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Experimental study on high temperature properties of carbon fiber sheets strengthened concrete cylinders using geopolymer as adhesive

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Abstract

Twenty plain concrete cylinders, including unconfined cylinders and confined cylinders with 1, 2 and 3 layers of carbon fiber sheets using geopolymer as adhesive, were tested in axial compression at ambient temperature and after exposure to elevated temperatures, to investigate the strengthening effect of carbon fiber sheet-geopolymer system. The failure modes, load-displacement curves, axial and hoop strains of confined cylinders were compared with that of unconfined cylinders. The failure modes of confined cylinders after exposure high temperature are similar with those of ones at room temperature. When temperature is up to 300^{o}C, the compressive strength of confined cylinders is a little more than that of ones at room temperature, and the ratio of increase on compressive strength which is 106.4% is double as that of at room temperature. However, the ductility of confined cylinders decreases significantly after exposure elevated temperatures. From stress-strain curves, it can be found that there is no obvious degradation on mechanical property after exposure to high temperatures. It shows that carbon fiber sheet-geopolymer system has an excellent resistance to high temperatures.

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Keywords: Concrete cylinders; Geopolymer; Carbon fiber sheets; High temperature; Compression

1. Introduction

Externally bonded fiber reinforced polymer (EB-FRP) is widely used for strengthening concrete structures, due to its advantages of light weight, high strength, corrosion resistance, and ease to application. In EB-FRP system, organic matrices, such as epoxy resin, are used as a primary adhesive. Organic matrix exhibits high strength at ambient temperature, but low resistance to high temperatures. The glass transition temperature (T_g) of epoxy resin is only about 82 ^{o}C [1], which results in its great strength degradation at high temperatures. In addition, emission of poisonous gas occurs when epoxy resin is in fire [1]. To deal with the drawbacks of organic matrix, inorganic matrices were developed recently [2,3,4,5]. Among the many types of inorganic matrices, a new class of material called geopolymers, attracted researchers' attention in the past decades [6-16].

Geopolymer is synthesized by alkaline solutions (such as sodium silicate and potassium silicate [6-16]) activating aluminosilicate source materials (such as metakaolin, fly ash, and slag [6-16]). Compared to organic matrix, inorganic geopolymers have advantages of resistance to high temperature, resistance to UV radiation and minimal toxic smoke under fire exposure.

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The mechanical properties of geopolymers, such as compressive and bending strength, at ambient temperature and after exposure to high temperatures, were extensively studied in literatures [9]. The bond performance using geopolymer as adhesive is also been explored recently. Menna C. et al. [1] used metakaolin-based geopolymer as adhesive to paste steel cord confining RC beams. Test results showed that geopolymer has good adhesion between concrete substrate and steel cords. Toutanji and Deng [3] compared the strengthening effect of carbon fiber sheets bonded with organic and inorganic matrices on reinforced concrete beams. Results showed the carbon fiber sheet-geopolymer (CFSG) system is effective in increasing strength and stiffness of reinforced concrete beams as that of organic matrix at ambient temperature. Toutanji and Zhao [4] reported that the ductility of reinforced beams strengthened by CFSG system is greatly lower than that of un-strengthened beams, but the load carrying capacity of strengthened beams increases with an increase in layers of carbon fiber sheets. Kurtz S. and Balaguru P. [5] also found that the inorganic and organic systems can provide comparable performance with respect to the increase in strength of RC beams strengthened by carbon fiber sheets. The above researches demonstrated that geopolymers exhibit similar bond properties with carbon fibers sheet and concrete substrate at ambient temperature. However, as for the high temperature properties of CFSG system, there is a lack of experimental data.

In this paper, 20 plain concrete cylinders, including unconfined cylinders and confined cylinders with carbon fiber sheets bonded by geopolymers, were tested in compression at ambient temperature and after exposure to elevated temperatures, to investigate the strengthening effect of CFSG system at ambient and high temperatures. The studied parameters include the number of fiber layers and the exposure temperatures.

2. Experimental program

The experimental program is composed of a large number of compression tests at ambient temperature and after exposure to elevated temperatures (100, 200, 300 ºC), on unconfined plain concrete cylinders and confined cylinders with carbon fiber sheets using geopolymers as adhesive.

2.1. Raw materials

The primary aluminosilicate source material used in geopolymer is metakaolin (MK) and fly ash (FA) mixture. The chemical composition of MK and FA is shown in Table 1. Commercially produced metakaolin with an average particle size of 0.017 mm, was supplied by Shanxi Jinkunhengye Ltd., China. Low calcium fly ash, with an average particle size of 0.032 mm, was supplied by Guangzhou Huangpu Power Plant. Potassium silicate solution with SiO_2/K_2O molar ratios of 1.0 was used as alkaline-silicate activator. Chopped carbon fibers (CF), with a content of 0.5 percent of MK-FA blend precursor in mass, were added to precursor as reinforcement agent. The length, diameter and density of chopped carbon fibers are 6 mm, 7 μm and 1.76-1.80 g/cm3 respectively.

Table 1. Chemical composition of FA and MK (wt, %)

	SiO_2	Al_2O_3	CaO	Fe_2O_3	TiO_2	SO_3	MgO	K_2O	P_2O_5	SrO	Na_2O	ZrO_2	MnO	Loss on ignition
FA	51.35	44.24	0.13	0.98	0.9	0	0.48	0.08	0.45	0	0.16	0	0.01	0.72
MK	45.3	41.2	3.77	3.18	1.62	0.75	0.44	0.38	0.36	0.11	0.09	0.08	0.05	2.4

Geopolymer pastes were synthesized with fly ash and metakaolin mixture (1:1) and alkali silicate solutions. The liquid/solid (L/S) mass ratio was 0.4 (the liquid consists of solvent in alkali silicate solutions; the solid materials consist of fly ash, matekaolin and solute of alkali silicate solutions). Geopolymer pastes were prepared by hand-mixing MK-FA precursor and short fibers for 2 min, then adding alkaline silicate solution and mixing all ingredients in a mixer about 7 min to ensure they were mixed thoroughly.

The materials of concrete cylinders used in this study were Type I Portland cement (Grade 32.5), tap water, crushed limestone with size of 5 to 25 mm and natural sand with size less than 5 mm. The mix proportion of ordinary concrete is listed Table 2. The water-to-binder ratio of concrete was 0.47.

Table 2. Mix proportion of concrete: kg/m^3

Cement	Fine aggregate	Coarse aggregate	Water
372	593	1260	175

The unidirectional carbon fiber sheets were used to confine concrete cylinders. The main parameters of the carbon fiber