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Shear bond assessment of UHTCC repair using push-out test

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HIGHLIGHTS

- Suitable interface treatment agent develops a good interface bond.
- Strength of the existing concrete has a beneficial effect on the shear bond strength.
- A rough substrate surface leads to a higher shear bond strength.
- Maintaining a good quality of two bond planes for precast repair system is important.

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ABSTRACT

This investigation is aimed at assessing the shear bond strength between existing concrete and an ultra-high toughness cementitious composite (UHTCC). The main issues relevant to a push-out test are the type of interface treatment agent, the strength of the existing concrete, the substrate surface treatment, and the surface treatment of the precast UHTCC. An analysis of variance (ANOVA) is presented to evaluate the significant factors. In addition, mathematical models are built to estimate the shear bond strength. The results indicate that the primers and bonding agents can improve the interface bond, and the highest shear bond strength is achieved using a polymer-modified material. The strength of the existing concrete has a certain influence on the bond. A substrate surface treatment is also a vital factor, and has a strong effect on the shear bond strength. However, excessive mechanical action leads to interface damage. There are two bond planes for precast repair specimens, and it is imperative to maintain a good quality and consistent speed failure for both. ANOVA is an acceptable and effective way to determine the significance. The proposed models have high accuracy and satisfactory prediction capability.

1. Introduction

Some deficiencies in concrete, such as high brittleness, small tensile strength, low impact resistance, and easy cracking, lead to deterioration problems, and even the destruction of aging infrastructure, therefore creating a significant demand for repeated maintenance and rehabilitation. A new type of cementitious material called ultra-high toughness cementitious composite (UHTCC) has been developed and suitable for durability repair of deteriorated concrete structures, which can overcome unlimited cracking and solve the tensile strength problem. UHTCC is designed through a modification of the fiber bridge action, and control of the interface frictional and chemical bonds. The fiber/matrix interface is adjusted to achieve the most appropriate strength, and is not too strong or too weak. The final cementitious material shows an extreme tensile ductility, very high strain-hardening and multiple-microcracking behaviors. UHTCC uses fine sand and a small fiber content of usually less than 2%. Its tensile strain is larger than 3%, and occasionally reaches 8% [1]. While the tensile ductility is usually about 150- to 300-times higher than that of plain concrete and normal fiber reinforced concrete, it can reach even up to as high as 500 times [2] that of these materials. Like metal materials, UHTCC achieved very prominent strain-hardening property. During strain hardening, the crack width is smaller than 100 μm.

In previous studies, the material properties of UHTCC were sufficiently researched and the technologies were shown to have become increasing mature. Research on the material properties has included the direct tensile property [3–5], uniaxial compression property [6,7], bending property [8,9], impact [10], fracture [11,12], shrinkage and creep [13–15], permeability [16,17], freeze–thaw cycle capability [18,19], and corrosion resistance

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[19,20]. The predominant characteristics of UHTCC make it suitable for infrastructure repair. The interface property between the repair material and existing concrete is considered a crucial issue. Research on the interface bond between UHTCC and existing concrete has included the dry shrinkage of the composite structure between UHTCC and concrete [21,22], the tensile property between UHTCC and concrete [23,24], a UHTCC overlaid concrete beam [2,25–29], a UHTCC permanent formwork [30], and a UHTCC protection cover [31,32]. Although existing researches have shown that the interface bond between UHTCC and existing concrete has made progress, systematic research in this area is still lacking.

The interface bond between the repair material and existing concrete has many influencing factors, such as the repair materials used, the type of primers, the strength of the existing concrete, the substrate surface roughness, and a pre-wetting of the concrete substrate.

The repair material is the factor most directly affecting the bond strength in a new-to-old repair system. Emberson and Mays [33] reported that a polymer-modified cementitious material is a good repair material and has higher bond strength than other repair materials. Talbot et al. [34] stated that the addition of latex, fibers, and silica fume in the repair material have a significant influence on the fracture mode. However, it was found that there is no direct improvement on the bond strength. Li et al. [35] studied two types of repair materials, a polypropylene fiber modified material and a gypsum modified material. The results indicate that the new-to-old concrete specimens show superior bond properties and high resistance to deicing salts. Xie and Shen [36] reported that polyacrylonitrile carbon fibers can effectively improve the performance of the repair material and enhance the shear and tension bond strength. In addition, Schrader and Kaden [37] mentioned that the permeability of the repair material and existing concrete should be similar to avoid a freeze thawing failure caused by impervious repair materials.

