

Study the Structural Behaviour of Ferrocement Beam

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Abstract

The need of the construction industry to look for a reliable and cheaper strengthening component for reinforced concrete structure has led to the usage of ferrocement which proves to be a promising solution. This paper describes the structural short-term behavior of a beam strengthened with ferrocement laminate and identifies its advantages. Beam which is strengthened with ferrocement laminate is compared to a control beam for analysis of the advantages of using ferrocement. From the experiment carried out, beam strengthened with ferrocement proves to have a higher cracking load, ultimate load as well as having a lower deflection in comparison to a normal beam.

Keywords: Reinforced concrete beam, ferrocement, strengthening, deflection

I. INTRODUCTION

Ferrocement is a type of building materials made up of a relatively thin layer of cement mortar reinforced with layers of continuous uniformly distributed wire mesh. The ACI Committee 549 [1] defined ferrocement as “a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small diameter wire mesh”. The cementing mix consists of cement and sand mortar while the reinforcement steel wire mesh has openings large enough for adequate bonding of the mixture. The uniform dispersion of the steel wire mesh and the close distribution of its opening transform the usually weak and brittle mortar mixture into a high performance building material distinctly different from normal reinforced concrete. This steel wire mesh is also responsible for ferrocement structures to have greater tensile strength and flexibility which is not found in ordinary concrete structures. It possesses higher tensile strength to weight ratio and a degree of toughness, ductility, durability and cracking resistance considerably greater than those found in other conventional cement based materials [2]. Since ferrocement is made of the same cementitious materials as reinforced concrete structure (RC), it is ideally used as an alternative strengthening component for rehabilitation work on any RC structures.

The most widely used construction materials in today's world would be concrete and steel combined to make reinforced concrete as can be seen in most building construction. However, the first known example of the usage of reinforced concrete started with the construction of boats when Joseph Lambot of France began to put metal reinforcing inside concrete in 1840s. That was the birth of reinforced concrete and from there subsequent developments followed. The technology at that period could not accommodate the time and effort needed to produce meshes of thousands of wires. Instead, large rods were used to make what is now called standard reinforced concrete.

One of the greatest assets of ferrocement is its relatively low unit cost of materials but in countries which demand higher cost of labor, the usage of ferrocement is not economical. For countries where unskilled, low-cost labor is available and can be trained, and as long as a standard type of construction is adhered to, the efficiency of labor will improve considerably, resulting in a reduced unit cost. With these conditions, ferrocement proves to be a more favorable option than other materials used in construction, all of which have a higher unit material cost and require greater inputs of skilled labor. The primary worldwide applications of ferrocement construction to date have been for tanks, roofs, silos and mostly boats. In this paper, the flexural behavior of beam strengthened with ferrocement laminate will be investigated. The result from the testing of ferrocement strengthened beam will be compared to a control beam to have a clearer insight into the advantages of using ferrocement. The cracking behavior and ultimate load carrying capacity will be highlighted in this paper.

The aims of the study are listed as follows:

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- To investigate the characteristic of short term deflection, cracking performance and ultimate flexural strength of ferrocement beam.
- To compare the short term deflection & ultimate flexural strength of ferrocement beam against a normal control beam.

2. LITERATURE REVIEW

Rehabilitation work has emerged as an important subject in an effort to deal with the problems of deteriorating infrastructure. For that purpose, several strengthening methods have been used in the past such as enlargement of cross section, reduction of span length, external post-tensioning, addition of new steel members and external plate bonding with FRP plate which result in various degree of success. There is a need to develop an alternative technique, which can be implemented at site with the help of semi-skilled labor available on site. The advantages of using ferrocement for strengthening work are its high tensile strength, easy application as well as its low cost in terms of materials and labors. This has led to a large scale of research on this material and thus produced a lot of information regarding the design and construction techniques using ferrocement.

