Flexural Response of Slotted Ferrocement Beams to Third-Point Loading

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Abstract

This paper presents the results of the study on the flexural response of slotted ferrocement beams to third-point loading. A total of thirty-five specimens are tested considering five treatments with seven replications each. The set-ups covered in the study are as follows: use of one layer and two layers of wire mesh reinforcements, use of deformed bar and use of both deformed bar and one layer of wire mesh reinforcements. A set of specimen with no reinforcement is used as control. Flexural strength tests are carried using a Universal Testing Machine (UTM) at a loading rate of 5 kN/m. Cracks spacing and location are measured using a ruler while crack widths are measured using vernier and micrometer calipers.

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Deformed bar reinforcement has significant contribution to the flexural strength of the beam. The wire mesh reinforcement added to the deformed bar reinforcements significantly increased the moment capacity and modulus of rupture. Furthermore, the provision of wire mesh decreases the spacing and width of cracks and increases the number of cracks at failure leading to an increase of flexural strength.

Keywords: Flexural strength, Ferrocement beams, Modules of rupture, moment

Introduction

Ferrocement is primarily consisted of mortar made with Portland cement, water, aggregates and reinforcement. A mineral admixture may be blended with the cement for special application (ACI 549.1-93). Steel reinforcement is provided with small aperture wire mesh and/or closely spaced small diameter bars or wires (Skinner, 1995).

Ferrocement possesses a degree of toughness, ductility, durability, strength and crack resistance that is considered greater than that found in other forms of concrete construction (Pama, 1990). It can be constructed with a minimum of skilled labor and utilizes readily available materials. The skills for ferrocement construction are quickly acquired and include skills traditional in many countries. Ferrocement construction does not require heavy plant or machinery, although it is labor intensive (Sharma and Gopalaratnum, 1980).

Objectives of the Study

The objectives of the study are as follows:

1. to determine if the provision of wire mesh reinforcement will lead to an increase in the flexural strength of the section;
2. to verify whether the reinforcing bar has a significant contribution to the flexural strength of the section;
3. to verify whether the reinforcing bar with one layer of wire mesh has significant contribution to the flexural strength of the section;

4. to evaluate the response of the slotted ferrocement beam to modulus of rupture; and
5. to evaluate the response at failure of the slotted ferrocement beam for number, spacing and width of cracks.

Review of Related Literature

Flexure in ferrocement is determined by subjecting the specimen, on simple supports, to third-point loading. As recommended, the width is not less than six times the mesh opening or wire spacing measured normally to the span direction (ACI 549.1-93).

Kobayashi, et. al. (1992) investigated the flexural impact damage of ferrocement. Specimens used have dimensions of 300mm width, 25mm thick and 600mm length. They were mounted as simply-supported beams with an unsupported length of 500mm. Results showed that the strain at first crack in impact test was approximately equal to that in the static test. Localized damage occurred under the load right after impact, and a linear relationship was observed between compressive strain and deflection after localized damage.

Wang, Naaman and Li (2001) investigated the bonding response of hybrid ferrocement plates with meshes and fibers. Eight series totaling 24 ferrocement plate specimens were prepared and tested under four-point loading. The specimens measured 304.8mm(L) x 76.2mm(W) x 12.7mm(H). It was found out that expanded steel mesh could be effectively used as reinforcement for ferrocement which increased the volume fraction of reinforcement leading to an increase in the modulus of rupture and a decrease in average crack spacing and width.

Desayi and El-Kholy (1992) conducted a study on the first crack strength and modulus of rupture of lightweight fiber reinforced concrete under flexure load using foamed blast furnace slag as the material to replace part of the volume of sand. The test specimens selected were rectangular in cross section, 200mm wide and 25mm thick and having an overall length of 100mm. The specimens were placed between two supports spaced 900mm apart in a reaction-loading frame. The specimens were subjected to third-point loading and the load was applied in increments of 100N for plain and 200N for reinforced specimens. It was observed that the first crack strength of lightweight fiber-reinforced specimens tested in flexure increased with increasing fiber volume of fraction and/or increasing number of mesh layers per specimen in all percentages of sand replacement used. It was further gathered that mesh wires were more effective in enhancing both first crack flexural strength and modulus of rupture. Mesh wires were found to be more effective than fibers in increasing the margin between first crack strength and ultimate flexural strength.

