The Study of Flexural and Ultimate Behavior of Ferrocement Lightweight Beam by using A.A.C Blocks

Vinayak S. Dusane[1], Kiran M. Deore[2]

[1]Student, Department of Civil Engineering, Late G. N. Sapkal College of Engineering, Nashik, Maharashtra, India.
[2]Assistant Professor, Department of Civil Engineering, Late G. N. Sapkal College of Engineering, Nashik, Maharashtra, India.

---***---

Abstract - *The purpose of this experimental work is to study the flexural and ultimate behavior of ferrocement lightweight beam by using A.A.C blocks. The investigations were carried out on R.C.C and ferrocement beams of size 150 mm X 150 mm X 700 mm. The concrete used for the R.C.C consisted of grade M25. While rich mortar was used for the construction of ferrocement beams. The central portion of the ferrocement beam was kept hollow and A.A.C bricks were installed in it. The results obtained from the experimental study indicated that the ferrocement beam gave intimation prior to the failure in the form of first crack whereas the R.C.C beam resulted in sudden failure as compared to the ferrocement components. Similarly, variations in deflection were seen between R.C.C. and ferrocement specimens. It was observed that Ferrocement specimen gave more deflection than the R.C.C counterpart. The maximum load carried by the R.C.C specimen was noted to be 85.40 kN whereas the maximum deflection was observed to be 7.83 mm. in case of ferrocement the maximum load and deflection were observed to be 62.10 kN and 15.69 mm respectively.*

***Key Words*: Ferrocement, Lightweight, Flexural Strength, Flexural cracks, Crack width limitation, Ductility.**

1. INTRODUCTION

R.C.C. structures in the past have been seen to show unexpected failure pattern far before the expiry of their actual service expiry. To counter this and many other aspects of the construction this experimental study focuses on ferrocement beams and its feasibility for use. The study aims at deriving and establishing the behavioral pattern of ferrocement beams under single point load for flexure. It was accomplished by using mortar over welded wire mesh instead of conventional concrete and steel reinforcements. The study aimed at not only determines the behavior but also to reduce the overall cost of constructing a beam. As ferrocement a technology does not require concrete as mortar is used for its casting. Wire mesh is opted for steel as a reinforcing member. The requirement of formwork is ruled out, thus reducing the overall cost. The overall aim of the present study is to investigate and improve the understanding and flexural behavior of composite beams and thereby studies other effective alternatives for the R.C.C system that is already in practice. Experimental tests were performed to investigate the beam designed in such a way that their failure will be expected. The beam will be loaded in one point load system and load will be applied until the cracks are developed.

1.1 Flexural Cracks

Flexural cracks on the side of the beam start at tension face and extend, up to the neutral axis. Crack width is seen to be huge in the tension side and is supposed to reduce as we move away from its origin. The cracks here are supposed to be uniformly spaced in the most heavily loaded portion of the beam. As we know near the mid span as sagging and over the supports in hogging. The main causes of flexural cracks in a beam are external load which directly result in bending causing flexural and diagonal cracks.

1.2 Flexural Strength

The measure of tensile strength of a beam or slabs is called as flexural strength. It typically identifies the amount of stress and force an unreinforced concrete beam can stand so that it is able to resist failures is simply referred to as flexural strength. Commonly called as bending strength / modulus of rupture / fracture strength.

1.3 Crack width limitations

It is essential that the maximum value of a crack should be less than 0.1 mm for non- corrosive and 0.5 mm for corrosive environments and water retaining structures. The value for the crack width in a square mesh can however be predicted.

2. EXPERIMENTAL PROGRAM

2.1 Introduction

In the current experimental study 6 beams of size 150 mm X 150 mm X 700 mm have been adopted. Three of which are made of R.C.C while the remaining 3 are ferrocement specimen and each beam will be subjected to single point loading in the universal testing machine. Load was gradually applied until the failure had occurred in the beam. The first crack load as well as the ultimate load carried by the beam along with its deflection had been noted.

2.1 Introduction

In the current experimental study 6 beams of size 150 mm X 150 mm X 700 mm have been adopted. Three of which are made of R.C.C while the remaining 3 are ferrocement specimen and each beam will be subjected to single point loading in the universal testing machine. Load was gradually applied until the failure had occurred in the beam. The first crack load as well as the ultimate load carried by the beam along with its deflection had been noted.

2.2 Problem Statement

The basic constituents for concrete are cement, sand and aggregate. These materials listed earlier are all heavy in nature. The consumption of the concrete is the highest in the world as it is known compared to any other material other than water. The compressive strength of the concrete is good in compression and steel bears good in tension. As it is known that a beam is a structural member that resists the loads applied on its axis. The primary mode of failure in a beam is observed to be bending. This load applied results in reaction forces generating at the support. Total effect of the forces on the beam is to prepare forces and moments within the beam. The beams are characterized by their manner of support, profile, Length & material.

2.3 Test Program

The test has been carefully designed so that the properties of the materials required for the casting of the specimens are determined. At the same time the flexural behavior of the beam is noted. The complete program consists of the following components:

1. Determination of the basic properties of the materials such as cement, sand, aggregate also steel as per the Indian standard specifications.
2. Casting of three beams of size (150 mm X 150 mm X 700 mm) using M25 grade concrete, followed by casting of three beams of similar size using rich mortar as per the Indian standard specifications.
3. The layout of the test set-up used for the experiments is shown in Fig. 1. All tests were carried out under simply supported condition. The load was applied by means of single point load at centre.
4. Computation of the first crack loads and the ultimate load carried by the beam at the same time determining the load and deflection relation of the beams.

Fig -1: Overview of the ultimate test setup in UTM.

3. MATERIAL PROPERTIES

Cement, fine aggregates, coarse aggregate, reinforcing bars, welded wire mesh, A.A.C. blocks are used in the designing and casting of beams. The specifications and properties of the materials are as under:

3.1 Cement

Cement of grade 53 was used for this study. the physical properties of the material as obtained from various tests are as listed and all the required tests were carried out in accordance with procedure laid down in IS: 8112-1989.

3.2 Fine and Coarse Aggregates

Locally available sand was used as fine aggregate in the cement mortar and concrete mix. The physical properties and sieve analysis of results of sand.

Crushed stone aggregate locally available of size 20 mm and 10 mm are used throughout the experimental study. The physical properties and sieve analysis of results of both aggregates.

Table -1: Physical Properties of Aggregates

Sr. No.	Characteristics	Tested Result of fine aggregates	Tested Result of coarse aggregates
1.	Specific Gravity	2.56	2.65
2.	Bulk Density	1.48	-
3.	Fineness Modulus	2.52	6.47
4.	Water Absorption	2.06%	3.645%
5.	Grading zone	Zone III	Zone II

3.3 Water

The quality of mixing water for mortar has a visual effect on the resulting hardened cement mortar. Impurities in water may interfere with setting of cement and will adversely affect the strength of cause staining of its surface and may also lead to its corrosion. Usually, water that is piped from the public supplies is regarded as satisfactory.

3.4 Reinforcing Steel

HYSD steel of grade Fe-500 of 8 mm, 10 mm, and 12 mm diameter were used in the beams for R.C.C. The 12 mm bars have been used in ferrocement beams. Apart from that welded wire mesh was used for ferrocement beams. The 12 mm bars are used as tension steel and the 10 mm bars are used as compression steel. 8 mm bars are used as shear stirrups.

