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Bond between CFRP rod panels and concrete using cementitious mortar

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HIGHLIGHTS

- 44 notched-beam bond tests to evaluate cementitious mortar in bonding CFRP rod panels (CRPs) to concrete.
- Mortar resulted in ultimate load ($P_{ult.}$) 86% that from epoxy, with a ductile rod slipping failure.
- $P_{ult.}$ of CRP was 1.17 and 7 times that of flat CFRP plate, for epoxy and mortar, respectively.
- A development length and bond strength of 125 mm and 460 kN/m, respectively, were found for mortar-bonded CRP.
- Effects of width ratio, rod spacing-to-diameter ratio, and rod diameter, rod surface condition, were investigated.

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ABSTRACT

Carbon-FRP rod panels (CRPs), generated from small diameter rods mounted on a fiberglass mesh, are becoming a viable retrofit option. The gaps between rods enable full encapsulation by adhesive, thereby enhancing bond to existing concrete members, compared to flat plates. Existing studies focused on epoxy adhesive. In this study, 44 notched-beam bond tests, were carried out to investigate the effectiveness of cementitious mortar in bonding CRP to concrete and to examine the effects of a number of material and geometric parameters, comparing CRP to flat plates and mortar to epoxy. Results showed that the mortar was able to achieve a comparable ultimate load ($P_{ult.}$), 86% that of epoxy, and a much more ductile failure by gradual rod slippage from the mortar. Compared to an equivalent CFRP plate, $P_{ult.}$ of CRP was 1.17 and 7 times, respectively, for epoxy and cementitious mortar. Brittle debonding failure dominated in CRP with epoxy and in CFRP plate with both epoxy and mortar. P_{ult} was found to vary linearly with the bond length of CRP, up to a development length of 125 mm. A value of 460 kN/m can be assumed for bond strength. Rod axial stress (σ_f) increased by 42%, when CRP panel-to-concrete width (b_f/bc) ratio increased from 0.25 to 0.5; decreased linearly by 13% when rod spacing-to-diameter (S/D) ratio increased from 3 to 8; decreased by 76% when rod diameter D increased from 2 to 4 mm. Sand coating the smooth rod resulted in a 45% increase in σ_f of the 4 mm rods but not the 2 mm rods, although failure shifted from gradual slippage to sudden debonding.

1. Introduction

Many structures worldwide, especially those in the transportation sector, have become seriously deteriorated because of aging, environmental effects such as freeze/thaw cycles, human errors in design and/or construction, inadequate maintenance and misuse of facilities among other factors [1–4]. Due to their excellent attributes of high strength, lightweight, resistance to corrosion, minimal change in structure's geometry, and ease of application, fiber reinforced polymer (FRP) composites have become a mainstream method in retrofit applications [5]. Conventionally, two methods are used in FRP concrete retrofits; namely, externally bonded reinforcement (EBR) and near surface mounted (NSM) reinforcement [6,7]. These two methods differ in the way FRP is attached to the concrete substrate where the first is externally bonded while the second is inserted in grooves made in concrete cover [6,8]. Several researches have reported some advantages of NSM over EBR, including better bond resistance, protection, and suitability for strengthening negative moment regions of slabs and decks [7–10].

Another FRP retrofitting technique has been developed recently [2,6,11] and applied in several bridge retrofit applications [12]. It consists of small diameter Carbon-FRP (CFRP) rods, typically 1–5 mm, aligned side by side at a uniform spacing, and is adhesively bonded on one face to a light fiber glass mesh, forming a panel which is commercially known as CRP [2] (Fig. 1(a)). Similar to

