Proceedings of the 4th International Conference on Civil Engineering for Sustainable Development (ICCESD 2018), 9~11 February 2018, KUET, Khulna, Bangladesh (ISBN-978-984-34-3501-6)

THE EFFECT OF FIRE ON THE STRENGTH OF CONCRETE MATERIAL

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ABSTRACT

Structural members exposed to fire may damage considerably and loss its durability even may collapse due to failure of the member of a building. This work presents the results of an experimental investigation of the effect of fire on the strength of concrete. Cylindrical and beam specimens were prepared and burnt in fire for a duration of one hour, without any imposed load during the burning. In both cases, two systems were followed for cooling the samples, (i) natural cooling in air (ii) forced cooling in water. Afterward the compressive and flexural strength of the specimens were examined. Surface cracking pattern and spalling in the specimens due to burning were also investigated. The result shows that the strength of concrete was considerably reduced due to burning in fire. The compressive strength of cylindrical specimens was decreased 60% and 44%, respectively, for forced and natural cooling of the specimens. In case of beam samples, the flexural strength was decreased 69% and 60%, respectively, for the forced and naturally cooled specimens. This research also reveals that the specimen cooled in air showed better performance compared to that cooled in water.

Keywords: *Concrete, compressive strength, fire, natural cooling, forced cooling.*

1. INTRODUCTION

The recent fire incidents are alarming the risk of fire and safety issues in Bangladesh. It is one of the major causes of huge damage and losses of properties in Bangladesh (Digester report, 2013). For building construction, concrete is one of the main load carrying parts of a reinforced concrete structure. However, the strength of concrete is significantly affected due to high temperature of fire. This may causes in undesirable structural failures (Ali et al., 2004; Georgali and Tsakiridis, 2005 and Xiao et al., 2005). During a fire, the temperature may reach up to1100°C in buildings and even up to 1350°C in tunnels (Hager, 2013). The exposure of concrete structural elements to high temperature leads to significant losses in its structural capacity due to the reduction in its strength of the concrete and most importantly due to loss of bond between aggregate and binding materials (Khalaf, 2017). So, the information on the degree of strength degradation is required for structural design of fire safety and structural repair after a fire incident. This evaluation of degree of deterioration of the concrete properties will enable engineers to decide whether a structure after exposure to high temperatures can be repaired rather than required to be demolished. Another essential concern is cooling of the concrete member during or after a fire incident. The method of cooling of a hot concrete member may affect its strength. If a concrete member is cooled slowly or naturally in air, the property of it may differ from that one cooled immediately in water. Because due to sudden cooling in water thermal stress is developed in the concrete. Thus, it is necessary to investigate the mechanical properties of concrete to predict about its lifetime and durability after a fire hazard. Hence, this study aims to investigate the effect of fire on the mechanical properties of concrete. The specific objectives of this study can be listed as below.

1. To investigate the effect of burning of concrete specimens in fire by testing the compressive and flexural strength of the burnt specimens.
2. To investigate the effect of cooling process on the hot specimens after burning in fire.
3. To investigate the physical effects of fire (spalling, cracks etc.) on the specimens.

2. METHODOLOGY AND EXPERIMENTAL PROGRAM

2.1 Materials

For the preparation of concrete, ordinary Portland cement, sylhet sand (fine aggregate) and locally available stone chips were used. The nominal size of the coarse aggregate was 19 mm. The properties of fine and coarse aggregates are presented in Table 1.

Table 1: Material properties.

