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Influence of interfacial characteristics on the shear bond behaviour between concrete and ferrocement

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HIGHLIGHTS

- Shear bond behaviour between concrete and ferrocement is experimentally studied.
- Surface roughness of concrete is the key factor affecting shear bond behaviour.
- Shear keys enhance post-peak bond behaviour at concrete-ferrocement interface.
- Adhesive shear keys provide more reliable resistance to shear than expansive shear keys.
- Wire mesh alleviates stress concentration and avoids failure of ferrocement.

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ABSTRACT

Interfacial bond behaviour between concrete substrate and strengthening materials is crucial for achieving the aims of structural strengthening or repair. This paper presents an experimental investigation on shear bond behaviour between concrete substrate and ferrocement through direct shear tests. Various interfacial characteristics, including surface roughness, type of shear keys and use of wire mesh in the overlay, are considered as test variables. Test results indicate that both surface roughness and shear keys significantly affect the shear bond behaviour between concrete and ferrocement. Specimens with highly roughened concrete surfaces obtained using jet hammer achieve higher shear bond strength and interfacial fracture energy than those with slightly roughened concrete surfaces obtained using needle gun. Installation of shear keys at concrete-ferrocement interfaces can significantly improve the post-peak shear bond behaviour as well as alter the failure mode from brittle to ductile. Shear keys have negligible influence on shear bond strength of specimens with properly roughened surfaces, but can significantly enhance their interfacial fracture energy. As compared with expansive shear keys, adhesive shear keys are more reliable to resist interfacial shear between concrete and ferrocement. Among others, L-shaped or end-extension adhesive anchors are the most effective shear keys for improving interfacial shear bond behaviour between concrete and ferrocement. In addition, the use of wire mesh has negligible influence on shear bond strength but can prevent brittle failure of the overlay. Overall, it is recommended to prepare the concrete substrate with a highly roughened surface and to provide adhesive shear keys with end extension anchored in ferrocement.

1. Introduction

Ferrocement, a kind of cementitious material or mortar reinforced with wire mesh, has been adopted for strengthening reinforced concrete structural members over the past few decades [1–4]. It is normally applied through a thin layer (e.g. 30 mm thick) on the concrete substrate [5]. Paramasivam et al. [1] successfully applied ferrocement laminates to the soffit of the beams to enhance their flexural stiffness and load capacities. The authors reported that proper interface treatment should be provided to utilize the strength of ferrocement. Nassif and Najm [2] investigated the flexural behaviour of ferrocement-concrete composite beams and demonstrated that shear transfer at ferrocement-concrete interface significantly affects the flexural behaviour of composite beams. Recently, the authors of this study strengthened reinforced concrete beam-column joints using ferrocement jackets [3,4]. Delamination of ferrocement from concrete substrate was observed, which has considerably affected the seismic performance of beam-column joints. Thus, it is essential to maintain a good bonding between

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concrete and ferrocement for achieving the strengthening purposes. Otherwise, delamination of overlay may take place leading to premature failure at the interface and reduce the efficiency of strengthening [6]. However, there are limited studies focusing on the bond behaviour between concrete and ferrocement.

The interfacial bond behaviour between concrete substrate and strengthening overlay is affected by many factors, e.g. surface roughness, curing condition, and strength of concrete substrate [7–9]. Accordingly, various approaches have been proposed to enhance the interfacial bond strength in the structural strengthening system. Santos and Julio [9], Gohnert [10] and Momayez et al. [11] demonstrated that the interfacial bond strength between concrete substrate and overlay increases with increasing surface roughness of substrate. It is necessary to implement an appropriate treatment to prepare a roughened surface of concrete substrate. Julio et al. [12] and Tayeh et al. [13] reported that sand-blasting is the most effective treatment to roughen a concrete surface. Other alternatives include the use of bonding agents and interfacial reinforcements to improve interfacial bonding. According to Garbacz et al. [14], pull-off bond strength of strengthening materials significantly increases when bonding agent is applied on a highly roughened surface. Beushausen [6] reported that application of bonding agent is effective to enhance the bond strength for the overlay with a low workability. Issa and Assaad [15] enhanced the pull-off bond strength between self-consolidating concrete and a cementitious repair material by utilizing a PVA-based latex. Xiong et al. [16] applied silane coupling agent on concrete substrate to improve bond quality of the repaired interfacial transition zone. Choi et al. [17] introduced large power-driven nails to transfer shear force between concrete substrate and overlay. The authors of this study [3] successfully applied one type of shear keys to prevent delamination of ferrocement from concrete substrate. Recently, Wu and Pantelides [18] proposed a steel collar with studs to increase bonding between old concrete and repair concrete, and successfully enhanced the structural performance of the repaired concrete column. In general, the above studies are mainly focused on thick-layered strengthening overlay. It is the objective of this study to examine experimentally the shear bond behaviour between concrete and thin-layered strengthening materials under monotonic loading and the influence of shear keys on their shear bond behaviour.

