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International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

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PAPER ID: 10A09D

FLEXURAL BEHAVIOR OF REINFORCED CONCRETE BEAMS STRENGTHENED WITH FERROCEMENT

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ARTICLEINFO

Article history:
Received 06 April 2019
Accepted 04 July 2019
Available online 12 July 2019

Keywords:
Ferrocement beam; static four-point bending test; shear connectors; load-mid span deflection relationships; flexural load carrying capacity.

ABSTRACT

The flexural behaviors of reinforced concrete beams strengthened by ferrocement are studied in this work. Three beam specimens with identical size and steel reinforcement are made to perform the experiments. The first beam is used as a reference while the second and the third beams are strengthened by ferrocement, composed of external steel reinforcing bars, wire mesh, and mortar cement. The surface of strengthening specimens is intentionally rough before wrapping by steel wire mesh and patched by mortar cement for the second beam, but for the third beam, shear connectors are provided between the concrete surface and ferrocement. All specimens are tested under static four-point bending test. The results show that significantly increased flexural strengths of strengthening specimens, the second and the third beams, over the reference specimen, are found, but ductility of the specimen with shear connectors is significantly larger than the others.

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1. INTRODUCTION

Strengthening and repair are necessary to upgrade the damaged structures instead of rebuild or reconstruction of the new ones. Several materials can be used for repairing or strengthening such as using steel plate, fiber-reinforced polymer (FRP) as well as ferrocement. Ferrocement material is a popular technique widely used to upgrade the RC structure. Ferrocement is a thin element, which employs cement mortar combined with a small diameter reinforcing mesh. Ferrocement material is easily bonded to the existing RC structure without the special skill, and there is no formwork required in this technique. The use of ferrocement can significantly enhance the load-carrying capacity, stiffness, and also can reduce the crack-width. The bond surface of RC beam or an existing structure is very important before strengthening with ferrocement.

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2. LITERATURE REVIEW

The technologies to use ferrocement beams have been studied a long time ago such as work of Balaguru et al (1979), to monitor fatigue behaviors and design of ferrocement beams. A more recent, Rafeeqi et al. (2012) studied the performance of ferrocement as material for flexural strengthening. Ferrocement is applied by Khan et al. (2013) to strengthening RC beams with focus on flexural study.

Sirimontree et al. (2015) applied ferrocement to strengthen reinforced concrete column. The study observed behaviors of reinforced concrete (RC) column under static axially loading, encased by longitudinal steel and ferrocement. Vertical steel reinforcements are applied to encase RC column specimens, then wrapped by varying amount of wire mesh and then covered with cement mortar. The experiment yielded significant improvement of strength and ductility of a strengthened column.

Madadi et al. (2017) conducted a study with experiments versus finite element analysis (FEA) on lightweight ferrocement matrix to observe compressive behaviors. The digital image correlation (DIC) and FEA were used to investigate load-displacement behavior, crack pattern, density, ductility, and elastic modulus were first assessed. Applying both techniques can be used to evaluate lightweight ferrocement for determining material characteristics.

A review of using ferrocement technology constructions and applications was summarized by Sakthivel and Jagannathan (2011).

This paper presents a study on the flexural strengthening of the RC beams using ferrocement. The effect of shear connectors between beam and ferrocement on the flexural performance is investigated. The flexural behavior including the load-mid span deflection relationships and the mode of failure is discussed.

3. EXPERIMENTAL STUDY

A total of three beams with an identical size, span length, and steel reinforcement are cast to perform the flexural test. Description of beam specimens is expressed in Table 1 and Figure 1. Average 28 days cube strengths (150×150×150 mm) of normal concrete and ferrocement used in producing test specimens are 57 and 54 MPa, respectively. The average yield strength of steel reinforcements for deform bars (DB12 (dia.12mm)) and round bars (RB9 (dia. 9mm)) from the tensile test are 429 and 358 MPa, respectively. The beams are strengthened by ferrocement at three sides with a thickness of 30 mm. Figure 2 presents the preparation of beam specimens. Finally, the four-point bending test of all beams is performed statically to failure, as shown in Figure 3.

Table 1: Description of beam specimens.

