International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163
Issue 8, Volume 2 (August 2015) www.ijirae.com

EXPERIMENTAL STUDY ON FRACTURE BEHAVIOUR OF FERROCEMENT BEAMS

Dr.P. Alagusundaramoorthy
Professor
Department of Civil Engineering
Indian Institute of Technology Madras
Tamilnadu, India

Dr.R.Veera Sudarsana Reddy
Principal
Narayana Engineering College
Gudur, SPSR Nellore (Dt)
Andhra Pradesh, India

Abstract- Tests are conducted on ferrocement beams under four point bending with simply supported boundary conditions on both edges to predict the fracture parameters. Beams with different relative notch depths, varying percentage of reinforcement and with different sizes are cast. All the beams are tested up to failure. During the test, the out of plane deflections at load points, crack mouth displacements (CMD) and crack opening displacements (COD) are measured. The apparent J-integral (J_{app}), critical crack opening displacement (COD_c) and the rotation factor (r) are calculated from the experimental data. The effects of variation of percentage of reinforcement, notch size and the cross section of the beam on the fracture parameters are evaluated. A set of conclusions is drawn based on the experimental study.

Keywords: Ferrocement Beams, Fracture parameters, notch depth.

1 INTRODUCTION

Ferrocement consists of closely spaced wire meshes which are impregnated with rich cement mortar mix and differs from conventional reinforced concrete. Ferrocement can be designed to have relatively high tensile strength which can be almost equal to its compressive strength. The wire mesh or expanded metal reinforcement in ferrocement limits cracks to fine width. These properties of ferrocement makes it a potential material for the construction of boats, shells of containment vessels, deep submersibles, sandwich structures for prefabricated structural houses, food storage silos and tanks. The evaluation of fracture parameters such as critical stress intensity factor (K_C) and critical strain energy release rate (G_C) based on Linear Elastic Fracture Mechanics (LEFM) concept which characterize the fracture behaviour of materials is found to be inapplicable for ferrocement due to its cementitious property. Hence the concept of Elastic Plastic Fracture Mechanics (EPFM) has to be used to study the fracture behaviour of ferrocement structural systems.

2 REVIEW OF LITERATURE

Many researchers had done extensive research work in evaluating the fracture parameters such as 'J'integral, critical crack opening displacement and rotation factor for cementitious materials both experimentally and analytically. Mindess et al (1977) based on their experiments evaluated the J – integral, critical stress intensity factor and critical strain energy release rate for the specimens cast with fibre reinforced concrete, cement paste and plain concrete. Rice (1968) presented the mathematical model for evaluating the J – integral, plastic plane strain yielding at a crack tip and the strain concentration at smooth ended notch tip based on the elastic plastic behaviour of materials with notches. Desayi and Ganesan (1986) conducted experiments on ferrocement beams with notches and calculated the fracture parameters such as apparent J – integral and rotation factor. Velazco et al (1980) conducted experiments on fibre reinforced concrete beams with varying depths and examined the applicability of various fracture parameters like K_C, J, CODc and R – curve.

3 TEST SPECIMENS

The specimens of two different lengths 1750 mm and 2000 mm, were cast. The breadth and depth of the specimens were kept as 100 mm and 200 mm, and 150 mm and 300 mm respectively. The beams were reinforced with square woven mesh of size 6 x 22 with spacing of 10 mm, 15 mm, 20 mm, and, 25 mm c/c along the depth direction. Cement mortar in the ratio 1:2 by weight with water cement ratio 0.5 was used. Beams were removed from the moulds after 24 hours of casting and cured for 28 days before testing. Details of specimens cast for testing were given in Table.1.

4 TEST DETAILS

All cast specimens were tested under four point bending (Fig.1), using the loading frame. The load was applied using a 500 kN jack and was measured by proving ring of capacity 300 kN as shown in Fig.2. The load point deflections were measured using dial gauges and that were fixed below the loading points.

