Effect of Heat and Impact on Self-Compacting Concrete Containing Polypropylene Fibers

***Hossein Pourali* [1)], *Saeed Azizi* [2)] *and M. Reza Esfahani* [3)]**

[1)] M.Sc., Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.
[2)] M.Sc., Department of Civil Engineering, Zahedan Branch, Islamic Azad University, Zahedan, Iran.
[3)] Professor, Department of Civil Engineering, Ferdowsi University of Mashhad, Mashhad, Iran.

ABSTRACT

Many primary behavioral properties of concrete, including flexural strength, fatigue resistance, impact, thermal shock and brittle fracture could be improved by using reinforcing fibers into the concrete. The present study deals with the physical and mechanical behavior of Self-Compacting Concrete (SCC) containing polypropylene fibers as well as the effect of polypropylene fibers on increasing the strength of SCC and increasing its impact resistance and thermal properties. To this aim, self-compacting concrete containing 0, 0.1 and 0.3 percent by volume of polypropylene fibers was used. In order to investigate the effect of heat on the fiber-reinforced concrete, experiments were carried out on the specimens with 28 days of age, which were exposed to 250°C temperature for 8 hours. In this research, 6 cylindrical compressive test specimens, 6 tensile test specimens and 15 rectangular beams are built. Results showed that tensile strength and impact resistance are improved by increasing the presence of fibers in SCC. It was found that by adding fibers, impact resistance has increased up to 140%. Concerning the effect of fibers on the heated concrete containing fibers, it was found that fibers reduce the negative effect of heat on compressive strength, tensile strength as well as on impact resistance.

KEYWORDS: Polypropylene fiber, Self-compacting concrete (SCC), Tensile strength, Impact resistance.

INTRODUCTION

After the September 11 attacks, many studies have been carried out on the impact of heat on concrete strength. Polypropylene fibers increase ductility, flexural stiffness and impact resistance of concrete. Drop-weight test has been proposed for evaluating the impact strength of SCC containing polypropylene fibers (Badr et al., 2006). Some research studied the impact resistance of high-strength concretes with different percentages of fibers (Mastali and Dalvand, 2016; Van-Ta Do et al., 2016). The results showed that the number of impacts causes primary cracks in the specimen which are very different. Also, the energy absorption of concrete significantly increased by 1 percent increase in fibers (Marar et al., 2001). By conducting extensive research on fiber-reinforced beams, the impact test method was presented in a new form. In this method, through creating a cut under the beams, the place and beginning of the crack are determined and by calculating the energy of the imposed impacts, various specimens are compared with one another. By using fibers, the impact resistance of concrete increased (Mohammed, 2015).

Exposure to high temperature will reduce the strength of concrete (Yuan and Li, 2015). Delamination phenomenon and segregation of the particles from the

Received on 9/10/2016.
Accepted for Publication on 17/10/2018.

concrete surface at the time of creating high temperature and confinement of water vapor inside and consequently an increase in the internal pressure inside the concrete are the major causes of such strength reduction (Al-Qadi et al., 2011). Since the 1980s, experiments began to study the effects of high temperatures on fiber-reinforced concrete behavior. Studies indicated the delamination of concrete under rapid temperature increase. On the other hand, high temperature reduces the high resistance as well as the modulus of elasticity in concrete (Metin, 2006; Ma, 2015). Other researchers conducted experiments to investigate the effect of fire on high-strength concrete. Studies showed the susceptibility of delamination in concrete under rapid temperature rise. On the other hand, high temperatures significantly reduce the resistance and modulus of elasticity of concrete (Azizi et al., 2012). Researchers examined the effect of increase in the transient temperature on load-displacement behavior of high-strength concrete. Some research showed that by experimenting on high-strength concrete, its characteristics will be changed after exposure to fire (Felicetti et al., 1996). During an experimental program carried out by the American Society of Standards and Technology, an investigation was carried out on the effect of high temperature on the mechanical properties and delamination possibility in high-strength concrete. In this test, the mechanical properties of high-strength concrete cylindrical specimens were evaluated under increasing temperature up to 600° C (Phan and Carino, 2002).