3.5 Welded Wire Mesh

These are electrically fused welded fabricated joint grids consisting of a series of parallel longitudinal wires with and accurate spacing. Generally, machines are used for making of such wires to précised dimensions. Widely used in agriculture, industries, transportation and many other sectors. In this experimental study the wire that was used had the square size of 10 mm X 10 mm.

3.6 Autoclaved Aerated Concrete brick

The A.A.C brick or autoclaved aerated concrete brick has been used in the study to fill the core of the ferrocement blocks instead of using mortar and creating a homogenous beam. The size of the brick was measured to be 230 mm X 100 mm X 70 mm.

3.7 Concrete Mix

As per the IS 10262-2009 & MORT&H mix proportions for one cum. of concrete.

Table -2: Quantity of material required for one cubic meter concrete

Description	M25
Mass of Cement (kg/m^3)	320
Mass of Water (kg/m^3)	138
Mass of Fine Agg. (kg/m^3)	751
Mass of Coarse Agg. (kg/m^3)	1356
Water Cement Ratio	0.43
Mass of Admixture	Nil

3.8 Mortar Mix

The range of mix proportion proposed for ferrocement application are 1:1.5 to 1:2.5 {Cement: Sand} but not greater than 1:3. While the appropriate water cement ratio was taken to be 0.35 to 0.5. The greater the sand content of the mix the greater will be the water requirement to maintain workability. During this experimental throughout the experiment the ratio was kept to be 1:2 whereas the water content ratio was taken to be 0.40.

4. SPECIMEN DESCRIPTIONS

In the current study a total of three R.C. beams and three Ferrocement beams were cast and cured under appropriate conditions. The mix design for the concrete was incorporated to be M25, and the steel used hereby was noted to be FE-500. The R.C.C. beam is designed to be and under reinforced section with the help of limit state method. The beam is designed in a way that 2 X 12 mm bars of steel are placed on the tension side. While 2 X 10 mm bars of steel are placed on the compression side, similarly 8mm bars of steel have been used as shear stirrups. The ferrocement beams were cast with the help of wire mesh. 2 X 12 mm bars were placed on the tension side of the beam as well. In ferrocement beams single layer of wire mesh was used and the central core of the beam was kept hollow and later on installed with A.A.C bricks 3 X (230 mm X 100 mm X 700 mm) per beam. The cross section of both R.C.C specimen as well as ferrocement specimen are shown in the below figure 2.

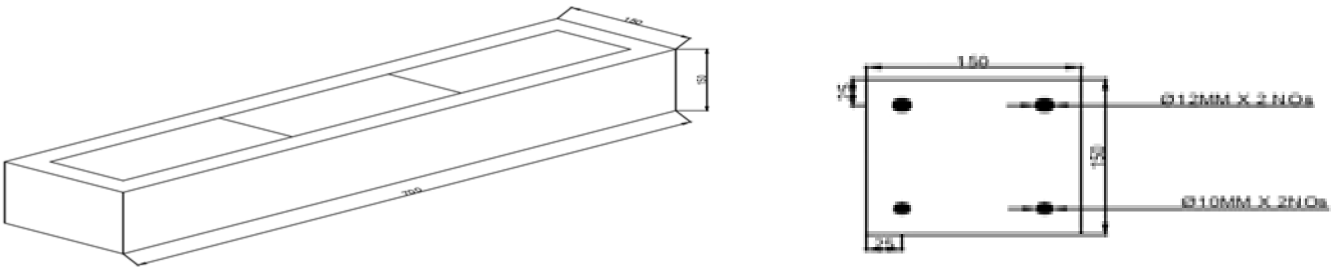

Fig -2: Outlined Cross- section of Specimen.

5. RESULTS AND DISCUSSION

5.1 Load Deformation characteristics

Initially the R.C.C beams were tested to failure and the data obtained during the test was recorded. Later on after the R.C. beams were tested completely the ferrocement beams were tested in the same manner and their relative data was recorded. The first rack load, ultimate load and deflection for each of the beam were recorded and tabulated accordingly. The beams were designated as RC-1, RC-2, RC-3 for R.C.C. whereas the ferrocement beams were designated as FE-1, FE-2, FE-3.

Following are the test results tabulated in deflection to load method with an interval of 5 kN load.

5.1.1 Load vs Deflection Observations for RC-1

The maximum amount of load carried by RC-1 was noted to be 85.40 kN at the same time the maximum deflection undergone by the beam was 7.83 mm. The beam resulted in brittle failure. First crack of the beam occurred at 73 kN.

Fig -3: Cracks developed on longitudinal section of RC- 1

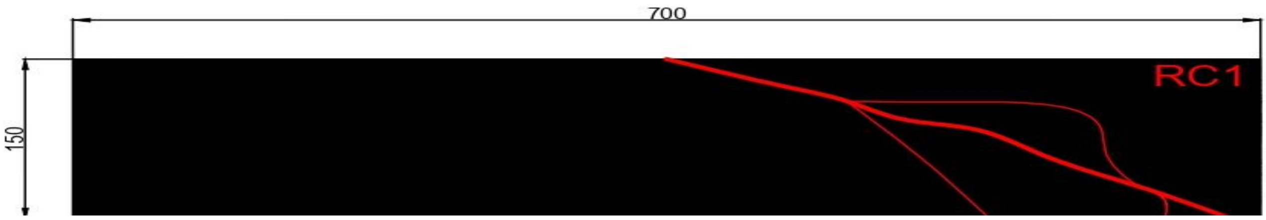

Fig -4: Drawing of crack pattern on longitudinal section for RC- 1

Table -3: Observations of Load and its corresponding Deflection of RC- 1

Sr. No.	Load (kN)	Deflection (mm)	Sr. No.	Load (kN)	Deflection (mm)
1	0	0.00	13	60	4.78
2	5	0.03	14	65	4.99
3	10	0.03	15	70	5.27
4	15	1.74	16	75	5.59
5	20	2.60	17	80	5.89
6	25	3.10	18	85.40	6.32
7	30	3.34	19	80	6.56
8	35	3.55	20	75	6.62
9	40	3.82	21	70	7.59
10	45	4	22	65	7.68
11	50	4.31	23	60	7.83
12	55	4.56			

