Effect of Fire Flame on Some Mechanical Properties of Self-Compacting Concrete

Assist. Lect. Haider Sadiq M.Ali(1)(*),
Prof. Dr. Nabeel A-M. Albayati(2),
Assist. Prof. Dr. Basman R. Mohammed(3),
Lect. Dr. Adil M. Jabbar(4)

1 Ph.D. Student, Civil Engineering Department, University of Technology, Baghdad / Iraq.
2 Civil Engineering Department, Ashur University College, Baghdad / Iraq
3 Civil Engineering Department, University of Technology, Baghdad / Iraq
4 Civil Engineering Department, College of Engineering, Wasit University, Wasit / Iraq
* Corresponding Author, Email: haider.sa@gmail.com

تأثير لهب النار على بعض الخصائص الميكانيكية للخرسانة ذاتية الرص

م. م. حيدر صادق محمدعلي(1)(*)،
أ. د. نبيل عبدالمجيد البياتي(2)،
م. د. بسمان رياض محمد(3)،
م. د.عادل مهدي جبار(4)

1 طالب دكتوراه، قسم الهندسة المدنية، الجامعة التكنولوجية، بغداد\العراق.
2 قسم الهندسة المدنية، كلية آشور الجامعة، بغداد\العراق.
3 قسم الهندسة المدنية، الجامعة التكنولوجية، بغداد\العراق.
4 قسم الهندسة المدنية، كلية الهندسة، جامعة واسط، واسط\العراق.

Abstract

This paper presents an experimental investigation of the effect of fire flame on self-compacting concrete. The experimental program included casting cylinder and prism concrete specimens for compressive strength, modulus of elasticity, modulus of rupture, and concrete density tests. The specimens are exposed to fire flame at 800 ºC approximately for 2 hours or 6 hours. Then the specimens were cooled either in a fast or slow manner. Test results show that the compressive strength was reduced by about (54 - 61)% for fire exposure of 6 hours and by (27 - 37)% for 2 hours of exposure and cooled slowly or fast, respectively. The type of cooling affects the percentage of reduction in compressive strength. Fast cooling reduces compressive strength more than slow cooling. The influence of fire flame on elastic modulus is more pronounced than on compressive strength. The modulus of rupture was reduced by 13% and 20% upon exposure to fire for 2 hours and 6 hours, respectively compared to the unburned specimens. The non-destructive test by Ultrasonic Pulse Velocity (UPV) tool is acceptable to assess the compressive strength of concrete after exposure to fire, whereas the Schmidt hammer test was found inaccurate for the assessment of compressive strength after fire exposure.

Keywords: Fire flame, Self-compacting concrete, compressive strength, Non-destructive test.

المستخلص

تقدم هذه الورقة البحثية استقصاء عملي عن تأثير لهب النار على الخرسانة ذاتية الرص. يتكون العمل من صب عينات أسطوانية وموشورية من الخرسانة لدراسة خصائص مقاومة الانضغاط، ومعامل المرونة، ومعامل التمزق، وكثافة الخرسانة. تتعرض العينات للهب نار عند 800 درجة مئوية تقريبا لمدة ساعتان أو 6 ساعات، ثم يتم تبريد العينات بطريقتين سريعة أو بطيئة (السريعة من خلال صب ماء مباشر بعد الحرق، والبطيئة هو ترك العينة تبرد تدريجيا في درجة حرارة الغرفة). أظهرت نتائج الاختبار أن مقاومة الانضغاط تقل بحوالي (54–61) ٪ عند التعرض لمدة 6 ساعات وبنسبة (27–37) ٪ عند التعرض لمدة ساعتين وعند تبريدها ببطء او بسرعة على التوالي. تؤثر طريقة التبريد على نسبة الانخفاض في قوة الانضغاط. يقلل التبريد السريع من قوة الانضغاط أكثر من التبريد البطيء. تأثير لهب النار على معامل المرونة أكثر وضوحا من قوة الانضغاط. ينخفض معامل التمزق بنسبة 13٪ و20٪ عند التعرض للحريق لمدة ساعتين و6 ساعات على التوالي، مقارنة بالعينة غير المحترقة. بين الاختبار غير الاتلافي بواسطة جهاز سرعة النبض بالموجات فوق الصوتية (UPV) مقبولية لتقييم قوة الانضغاط للخرسانة بعد التعرض للحريق، في حين أن اختبار مطرقة شميدت غير دقيق لتقييم قوة الانضغاط بعد التعرض للحريق.

