. = Air cooling system, W.C. = Water cooling system.

- Loss of strength, + gain of strength

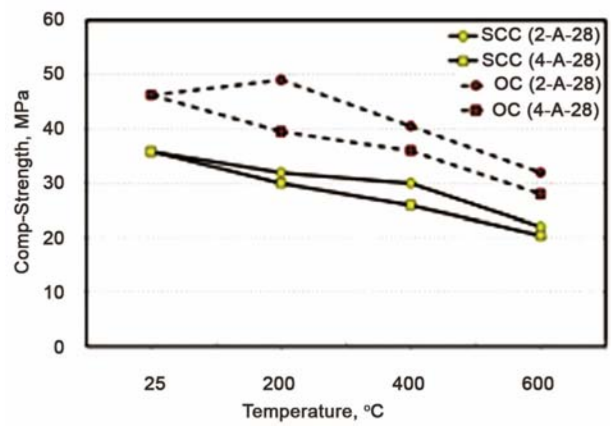

Fig. 5—The effect of heating time (2 h and 4 h) on the compressive strength of OC and SCC samples when using air cooling (after 28 days storage time)

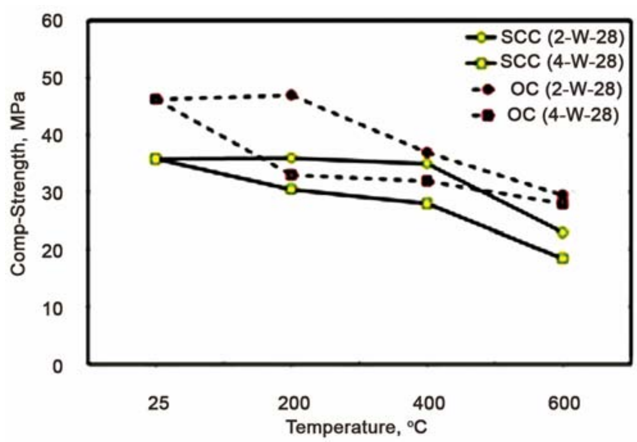

Fig. 6—The effect of heating time (2 h and 4 h) on the compressive strength of OC and SCC samples when using water cooling (after 28 days storage time)

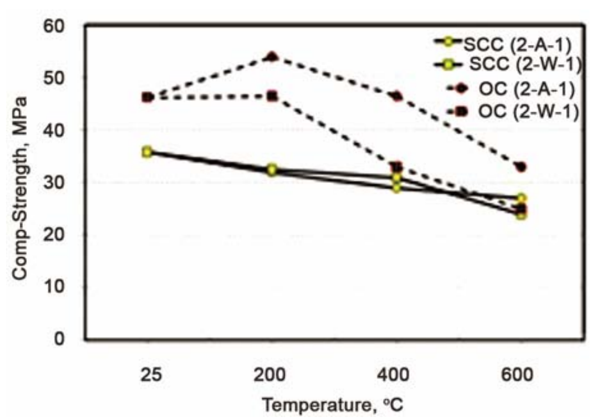

Fig. 7—The effect of cooling systems on the compressive strength of OC and SCC when exposed to elevated temperature for 2 h (after 1-day storage time)

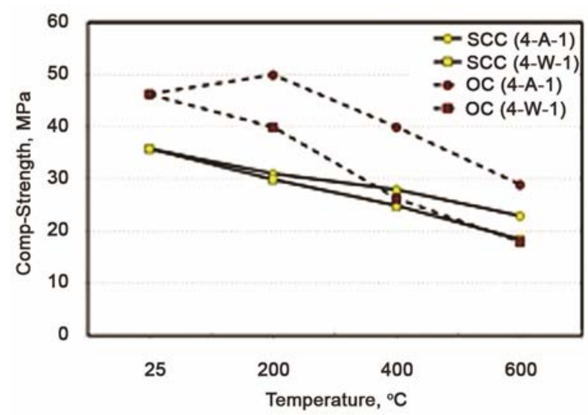

Fig. 8 —The effect of cooling systems on the compressive strength of OC and SCC when exposed to elevated temperature for 4 h (after 1-day storage time)

