

# Strengthening of Reinforced Concrete Beams using Carbon Fiber Sheets bonded with Cement-Based Mortars.

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## 1. INTRODUCTION

A structure may need repair or strengthening for various reasons: the structures may have to carry larger loads; damage due to accident; errors made during design or construction phase; or corrosion damage of the structural members. Various methods have been used to repair/strengthen reinforced concrete members. In recent years, fiber reinforced polymers (FRP) composite materials have been introduced to the civil engineering field which showed a promising potential in the repair and strengthening of concrete structures. In this method continuous fiber sheets are bonded to the surface of a concrete structure using organic resins. However the FRP strengthening technique has a few drawbacks, which are attributed to the organic resin used to impregnate and bond the fiber to the concrete surface. Some of these drawbacks may be summarized as follows: 1) poor performance of epoxy resins at high temperatures; 2) relatively high cost of epoxy resins; 3) it might be harmful to worker if not handled properly; and 4) incompatibility of epoxy resins with substrate materials. These problems could be solved if a cement-based matrix is used instead of epoxy matrix [1 -3].

## 2. EXPERIMENTAL PROGRAM

### 2.1. Specimen details

A total of 5 reinforced concrete beams were tested in this study as summarized in Table 1. Beam BC was a control beam without strengthening, while beam BE was strengthened by bonding carbon fiber (CF) sheet at the bottom of the beam using epoxy. On the other hand beam BM2 was strengthened by bonding CF sheet at the bottom of the beam using readymade repair mortar that only required addition of water. Beam BM2\_US is strengthened similar to BM2 with the addition of two U-shaped CFRP strips applied on top of the CFRP sheet around the cross-section at one third of the span length (see Figure 1). BM2\_SP is similar to beam BM2, however, super plasticizer was added to the mortar to enhance workability of the mortar.

The specimens were 2.7 m long, 100 mm wide and 150mm high. All beams were reinforced with two 10 mm diameter bottom bars (tensile reinforcement) and two 8 mm top (compression) bars. The clear concrete cover was 20 mm on all sides of the specimen. For stirrups, 6 mm plain bars spaced at 290 mm were used in all specimens.

Table 1: Beams description

Specimen designation	Remarks
BC	Control beam
BE	Strengthened with CF sheet bonded with epoxy
BM2	Strengthened with CF sheet bonded with mortar
BM2_US	Strengthened with CF sheet bonded with mortar in addition to U-shaped strips
BM2_SP	Strengthened with CF sheet bonded with mortar with super plasticizer

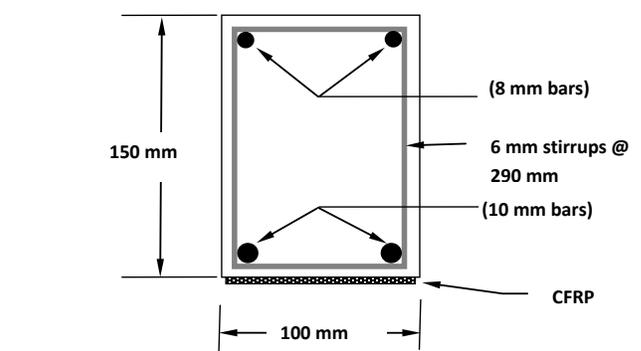
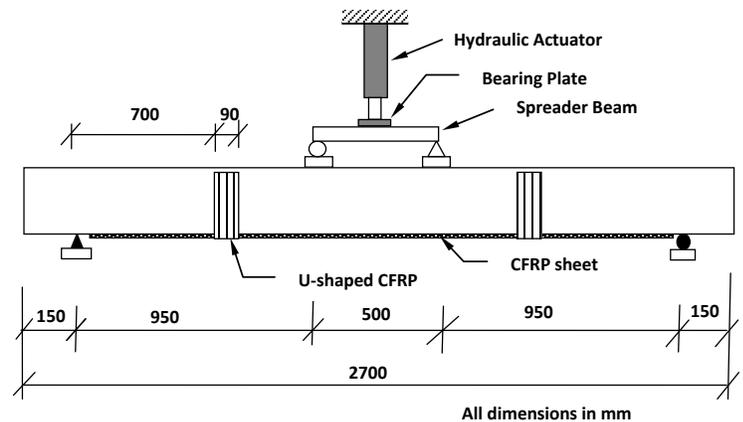


