D-2-8 Surface waterproof, fast setting and high early strength repair material derived from metakaolin geopolymer by hydrophobic modification

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ABSTRACT: Protecting the surface of geopolymer is essential for improving its durability under certain exposure conditions. In this work, a novel surface waterproof, fast setting geopolymer repair material was proposed based on alkali activation of metakaolin and hydrophobic modification. The experimental results show that surface hydrophobic modification of geopolymer is completely achieved due to the increasing static water contact angle on the surface of modified geopolymer from 19° to 95° and the floating of specimens on water level after surface hydrophobic modification. Surface hydrophobic modification of geopolymer matrix obviously improves waterproof properties and reduces water absorption of geopolymer after 28 days of exposure. This newly developed geopolymer repair material has short setting time, high flow and high early compressive strength and bonding strength of the interfacial bonding zone as indicated by the dense microstructure.

KEY-WORDS: Geopolymer; Waterproof; Hydrophobic modification; Metakaolin; Repair material.

INTRODUCTION

The common deterioration form of concrete materials starts from or near the surface, the quality of which determines the penetration rate of outer aggressive gases and ions [1] and cracks on the surface also damage the appearance and cause re-deterioration of repaired regions. Repair of deteriorated concrete structures are essential not only to utilize them for intended service-life but also to assure the safety and serviceability of the associated components. Selecting suitable repair materials for concrete requires an understanding of compatibility between the substrate and repair materials and behavior of concrete materials in the exposure conditions [2].
In recent years, research work on repair materials and technologies have been undertaken to enhance the durability of concrete [3-6]. However, the previously reported findings mainly focused on cement based repair materials and the solved main problem was the bonding between substrate and repair material, which was enhanced from aspects of microstructure densification and pore refinement, adjusting of curing conditions and mix proportions or the addition of mineral admixtures. On reviewing the existing literatures, techniques and reports on achieving waterproof, fast setting and high strength geopolymer repair material by surface modification were scant and limited even though some primary work about geopolymer repair materials has been carried out [7-9].

In this work, the liquid surface modification agent was synthesized for the modification of geopolymer repair material. A new waterproof, fast setting geopolymer with hydrophobic surface and high early strength was developed and the microstructure of interfacial bonding zone was investigated.

EXPERIMENTAL

Metakaolin was obtained by calcination of kaolinite at 850°C. Alkali activator was a combination of sodium silicate and sodium hydroxide in analytical reagent degree. The liquid portions of alkali activator were 10 M sodium hydroxide and sodium silicate with 14.51% Na_2O, 33.39% SiO_2, and 48.53% H_2O. Geopolymer specimens were synthesized by alkaline activation of metakaolin in the liquid alkali activator mentioned above (modulus of alkaline activator Ms=1.5, the mass ratio of sodium silicate and sodium hydroxide =8:1). The liquid/solid mass ratio equals to 0.5, in which the liquid material consists of alkali activator and the solid material is metakaolin.

Fresh geopolymer were cast into triplet steel cubes molds with size of 40 × 40 × 40 mm^3 and vibrated to remove entrained air bubbles. After hardening, the samples were released from the molds and were subjected to further curing in a standard condition of 20 °C and 95% relative humidity up to acquired days for other tests.

The waterproof layer on the surface of geopolymer samples was built by the methods proposed in Ref. [9] published previously by the authors of this work. The workability of geopolymer repair material was measured by using a flow table test to check the flow diameter of fresh pastes before casting. The process of setting was determined by the Vicat penetration test. Compressive strength was performed on cubes with the dimensions of 40 × 40 × 40 mm^3 at 3h, 6h, 1day, 3days and 28 days, respectively. The bonding strength was used to measure the bond strength between the cement mortar substrate and the repair material. The contact angle was measured with the sessile drop method by using the contact angle goniometer, an OCA20 measuring system (Dataphysics, Filderstadt, Germany) with a maximum error was 0.05°.