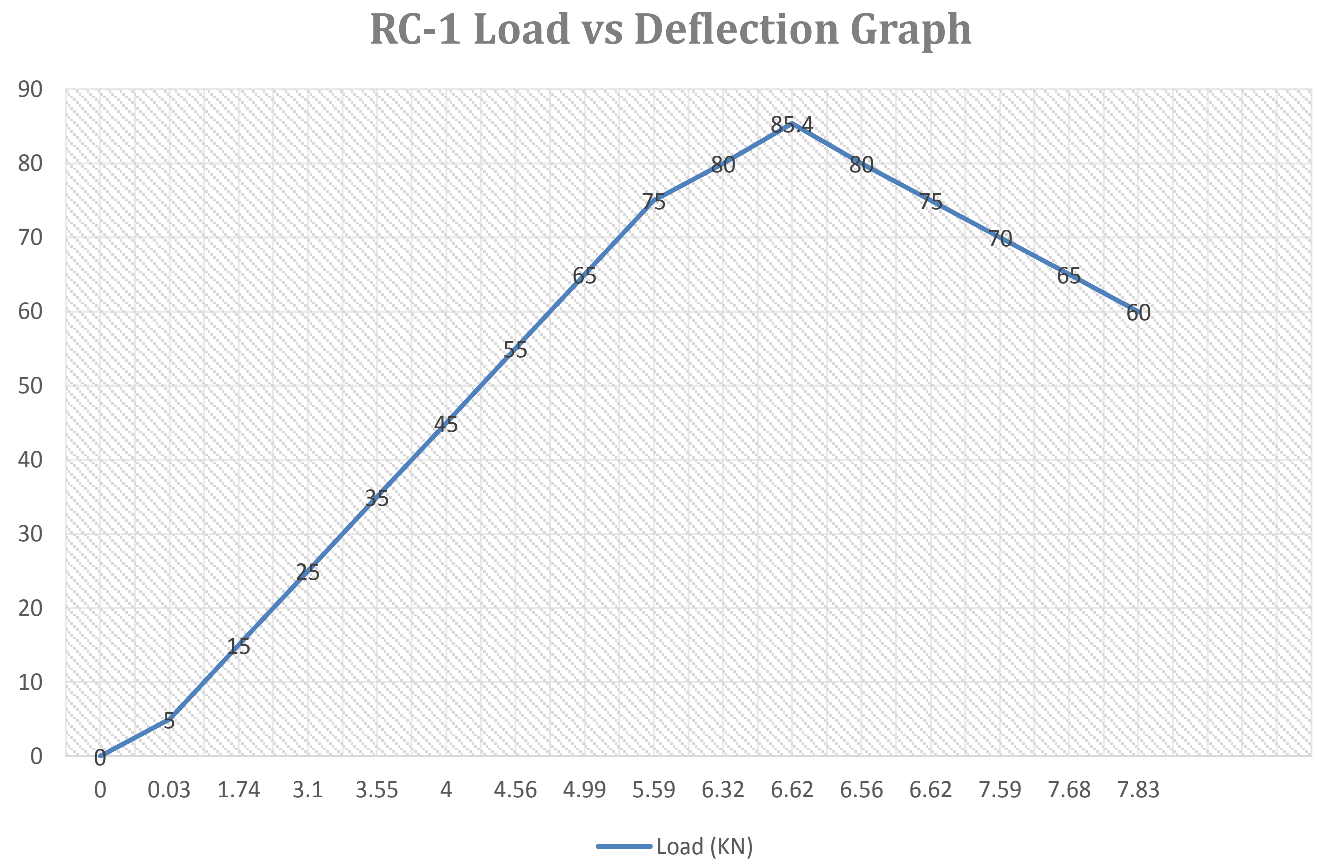

Fig -5: Graph showing the load vs deflection relation for RC- 1

5.1.2 Load vs Deflection Observations for RC-2

The beam RC-2 similar to the other RCC specimen showed lower deflection values.

Fig -6: Cracks developed on longitudinal section of RC- 2

The difference between the first and the final cracks were not seen to be much. First crack for this beam was observed at 68.45 kN whereas ultimate failure occurred at 82 kN.

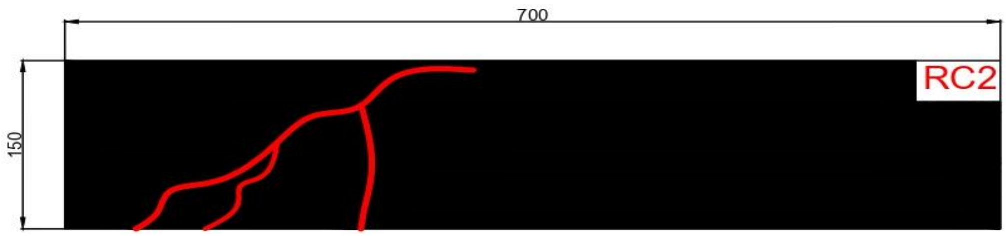

Fig -7: Drawing of crack pattern on longitudinal section for RC- 2

Table -4: Observations of Load and its corresponding Deflection of RC- 2

Sr. No.	Load (kN)	Deflection (mm)	Sr. No.	Load (kN)	Deflection (mm)
1	0	0.00	13	60	0.90
2	5	0.09	14	65	1.31
3	10	0.09	15	70	1.45
4	15	0.09	16	75	1.85
5	20	0.09	17	80	2.30
6	25	0.09	18	82	2.55
7	30	0.08	19	80	2.87
8	35	0.08	20	75	3.98
9	40	0.05	21	70	4.24
10	45	0.11	22	65	4.59
11	50	0.35	23	60	5.11
12	55	0.62	24	55	5.47

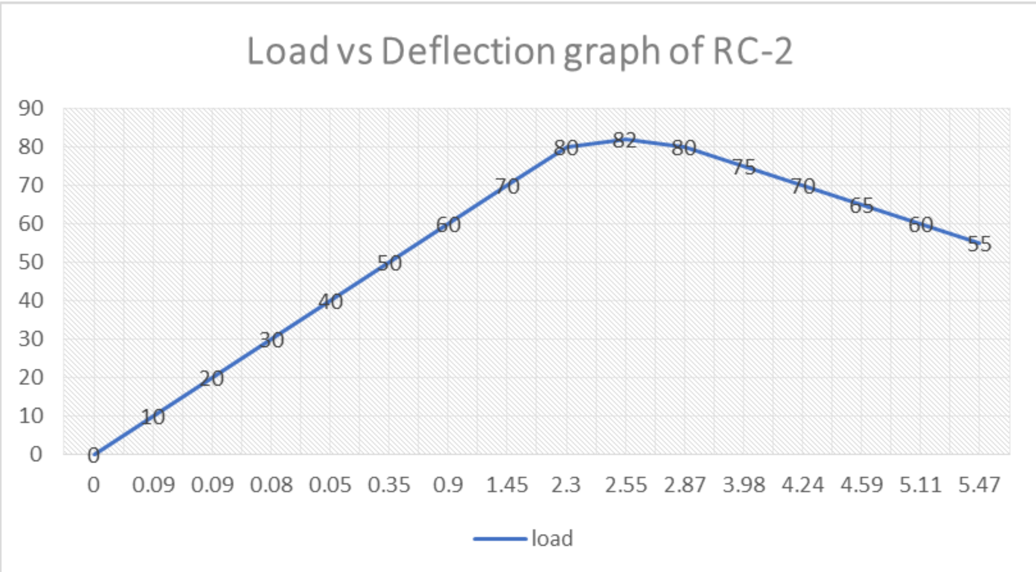

Fig -8: Graph showing the load vs deflection relation for RC- 2

5.1.3 Load vs Deflection Observations for RC-3

The highest value of deflection observed for RC-3 was 6.38 mm while the values for first crack load and ultimate load were noted to be 74.26 kN and 79.63 kN respectively.

