FIRE FLAME EFFECT ON THE STRENGTH OF SELF – COMPACTING CONCERETE

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Abstract:

This study aims to investigate the effect of fire flame on some mechanical properties of self-compacting concrete specimens. To determine the workability, different test methods are adopted in this research such as slump-flow, T50 slump-flow, L-box, U-box and V-funnel. The concrete specimens were subjected to fire flame at the lower surface only to reach temperatures around 400,500 and 600 $^{\circ}$C for one hour, then they were cooled gradually to room temperature. After that, they were tested for weight loss, compression, splitting and flexural and compared with specimens not subjected to fire flame (reference mix).

Based on the results of this work, it may found that the compressive strength of self-compacting concrete decreases with fire temperature exposure. The residual values of compressive strength were (71-88) % of the strength for the reference specimens. The flexural strength is more sensitive to fire flame temperatures. The residual flexural strengths were in the range of (58- 81) % of the flexural strength for the reference specimens. The splitting tensile strength was extra sensitive than the compressive strength. The residual splitting tensile strength were in the ranges of (58- 90) % of the splitting strength for the reference specimens. The weight loss of concrete specimens increases with increasing fire temperature. The reduction in weight loss ranged between (3.47-6.17) % relative to reference specimens.

Key wards: SCC, Fire flame, Warkability, Mechanical properties.

تأثير لهب النار على مقاومة الخرسانة ذاتية الرص

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الخلاصة

تهدف هذه الدراسة للتحقق من تأثير لهب النار على بعض الخواص الميكانيكية للخرسانة ذاتية الرص. لقياس قابلية التشغيل, استخدمت عدة طرق منها فحص الانسياب, زمن الانسياب, الصندوق على شكل حرف L, الصندوق على شكل حرف U, القمع على شكل حرف V. تم تسليط لهب النار على السطح السفلي للنماذج الخرسانية للوصول الى حرارة 400 ,500 و 600 م^{0} لمدة ساعة واحدة, بعدها تم تبريد النماذج تدريجيا الى درجة حرارة الغرفة. تم قياس فقدان الوزن, الانضغاط, الانشطار والانثناء للخرسانة ذاتية الرص ومقارنتها مع نماذج غير معرضة الى النار (خلطة مرجعية).

بناءا على النتائج, تناقصت مقاومة الانضغاط بزيادة التعرض الى درجة الحرارة. القيم المتبقية لمقاومة الانضغاط كانت تتراوح بين (71 – 88) % قياسا الى الخلطة المرجعية, كما وجد ان مقاومة الانثناء حساسة اكثر الى حرارة لهب

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النار. وان القيم المتبقية لمقاومة الانثناء تراوحت بين (58 – 81) % قياسا الى الخلطة المرجعية. مقاومة الانشطار وجدت بانها حساسة اكثرمن مقاومة الانضغاط الى حرارة لهب النار. حيث كانت القيم المتبقية لمقاومة الانشطار تتراوح بين (58 – 90) % قياسا الى الخلطة المرجعية. كما لوحظ ان النقصان بالوزن يزداد بزيادة درجة حرارة الحرق. وتراوحت قيم النقصان بالوزن بين (3,47 - 6,17) % قياسا الى الخلطة المرجعية.

Introduction:

Self- Compacting Concrete (SCC) has been described as “the most revolutionary development in concrete construction for several decades “. SCC describes a concrete with the ability to compact it self only by means of its own weight without the requirement of vibration. It fills all voids, even in highly reinforced concrete members and flows free of segregation [1].

Building codes require that the resistance to fire be considered for most buildings. The type of occupancy, the size of building and its position on the property all affect the fire resistance ratings required for various building elements [2]. The fire resistance of columns filled with plain concrete is limited to one and two hours. Failure occurs because of a reduction in the compressive strength of the concrete with increased temperature together with rapid crack propagation in the concrete, resulting in premature failure of the concrete core. Filling a hollow steel column with concrete increases the column's load-carrying capacity as well as its fire resistance [3].