كلمات مفتاحية: خرسانة ذاتية الرص، لهب النار، مقاومة الانضغاط، مطرقة شميدت، فحص غير اتلافي.

1 - Introduction

The development of Self Compacting Concrete (SCC) was started in 1980 in Japan. Many research works have been carried out to find the rational mix-design method and testing to make SCC. The most important investigations were carried out by Ozawa et.al., (1989). In 1988, the SCC prototype was completed in Japan by using available materials and introduced to construct durable concrete structures having highly congested reinforcement. The prototype performed satisfactorily concerning drying and hardening shrinkage, the heat of hydration, denseness after hardening, and other properties, Sanghi Bulletin (2006).

In EFNARC (2002), the organization published its “Specification and Guidelines for self-Compacting concrete”, which provided the latest information to researchers and producers at that time.

Five European organizations, (BIBM), (CEMBUREAU), (ERMCO), (EFCA) and (EFNARC) created a “European Project Group” to review the current best practice and produce a new document covering all aspects of SCC. This document “The European Guidelines for Self-Compacting Concrete” serves to particularly address those issues related to the absence of European specifications, standards, and agreed test methods, BIBM, *et al.* (2005).

ACI 237R-07 (2007) Code defined SCC as “highly flow-able, no segregation concrete that can spread into place, fills the formwork, and encapsulates the reinforcement without any mechanical consolidation”.

The concrete mix can be classified as self-compacting concrete when achieves the three requirements below Ravindrarajah, *et al.* (2003)

1) Filling ability: It is the feature of SCC to flow under its self-weight and to fill the formwork.

2) Passing ability: It is the feature of SCC to flow through narrow spaces without blocking, such as congested reinforcement, and flow around obstacles, such as sharp corners.
3) Segregation resistance: It is the feature of SCC to continue homogeneously during and after transporting and placing.

To achieve the requirements of these properties, SCC must provide high deformability and keep a highly stable mixture by applying the following three points: Okamura *et al*. (2003).

1) Limitations of coarse aggregate: The size and shape of coarse aggregate affect directly the flow and passing ability of SCC, where the flow ability and passing ability decrease when the maximum size of the coarse aggregate increase, Khaleel, *et al*. (2007).
2) Low water-to-powder ratio: Powdered materials that can be added are very fine smooth particles, such as limestone powder, glass filler, silica fume, fly ash, and quartzite filler. Those materials are used with SCC to maintain sufficient viscosity of the mix, this means low segregation and bleeding. On the other hand, filler materials reduce the heat generation of cement hydration and reduce the cost of concrete materials, Al-Jabri (2005).
3) Using super plasticizer: The use of a super plasticizer is necessary and essential in SCC to give a highly fluid concrete mix and increase flowability (workability). Also, super plasticizer reduces the required water-powder ratio, Hamilton (2005). Figure 1 shows a mechanism for achieving SCC.

