BOND PERFORMANCE BETWEEN NSM FRP RODS AND CONCRETE USING ECC AS BONDING MATERIALS

Shutong Yang[1, 2, *], Shiwei Wang[3], Xianfei Fang[3], Yunlai Tao[3]
[1]Department of Civil Engineering in College of Engineering, Ocean University of China, Qingdao 266100, P.R.China. *Email: shutongyang2013@163.com
[2]Collaborative Innovation Center of Engineering Construction and Safety in Blue Economic Zone, Qingdao 266033, P.R.China
[3]Quality Supervision Bureau of Zhoushan Transportation Engineering, Ningbo 315000, P.R.China

ABSTRACT

The pull-out test of near-surface-mounted (NSM) FRP (fiber-reinforced plastics) rod from concrete was performed using engineered cementitious composites (ECC) as bonding materials. The feasibility of cementitious materials in NSM FRP strengthened concrete was then analyzed. Carbon FRP (CFRP) rods and Basalt FRP (BFRP) rods with spiral surfaces and diameters of 8 mm were used in the test. The bonding lengths are 5 times and 10 times of the FRP diameter, respectively. Results show that the failure modes of all the specimens using ECC as bonding materials are pull-out of FRP rods with ductile behavior. Moreover, specimens with NSM FRP rods using epoxy are prepared as control specimens to evaluate the feasibility of ECC. For CFRP rods, the pull-out load-bearing capacity of specimens using ECC is 70% and 50% of that in specimens using epoxy for 5 times and 10 times of the FRP diameter, respectively. For BFRP rods, the load-bearing capacity of specimens using ECC is 75% and 55% of that in specimens using epoxy for 5 times and 10 times of the FRP diameter, respectively. Thus, ECC can be applied in NSM FRP strengthened concrete structures as the bonding materials.

KEYWORDS

Concrete, FRP rod, ECC, NSM FRP strengthening, ductility.

INTRODUCTION

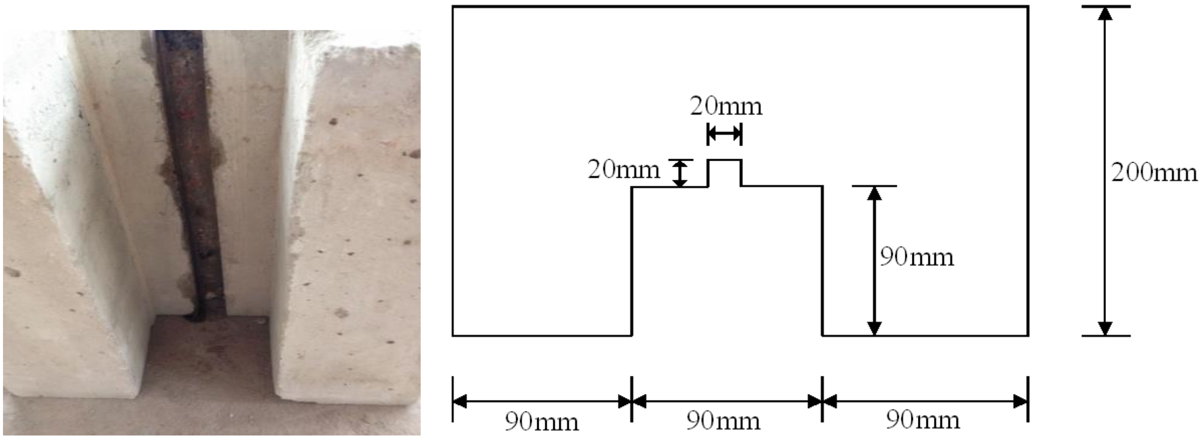
Fiber-reinforced plastics (FRP) have been widely used in civil engineering in the form of FRP rods, FRP sheets or FRP plates because they have high strength, low density, high resistance to corrosion, and can be transported easily compared to steel plates. A new technique known as NSM (near-surfaced-mounted) FRP rod or plate strengthening concrete structure appears in the field of retrofitting and has been extensively studied in the past decade. The FRP rod or plate in this technique is inserted into a groove cut in the surface of concrete using bonding materials, and improves the bending-resistance and shear capacity of the concrete structure.