Testing Program

Specifications of Materials Used

Polypropylene fibers used in this test were filamentary. Fibers are the product of Zhikava Company. Used fiber properties are shown in Table 1. Super-plasticizer used in the above mixture is a modified polycarboxylate plasticizer made by Fosroc Company.

Table 1. Used fiber properties

Type of fibers	Color	Size of fibers (mm)	Tensile strength (MPa)	Density (kg/m^3)	Melting point
PP	White	12	350	900	160 ° C

In this study, ACI-211 volumetric methods are used for the design of concrete mixtures. To achieve a cylindrical compressive strength of 30 MPa, water-cement ratio was considered for SCC 0.46 and for ordinary concrete 0.5, while the amount of cement was respectively considered 350 and 400 kg per cubic meter. To select the other two components; i.e., fibers and super-plasticizer, trial and error and previous research were used. Given that a high percentage of polypropylene fibers reduces resistance as well as SCC efficiency, polypropylene fiber volume was limited to 0, 0.1 and 0.3% in this study.

Impact Resistance Test

Free fall test is the most well-known method to test impact among researchers. Equation (1) represents the principle of energy conservation between two points in the path of the falling object. This equation is true in case the energy loss is prevented in the path of movement. Cases such as air friction or unwanted impacts during the path can waste energy (Taylor, 2005).

$$M.g.h1 + 1/2\ M.V12 = M.g.h2 + 1/2\ M.V22 \qquad (1)$$

The American Concrete Institute has offered a method based on free fall to investigate the impact resistance of fiber-reinforced concrete. In this study, two methods are suggested to conduct the experiments. The first method is based on a lubricated ball bearing. Balls are lifted by a screw, a rope and a pulley and released after complete standstill. Assuming that the weight of the rope pulley with its axis is ignored, the ball will be in the form of a free fall. But in practice and by testing this device, it was observed that the conditions of this fall are not met and the ball speed will decrease compared to the ideal state. The second method is using electromagnetic energy. In this method, an electrical magnet is responsible for keeping the ball until the falling moment. Since in this method, the ball has no contact with the surrounding, its movement is a complete free fall. The only reducing factor is air friction. Through controlling the testing environment and preventing the blow of wind, the amount of this error is reduced as much as possible (Mohammadi et al., 2009). Figure 1 illustrates this device.