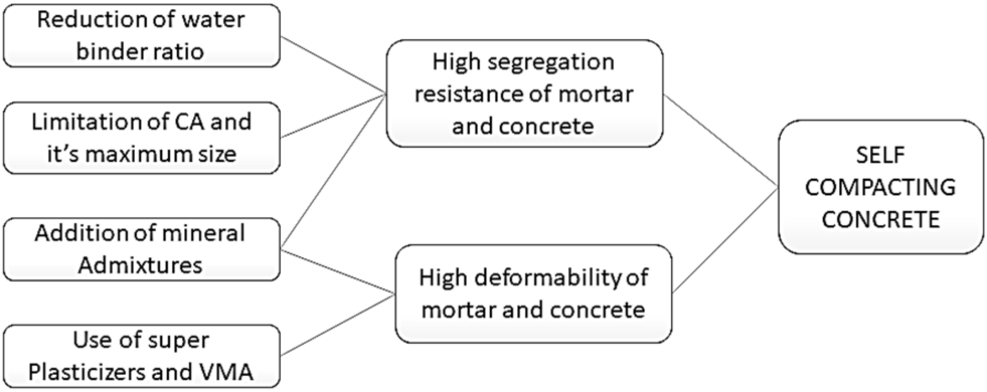
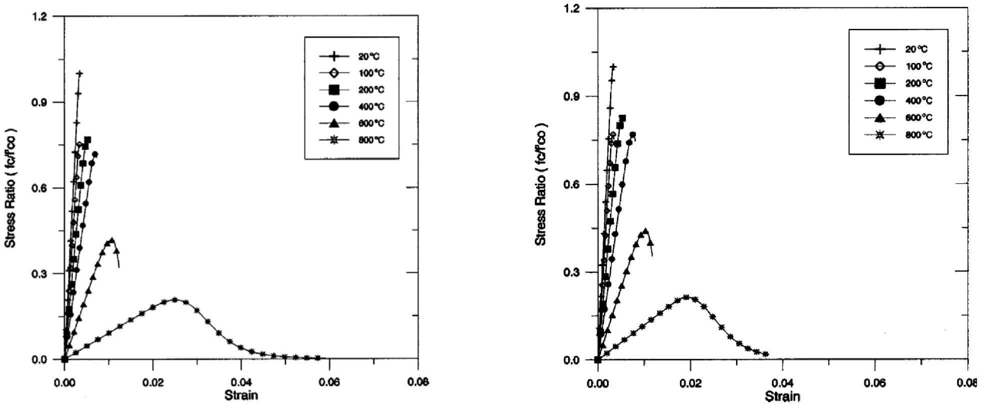


Figure 1: Mechanism of Achieving SCC.

The application of self-compacting concrete began throughout the entire world. Presently it is a very eagerly used material both in construction sites and in the production of precast members. Practical application was extended from large infrastructure buildings (bridges, tanks, retaining walls, tunnels, etc.) onto architectural buildings. SCC appears here as a structural material in load-bearing members but at the same time, it also appears frequently as architectural concrete. Arlanda Airport Control Tower, Stockholm, Sweden (2001), Okrajnov-Bajić, *et al.* (2009) was an example of using SCC. The total height of the tower is 83 m. The tower was completed and opened in 2001. Today it represents a symbol of Stockholm. SCC was used to achieve the concreting speed of a standard floor height h=3.27 m in a 4-day climbing cycle of formwork and to ensure high-quality concrete placing without vibration. The decreased noise level during concrete placing enabled concreting during the night shift.

Okrajnov-Bajić, *et al.* (2009) also presented a Burj Khalifa in Dubai, UAE as a second example of using SCC. This structure represents the state of the art in super high-rise buildings. During its construction, the most recent accomplishments in all fields have been united, including concrete production technology. Several different concrete mixes were used in this project. It was necessary to place 230000 m3 of fresh concrete. In the course of the construction of the building, the concrete was pumped to higher and higher heights so it was necessary to provide the extraordinary flowing ability of concrete through pipes. Thus, SCC concrete was poured usually at night to enable work at lower temperatures and higher humidity.

Cheng *et al.* (2004), manage to capture the response of high-strength concrete HSC under elevated temperatures ranging from 20ºC up to 800 ºC for four different types of HSC. For all samples, it was noticed insignificant loss for temperatures below 400 ºC and an almost 75% loss in strength for temperatures above 400ºC up to 800ºC. It was also noticed that ultimate strain changes with changing aggregate type, as for carbonate aggregate samples had larger ultimate strain than siliceous aggregate samples. The previous remarks can be noted clearly in Figures 2 (a and b).



(a) **(b)**

Figure 2: Stress-strain curves (a) carbonate aggregate high-strength concrete, (b) siliceous aggregate high-strength concrete, Cheng et.al. (2004).

This paper introduces an experimental study of the effecting burning temperature on the mechanical properties of SCC. The tests are divided into two sections based on the particular exposure situations during the test which are room temperature and burning temperature (800 ± 5) º C.

