Flexural Behavior of Strengthened and Repaired R.C. Beams by using Steel and Coir Fiber Concrete Jacket

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***Abstract*— Retrofitting refers to the addition of new technology or features to older systems. In terms of civil engineering it refers to the strengthening of old structures. Many existing reinforced concrete structures do not meet the current design standards because of inadequate design and/or construction or need structural upgrading. They are in urgent need of rehabilitation, repair or reconstruction because of deterioration due to various factors like corrosion, lack of detailing, failure of bonding between beam-column joints, increase in service loads, etc., leading to cracking, spalling, loss of strength, deflection, etc. Innovative techniques for repair have many advantages over conventional techniques.**

This paper focuses exclusively on flexural behavior of RCC beams and the fibre reinforced concrete composite wrapped retrofitted RCC beams. Beams were retrofitted with 20mm and 30mm steel and coir fibre reinforced concrete composite layers using epoxy resins. A total of 23 Nos. of RCC beams of 150mm x 150mm x 700mm in size were casted, 3 beams were tested for ultimate loads, 20 beams were loaded up to 75% of ultimate load and then unloaded to dead load and retrofitted. Mild Steel Hooked End fibre matrix, coir fibre matrix and a combination of both fibres in matrix were used to retrofit the RCC beams. Dosages of 2.0%, 3.0%, 4.0% of steel fibers and 1.5%, 2.0%, 2.5% of coir fibers and combination of steel and coir fibers (1-0.5%, 1.5-1%, 2-1.25%) by weight of cement were used and the behavioral and flexural study was performed. Finally the investigation and comparison of experimental results were studied with the help of statistical data obtained by testing of specimen.

2.0% addition of steel fibers to matrix and then retrofitting with it increases the flexural strength by 58.77% for 20mm layer and increase in dosage correspondingly increases the flexural strength. Out of all iterations steel fiber gives more increase in strength i.e. 88.59% for 4% addition of steel in concrete of 30mm layer for jacketing.

From this exhaustive and extensive experimental work it was found that with increase in steel fiber content in matrix used for jacketing there is considerable increase in flexural strength. This may help us to use such fibre reinforced concrete for retrofitting of RCC beams economically.

Keywords—RCC beams; cracks; flexural strength; steel; coir

I. INTRODUCTION

Many existing buildings have been designed according to old codes and may not be resistant enough to failure as they do not satisfy the detailing requirements or due to mistakes in construction and may collapse. For several years, new rules have been introduced in order to avoid such deficiencies in new constructions, but some existing ones need to be retrofitted. There are various methods for strengthening and repairing of RC beams such as externally bonded steel plates, RC jacketing and externally bonded fiber reinforced polymer (FRP). All these techniques can be successfully used but have some limits. In particular, the use of RC jacket is possible by adding layers of concrete with thickness larger than 60-70 mm due to the presence of re-bars as that require a minimum concrete cover of 20mm. Although the technique of bonding steel plates to concrete externally has proved to be effective in increasing strength and stiffness of reinforced concrete elements, it has the disadvantages of being susceptible to corrosion and costly also. The use of externally glued FRP may have problems of fire resistance.

In this context, the use of steel fibre and coconut coir fibre has significantly increased in construction and civil engineering fields due to its enhanced flexural, tensile, compressive and fatigue properties. In the last decade the development of strong epoxy glue has led to techniques which have great potential in the field of upgrading structures. Recently a new technique has been developed for strengthening and repairing beams. This technique is based on the application of a thin jacket in high performance fiber reinforced concrete (HPFRC) with a high compressive strength and a hardening behaviour in tension. This method has more advantages such as increase in ultimate load carrying capacity, enhancement of serviceability limit state, resistance to fire and avoiding corrosion problems that appear in steel plate jacket. The main objective of this work was to strengthen and the beams using high strength concrete with steel fiber and coir fibre as they are effective in increasing the ductility and bond between the components of concrete. Therefore in the present work steel and coir fibres were used individually as well as in mixture in different proportions to assess the performance of concrete and the beam.