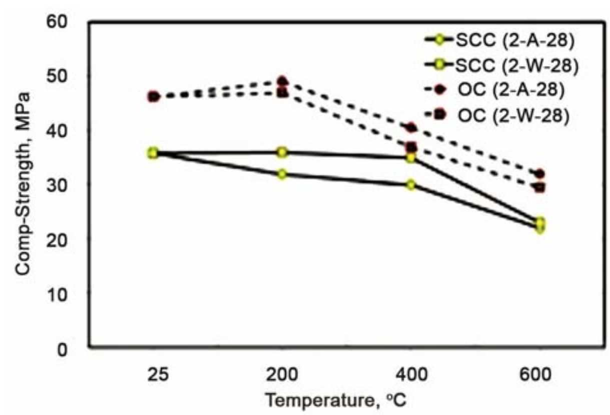

Fig. 9—The effect of cooling systems on the compressive strength of OC and SCC samples after heating time of 2 h (after 28 days storage time)

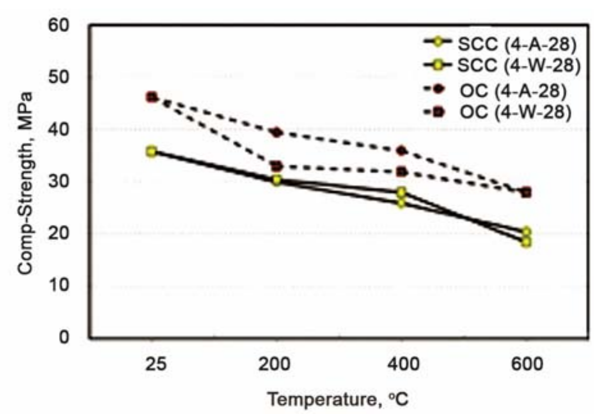

Fig. 10—The effect of cooling systems on the compressive strength of OC and SCC samples after heating time of 4 h (after 28 days storage time)

target temperature and heating time. Increasing the heating time from 2 h to 4 h further decreases the compressive strength values according to Table 12 which satisfies previous studies[16-20,29].

According to these results, when the temperature is increased up to 200°C in a 2 h heating time, there is an increase of compressive strength by 16.6% for OC but a decrease by 10.6% for SCC. Previous studies indicate the increase in normal strength concrete caused by evaporation of free water and removal of water of crystallization from the cement paste[30].

Test results also indicate that, when the temperature increased up to 400°C in a 2 h heating time, there is a little decrease of compressive strength by 1% and 19% for OC and SCC, respectively. For this heating time and for the temperatures of 600°C, compressive strength loss is about 28% for OC and 24% for SCC.

As shown in Table 12, for a heating time of 2 h and 4 h at 600°C and a storage time of 1 day, all tested concretes have revealed a compressive strength loss. The largest value of strength loss is 37.4% for OC (4 h) and 35.8% for SCC (4 h) when cooling in air, while these values became 61% for OC (4 h) and 48% (4 h) for SCC when cooling using water. For a heating time of 2 h or 4 h at 600°C and a storage period of 28 days, the values of compressive strength are decreased as compared to a 1-day storage period. The largest value of strength loss is 39.5% for OC (4 h) and is by 42.7% for SCC when cooling in air. These values decrease also when cooling using water with values of 39.5% for OC and 48.3% for SCC.

Effect of cooling methods

As can be seen from Figs 7-10, generally the compressive strength loss due to water-cooling is

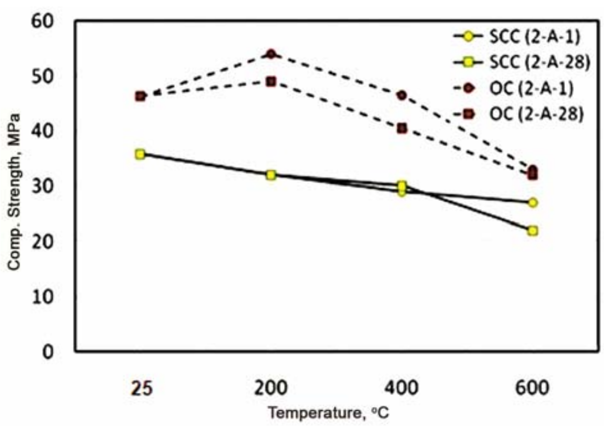

Fig. 11—The effect of storage time (1 and 28 days) after heating time of 2 hours on the compressive strength of OC and SCC samples when using air-cooling

