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Evaluation of the bond strength of a novel concrete for rapid patch repair of pavements

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HIGHLIGHTS

- Combined effects of surface roughness, bonding agents and curing age were investigated through orthogonal experiments.
- Bond strength was evaluated using a self-designed test device (Patent Number: ZL 2017 2 1680364.4).
- Freeze-thaw cycle test was conducted to validate the results of orthogonal experiments.
- RRM concrete appears to be a promising material for rapid repair of concrete pavements.

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ABSTRACT

Patch repair is an important category in the repair or restoration of pavements. The effectiveness of the repair largely depends on the bond strength between the repair material and the concrete substrate. In the present work, surface roughness, bonding agents and curing age of the repair materials have been taken into consideration to evaluate the applicability and serviceability of a novel rapid repair material for concrete pavement. A three-factor and four-level orthogonal experiment was designed for systematic investigation. The bond strength of the combined specimens was measured using splitting tensile test and direct shear test. It is found that the splitting tensile strength varied from 1.21 MPa to 2.43 MPa and the direct shear strength varied from 2.84 MPa to 5.92 MPa and the bond strength has a good correlation with surface roughness and curing age. Different failure modes and the shear-slip characteristics were analyzed to understand the actual bond performance of combined specimens. It can be concluded that the slip distance of high surface roughness concrete was almost three times that of low surface roughness. In addition, the freeze-thaw cycle test of the combined specimen was conducted to validate the compatibility of the designed repair material with the concrete substrate. It is found that the he splitting tensile strength and direct shear strength of high surface roughness specimens reduced to 74.5% and 66.3% of its original bond strength after 100 times of freeze-thaw cycles, respectively. The rapid repair material studied in this study can act as a promising alternative for rapid patch repair of concrete pavements.

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1. Introduction

Cement concrete has been widely used in the construction of pavements, municipal roads and airport runways due to the characteristics of high strength, longevity and good stability [1]. However, the transportation infrastructures suffer from premature deterioration or damage due to the combined effects of environmental and mechanical loadings. The rehabilitations and restorations cost of the infrastructures was close to and even exceeded new construction cost [1]. Similarly, according to a survey by The Road Information Program, 32 percent of major roads in the US are in either poor or mediocre condition and require immediate repair or maintenance [2]. Consequently, rapid repair of the deteriorated pavements is essential to eliminate congestions and environmental impacts induced by poor road conditions, and most importantly, for safety concerns.

In recent years, researchers have developed many rapid repair materials (RRM) for the rehabilitation of concrete pavements, which can be divided into three categories: cement-based materials, polymer modified cement-based materials, and polymer or resin materials [3–6]. However, variation in results obtained by different researchers could be attributed to the difference in raw materials, specimen geometry and test methods.

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Some works [7,8] indicated that Ordinary Portland Cement (OPC) often led to interface failure stemming from large autogenous shrinkage stress. Subsequently, numerous studies have been conducted focusing on the preparation of rapid repair materials using various sort of admixtures, for example, fly ash [9,10], silica fume [10,11], recycled aggregates [12], industrial or agricultural by-products [13]. Due to low dry shrinkage, short setting time, good compatibility and high bond strength with the concrete substrate, magnesium phosphate cement (MPC) are suitable for rapid repair of concrete structures used in pavements, airport runways, bridge decks and key municipal roads, etc [14–17]. However, due to the strong heat release in the reaction process, MPC is sensitive to the ambient temperature and reaction heat and rate in hot weather need to be properly investigated [16].