The behaviour of structures exposed to fire is usually described in terms of the concept of fire resistance, which is the period of time under exposure to a standard fire time-temperature curve at which some prescribed form of limiting behaviour occurs [4]. There are two key components to concrete’s successful performance in fire: first its basic properties as a building material and secondly, its functionality in a structure. Concrete is non-combustible (it does not burn) and it has a low rate of temperature rise across a section (it is fire shielding), which means that in most structures concrete can be used without any additional fire protection. Many of concrete’s fire resisting properties are consistent no matter whether it is structurally normal or lightweight, or produced as concrete masonry or autoclaved aerated concrete [5].

High temperatures due to fire have a significant effect on the strength and deformation characteristics of various structural components, such as columns, beams, slabs, shear wall, etc. Therefore, a good understanding of the structural behavior and response of concrete exposed to fire is important towards saving of human lives and avoiding costly damage of structures [6]. The change in concrete properties due to high temperature depends on the type of coarse aggregate used. Aggregate used in concrete can be classified into three types:

carbonate, siliceous and lightweight. Carbonate aggregates include limestone and dolomite.Siliceous aggregate include materials consisting of silica and include granite and sandstone. Lightweight aggregates are usually manufactured by heating shale, slate, or clay [7].

The strength and behavior of materials under elevated temperature conditions is not determined by subjecting the specimens to actual fire conditions but by increasing the temperature of the specimen using some form of heating (e.g. electrical resistance heating) such that the specimen is soaked at a given temperature so as to achieve close uniform temperature conditions throughout the specimen [8].

The effect of fire on structural members depends on different factors such as the temperature, nature, and distribution of fire loading, ventilation and compartment size [9]. One of these structural members is reinforced concrete slabs. This type of structural members may be subjected to high temperatures during fire, which will cause change in properties of its constituents, namely concrete and steel, therefore, in reinforced concrete structural design of buildings, it may be necessary to design not only for the dead and live loads, but also for fire resistance [10].

Research Significance:

The firing process plays an important role in the durability and performance of the resulting concrete product. The main purpose for this paper is to evaluate the effect of direct fire flame on the behavior of self-compacting concrete. The investigated properties were 28 days compressive strength, splitting tensile strength and flexural strength.

Experimental program:

Table (1) describes the details of the investigated concrete specimens.

Table (1): Details of self-compacting concrete specimens.

Mix Notation	Specimen No.	Exposure Temp. (°C)	Diamension (cm)
SCC & NC	C_1^*	Lab. tempereture	15*15*15
	C_2	400	15*15*15
	C_3	500	15*15*15
	C_4	600	15*15*15
	S_1^*	Lab. tempereture	10*20
	S_2	400	10*20
	S_3	500	10*20
	S_4	600	10*20
	P_1^*	Lab. tempereture	10*10*40
	P_2	400	10*10*40
	P_3	500	10*10*40
	P_4	600	10*10*40

C^* = cube. S^* = cylinder. P^* = prism.

To determine the workability, different test methods are adopted such as slump-flow, T50 cm, L-box, U-box and V-funnel. The compressive strength of concrete was obtained by 150 mm cube specimens; the splitting tensile strength was tested using cylinders having a diameter of 100 mm and a height of 200 mm. The flexural strength was obtained using prisms of (100*100*400) mm. The specimens were cast, cured for 14 days in water, then they were air dried for testing at an age (28 days), then they were subjected to fire flame. These specimens were exposed to fire temperature levels 400,500 and 600 °C at the lower surface of specimens with exposure duration of one hour. After 24 hours; they were tested to failure.

Materials and Mixes:

Cement

Ordinary Portland cement (O.P.C) produced in Iraq/ Sulaimania was used throughout this investigation. This cement complied with the Iraqi specification No.5/1984.

Fine Aggregate :

Al-Akhaidher well graded natural sand was used in this investigation-its grading conforms to the Iraqi specification No. 45/1984,Zone 2.

Coarse Aggregate:

The coarse aggregate was Al-Nibaee gravel with a maximum size of 19 mm. The coarse aggregate used conforms to the Iraqi specification No.45/1984.

Super-plasticizer:

To achieve high workability needed to produce SCC, super-plasticizers (carboxilated polyether) were used. A super-plasticizer known as Ura-plast SF was used in producing SCC. According to ASTM C494-92, this SP is classified as type G, because it has a retarding effect on the SCC.

Limestone powder:

Limestone powder, which has been brought from a chemical bureau, is used to increase the amount of powder content (cement + filler) in the SCC mixes. Particle size less than 0.125 mm was used to increase the workability and density of the SCC.