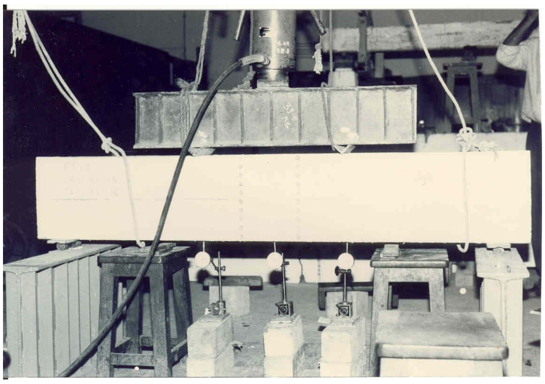

Fig.1. Loading Pattern

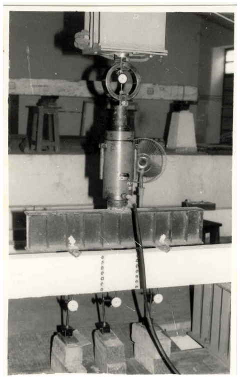

Fig.2. Experimental Set up

The CMD and COD were measured using vernier calipers and microscope respectively. A ferrocement beam with notch (FCN24) before testing is shown in Fig.3. While loading the specimens, photographs were taken at regular intervals for the crack propagation and the crack growth pattern of the specimen FCN24 is shown in Fig.4.

Fig.3. Ferrocement beam with notch

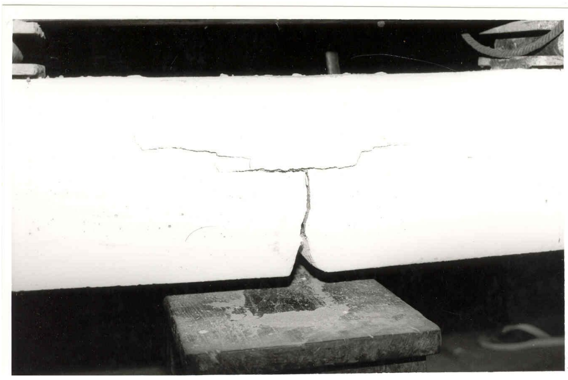

Fig.4. Crack growth pattern for specimen (FCN 24)

5 RESULTS AND DISCUSSIONS

While testing it was observed that first crack appeared below the load points for unnotched beams and at the notches for notched beams. After first crack, branching of cracks took place and all specimens failed quickly as soon as the crack propagated beyond the neutral axis and producing snapping of wires noise. Graphs were plotted for the load and load point deflections for the four groups of specimens such as 150 mm x 300 mm x 1750 mm, 100 mm x 200 mm x 1750 mm, 100 mm x 200 mm x 2000 mm and 150 mm x 300 mm x 2000 mm and for the specimen group 150 mm x 300 mm x 1750 mm with notch depth 0 mm, 40mm, 80 mm and 120 mm was shown in Fig.5.

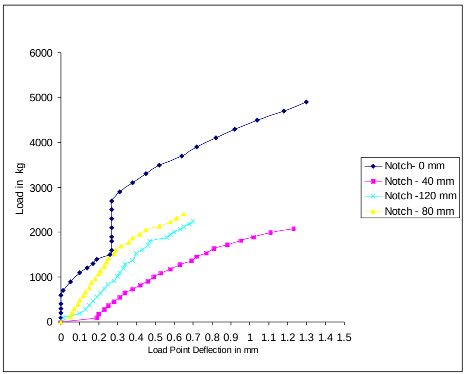

Fig.5. Load Vs Load Point Deflection

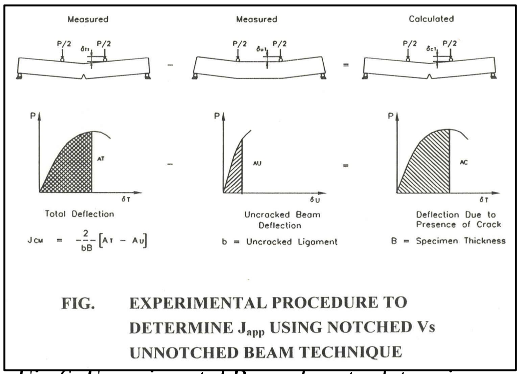

Fig.6. Experimental Procedure to determine JCM using notched Vs Unnotched beam technique

The apparent J integral was calculated as per the procedures shown in Fig.6 (Mindess et al 1977). Load Vs CMD and COD Vs CMD graphs were also drawn for all notched specimens and for the specimen FCN3 is shown in Fig.7 and Fig.8. The rotation factor ‘r’ was evaluated from the graphs plotted using the procedure proposed by Velazco etal (1980).

