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Full Length Article

Mechanical properties and spalling at elevated temperature of high performance concrete made with reactive and waste inert powders

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A B S T R A C T

In this article, the efficiency of waste glass powder was investigated in enhancing the mechanical properties of concrete at high temperature. Chemical composition of this powder reveals that it plays good role as effective inert very fine material in concrete strength improvement. Conventional reactive pozzolanic powder of silica fume was used also in present work to show the degradation degree in concrete strength under firing in comparison to concrete made with waste glass powder. The experimental program was comprised of tests for examining fire resistance and mechanical properties of high strength concrete (HSC) after firing. Fifty-six concrete cylinders and prisms were manufactured for measuring their compressive and flexural strengths, modulus of elasticity and stress-strain behavior at high temperature. Failure modes were considered also for the specimens after fire exposure. Results demonstrate the great role of waste glass powder in conserving residual strength at high temperature. Accordingly, it is proved that the HSC made with waste glass powder has strength at high temperature more than that for concrete fabricated by silica fume.

1. Introduction

The functional properties of infrastructures have been improved during recent years via using advanced constructional materials. Thus, high strength concrete with a compressive strength up to 120 MPa or more was widely utilized in concrete structures [1]. Most types of HSC can be fabricated by ultra-fine powder of silica fume to get excellent strength and durability [2]. High performance concrete is usually made with high dosage of cement, silica fume, superplasticizer, fine aggregate [3] and steel fibers as optional component [4]. This material with superior behavior has been employed extensively in civil engineering works such as prestressed concrete elements, nuclear storage structures, marine constructions, petroleum projects, bridges, etc [5,6]. Glass powder can be used in lieu of silica fume to produce HSC [7–11]. Nowadays, the employment of waste materials such as waste glass powder is interesting for civil engineers as eco-technology to protect the environment. Very fine grading of glass powder plays a great role to make it good filler which results in high performance of concrete. It is worth to mention that the waste glass powder with particle size of 100 μm or smaller show a pozzolanic reactivity in concrete [7].

Fire is regarded one of the main risks for concrete constructions. The exposure to high temperature induces some defects in concrete structures, namely, cement paste dehydration, increasing in porosity, expansion and creep, high pore pressure, and spalling [12,13]. Measurements of concrete fire safety are represented in terms of firing duration of structures and their resistance which depends on heat transmission, structural stability, and integrity [14,15]. In general, concrete provides reasonable strength under fire in comparison to the other constructional materials [16] due to the slight thermal conductivity of concrete inert components (aggregates). The performance of concrete structural elements under fire is partially based mechanical and thermal characteristics of the used concrete. These properties are altered with respect to the associated fire temperature. In the other words, concrete behavior at elevated temperatures is dependent on the characteristics of concrete components. Accordingly, it was proved that the deterioration of HSC strength after firing is quicker than that of normal concrete [17–22] due to the low porosity and high density of HSC which induce high pore pressure during heating.

The compressive and tensile strengths and other properties of HSC at elevated temperature have been investigated in previous studies [23–44]. However, studies concerning the effect of heating

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Table 1
Characteristics of the used cement.

Property	Initial setting time	Final setting time	Specific gravity	Fineness
Test results	151 min	2.25 h	3.2	306 m^2/kg

Table 2
Properties of the silica fume.

Tests	Results
% Retain on 45 μm sieve	2
Bulk density in kg/m^3	1002
Pozzolanic activity index	128
% Moisture content @105 °C	0.06
% Loss on ignition @750 °C	0.38
% Silicon dioxide (SiO_2)	92.4

Fig. 1. The used waste glass powder.

Table 3
Chemical composition of the used waste glass powder.

Composition	% by Mass
SiO_2	67.78
Al_2O_3	3.00
Fe_2O_3	0.68
CaO	24.32
MgO	2.60
SO_3	1.00
Na_2O	1.99
K_2O	0.36
TiO_2	0.10
P_2O_5	0.11
MnO	0.03
SrO	0.76

Table 4
Physical properties of the used waste glass powder.

Specific gravity	2.60
Density	1.3 gm/cm^3
Fineness passing 850 μm	95%

Table 5
Mix proportions of high strength concretes.

Constituent	HSC with silica fume	HSC with waste glass powder
Cement (kg/m^3)	934	934
Silica fume (kg/m^3)	234	–
Glass powder (kg/m^3)	–	234
Fine sand (kg/m^3)	1030	1030
Superplasticizer (kg/m^3)	47	47
Steel fiber (kg/m^3)	40	40
Water (kg/m^3)	210	210
W/C (Ratio)	0.225	0.225

Fig. 2. High temperature furnace.

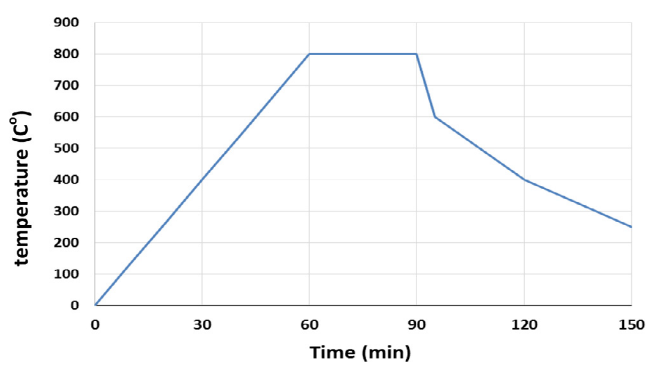

Fig. 3. The used furnace temperature function in present study.

Table 6
Strength of the control HSC samples at 25 °C.

Sample designation	Compressive strength (MPa)	Flexural (tensile) strength (MPa)	Initial modulus of elasticity (GPa)
RPC-C-SF25[a]	142	–	52.8
MRPC-C-GP25[b]	81	–	40.4
RPC-P-SF25[c]	–	6.7	–
MRPC-P-GP25	–	5.9	–

[a] RPC is HSC made with silica fume, C is Cylinder, SF is Silica Fume, and the last number is represented temperature in°C.
[b] MRPC is HSC made with waste glass powder, and GP is Glass Powder.
[c] P is Prism.