The method of NSM FRP strengthening has many advantages over that of externally bonded FRP plate or sheet. The FRP is embedded in the concrete cover and the effect of abrasion and impact on FRP can be then avoided. The bonded area of NSM FRP to concrete is increased and the strengthening efficiency is improved. Cement-based materials can be used as bonding materials instead of epoxy. Thus, the technique of NSM FRP strengthening can be adopted under the condition of high temperature and humidity. It becomes a hot topic in concrete strengthening since the new technique was first used in Sweden in 1940s (Asplund 1949). Large amount of theoretical and experimental work were performed, including bond performance between NSM FRP and concrete (De Lorenzis et al. 2002, 2007; Galati and De Lorenzis 2009; Soliman et al. 2011; Yang et al. 2009) , study on flexural strengthening (Al-Mahmoud et al. 2012; Capozucca 2009; Kotynia 2012; Kreit et al. 2011; Oehlers et al. 2008; Oudah and EI-Hacha 2012; Wahab et al. 2011; Wang et al. 2011; Yao et al. 2008) and shearing strengthening (Dias and Barros 2013) of concrete structures with NSM FRP.

Epoxy is usually used as bonding materials and the interfacial failure mode between FRP rod and concrete is splitting of epoxy layer which is significantly brittle. Moreover, the performance of epoxy is very sensitive to high temperature and humidity. Therefore, it is necessary to adopt a new type of cementitious materials instead of epoxy as bonding materials and change the brittle interfacial failure to ductile behavior. Engineered cementitious composites (ECC) may be an alternative, which were first designed by Li and Leung (1992) based on micro-mechanics and fracture mechanics and express ductile and strain-hardening behavior. Researchers have carried out much theoretical and experimental work on the optimal designed fiber-reinforced concrete and gain a lot of significant findings (Li et al. 2001, 2007; Xu et al. 2008, 2009; Gao and Xu 2007; Zhang et al. 2010, 2011). The intention of this paper is to study the feasibility of ECC used as bonding materials in NSM FRP rod strengthened concrete structure. Pull-out test of NSM FRP rod from concrete was performed and the failure mode was observed to determine the ductile behavior.

EXPERIMENTAL PROGRAMME

C-type concrete specimen was prepared in Fig. 1 to eliminate the eccentric effect in the pull-out test. The sizes of cross-section of specimen are seen in Fig. 1(b). The groove has sectional sizes of 20 × 20mm^2. The height of specimen is 300 mm.



(a) (b)

Figure 1 C-type concrete specimen

Commercially available premixed concrete was used in the experiment with the mix proportion and basic mechanical parameters in Table 1. Two types of FRP rods with spiral wound surfaces and diameters of 8 mm, i.e., CFRP (carbon FRP) rod and BFRP (basalt FRP) rod, are used in the test. The basic mechanical parameters are shown in Table 2.

Table 1 Mix proportion and basic mechanical parameters of concrete

Mix proportion water : cement : sand : gravel	28-day cubic compressive strength (MPa)	28-day elastic modulus (GPa)
0.47:0.7:1.9:2.52	33.86	30.65

Table 2 Basic mechanical parameters of FRP rods

Type of FRP rod	Density (g/cm^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Fracture elongation (%)
CFRP rod	1.5-1.6	3200	140	1.5
BFRP rod	1.9-2.1	1200	50	1.6

ECC are used as bonding materials and the detailed mix proportion is seen in Table 3. Herein, the cement is P. O. 42.5 common Portland cement (Chinese Standard GB 175 2007). Ultra-fine fly ash is adopted partially instead of cement and quartz sands are used as fine aggregates in the test. Polycarboxylate-based high-range water reducer is utilized as admixture. Reinforcing materials used in the test are Polyvinyl Alcohol (PVA) fibers with diameters of 39 μm and lengths of 12 mm. A four-point-bending test as shown in Fig. 2 is carried out to study the mechanical properties of the ECC. The load-displacement at mid-span curve is seen in Fig. 3.