Materials	Properties	Value
Coarse Aggregate	Specific Gravity	2.45
	Absorption, %	3.34
	Unit Weight, Kg/m³	1510
Fine Aggregate	Specific Gravity	2.54
	Absorption, %	2.74
	Fineness Modulus	2.65
	Unit Weight, Kg/m³	1615

2.2 Preparation of test Specimens

The casting of specimens was completed with a mix ratio of 1:1.5:3, giving a water to cement ratio of 0.635 with target strength of 3500 psi (24 MPa). At each time of casting of concrete specimen slump was determined and it was within 100-120 mm. Nine cylindrical specimens of diameter 100 mm and height 200 mm were prepared to determine the compressive strength of concrete after burning in fire. Among these nine specimens, three specimens were used as the reference specimens (virgin specimen), which were tested without burning in fire and other six specimens were burnt in fire. Out of six specimens, which were burnt in fire, three were cooled naturally in air and three were cooled forcedly in water. Similar to the cylindrical specimens, nine numbers of beam specimens of 100 × 100 mm cross section and 450 mm long were casted to examine the flexural strength of concrete. Among the nine specimens, three were kept for testing without burning (virgin specimens) and six were kept for burning in fire. Among the six specimens, which were kept for burning, three were cooled naturally in air and three were cooled forcedly in water.

2.3 Burning of the specimens

(a) (b)

Figure 1: Placing the specimens in the fire chamber; (a) cylindrical specimens, (b) beam specimens.

A fire chamber was prepared to burn the samples in fire as shown in Figure 1. The chamber was in a dimension of 500×500×600 mm. The specimens were kept inside the chamber and fire was produced by dry wood. The wood was placed by layer so that the sufficient oxygen could flow during fire. Then specimens were placed on a platform prepared by steel placing above the layer of fire wood. The fire temperature during burning of the specimens was about 800 – 1000°C. For both cases, the specimens were burnt in fire for a duration of one hour, without any imposed load on the specimens during the burning.

2.4 Cooling of the specimens

After burning the specimens, they were cooled in two processes. Among the six cylindrical specimens, three were immersed in water immediately after burning in fire and three were kept in open air for natural cooling. The first process of cooling represents the immediate cooling of the specimens which is resemble to the application of water in a building for the suppression of fire by the fire-fighters during a fire incident in that building and the second process resembles to the cooling of the structural members of a building after a fire incident without any application of water or any other fire suppression agent. The same two cooling processes were applied to beam specimens.

2.5 Testing of the specimens

After performing the burning and cooling processes, the specimens were tested in the laboratory. The cylindrical specimens were crushed by compressive testing machine and the ultimate capacity of the samples was recorded. The flexural strength of concrete beams was determined by testing the specimens following the three point loading test method. The results are summarised in the following sections.

3. RESULTS AND DISCUSSIONS

3.1 Compressive strength of the cylindrical specimens

In this study, nine cylindrical specimens were tested and the compressive strength of concrete was determined. Among the nine specimens, as described in the previous section, three were tested without burning (vergin sample), six samples were burnt in fire. The specimens were burnt for 60 minutes. After the burning the specimens in fire, three were kept in open air for natural cooling and three were immersed in a water chamber for immediate cooling. Afterward, the specimens were tested in compression testing machine and the results are summarised in Table 2.

Table 2: Test results of compressive strength of the cylindrical specimens.

Test condition		Sample No	Compressive Strength (MPa)	Average Compressive Strength (MPa)	Average % Loss of Strength with Respect to the Virgin Sample
Samples without burning in fire	Virgin sample	1	23.17	23.33	—
		2	23.44		
		3	22.95		
Samples burnt in fire	Natural cooling	1	14.63	12.95	44%
		2	12.40		
		3	11.82		
	Forced cooling	1	10.24	9.25	60%
		2	9.13		
		3	8.51		

The strength of samples, burnt and cooled at different ways, was compared to that of the virgin sample and presented in Figure 2. In the analysis it has been observed that the

strength of concrete was decreased considerably due to the burning in fire. The average compressive strength of the unburnt specimens was 23.33 MPa, whereas this strength for burnt samples was only 12.95 and 9.25 MPa, for naturally and forcedly cooled specimens, respectively. The average percent loss of strength due to burning in fire was 44% and 60%, for naturally and forcedly cooled specimens, respectively.

This study also reveals that the specimens cooled in air showed better strength compared to that cooled in water. The possible reason is that due to sudden cooling in water, the outer surface of the sample was cooled immediately but the inner part of the sample was in high temperature. As a result, thermal stress was developed in the sample which may lead to crack in the specimens. However, this requires further detail investigation to examine the specific reason for degradation of strength due to sudden cooling of hot concrete specimens in water.