2 - Experimental Work

2 - 1 Materials Used in the Mixture

Optimum proportions must be selected according to the mixed design methods, considering the characteristics of all materials used. Satisfactory SCC is achieved by more stringent requirements of the ingredients in selecting suitable materials and in good quality control and proportioning. Ordinary Portland cement (Type I), Al-Ekhaidher natural sand with a fineness modulus of (2.6) and grading limits in zone 2 having rounded particle shape is used throughout the experiments. Rounded gravel of a maximum size of 10 mm and 2.6 specific gravity is also used in the mixtures. Sika-viscocrete® -5930L was used as high range water reducing admixture through the concrete mix production to reduce the water-to-cement ratio and enhance workability. Limestone powder is used as a partial replacement for cement. In general, the cement in SCC mixtures is partially replaced by fillers like limestone powder to improve certain properties such as increasing the amount of powder (filler + cement) to be more cost-effective compared to the use of cement alone, improving resistance to segregation, increase early compressive strength and workability, avoid extreme heat generation during hydration process, and improve concrete mixes fluidity and cohesion.

2 - 2 Self-Compacting Concrete Mix

The SCC mix was achieved according to EFNARC (2002) to satisfy SCC's fresh requirements of concrete properties. In the present work, the content of cement was 300 kg/m3, the content of fine aggregate was 797 kg/m3, the content of coarse aggregate was 767kg/m3, the content of limestone powder was 170 kg/m3 and water content was 190l/m3. The super-plasticizer content was 4.9 l/m3 (1.4 liters per 100kg of cement) and the w/p ratio was 0.36. This mix satisfies all the limits recommended by EFNARC's mix design method. The intended compressive strength was 40 MPa.

2 - 3 Heating Furnace

The heating furnace was manufactured using a fire brick available in the local market, a fire brick size is (228×112×63) mm as shown in Figure 3. This type of brick is used for fireplaces, kilns, and furnaces on the inside lining. This brick has a strong insulator, which helps to make the applications more energy-efficient with minimal heat loss and it's bearing a temperate of up to 1600 ºC.

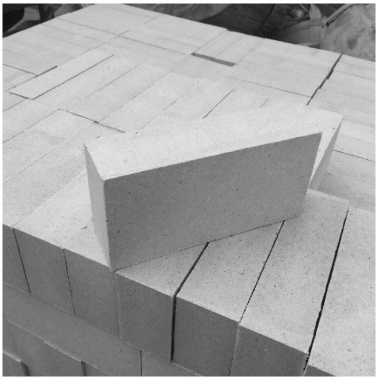


Figure 3. Fire brick sample

3 - Experimental Results of Burned Hardened Concrete (SCC)

The experimental results of specimens obtained from the tests of both cases of unburned and burned concrete. The results are divided into the following sections:

i. Destructive test results including compressive strength, splitting tensile strength; modulus of rupture, and modulus of elasticity for SCC specimens.
ii. Non-Destructive test results of SCC specimens.

3 - 1 Destructive Test

To specify the properties of SCC, an average of three concrete (150×300) mm cylinders were tested for each property. Table 1 shows the mechanical properties of the test results obtained for the used SCC mix at 56 days. As well, Table 2 shows the mechanical properties of the test results obtained for the burned SCC cylinder specimens at the same age as that of unburned specimens. The burned specimens are tested 24 hours after cooling (for both cases; Fast and Slow cooling) for calculating the effect of fire exposure and burning time on compressive strength.

As shown in the tables, these properties include concrete cylinder compressive strength, concrete unit weight (density), modulus of Elasticity, and modulus of rupture.

Table 1. Mechanical properties of the control specimen at ambient temperature.

Mix type	Density (kg/m3)	Compressive Strength (MPa)	Modulus of rupture (MPa)	Modulus of Elasticity (GPa)
SCC	2384	40	4.12	33.1

Table 2. Mechanical properties of the burned ed cylinder specimens

The fire exposed Temp. °C	Type of Cooling	Burning Duration (Hours)	Compressive Strength (MPa)	Density (kg/m^3)	Modulus of rupture (MPa)	Modulus of Elasticity (GPa)
800	Slow	2	29.3	2320	2.2	10.9
800	Fast	2	25.1	2332	2.1	10.1
800	Slow	6	18.4	2273	1.7	8.9
800	Fast	6	15.6	2301	1.55	7.8

3 - 1 - 1 Effect of Fire on Compressive Strength

As shown in Table 2, the compressive strength decreases with increasing the duration of burning and after fast cooling. The percentage of reduction increases as the fire exposure time rises. That demonstrates a relative decrease in compressive strength of each specimen thermally treated up to (2 and 6) hours of fire exposure in comparison to its original compressive strength just before burning. The cylinder compressive strength of burned specimens decreased by about (27 to 37) %, and (54 to 61) % of the unburned cylinder strength at (2 hours) and (6 hours) respectively. Also, it's obvious from the results that the rate of cooling has a valuable effect on the compressive strength of concrete. Fast cooling caused a higher reduction in strength than slow cooling. Figure 4 shows the reduction in compressive strength with burning time.