Abdul Samad, et. al. (1998) investigated ferrocement box beams subjected to two-point load test which induces pure bending moment. The box beam specimens had an unsupported span of 1800mm. The dimensions were: width of 170mm, thickness of each leg of 35mm and varying thickness of upper and lower sides ranging from 35mm to 41mm so that overall thickness of the box beam varied from 265mm to 291mm. All specimens were subjected to third-point loading with varying a/h ratio, ***a*** being the distance from support of the nearest point load and ***h***, the overall thickness of the specimen. It was learned that the lower the a/h ratio, within the range less than or equal to one, the more prominent is the diagonal tension occurrence; while higher value of a/h ratio (greater than unity) tended to develop flexural failure of the beam. It was proven further that the ferrocement box beam behaved elastically before the first crack. Al-Kubaisy (1998) also concluded that the location of the critical diagonal crack in simply-supported rectangular ferrocement beams was influenced by the shear span-to-depth ratio, a/h, and to a lesser extent by the mortar compressive strength, f'_c. The specimens used had dimensions of 40mm thick, 100mm width and span of 400mm. The specimens were subjected to a single-point loading with variable a/h ratio.

In this study, the slotted ferrocement beam was evaluated as to its flexural response to third-point loading. The section will have dual functions, that as a beam and at the same time, as an element to hold wall section into position.

The Experiment

The experiment uses five treatments with seven replications per treatment. The treatments were as follows: T1 – Control, T2 – Deformed Bar Reinforcement, T3 – One layer of Wire Mesh Reinforcement, T4 – Two layers of Wire Mesh Reinforcement, and T5 – Deformed Bar and Wire Mesh Reinforcement. A Single-Factor Experiment with five levels of the factor was employed to investigate the significance of each factor and the interaction between variables. The analysis of the data was done using one-way Analysis of Variance (ANOVA). A Duncan's multiple comparison with 95.0% confidence level was used to determine which means were significantly different from each other. Figure 1 shows the section and isometric projection of the beam specimen, while Figure 2 shows the composition of the diferrent specimens. Specimens were tested in a Universal Testing Machine (UTM). Specimens were painted with white chalk prior to testing in order to facilitate identification of cracks during testing.

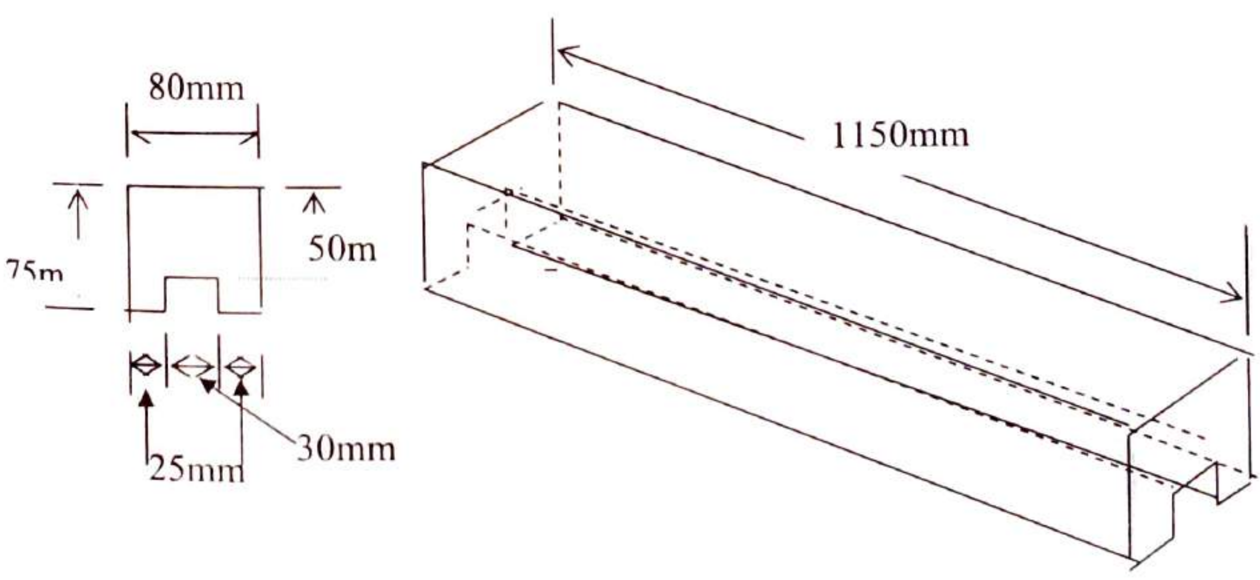
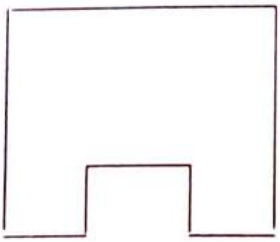
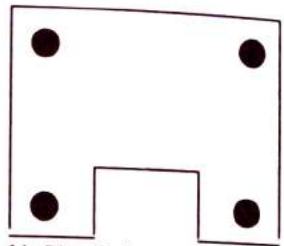