Polymer modified concrete as an important class of rapid repair material for concrete infrastructure, on the other hand, has many outstanding advantages: low thickness, superior chemical resistance, low cure shrinkage and permeability and adhesion characteristics [18–20]. Ghasan Fahim Huseien et al. [21] provided an exhaustive and informative overview on the past development and recent progress of geopolymer mortars (GPMs). They summarized the properties of GPMs as repair materials from the aspects of strength, addition, setting time, mix proportion, bond strength and microstructure and concluded that GPMs are effective repair materials for deteriorated concrete and structure protection as they possess the characteristics of far lower carbon footprint, less cracking, more resistant to corrosive elements such as sea salt, excellent frost resistance and particularly, bonding strength. In this type of material, epoxy-based polymer concretes/mortars are the most commonly used [22]. Saccani et al. [23] investigated the behavior and durability of epoxy-modified mortar and indicated that the repair material performed well when exposed to thermal and environmental stresses and provided higher durability and bonding strength when combined with epoxy-modified primer. Rodrigo H. Geraldo et al. [24] investigated alkali-activated mortars (AAM) as repair material to reinforced concrete and found that AAM developed a fast and good strength (30 MPa after 24 h) and had good adherence to the substrate. Jung et al. [25] studied the serviceability of polymer concrete by measuring basic mechanical properties using embedded FBG (fiber bragg grating) optic sensors and reported that the thermal expansion coefficient of polymer concrete was much higher than that of cement concrete. Based on analysis of the geopolymerization process, Yanping Li et al. [26] discussed the mechanism of how raw material formulation affects fresh and mechanical properties of geopolymer concrete. Besides, a design of experiment (DOE) approach was proposed to quantify the effects of silica concentration, hydroxide concentration, and slag replacement percentage on setting time, 7-day, and 28-day compressive strength. What's more, it had reported that the applicability of polymer concrete could be improved through the supplement of silicone rubber [27,28] and using some other polymers, for example, latex [29], high calcium fly ash geopolymer [30] and ultra-fine slag based geopolymer [31].

There are few literatures available about the use of polymer or resin materials for rapid patch repair, which is classified as third type of rapid repair material. However, these materials have been successfully applied in the case of full-depth repair. Priddy et al. [32,33] investigated the applicability of commercially available, rigid polyurethane foams for the expedient airfield repairs. They mentioned that the pavement repair technique can be completed within 4–6 h and can support threshold and objective aircraft pass levels. However, foam backfill materials used in these studies are reported to be sensitive to ambient moisture, which has a great influence on the quality of the expedient pavement repair [32]. Besides, this technique relies heavily on proprietary devices, which may increase logistic burden.

It is well recognized that the effectiveness of a repair is strongly influenced by the quality and behavior of the interface created between the repair material and the old concrete [34]. Regardless of the rapid repair material, it is well documented that the bond strength between the substrate and the repair material plays crucial role for carrying capacity and long-term performance of the repaired pavement [3,35–39]. Many factors including interface stiffness [40], surface roughness [36,37,41,42], adhesive agents [43–46], curing regime [47,48] and the age of the repair materials influence the bond strength. For example, some researchers claim that both an increase in surface roughness and the application of bonding agents are imperative to good bond performance [41,42,44,49–51].

It is reported that the measured bond strength is greatly dependent on the test method [35]. The existing test methods to evaluate the bond strength between substrate and repair materials can be divided into three categories [3,35,41,52,53]. The first category is to evaluate the bond strength under tensile stress, for example, pull-off [54], the flexural test [55] and splitting [38,56]. The second category of the test methods measures the bond strength under shear stresses, for example, the direct shear test [39]. The third category is to determine the bond strength under the combination of compressive stress and shear stress, which is commonly referred to the slant shear test [8,57,58]. The difference between these test methods is that the stress state of the test specimens is different.

In this study, a three-factor and four-level orthogonal experiment was conducted to evaluate the bond strength between the concrete substrate and a novel rapid repair material for concrete pavements. The three factors adopted herein are surface roughness, bonding agents and curing age. The bond strength was measured by splitting tensile test and direct shear test, for comparison. In addition, freeze-thaw cycle test was carried out to validate the compatibility of the repair material and assess the influence of surface roughness on bond strength.

2. Experimental procedure

2.1. Materials

2.1.1. Cement

The chemical compositions of the cement and RRM used in the study are shown in Table 1.

2.1.2. Rapid repair material (RRM)

The rapid repair material is a kind of polymer modified cementitious material with the characteristics of rapid-setting, high early strength, small shrinkage, excellent workability and good durability developed by Haimu Transportation Technology Co. Ltd, Chongqing, China [59,60]. It has been successfully applied in the emergency repair of airport pavement and municipal roads bridge decks.

2.1.3. Bonding agents

Three bonding agents were chosen in this study, (a) RRM paste (RRMP) (water: cement = 0.4), (b) polyvinyl formaldehyde adhesive (commonly known as 108 glue) modified RRM paste (GM-RRMP) (adhesive: water: cement = 2:4:15) and (c) epoxy resin.

2.2. Specimens preparation

2.2.1. Mix proportions

Ordinary concrete was used to prepare the concrete substrate. The proportions of concrete substrate and RRM concrete mixtures are given in Table 2.

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