It is well known that the chemical reactions of cement with water produce several types of micro compounds including long needle shape of ettringite, massive crystals of calcium hydroxide, and fine fibrous crystals of calcium-silicate-hydrates (C-S-H), besides the voids and aggregate particles. The bond strength between coarse aggregate and cement paste depends on the intensity of those micro compounds and the distribution around the aggregate particles which divide them into a bulk paste and interfacial transition zone. The chemical composition of each of these micro compounds contains water molecules inside their structure. Upon exposure of the concrete to high temperatures due to fire, the chemically combined water is extracted from the microstructure, which alters the structure into a more brittle material.

In the case of small specimens such as concrete cylinders, the heat generated by the fire reaches the inside of the cylinder and may or may not reach the core to cause the exit of water molecules chemically combined with the microstructure of the hydrated cement compounds and weaken the concrete.

When the period of exposure to fire is prolonged, the water withdrawn from the microstructure increases, causing a decrease in strength and durability. That behavior relies on the size of the specimen exposed to the fire and the period of exposure. It is clear from (Table 2) that the 2 hours of exposure to fire causes the extraction of low molecules of water, while 6 hours of exposure to fire causes the extraction of more molecules of water to decrease the strength of concrete greatly, reaching about two-thirds its strength.

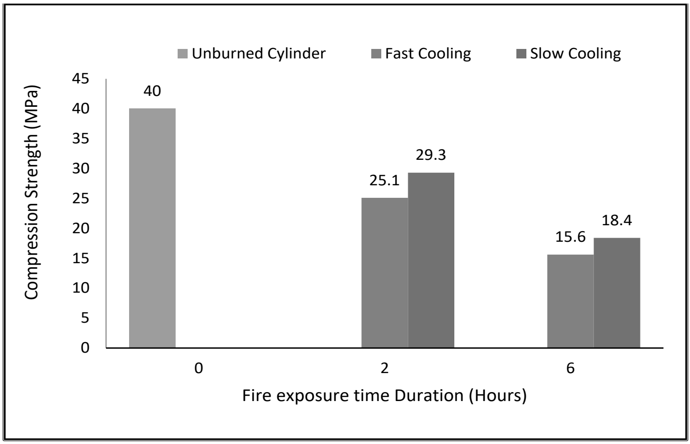


Figure 4. Effect of burning on Compressive strength.

3 - 1 - 2 Effect of Fire on Unit Weight (Density) of SCC

Also, to understand the effect of the burning on the unit weight of concrete, the same concrete cylinders that were used for compressive strength tests were weighed before and after burning. The results show that the concrete density decreases with increasing the duration of burning by about (2 to 8) %. The amount of decrease in the concrete density is small compared to the decrease in strength because the extracted water particles have a low weight compared to the other solid components of the concrete.

3 - 1 - 3 Effect of Fire on the Modulus of Rupture

On the other hand, SCC prisms with dimensions of (100×100×400) mm were tested to evaluate the modulus of rupture. Three prisms for each unburned and burning for a duration of (2 and 6) hours and each cooling type (Fast and Slow) were tested. Generally, the effect of the fire exposure duration on the modulus of rupture after burning to (2) hours and (6) hours, the modulus of rupture was found to be reduced by (13%) and (20%), respectively compared to the unburned specimen as shown in Figure 5. When concrete is exposed to fire with high temperatures, the cement paste contracts, and the aggregates expand, as a result, the transition zone and the bond between the cement paste and the aggregates are weakened. After being subjected to fire, this process and decomposition of hydration products cause deterioration and strength loss in concrete.