The characteristics of overlay also affect the shear bond behaviour between concrete substrate and overlay. Momayez et al. [11] and Kuroda et al. [19] demonstrated that bond strength between new-to-old paste or concrete can be enhanced by using fly ash and silica fume in the overlays, respectively. This is mainly attributed to the improvement at interfacial transition zone between concrete and the overlay. Chen et al. [20] reported that addition of short carbon fibres in mortar at the amount of 0.5% by weight of cement increases the bond strength of new-to-old concrete. Similarly, Zanotti et al. [21] found that the bond strength between concrete and geopolymer repair mortar is significantly enhanced with the incorporation of PVA fibres in the repair mortar. For the ferrocement overlay, presence of wire mesh in mortar may also improve its bonding with concrete substrate. Thus, it is necessary to examine the influence of wire mesh in mortar on the bond behaviour between concrete and ferrocement.

To properly evaluate the interfacial bond strength between concrete substrate and ferrocement under monotonic loading, direct shear test is performed for concrete substrate overlaid with ferrocement. This is achieved through single shear in the absence of normal constraint for ferrocement-concrete specimens. Test variables include surface roughness, types of shear key, and the use of wire mesh in mortar. Interfacial bond behaviour between concrete and ferrocement is presented and discussed in terms of failure mode, peak bond strength, post-peak bond strength and interfacial facture energy.

2. Experimental programme

Bond strength between concrete substrate and strengthening material is widely assessed through tensile bonding test, e.g. pull-out test as specified in ASTM C1583 [22] and BS EN 1015-12 [23]. It can be used as an indicator for interfacial bond strength. However, it cannot properly reflect the stress status at the interface between concrete and strengthening materials. The specimens used in pull-out test are subjected to pure tension rather than shearing [24]. Alternatively, slant shear test in combined shear and compression is adopted to estimate the shear bond behaviour between concrete and strengthening materials. The slant shear bond strength is highly affected by the normal constrain which is related to inclination of slant plane. This is also not the actual stress status between concrete substrate and strengthening materials. Thus, a direct shear bond test is proposed and used to estimate the interfacial bond behaviour between concrete substrate and ferrocement in this study.

2.1. Description of specimens

Totally 16 specimens with various interfacial characteristics were prepared and tested to failure. They are divided into 8 groups according to interfacial characteristics, i.e. 2 specimens in each group. The specimens have identical dimensions as shown in Fig. 1. The concrete substrate with a dimension of 200 mm × 200 mm × 180 mm was overlaid by a 30 mm thick ferrocement. Ferrocement was prepared with either one layer of wire mesh or without wire mesh.

Three levels of surface roughness, named as-built, low roughness and high roughness, were considered for concrete substrate. Low roughness and high roughness were prepared using needle gun and jet hammer, respectively. Surface roughness was assessed for each specimen by a roughness depth which is defined as the volume of sand needed to fill up the surface to the highest point divided by surface area [25,26].

Four types of shear keys were considered for concrete-ferrocement in this study as shown in Fig. 2. M6 expansive anchors in Fig. 2(a) are mechanically anchored. M6 and M8 anchor bolts in Fig. 2(b) and (c) have an embedded depth of 65 mm and 45 mm, respectively. L-shaped anchors in Fig. 2(d) have an embedded depth of 65 mm and extends 45 mm into ferrocement. M6 anchors, M8 anchors and L-shaped anchors were installed using a commercially available adhesive glue. All of shear keys were installed with 20 mm protruded into ferrocement. Interfacial characteristics of concrete-ferrocement specimens in each group are summarized in Table 1.

2.2. Materials

Concrete substrate was cast using ready-mixed concrete. Concrete specimens were cured in water for 28 days before applying the ferrocement overlay. Compressive strengths of concrete (obtained from 100 mm test cubes) at the 28th day and the date of testing are 57.5 MPa and 69.2 MPa, respectively.

Mortar used for ferrocement was prepared with cement, finely graded sand, fly ash and silica fume. Weight proportion of mortar is 1 part cement to 2.5 parts sand. Sand is graded by passing a 1.18 mm sieve to BS 1015-1 [27]. Binder comprises 80% cement and 20% fly ash by weight. Water-to-cement ratio is fixed at 0.4. Silica fumes and superplasticizer are added at 7% and 2% by weight of binder, respectively. Compressive strength of mortar based on 100 mm cubes is 74.2 MPa at the date of testing.

L-shaped anchors are made of 8 mm diameter high strength steel bars with yield strength of 540 MPa. M6 and M8 adhesive anchors are machined from steel bars with nuts welded at one end and have the yield strengths of 540 MPa and 430 MPa, respectively. M6 expansive anchors are commercial products. WM1.45

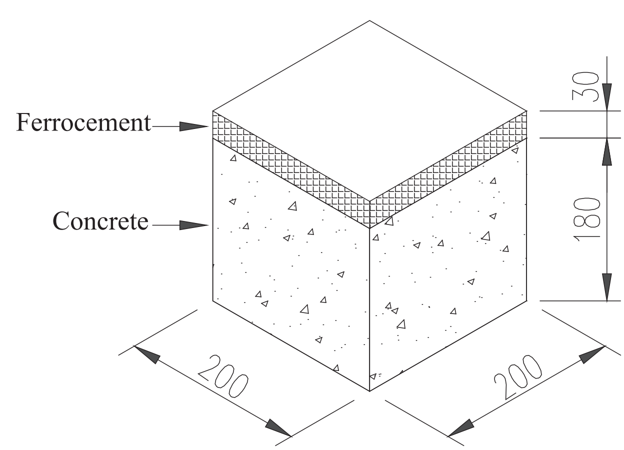

Fig. 1. Dimensions of the specimen (in mm).