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Flexural retrofitting of geopolymer RC beam with ferrocement laminates

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ABSTRACT

The present paper deals with the experimental investigation carried out to study the effect of Ferrocement laminates on the strengthening of Geopolymer reinforced concrete rectangular beams. Various rehabilitation techniques have been proposed yet but among these techniques, external strengthening provides a practical and cost-effective solution when compared to other repair methods. Reinforced concrete components are formed to exhibit distress and get deteoriated due to various factors and hence need strengthening. Ferro cement is most commonly used as retrofitting material due to their easy availability durability and their property of being cast to any shape without needing significant formwork. In this investigation, we examined the performance of R.C. beam strengthened by Ferro cement, 15 beams of the rectangular cross-section were cast using m20 grade concrete and were tested for collapse load. Further beams were stressed up to 70%, 80% &90% respectively. The investigation shows that up to 80% of the pre-damaged beams can be strengthened using Ferro cement. The need for 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. In this paper, reinforced concrete beams strengthened with Ferrocement laminates attached to the soffit of the beams and control beam are observed through experimental study. Experimental results show that the strengthened beams and control beam are observed through experimental study. Experimental results show that the strengthened beams have increased ultimate moment capacity and also, it shows better serviceability performances in terms of crack control and deflection.

Keywords— *Geopolymer, Ferrocemnet laminates, RC Beam*

1. INTRODUCTION

Due to an increase in infrastructure developments, the demand for concrete would be increased. Concrete is one of the most widely used construction material. Worldwide concrete consumption was estimated to be 8.8 billion tons per year. The year environmental issues associated with the production of OPC are well known. Among the greenhouse gases, carbon dioxide contributes 65% of global warming. The cement industry is responsible for about 6% of all carbon dioxide emission, because of production of one ton of Portland cement emits approximately one ton of carbon dioxide into the atmosphere. Cement production is also highly energy intensive, after steel and aluminium.

1.1 Geopolymer

Geopolymer is members of the family of inorganic polymers. The chemical composition of the Geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline. The polymerization process involves a substantially assist chemical reaction under the alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

1.2 GGBFS

Ground Granulated Blast Furnace Slag (GGBFS) is obtained by quenching molten iron slag from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and grounded into a fine powder.

1.3 Aggregates

Coarse and fine aggregates used by the concrete industry are suitable to manufacture Geopolymer concrete. The aggregate grading curves currently used in concrete practice are applicable in the case of Geopolymer concrete.

Different grades. The sodium silicate solution A53 with SiO_2 to Na_2O ratio by mass of approximately 2, that is SiO_2 = 29.4%, Na_2O = 14.7% and water = 55.9% by mass, is recommended.

2. MIX DESIGN FOR CONCRETE (GEO POLYMER)

2.1 For M40 grade considering for 1m^3 of concrete

(a) Type of Cement - PPC 43 grade
(b) Type of Coarse aggregate - Crushed angular aggregate (20mm and 10 mm in size)
(c) Type of Fine aggregate - River Sand
(d) Maximum Ferro Cement Content - 450 kg/m^3
(e) Maximum water-cement ratio - 0.5
(f) Exposure Condition - Moderate
(g) Specific Gravity

- Of Cement - 3.15
- Of Geo Polymer - 2.60
- Of Coarse aggregate (20 mm) - 2.89 (10 mm) – 2.77
- Of Fine aggregate - 2.62
- Of Water - 1

(h) Water Absorption content (%)

- Of Coarse aggregate - 0.43
- Of Fine aggregate - 1.00
- Moisture Content - Nil

Step 1: (Target Average Compressive Strength of 150 mm at 28 days of curing)

$$f_{ck}' = f_{ck} + 1.65S$$

$$= 40 + 1.65(5)$$

Where S = standard deviation = 5

$$= 48.25 \text{ N/mm}^2$$

Step 2: (Water-Cement ratio)
Considering Moderate exposure condition based on IS 456-2000/Table 5

$$Maximum\ Water - Cement\ ratio\ is\ 0.5$$

We consider Water-Cement ratio as 0.45, the minimum cement content for design mix is 450 kg/mm^2

$$free\ water\ amount\ is\ 450 \times 0.45 = 202.50\ liters$$

Step 3: (Mix Calculations)
Metakaolin added 0%, 5% and 10% to perform Trial 1, 2 and 3.

