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Transport properties of high volume fly ash or slag concrete exposed to high temperature

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HIGHLIGHTS

- Transport properties of HVFA or slag concretes were studied after high temperature.
- Transport properties of concrete increased significantly after exposure to 400 °C.
- Slag concrete behaved better than fly ash concrete for all high temperature.
- 30–50% fly ash or 50–70% slag replacement are optimal content for high temperature.

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ABSTRACT

In this study, transport properties of high volume fly ash or slag incorporated concretes after exposure to high temperature were investigated experimentally. Concretes with the content of 0%, 30%, 50%, 70% and 90% fly ash or slag were prepared and moist cured until 28 days. Fly ash and slag concrete samples were exposed to high temperatures at 400 °C, 600 °C and 800 °C for an hour in a computer controlled, electrically heated kiln. Then, the specimens were left to cool down to the laboratory temperature. Subsequently, absorption, void ratio, sorptivity, chloride ion permeability and compressive strength tests were carried out on the specimens. Test results showed that transport properties of concrete increased significantly after exposure to 400 °C, as well as, compressive strength dropped remarkably. Test results also revealed that inclusions of fly ash or slag influenced the transport properties considerably. It is concluded that a blend of, at about, 30–50% fly ash and 50–70% slag as a cement replacement is found to be the optimal content for exposure to high temperature. Rapid chloride permeability test results revealed that slag concrete bound more chloride than fly ash concrete. Slag concrete behaved better than fly ash concrete did under high temperature exposure for all case, some of slag concrete even behaved better than Portland cement concrete in terms of compressive strength reduction.

1. Introduction

Construction activities over the world use huge amount of cement and this activity results with CO_2 emission to atmosphere which is considered one of the large environmental problems [1]. Therefore, there is a need arises to get permanent and environment friendly binding materials that would reduce the Portland cement fabrication as one of large contributor to emission. One of the efforts to obtain more green-world friendly concrete is to substitute the amount of Portland cement utilized in concrete with by-product or waste materials [2]. The most worldwide available by-product materials are pulverized fuel or fly ash and blast furnace slag in fine powder form. Both, fly ash and slag are known as by-products from the industrial processes and embedding them in concrete production is one of the easiest and environmentally useful alternative to other conventional disposal methods. It is known that fly ash is accepted as a secondary product of thermal electrical power plants due to the combustion of powdered coal in the coal-firing furnaces. In general, many researchers utilized up to 30% fly ash in concrete as cement substitution. Nowadays, modern standards permit a substitution amount up to 55% cement with fly ash in cement mixture CEM IV. Fly ash can substitute 50–70% cement in high volume fly ash concrete. On the other hand, powdered amorphous slag is known as a valuable waste product from metal mostly steel industry [3–6]. Replacement amount of cement with slag varies from 30% up to 85%. However, generally 50% replacement ratio is used in most applications [2,5]. Fly ash and slag finely divided residues are widely used as a pozzolanic inclusion or partial substitution in cement to improve the engineering properties and resistance of concrete to environmental

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influence, and fabricate a concrete with high performance and strength [3,7].

In the literature, there are many researches present on the high volume fly or and slag concretes. On the other hand, there are few studies available regarding the performance of high volume fly ash and slag concretes subjected to high temperatures. The ingredients such as high volume fly ash and slag played a very important role on residual transport characteristics of concrete under high temperature exposure.

Rashad [5] investigated high temperature study using high volume fly ash in concrete blended with blast furnace slag. He replaced fly ash with cement at a level of 70% to produce high volume fly ash concrete. Fly ash concrete was altered by replacing slag with ash at level of 10% and 20% by weight. He concluded that slag inclusion showed undesired influence on high volume fly ash concrete. He also [2] studied on high volume slag pastes exposed to high temperatures. Author used slag as a replacement of Portland cement at levels of 0%, 85%, 90%, 95% and 100%, by mass. Test results showed that amount of optimal slag content was about 85% which showed remaining compressive strength found to be comparable to control concrete made with Portland cement only at 600 °C and 800 °C.

Poon et al. [8] studied on high strength concrete made with silica fume, fly ash and slag. They exposed the concrete produced to elevated temperature up to 800 °C. Based on their laboratory study, they concluded that 30% replacement amount of fly ash is an optimal value for high strength concrete after high temperature exposure. Furthermore, 40% replacement of cement with blast furnace slag in normal strength concrete was found to be an optimal replacement ratio.

Aydin and Baradan [9] worked on the influence of elevated temperature (300, 600, and 900 °C for 3 h) on pumice mortars containing fly ash at levels of 20%, 40% and 60%. Findings of laboratory study indicated that the pumice mortar made with inclusion of 60% fly ash showed the best performance in particular exposed to at 900 °C temperature.

Tang and Lo [10] studied on normal and high strength fly ash concrete that exposed to high temperatures ranging from 200 to 600 °C. Generally, a better performance was observed on fly ash concrete in terms of remaining properties of concrete including fracture and mechanical property at elevated temperature in comparison to control concrete.

