The Flexural Behavior of Beams Strengthened with FRP grid and ECC

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Introduction

Engineered Cementitious Composite (ECC) is a new kind of random short fiber reinforced cementitious composite with extra high ductility. Unlike common FRC, ECC is developed by optimizing the microstructure of the composite which exhibits strain-hardening behavior with tensile strain capacity more than 3%, yet the fiber content is typically 2% or less by volume. Due to the characteristic of the multiple cracking, ECC has lots of advantages on durability, safety and sustainability, which can overcome the deficiency of concrete for its brittle behavior and low ductility and is valuable for cementitious composites produce, roads and bridges construction as well as rehabilitation of old structures.
Figure 1 is a typical uniaxial tensile stress - strain curve of ECC [1]. After the initial crack is generated, ECC enters into the plastic deformation stage, during which the strain - hardening process associating with micro-cracks continuously develops, showing great toughness. The ultimate tensile strain was more than 5%, which was almost 500 times of ordinary concrete. Restricted by crack bridging stress, the crack width always kept in a small range of values with the maximum crack width smaller than 60μm. The Flexural behavior of ECC is usually obtained by a four-point bending test. The size of ECC beam in Figure 2 is 304.8mm × 76.2mm × 12.2mm, and its ultimate deflection is 22mm which is 40 times of the ordinary concrete [2] specimen.

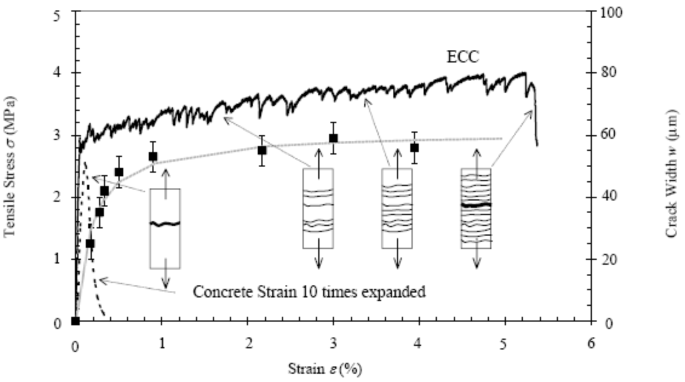

Figure 1. A typical tensile stress - strain curves and crack development of ECC

FRP grid is made from glass, aramid, or carbon fibers (or combinations) impregnated with an appropriate resin system, such as polyester, vinylester or epoxy to form a grid (Fig. 3). Besides the inherent corrosion resistance, the grid form itself is advantageous in that the intersections provide anchorage and mechanical interlock in the concrete, facilitating good stress transfer. Again, due to the non-corrosive and alkali-resistant (based on resin selection) nature of the grid, cover requirements are reduced, resulting in lighter slabs and optimizations of other concrete elements.
FRP grid is usually fixed and bonded to work with original concrete by a thin layer of concrete. Once the concrete cracked due to brittle and was broken, the bonding between FRP grid and original concrete will be exposed without protection, thus they may not work together and cause structural damage. So it often uses polymer cement mortar as a spray thin concrete to integrate FRP grid with original concrete. Considering the high strength and high toughness of ECC material, ECC/FRP grids work together may achieve good mechanical properties. In this paper, the flexural behavior of concrete beams reinforced together with FRP grid and ECC is preliminary studied to inspect its differences from beams reinforced with steel and carbon fiber sheet.

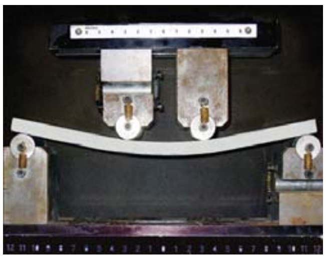
Figure 2. Four point bending test of ECC

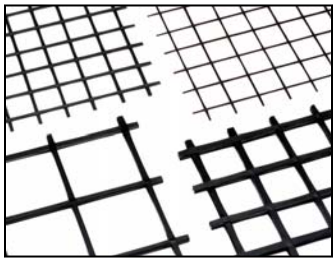
Figure 3. FRP grid

Experimental Programs

Three different repair materials, carbon fiber sheet, polymer cement mortar/FRP grid and ECC/FRP grid were used in this study.

Table1. Materials

material	type	tensile strength (MPa)	compressive strength (MPa)	elastic modulus (MPa)
carbon fiber sheet	Toray 30	3500	/	2.1×10^5
CFRP grid	NEFMAC C6-50	1400	/	1×10^5
ECC	PVA-ECC	5.1	63±2	/
polymer cement mortar	NEFCRETE	/	57±2	/
concrete	C30	/	36±2	/
rebar	HPB235	298	/	/

ECC used in this paper comprised Portland Type I cement, water, silica sand with 0.1mm nominal grain size and 2% poly-vinyl-alcohol (PVA) fibers. These PVA fibers had a length of 12mm and a diameter of 39μm, respectively.

Table2. Beams

No.	Reinforcement
S1	reinforced concrete beam as a reference
S2	reinforced with carbon fiber sheets on the underside
S3	reinforced with FRP grid and NEFCRETE on the underside
S4	reinforced with FRP grid and ECC on the underside

Four rectangular flat concrete beams were studied. They have the same size and reinforced rebar. The four point bending tests were carried out and the load & strain were recorded by sensors (S4 as sample shown in Fig.4).