The strengthening of reinforced concrete beams using ferrocement laminates attached onto the surface of the beams has been carried out by Paramasivam, Lim and Ong [2]. In the research, they have come to the conclusions that the addition of ferrocement laminates to the soffit (tension face) of the beams tested statistically substantially delayed the first crack load, restrained cracks from further widening and increased the flexural stiffness and load capacities of the strengthened beam. The improvements in mid-span deflection and load capacities are lower in beams where the composite action was lost between the original beam and the strengthening ferrocement laminates. Thus, it is suggested that the surface of the beam to receive the ferrocement laminate to be roughened and provided with closely spaced shear connectors in order to ensure full composite action.

Nassif and Najm [3] conducted an experimental and analytical investigation of ferrocement-concrete composite beams whereby the method of shear transfer between composite layers is examined. It was concluded from this study that full composite action between both layers cannot be attained based on rough surfaces without shear studs and a minimum of five studs should be used to ensure full composite action. Shear studs with hooks exhibited better pre-cracking stiffness as well as cracking strength compared to all other types of studs. It was also concluded that beam specimens with square mesh are better for crack control than beam with hexagonal mesh.

A research done by Jumaat and Alam [4] showed that the spacing of the shear connectors used for the purpose of strengthening of beam also affects the formation of first crack, mid-span deflections and also the load capacity of the beam. The improvements in cracking, deflection and ultimate load was greater with smaller shear connector spacing. They also concluded that the performance of the strengthened beam with higher volume fraction of reinforcement in ferrocement laminate was slightly better than the one with lower volume fraction. It has also been found that pre-cracked beams prior to repair did not affect the ultimate load capacities of the strengthened beams.

The shear behavior of ferrocement thin webbed sections had been studied by Ahmad, Lodi and Qureshi [5] whereby they studied the shear behavior of ferrocement channel beams by conducting tests under transverse loads for 15 beam specimens. The dominant parameters which are the shear span to depth ratio, 'a/h', the volume fraction of the reinforcement and the strength of mortar, were varied to determine its effect on the cracking shear strength. Results from their studies showed that the cracking and ultimate shear strength of ferrocement channel beams increases as the shear span to depth ratio decreases and/or the amount of wire mesh or mortar strength increases. The crack initiation and failure mechanism of the ferrocement beams were greatly influenced by the shear span to depth ratio. They observed that at shear span to depth ratio less than 2.0, first cracking usually occurs near the mid depth of the section; whereas bottom fibre flexural cracks appear first at higher shear span to depth ratios.

Kazemi and Morshed [6] performed an experimental study to strengthen shear deficient short concrete columns using ferrocement jacket reinforced with expanded steel meshes. Ferrocement was found to be good for crack control purposes. Concrete specimens that were strengthened with expanded meshes showed distributed fine shear cracking even at the large amounts of displacement ductility capability. They also concluded that a small amount of expanded meshes is sufficient to increase the shear strength considerably but a larger steel volume was needed to attain a good amount of ductility. According to their finding, ties were not as effective as expanded meshes in shear strengthening of concrete columns.

The flexural behaviour of reinforced concrete slabs with ferrocement tension zone cover had been investigated by Al-Kubaisy and Jumaat [7]. Their research proves that reinforced concrete slabs with ferrocement tension zone cover are superior in crack control, stiffness and first crack moment compared to similar slabs with normal concrete cover. Deflection near serviceability limit was significantly reduced in specimens with ferrocement cover.

Finite element method of modeling ferrocement strengthened beam has also been done using ANSYS software to simulate the behavior of ferrocement beam. Elavenil and Chandrasekar [8] did a research on this and has come to the conclusion that finite element models represented by load-deflection plot at mid-span shows good agreement with the experimental and theoretical results. The research also shows that load carrying capacity as well as the ultimate load of ferrocement strengthened beam is higher than that of the control beam. The mid-span deflection at any given load is also lower than that of control beam.

Research has shown that ferrocement is effective for strengthening purposes for various types of reinforced concrete members such as beams, columns and slabs in terms of increasing the flexural strength, crack control as well as deflection. Columns reinforced with ferrocement jacket also had increased shear strength and higher ductility. Construction costs will be slightly higher with ferrocement cover but this is greatly offset by the money spent on repairing damaged structures

caused by cracking or spalling of normal concrete cover. In addition to that, ferrocement allows the existing conventional concrete material and practices to be used and thus, is more practical as a strengthening material compared to others. The usages of ferrocement and its advantages compared to a normally reinforced beam is an interesting topic for further investigation. The short-term behavior, cracking load as well as cracking behavior could be analyzed further to gain more understanding of the advantages of ferrocement.