Specimen	Description
BR	Reference beam specimen
BF	Beam strengthened by external steel reinforcement wrapped by ferrocement without shear connectors
BFS	Beam strengthened by external steel reinforcement wrapped by ferrocement with 6 mm. diameter round bar shear connectors (see Figure 1)

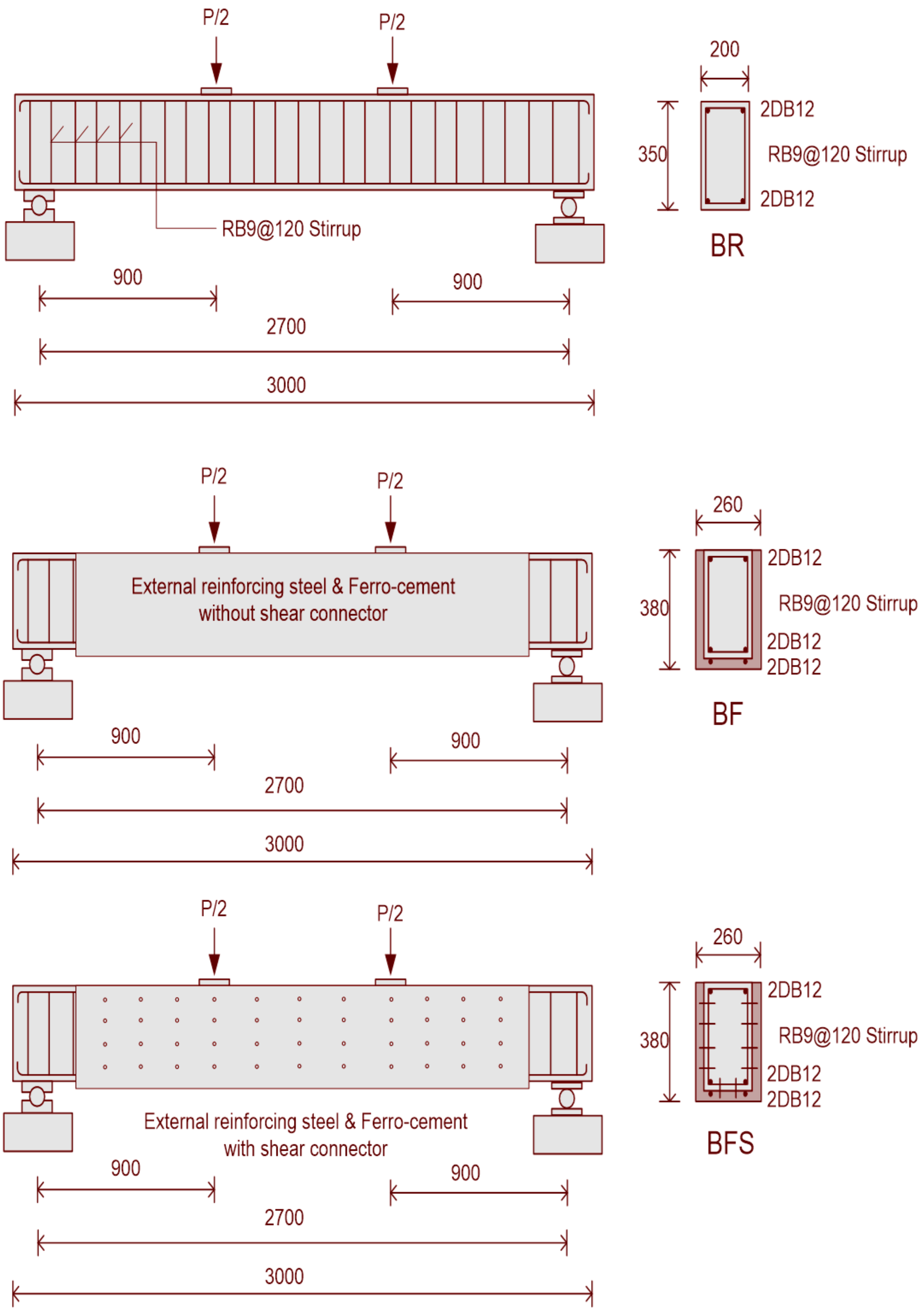

Figure 1: Details of beam specimens

Figure 2: Preparation of test specimens.