Water:

Ordindry drinking (tap) water was used throughout this work for both mixing and curing of concrete.

Mix Design and Proportions:

The concrete mix was designed according to the Japanese mix design method that mentioned by [11], to satisfy the fresh requirements of this type of concrete. The proportions of the concrete mixes are summarized in Table (2).

Table (2) : Mix proportions.

Mix	Cement (kg/m^3)	Filler (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	SP by w.t of Cement (%)	w/c (%)
SCC	450	75	725	750	2	45
NC*	347	---	810	968	---	55

NC * [12].

Mixing of Concrete:

The concrete was mixed in a horizontal drum laboratory mixer, with a capacity of 0.1 m^3. The sequence of mixing is shown in Figure (1).

Sand + 1/3 of water	Mixing 1 minute
Cement +filler +1/3 of (water +SP)	Mixing 0.5 minute
½ coarse aggregate+1/3 of (water + SP)	Mixing 0.5 minute
½ coarse aggregate +1/3 SP	Mixing 1 minute

Figure (1): Ribbon Diagram Mixing Sequence.

Concrete Burning and Cooling Process:

The concrete specimens were subjected to fire flame from a network of methane burners. The fire flame hit the lower face of the specimens. When the target temperature was reached, the temperature was continuously measured by thermometers, which was positioned in the bottom surface of the specimen in contact with the flame. After burning, the concrete specimens were allowed to be air cooled for (24 hrs) in the laboratory to the room temperature which is in the range of 23 $^{\circ}$C.

Testing fresh concrete:

It is important to appreciate that none of the test methods for SCC has yet been standardized, and the tests described in this paper are not yet definitive.

1st : Slump flow Test and T50 cm Test

The slump flow is used to assess the horizontal free flow of SCC in the absence of obstructions (flowability, stability). The following formula was used to calculate the Flow test:-

$$\text{Slump Flow} = \frac{\text{Dmax} + \text{Dperp.}}{2} ---------- \quad \textbf{(1)}$$

Where:

$D_{max.}$= maximum diameter (mm).

$D_{perp.}$= diameter perpindicular to maximum diameter (mm).

2nd : L-Box Test

L-box test is used to measure filling ability, passing ability and segregation of the Self-Compacting Concrete. The passing ability (PA) is calculated from the following equation.

$$PA = H_2/H_1 \text{------------------------} \quad \textbf{(2)}$$

3rd : U-Box Test

U-box test is used to measure the filling ability of SCC. The filling ability (FA) is calculated from the following equation.

$$FA = U_2 - U_1 \text{------------------------} \quad \textbf{(3)}$$

4th : V-Funnel Test

V-funnel test is used to determine flow ability and stability of SCC. Filling ability was evaluated by measuring the time (in seconds) taken for the mix to completely empty out through the V-funnel. For SCC, the flow time should be between 6 and 12 seconds.

Testing hardened concrete

Compressive Strength Test

For the hardened concrete, the compressive strength test was carried out according to B.S 1881: part 116: 1983. A total number of 24 cubes of 150 mm were tested by using using a spelling compressive machine of (3000 kN) maximum capacity. Each result of compressive strength obtained is the average for three specimens.

Splitting Tensile Strength Test

The splitting tensile strength was determined according to the procedure outlined in BS 1881: part 117: 1983. A total number of 24 cylinders (100*200) mm were tested. Each splitting tensile strength result was the average of strength for three specimens. The splitting tensile strength is calculated from the equation:

$$ft_s = \frac{2P}{\pi LD} ---------- \quad \textbf{(4)}$$

Where:

ft_s =tensile strength (N/mm^2). P=the applied compressive load (N).

L=the cylinder length (mm). D=the cylinder diameter (mm).

Flexural Strength Test

Modulus of rupture test according to BS 1881:118:83 was performed using two-point load test and calculated from the simple beam bending formula:

$$R = \frac{pl}{bd^2} ---------- \qquad \textbf{(5)}$$

Where:

p=maximum applied load (N). , *l*=span length (mm).

b=specimen width (mm). , *d*=specimen depth (mm).