Fig -9: Cracks developed on longitudinal section of RC- 3

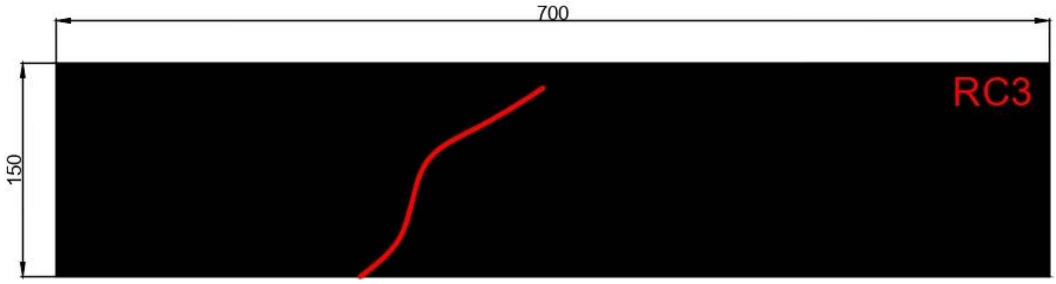

Fig -10: Drawing of crack pattern on longitudinal section for RC- 3

Table -5: Observations of Load and its corresponding Deflection of RC- 3

Sr. No.	Load (kN)	Deflection (mm)	Sr. No.	Load (kN)	Deflection (mm)
1	0	0.00	13	55	3.05
2	5	0.12	14	60	3.63
3	10	0.02	15	65	3.75
4	15	0.09	16	70	4.88
5	20	0.29	17	75	4.96
6	25	0.55	18	79.63	5.35
7	30	0.88	19	75	5.62
8	35	1.31	20	70	5.89
9	40	1.88	21	65	5.97
10	45	2.05	22	60	6.24
11	50	2.29			

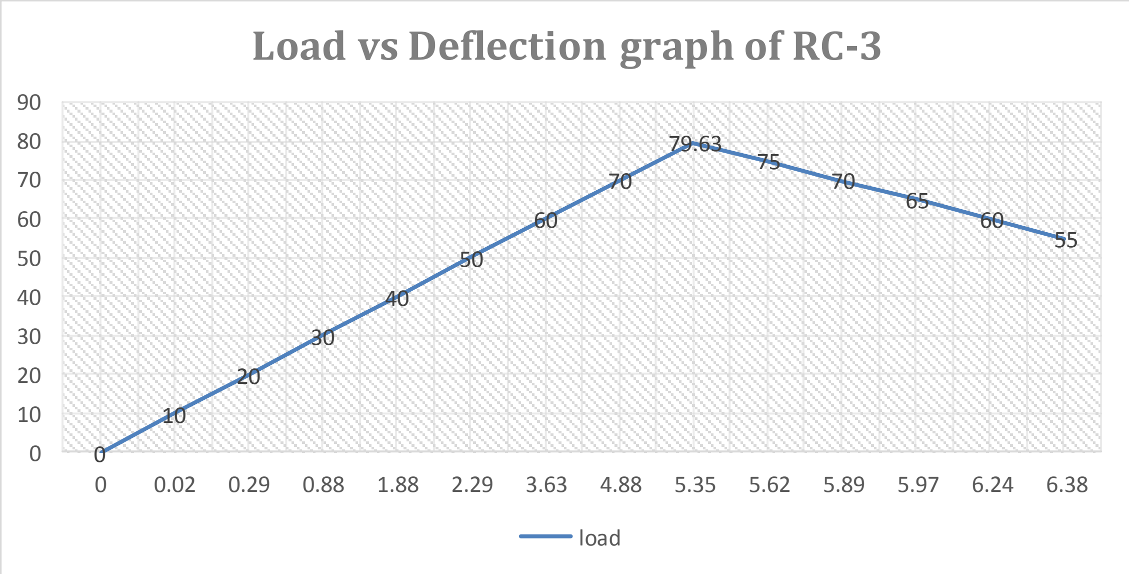

Fig -11: Graph showing the load vs deflection relation for RC- 3

5.1.4 Load vs Deflection Observations for FE-1

The ferrocement beams showed greater deflection values. It was noted during the testing that the ferrocement beams showed huge difference between the occurrence of the first crack and the ultimate cracks. In the case of FE-1 the first crack was observed at 19.38 kN and the ultimate load was seen at 62.10 kN. The maximum deflection given by the beam was noted to be 15.69 mm.

Fig -12: Cracks developed on longitudinal section of FE- 1

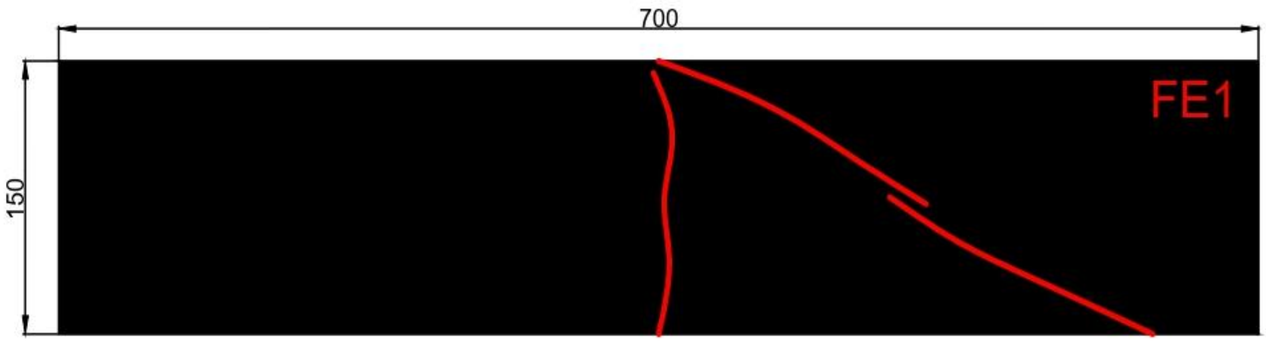

Fig -13: Drawing of crack pattern on longitudinal section for FE- 1

Table -6: Observations of Load and its corresponding Deflection of FE- 1

Sr. No.	Load (kN)	Deflection (mm)	Sr. No.	Load (kN)	Deflection (mm)
1	0	0.00	10	45	7.33
2	5	2.06	11	50	8.82
3	10	2.41	15	55	11.20
4	15	2.5	13	60	13.87
5	20	3.01	14	62.1	14.20
6	25	3.75	15	60	14.86
7	30	4.22	16	55	15.01
8	35	5.58	17	50	15.69
9	40	6.87			