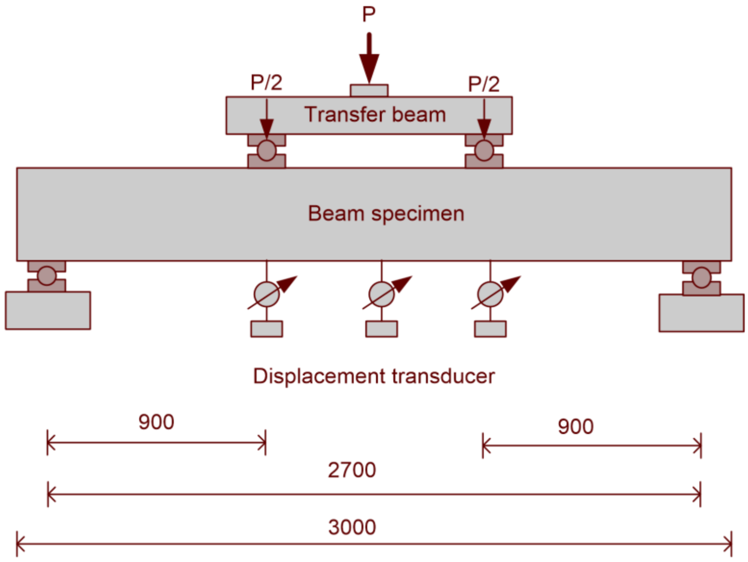

Figure 3: The four-point bending test of beam specimens.

4. RESULTS AND DISCUSSION

Figure 4 gives the load-mid span deflection relationships for all beams. Cracks pattern of test specimens is shown in Figure 5. Table 2 shows the values of the cracking load, yield load, ultimate load, and ultimate deflection of all beams.

The cracking, yield, ultimate loads, and ultimate deflection of the reference beam (Beam BR) are 27.3 kN, 65.6 kN, 79.6 kN, and 59.6 mm, respectively. Generally, the beam failed by yielding of tensile reinforcement followed by the crushing of concrete (under-reinforced section).

For the beams strengthened with ferrocement, without shear connectors, the cracking, yield, ultimate loads, and ultimate deflection of Beam BF are 51.2 kN, 119.9 kN, 137.3 kN, and 50.3 mm, respectively. The cracking, yield and ultimate loads are higher than those reference beam by 88%, 83%, and 72.5%, respectively, while the ultimate deflection decreased by 16%. With shear connectors, the cracking, yield, ultimate loads, and ultimate deflection of Beam BFS are 49.2, 133.5 kN, 142.8 kN, and 75.1 mm, respectively. The cracking, yield, ultimate loads, and ultimate deflection are higher than those reference beam by 80%, 104%, 79%, and 26%, respectively.

Based on the experimental results, it can be observed that the ferrocement can significantly enhance the flexural capacity in terms of the cracking, yield, and ultimate loads. The ultimate load of beams with and without shear connectors are similar. However, it was observably seen that the ductility of the beam with shear connectors was higher than that without shear connectors because of the different mode of failure. Figure 6 shows the comparisons of the failure modes between strengthened beams with and without shear connectors. Without shear connectors, the beam failed by the delamination between ferrocement and beam due to the shear flow, as shown in Figure 6(a). The load was suddenly dropped after the ultimate load. It directly affects to the ductility of the beam because of the loss of the horizontal shear flow between beam surfaces. With shear connectors, the good bond at failure between ferrocement and beam surface was found, as shown in Figure 6(b).

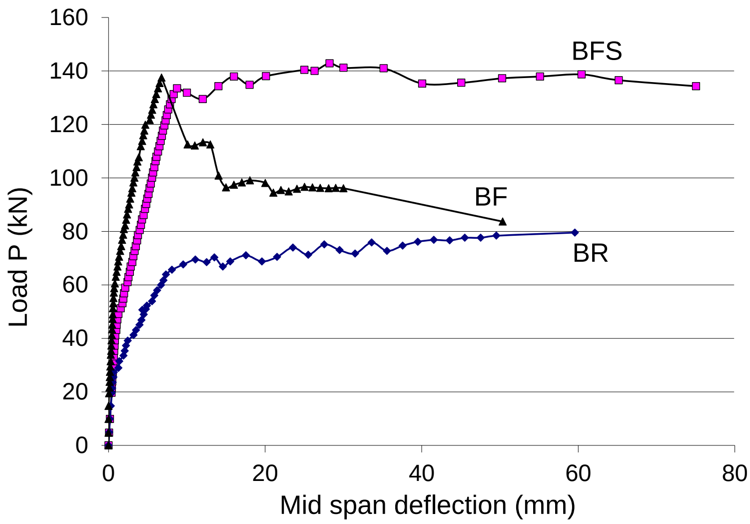

Figure 4: Load-mid span deflection relationships.