2.2 Trial 1

$$Volume\ of\ concrete: 1m3$$

$$Volume\ of\ cement: \frac{mass of cement}{specific gravity of cement} X \frac{1}{1000}$$

$$= \frac{450}{3.15} X \frac{1}{1000}$$

$$= 0.1428 \text{ m}^3$$

$$Volume\ of\ water: \frac{mass of water}{specific gravity of water} X \frac{1}{1000}$$

$$= \frac{203}{1} X \frac{1}{1000}$$

$$= 0.203 \text{ m}^3$$

$$Volume\ of\ all\ aggregates\ (f): [1 - (Volume\ of\ Cement + Volume\ of\ water)]$$

$$f = [1 - (0.1428 + 0.203)]$$

$$f = 0.6542 \text{ m}^3$$

$$Volume\ of\ Coarse\ aggregate\ (20\ mm): [f\ X\ Volume\ of\ Coarse\ aggregate\ (20mm\ size\ of\ 36\%)\ X\ Specific\ Gravity\ of\ Coarse\ aggregate\ X\ 1000]$$

$$= [0.6542 \text{ X } 0.36 \text{ X } 2.89 \text{ X } 1000]$$

$$= 680 \text{ kg}$$

$Volume\ of\ Coarse\ aggregate\ (10\ mm): [f\ X\ Volume\ of\ Coarse\ aggregate\ (10\ mm\ size\ of\ 24\%) X\ Specific\ Gravity\ of\ Coarse\ aggregate\ X\ 1000]$

$= [0.6542\ X\ 0.24\ X\ 2.77\ X\ 1000]$

= 434 kg.

∴ Total Coarse aggregate = 680 + 434

= 1114 kg.

$Volume\ of\ Fine\ aggregate: [f\ X\ Volume\ of\ fine\ aggregate\ X\ Specific\ Gravity\ of\ fine\ aggregate\ X\ 1000]$

$= [0.6542\ X\ 0.4\ X\ 2.62\ X\ 1000]$

= 686 kg.

Water Content

Considering the water absorption content for calculating the water content in the concrete.

$For\ Coarse\ aggregate\ = Volume\ of\ Coarse\ aggregate\ X\ its\ Absorption\ content$

$= 1080\ X\ 0.43$

$= 4.64\ liter$

$For\ Fine\ aggregate\ = Volume\ of\ fine\ aggregate\ X\ its\ Absorption\ content$

$= 686\ X\ 1$

$= 6.86\ liters$

$\therefore Total\ water\ content\ = 202.45 + 4.64 + 6.86$

$= 214\ liters$

2.3 Trial 2

$Volume\ of\ concrete: 1m3$

$$Volume\ of\ cement: \frac{mass of cement}{specific gravity of cement} X \frac{1}{1000}$$

$$= \frac{427.5}{3.15} X \frac{1}{1000}$$

$= 0.1357\ m^3$

$$Volume\ of\ Metakaolin: \frac{mass of metakaolin}{specific gravity of metakaolin} X \frac{1}{1000}$$

$$= \frac{22.5}{2.60} X \frac{1}{1000}$$

$= 0.0100\ m^3$

$$Volume\ of\ water: \frac{mass of water}{specific gravity of water} X \frac{1}{1000}$$

$$= \frac{203}{1} X \frac{1}{1000}$$

$= 0.203\ m^3$

$Volume\ of\ all\ aggregates\ (f): [1 - (Volume\ of\ Cement\ + Volume\ of\ metakaolin\ + Volume\ of\ water)]$

$f\ = [1 - (0.1357 + 0.0100 + 0.203)]$

$f\ = 0.6513\ m3$

$Volume\ of\ Coarse\ aggregate\ (20\ mm): [f\ X\ Volume\ of\ Coarse\ aggregate\ (20mm\ size\ of\ 36\%) X\ Specific\ Gravity\ of\ Coarse\ aggregate\ X\ 1000]$

