PERFORMANCE OF CONCRETE IN FIRE WITH PARTIAL REPLACEMENT OF CEMENT WITH WASTE CERAMIC POWDER

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ABSTRACT

Use of recycled waste materials in production of concrete are getting attention as it enables reuse of resources, facilitates an effective way of waste management and finally, lessens the effect on environment. However, as the fire incident is one of the most recurring disasters in Bangladesh in the last few decades, the performance of concrete produced with any recycled materials should be investigated. In this study, we used waste ceramic powder as a partial replacement of cement in production of concrete and then the performance of the concrete was examined after experiencing a fire incident. Nine beams of size 450×100×100 mm were produced in this work; among them three were produced without mixing any ceramic powder and named as controlled specimens and other six were produced mixing with 20% waste ceramic powder as partial replacement of cement. Among these six beam specimens prepared with ceramic powder, three were burnt in fire and other three were kept unburned. All of the specimens were tested and the flexural strength was determined. The result shows that the flexural strength of the beam specimens was 30% reduced due to the replacement of cement with ceramic powder; the strength of specimens was further 30% reduced due to burning in fire. The outcome of this research will be helpful to the building designers and engineers in designing a fire resistant building and also retrofitting of a structure after an incident of fire.

***Keywords**: Fire, Waste ceramic powder, Concrete with recycle waste material, Flexural strength.*

1. INTRODUCTION

Use of waste in concrete is increasing due to recycling of waste materials. Recycled coarse and fine aggregates are being used in the past few decades in concrete. Use of powder as a replacement of cement is also getting attention. Every year a huge amount of ceramic tiles become waste due to damage of tiles during conveying, handling and placing in position (Senthamarai & Devadas Manoharan, 2005). Ceramic and glass waste generation in six major cities of Bangladesh (namely, Dhaka, Chittagong, Khulna, Rajshahi, Barisal and Sylhet) was 21075 tonnes in 2005 and it is projected to reach to 128850 tonnes in 2025 (Alamgir and Ahsan, 2007). However, the uses of this waste material give advantages of recycling of the resources which in return contribute to protect the environment. This also provides an effective way to waste management and eventually lessen the cost of construction.

Recently, fire incidents in buildings and factories are frequently occurring hazard in the last few decades in Bangladesh (Department of Disaster Management, 2013). Therefore, there is a growing concern on the fire safety of a building. Though concrete is an incombustible material (Mróz, Hager & Korniejenko, 2016), the strength of a structural element (beam, column etc) can be considerably affected by a fire incident due to high temperature; this may cause in undesirable structural failures (Georgali & Tsakiridis, 2005; Xiao & Konig, 2005; EN 1992-1-2, 2004). The situation may be more dangerous, specially, when this element is made of concrete that contains waste ceramic powder as the ceramic powder does not contribute to the strength of concrete. Therefore, it is necessary to examine the consequence of fire on ceramic based concrete. Therefore, it is necessary to examine the consequence of fire on ceramic based concrete.

In this study, the effect of fire on the flexural strength of concrete, produced by incorporating waste ceramic powder as replacement of cement, has been investigated. The outcome of this study may be beneficial to the engineers, designers, and researchers to take into account the effect of fire during the design period and rehabilitation program after an incident of fire. Furthermore, the use of ceramic waste will reduce the emission of CO_2 due to the replacement of cement by the ceramic waste and resulting contribution to the environment.

2. MATERIALS AND METHODS

2.1 Materials

Locally available materials were used to produce concrete. The Ordinary Portland Cement (OPC) was used as binder, 19 mm downgraded stone chips was used as coarse aggregate, Sylhet sand was used as fine aggregate and ceramic powder as replacement of cement. The properties of materials were determined according to relevant ASTM standards as mentioned in Table 1.

Table 1: Material properties

Materials	Properties	Values	ASTM Standards
Coarse aggregate	Specific gravity (SSD)	2.85	ASTM C 127
	Unit weight, kg/m^3	1570	ASTM C 29
	Maximum size, mm	19	ASTM C 136
Fine aggregate	Specific gravity (SSD)	2.49	ASTM C128
	Fineness modulus	2.76	ASTM C 136
	Unit weight, kg/m^3	1615	ASTM C 29
	Absorption, %	4.55	ASTM C128

Ceramic white tiles were collected from the locally available ceramic waste. Afterwards, the tiles were grinded into powder and passed through #200 sieve (0.075mm). The chemical composition of ceramic waste powder varies according to the type of ceramic tile. The largest proportion of chemical in ceramic waste powder is SiO_2 which is around 65% and the second largest compound is Al_2O_3

which is about 18% (Effting, Folgueras, Güths, & Alarcon, 2018; Morris, Kanali, Gariy & Ronoh, 2018). Other chemical compounds are K_2O, Fe_2O_3, CaO, MgO, Na_2O, TiO_2 and some other compounds in a very minor quantity. The chemical composition of ceramic waste powder is presented in Table 2.