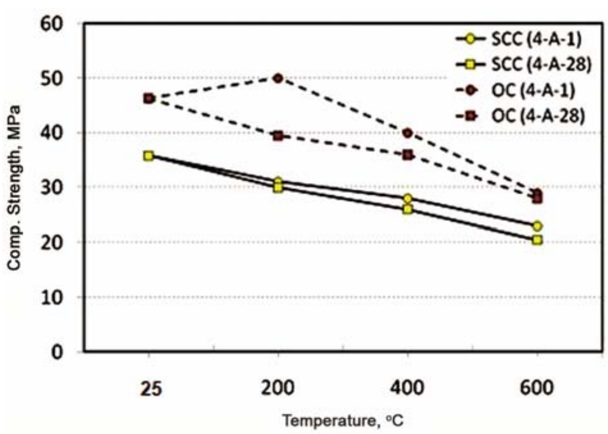

Fig. 12—The effect of storage time (1 and 28 days) after heating time of 4 h on the compressive strength of OC and SCC samples when using air-cooling

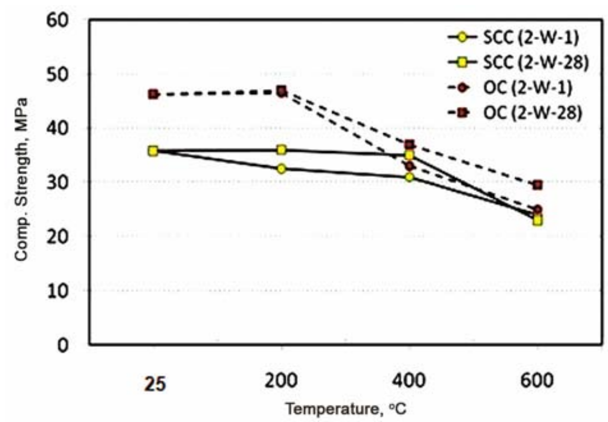

Fig. 13—The effect of storage time (1 and 28 days) after heating time of 2 h on the compressive strength of OC and SCC samples when using water-cooling

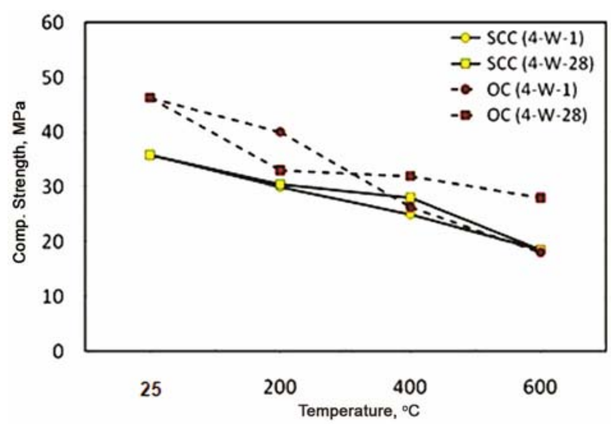

Fig. 14—The effect of storage time (1 and 28 days) after heating time of 4 hours on the compressive strength of OC and SCC samples when using water-cooling

more than due to air-cooling by about 5-25% for OC which satisfies Annerel and Taerwe[31].

In SCC when the heating time is 2 h, the loss of compressive strength due to air-cooling is more than that of water-cooling by about 2-10% up to 400°C.

At 600°C the air-cooling caused less compressive strength loss compared to water-cooling due to the effect of air slow cooling compared to water fast cooling. Fast cooling causes fast volume changes which can result in large internal stresses and leads to micro-cracking and fracture as reported by Fehérvári[32] and Fehérvári and Nehme[33] as given in Table 12.

When the heating time is 4 h, the behavior of SCC is nearly the same as OC but with little values for 1-day storage time. As the storage time increased to 28 days, the water-cooling is better at 400°C but on other temperatures the same pervious behavior for 2 h heating time.

Compressive strength loss of heated concretes results mainly from the change that occurs in the concrete microstructure during the heating process. Some complicated processes of shrinkage, decomposition, and expansion occur during elevated temperature according to Min *et al*.[34]

Effect of storage time after heating

Table 12 and Figs 11-14 show that the strength decreases by increasing storage time for normal strength concrete OC after heating (additionally 5-20% strength loss) when cooling in air, from where it slowly recovers. The strength recovery is fastest for the samples cooling in water. The test results are in agreement with the reported results[30]. In SCC, values decreases but with little values (by about 5-10%) compared to OC at different elevated temperature when stored for 28 days as givan in Table 12.

