EXPERIMENTAL STUDY ON HIGH TEMPERATURE MECHANICAL PROPERTIES OF ALUMINATE CEMENT MORTAR MIXED WITH FIBER

by

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The aim of the present paper is to study the mechanical properties of aluminate cement mortar mixed with different chopped fibers under high temperature. The specimens with a size of 40 mm × 40 mm × 160 mm is treated at various temperatures of 25 °C, 200 °C, 400 °C, 600°C, and 800 °C. The compressive and flexural strength of the aluminate cement mortar and its micro-structures are tested. The results show that the chopped steel fibers and basalt fibers are effective in improving the high temperature mechanical properties of aluminate cement mortar. When the volume fraction of chopped steel fibers is 2%, the compressive strength and flexural strength of the test block treated at the temperature of 800 °C increase by 18.3% and 128.6%, respectively.

Key words: *aluminate cement, chopped steel fiber, chopped basalt fiber, high temperature, electron microscope scanning*

Introduction

The textile reinforced concrete (TRC) is a new type of fiber-reinforced composite material with the advantages of good crack resistance, bending resistance and high bearing capacity [1]. They can be constructed easily and consequently can be used for the reinforcement and repair of concrete structures [2]. Generally, the TRC used for reinforcement is located on the surface of the building structure. Consequently, TRC needs to have excellent high temperature resistance to cope with high temperature, fire and other emergencies. Tlaiji *et al.* [3] conducted a high temperature test on TRC made of the cement matrix and glass fiber woven mesh. The results show that the high temperature cooling process in the range of 25 °C to 150 °C has a positive effect on the mechanical properties of the TRC structure, and the residual ultimate strength and maximum axial strain of the TRC structure drop sharply when the temperature rises from 150 °C to 600 °C. Results from Nguyen *et al.* [4] show that the chopped glass fibers can improve the cracking mode of the structure and increase the axial strain and mechanical properties after high temperature treatment.

The steel fiber added to the concrete can alleviate the damage of the concrete at high temperature, inhibit the volume change, improve the deformation resistance ability, and ameliorate the mechanical properties after high temperature treatment [5, 6]. The excellent crack resistance and toughness of basalt fiber can inhibit the development of cracks, reduce the possibility of cracking, enhance the toughness and stability and improve the mechanical properties of structures under high temperature [7]. Polypropylene fiber can alleviate the internal damage

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and deterioration and reduce the pore growth rate and strength loss rate of concrete which play a significant role in improving the mechanical properties of concrete under high temperature [8]. After high temperature treatment, the hydration products of concrete are dehydrated and decomposed seriously. Meanwhile, the slurry structure is loose and porous, and the elastic modulus and compressive strength decrease sharply [9, 10]. Active admixtures such as fly ash, silica fume and metakaolin can significantly improve the high temperature performance of concrete [11]. Aluminate cement is a cement mainly made of calcium aluminate, which is of rapid hardening and high temperature resistance. Its hydration products can improve the high-temperature mechanical properties of concrete [12].

In this paper, aluminate cement is used as the main cementitious material. The steel fibers and basalt fibers are added to the aluminate cement mortar. The working performance, mechanical properties and micro-morphology changes of aluminate cement mortar after high temperature treatment would be analyzed. The influence mechanism of chopped steel fiber and chopped basalt fiber on aluminate cement mortar would be revealed.

Experimental design

Materials and mix proportion

The CA50-A600 type aluminate cement are produced by Zhengzhou Jianai Special Aluminate Cement Co., Ltd. Grade II fly ash is produced in Gongyi City, Zhengzhou, Henan province in China. The content of silica in silica fume is 98%. Figure 1 shows the morphology of the chopped steel fibers and chopped basalt fibers used in this paper and their physical properties of the chopped steel fibers and chopped basalt fibers are summarized in tab. 1.

(a)

(b)

Figure 1. (a) Chopped steel fiber and (b) chopped basalt fiber

Table 1. Physical properties of fiber

Fiber type	Length [mm]	Single diameter [m]	Density [gcm^{-3}]	Strength of extension [MPa]	Elasticity modulus [GPa]
Chopped steel fiber	6	120	7.8	3000	210
Chopped basalt fiber	7	120	2.7	2400	96

Polycarboxylic acid high performance water-reducing agent with a water-reducing rate exceeding 25% and a solid content of 25% is used. Ordinary machine-made sand with two particle sizes ranging from 0~0.6 mm and 0. 6~1.2 mm and tap water are used, tabs. 2 and 3.