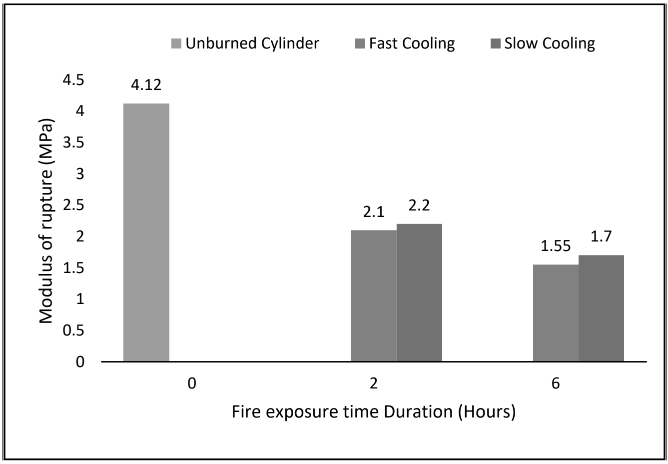


Figure 5. Effect of burning on Modulus of rupture

3 - 1 - 4 Effect of Fire on Modulus of Elasticity

The modulus of elasticity of concrete decreases due to fire exposure and it is more pronounced than the decrease in concrete compressive strength. The effect results of high fire exposure on the modulus of elasticity were listed in Table 2 and shown in Figure 6.

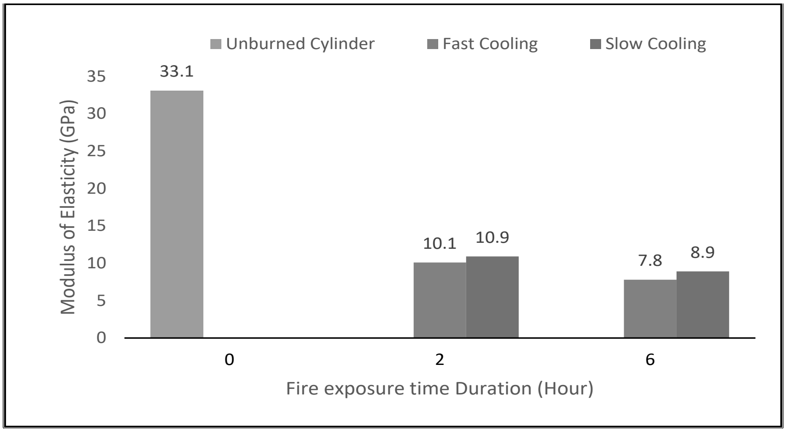


Figure 6. Effect of burning on Modulus of Elasticity.

It is clear that the degradation in the elastic modulus of elasticity of concrete was 68 % and 75 % for (2 and 6) hours, respectively, of its original value of unburned specimens. As well, the degradation is present due to the cooling methods, it was higher in fast cooling than in slow cooling, where it was about a 3% decrease in fast cooling.

Such reduction in modulus of elasticity is distinctly due to micro-structural damage of concrete with increasing temperature due to excessive thermal stresses and physical and chemical changes, Al-Kamaki (2015) and Kodur (2014).

3 - 2 Non-Destructive Test of Hardened SCC

3 - 2 - 1 Ultrasonic Pulse Velocity (UPV)

Ultrasonic pulse velocity equipment measures the transit time of a pulse between transducers placed on the surface of a body of concrete. The pulse velocity can then be calculated using the measured path length through the concrete. For strength estimation, it will be necessary to place the transducers on opposite faces of the concrete element. It may be possible to improve strength measurement value if the density is known, or by combination with measured rebound numbers. The pulse velocity depends on Young's modulus, Poisson's ratio, and the density of the medium. It is necessary to consider the various factors which can influence pulse velocity and its correlation with various physical properties of the concrete, such as moisture content, the temperature of the concrete, path length, shape, and size of the specimen. Table 3 shows an ultrasonic pulse velocity test that measures values of compressive strength (f'_{cupv}), for unburned cylinder specimens and compared to compressive strength (f'_c) obtained from the compression test machine.

Resultantly, it is clear that the UPV test awards higher values for concrete by about 5%.