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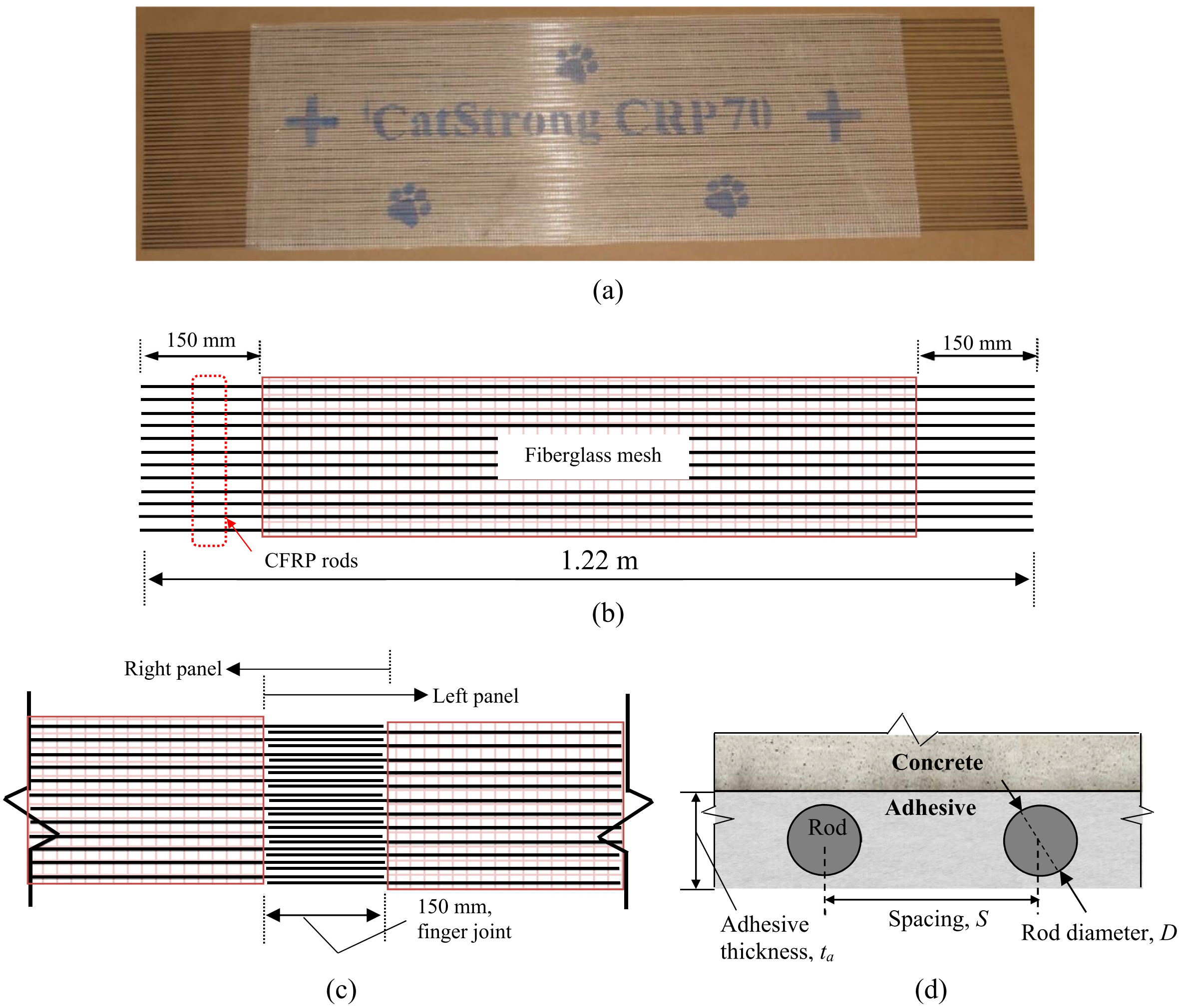

Fig. 1. CFRP rod panel, (a) picture, (b) schematics, (c) two panels connected by finger joint, (d) application on concrete.

EBR, CRPs are externally bonded to concrete (Figs. 1(d), 2(a)); however, the rods are fully embedded in adhesive, which also resembles NSM reinforcement. Several advantages have been reported for CRPs compared with EBR including: increased bond resistance due to full embedment and using small circular rods, hence increasing FRP area in contact with adhesive [13]; ease of application by using short-length panels (typically 1.22 m) connected by a finger joint, instead of continuous (full-length) plates [2]; possible multi-stage application by stopping work at any panel, leaving the finger joint area uncovered with adhesive, and resuming work at another time, which minimizes disruption of structural function, especially in highway bridge rehabilitation [12–14].

Two panels are widely produced and utilized in field applications, namely CRP 070 (with rod diameter (D) of 2 mm and rod spacing (S) of 6.35 mm) and CRP 195 (with D of 4 mm, and S of 9.5 mm). The three-digit number after CRP (e.g. CRP 070) refers to the panel's tensile strength per unit width in US customary units. For example, CRP 070 can resist 70 kip/ft (or 1037 kN/m, in SI system) of tensile load. Several studies were performed on CRP, and confirmed its effectiveness. In Jawdhari et al. [13,14], bond properties of CRPs were determined through direct shear tests and notched beam flexure tests, respectively. Peiris and Harik [12] established the development length for CRPs with steel substrate. Jawdhari et al. [2,15] carried out flexural tests on full-scale RC beams strengthened with CRP 070 and CRP 195, respectively. Numerical analyses, field applications, and design and construction issues are given in [11–12,16–17]. In all studies thus far on this system, epoxy adhesive has been used.

The use of epoxy resin has several limitations including: environmental factors (emission of toxic fumes and steroids); moisture impermeability; inability to install in low temperatures and on wet surfaces; short shelf and pot lives; poor performance at elevated temperatures [3–5]. Cementitious mortars are good alternatives to mitigate some of these problems. Wetting and impregnation of fibers is oftentimes a concern for the bond between the cementitious mortar and FRP; this can be mitigated by adding polymers and silica fume [18–20]. One system that has received great attention is fiber reinforced cementitious mortar (FRCM), which consists of an open mesh of fibers or sheets embedded in the mortar [5,21]. Cementitious mortars are also utilized in NSM technique [4,22].

Multiple research has already confirmed the effectiveness of FRCM and mortar-bonded NSM techniques over epoxy-bonded FRPs in retrofitting RC members at elevated temperatures [5,23–26]. Hashemi and Al-Mahaidi [3] tested six RC beams under four-point bending, examining the effectiveness of cementitious mortar in bonding CFRP fabric or textile to RC beams. The mortar was found to be very effective in bonding CFRP textile, were it resulted in an ultimate load of about 80% that achieved using epoxy adhesive. In another study, cementitious mortar was used to bond NSM CFRP strips to strengthen RC beams in torsion [4]. The mortar resulted in 74–83% ultimate capacity, compared to epoxy resin. FRCM technique was also used to strengthen two-way RC slabs