3. EXPERIMENTAL PROGRAMME

Description of Test Specimens

Two concrete beams of Grade 30 were cast for the experimental testing carried out in the laboratory. One beam is strengthened with ferrocement on its soffit while the other beam is without ferrocement which act as a control beam. The beam were measured 1500 mm in length with cross section of size 150 mm×150 mm. Both the beams were cast using the same reinforcement which is 2 bar of 10 mm diameter for top and bottom steel reinforcement. The shear reinforcements were of 6 mm diameter bars spaced at 150mm center to center. In ferrocement laminate, square wire mesh with 1 mm diameter and spacing of 14 mm was used.

Materials Properties

Normal weight concrete designed to achieve compressive strength of 30 N/mm² after 28-days was used. Ordinary Portland cement, sand and coarse aggregate of maximum size 20mm were mixed in the proportion 1:1:2.5 by weight with a water to cement ratio of 0.45. Slumps of 65 mm were recorded prior to casting. Steel reinforcements which were selected for tension and compression reinforcement was 10mm diameter bars with characteristic strength of 460 N/mm². For shear reinforcement, steel bars of 6 mm diameters with characteristic strength of 250 N/mm² were used.

For the beam strengthened with ferrocement, 5 L-shaped bars of 6-mm diameter were used as shear connector. For the strengthening mortar, cement and sand were mixed in the proportion of 1:2 by weight and water to cement ratio of 0.4 which gives compressive strength of 30 N/mm² after 28-days.

Surface Preparation

During casting of the beam to be strengthened by ferrocement, the soffit of the beam is cast in such a way that it is rough and the aggregates were exposed as shown in Figure 1. The purpose of providing this rough layer is to ensure a better bonding between the original concrete beam and the ferrocement layer when mortar is applied.

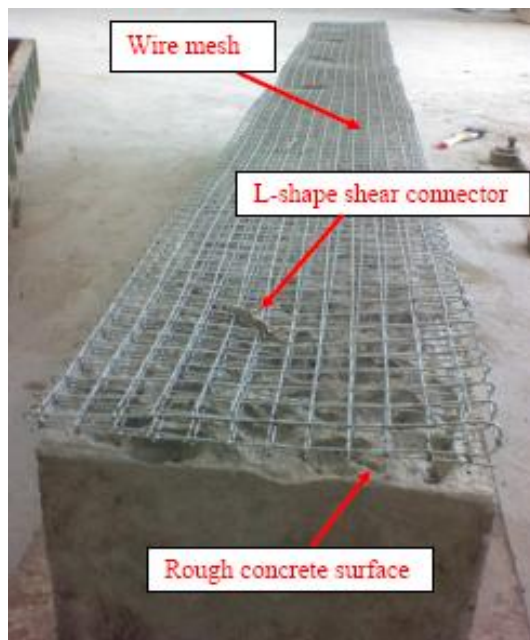


Figure 1: Attachment of wire mesh to the beam.



Figure 2: Ferrocement laminate attached to beam.

Strengthening of Beam

To form the ferrocement beam, 3 layers of square wire mesh of 14-mm opening were attached to the soffit of the beam. Five L-shaped shear connector were used to secure the wire mesh from peeling off during testing. Mortar is placed through

hand plastering whereby mortar is forced through the mesh. Surfaces are finished to about 30mm to assure proper cover to the last layer of wire mesh and leave to dry for about 1 week before it undergoes flexural testing (Figure 2).