Weight Loss Test

This test was carried out for self-compacting concrete specimens to obtain information about the weight loss due to exposure to fire. The cube specimens of the self-compacting concrete were weighted before and after exposure to fire.

Results and Discussion

Table (3) shows the effect of the exposure to fire flame on some mechanical properties of self-compacting concrete such as compressive strength, modulus of rupture, weight loss and splitting tensile strength.

Figure (2) shows the relation between compressive strength and firing temperatures for self-compacting concrete specimens with lime stone powder. It is obvious from the results that compressive strength decreases significantly after exposing to fire. At all temperatures, the percentages of residual compressive strength were between (71-88) % relative to reference mix. The decrease in compressive strength of concrete may be attributed to the break down of interfacial bond due to incompatible volume changes between cement paste and aggregate during heating and cooling.

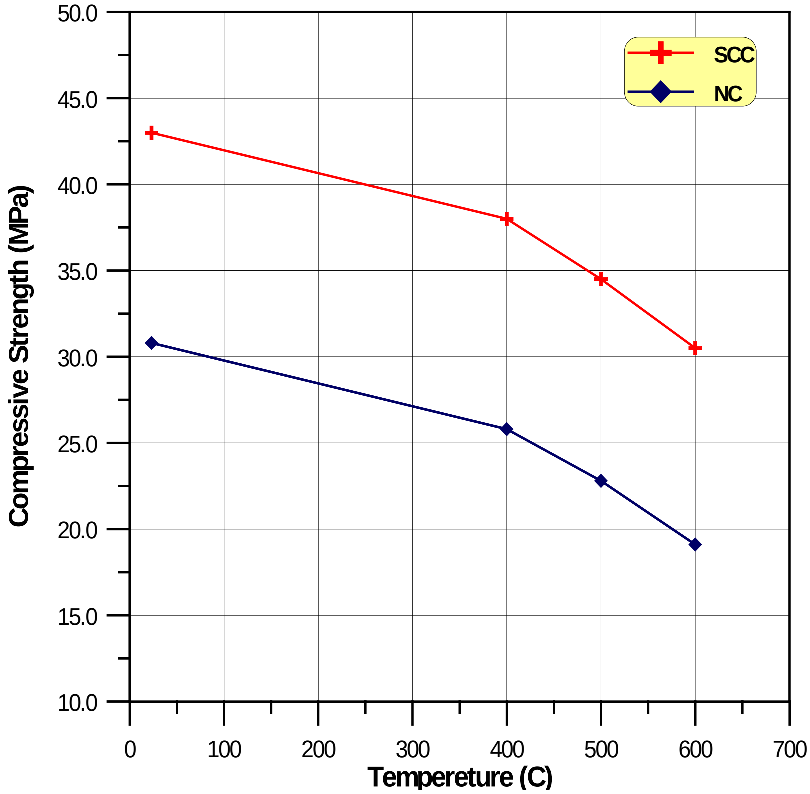

Figure (2): Relationship between compressive strength and firing tempreture.

Table (3): The Effect of fire temperatures on the mechanical properties of concrete.

Series	Specimen No.	Exposure Temp(C^0)	strenfgth (MPa)	(fc)a/ (fc)b	(fr)a/ (fr)b	(fs)a/ (fs)b	w (kg)	Weight Loss(%)
C	1	23	43	1.00			7.78	0.00
	2	400	38	0.88			7.51	3.47
	3	500	34	0.79			7.35	5.50
	4	600	30.5	0.71			7.30	6.17
S	1	23	5.4			1.00		
	2	400	4.85			0.90		
	3	500	3.9			0.72		
	4	600	3.15			0.58		
P	1	23	5.2		1.00			
	2	400	4.25		0.81			
	3	500	3.75		0.72			
	4	600	3.05		0.58			

(fc)a = Compressive strength (cube) after exposure to fire flame.

(fc)b = Compressive strength (cube) before exposure to fire flame.

(fr)a = Modulus of rupture after exposure to fire flame.

(fr)b = Modulus of rupture before exposure to fire flame.

(fs)a = Splitting tensile strength after exposure to fire flame.

(fs)b = Splitting tensile strength before exposure to fire flame

(w) = Weight of concrete cube after exposure to fire flame.