Table 2. Mix proportion of concrete [kgm^{-3}]

Cement	Fly ash	Silica fume	Fine aggregate (0-0.6 mm)	Coarse aggregate (0.6 mm-1.2 mm)	Water	Water reducing agent
682	243.5	48.7	405	810	389.6	13.64

Table 3. Test groups

Specimen	Volume fractions of chopped steel fiber [%]	Specimen	Volume fractions of chopped steel fiber [%]
CAS-0.5	0.5	CAB-0.25	0.25
CAS-1	1	CAB-0.5	0.5
CAS-1.5	1.5	CAB-0.75	0.75
CAS-2	2	CAB-0.1	1

Note: When the fiber content is 0, the specimen is called CA – coarse agregate.

Experimental scheme

A total of 135 specimens with a size of 40 mm × 40 mm × 160 mm were prepared. The fresh mortar was firstly poured into the trial mold without vibrating. Then they were demoulded after 24 hours in the standard curing room, fig. 2. After 28 days of standard curing, the compressive strength and flexural strength of the specimens were tested.

Figure 2. Specimens curing

A muffle furnace was used to heat the specimens. Before heating, the test block was dried in an oven for 1 hour at temperature of 60 °C, and then they were weighed. At a heating rate of 10 °C per minute, the dried specimens were heated to the target temperature of 25 °C, 200 °C, 400 °C, 600 °C, and 800 °C. After 2 hours, they were taken out to cool to room temperature naturally and weighed.

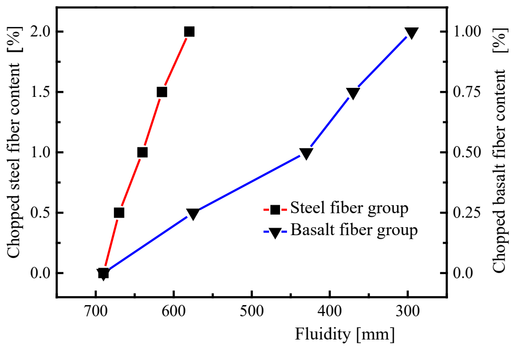

Figure 3. Fluidity of the aluminate cement mortar with different fibers

Results and discussion

Fluidity

Figure 3 shows the expansion changes of aluminate cement mortar with different fibers. It can be seen that the degree of expansion has a downward trend with the increase of fiber content. On one hand, when the basalt fiber content is 0.25%, 0.5%, 0.75% and 1%, the expansion degree of aluminate cement mortar is reduced by 16.7%, 37.7%, 46.4%, and 57.2%, respectively. On the other hand, when the steel fiber content is 0.5%, 1%, 1.5%, and 2%, the expansion degree of aluminate cement mortar is reduced by 2.9%, 7.2%, 10.9%, and 15.9%, respectively. Obviously, the expansion degree of aluminate cement mortar with basalt fiber is lager than that with steel fiber. It indicates that the basalt fiber has a greater influence on the fluidity of concrete.

Mass loss

Figure 4 shows the changes of the mass loss rate of test blocks treated by different temperature. At the temperature of 200 °C, the mass loss is low because only the free water in the test block is evaporated [13]. However, in the range of 200~400 °C, the mass loss rate of the test block significantly increases by 215%, which is result from the poor volume stability of the aluminate cement. Corresponding, the porosity of the test block also increases significantly. When the temperature reaches 800 °C, the mass loss of the test block gradually stabilizes due to that only a small portion of the hydration products are dehydrated and decomposed into Al_2O_3.

In addition, at the temperature of 600 °C, the mass loss of aluminate cement mortar increases obviously with the fiber content. For example, the mass loss rate of mortar increases from 12.4% to 14.3% when the steel fiber content increases from 0.5% to 2% while that increases from 12.53% to 13.3% when the basalt fiber content increases from 0.25% to 1%.

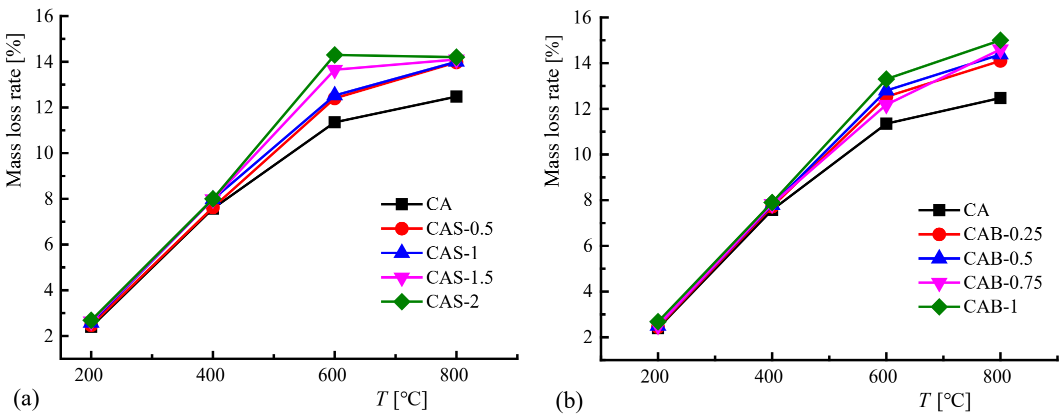

Figure 4. (a) The mass loss rate of aluminate cement mortar mixed with the chopped steel fibers and (b) the mass loss rate of aluminate cement mortar mixed with the chopped basalt fibers group