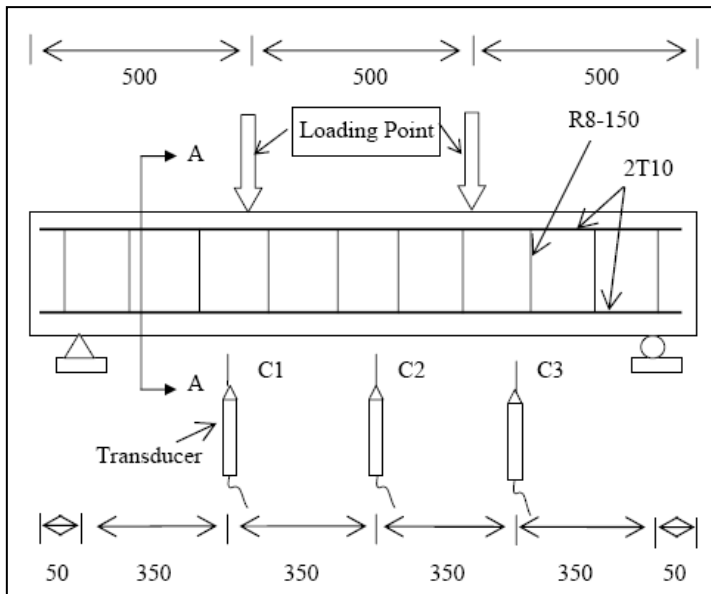


Figure 3: Experimental set-up.

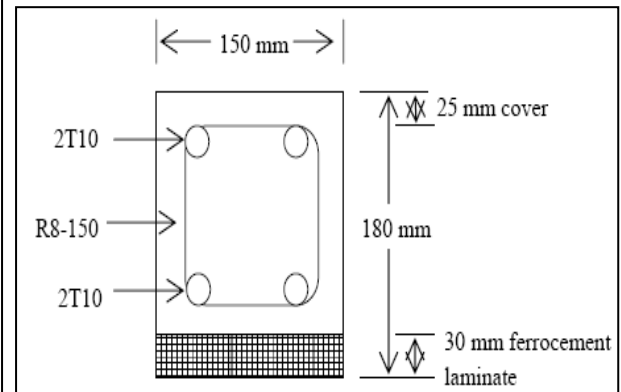


Figure 4: Cross section A-A

Test set-up and instrumentation

All the beams were tested under 2-point loading over a span of 1400mm and also instrumented for the measurement of mid-span deflections. Figure 3 and figure 4 shows the loading point on the beam and the cross-section of ferrocement beam respectively. Loading is applied until the beam collapsed and the ultimate load is then noted. The ultimate load capacity and mid-span deflection of the ferrocement strengthened beam is then compared with that of a normal beam.

Linear displacement transducers were used to measure the mid-span deflection of the beam. The deflection readings were recorded by a portable data logger. Before testing, it was made sure that the transducer was touching the soffit of the test beams. During testing, the load was applied by two hydraulic jacks attached to the pressure gauge. The pressure gauge records the applied load in unit bar or psi and based on past experiments, 1 unit bar of pressure from the meter corresponds to 0.31 kN. Cracks were visually detected using a magnifying glass and its propagation was traced and the corresponding loads were recorded on the surface of the beam.

All the beams were tested with concentrated load applied in 10 bar (3.1 kN) for the first time and 5 bar (1.55 kN) subsequently. The developments of crack were traced using a marker and the first crack loads were also recorded. For every load increments, the corresponding deflections were printed out from the data logger. Loading continued until the cracking on the beam were severe enough. Cracks started at the soffit of the beam and moved vertically as more load is applied. Loading is applied incrementally and stop once the cracks has passed the neutral axis of the beam. The cracking pattern is as shown in Figure 5.



Figure 5: Cracking pattern of ferrocement strengthened beam

4. RESULTS AND DISCUSSIONS

The results of the tests for the normal beam and ferrocement beam are summarized in Table 1 and Table 2 respectively. It can be seen that on the same value of load, the beam which is reinforced with ferrocement has lesser value of deflection compared to the beam without ferrocement. This shows that ferrocement can enhance the beam's structural performance. Taking the loading of 6.20kN for example, the beam strengthened with ferrocement shows a mid-span deflection of 0.22mm and still within the elastic range while the control beams shows a mid-span deflection of 0.80mm. This shows an improvement of about roughly 70% for the ferrocement beam. The transducers at positions C1 and C3 give almost the same reading. This indicates the symmetrical behavior of the beam.