Effect of concrete type

As can be seen from Figs 3-14, in general the strength loss of SCC surpasses that of OC for a heating time less than 4 h. This difference is notable, especially in the range up to 400°C. As the temperature increases, the values of strength loss are closest (up to the range of this study, 600°C).

Using chemical curing agent to produce SCC decreases the ability of concrete to resist elevated temperature by about 10-20% compared to OC without chemical curing agent.

Splitting tensile test results

The percentages of loss in concrete splitting tensile strength for OC and SCC are given in Table 13 and Figs 15-26.

Effect of elevated temperature and heating time

Figures 15-18 illustrate that the splitting tensile strengths of OC and SCC drop with target temperature and heating time. Increasing the heating time from 2 h to 4 h decreases the tensile strength values as shown in Table 13, which agree with the earlier studies[17,19,29].

According to the test results, when the temperature is increased up to 200°C and for 2 h heating time and cooling using air, there is a decrease in tensile strength by about 25% and 38.9% for OC and SCC respectively.

Test results indicated that when the temperature increased up to 400°C for 2 h heating time and using

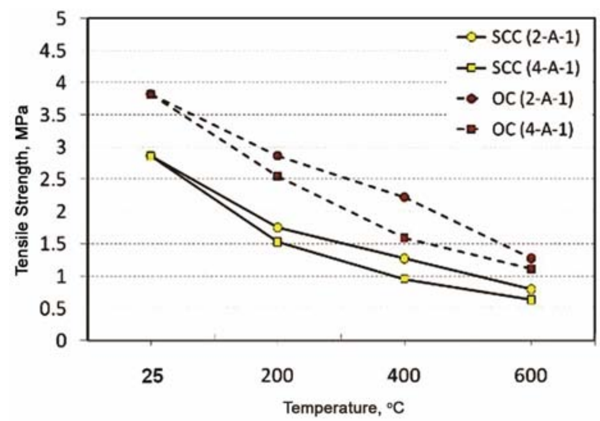

Fig. 15—The effect of heating time (2 h and 4 h) on the tensile strength of OC and SCC samples when using air cooling (after 1-day storage time)

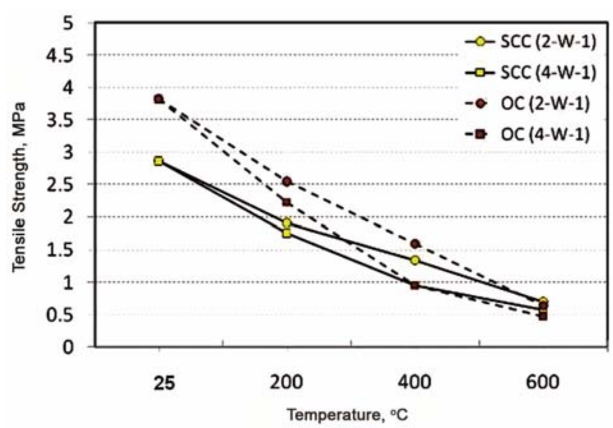

Fig. 16—The effect of heating time (2 h and 4 h) on the tensile strength of OC and SCC samples when using water cooling (after 1-day storage time)

air cooling system, there is a remarkable decrease in tensile strength by about 41.7% and 55.6% for OC and SCC, respectively. As heating time increased to 4 h, tensile strength loss is about 58.3% and 66.7% for OC and SCC respectively. Increasing the heating time increases the loss in strength which satisfies reviewed researches.

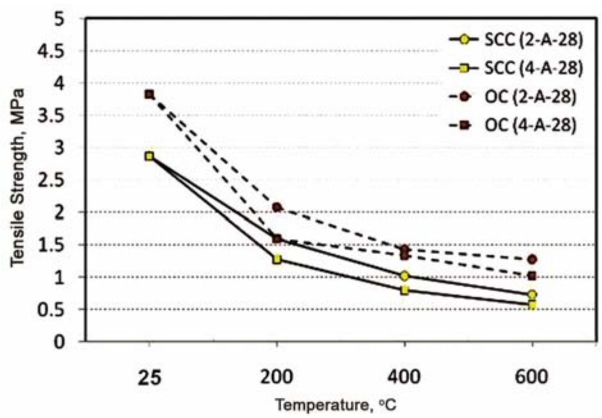

Fig. 17—The effect of heating time (2 h and 4 h) on the tensile strength of OC and SCC samples when using air cooling (after 28 days storage time)