Figure 1. Section and isometric projection of specimen



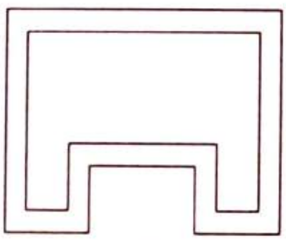
a) T_1 : No reinforcement

Mortar only
(Control)

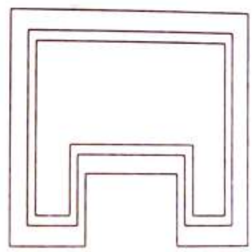


b) T_2 : Rebar only with

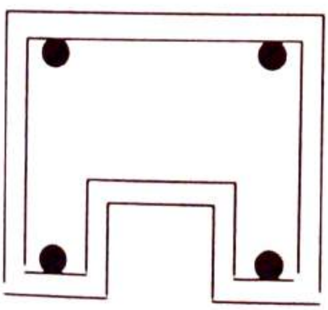
4 – 6mm diameter
$A_s = 53.76mm^2$
$A_s' = 53.76mm^2$



c) T_3 : with one layer of
12.5mm x 12.5mm x 0.75mm
square welded wire mesh



d) T_4 : with two
layers 12.5mm x
12.5mm x 0.75mm
square welded wire
mesh



e) T_5 – 4-6mm diam. rebar with one layer of 12.5mm x 12.5mm x 0.75mm square welded wire mesh

Figure 2. Composition of the different specimens

The parameters determined in this experiment were the moment at failure, the modulus of rupture, the spacing of cracks at failure, the width of cracks at failure, and number of cracks at failure. **Moment at failure** is measured as the sum of the moment due to applied load and the moment due to weight of the specimen. The **modulus of rupture** is defined as the theoretical tensile stress reached at the bottom fiber of the test beam. From the property of the beam section, the following formula was used to compute the *modulus of rupture*: If the fracture occurred within the middle-third of the beam, the modulus of rupture (f_{bt}) was calculated to the nearest 0.1MPa (15 psi), using: $f_{bt} = 175Py_b / I$

If fracture occurred in the tension surface outside the middle-third of the span length but not more than 5% of the span length, $f_{bt} = Pay_b / 2I$

where: P = the load at first crack in Newton

I = the moment of inertia of the slotted beam section in mm^4

y_b = the location of the neutral axis measured from bottom of beam in mm

a = the average distance line of fracture and the nearest support measured on the tension surface of the beam in mm

If fracture occurred in the tension surface outside the middle-third of the span length and at more than 5% of the span length, the results of the test were discarded.

The **spacing of cracks** was measured from the first crack nearest the left supports to the next set of cracks. Actual **widths of cracks were** measured using vernier and micrometer calipers. A digital camera was used to read very minute cracks. Measurement was subsequently done in the computer. **Numbers of cracks** were actually counted. A magnifying glass was used in identifying further the location and number of cracks.