Table 3. UPV test results of cylinder specimens and beams

Specimen No.*	Cylinder Compressive Strength f'_{cupv} (MPa) **	Cylinder Compressive Strength f'_c (MPa) ***	Variance f'_{cupv}/f'_c for Cylinder
SCC_0.8R	42	39	+7.7%
SCC_0.8S6	42	40	+5.0%
SCC_0.8F2	43	40	+7.5%
SCC_0.8F6	42	38	+10.5%
SCC_0.8S2	41	41	0.0%
SCC_1.0R	43	40	+7.5%
SCC_1.0S6	43	41	+4.9%
SCC_1.0F2	40	39	+2.6%
SCC_1.0F6	41	42	-2.4%
SCC_1.0S2	40	38	+5.3%
SCC_1.2R	42	39	+7.7%
SCC_1.2S6	44	41	+7.3%
SCC_1.2F2	41	38	+7.9%
SCC_1.2F6	43	42	+2.4%
SCC_1.2S2	40	41	-2.4%
Average	41.8	40	+4.7%

* **Specimen coding: (0.8, 1.0, 1.2) refers to the a/d ratio, (S, F) refers to the Slow or Fast cooling method, and (2, 6) refers to fire exposure duration in hours.**

** **Each value represents an average of three test results by UPV.**

*** **Each value represents the average of three test results.**

In the same manner, burned cylinder specimens were also tested by UPV to evaluate the differences in compressive strength between UPV and the prevalent test, ASTM C39M (2016). The results are shown in Table 4 for all cylinders, the cooling effect and fire exposure time are taken into account.

Table 4. UPV test results of burned cylinder specimens and beams

Condition	Burning Duration (Hours)	Type of Cooling	Compressive Strength (MPa)		Variance $(f'_c)_{upv} / f'_c$ for Cylinder
			Cylinder $(f'_c)_{upv}$	Cylinder f'_c	
Unburned	--	--	41.8	40	+4.7%
Burned	2	Slow	30.0	29.3	+2.5%
	2	Fast	25.8	25.1	+3.0%
	6	Slow	18.6	18.4	+1.5%
	6	Fast	15.8	15.6	+1.7%

As shown in Table 4, the variance of the strength of concrete in compression by UPV test is decreased for burned concrete specimens to (2.5-3) % and (1.5-1.7) % for (2 hours) and (6 hours), respectively. This result makes it acceptable to use the non-destructive UPV test to assess the compression strength (f'_c) of reinforced concrete structures after exposure to a fire incident.

3 - 2 - 2 Rebound Number Test (Schmidt Hammer)

This is a non-destructive test for estimating the concrete compressive strength. The Schmidt rebound hammer method is simple to use and provides a quick, inexpensive means of checking the uniformity of in-place hardened concrete. This test relies on measuring the concrete strength by measuring the hardening at the surface. It is used to identify the concrete compressive strength of the member by using calibration curves of the relationship between rebound number and compressive strength. The rebound hammer test is carried out under the guidance of ASTM C805 (2018) to assess the general quality, uniformity, and compressive strength of concrete. The minimum number of test readings was 10.

The Rebound number test is performed on concrete specimens after fire exposure for two durations (2 and 6) hours and for two methods of cooling, and the readings are taken in the same positions, this work is done to compare the effect of burned in rebound number on compression strength. Table 5 shows the compression strength $(f'_{c\,SH})$ variation of the rebound number test after and before burning with regular compressive strength (f'_c).

Table 5. Rebound number test measurements of burned specimens

Condition	Burning Duration (Hours)	Type of Cooling	Compressive Strength (MPa)		Variance $(f'_c)_{SH}/f'_c$
			Cylinder $(f'_c)_{SH}$	Cylinder f'_c	
Unburned	--	--	42	40	+5%
Burned	2	Slow	25	29.3	-14.7%
	2	Fast	21	25.1	-16.3%
	6	Slow	15	18.4	-13.0%
	6	Fast	13	15.6	-16.7%

As shown in Table 5, the variance of the strength of concrete in compression by the Schmidt Hammer test is increased for burned concrete specimens up to 16.7% compared to 5% for unburned specimens. This result is rather high and maybe not be acceptable to use this type of non-destructive test to assess the compression strength (f'_c) of reinforced concrete structures after being exposed to a fire incident.