Figure 1: Loading Set Up & Beam Cross-Section

## 2.2. Material properties

Unidirectional carbon fiber sheets were used for the bottom longitudinal sheets. Thickness of the sheet was 0.11 mm (dry fibers), tensile strength of 3800 MPa, modulus of elasticity of 240 GPa, and ultimate elongation of 1.55% as indicated in the data sheets provided by the manufacturer. The composite (fiber and epoxy) thickness of the CFRP sheet was 1 mm on average. Ordinary portland cement was used for the concrete mix along with a maximum aggregate size of 10 mm. The concrete mix was proportioned by weight as follows, aggregate : sand : water : cement = 60 : 67 : 16 : 25, with a water to cement ratio of 0.64. The concrete had a 28-day compressive strength on average of  $40 \pm 1.6$  MPa and a tensile splitting strength of 3.9 MPa. The average yield strength of the 10mm diameter reinforcing bars was measured to be 460 MPa and modulus of elasticity was 200 GPa. The yield strength of the 6mm diameter plain reinforcing stirrups was 250 MPa.

## 2.3. Test set up

All specimens were loaded in four-point loading (see Fig. 1). The load was applied using a 250 kN hydraulic actuator through a spreader steel beam to the specimen. Four linear variable displacement transducers (LVDTs) with a range capacity of 100mm were used to measure the load-line and mid-span deflections of the beam during testing. All beams were tested to failure using load control with a rate of 0.05 kN/s for loading up to 13 kN (yielding load) and displacement (stroke) control with a rate of 0.05 mm/s was used to apply the loading from 13 kN to failure.

## 3. RESULTS AND DISCUSSION

Figure 2 presents the load-midspan-deflection curves for all tested beams. The results showed that beam strengthened with epoxy bonded CF sheet was superior in terms of load transfer between the CF sheet and the beam concrete surface in comparison to beams strengthened with mortar bonded CF sheets. The beam strengthened using epoxy bonded CF sheet (beam BE) was able to resist a load of 27 kN at failure which is approximately 59% higher than the failure load of the un-strengthened control beam (beam BC) which was recorded as 17 kN. The failure of beam BE was due to rupture of the CF sheet. All other beams strengthened with CF sheets bonded with mortar were able to resist loads of approximately 18.3 kN which is higher than the control beam; however, due to bond failure at the interface between the CF sheet and the concrete beam surface (see Fig. 3) this increase in load was not maintained and the load dropped to a level similar to the control beam once this bond failure was initiated. One reason for this mode of failure that the mortar is a paste like, even with the addition of super plasticizer, and it was not possible to completely penetrate and wet the CF sheet fibers. However, the epoxy has low viscosity and penetrated through the CF fibers creating excellent bond with the concrete surface. The U-shaped CF strips improved slightly the bond and the ductility as indicated by large deflections at failure.

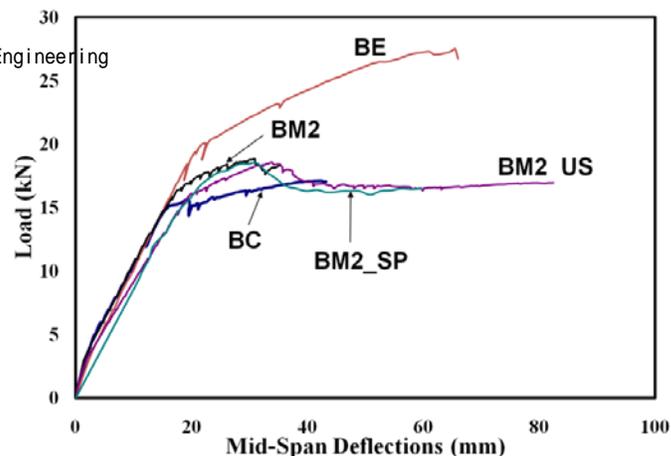


Figure 2: Load-deflection curves of beam specimens



Figure 3: Bond Failure in CF sheets bonded with mortar

## 4. CONCLUSIONS

This study presented test results of strengthened reinforced concrete beams using CF sheets bonded with epoxy or mortar. Based on the test results it can be concluded that epoxy bonded CF sheet performed better than mortar bonded sheets. To improve the performance of mortar it is required to improve the workability of the mortar and viscosity and the wetting and penetration of the mortar through the CF sheets as well as the tensile strength of the mortar.

## 5. REFERENCES

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