Results and Discussion

Moment at Failure

It was observed that there was statistically significant difference between the means for the various groups at 5.0% significance level. However, as shown in Figure 3, T1, T3 and T4 had their ranges overlapping each other indicating that those treatments do not have significant difference. In the same figure, the ranges of T2 and especially T5 were far from the other treatments. The result showed that T5 can absorb significant amount of loading before failure. The observation can be shown further in Table 1, the Duncan's multiple comparison for each treatment.

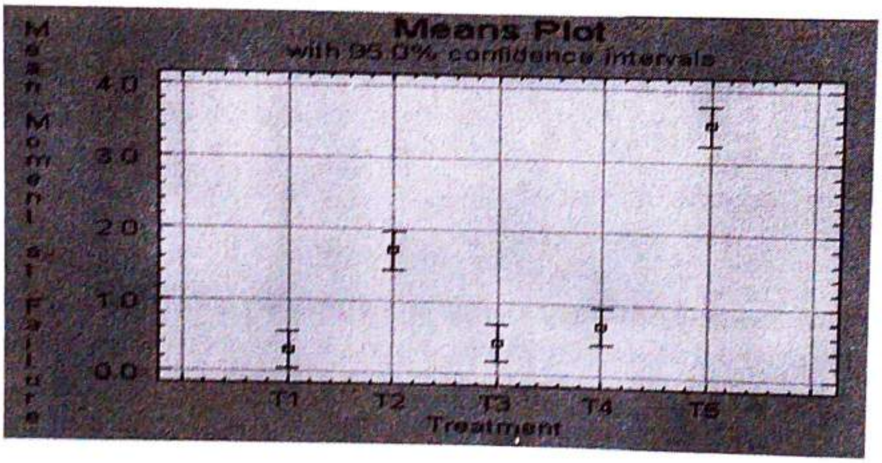


Figure 3. Plot of Mean Moment at Failure versus Treatment

Table 4.13. Multiple comparison for each treatment of the Moment at failure using Duncan's multiple comparison procedure.

Contrast	Difference
T1 - T2	*-1.404
T1 - T3	-0.140
T1 - T4	*-0.396
T1 - T5	*-3.217
T2 - T3	*1.263
T2 - T4	*1.008
T2 - T5	*-1.813
T3 - T4	-0.256
T3 - T5	*-3.077
T4 - T5	*-2.821

* denotes a statistically significant difference.

Modulus of Rupture

In treatment T2, most of the specimen had their cracks occurring more than 5.0% outside the middle third so that the computed modulus of rupture was invalidated and set equal to zero. The ANOVA of modulus of rupture showed that there was statistically significant difference between the means of various groups at 5.0% significance level. Table 2 also showed that the result of the multiple comparison for each treatment using the Duncan's multiple comparison procedure with T1-T3 – T4 not significantly different from each other.

Table 2. Multiple comparison for each treatment of the Modulus of Rupture using Duncan's multiple comparison procedure.

Contrast	Difference
T1 - T3	-1.161
T1 - T4	*-3.156
T1 - T5	*-13.051
T3 - T4	-1.995
T3 - T5	*-11.890
T4 - T5	*-9.895

* *denotes a statistically significant difference.*

Figure 4 showed that T5 had a much wider range of data and farther from the other treatments. The result showed that only T5 can absorb significant amount of modulus of rupture.