Figure (3) shows the relationship between residual flexural strength and firing temperatures. It can be seen that the reduction in flexural strength is more pronounced than that in compressive strength. At all temperatures, the percentages of residual flexural strength were in the range of (58-81) % relative to reference mix. This reduction is due to the evaporable water causing triaxial tension within the concrete [13].

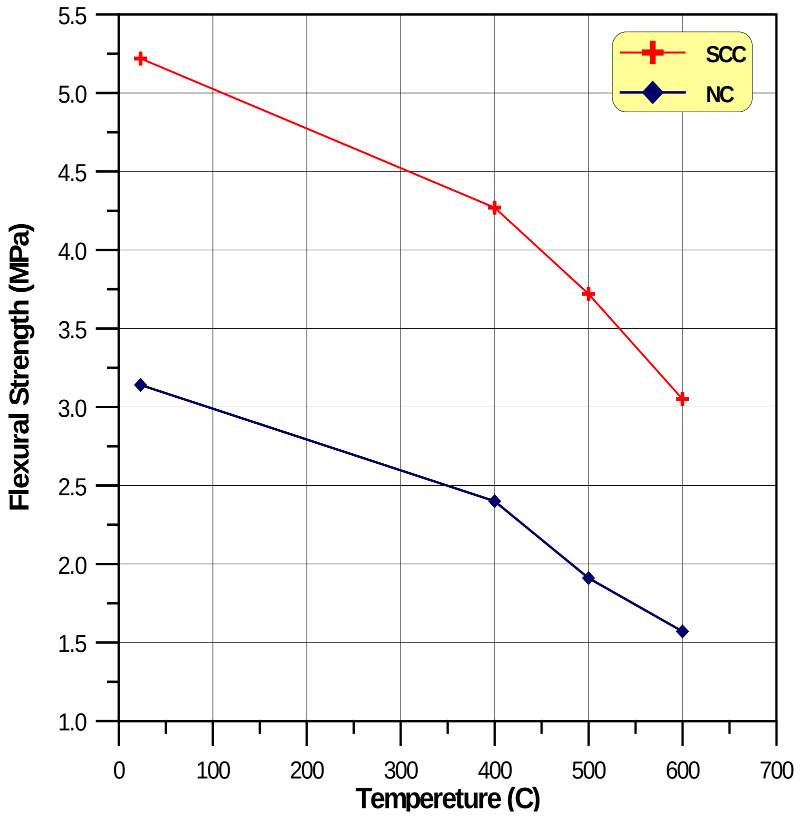

Figure (3): Relationship between flexural strength and firing tempreture.

Figure (4) shows the relationship between the splitting tensile strengths and fire flame temperatures. It can be observed that concrete deteriorates at a faster rate when tested in tension rather than in compression. At all temperatures, the percentages of residual splitting tensile strength were in the ranges of (58-90) % relative to reference mix. This reduction is due to the formation of tensile stresses during the contraction of hardened cement paste upon cooling ,which , when superimposed onto the already existing tensile stresses formed during heating, would cause further reduction in splitting strength. This trend is similar to that mensioned by [12].