II. Test Specimen

A) Materials used

1) *Cement:* Ordinary Portland cement (OPC) of 53 grade of Birla Super Cement is used in this experimental work.
2) *Fine aggregates:* Natural river sand was used having specific gravity 2.6gm/cc and Fineness modulus(FM) as 2.83.
3) *Coarse aggregate:* consist of 10 mm and 20 mm crushed granite aggregate. 10 mm aggregate having specific gravity 2.8gm/cc and FM as 2.01. 20mm aggregate having specific gravity 2.6 gm/cc and FM as 2.73.
4) *Steel and coir fibers:*

TABLE I
PROPERTIES OF FIBERS

Particulars	Mild Steel	Coir[4]
Type	Hooked end	-
Length(mm)	50	50
Diameter (mm)	0.6	0.3 to 0.53
Aspect ratio	83	94-166
Minimum tensile strength (MPa)	345	108-252
Modulus of elasticity(GPa)	210	2.5-4.5
Density (gm/cm^3)	7.8	0.67-1

5) *Steel reinforcement details:* Fe-500 10mm diameter tor steel bars were used for main reinforcement and stirrups with clear cover of 20mm.
6)

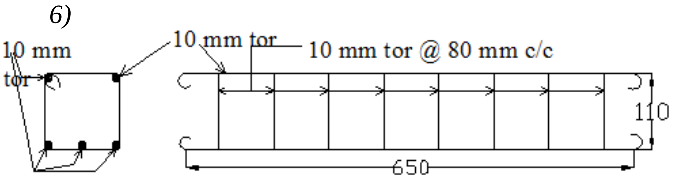

Figure 1 *(Steel reinforcement details)*

A. Mix Proportion

Design concrete mix of M20 i.e. 1:1.77:2.89 by weight with w/c ratio 0.45 is used. It was mixed in a batch size 0.024m³. All 23 beams were casted in conventional manner. Cement, sand and coarse aggregate were uniformly mixed and water was added to it gradually to prepare the mix.

TABLE II
MIX PROPORTION AND CONCRETE BATCH (M20)

Particulars	Size mm	Volume m^3	Cement kg/m^3	Aggregate (kg/m3)			Water lit/ m^3
				Fine	Coarse		
					10 mm	20 mm	
Mix propor-tion	-	1.0	383	546	475	712.8	191.6
Beam	150x150x700	0.015	6.05	8.62	7.50	11.26	3.027
Per Batch	-	0.024	9.2	13.11	11.4	17.12	4.6

B) *Methodolology*

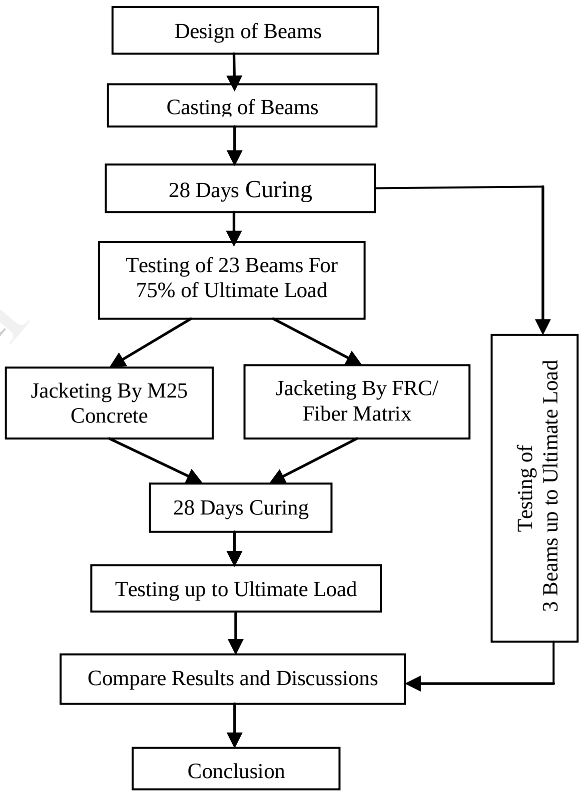

Figure 2*(Methodology)*

B. Casting Procedure of all beams

The moulds were prepared using plywood. The length of beam was 700mm with cross section 150 mm x 150 mm. The design mix ratio of M20 was adopted for casting the beam. 23 under reinforced beams were cast, 3 as control specimens and 20 beams for retrofitting. Three bars of 10 mm tor were provided as tension reinforcement, 2 anchor bars of 10mm tor at top of the beam and bars of 10 mm tor were provided as shear reinforcement**.** All beams and control specimens were cast and wet cured for 28 days.

Figure 3 *(Casting of beam.)*

C. Pre-Retrofitting Loading

Except for the control beam B_1,B_2,B_3 which were loaded monotonically up to failure(ultimate load), all other beams were loaded up to about 75% of the ultimate load of the control beam (load equivalent to full service dead and live loads). During loading, the specimen was visually inspected and cracks were marked. The specimen was then unloaded to dead load only and then retrofitting was carried out by jacketing it with fiber matrix.