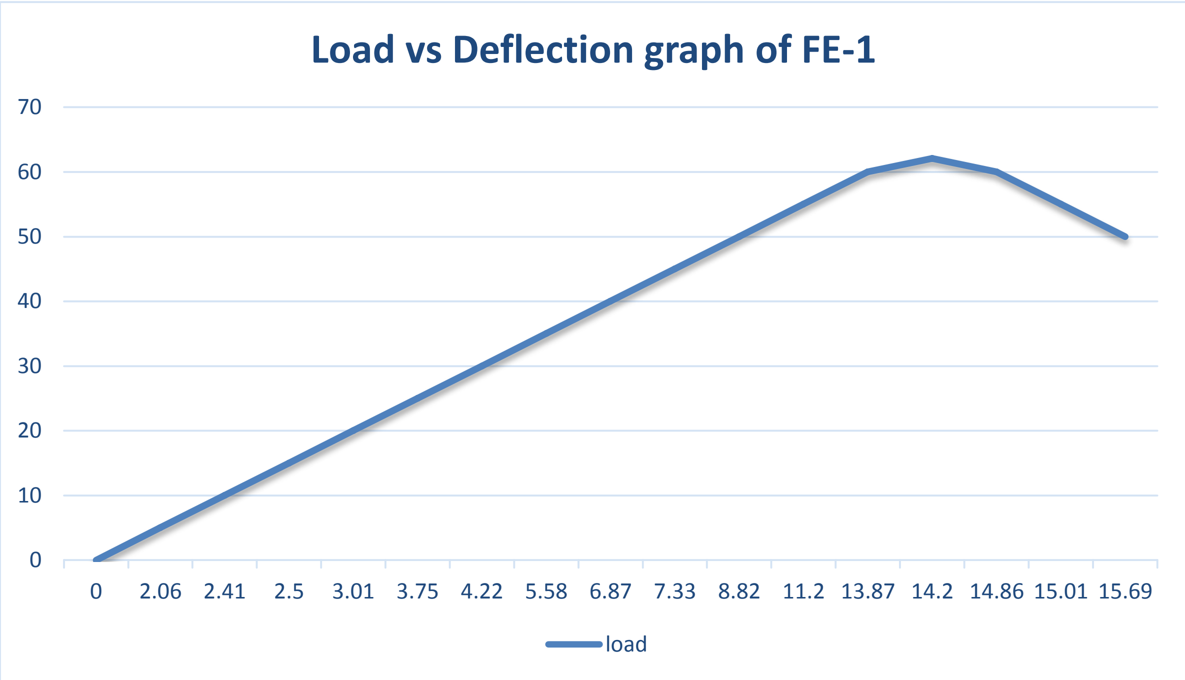

Fig -14: Graph showing the load vs deflection relation for FE- 1

5.1.5 Load vs Deflection Observations for FE-2

The beam FE-2 showed maximum deflection of 12.78 mm whereas the first crack was seen at 21.10 kN and the ultimate load was noted at 55.82 kN.

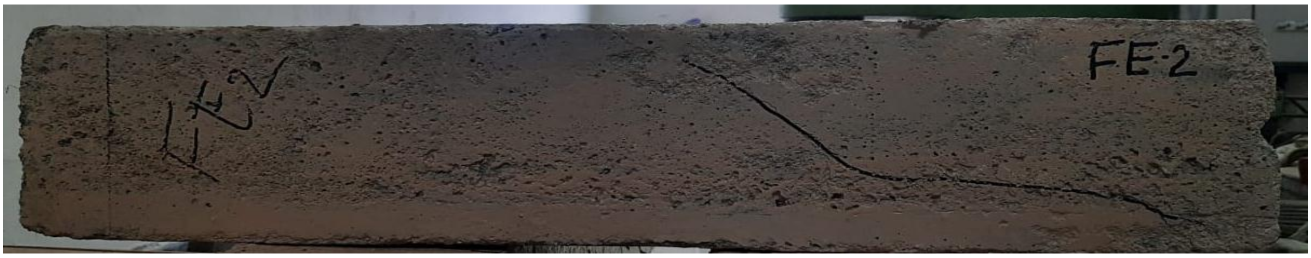

Fig -15: Cracks developed on longitudinal section of FE- 2

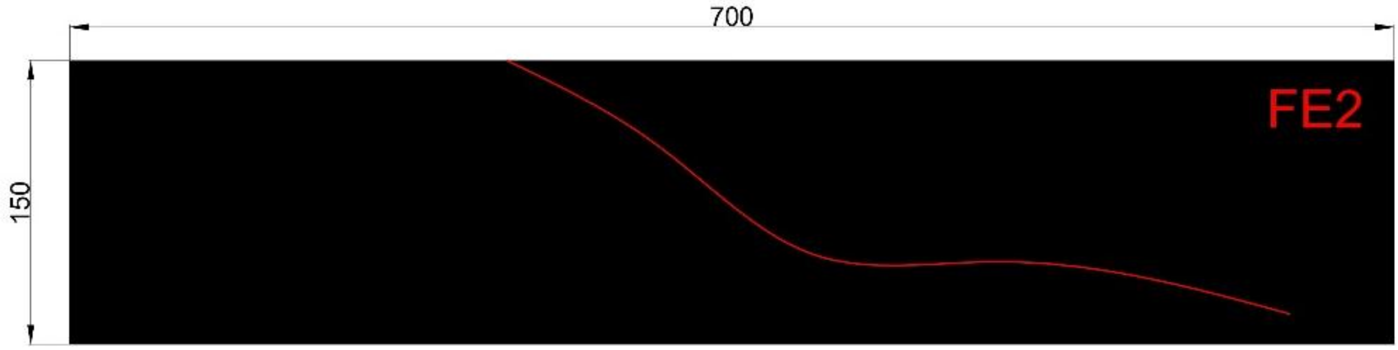

Fig -16: Drawing of crack pattern on longitudinal section for FE- 2

Table -7: Observations of Load and its corresponding Deflection of FE- 2

Sr. No.	Load (kN)	Deflection (mm)	Sr. No.	Load (kN)	Deflection (mm)
1	0	0.00	8	35	8.69
2	5	1.09	9	40	9.37
3	10	1.09	10	45	10.27
4	15	1.26	11	50	10.34
5	20	3.65	12	55.82	11.18
6	25	4.87	13	50	12.78
7	30	5.09			

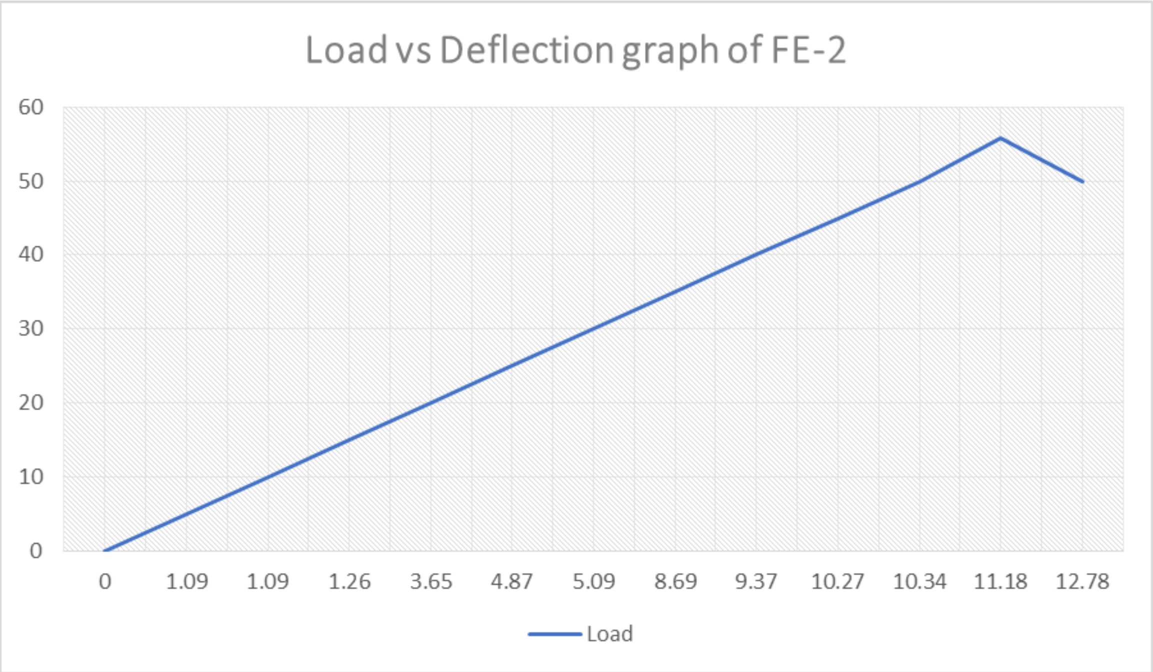

Fig -17: Graph showing the load vs deflection relation for FE- 2

5.1.6 Load vs Deflection Observations for FE-3

FE-3 was the final beam among the test specimen. The first crack load and the ultimate load for this beam were seen at 19.56 kN and 51.20 kN respectively. Similarly to other ferrocement beams this specimen showed higher deflection values.