Table 2: Chemical composition of ceramic waste powder (Effting et al., 2010).

Materials	**Chemical Composition (%)**
SiO_2	63.36
Al_2O_3	18.2
Fe_2O_3	2.77
CaO	1.74
Na_2O	0.34
K_2O	3.87
MnO	0.02
TiO_2	0.80
MgO	2.04
P_2O_2	0.05

2.2 Casting and curing of beam specimens

Concrete mix design was performed according to ACI 211.1. The mix ratio was 1:2.75:3.5 with a mixing water to cement ratio of 0.63. The target cylindrical strength of the concrete was 27.5 MPa (4000 psi) and the achieved strength was 25.94 MPa (3775 psi) which has been considered as satisfactory. Nine rectangular beams of 450×100×100 mm in size were casted as shown in Figure 1.

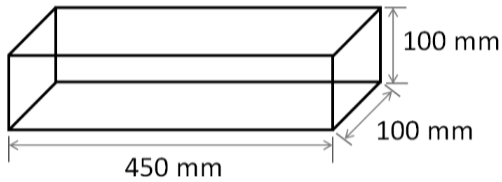

Figure 1: Size of the beam specimen

Three beams were prepared without mixing ceramic powder and six were prepared mixing with 20% ceramic powder as a replacement of cement. The concrete mixing was performed according to ASTM C192 using a standard concrete mixture. At each time of concrete specimen casting, slump was determined and it was within 50 mm. All of the specimens were cured for 28 days. The mixing ratios of concrete are presented in Table 3.

Table 3: Mix ratio of concrete

Sample	**Cement**	**Sand**	**Stone Chips**	**w/c ratio**	**Ceramic Powder**	**Number of samples**
Without ceramic powder (100% cement + 0% ceramic powder)	1	2.75	3.5	0.63	0	3
20% ceramic powder as a replacement of cement (80% cement+ 20% ceramic powder)	0.8	2.75	3.5	0.63	0.2	6

2.3 Burning and cooling of the specimens

A fire chamber of size 2.5 × 1.0 × 0.75 m was prepared to burn the beam specimens. The fire was produced by locally available natural wood. The specimens were burnt in fire for duration of 60 mins and the temperature of fire was 950 °C with a fluctuation of 50 °C at the contact surface of the specimens. The temperature was measured using a thermocouple. After burning, the specimens were kept for natural cooling. In this process, the specimens were cooled for about 24 hours in the air.

2.4 Testing of the specimens

Nine beam specimens were tested and the flexural strength was determined. Among the nine specimens, three specimens (without ceramic powder) tested without burning in fire. Among the other six specimens which were produced with ceramic powder, three were tested without burning in fire and three were tested after burning and cooling. Summary of the testing conditions of the specimens are presented in Table 3.

Table 3: Testing condition of beam specimens

Sample description	**Burning condition**	**Number of specimens**
Without ceramic powder (100% cement + 0% ceramic powder)	Unburnt (Controlled specimen)	3
20% ceramic powder as a replacement of cement (80% cement+ 20% ceramic powder)	Unburnt	3
	Burnt in fire	3

The specimens were tested in the laboratory using third-point loading method according to ASTM C78 and the rupture loads were determined. The experimental setup of the specimens is presented in Figure 2. The flexural strength was calculated by using the following equation –

$$\sigma = \frac{PL}{bd^2} \quad (1)$$

Where, σ = flexural strength, P = failure load, L = loading span length of the beam, b = width of the beam and d = depth of the beam.

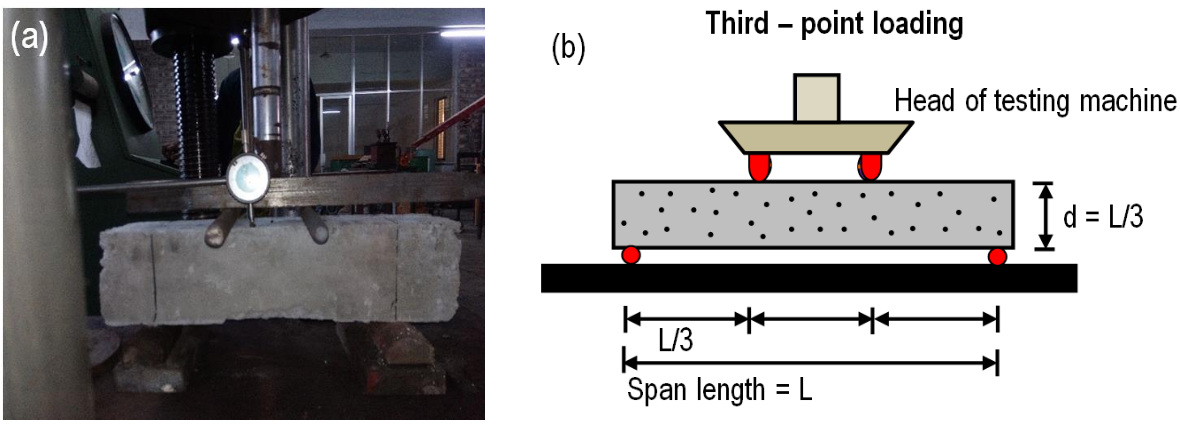

Figure 2: Flexure Test of Concrete by third-point loading method; (a) Photograph of test setup, (b) Schemetic view of test setup.