Figure 4 *(Pre-retrofitting flexural loading.)*

III. RETROFITTING

Retrofitting of all the beams is done by U-shaped jacketing i.e jacketing it on 3 sides with fiber matrix having different fibers like steel, coir and both in combination in different proportions.

D. Mix Proportion for fiber-matrix jacketing

Design concrete mix of M25 i.e. 1:1.45:3.71 by weight with w/c ratio 0.47 is used. Cement, sand and coarse aggregates and fibers were distributed uniformly in the dry mixture. The materials were dry mixed for 1 minute before adding water gradually. Fibers dispersed in mix without causing balling effect. Different dosages of 2.0%, 3.0%, 4.0% of steel fibers and 1.5%, 2.0%, 2.5% of coir fibers and combination of steel and coir fibers (1-0.5%,1.5-1,2-1.25%) by weight of cement were used to make total 9 fibre matrices.

TABLE III
MIX PROPORTION AND CONCRETE BATCH(M25)

Particulars	Jacketing layer size	Volume m^3	Cement kg/m^3	Aggregate (kg/m3)			Water lit/ m^3
				Fine	Coarse		
					10 mm	20 mm	
Mix propor-tion	-	1.0	383	546	475.2	712.8	191.6
Beam layer	20mm	0.006	2.44	3.551	3.635	5.452	1.512
Beam Layer	30mm	0.010	3.8	5.51	5.639	8.458	1.786
Per Batch	-	0.025	9.5	13.77	14.09	21.14	5.012

E. Retrofitting of beams

The full wrapping technique around 3 of the beam (bottom and side faces) is used as the method of retrofitting. Before retrofitting, the concrete surface of beam is made rough using a wire brush and then cleaned with water to remove all dirt and debris. The beams are allowed to dry for 24 hours. After that, the epoxy resin (Nito-Bond)is mixed in accordance with manufacturers' instructions. The mixing is carried out in a plastic container (Base: Hardener = 1Kg : 5Kg). After uniform mixing, the epoxy resin is applied to the concrete surface. The beams are allowed to cure for 1 hour. The beams are then retrofitted by jacketing it with fibre-matrix layer of different compositions of thickness 20mm and 30 mm for each composition. These beams were cured for a period of 28 days.

Figure 5 *(Retrofitting of beams)*

IV. TEST PROGRAM

F. Flexural Testing of Beams

Flexural testing of Beams is carried out in Universal testing machine (UTM), by using centre point loading assembly. The machine used for testing is of capacity 100 tones and capable of applying load approximately at the rate of 400kg/min for the 15cm specimen. Bearing surface of the supporting rollers has been wiped and cleaned before placing the specimen. The beam specimens were kept under the UTM using 2 supports at spacing of 675mm c/c. Loading assembly is kept over a beam by maintaining same distance from both supports as shown in figure 4. After that the load is applied to the beam at the rate of 400kg/min. The load has been increased until the specimen fails, and the maximum load applied to the specimen during the test was recorded.

The Deflecto-meter is attached to the assembly to note the deflection of beam at particular interval of load. Deflecto-meter is detached after decreasing load taken by specimen after its failure.

Formation of cracks has been observed during failure of specimen. The load was noted at the point where the first crack was appeared clearly to naked eye. The observation shows 3mm crack was appeared, at the point of application of load.

Figure 6. *(Flexural testing of beams.)*

G. Calculations

The flexure of the specimen shall be in terms of its ultimate moment carrying capacity.

$$M = \frac{P \times L \times 9.81}{4 \times 1000}$$

Where

P = ultimate load in applied in kg

L = c/c distance between supports in m

V. RESULTS AND DISCUSSIONS

H. Abbreviations

B: Control beam(loaded up to ultimate load)

SJB: Steel fiber reinforced concrete Jacketed Beam

CJB: Beam Jacketed with Coir fiber reinforced concrete

MJB: Beam Jacketed with concrete having a combination of fibers

SF: Hook end steel fiber

CF: Coir fiber

Ultimate load of control beam = 5700kg

$$\text{Ultimate Bending Moment of B} = \frac{5700 \times 0.675 \times 9.81}{4 \times 1000}$$

= 9.435 kN-m

During pre-retrofitting loading stage all beams were loaded up-to 75% of its ultimate load i.e up to 4275kg(approx. 4300kg)