Fig -18: Cracks developed on longitudinal section of FE- 3

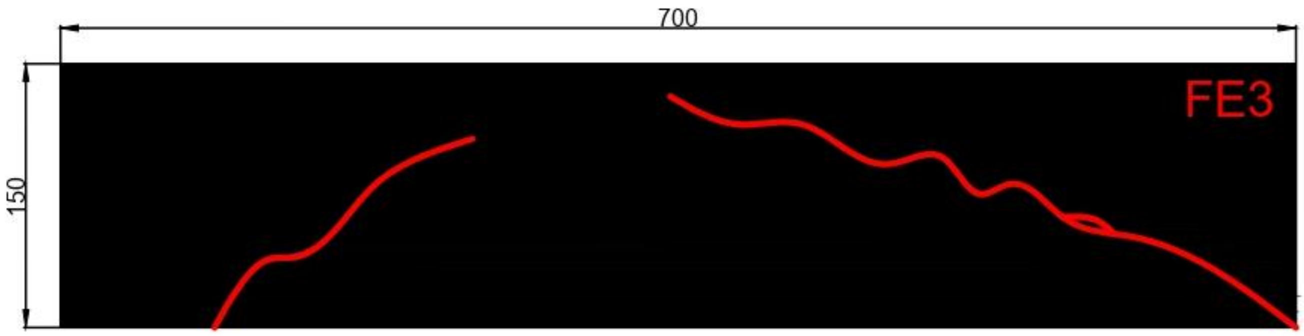

Fig -19: Drawing of crack pattern on longitudinal section for FE- 3

Table -8: Observations of Load and its corresponding Deflection of FE- 3

Sr. No.	Load (kN)	Deflection (mm)	Sr. No.	Load (kN)	Deflection (mm)
1	0	0.00	8	35	6.15
2	5	2.16	9	40	7.52
3	10	2.41	10	45	10.97
4	15	3	11	50	11.26
5	20	3.37	12	51.20	13.69
6	25	3.99	13	50	14.12
7	30	4.61			

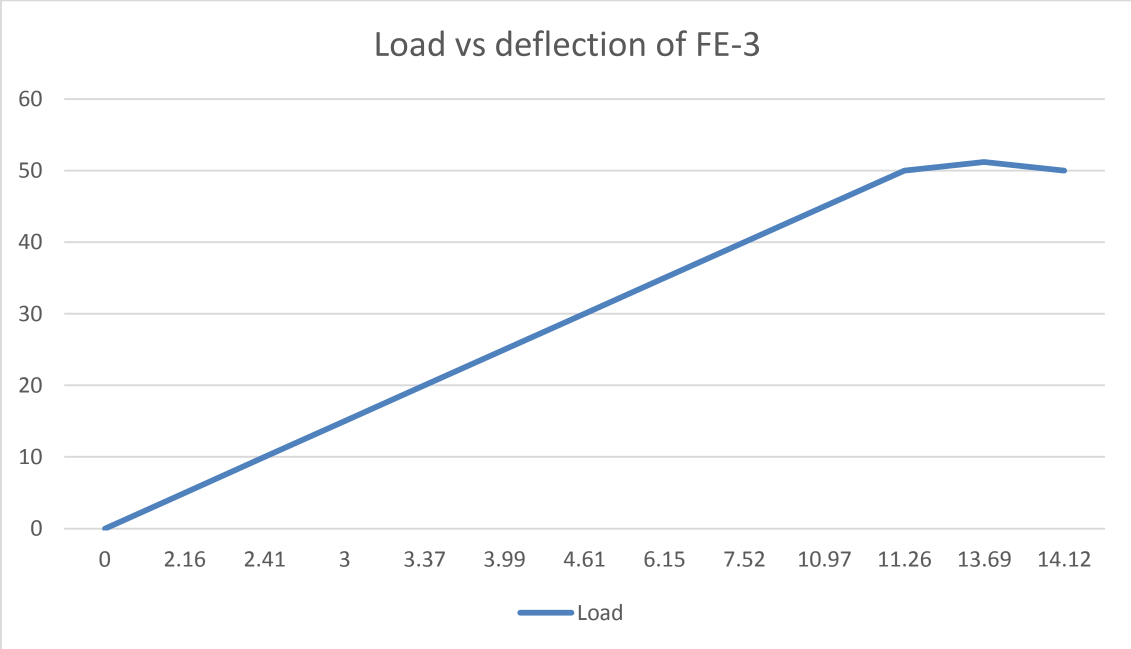

Fig -20: Graph showing the load vs deflection relation for FE- 3

5.2 Ductility characteristics

Table 9 below summarised the first cracking load, ultimate load and its respective deflections, ductility ratio. The ductility ratio is the ratio of deformation at ultimate load to the deformation at first crack load. Average ductility ratio of three ferrocement tested beams is around 3 and average ductility ratio of three reinforced concrete tested beams is around 1. Therefore it seems that feerocement beam is three times ductile than RC beam. These ductility ratios along with large deflection give sufficient warning before failure of specimens.

Table -9: Ductility Ratio of beams

Sr. No.	Beam	First Crack Load and its corresponding deflection	Ultimate Load and its corresponding deflection	Ductility Ratio	Avg. Ductility Ratio
1	RC-1	73 (5.45 mm)	85.40 (6.32 mm)	1.159	1.35
2	RC-2	68.45 (1.41 mm)	82 (2.55 mm)	1.808	
3	RC-3	74.26 (4.94 mm)	79.63 (5.35 mm)	1.083	
4	FE-1	19.38 (2.97 mm)	62.10 (14.20 mm)	4.781	3.987
5	FE-2	21.10 (3.70 mm)	55.82 (11.18 mm)	3.013	
6	FE-3	19.56 (3.35 mm)	51.20 (13.96 mm)	4.167	

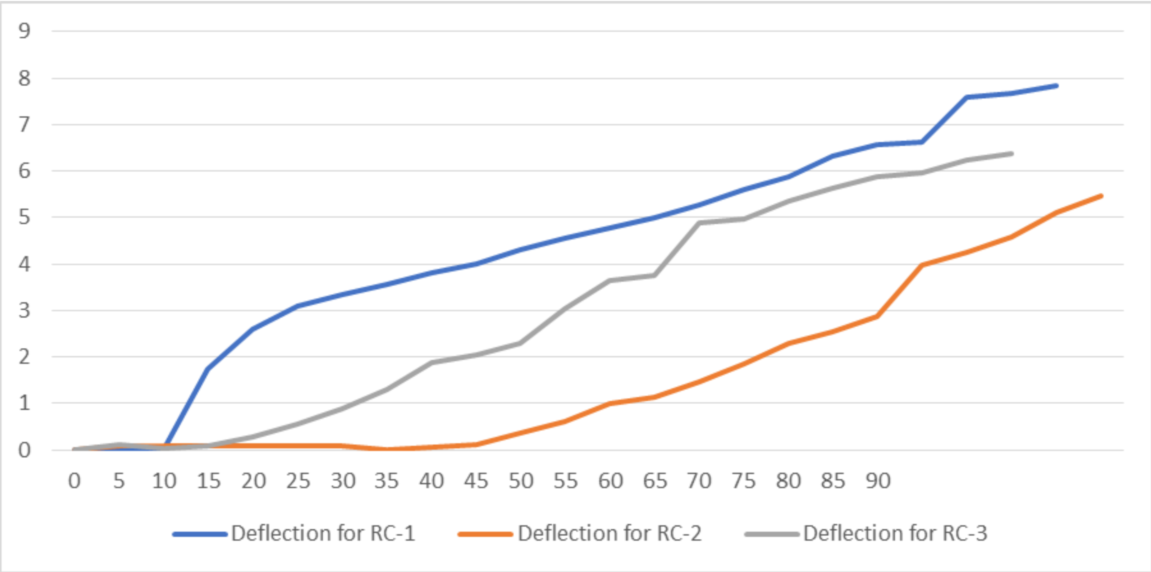

Fig -21: Shows deflection behavior of all three R.C.C beams under similar loading.