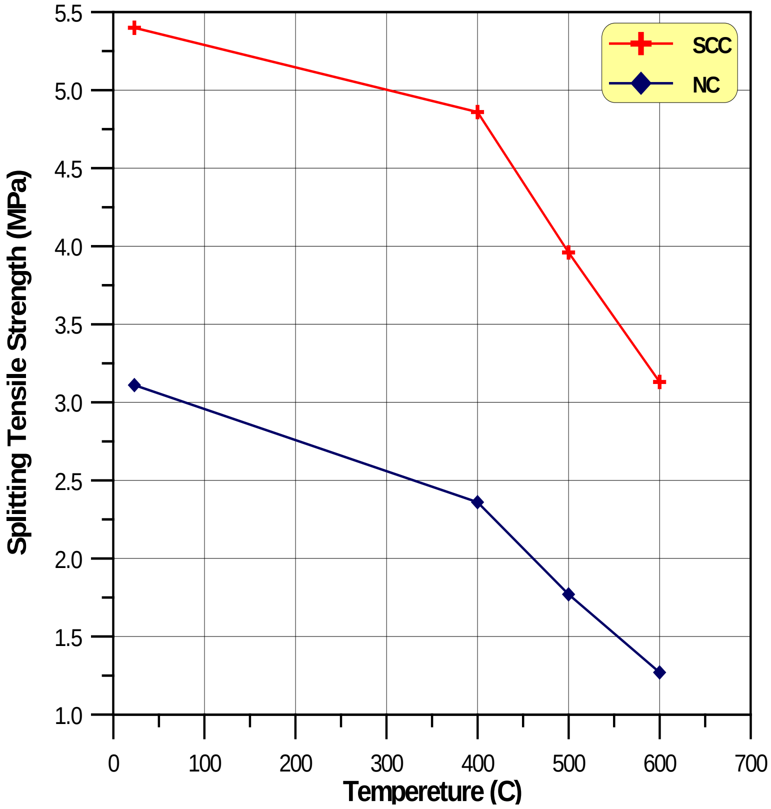

Figure (4): Relationship between splitting tensile strength and firing tempreture.

Figure (5) shows the relationship between the weight loss and temperature. For all exposure temperatures, the decrease in weight was (3.47-6.17) % relative to reference mix. This is due to the removal of the capillary and adsorbed water from the cement paste and loss of gypsum water at 400 °C [13]. While at 500°C, the decrease in weight is due to the loss of the interlayer calcium silicate hydrate water and some of the chemically combined water from the calcium silicate hydrate and sulfoaluminate hydrates. A further reduction took place at 600°C due to the further dehydration of the cement paste due to decomposition of calcium hydroxide [13].

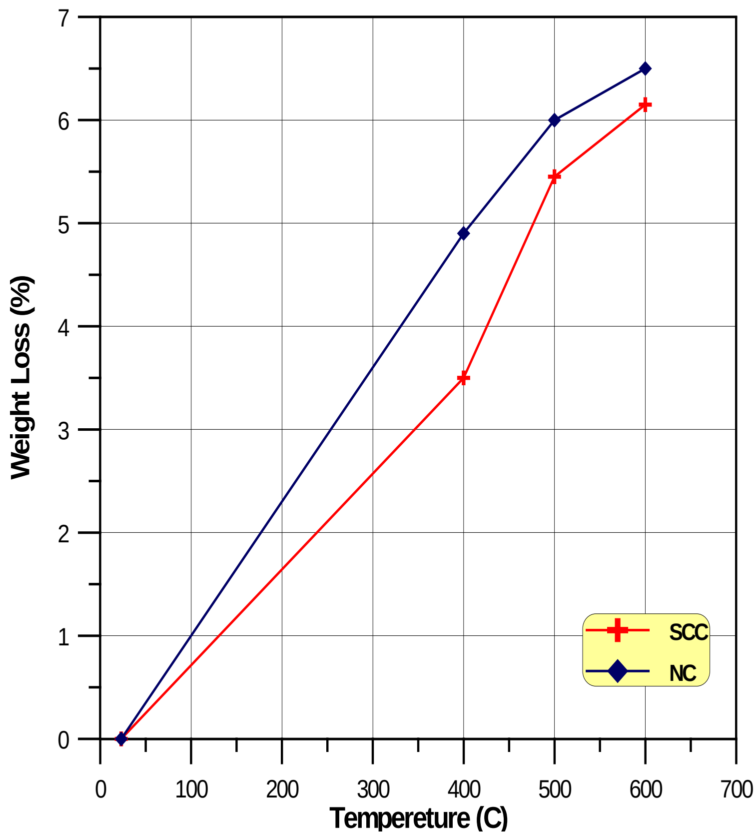

Figure (5): Relationship between weight loss and firing tempreture for cubes.

Conclusions*:*

Based on the tests results of the present study, the following conclusions can be drawn:-

1. The fire flame affected on the mechanical properties of self-compacting concrete. Furthermore; at all temperatures, the percentages of residual compressive strength were between (71-88) % relative to reference mix.
2. At all temperatures, the percentages of residual flexural strength were in the range of (58-81) % relative to reference mix and the percentages of residual splitting tensile strength were in the ranges of (58-90) % relative to reference mix.
3. The weight loss of concrete specimens increases with increasing fire flame temperature. For all exposure temperatures, the decrease in weight was (3.47- 6.17) %.
4. The splitting tensile strength and modulus of rupture were extra sensitive to the fire flame temperature than the compressive strength.

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