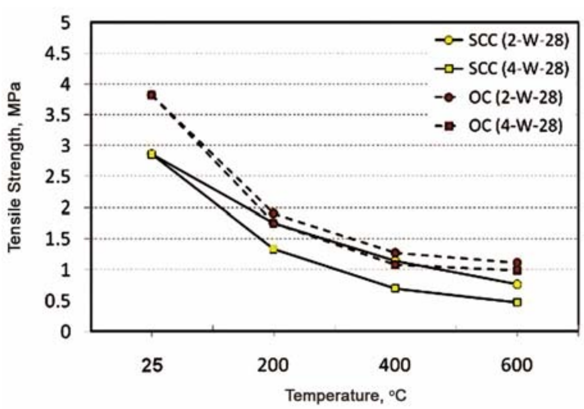

Fig. 18—The effect of heating time (2 h and 4 h) on the tensile strength of OC and SCC samples when using water cooling (after 28 days storage time)

As shown in Table 12, for a heating time of 2 h and 4 h at 600°C and storage time of 1-day, all tested concretes have a noticeable tensile strength loss. The largest value of strength loss is 70.8% for OC (4 h) and 77.8% for SCC (4 h) when cooling in air, while these values became 87.5% for OC (4 h) and 80% for SCC (4 h) when cooling using water. For a heating time of 2 h and 4 h at 600°C and storage time of 28-day, the values of tensile strength are decreased compared to the 1-day storage time. The largest value of strength loss is 73.3% for OC (4 h) and 80% for SCC when cooling in air, while these values decreased also when cooling using water more than using air cooling with values 74.2% for OC and 83.3% for SCC.

The obtained test results show that, the tensile strength values decrease with increasing the target temperature and heating time which satisfies previous studies.

Effect of cooling methods

Figures 7-10 illustrated that the using of air cooling is more effective (if possible) for ordinary concrete because the loss of strength increases due to water cooling. In SCC, using water as a cooling system enhance the residual tensile strength up to 400°C but increases the temperature (more than 400°C) or heating time (more than 2 h) decreased the residual tensile strength (in other words increased the loss of strength).

Effect of storage time after heating

Storage time after exposing to elevated temperature increases the loss of splitting tensile strength as

Table 13—Percentage of tensile strength loss as function of temperature, heating time and storage time

Type of concrete	Heating time (h)	Storage time (days)	% Loss of tensile strength values					
			200°C		400°C		600°C	
			A.C.	W.C.	A.C.	W.C.	A.C.	W.C.
OC	2	1	-25	-33.3	-41.7	-58.3	-66.7	-83.3
		28	-45.8	-50	-62.5	-66.7	-66.7	-70.8
	4	1	-33.3	-41.7	-58.3	-75	-70.8	-87.5
		28	-58.3	-54.2	-65	-71.7	-73.3	-74.2
SCC	2	1	-38.9	-33.3	-55.6	-53.3	-72.2	-75.6
		28	-44.4	-38.9	-64.4	-60	-74.4	-73.3
	4	1	-46.7	-38.9	-66.7	-66.7	-77.8	-80
		28	-55.6	-53.3	-72.2	-75.6	-80	-83.3

A.C. = Air cooling system, W.C. = Water cooling system.
- Loss of strength, + gain of strength

shown in Table 13. Figures 23-26 illustrate that the tensile strength decreases by increasing storage time for OC and SCC after heating (additionally 10-20% strength loss) when cooling in air or by water.

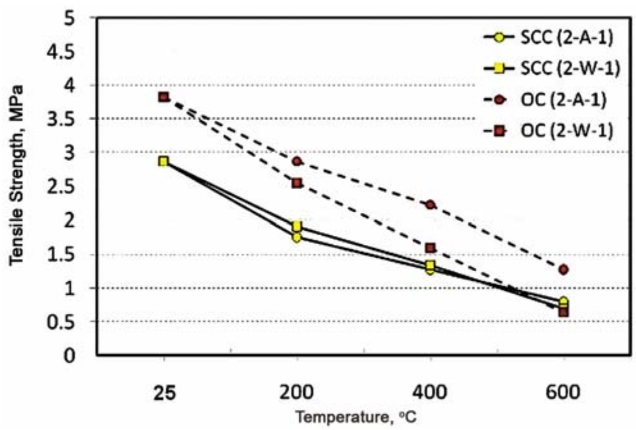

Fig. 19—The effect of cooling systems on the tensile strength of OC and SCC when exposed to elevated temperature for 2 h (after 1-day storage time)