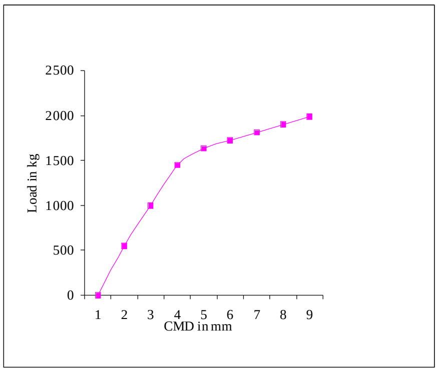

Fig.7. Load Vs CMD for specimen FCN3

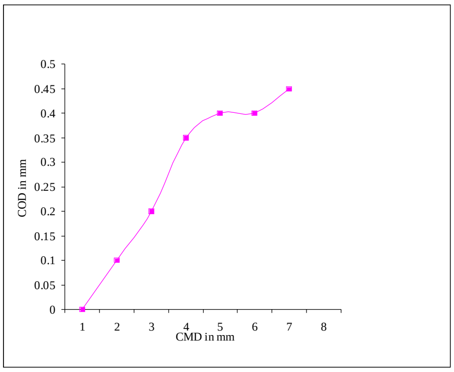

Fig.8. COD Vs CMD for specimen FCN3

The calculated values of J_{app}, COD_C and ‘r’ were shown in Table.2. The values of J_{app} in Table.2 shows that there is no particular trend in the variation of J_{app} with respect to notch depth.

6 SUMMARY AND CONCLUSIONS

The main aim of the present investigation is to determine experimentally the fracture parameters such as the apparent J integral, critical crack opening displacement and the rotation factor to define the fracture behaviour of ferrocement beams with notches. A brief introduction about ferrocement and its applications are focused. The review of literature regarding the fracture behaviour of ferrocement beams with notches are highlighted. The fracture parameters such as J_{app}, COD_C and ‘r’ are calculated by casting and testing of thirty four ferrocement beams of size 150 X 300 X 1750 mm, 100 X 200 X 1750 mm, 150 X 300 X 2000 mm, 100 X 200 X 2000 mm.Out of thirty four beams, twenty two beams were cast with notch depths of 20, 26.67, 30, 40, 50, 53.33, 60, 75, 80, 90, 120 and 150, and twelve beams were cast without notch. While casting the beams cement mortar cubes were also cast to find strength of cement used for casting. Before testing all specimens were instrumented with dial gauges at the load points to measure the load point deflections. All the beams were tested upto failure and the load at first crack and failure load were recorded. Graphs were plotted between load and load point deflection, load Vs CMD, COD Vs CMD to calculate the apparent J integral, critical crack mouth displacement, and rotation factor respectively.

The parameters which characterize the fracture behaviour of ferrocement beams such as J_{app}, COD_C and ‘r’ are evaluated by casting and testing of ferrocement beams with and without notches under four point bending.

The following main conclusions were drawn based upon the test results.

1. The critical crack opening displacement COD_C is found to be sensitive to notch depth, size of beam and addition of mesh reinforcement.
2. The values of the apparent J integral obtained for ferrocement beams are sensitive to the addition of mesh reinforcement.
3. There is no particular trend in the variation of apparent J integral with respect to notch depth and size of beam.
4. The average values of rotation factor for ferrocement beams are dependent upon the specimen size and are found to be 0.12, 0.47, 0.09 and 0.15 for beams of size 150 X 300 X 1750 mm, 100 X 200 X 1750 mm, 150 X 300 X 2000 mm, and 100 X 200 X 2000 mm respectively.

REFERENCES

[1]. ANTONIO NANNI AND RONALD F ZOLLO, Behaviour of Ferrocement Reinforcement in Tension. Proc. Journal of ACI Materials, July – August (1987) 273 – 277.
[2]. BROWN, J.H. Measuring the Fracture Toughness of Cement Paste and Mortar. Magazine of Concrete Research, 24, No. 81 (1972) 185 – 196.
[3]. BROWN, J.H. The Failure of Glass–Fibre–Reinforced Notched Beams in Flexure. Magazine of Concrete Research, 25, No. 82 (1973) 31 – 38.
[4]. DESAYI, P., AND GANESAN, N. Fracture Behaviour of Ferrocement Beams. Proc. ASCE, Journal of Structural Engg, 112 (7) (1986) 1509 – 1525.