Table 3 Mix proportion of ECC in the test

Binding materials			Water-to-binder ratio	Sand-to-binder ratio	High-range water reducer	Volume of PVA fiber
Cement	Fly ash	Silica fume				
0.5	0.4	0.1	0.26	0.8	1.8%	1.7%

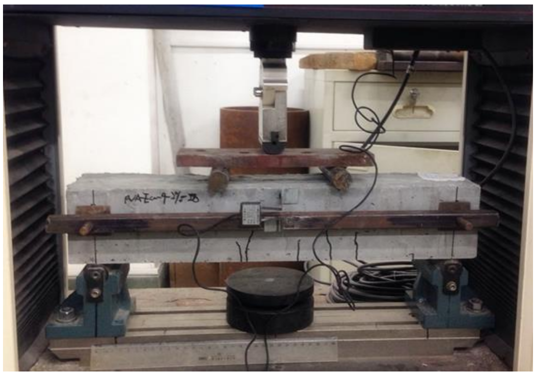


Figure 2 Four-point-bending test for ECC

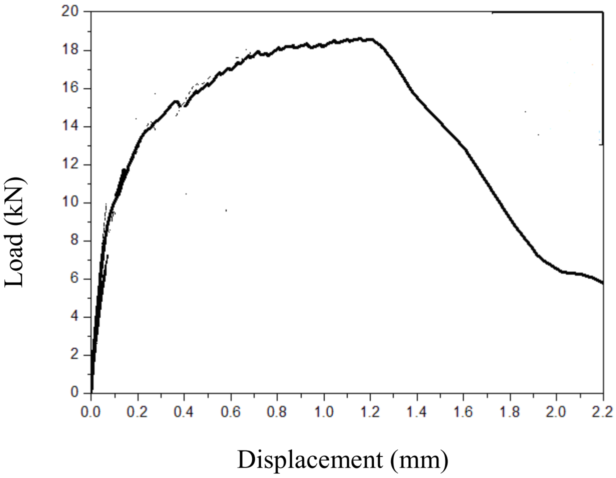


Figure 3 Load-displacement at mid-span curve for ECC

The bonding lengths *L* are 5 times and 10 times of the rod diameters *d*, respectively, for both CFRP and BFRP rods. Thus, four groups of specimens are tested. Moreover, epoxy is adopted as another type of bonding materials for reference and then four groups of control specimens are prepared in the experiment. The basic properties of the epoxy are shown in Table 4. All the specimens are tested using an Electrical Universal Testing System with a maximum range of 100 kN after 28-day curing. The test setup is seen in Fig. 4. An extensometer with the maximum range of 50 mm was used to measure the relative slip between the rod and the concrete block at the loaded end. One arm of the extensometer was fixed on the rod and the other arm touched a short column adhering on the top of the load-bearing plate but very near to the rod. The pull-out load *P* was measured using a load cell set in the testing machine. The rate of loading was controlled by the displacement of the loading head, and fixed at 0.2 mm/min. The readings from the load cell and the extensometer were collected in a data acquisition system.

Table 4 Basic properties of epoxy in the test

Tensile strength (MPa)	Tensile elastic modulus (MPa)	Elongation (%)	Modulus of rupture (MPa)	Cmpressive strength (MPa)
52	2526	2.7	77	89