TABLE IV
DOSAGE OF FIBER-MATRIX IN JACKETS OF BEAMS

Retrofitted Beam	**1**	**2**	**3**
SJB	2.0%	3.0%	4.0%
CJB	1.5%	2%	2.5%
MJB	SF1%-CF0.75%	SF1.5%-CF1%	SF2%-CF1.25%

TABLE V
RESULT OF FLEXURAL TESTING OF BEAMS

Jacketed Beam	**Ultimate Moment (kN-m) for different thickness jacketed layer**		**Increase in strength as compared to un-retrofitted beams (%)**	
Thickness of jacketed layer	***20mm***	***30mm***	***20mm***	***30mm***
SJB-1	14.98	15.47	58.77	64.03
SJB-2	15.64	16.38	65.78	73.68
SJB-3	16.38	17.79	73.68	88.59
CJB-1	14.4	15.14	52.63	60.52
CJB-2	15.23	15.56	61.40	64.91
CJB-3	15.97	16.14	69.29	71.05
MJB-1	14.40	14.89	52.63	57.89
MJB-2	15.31	15.64	62.28	65.78
MJB-3	16.05	16.38	70.29	73.68

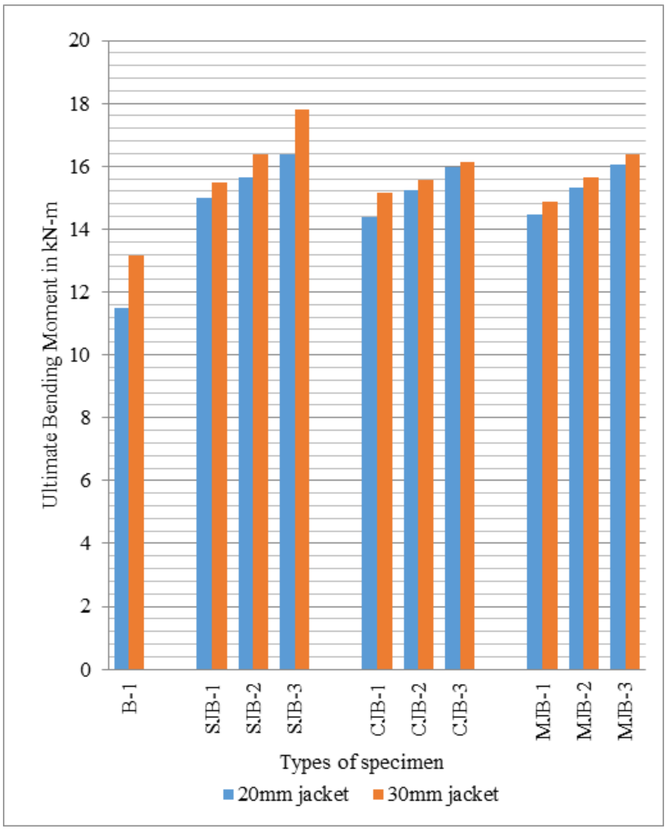

Figure 7. *(Ultimate moment of jacketed beams)*

Load-deflection curves plotted for all beams containing different dosage for same type of fiber in one set of graphs.

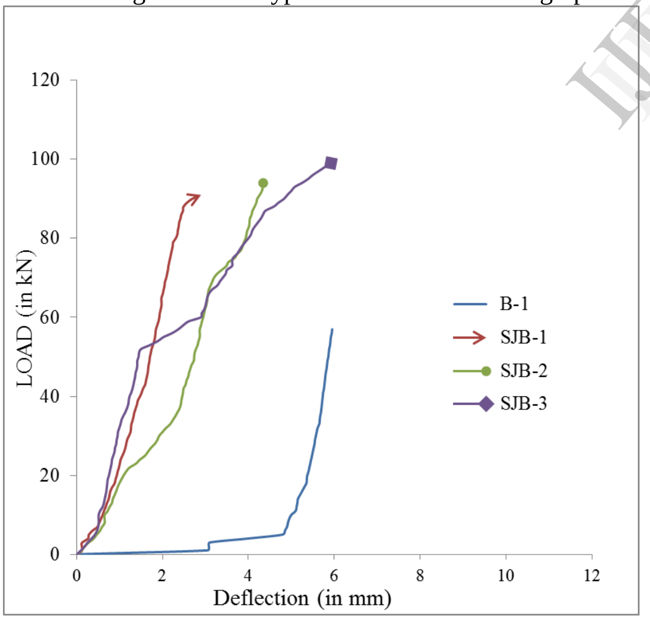

Figure. 8 *(Load – deflection curve of steel fiber reinforced concrete 20 mm layer jacketed beam).*

This graph shows the deflection of beam with change in load on the beam. It shows that as the steel fiber content in jacket increases load carrying capacity of beam increases.