[5]. HALVORSEN, G.T. J–Integral Study of Steel Fibre Reinforced Concrete. Proc. International Journal of Cement Composites, 2 (1) (1980) 13 – 22.
[6]. MINDESS, S. LAWRENCE, F.V. AND KESLER, C.E. The J–Integral as a Fracture Criterion for Fibre Reinforced Concrete. Proc. Cement and Concrete Research, 1 (6) (1977) 731 – 742.
[7]. MINDESS, S. The Fracture of Fibre–Reinforced and Polymer Impregnated Concretes. Proc. the International Journal of Cement Composites, 2 (1) (1980) 3 – 11.
[8]. RICE, J.R. A Path Independent Integral and the Approximate Analysis of Strain Concentration by Notches and Cracks. Proc. ASME, Journal of Applied Mechanics, 35 (1968) 379 – 386.
[9]. VELAZCO, G., VISALVANICH, K. AND SHAH, S.P. Fracture Behaviour and Analysis of Fibre Reinforced Concrete Beams. Proc. cement and concrete research, 10 (1) (1980) 41 – 51.
[10]. VISALVANICH, K. AND NAAMAN, A.E. Fracture Model for Fibre Reinforced Concrete. Proc. Journal of the American Concrete Institute, 80 (2) (1983) 128 – 138.
[11]. WECHARATANA, M. AND SHAB, S.P. A Model for Predicting Fracture Resistance of Fibre Reinforced Concrete. Proc. Cement and Concrete Research, 13 (6) (1983) 819 – 829.

Table.1. Details of Specimens Cast for Testing

S.No	Specimen	Size of the beam			Effective Span (mm)	Spacing of reinforcement along depth direction (mm)	Notch depth (mm)
		Length (mm)	Breadth (mm)	Depth (mm)			
1	FCUN1	1750	150	300	1550	20	0
2	FCUN2	1750	150	300	1550	20	0
3	FCN3	1750	150	300	1550	20	40
4	FCN4	1750	150	300	1550	20	80
5	FCN5	1750	150	300	1550	20	120
6	FCUN6	1750	100	200	1550	20	0
7	FCUN7	1750	100	200	1550	20	0
8	FCN8	1750	100	200	1550	20	26.67
9	FCN9	1750	100	200	1550	20	53.33
10	FCN10	1750	100	200	1550	20	80
11	FCUN11	2000	100	200	1800	10	0
12	FCN12	2000	100	200	1800	10	20
13	FCN13	2000	100	200	1800	10	40
14	FCN14	2000	100	200	1800	10	60
15	FCN15	2000	100	200	1800	10	80
16	FCN16	2000	100	200	1800	10	100
17	FCUN17	2000	150	300	1800	10	0
18	FCN18	2000	150	300	1800	10	30
19	FCN19	2000	150	300	1800	10	60
20	FCN20	2000	150	300	1800	10	90
21	FCN21	2000	150	300	1800	10	120
22	FCN22	2000	150	300	1800	10	150
23	FCUN23	1750	150	300	1550	25	0
24	FCN24	1750	150	300	1550	25	75
25	FCUN25	1750	150	300	1550	15	0
26	FCN26	1750	150	300	1550	15	75
27	FCUN27	1750	150	300	1550	10	0
28	FCN28	1750	150	300	1550	10	75
29	FCUN29	1750	100	200	1550	25	0
30	FCN30	1750	100	200	1550	25	50
31	FCUN31	1750	100	200	1550	15	0
32	FCN32	1750	100	200	1550	15	50
33	FCUN33	1750	100	200	1550	10	0
34	FCN34	1750	100	200	1550	10	50

Table. 2. Values of J_{app}, CMD_c and COD_c for Ferrocement Beams

S No	Specimen	Notch depth (mm)	Spacing of reinforcement (mm)	J_{app} (kN/m)	CMD_c (mm)	COD_c (mm)
1	FCN3	40	20	0.2590	3.60	1.62
2	FCN4	80	20	0.3429	3.60	0.926
3	FCN5	120	20	0.3806	2.90	0.461
4	FCN8	26.67	20	0.3340	1.80	0.810
5	FCN9	53.33	20	0.009	2.40	0.617
6	FCN10	80	20	0.525	1.80	0.286
7	FCN12	20	10	0.9939	2.18	1.266
8	FCN13	40	10	1.9859	1.78	0.678
9	FCN14	60	10	1.5877	2.84	0.751
10	FCN15	80	10	5.4453	4.30	0.807
11	FCN16	100	10	6.4788	3.80	0.507
12	FCN18	30	10	1.7700	1.30	3.989
13	FCN19	60	10	3.0398	1.20	1.314
14	FCN20	90	10	1.5150	0.85	0.578
15	FCN21	120	10	0.8620	0.70	0.444
16	FCN22	150	10	3.5200	0.06	0.060
17	FCN24	75	25	0.8370	2.15	0.569
18	FCN26	75	15	1.1150	2.60	0.688
19	FCN28	75	10	1.4240	2.00	0.529
20	FCN30	50	25	0.0810	0.75	0.439
21	FCN32	50	15	1.1840	1.25	0.731
22	FCN34	50	10	1.4240	1.50	0.878