* Highlighted value indicate the starting of cracking stage

Load (bar)	Load (kN)	Deflection (mm)		
		C1	C2	C3
0.00	0.00	0.00	0.00	0.00
10.00	3.10	0.06	0.10	0.08
15.00	4.65	0.20	0.40	0.27
20.00	6.20	0.52	0.80	0.69
25.00	7.75	0.87	1.29	0.98
30.00	9.30	1.18	1.83	1.50
35.00	10.85	1.78	2.62	2.04
40.00	12.40	2.17	4.40	2.54
45.00	13.95	4.63	7.42	5.11
50.00	15.50	7.48	11.16	7.63

Table 1: Test results for the control beam.

Load (bar)	Load (kN)	Deflection (mm)		
		C1	C2	C3
0.00	0.00	0.00	0.00	0.00
10.00	3.10	0.02	0.06	0.03
15.00	4.65	0.05	0.14	0.05
20.00	6.20	0.11	0.22	0.15
25.00	7.75	0.25	0.40	0.31
30.00	9.30	0.61	0.70	0.54
35.00	10.85	0.74	1.18	0.69
40.00	12.40	0.89	1.85	0.88
45.00	13.95	1.52	2.60	1.75
50.00	15.50	2.10	3.47	2.50
55.00	17.05	2.92	4.48	3.60
60.00	18.60	4.81	8.94	6.87

Table 2: Test results for the ferrocement beam.

From Figure 6, it can be seen that both beams behaved in the same pattern. Initially, during the uncracked stage, both the plot shows a steep increase. Once the cracking point has been reached, the gradient decreases until it almost become flat when it reaches the ultimate load. Since both the beams are made of the same cementitious materials, this behavior is expected with the only difference being the beam strengthened with ferrocement which shows a higher cracking point as well as higher ultimate loading point.

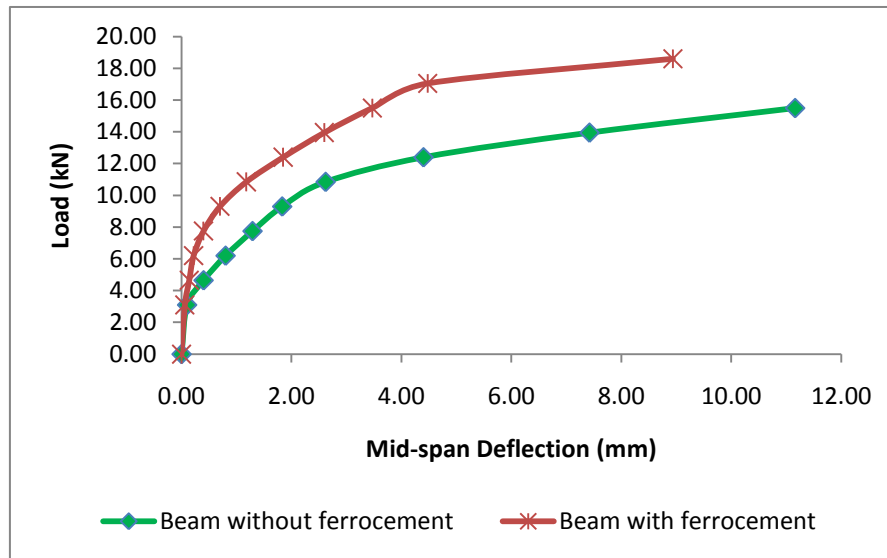


Figure 6: Plot of load (kN) vs mid-span deflection for both the beams.

When the beams were loaded, the concrete layer at the tension zone is able to resist the tensile forces exerted before the concrete tensile strength at the bottom of the beam has exceeded. This also means the deflection of the beam would increase steeply after cracking at the beam has occurred. Thus, the rate of increase in deflection of the beam can be used to detect the starting point of cracking in the concrete beam. For comparison, the rate of increase of deflection for every 10 bar is computed in Table 3 and Table 4.