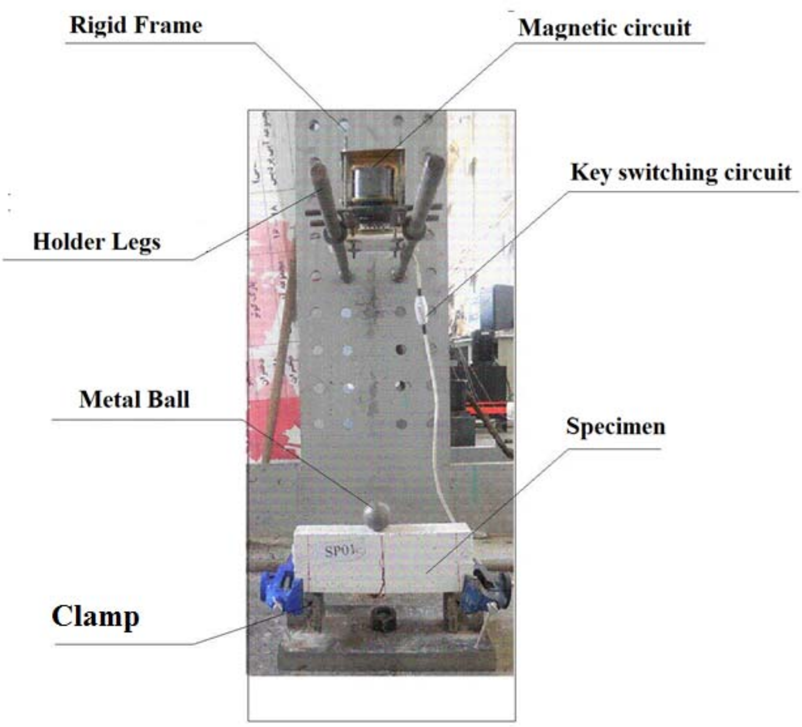


Figure (1): Impact test machine with an electromagnet

In this study, the second method is used. To this aim, a round, metal and hard ball is used as the falling object. The globular shape of this ball prevents the possibility of its rotation. Its hardness prevents damage after colliding with the concrete surface. Height intended as the falling height is the distance between the center of the ball and the concrete surface. Since the ball is stationary while contacting the magnet, its primary speed in Equation (1) is zero. Also, by selecting the height of the ball when hitting the specimen, the second height can be considered zero as the base height. In the presented standard in ACI, specimens are considered cylinders with a diameter of 152 mm and a thickness of 63.5 mm. Since the distribution of cracks is invisible in these types of specimens, in the method proposed, cube specimens with the dimensions 50 x 100 x 280 mm are used. The clamp of this system is designed and performed with a two-headed joint. The clamp is connected to the earth in a rigid form to properly transfer energy. The ball stops after hitting the concrete. Considering the principles of conservation, kinetic energy is transferred to the ball through the concrete matrix into the two clamps and then into the earth. This energy transfer results in the creation of thin cracks in the primary impacts and the spread of these cracks in the next impacts. The energy imported into the concrete in each shock equals the potential energy stored in the ball before falling. This energy is developed in the form of Equation (2):

$$E= M.g.h1 \quad (2)$$

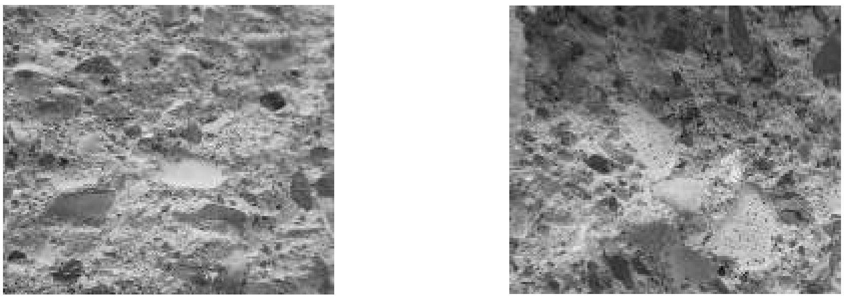
At this stage of the test, the prism specimen was put on the clamp and kept fixed in its place. Height of falling was different in each time. Globular metal balls of 520 and 920 grams were used at this stage of the test. Energy absorbed by the concrete is obtained by multiplying the number of impacts by the amount of energy of a collision. Equation (3) shows this value.

$$E= \sum M.g.h1 = n. (Mgh1) \quad (3)$$

In this regard, "h1" is the height of drop-weight and "n" is the number of impacts until the complete crush of the specimen. We can calculate concrete fracture energy with the aid of Equation (3).

Heating and Impact Resistance Test

At the time of fire, the temperature of concrete rapidly increases. During temperature increase, complex chemical and physical changes occur in concrete. When the concrete is exposed to high temperatures, first free water of concrete starts to evaporate at temperatures from 100 to 200°C and with an increase in the temperature, chemical water is released in the concrete. Due to the limited number of narrow openings, the water is confined inside the concrete. Therefore, the vapor pressure produced can't squeeze through the openings, which leads to internal tensile tension and then creates cracks on the concrete surface. In order to deal with these problems, polypropylene fibers are used with respect to their special properties. Polypropylene fibers reduce fracture and increase fire resistance. Polypropylene fibers melt at 160° C and when exposed to fire, channels are created within the concrete. These channels allow water vapor out of the concrete and the pressure will decrease, which prevents delamination of the concrete surface. If the gas is trapped in the internal structure of concrete, then the internal tensile stress at 300° C becomes approximately 8 N/mm^3. At the temperature of 350 ° C, this amount will be doubled (Ma, 2002). Figure 2 shows the holes and channels in the concrete after heating.



A) Before heating B) After heating

Figure (2): Holes and channels created in the concrete after heating

In this study, we dealt with the effect of temperature on the mechanical and impact features of concrete. In both cases, specimens without the effect of heating and those exposed to heating are examined. The specimens under the effect of temperature were placed in the furnace at a temperature of 250°C for 8 hours and then different experiments were conducted on them. Specifications of the specimens are shown in Table 2.