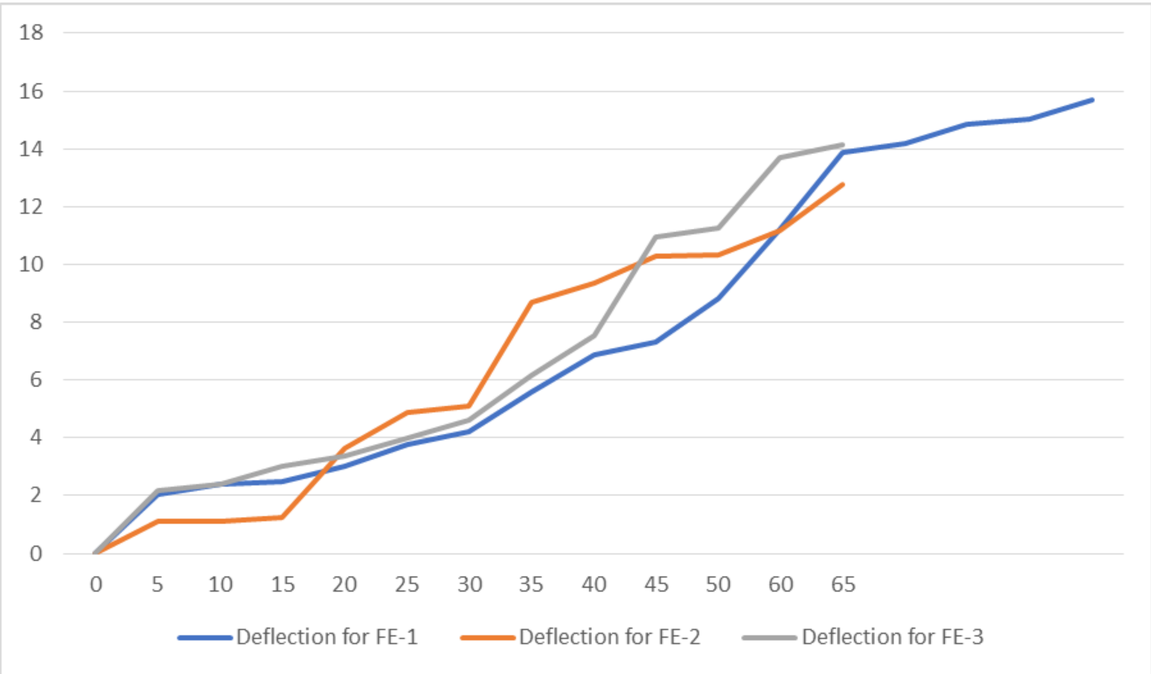

Fig -22: Shows deflection behavior of all three Ferrocement specimens under similar loading

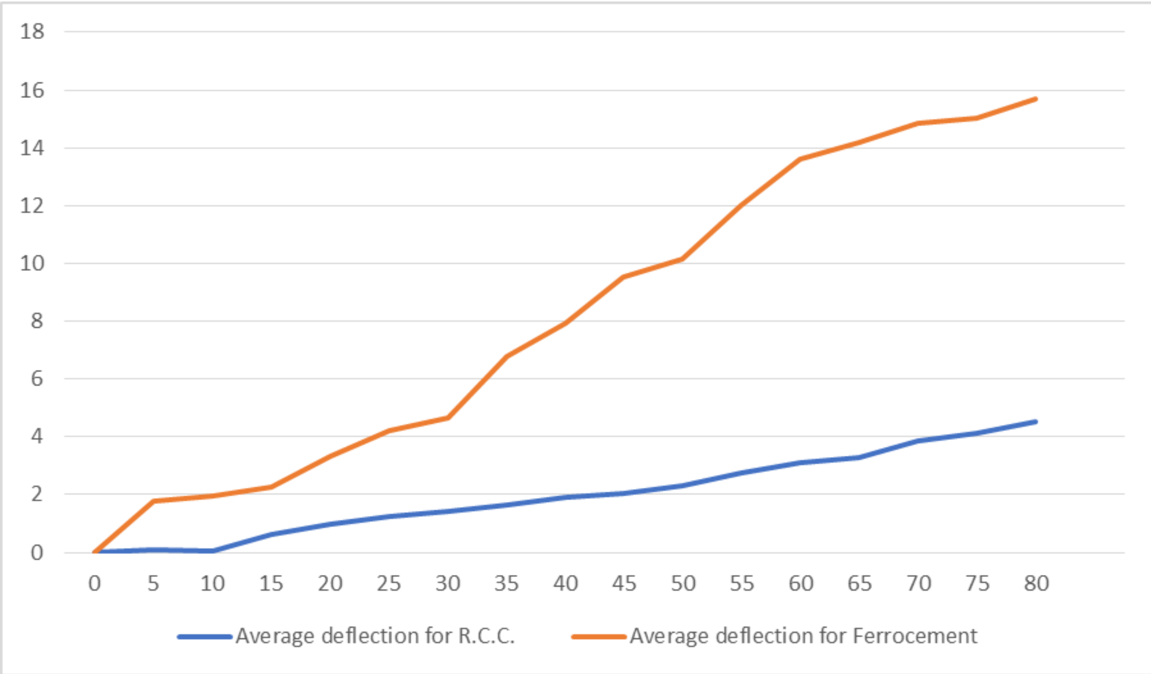

Fig -23: Shows Comparative deflection graph of R.C.C and Ferrocement under similar loading.

The average ultimate failure loads were found as 80.34 kN and 56.37 kN for RC beam and FE beam, respectively. The average deflection at ultimate failure loads was noted as 4.74 mm and 13.11 mm for RC beam and FE beam, respectively. Ultimate load taken by RC beam is 42.5% more than FE beam but at the same time FE beam reduced 40 % of its dead weight. Average deflection at ultimate failure loads of FE beam is 2.76 times more than RC beam. Table 10 shows the ultimate load carried by beams for different volume reduction percentage.