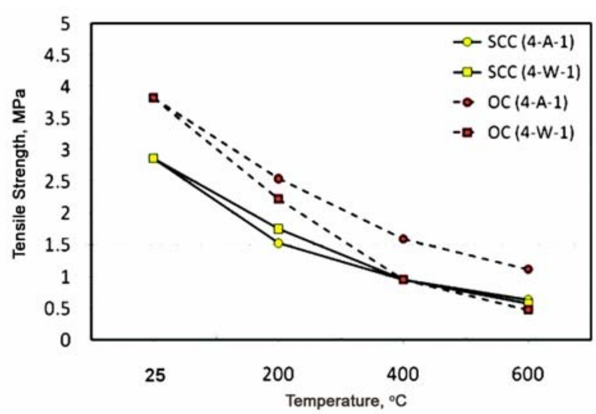

Fig. 20—The effect of cooling systems on the tensile strength of OC and SCC when exposed to elevated temperature for 4 h (after 1-day storage time)

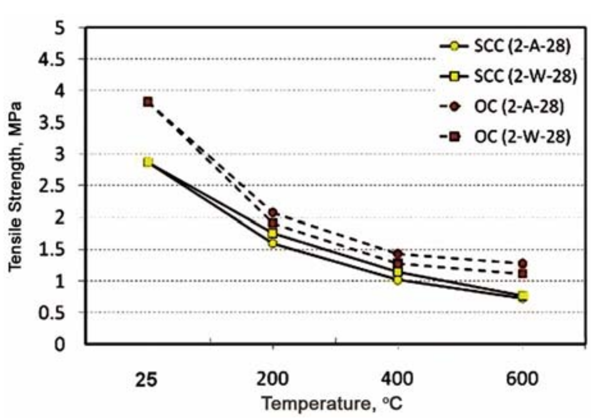

Fig. 21—The effect of cooling systems on the tensile strength of OC and SCC samples after heating time of 2 h (after 28 days storage time)

Effect of concrete type

As shown in Figs 15-26, in general the tensile strength loss of SCC surpasses that of OC for a heating time less than 4 h (in the range of the study). As the temperature increases, the values of strength

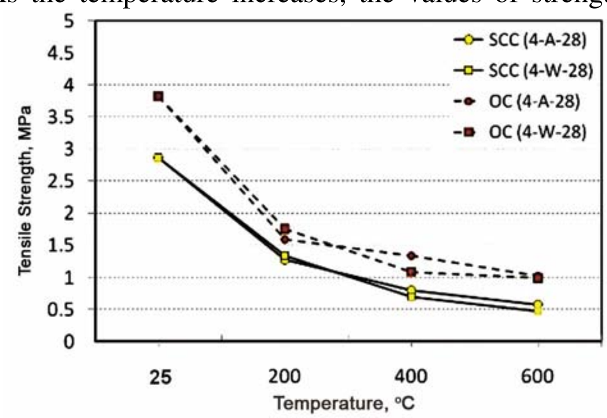

Fig. 22—The effect of cooling systems on the tensile strength of OC and SCC samples after heating time of 4 h (after 28 days storage time)

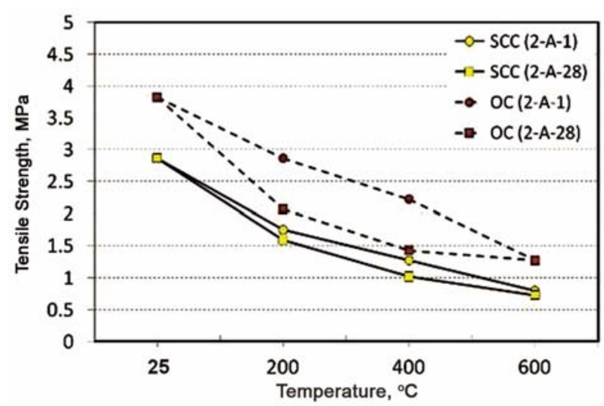

Fig. 23—The effect of storage time (1 and 28 days) after heating time of 2 h on the tensile strength of OC and SCC samples when using air-cooling