Li et al. [11] investigated the influence of high temperatures (from 150 °C up to 700 °C) on concrete containing blast furnace slag, at replacement of 10%, 30% and 50% by mass of cement. Study showed that the temperatures above 400 °C were more effective in terms of remaining compressive strength. Moreover, after exposure to 500 °C, the remaining percentage of compressive strength of concrete containing 0%, 10%, 30% and 50% slag were 60, 62, 44 and 41 MPa, respectively.

There are high temperatures studies on concrete made with fly ash or and slag up to 40% and 50% replacement level, however, high temperatures studies on concrete containing fly ash or slag more than 50% replacement ratio is scanty. The main purpose of this investigation is to evaluate the transport properties of very high volume fly ash or slag incorporated concretes before and after exposure to high temperature. A testing program was prepared with four different (30%, 50%, 70%, and 90%) fly ash or slag content to evaluate the effects of high volume usage of fly ash and slag in concrete on transport properties when exposed to high temperatures.

2. Experimental investigations

2.1. Materials and mix proportions

Portland cement (PC), class F fly ash and ground granulated blast furnace slag were used in the production of the concrete mixtures. Oxide compositions and physical characteristics of cement, fly ash and slag are presented in Table 1. Natural fine and coarse aggregate were used. Maximum size of aggregate was 19 mm. Particle size distribution and physical properties of aggregates used were given in Table 2. A very effective polycarboxylate based superplasticizer was used. Its specific gravity was 1.1 and pH values were in the range of 5–7. Superplasticizers were used in the production of concrete to maintain workability.

Table 1
Oxide composition and physical properties of cement, fly ash and slag.

	Cement	Fly ash	Slag
Oxide Comp.			
SiO_2	19.6	59.5	38.4
Al_2O_3	4.9	22.2	10.6
Fe_2O_3	3.1	3.9	0.8
CaO	61.4	5.6	34.2
MgO	3.0	–	6.9
SO_3	3.6	0.2	1.5
Na_2O	0.7	2.7	0.2
LOI	2.3	0.2	3.1
Physical			
Blaine (cm^2/g)	3870	3060	4300
+45 μm (%)	3.0	9.6	1.0
Density (g/cm^3)	3.15	2.18	2.87

The mixture ingredients of the concrete are provided in Table 3; proportion to coarse aggregate to fine aggregate was 1. As it is seen in Table 3, nine concrete mixtures were prepared. These include one control concrete made with only cement and eight concretes with 30%, 50%, 70%, and 90% cement replacement by fly ash or slag with a water binder materials ratio as 0.35. Cement or binder dosage was 500 kg/m^3 for all concrete mixtures.

2.2. Casting and curing of test specimens

A laboratory concrete mixer with 50 L capacity was utilized in preparation of all concrete mixtures. Mixture time was 5 min for each mixture. Slump tests were measured to determine the workability in accordance with ASTM C143 [12]. Concrete mixes was designed to have a constant slump of 190 ± 10 mm. To maintain that constant workability for each fresh concrete mixture, different amount of superplasticizer presented in Table 3, was used. Mechanical vibration was applied for casting and compacting the fresh specimens. Cylinders with a dimension of Ø100 × 200 mm were prepared from each mixture to determine transport characteristics. The measured properties were water absorption, water porosity, water sorptivity and rapid chloride permeability. After preparing specimens, they were stored in the casting room for 24 h. Specimens were covered by wet burlap to prevent water loss. After demolding the specimens, they were taken to moist curing chamber, and maintained at 21 ± 1 °C and more than 95% relative humidity until testing at 28 days.

2.3. Test procedures

Transport tests cover the determinations of percent absorption, percent voids, water absorption rate and chloride ion permeability of concrete produced. After 28 days curing, disc samples cut from Ø100 × 200 mm cylinder specimens were used for transport tests measurement. Thickness of disc samples was 50 mm. High temperature tests were also conducted on the Ø50 × 100 mm disc samples. Specimens were exposed to 400 °C, 600 °C and 800 °C temperatures for 1 h in a computer controlled electrically heated kiln. Temperature increment in furnace was set at 5 °C/min. After exposure to high temperature, the specimens were cooled in the furnace for 24 h to cool down to room temperature. After cooling period, three specimens were subjected to transport properties tests. Water absorption and porosity of concrete and sorptivity tests were carried out according to ASTM C642 [13] and ASTM C1585 [14], respectively. Water sorptivity rate was measured at 1, 5, 10, 20, 30, 60, 120, 240, 360, 480 and 600 min after starting the test procedure. The sorptivity test setup is illustrated in Fig. 1.

ASTM C1202 [15] specification was taken as a reference for the rapid chloride permeability test (RCPT) measurement. Disc specimens with 50 mm thickness were put between two cells. One of the cell was filled with 3.0% NaCl solution and other cell was filled with 0.3 N NaOH solution. Electrical current with 60 V was applied between cells for 6 h, then total charge passed in coulomb value was recorded by computer, it was taken as the chloride ion penetration value. The rapid chloride permeability test setup is shown in Fig. 2.

3. Experimental results

3.1. Absorption results

In the current investigation, the absorption value of specimens were used to evaluate the most undesired condition of high tem-