Table 2. Specifications of specimens

Name of specimen	Percentage of fiber	Weight of balls (gr)	Height of fall (m)	Temperature of specimen (°C)
SCC-S1	0	520	0.5	20
SCC-B1	0	920	0.5	20
SP01-S1	0.1	520	0.5	20
SP01-S2	0.1	520	1	20
SP01-B1	0.1	920	0.5	20
SP01-B2	0.1	920	1	20
SP03-S1	0.3	520	0.5	20
SP03-S2	0.3	520	1	20
SP03-B1	0.3	920	0.5	20
SP03-B2	0.3	920	1	20
SCC1-S1-T	0	520	0.5	250
SP01-S1-T	0.1	520	0.5	250
SP01-S2-T	0.1	520	1	250
SP03-S1-T	0.3	520	0.5	250
SP03-S2-T	0.3	520	1	250

Experimental Results

Diameter of Slump Flow of Self-compacting Concrete

In Table 3, the diameter of slump flow of SCC is expressed without and with fibers, based on the proposed method in ASTM C 230 standard.

As the results in Table 3 show, an increase in the percent of fibers severely reduces the efficiency of the concrete. This issue is a key factor in the selection of the optimal percent of fibers.

Table 3. The diameter of the slump flow of self-compacting concrete with and without fiber

Name of Plan	SSC-1	SP-01	SP-03
Diameter of flow	650	490	300
Percentage of fibers	0	0.1	0.3

Compressive Strength

Specimens SCC-T, SP01-T, SP03-T SCC, SP01, SP03, as shown in Figure 3, are under compressive strength test. Compressive strength values of SCC without fibers (control specimen) and specimens containing fibers are shown before and after heating in Table 4. It is observed that in SCC containing fibers, the maximum percentage of compressive strength is related to 7-day resistance and specimen SP01 has had the highest strength by a 10 percent increase in resistance at the age of 7 days. After heating, fiber-reinforced concrete showed a very appropriate performance. The percent of strength reduction obtained after heating is 38 percent in the specimen without fibers, but in specimens containing fibers, this strength reduction is much lower, so that it is 16% for 0.1 percent of fibers and 26% for 0.3 percent of fibers.

Table 4. Compressive strength of SCC containing fibers

Design name	Compressive strength (MPa)	
	7 days	28 days
SCC control	23.4	32.6
SP01	25.7	35.3
SP03	24.1	31.3
SCC control-T	-	20.1
SP01-T	-	27.4
SP03-T	-	24.1

Figure (3): Compressive test set-up

Splitting Tensile Strength

The specimens were tested for tensile strength as shown in Figure 4. Table 5 shows the splitting tensile strength of control specimens containing fibers, as well as the heated specimens at different ages.

Figure (4): Splitting tensile test setup

Table 5. Tensile strength of control specimens and specimens containing fibers, as well as heated specimens at different ages

Design name	Tensile strength (MPa)	
	7 days	28 days
SCC control	3.1	3.6
SP01	3.6	4.0
SP03	4.1	4.4
SCC control-T	-	2.3
SP01-T	-	3.5
SP03-T	-	3.4

In Table 5 above, it is shown that in the specimens under the effect of heating, the maximum percentage of improved strength was related to specimen SP01, which by an approximately 12 percent reduction has the minimum percent of strength reduction to the primary concrete. It is clear that not all the specimens suffer with the reduction in tensile strength by adding fibers and that polypropylene fibers had a positive effect on the enhancement of tensile strength in all ages.

Impact Resistance

To carry out the test, two balls and two different heights have been used. Results of impact test are shown in Table 6. In this table, the numbers of necessary impacts to create the first crack and the complete fracture of the specimen are shown. Also, the information about the weight of the ball and its height of fall as well as the fracture mode of the specimens is presented. In Figure 5, the place of crack and fracture mode of specimen SP01-B1 are shown.