Table -10: Ultimate load taken by RC and FE beams

Beam	Volume reduction percentage	Ultimate Load and its corresponding deflection	Average ultimate load	Average deflection at ultimate load
RC-1	0 %	85.40 (6.32 mm)	80.34	4.74
RC-2	0 %	82 (2.55 mm)		
RC-3	0 %	79.63 (5.35 mm)		
FE-1	40 %	62.10 (14.20 mm)	56.37	13.11
FE-2	40 %	55.82 (11.18 mm)		
FE-3	40 %	51.20 (13.96 mm)		

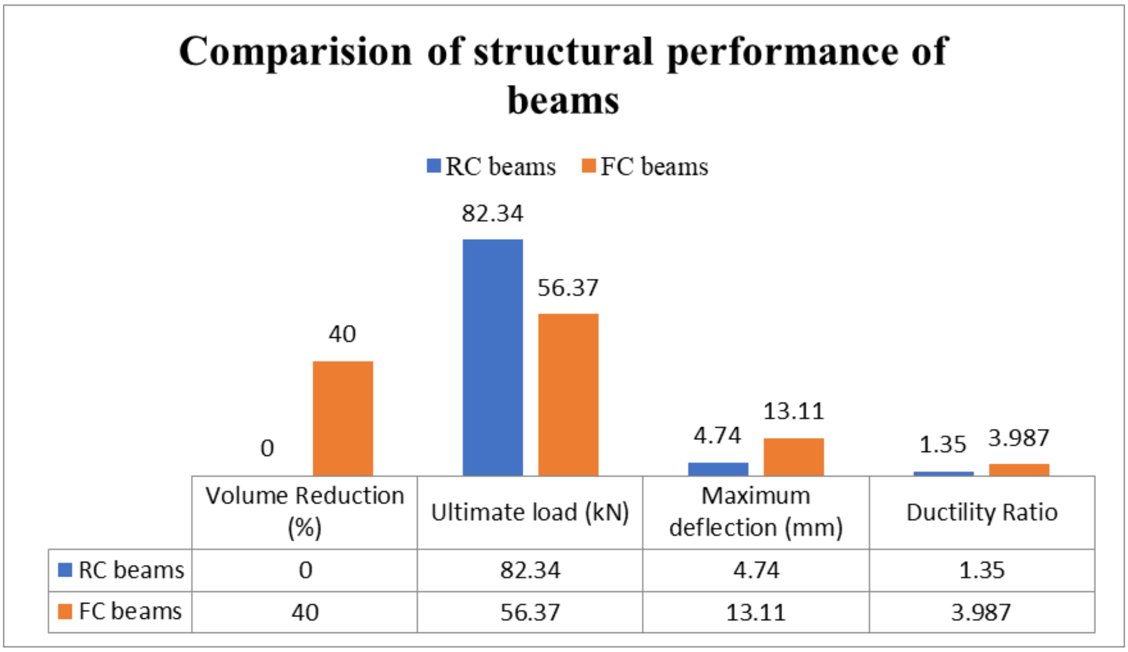

Fig -24: Comparison of structural performance of RC beams and FE beams

6. CONCLUSIONS

6.1 Conclusions

Ferrocement has always been referred to as the architect's material, in this experiment an attempt was made to establish weather members cast of it can be utilized as effective structural members without compromising the strength as well as functionality of the member. From the results mentioned earlier the following conclusions can be drawn:

1. The R.C.C. specimen showed brittle failure, in the sense that no prior intimation is received during or before the failure. Whereas in ferrocement prior intimation is received in the form of first crack load more deflection is observed in the ferrocement beams.

2. No formwork or less formwork was required for the casting of the ferrocement specimen, thus reducing the overall cost of the product.

3. Even though the ferrocement beams are lightweight it was observed that no compromise whatsoever was made in the strength of the beam.

4. Being a lightweight section, the design of the structural members becomes efficient and economical.

6.2 Recommendations for future work

1. While working on ferrocement beams more layer of wire mesh should be provided along with chicken mesh.

2. Time dependent effects are needed to be incorporated in the present study.

3. Tests along with bending should be carried out for e.g. torsional testing, Earthquake testing etc.

4. Care should be taken while preparing the mix for R.C.C as well as for the ferrocement beams.

5. Modifications should be carried out to test the dynamic behavior of the composite concrete beam.

ACKNOWLEDGEMENT

As it is known that a good ship cannot alone sail stormy waters, similarly this article could never have been possible without our guide Prof Kiran M. Deore. It was your constant guidance that led us through the times of difficulties during the work and their in-kind contribution is gratefully acknowledged. The experimental work was carried in the Concrete Lab of Late G. N. Sapkal College of Engineering Nashik, Maharashtra (India). The assistance of the laboratory staff is also acknowledged

REFERENCES

[1] Ibrahim G Shabaan, Yousuri B. I. shaheen, Essam L. Elsayeed, Osama, (2018), Flexural behavior and theoretical prediction of lightweight ferrocement composite beams, Construction and building materials page 802-816.

[2] Ashwin P Anand, Jishnu P P, Melvin Joseph, Mari Ittiachan, (2019), Design of Residential Building using Ferrocement Technology. Issue 5th May 2019.

[3] G. J. Al- Sulaimani, I. A. Basunbul & E. A. Mousselhy, (1990) Shear Behavior of Ferrocement box beams. 21st April 1990.

[4] Eethar Thanon Dawood, Abdalaziz Saad Shawkat, Mafaz Hani Abdullah, (2021), Flexural performance of ferrocement based on sustainable high- performance mortar, Case Studies in Construction Materials, Volume 15, 10th May 2021

[5] P. Desai and N. Ganesan, (1986), Fracture properties of ferrocement using double cantilever beam specimens, The International journal of Cement Composites and Lightweight Concrete, Volume 8, Number 2. (1986) page 121-132.

[6] Taha A. El Sayeed, Abeer M. Erfan, (2018), Improving Shear Strength of beams using Ferrocement Composite, Construction and building Materials, Volume 172, Pages 608-617.

[7] Rajesh S. Rajguru, Manish Patkar, (2021), Torsional behavior of strengthened RC beams by ferrocement, Materials Today: Proceedings.

[8] Ibrahim G. Shaaban, Yousry B. Shaheen et al, (2018), Flexural behavior and theoretical prediction of lightweight ferrocement composite beams, Volume 9 Case studies in construction materials

[9] Gopal Charan Behera, Rao T. D. Gunneswar et al (2013), Torsional Strength of Ferrocement "U" Wrapped normal strength beams with only transverse reinforcement, Procedia Engineering, The 2nd International Conference on Rehabilitation and Maintenance in Civil Engineering, Page 752-763.

[10] Noor Ahmed Memon et al (2007), Ferrocement encased lightweight aerated concrete: A Novel approach to produce sandwich composite. Page 4035-4038.

[11] P. Paramasivam et al (1998), Strengthening of RC Beams with Ferrocement laminates. Cement and Concrete composites. Page 53-65.

[12] M. J. Shannag, S. M. Mourad (2012), Flowable high strength Cementous matrices for ferrocement applications, Construction and Building Materials, Page 933-939.

[13] Bo Li, Eddie Siu Shu Lam, (2018), Influence of Interfacial characteristics on the shear bond behavior between concrete and ferrocement. Page 462-469.

[14] P. Desayi and N. Ganesan, (1984), Determination of maximum crack width in ferrocement flexural elements of channel cross section. International Journal of cement composites and lightweight concrete volume 6 number 3. Page 169-177.

[15] P. Desayi and N. Ganesan, (1986), Fracture properties of ferrocement using double cantilever beam specimens. Page 121-132.

BIOGRAPHIES

BE Student, Department of Civil Engineering, Late G. N. Sapkal College of Engineering, Nashik, Maharashtra, India.

Assistant Professor, Department of Civil Engineering, Late G. N. Sapkal College of Engineering, Nashik, Maharashtra, India.