Compressive strength

Figure 5 shows the changes of compressive strength of aluminate cement mortar with respect to the temperature. It can be seen that the compressive strength of aluminate cement mortar tends to decrease with the increase of temperature. At the temperature of 25~400 °C, the compressive strength decreases rapidly and the residual rates of compressive strength of all test blocks are within 45% when the temperature is 400 °C. According to the study [14], the peraluminate cement is prone to hydration at 250~330 °C. Therefore, the mass loss of concrete increases and the stability of the test block decrease, resulting in a rapid decline in the compressive strength of concrete.

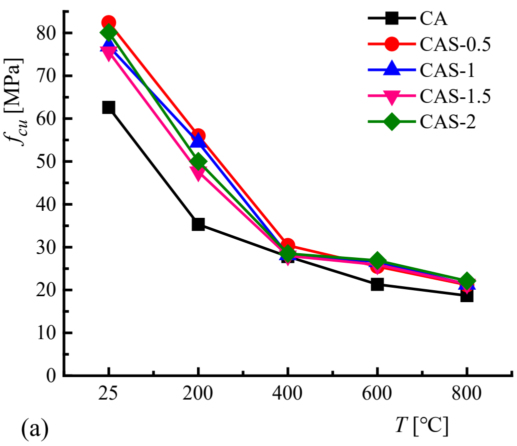

Figure 5. (a) Changes of the compressive strength of aluminate cement mortar with the chopped steel fiber under different temperature and (b) changes of the compressive strength of aluminate cement mortar with the chopped basalt fiber under different temperature

As shown in fig. 5, the type and content of fiber have an important influence on the compressive strength of aluminate cement mortar. Obviously, the compressive strength of aluminate cement mortar is enhanced due to the addition of chopped steel fiber or basalt fiber. The influence of fiber content on the compressive strength of aluminate cement mortar is shown in fig. 6. It can be seen that he compressive strength of the specimens can significantly increase with the increase of the fiber content at 600 °C and the increase rates under adding the steel fiber and basalt fiber are 20~26% and 4~30%, respectively. However, at other temperatures, the improvement effect is not obvious.

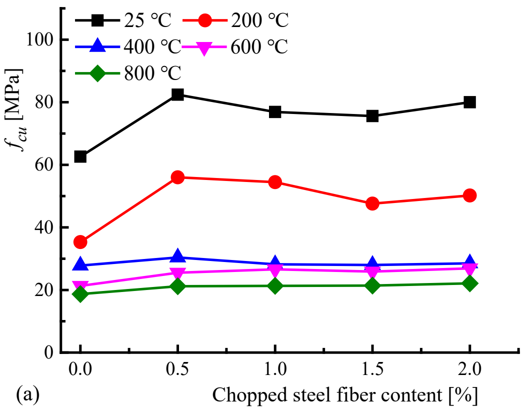

Figure 6. Effect of the fiber content on the compressive strength of aluminate cement mortar at different temperature

There are three reasons for the results:

– The steel fiber can alleviate the damage of the concrete, inhibit the volume change of the specimens, and improve the compressive strength.
– Compared with basalt fiber, thermal conductivity of steel fiber is better and it can alleviate the thermal damage caused by excessive temperature difference between the inside and outside of concrete.

– Basalt fiber can reduce the probability of concrete bursting at high temperature, but it maybe not significant in improving the compressive strength of concrete.

Flexural strength

Figure 7 shows the Changes of flexural strength of the specimens with respect to the temperature. With the increases of temperature, the flexural strength of the specimen trends to reduce. At the same temperature, the flexural strength gradually increases as the fiber content increases. However, under higher temperature, there are huge differences in the improvement of flexural strength of aluminate cement mortar with different fibers. Obviously, adding the steel fiber to the aluminate cement mortar can improve its flexural strength more significantly. The reason for above results may be the different cohesion between the two fibers and mortar matrix under high temperature. The steel fiber is of better excellent thermal conductivity than the basalt fiber reducing influence of temperature difference on the decomposition of mortar, which results in lower loss of the adhesion between the steel fiber and the slurry.