Microstructure of specimens was performed using a Japanese Netherlands FESEM Quanta SU8010 electron microscope, operating at an accelerating voltage of 15 kV for photomicrographs. Water absorption was measured by drying a specimen to a constant mass in an oven at 105 °C and allowed to cool in an air-tight container for 24h. Each specimen was then weighed and immediately immersed in water, on removal from the water, the surface of the specimens was wiped and weighed again. The water absorption, measured at 1h, 2h, 6h, 1 day, 3 days and 28 days, respectively, was calculated from the increase in mass of the specimen and expressed as a percentage of the dry specimens.

RESULTS AND DISCUSSION

Static water contact angles of geopolymer before and after surface hydrophobic modification are provided in Fig. 1a-b. It could be observed that the contact angle on the surface of geopolymer before modification is about 19° in Fig. 1a, while it significantly increases to 95°on the surface of modified geopolymer as indicated in Fig. 1b. It can be concluded that surface hydrophobic modification of geopolymer is completely achieved.

Waterproof performances of geopolymer before and after surface hydrophobic modification are illustrated in Fig. 1c-1d. It can be observed that powder geopolymer floats on the water level after surface hydrophobic modification due to waterproof modification. Also, water drops stand on the cubic geopolymer surface after modification. The effects of surface hydrophobic modifier on water absorption of geopolymer at various water curing ages are shown in Fig. 1e. It is observed that the water absorption varies between 0.01% and 0.52%. It exhibits very low absorption characteristic when compared to geopolymer with water absorption as high as 4-22% by Alomayri et al. [10] and 10-13% by Nazari et al. [11]. Prolonged exposure to water for 28 days appears to have little significant influence on the water absorption properties. Surface hydrophobic modification improves waterproof properties and reduces water absorption of geopolymer repair material.

Geopolymer repair material indicates 212 mm flow diameter, which is higher than other repair materials with flow of 140-150 mm developed by Dawood [4], and the setting time is about 24 min, which is significantly shorter than that of other repair material prepared by Wu [12] and Phoo-ngernkham [7] with hardening time more than 30 min at room temperature.

A group of six specimens are tested and the mean values for compressive strength of geopolymer and bonding strength are given in Fig. 2. It can be observed that the geopolymer repaired samples have obviously high compressive strength and bond strength at different curing times. Importantly, at 3h early curing time, the compressive strength and bond strength reach about 10 MPa and 0.6 MPa, respectively. The compressive strength is significantly higher than the repair materials prepared by Liu [3] with only 7.6 MPa at 7 days, by Qiao [5] with around 20 MPa but at 1 day and by Alanazi [8] with around 5MPa at 1 day. For the pull-off test, the failure of the specimen mainly occurs at the interface between repair material and mortar substrate.