Figure (5): Fracture of specimen SP01-B1

Table 6. Results of impact test

Number of specimen	Percentage of fibers	Weight of balls (gr)	Fall height (m)	Number of impacts until first crack	Number of impacts until final crack	Place of first crack
SCC1-S1	0	520	0.5	9	9	Midspan
SCC1-B1	0	920	0.5	3	3	Midspan
SP01-S1	0.1	520	0.5	14	15	Midspan
SP01-S2	0.1	520	1	7	8	Midspan
SP01-B1	0.1	920	0.5	6	8	Midspan
SP01-B2	0.1	920	1	2	2	Midspan
SP03-S1	0.3	520	0.5	18	22	Surface crush
SP03-S2	0.3	520	1	9	10	Support
SP03-B1	0.3	920	0.5	8	8	Midspan
SP03-B2	0.3	920	1	3	3	Midspan

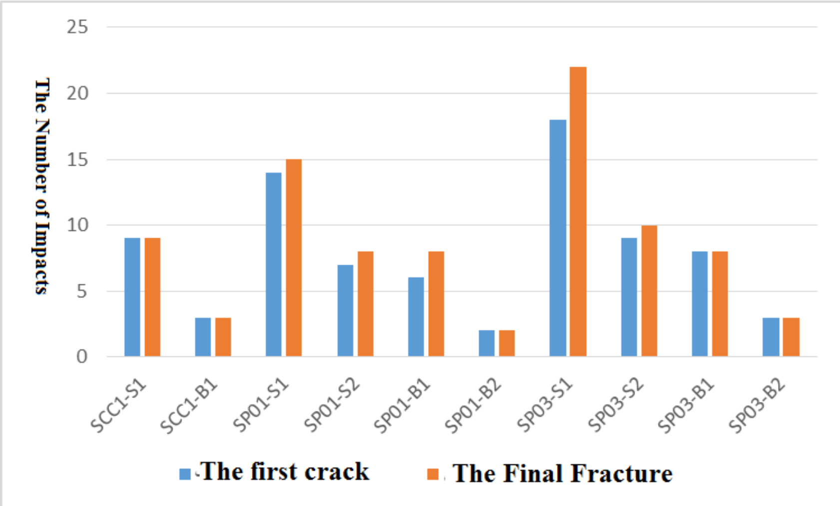


Figure (6): Number of impacts for first crack and number of impacts for final fracture

Table 7 and Figure 7 show the results of impact test, with a 520 gram ball and 0.5 meter height of fall. Three types of surface fracture, crack in the middle of the scamp and crack in the scamps were seen in the specimens as shown in Figure 8. The results of Table 7 indicate a significant increase in fracture energy according to the increase in the percentage of fibers. In specimen SP03 containing 3.0 percent of fibers, fracture energy has increased more than 2 times compared to the SCC specimen (control).

Table 7. Results of impact test with a 520 gram ball and 0.5 meter height of fall

Number of specimen	Percentage of fibers	Weight of ball (G)	Height of fall (m)	Energy of each impact (joules)	Number of impacts to final fracture	Fracture energy (joules)
SCC1-S1	0	520	0.5	2.55	9	23.8
SP01-S1	0.1	520	0.5	2.55	15	39.1
SP03-S1	0.3	520	0.5	2.55	22	57

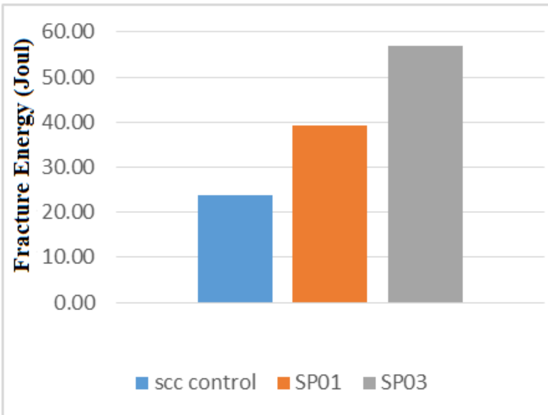


Figure (7): Fracture energy of specimens

(A) Midspan

(B) Support

(C) Surface crush

Figure (8): Types of fracture

Prism specimens were placed in the furnace for 8 hours at 250° C. Figure 9 shows the fracture energy of S1 specimens. In Table 8, the results of the impact test are shown on heated specimens using a 520 gram ball and a drop height of 0.5 meters. As Figure 10 indicates, heating the specimens will reduce the impact resistance. But specimens containing fibers show less decrease of resistance. This reduction in resistance for the specimen with no fibers (control) is 46 percent, for specimen containing 0.1 percent of fibers is 26% and for specimen with 0.3 percent of fibers is 29%. The results of Fig. 6 indicate that fibers with 0.1 percent showed a lesser decrease in the rate of impact resistance.