Various scholars have studied the effects of the primers on the bond strength between the repair material and existing concrete. Austin et al. [38] conducted tensile bond testing and examined the effect of an acrylic modified primer on the bond strength. The results indicate that the bond strength can be greatly enhanced by this type of primer. However, proper usage must be maintained, and drying should be avoided before casting a new repair material. Saccani and Magnaghi [39] found that a modified primer using epoxy resin is able to provide a chemical linking of the resin and improve the durability and bond properties of the repair structure. Li [40] indicated that the primer is a vital factor for the transition zone of new-to-old concrete. The author used two types primers, a fly ash modified primer and an expansive agent modified primer, both of which were shown to be able to enhance the bond strength. In particular, the long-term bond strength is significantly increased using a fly ash modified primer. He [41] carried out slant shear and bending tests, and found that a SBR modified cement slurry primer exerts the best bonding effect.

The influences of the strengths of existing concrete and repair materials have been explored in recent years. Zhao et al. [42] stated that the tensile bond strength increases with an increase in the strength of the repair material, and that the strength of the repair material should be higher than that of the existing concrete. Huang et al. [43] showed that the increasing strength of the existing concrete and the repair materials leads to a high bond strength, but the effects of such improvement are small.

Austin et al. [38,44] reported that for both tensile bond test and shear bond test, when the substrate surface is sufficiently sound, the bond strength increases with an increase in the surface roughness. Fiebrich [45] showed that the very high surface roughness of a concrete substrate is not always able to enhance the adherence between the existing concrete and the mortar layers. The bond strength of a substrate made up of 60–80% visible aggregate was only slightly greater than that of a substrate with 30–40% visible aggregate. In addition, 30–40% visible aggregate makes up the best substrate surface treatment. Zhao et al. [42] showed that the tensile bond strength increases with an increase in the roughness amplitude. The best roughness obtained using chiseling and water-jetting in a concrete substrate was 4.7 and 2.8 mm, respectively. Momayeza et al. [46] indicated that the rough surface treatment of the substrate increases the bond strength. The bond strength based on a pull-off test increased by 9%, and that using a slant shear test increased by 25%. Garbacz et al. [47] found that when a primer is not used in the repair system, the surface roughness of the existing concrete is an important factor. The primer is a more important factor than the roughness because the primer can unify the bond level, fill in the surface defects, and improve the interfacial microstructure. In addition, Silfwerbrand [48] indicated that the surface roughness is not the main factor for the bond strength, and the precaution is more important. Debris removal and cleaning of an unsound surface of existing concrete, as well as good compaction and curing, should be applied. Abu-Tair et al. [49] concluded that chiseling with a hammer is a common surface treatment method for cleaning a loose concrete surface. However, this method can easily damage the substrate and decrease the interface bond.

Pre-wetting the concrete substrate before applying a repair material is a construction technique used to improve the interface bond. Warris [50] reported that the dry surface of a substrate shows a good interface bond between new and existing concrete. However, Sasse and Fiebrich [51] pointed out that it is necessary to pre-wet the substrate surface, particularly for a dry construction environment. Chorinsky [52] mentioned that excess wetness or dryness on the surface of a substrate lead to a decrease in the bond strength, and that a suitable amount of moisture is needed. Saucier and Pigeon [53] stated that Standard A23.1 of the Canadian Standards Association necessitates the pre-wetting of the surface of the concrete substrate.

No clear relationship has been established regarding the shear bond properties between UHTCC and existing concrete. The aim of this paper is to evaluate the various influencing factors, including the type of interface treatment agent, the strength of the existing concrete, the substrate surface treatment, and the surface treatment of precast UHTCC, and to establish mathematical models for estimating the shear bond strength.

2. Experiment studies

2.1. Push-out test

In total, 28 groups of composite specimens were designed to investigate the bond behavior between UHTCC and existing concrete. Two types of repair material were applied during this test for comparison: fresh UHTCC and precast UHTCC. The variables included the type of interface treatment agent, the strength of the existing concrete, the substrate surface treatment, and the surface treatment of precast UHTCC, which are listed in Table 1. In this test, the interface treatment agents include primers and bonding agents. Paste was used in a fresh UHTCC repair system as a primer. Mortar was applied to the precast UHTCC repair system as a bonding agent. The amplitude of roughness was measured using a sand placement method [54].

Push-out test is an effective approach for evaluating the interfacial shear bond properties. This test use symmetrical specimen and symmetrical loading, which avoid subjecting to bending moment and stress concentration at the edge of bond plane that occur in other direct shear test, and keep a pure shear state [55,56]. In this test, a push-out test was conducted to evaluate the shear bond strength between UHTCC and concrete. The dimensions and configuration of the composite specimen are shown in Fig. 1. The shear bond strength can be calculated according to the following expression:

$$f_s = \frac{P}{2A}, \tag{A}$$