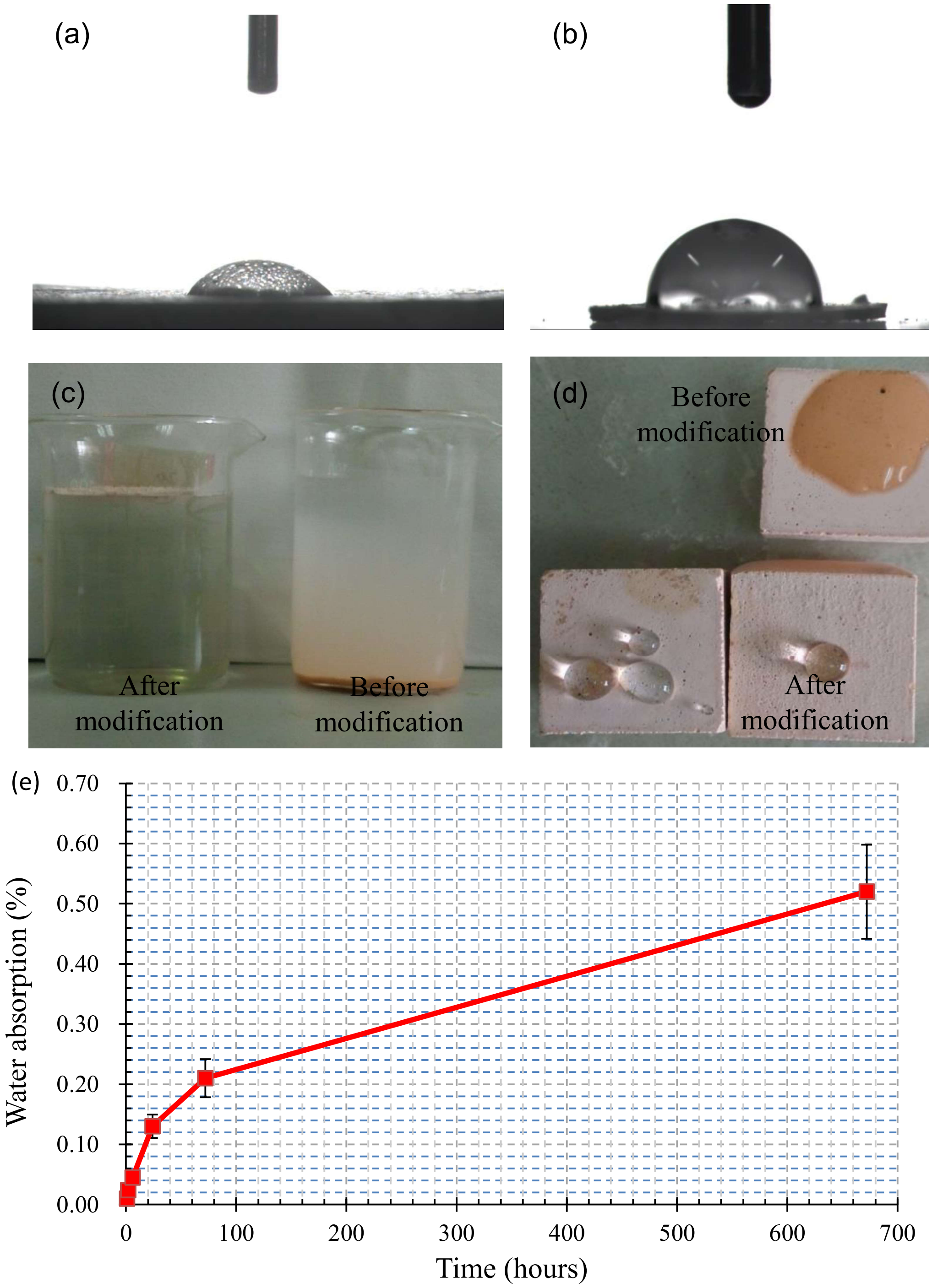

Fig.1. Contact angle of geopolymer before (a) and after (b) modification; (c) waterproof performance of geopolymer before and after surface hydrophobic modification; (d) water absorption of geopolymer after modification.

In order to investigate the bonding characteristics between repair material and cement mortar substrate, SEM analyses were carried out in Fig. 3 for the bonding area between geopolymer repair material and cement mortar substrate. It reveals the dense microstructure of geopolymer repair material and interfacial bonding zone (Fig. 3) and lower porosity (Fig. 4), which leads to the high compressive strength of geopolymer repair material and high bonding strength between geopolymer and substrate as demonstrated in Fig. 2.

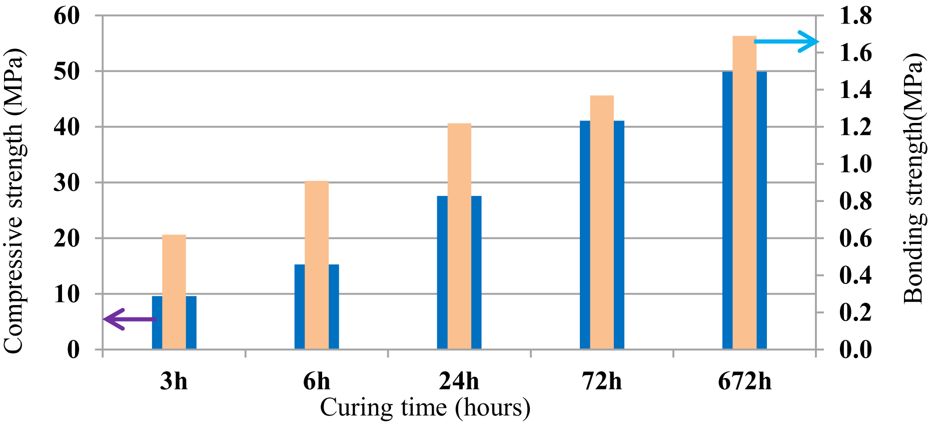

Fig.2. Compressive strength and bonding strength of geopolymer repair material.