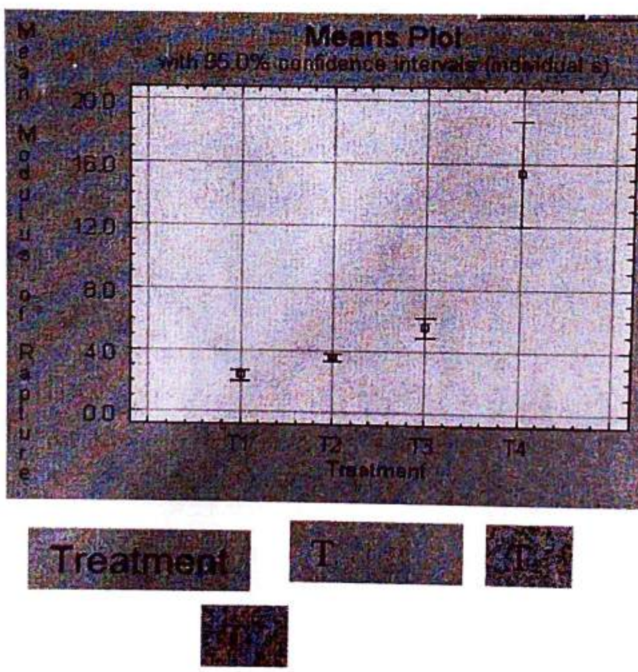


Figure 4. Plot of Mean Modulus of Rupture versus Treatment.

Spacing of Cracks at Failure

Treatment T1 has only one set of cracks per specimen. In T3, five of the seven specimens had only one set of crack so that spacing of cracks at failure of T1 and T3 were set at infinity and were not included from the analysis. The ANOVA of the three remaining treatments showed that there was statistically significant difference between the means of various groups at 5.0% significance level. Figure 5 showed that the mean spacing of cracks for T2 is larger, while for T4 and T5, the mean spacing of cracks are closer. T4 and T5 and they are not statistically significant in difference. In actual test, the cracks in T2 are located outside the middle third and are fewer in numbers while T4 and T5 had their cracks larger in number and are located within the middle third.

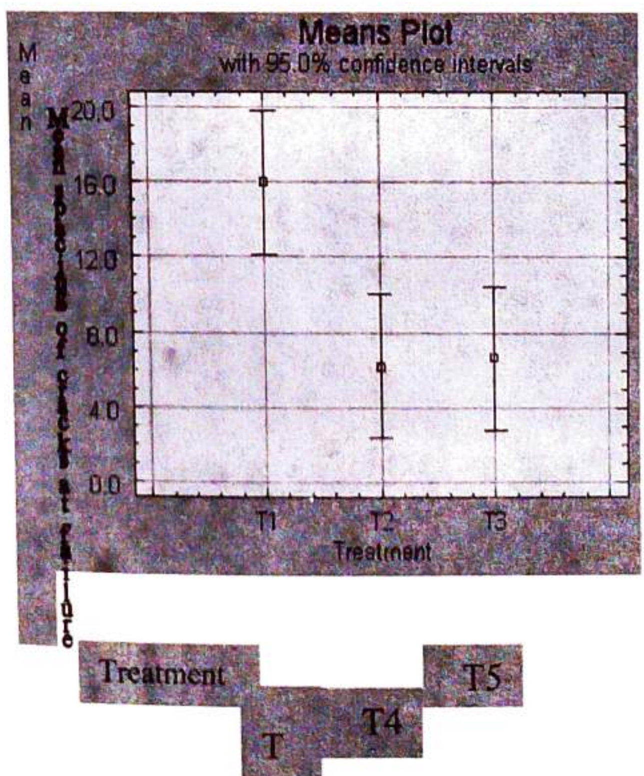


Figure 5. Plot of Mean Spacing of Cracks at Failure versus Treatment.

Width of Cracks at Failure

All specimens in treatment T1 had complete separation during cracking so that the width of the crack was considered infinite and excluded from the analysis. The ANOVA for width of cracks at failure showed that it has statistically significant difference between the means of the various groups at 5.0% significance level. Figure 6 showed that the mean width of cracks for T2, T4 and T5 were more or less closer to each other, the ranges for the minimum and maximum values were overlapping, indicating that the three treatments are not significantly different from each other. T3 had values different from the other three treatments.