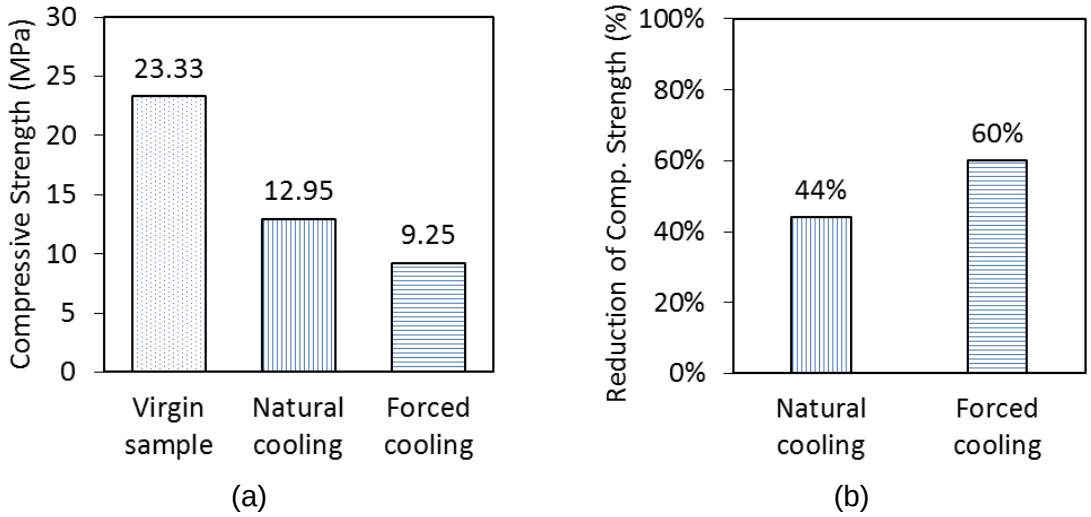

Figure 2: Comparison of test results of compressive strength of cylindrical specimens at different conditions; (a) compressive strength, (b) reduction of compressive strength.

3.2 Flexural strength of the beam specimens

Nine beam specimens were tested and the flexural strength of concrete was determined. The flexural strength from the tests of the specimens at ambient temperature and after exposed to fire at high temperature are presented in Table 3.

Table 3: Test results of flexural strength of the beam specimens.

Test Condition		Sample No	Flexural Strength (Mpa)	Average Flexural Strength (Mpa)	Average % Loss of Strength with Respect to the Virgin Sample
Specimens without burning in fire	Virgin sample	1	6.80	6.40	-
		2	6.45		
		3	5.98		
Specimens burnt in fire	Air cooling	1	2.90	2.55	60%
		2	2.48		
		3	2.28		
	Water cooling	1	2.27	2.00	69%
		2	2.02		
		3	1.85		

In the analysis, it has been observed that the strength of the specimens was significantly reduced due to burning in fire. The effect of cooling process on the strength of beam was also examined in the experiment, as it was done in the cylindrical specimens. In the analysis it has been found that the average flexural strength was 6.4 MPa at ambient temperature whereas this value was 2.55 MPa and 2.0 MPa for naturally and forcedly cooled specimens, respectively. Due to burning in fire, the flexural strength was reduced about 60% and 69% for natural cooling and forced cooling of the specimens, respectively. The result also reveals that due to sudden cooling of the sample in water, the strength of the concrete reduced more than the sample cooled slowly in natural air. The comparison of results is also presented graphically in Figure 3.