* Highlighted value indicate the starting of cracking stage

Load		Beam without ferrocement (mm)		
Bar	kN	C1	C2	C3
0 – 10	0.0 – 3.1	0.06	0.10	0.08
10 – 20	3.1 – 6.2	0.46	0.70	0.61
20 – 30	6.2 – 9.3	0.66	1.03	0.81
30 – 40	9.3 – 12.4	0.99	2.57	1.04
40 – 50	12.4 – 15.5	5.31	6.76	5.09

Table 3: Increase of deflection for every 10 bar (3.1kN) loadings (beam without ferrocement).

Load		Beam with ferrocement (mm)		
Bar	kN	C1	C2	C3
0 – 10	0.0 – 3.1	0.02	0.06	0.03
10 – 20	3.1 – 6.2	0.09	0.16	0.12
20 – 30	6.2 – 9.3	0.50	0.48	0.39
30 – 40	9.3 – 12.4	0.28	1.15	0.34
40 – 50	12.4 – 15.5	1.21	1.62	1.62

Table 4: Increase of deflection for every 10 bar (3.1kN) loadings (beam with ferrocement).

It can be seen from Table 3 and Table 4 that when cracking occurs, an abrupt rate of deflection value is observed. For example, for beam strengthened with ferrocement, the initial increase in deflection are about 0.30 mm per 10 bar of load applied. But once the loading reached about 40 bars, an abrupt increase of about 1.10mm is observed. Thus, it can be conclude that cracking occurred at this point of loading. Comparing the cracking point of both the beams whereby the ferrocement beam first develop cracks at a loading of 12.40 kN while the control beam starts to crack at a load around 6.20 kN, it shows that ferrocement laminate increases the cracking load of the beam by about 50%. From the load-deflection curve in Figure 6, it can be predicted also that ferrocement beam increases the ultimate load of the beam by approximately 17%.

5. CONCLUSION

Based on the results from the experiment carried out, it can be concluded that ferrocement can increase and thus strengthen the beam in terms of its cracking load as well as deflection. It reduces the beam's mid-span deflection and increases its strength as compared in the experiment carried out. The experiment indicates the following:

- The ferrocement beam shows the same load versus deflection pattern as found in the control beam.
- The ferrocement beam increases the first cracking load of the beam by about 50%.
- Deflection measured in the beam strengthened with ferrocement is roughly 70% less than the deflection found in control beam within the elastic limit.
- Ferrocement laminate increases the ultimate load of the beam by about 17%.

REFERENCES

- [1] ACI Committee 549 report, *Guide for the Design, Construction and Repair of Ferrocement*, ACI 549.1R-93, 1993
- [2] Paramasivam, P., Lim, C. T. E. and Ong, K. C. G., 1997. *Strengthening of RC Beams with Ferrocement Laminates*, Cement and Concrete Composites, 20:53-65
- [3] Nassif, H. H. and Najm, H., 2003. *Experimental and analytical investigation of ferrocement-concrete composite beams*, Cement & Concrete Composites, 26:787-796
- [4] Jumaat, M. Z. and Alam, M. A. 2006. *Flexural Strengthening of Reinforced Concrete Beams Using Ferrocement Laminate with Skeletal Bars*, Journal of Applied Sciences Research, 2(9):559-566
- [5] Ahmad, S. F., Lodi, S. H. and Qureshi, J. 1995. *Shear behaviour of ferrocement thin webbed sections*, Cement and Concrete Research, 25(5):969-979
- [6] Kazemi, M. T. and Morshed, R., 2005. *Seismic shear strengthening of R/C columns with ferrocement jacket*, Cement and Concrete Composites, 27:834-842
- [7] Al-Kubaisy, M. A. and Jumaat, M. Z., 2000. *Flexural behaviour of reinforced concrete slabs with ferrocement tension zone cover*, Construction and Building Materials, 14:245-252
- [8] Elavenil, S. and Chandrasekar, V., 2007, *Analysis of Reinforced Concrete Beams Strengthened with Ferrocement*, International Journal of Applied Engineering Research, Volume 2, Number 3, pp. 431-440.