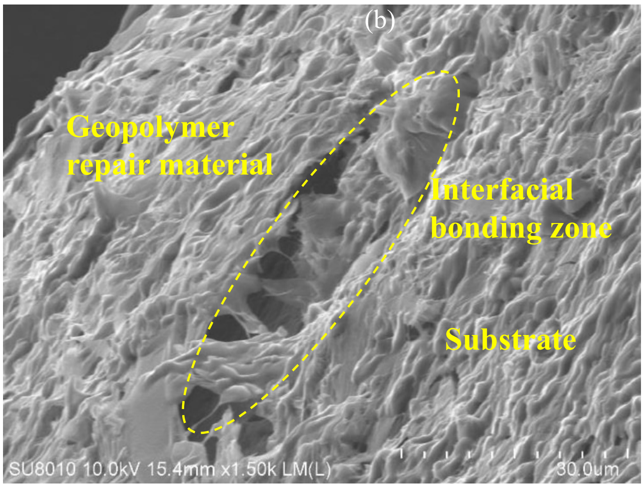

Fig.3. Bonding characteristics between repair material and cement mortar substrate.c-2

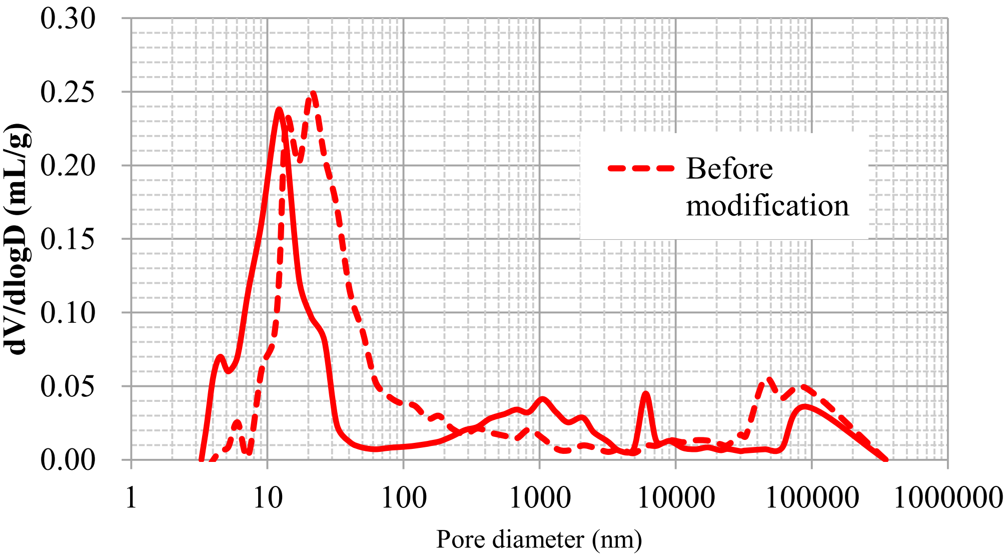

Fig.4. Pore size distribution of geopolymer before and after modification.

CONCLUSIONS

In this work, a novel waterproof, fast setting geopolymer repair material with hydrophobic surface and high strength was developed. Surface hydrophobic modification was completely achieved due to the increasing contact angle on the surface of geopolymer from 19° to 95°, the floating of specimens on the water surface and low water adsorption. This newly developed geopolymer repair material has short setting time, high flow and high compressive strength and bonding strength of the interfacial bonding zone as indicated by the dense microstructure. This newly developed geopolymer repair material could be used for the road concrete repair or as protection coatings for marine concrete.

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