4 - Conclusions

This paper investigates the effect of fire flame at 800 ºC on SCC mechanical properties. The duration of exposure to fire was either 2 or 6 hours, while cooling was either fast or slow. The following conclusions can be obtained:-

1. The compressive strength decreases with increasing the duration of burning. Exposure to fire for 6 hours reduces strength by 54 % to 61 % at slow and fast cooling respectively, while exposure to 2 hours reduces it by 27 % to 37 % at slow and fast cooling, respectively.
2. The type of cooling affects the percentage of reduction in compressive strength. Fast cooling reduces compressive strength more than slow cooling.
3. The concrete density decreases with increasing the duration of burning by about (2 to 8) %.
4. The modulus of rupture reduces by 13% and 20% upon exposure to fire for 2 hours and 6 hours, respectively compared to the unburned specimen.
5. The influence of fire flame on elastic modulus is more pronounced than on compressive strength. It decreases by about 67 % to 69 % upon exposure to fire for 2 hours, and by 73 % to 76 % when exposed to fire for 6 hours and cooled slow and fast, respectively.
6. It is acceptable to use the non-destructive UPV test to assess the compression strength of reinforced concrete structures after exposure to a fire incident, while the Schmidt hammer test is less accurate for the assessment of compressive strength after fire exposure.

References

- ACI 237R-07, (2007), Self-Consolidating Concrete", American Concrete Institute, PP 30.
- Al-Jabri, L.A., (2005), The Influences of Mineral Admixtures and Steel Fibers on the Fresh and Hardened Properties of Self-Compacting Concrete, M.Sc. Thesis, University of Al-Mustansiriya, Iraq, PP 135.
- Al-Kamaki, Y.S.S., (2015), Strengthening of Fire-damaged RC Columns Using CFRP Fabrics, Ph.D.Tthesis, Swinburne University of Technology, Melbourne, Australia.
- ASTM C39/C39M-16a, (2016), Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, Developed by ASTM Subcommittee C09.61 on Concrete and Concrete Aggregates, Vol. 04.02, West Conshohocken, PA, USA, PP 7.
- ASTM C805/C805M-18, (2018), Standard Test Method for Rebound Number of Hardened Concrete, Annual Book of ASTM Standards, Vol. 04.02 Concrete and Aggregates, West Conshohocken, PA, United States, PP 4.
- BIBM, CEMBUREAU, ERMCO, EFCA, and EFNARC, (2005), The European Guidelines for Self-Compacting Concrete; Specification, Production and Use, PP 68.
- Cheng, F.-P., Kodur, V. K., and Wang, a. T.-C., (2004), Stress-strain Curves for High Strength Concrete at Elevated Temperatures, Journal of Materials in Civil Engineering, Vol. 16, Issue 1.
- EFNARC, (2002), Specifications and Guidelines for Self-Compacting Concrete, Association House, 99 West Street, Farnham, Surrey GU9 7EN, UK.
- Hamilton, H. R. (2005), Self-Consolidating Concrete (SCC) Structural Investigation, Summary of Final Report, BD 545_21.
- Khaleel, O.R., (2007), The Effect of Coarse Aggregate Properties on the Behavior of Self-compacting Concrete, M.Sc. Thesis, University of Technology, Iraq, PP 123.
- Kodur, V., (2014), Properties of Concrete at Elevated Temperatures, ISRN Civil Engineering, Vol. 2014, Article ID 468510, PP 15.
- Okamura, H. and Oychi, M., (2003), Self-Compacting Concrete, Journal of Advance Concrete Technology, Vol. 1, No. 1, PP 5-15.
- Okrajnov-Bajić, R., Vasović, D., (2009), Self-compacting Concrete and Its Application in Contemporary Architectural Practice, SPATIUM International Review, No. 20, PP 28-34.
- Ozawa K., Maekawa K., Kunishima M. and Okamura H., (1989), Development of High-performance Concrete Based on the Durability Design of Concrete Structures, Proceedings of the Second East-Asia and Pacific Conference on Structural Engineering and Construction (EASEC-2), Vol. 1, PP 445-450.

- Ravindrarajah, R. S., Farrokhzadi, F. and Lahoud, A., (2003), Properties of Flowing Concrete and Self-Compacting Concrete with HighPerformance Superplasticizer, In O. Wallevik and I. Nielsson eds., Proceedings of the 3rd International RILEM Symposium, PP 17.
- Sanghi Bulletin, Bulletin of Sanghi Industries Limited, (2006), Sanchi Cement 4U, Issue-1, Editor–4U, A Quarterly Bulletin from Care Services, PP 1-4.