The weights of the specimens were also measured before and after burning. Afterward, the weight loss due to dehydration from the samples was calculated.

3. RESULTS AND DISCUSSIONS

In this study, nine beams of 450×100×100 mm in size were prepared of which three were controlled specimens produced without using ceramic powder and six were produced with using 20% ceramic powder. Among six specimens with ceramic powder, three beams were burnt in fire and other three were tested without burning in fire. After burning, three specimens were kept for cooling and all of them were tested for flexural strength.

The flexural strength of the specimens was tested at ambient temperature and the results are presented in the Table 4 and a graphical comparison is presented in Figure 3. The flexural strength of the controlled specimen was 5.17 MPa; however, the strength of the specimen was reduced about 30% due to replacement of cement with 20% ceramic powder. The strength of the beam with ceramic powder further 30% reduced due to burning in fire. This reduction of strength was due to the physical damage in the specimens which was caused by spalling and micro-crack in the specimens. The spalling in the specimens was caused due to generation of water pressure developed in the concrete and due to the generation of thermal incompatibility among the different ingredients of concrete. Water was leaking out from the specimens during burning which indicate the escaping of water from the specimens. The failure of the beam due to load is shown in Figure 4. The spalling in the specimens is also shown in Figure 5.

Table 4: Flexural strength of the beam specimens

Type of Specimens	**Test Conditions**	**Sl. no**	**Flexural Strength (MPa)**	**Average flexural Strength (MPa)**	**Reduction of Strength w.r.t. Controlled Specimen**
Without ceramic powder	Unburnt (Controlled specimen)	1	5.04	5.17	
		2	5.4		
		3	5.07		
With ceramic powder	Unburnt	1	3.6	3.55	30
		2	3.6		
		3	3.44		
	Burnt	1	2.04	2.10	60 (40)*
		2	2.1		
		3	2.16		

* 40% reduction of strength w.r.t. unburnt sample prepared with ceramic powder.

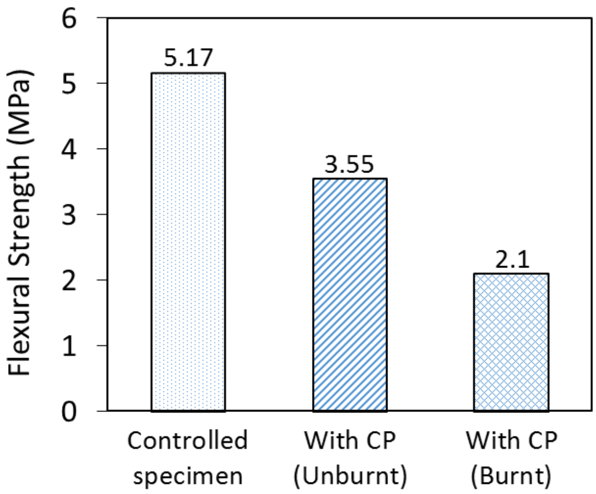

Figure 3: Comparison of flexural strength of beam specimens

Figure 4: Failure of the beam in third-point loading test.

Figure 5: Spalling of concrete in the beam due to burning in fire.

The weight of the sample was reduced due to escaping of water from the specimens. The average loss was about 5%. This loss was resulting from dehydration of the sample. The entrapped water in the specimens was coming out due to high temperature in the sample. Table 5 represents results on the weight loss of the specimens due to burning in fire.

Table 5: Weight loss of specimens due to burning in fire

Sl. No.	**Weight before burning (kg)**	**Weight after burning (kg)**	% Loss of Weight	Avg. % Loss of Weight
1	12.85	12.14	5.53	
2	13.99	13.26	5.29	5.07
3	13.45	12.86	4.40	

4. CONCLUSIONS

In this study, the effect of fire on the flexural strength of concrete prepared with waste ceramic powder as partial replacement of cement has been investigated. Nine beam specimens of 18x4x4 in size were prepared of which three were controlled specimens made without using ceramic powder and six were made with using 20% ceramic powder. Among the six specimens, three were burnt in fire and three were tested without burning. All of the samples were tested and the flexural strengths were determined. The result shows that the flexural strength of the beam specimens was 30% reduced due to replacement of cement with ceramic powder; the strength of specimens was further 30% reduced due to burning in fire. The use of waste ceramic powder as replacement of cement in concrete can be useful for both environmental and economic aspects. However, use of ceramic waste in concrete should be considered by taking into account the effect of fire in the concrete frame. Furthermore, this effect should be considered in case of repairing/refurbishing a building after an incident of fire.

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