Table 8. Impact test results for specimens under the effect of heat and impact of a 520 gram ball with a drop height of 0.5 m

Number of specimen	Percentage of fibers	Weight of ball (G)	Height of fall (m)	Energy of each impact (joules)	Number of impacts to final fracture	Fracture energy (joules)
SCC1 -S1	0	520	0.5	2.55	8	23.8
SP01-S1	0.1	520	0.5	2.55	16	39.1
SP03-S1	0.3	520	0.5	2.55	22	57
SCC 1 -S1-T	0	520	0.5	2.55	6	12.7
SP01-S1-T	0.1	520	0.5	2.55	12	26.4
SP03-S1-T	0.3	520	0.5	2.55	10	29.8

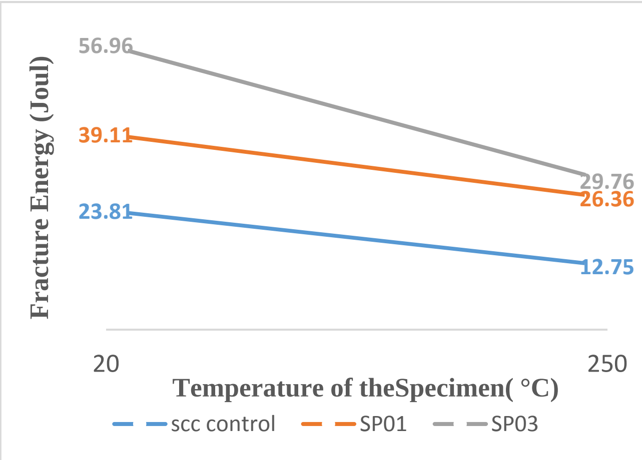


Figure (9): Impact test results for specimens under the effect of heat, 520 gram ball with a drop height of 0.5 m

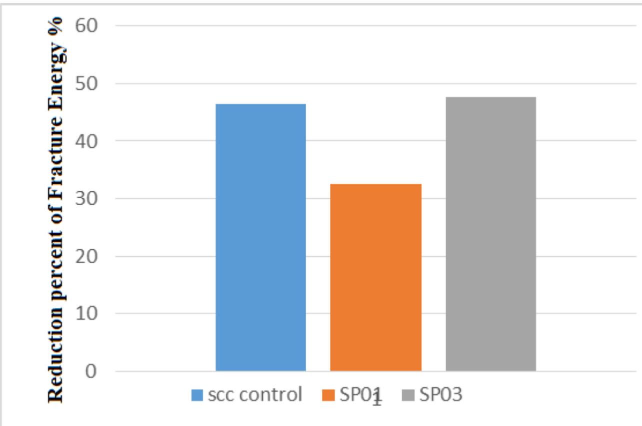


Figure (10): Reduction percent of fracture energy of heated S1 specimens

CONCLUSIONS

By increasing the fiber content in the control specimens, the slump flow diameter of specimens drastically reduced. Slump flow diameter was changed from 650 mm in the specimen without fiber to 490 mm in the specimen containing 0.1 percent of fibers and to 300 mm in the specimen containing 0.3 percent of fibers.

Specimens containing fibers have a higher tensile strength and impact than control specimens (SCC without fibers), but considering compressive strength, by increasing the amount of fibers, it didn't necessarily increase. The optimal percent of the fibers for the compressive strength obtained was 0.1 percent, which led to an 8% increase in compressive strength of 28 days. Compressive strength of the specimens declined with increasing temperature. This decrease is not identical in specimens with different percents of fibers. The least percent of reduction in compressive strength of the heated specimens is in specimens containing 0.1 percent of fibers, amounting to 16%.

