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Bond behaviour between NSM CFRP laminate and concrete using modified cement-based adhesive

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HIGHLIGHTS

- Experimental and finite element analysis of bond of NSM CFRP laminates using modified cement-based adhesive.
- The test results show the efficiency of the modified cement-based adhesive as a bonding agent for NSM strengthening.
- Excellent mechanical bonding properties have been achieved compared to externally bonding.
- The cementitious adhesive showed a considerable ductile behaviour.
- Good correlation between experimental and finite element analysis has been achieved.

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ABSTRACT

Near-surface mounted (NSM) techniques have been successfully utilized for the strengthening of concrete structures with CFRP composites. Although the adhesive most commonly used for strengthening of structures is epoxy, this adhesive is suitable only for low temperature environments due to the deterioration of its mechanical properties at elevated temperatures, in addition to its other disadvantages such as flammability and emission of toxic fumes. Substituting the epoxy with cementitious adhesive is therefore of great interest. However, few investigations on the strengthening of concrete structures using cementitious bonding materials have been reported, particularly for NSM CFRP strengthening systems. Since the bond between NSM FRP reinforcement and the concrete substrate plays a major role in the efficiency of NSM strengthening systems, in this paper, the bond properties of NSM CFRP laminate using modified cement-based adhesive are investigated. 15 concrete specimens were studied, and parameters including bond length, strain distribution, and bond-slip curve were considered. Finite element simulation was conducted to verify the experimental results using ATENA Software from Cervenka. The results showed excellent bond properties with reasonable correlation between experimental and finite element analysis results.

1. Introduction

Over the past few decades, extensive investigations have been conducted on the strengthening of concrete structures with externally-bonded CFRP composites [1]. A large number of structures has been retrofitted using this technique world-wide [2]. However, since this technique requires more surface preparations, and the fibre is prone to external damage, a protective cover is required to protect the fibre from external mechanical damage. In addition, premature debonding at the fibre ends is the critical failure mode, resulting in sudden drops in the resistance of members strengthened using this technique [3,4]. More recently, the near surface-mounted (NSM) strengthening technique has been successfully utilized for strengthening of concrete structures, as it provides better protection from external damage, requires less preparation, and has better bond properties [5]. Different types of fibres have been applied with this technique, including bars and laminate strips using epoxy adhesive. In spite of the excellent bond properties provided by the epoxy, there is a need to replace this adhesive to reduce the harm of toxic fumes and avoid the degradation of mechanical properties of epoxy under high temperature exposure. Cementitious bonding material may be a good alternative to the epoxy [6–9]. Since modified cement-based adhesive has successfully achieved excellent bond strength with NSM CFRP textile [10], the application of this adhesive with different fibre types such as CFRP laminate needs to be investigated.

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The importance of using CFRP laminates in practical applications derives from their excellent mechanical properties and their availability in different dimensions. A testing program was conducted in order to study the efficiency of the bond between CFRP laminate and concrete using modified cement-based adhesive. Different factors were studied in this investigation, including bond length, stress-strain distribution and stress-slip relationships.

2. Experimental program

2.1. Specimen details

The specimens adopted in this research consisted of 15 concrete prisms with dimensions of 75 mm × 75 mm × 250 mm strengthened with NSM CRP laminate using modified cement-based adhesive through longitudinal slits cut in the surface of specimens with dimensions of 4 mm width and 18 mm depth. CFRP laminate with dimensions of 1.4 mm thickness × 10 mm width was used. Different bond lengths were used: 50, 100, 150, 200, and 250 mm. Three identical specimens were used for each bond length labeled 'a', 'b', and 'c'. Table 1 illustrates the details of specimens. The testing of specimens was conducted using a single-lap shear test apparatus.

2.2. Specimen preparation

After 28 days of curing for concrete prisms, grooves 4 mm thick × 18 mm wide were cut in the concrete surface. These dimensions were selected to provide sufficient adhesive layer around the CFRP strip as recommended for NSM CFRP strips by Paretti and Nanni [3]. The adhesive bonding was applied 50 mm away from the edge of the concrete prism to avoid premature failure in the concrete due to stress concentration. The fibre was extended 100 mm off the prism to fix the aluminium plates used for gripping. Air pressure was used to remove the dust from the grooves. The grooves were wetted with water prior to application of the adhesive, and then filled with the adhesive using a steel blade. The CFRP strips were inserted in the centre of the grooves width and placed at 6 mm depth from top and 2 mm from bottom of groove depth to provide an adhesive layer around the fibre, and then the surface was leveled. The specimens were cured for 2 weeks using wet cloth on the adhesive layer.

The specimens were instrumented to record the strain by installing 5 strain gauges embedded along the fibre strip with the direction of the load along the 150 mm bond length in specimen LC150. These gauges were protected using M-coat A and a wax coating to provide a water-resistant layer, as shown in Fig. 1. The specimen dimensions and strain distribution are illustrated in Fig. 2, and an instrumented specimen after curing is shown in Fig. 3.

Table 1
Specimen details.

Specimen Details	Bond length (mm)	Number of specimens
LC50	50	3
LC100	100	3
LC150-SG	150	3
LC200	200	3
LC250	250	3

L: laminate, C: cement-based, SG: strain gauges.

Fig. 1. Strain gauges protected by M-wax coating.

2.3. Materials

The CFRP laminate manufacturer is BASF and the product is MBrace laminate. The mechanical properties of the CFRP laminate were assessed by conducting a tensile test according to ASTM: D3039 [11]. The concrete prisms were cast using one concrete batch. The concrete and mortar compressive tests were conducted according to AS1012.9 (Standards Australia, 1999) and AS1012.11 (Standards Australia, 2000) [12,13] respectively and tensile strength of mortar was tested according to AS 1012.10 (Standard Australia, 2000) [14]. The mechanical properties are shown in Table 2. The mix design materials were used according to the modified cement-based adhesive were developed by Al-Abdwais and Al-Mahaidi [10] as illustrated in Table 3.

2.4. Testing set-up

The test was conducted using a single shear-lap test set-up. A 100 MTS universal testing machine was used for the loading. The load and displacement were measured using load cells and extensometers. The displacement was measured at the loading point and the same lengths of the CFRP laminate out of the bond zone were used to ensure equal elastic elongation of this part. The CFRP laminate was aligned precisely and vertically with loading direction of the grips to ensure pure axial load using laser level to prevent any bending moment on the fibre. The loading was applied on the specimens at a displacement-controlled rate of 0.2 mm/min. Figs. 4 and 5 illustrate the dimensions and test set-up for the specimens with CFRP laminate.

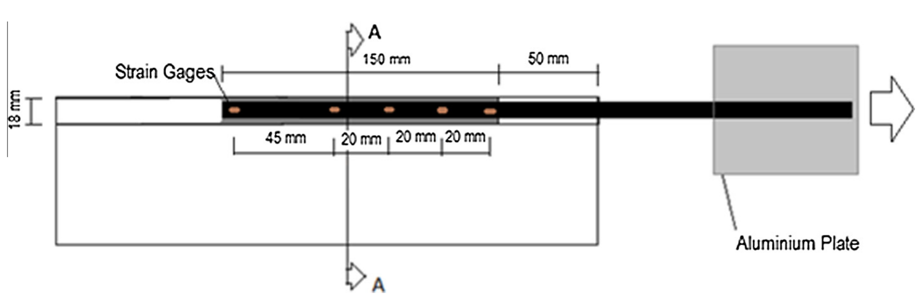

Fig. 2. Specimen dimensions and strain gauge layout of LC150-SG specimen.