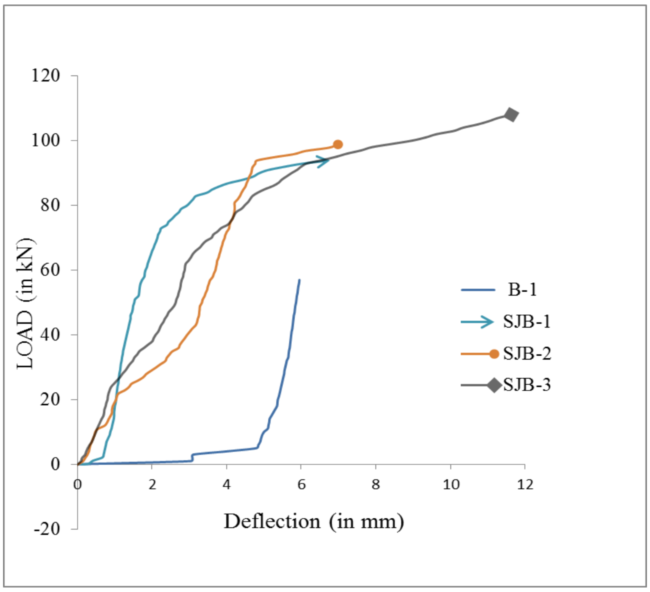

Figure. 9 *(Load – deflection curve of steel fiber reinforced concrete 30mm layer jacketed beam)*

From the above graph we see that as the thickness of jacketing layer is increased the ultimate moment carrying capacity of beam increases for the same percentage of steel.

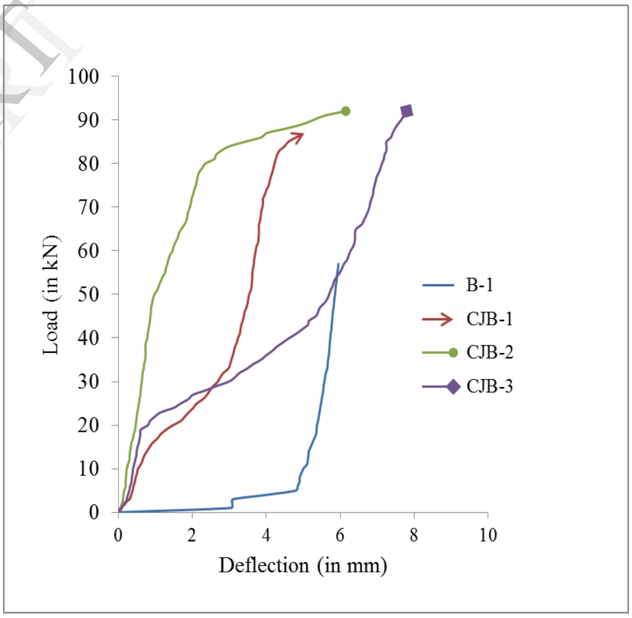

Figure. 10*(Load – deflection curve of coir fiber reinforced concrete 20mm layer jacketed beam)*

This graph shows the deflection of beam with change in load on the beam. It shows that as the coir fiber content in the jacket increases load carrying capacity of beam increases.

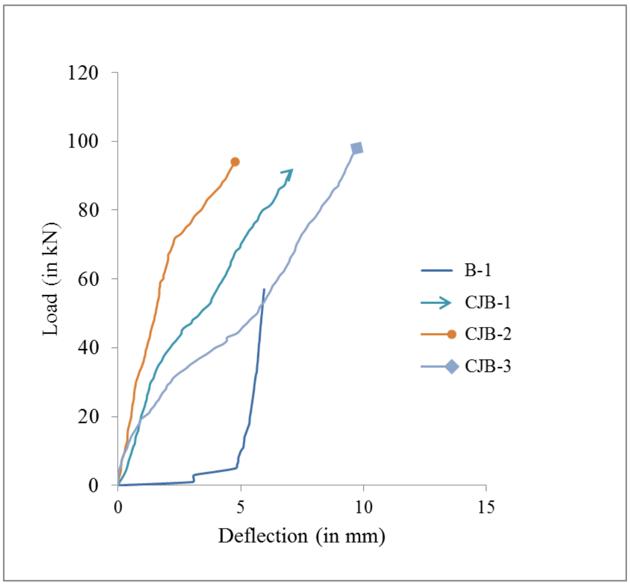

Figure 11 *(Load – deflection curve of coir fiber reinforced concrete 30mmlayer jacketed beam)*

From the above graph we see that as the thickness of jacketing layer is increased the ultimate moment carrying capacity of beam increases for the same percentage of coir.