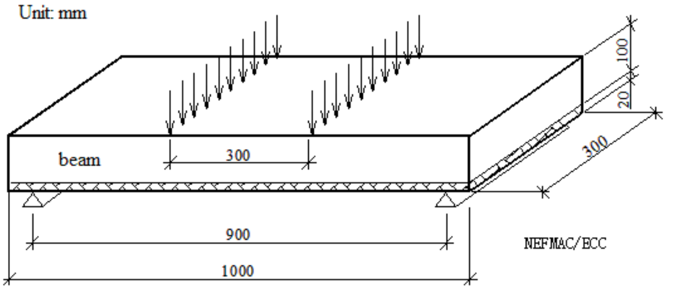

Figure4. Beam S4 (S3)

Experimental results

Figure 5 shows the load-displacement relationships of the beams. Table 3 shows part of the experiment results.

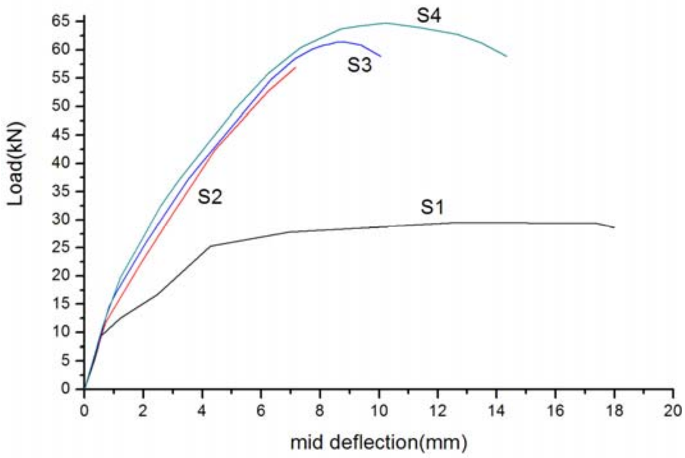

Figure5. Load-displacement relationships of beams

Table3. Experiment results

No	Cracking load (kN)	Ultimate load (kN)	theoretical ultimate load (kN)	number of cracks on the underside	Crack width (mm)
S1	12	31	23	6	1.2~3.1
S2	16	56.9	59	11	0.2~1.7
S3	16	61.5	60	24	0.2~0.8
S4	24	64.7	60	56	0.01~0.1

Beam S2 was damaged due to the debonding of fiber sheet, no obvious sign was observed before failure, which showed a brittle debonding failure and shear failure. The failure modes of S3 and S4 were similar to fiber sheet debonding failure in appearance, but more obvious signs were observed before beam damaged. Debonding between concrete and NEFCRETE (or ECC) lasted for a long while prior to the failure, the deflection of the beam increased obviously from the initiation of debonding till the final failure.

Specifically, ECC layer could still keep intact after the beam damaged, the cracks were many but tiny, the maximum crack width was only 0.1mm, and most of the crack widths were less than 0.05mm.

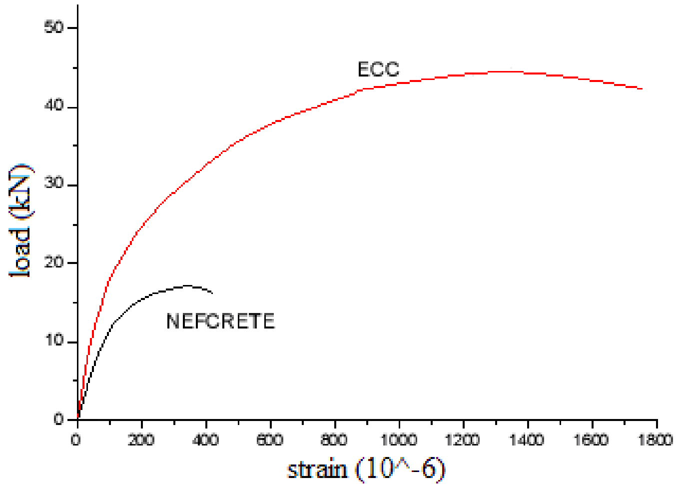

Figure6. Load-strain curve of ECC and NEFCRETE

As shown in Figure 6 and table 3, mechanical properties of ECC in flexural reinforcement were much better than NEFCRETE. Due to the multiple cracks, working durations for ECC with the presence of cracks were much higher than NEFCRETE, and the deformation capability is also significantly higher than NEFCRETE.

The crack control performance of ECC is also better than NEFCRETE in terms of the amount of crack, crack width and the integrity after failure.

Discussion and conclusions

1. The results of all tested beams were consistent with the expectation. The bearing capacity and the safety reserve of beams reinforced with FRP grid were better than beams strengthened by carbon fiber sheet. ECC/FRP grid system showed good ductility that can fix the deficiency in brittleness to a certain extent of traditional FRP reinforcement.
2. The mechanical property and crack-resistance property of ECC in flexural reinforcement were also significantly better than concrete and NEFCRETE.
3. Compared to traditional reinforcement by externally bonded with FRP sheet, FRP grid has advantages in resistance to aging, high temperature resistance and other aspects.
4. If we can improve the bonding effect between FRP grid and concrete, flexural reinforcement effect of FRP grid will be further increased.

References

1. Victor C. Li., 2005. “Engineered Cementitious Composites.”

2. Shuxin Wang, Victor C. L., 2003. “Polyvinyl Alcohol Fiber Reinforced Engineered Cementitious Composites: Material Design and Performances.”