Table 2: Experimental results.

Specimen	Cracking load (kN)	Yield load (kN)	Ultimate load (kN)	Deflection at yield load (mm)	Ultimate deflection (mm)
BR	27.3	65.6	79.6	8.1	59.6
BF	51.2	119.9	137.5	4.7	50.3
BFS	49.2	133.5	142.8	8.8	75.1

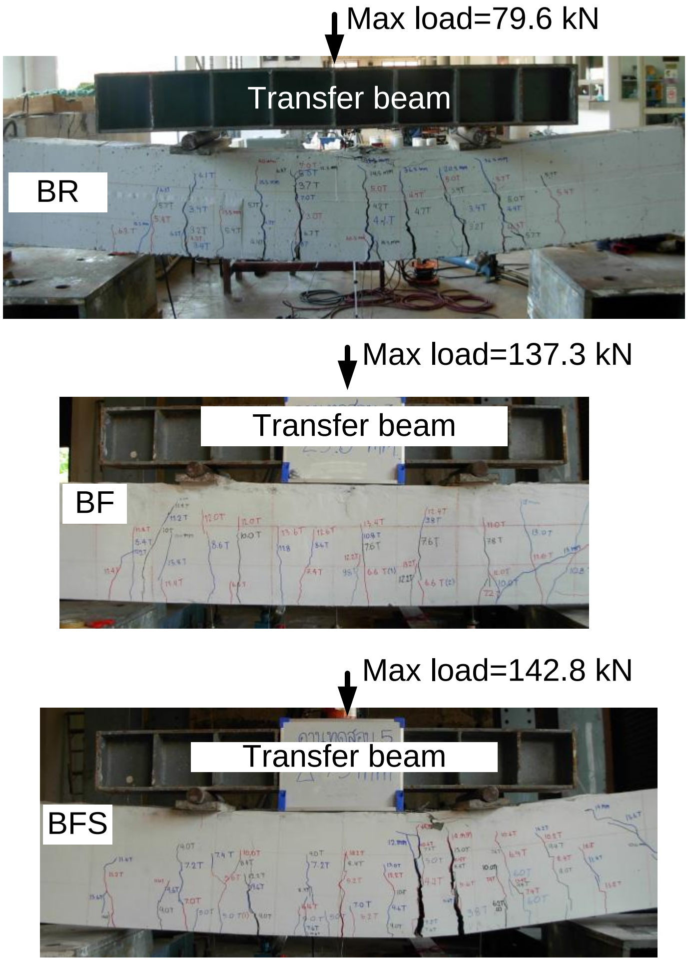

Figure 5: Cracks pattern of the test specimen at failure.

(a) Separation of Ferro-cement from the beam due to the shear flow

(b) Ferro-Cement and beam surface are bonded at failure load

Figure 6: Effect of shear connectors on composite action between ferrocement and beam surface.

5. CONCLUSION

This paper investigated the flexural behavior of RC beams strengthened with ferrocement. The effect of shear connectors is observed. Based on the experimental study, the following conclusion can be made:

1. The strengthened beams with ferrocement showed an increase in flexural load carrying capacity over the reference beam up to 79%.

2. The good ductility performance can be obtained in beam strengthened ferrocement with shear connectors, which is larger than the reference beam up to 26%.

6. AVAILABILITY OF DATA AND MATERIAL

Studied data and detail is included in this article.

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Note: The original of this article was reviewed, accepted, and presented at the 4th International Conference-Workshop on Sustainable Architecture and Urban Design (ICWSAUD2019), a joint conference with 4th International Conference on Engineering, Innovation, and Technology, during 24-26 June 2019 at Vistana Penang Bukit Jambul Hotel, Penang, Malaysia.