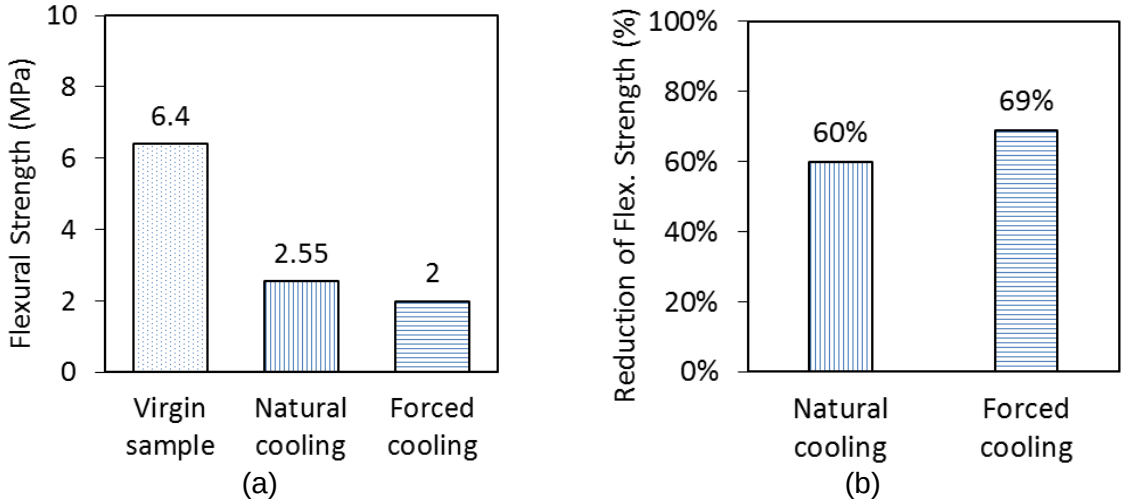

Figure 3: Comparison of test results of flexural strength of beam specimens at different conditions; (a) flexural strength, (b) reduction of flexural strength.

3.3 Spalling and cracks in the specimens

Spalling and cracking are common phenomenon in concrete during burning in. As concrete is not a product of a single material, when it is exposed to fire or high temperature, cracks develop in it due to the thermal incompatibility among the individual ingredient of concrete (i.e. coarse aggregate, fire aggregate and cement). Spalling results in loss of volume in concrete member and reduction in the load bearing capacity of the member. These phenomena were also observed in our experiment during the burning of the samples and shown in Figures 4. In the analysis, it has been found that the affected average surface area and volume of spalling in the tested specimens were 4% and 2.5%, respectively, for cylindrical specimen. Similarly, the reduction of area and volume was found to be about 0.64% and 0.52%, respectively, for the beam specimen.

(a) (b)

Figure 4: Spalling and cracks in specimens; (a) spalling in cylindrical specimen, (b) cracks in beam specimen.

4. CONCLUSIONS

This study was aimed to evaluate the behaviour of concrete beam exposed to fire. The effect of cooling process on the burnt specimens of concrete was also investigated. Nine cylindrical and nine beam specimens of concrete were prepared for test. Among the nine cylindrical specimens, three were used as virgin specimens, which were tested without burning in fire and six specimens were burnt in fire. To examine the effect of cooling process, out of six specimens burnt in fire, three were cooled naturally in air and three were cooled immediately in water. The natural cooling in air represents the slow process of cooling and forced cooling in water represents immediate cooling which is resemble to the suppression of fire by the fire-fighters during a fire incident in a building. Same procedure was also followed for the nine beam specimens. Subsequently, all of the specimens were tested in the compression testing machine.

The result shows that both compressive and flexural strength of concrete were reduced significantly due to burning in fire. The strength of concrete was also affected by the cooling process of the sample. It has been found that the strength of concrete was reduced more due to immersion in water compared to the samples cooled naturally in air. The compressive strength of concrete was reduced about 60% and 44% for forced cooling and natural cooling, respectively, compared to that of the unburnt specimen. In case of the beam specimens, the flexural strength of concrete was reduced, due to burning in fire, about 60% and 69%, for natural cooling and forced cooling of the samples, respectively. The spalling of concrete due to burning in fire was 2.61% and 0.52% in volume of the specimen for cylindrical and beam specimen, respectively. Further study is recommended to examine the effect of fire on reinforced concrete beam.

ACKNOWLEDGEMENTS

The authors want to express gratefulness to the technicians of the Engineering Materials Laboratory of Department of Civil Engineering, Khulna University of Engineering & Technology, for their warmth cooperation.

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