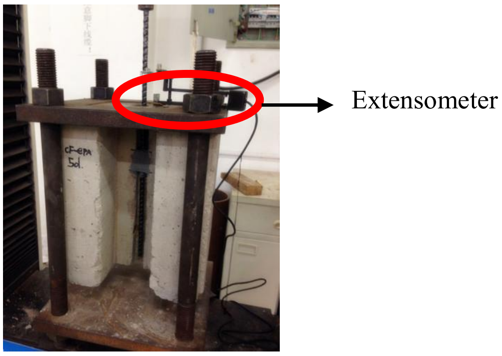


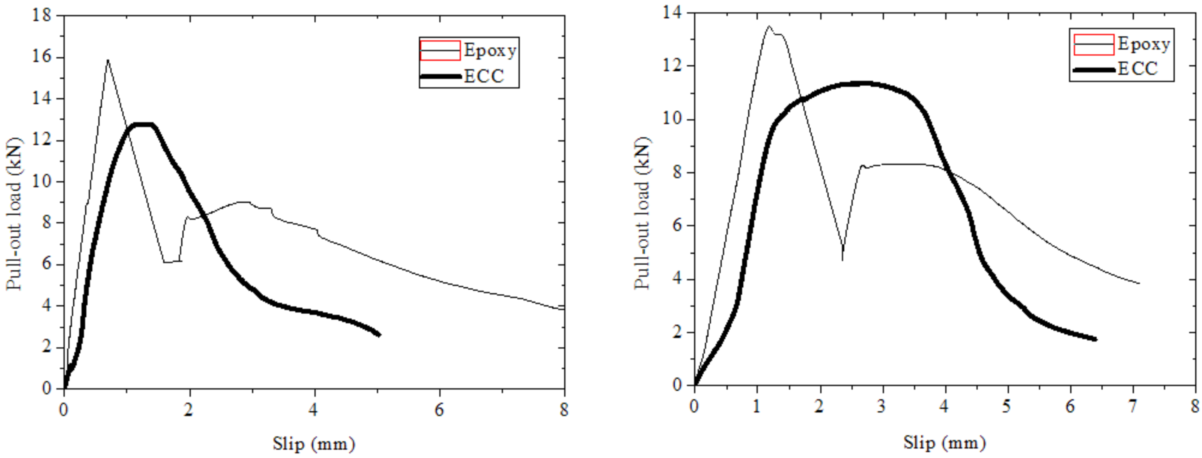
Figure 4 Photo of test setup

RESULTS AND DISCUSSION

When the bonding materials are ECC, all the specimens are in failure by pull-out of FRP rods from concrete blocks without splitting as shown in Fig. 5(a). Very thin cracks can be detected in the ECC layer but the crack propagation is apparently delayed by the PVA fibers due to the high crack-resistance and toughness of ECC. Ductile failure mode can be obtained by using ECC as bonding materials. However, the specimens with epoxy as bonding materials fail by splitting failure of epoxy layer as shown in Fig. 5(b) which is significantly brittle. Fig. 6 shows typical load-slip curves for the two types of FRP rods. There is a slowly descending part in the curve for ECC as bonding materials but a sharply reduction is observed for epoxy as bonding agent when the peak load is exceeded. After the point B, the epoxy layer is actually split and only residual friction remains between the FRP rod and epoxy. Therefore, the ductile behavior can be evaluated based on the stage from the beginning of loading to the start of frictional part. Obviously, the better ductility is observed in the specimens using ECC as bonding materials.

(a) ECC (b) Epoxy

Figure 5 Failure modes of specimens using different bonding materials



(a) CFRP rod (b) BFRP rod

Figure 6 Typical load-slip curves

The maximum pull-out load is lower when ECC is used as bonding materials. For CFRP rods, the pull-out load-bearing capacity of specimens using ECC is 70% and 50% of that in specimens using epoxy for L=5d and

L=10*d*, respectively. For BFRP rods, the load-bearing capacity of specimens using ECC is 75% and 55% of that in specimens using epoxy for *L*=5*d* and *L*=10*d*, respectively. But the ductility of specimens with ECC is significantly improved. Thus, ECC can be applied in NSM FRP strengthened concrete structures as the bonding materials.

CONCLUSIONS

The technique of NSM FRP strengthening concrete structures has been gradually applied in civil engineering. Epoxy is usually used as the bonding materials, and then the failure mode is always splitting of the epoxy layer which is significantly brittle. Thus, it is necessary to select a type of cementitious materials with good ductility as bonding materials instead of epoxy. Engineered cementitious composites (ECC) have been adopted in structural retrofitting due to the high strength and high toughness. The intention of this paper is to study the feasibility of ECC used as bonding materials in NSM FRP rod strengthened concrete structure. The pull-out test of NSM FRP rod from concrete was performed using ECC as bonding materials. The feasibility of cementitious materials in NSM FRP strengthened concrete was then analyzed. CFRP rods and BFRP rods with spiral surfaces and diameters of 8 mm were used in the test. The bonding lengths *L* are 5 times and 10 times of the FRP diameters *d*, respectively. Results show that the failure modes of all the specimens using ECC as bounding materials are pull-out of FRP rods with ductile behavior. Moreover, specimens with NSM FRP rods using epoxy are prepared as control specimens and brittleness is most significant in these specimens. For CFRP rods, the pullout load-bearing capacity of specimens using ECC is 70% and 50% of that in specimens using epoxy for *L*=5*d* and *L*=10*d*, respectively. For BFRP rods, the load-bearing capacity of specimens using ECC is 75% and 55% of that in specimens using epoxy for *L*=5*d* and *L*=10*d*, respectively. Thus, ECC can be applied in NSM FRP strengthened concrete structures as the bonding materials.

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