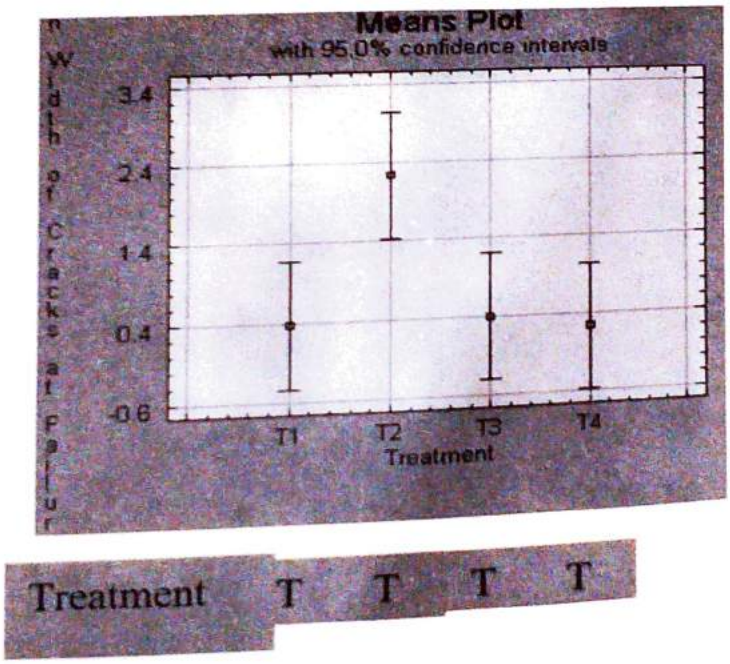


Figure 6. Plot of Mean Width of Cracks at Failure versus Treatment.

Number of Cracks at Failure

The ANOVA for number of cracks at failure showed that there was statistically significant difference between the means of the various groups at the 5.0% significance level. In Figure 7, it can be observed that the mean as well as the minimum and maximum range of values for T1 and T3 is overlapping while T2 is not far so they can be lumped in one group with no significant difference. Whereas, T4 and T5 have means located farther. Although, the range of minimum and maximum values is different, the two treatments are statistically and significantly different at 95% confidence interval.

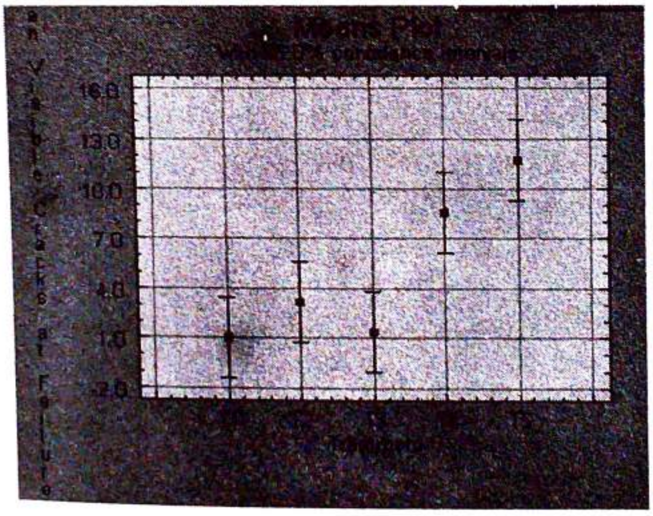


Figure 7. Plot of Mean Number of Cracks at Failure versus Treatment.

Conclusions

The following conclusions are drawn based on the results of the test:

1. The provision of wire mesh increased the flexural strength of the slotted ferrocement beam.
2. One layer of wire had no significant contribution to the flexural strength of the slotted ferrocement beam.
3. The deformed reinforcing bar had significant contribution to the flexural strength of the slotted ferrocement beam.
4. The wire mesh reinforcement added to the deformed bar reinforcement significantly increased the moment capacity of the section.
5. The provision of wire mesh had significantly increased the modulus of rupture.
6. The provision of wire mesh increased the number of cracks and reduced the spacing and width of cracks resulting in the increase of moment capacity.

Recommendations

The following recommendations are based from the results of the study on the flexural response of slotted ferrocement beams to third-point loading:

1. The aggregates to be used must be properly selected and graded in order to obtain a higher mortar compressive strength. It is recommended further that a proper mix design will be formulated first before a test will be conducted.
2. Deformed reinforcing bar with wire mesh for the slotted ferrocement beam can be used. However, further studies will be conducted to determine the size limits of the reinforcing bar as well as the suitable number of layers of wire mesh.
3. Studies will be conducted to redesign the mode of connecting a slotted ferrocement beam to a column member.

4. Studies will be conducted to determine the tensile and compressive capability of slotted ferrocement sections.

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