Existence of polypropylene fibers in the concrete mixture increases tensile strength of fiber-reinforced concrete at normal temperature, but tensile strength of the specimens will decrease with increasing temperature. This decrease is not identical in specimens with different percents of fibers. The least percent of reduction in compressive strength of the heated specimens is equivalent to 12% and is related to specimens with 0.1 percent of fiber volume.

The impact strength of fiber-reinforced concrete at normal temperature increased with the increase in the percent of fibers. By adding 0.1 percent of fibers in concrete, impact resistance increased by 63% and by adding 0.3 percent of fibers, impact resistance increased by 140 percent. But the energy fracture of the heated specimens reduced. Specimens containing 0.1 percent of fibers had the lowest amount of reduction in resistance of 32 percent compared to the control specimen.

Regarding the positive effect of fibers on compressive strength, it may be concluded that at high temperatures, fibers melted resulting in the creation of openings for the extraction of water vapor. Therefore, the pressure in concrete is reduced, resulting in the decrease in thin, internal cracks of the specimens.

Funding

This research received no specific grant from any funding agency in the public, commercial or non-profit sectors.

REFERENCES

Azizi, S., Narmashiri, K., Gholizadeh, M., and Mehmandoost, K.H. (2012). "Seismic strengthening of low-rise steel structures: a case study in Mashhad". Procedia-Engineering, 50, 913-925.

Badr, A., Ashour, A.F., and Platten, A. (2006). "Statistical variations in impact resistance of polypropylene fibre-reinforced concrete". International Journal of Impact Engineering, 32, 1907-1920.

Felicetti, R., Gambarova, P.G., Rosati, G.P., Corsi, F., and Giannuzzi, G. (1996). "Residual mechanical properties of HSC subjected to high-temperature cycles". Proceedings of 4th International Symposium on Utilization of High-Strength/High-Performance Concrete, Paris, France, 579-588.

Guanglin Yuan, and Qingtao Li. (2015). "The use of surface coating in enhancing the mechanical properties and durability of concrete exposed to elevated temperature". Construction and Building Materials, 95, 375-383.

Ma, Y. (2002). Cited by 14 related articles, Materials and Structures/Mat~riaux et Constructions, 35, April, 165-169.

Marar, Khaled, and Eren. (2001), "Relationship between impact energy and compression toughness energy of high-strength fiber-reinforced concrete". Materials Letters, (47), 297-304.

Mastali, M., and Dalvand, A. (2016). “The impact resistance and mechanical properties of fiber-reinforced self-compacting concrete (SCC) containing nano-SiO_2 and silica fume”. European Journal of Environmental and Civil Engineering.

Metin, H. (2006). "The effects of high temperature on compressive and flexural strengths of ordinary and high-performance concrete". Fire Safety Journal, (41), 155-163.

Mohammadi, Y., Carkon-Azad, R., Singh, S.P., and Kaushik, S.K. (2009). "Impact resistance of steel fibrous concrete containing fibres of mixed aspect ratio". Construction and Building Materials, 23, 183-189.

Mutaz Kadhim Medhlom, and Mohammed Hashim Mohammed. (2015). “Strengthening of modified reactive powder concrete columns with CFRP”. Jordan Journal of Civil Engineering, 10 (1).

Phan, L.T., and Carino, N.J. (2002). “Effects of test conditions and mixture proportions on behavior of high-strength concrete exposed to high temperatures”. ACI Materials Journal, 99 (1), 54-66.

Qianmin Ma, Rongxin Guo, Zhiman Zhao, Zhiwei Lin, and Kecheng He (2015). “Mechanical properties of concrete at high temperature: a review”. Construction and Building Materials, 93, 371-383

Saoud Al-Qadi, N., Nasharuddin Bin Mustapha, K., Naganathan, S. Qahir. (2011). "Effect of polypropylene fibres on fresh and hardened properties of self-compacting concrete at elevated temperatures". Australian Journal of Basic and Applied Sciences, 5 (10), 378-384.

Taylor, John R. (2005). "Energy in classical mechanics". University Science Books, 105-106.

Van-Ta Do, Huu-Duc Nguyen-Tran, and Doo-Man Chun. (2016). “Effect of polypropylene on the mechanical properties and water absorption of carbon-fiber-reinforced-polyamide-6/polypropylene composite”. Composite Structures, 150, 15 August, 240-245.