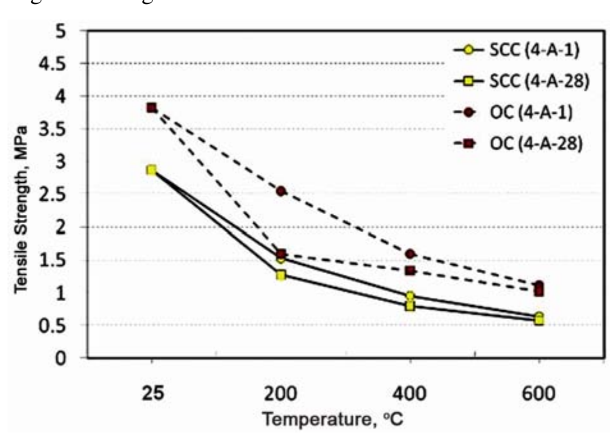

Fig. 24—The effect of storage time (1 and 28 days) after heating time of 4 h on the tensile strength of OC and SCC samples when using air-cooling

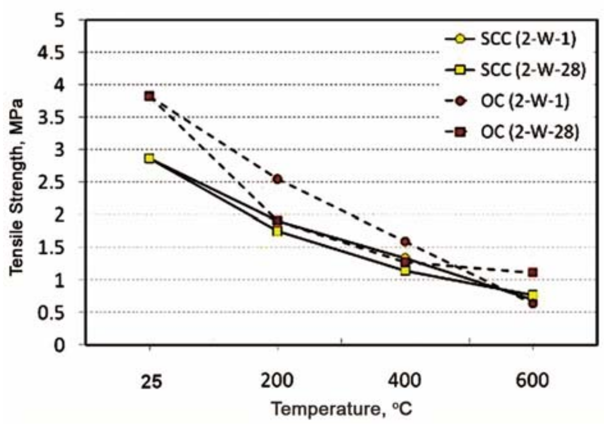

Fig. 25—The effect of storage time (1 and 28 days) after heating time of 2 h on the tensile strength of OC and SCC samples when using water-cooling

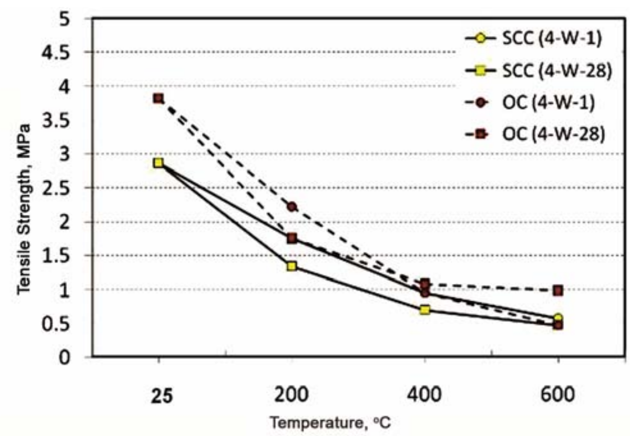

Fig. 26—The effect of storage time (1 and 28 days) after heating time of 4 h on the tensile strength of OC and SCC samples when using water-cooling

loss become closest (up to the target temperature in this study, 600°C as given in Table 13.

Conclusions

In this study, a series of experiments have been performed to investigate the residual strength of OC and SCC subjected to elevated temperatures ranging from 200°C to 600°C for a heating duration between 2 h and 4 h. After subjected to elevated temperature, they are cooled down in air or water and stored for 1 and 28 days and then mechanically tested. Based on the experimental results presented the following conclusions can be drawn:

(i) The residual strength of SCC is affected mainly by target temperature, heating time and cooling method.

(ii) The loss of strength of SCC increases with the elevated temperature and the exposed period.

(iii) Compared to the residual compressive strength test results, the residual splitting tensile strength of SCC always drops continuously with elevated temperatures.

(iv) Air-cooling (as a slow cooling method) is more effective compared to water cooling (as fast cooling method) at high temperatures.

(v) Water-cooling may induce an additional reduction of the compressive and tensile strength of about 5-25% for OC but not effective for SCC up to 400°C.

(vi) Using water-cooling is suitable for SCC up to 400°C with heating time up to 2 h but when heating duration increases to 4 h or temperature increases to 600°C the air-cooling is preferable.

(vii) Lengthening the storage time of the OC or SCC will decrease their residual strengths.

Finally, it can be concluded that, one can activate the use of self-curing concrete in even elevated temperature with taking into consideration the loss of strength. The use of SCC may consider as an alternative solution to the use of conventional curing concrete in infrastructures.

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