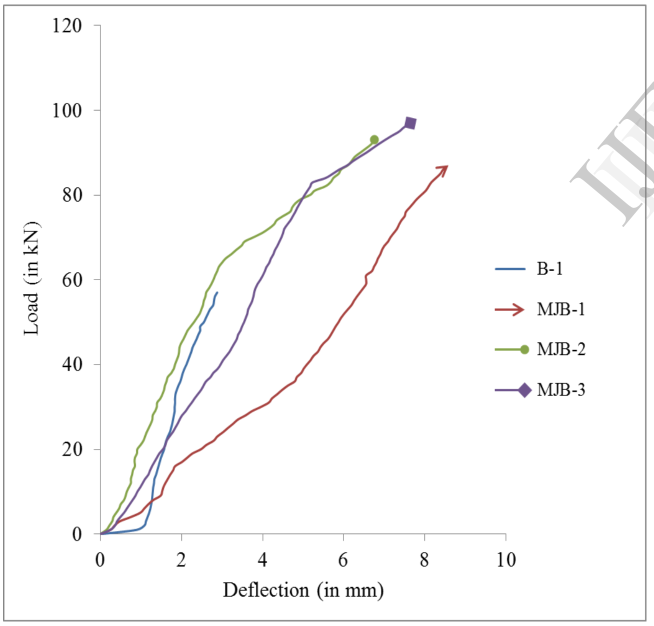

Figure 12 *(Load – deflection curve of steel and coir fiber reinforced concrete 20mm layer jacketed beam)*

This graph shows the deflection of beam with change in load on the beam. It shows that as the steel and coir fiber content in jacket increases load carrying capacity of beam increases

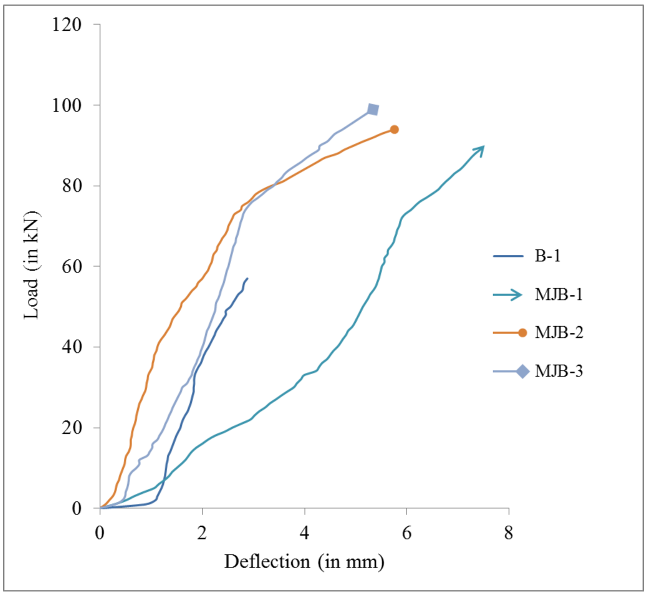

Fig. 13 *(Load – deflection curve of steel and coir fiber reinforced concrete 30mm layer jacketed beam)*

From the above graph we see that as the thickness of jacketing layer is increased the ultimate moment carrying capacity of beam increases for the same percentage of coir and steel.

VI. CONCLUSION

Based on the test results and discussions above, the following conclusions can be drawn:

- As fibre content in jacket increases or thickness of jacket increases or both are increased the ultimate moment carrying capacity increases significantly.
- Adding 4% steel fiber to the concrete jacket of 30mm has a significant increase i.e 88.59% in ultimate bending moment of beam.
- The final deflection is more after jacketing of beams as the beam is pre-loaded up to 75% of ultimate load.
- The strengthening and repairing with fibre reinforced concrete jacket decreased the number of cracks in the beam and they were concentrated in middle portion of the beam.
- The epoxy resin (Nito-bond) plays an effective role in enhancing the bond between main beam and jacket and preventing the de-bonding failure.
- From the above results we observe that maximum increase in ultimate bending moment of beam is firstly due to use of steel individually, secondly due to use of combination of fibres, lastly due to coir fibres.

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