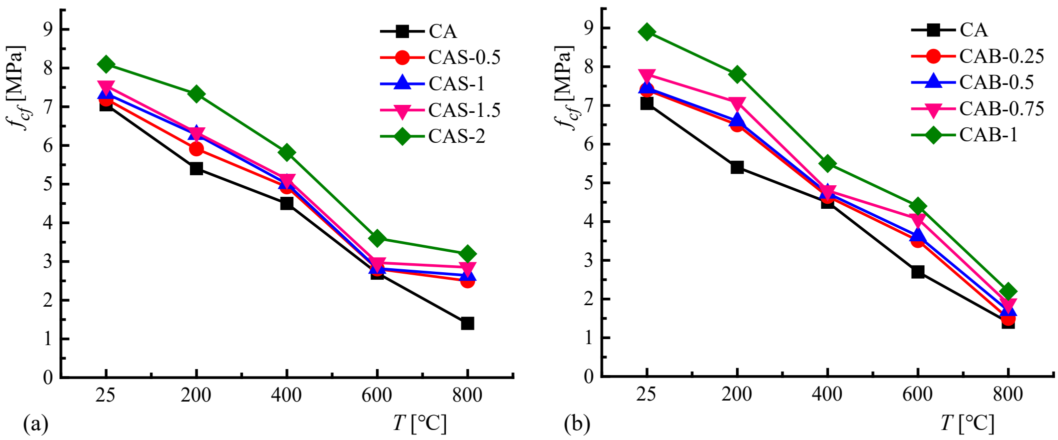

Figure 7. (a) Changes of the flexural strength of aluminate cement mortar with the chopped steel fiber under different temperature and (b) changes of the flexural strength of aluminate cement mortar with the chopped basalt fiber under different temperature

Micro-structure characteristics of the aluminate cement mortar

Based on the SEM experiments, the micro-structure changes of aluminate cement mortar are shown in fig. 8. It can be observed from fig. 8(a) that the hydrated product of the aluminate cement (C_2ASH_8) is of a crystalline block structure at 25 °C. After the high temperature treatment with 600 °C, some undecomposed C_2ASH_8 crystals and $C_{12}A_7$ crystals can be still observed, fig. 8(b). However, at the temperature of 800 °C, the surface of the slurry structure is seriously damaged as a result of the decomposition of unhydrated cement particles and fine aggregate components, as well as the dehydration and decomposition of AlO(OH). Further, fig. 8(f) is an enlarged view of the slurry structure at 800 °C. Figure 8(g)-8(i) show the micro-morphology of the aluminate cement mortar with steel fiber at 600 °C and 800 °C. There are obvious cracks in the pores of the basalt fiber and around it. Therefore, the increase of strength of aluminate cement mortar is not obvious or even worse.

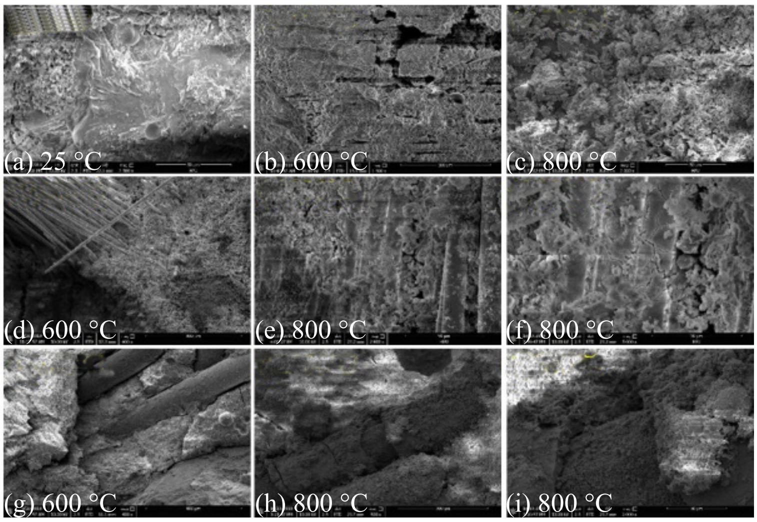

Figure 8. Micro-structure characteristics of the aluminate cement mortar under different temperature

Conclusion

At the present work, mixing the chopped steel fibers and basalt fibers into aluminate cement mortar can reduce its flow properties. The chopped steel fibers would improve the mass loss of aluminate cement mortar after high temperature treatment, while the chopped basalt fibers have less effect on that. The chopped steel fiber and basalt fiber have better advantage in improving the flexural strength than the compressive strength of aluminate cement mortar. Specially, when 2% chopped steel fibers and 0.75% chopped basalt fibers are added, the aluminate cement mortar has better flow properties, compressive strength and flexural strength. In addition, the mechanical properties of aluminate cement mortar with the steel fibers and basalt fibers are also improved at high temperature. Compared with the chopped basalt fibers, the chopped steel fiber is well bonded to the matrix without large cracks and pores. Meanwhile, the microstructure of the slurry is continuous and dense, and the damage degree at high temperature is low.

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Nomenclature

f_{cf} – flexural strength, [MPa]

f_{cu} – compressive strength, [MPa]

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