$= [0.6513\ X\ 0.36\ X\ 2.89\ X\ 1000]$

$= 678\ kg.$

$Volume\ of\ Coarse\ aggregate\ (10\ mm): [f\ X\ Volume\ of\ Coarse\ aggregate$

$$(10\ mm\ size\ of\ 24\%) X\ Specific Gravity\ of\ Coarse\ aggregate\ X\ 1000]$$

$$= [0.6513\ X\ 0.24\ X\ 2.77\ X\ 1000]$$

$$= 432\ kg.$$

$$\therefore Total\ Coarse\ aggregate = 678 + 432$$

$$= 1110\ kg.$$

$$Volume\ of\ Fine\ aggregate: [f\ X\ Volume\ of\ fine\ aggregate\ X\ Specific\ Gravity\ of\ fine\ aggregate\ X\ 1000]$$

$$= [0.6513\ X\ 0.4\ X\ 2.62\ X\ 1000]$$

$$= 682.5\ kg.$$

Water Content

Considering the water absorption content of aggregates for calculating the water content in the concrete.

$$For\ Coarse\ aggregate = Volume\ of\ Coarse\ aggregate\ X\ its\ Absorption\ content$$

$$= 1080\ X\ 0.43$$

$$= 4.64\ liters$$

$$For\ Fine\ aggregate = Volume\ of\ fine\ aggregate\ X\ its\ Absorption\ content$$

$$= 686\ X\ 1$$

$$= 6.86\ liters$$

$$\therefore Total\ water\ content = 202.45 + 4.64 + 6.86$$

$$= 214\ liter$$

2.4 Trial 3

$$Volume\ of\ concrete: 1m3$$

$$Volume\ of\ cement: \frac{mass of cement}{specific gravity of cement} X \frac{1}{1000}$$

$$= \frac{405}{3.15} X \frac{1}{1000}$$

$$= 0.1285\ m^3$$

$$Volume\ of\ Micro\ Silica: \frac{mass of metakaolin}{specific gravity of metakaoin} X \frac{1}{1000}$$

$$= \frac{45}{2.60} X \frac{1}{1000}$$

$$= 0.0200\ m3$$

$$Volume\ of\ water: \frac{mass of water}{specific gravity of water} X \frac{1}{1000}$$

$$= \frac{203}{1} X \frac{1}{1000}$$

$$= 0.203\ m^3$$

$$Volume\ of\ all\ aggregates\ (f): [1 - (Volume\ of\ Cement + Volume\ of\ metakaolin + Volume\ of\ water)]$$

$$f = [1 - (0.1285 + 0.0200 + 0.203)]$$

$$f = 0.6485\ m3$$

$$Volume\ of\ Coarse\ aggregate\ (20\ mm): [f\ X\ Volume\ of\ Coarse\ aggregate\ (20mm\ size\ of\ 36\%) X\ Specific\ Gravity\ of\ Coarse\ aggregate\ X\ 1000]$$

$$= [0.6485\ X\ 0.36\ X\ 2.89\ X\ 1000]$$

$$= 675\ kg.$$

$$Volume\ of\ Coarse\ aggregate\ (10\ mm): [f\ X\ Volume\ of\ Coarse\ aggregate\ (10\ mm\ size\ of\ 24\%) X\ Specific\ Gravity\ of\ Coarse\ aggregate\ X\ 1000]$$

$$= [0.6485\ X\ 0.24\ X\ 2.77\ X\ 1000]$$

$$= 431\ kg.$$

$$Total\ Coarse\ aggregate = 675 + 431$$

$$= 1106\ kg.$$

$$Volume\ of\ Fine\ aggregate: [f\ X\ Volume\ of\ fine\ aggregate\ X\ Specific\ gravity\ of\ fine\ aggregate\ X\ 1000]$$

$$= [0.6485\ X\ 0.4\ X\ 2.62\ X\ 1000]$$

$$= 680\ kg.$$

Water Content

Considering the water absorption content of aggregates for calculating the water content in the concrete

$$For\ Coarse\ aggregate = Volume\ of\ Coarse\ aggregate\ X\ its\ Absorption\ content$$

$$= 1080\ X\ 0.43$$

$$= 4.64\ liters$$

$$For\ Fine\ aggregate = Volume\ of\ fine\ aggregate\ X\ its\ Absorption\ content$$

$$= 686\ X\ 1$$

$$= 6.86\ liters$$

$$\therefore Total\ water\ content = 202.45 + 4.64 + 6.86 = 214\ liters$$

Now, converting the above mix designs for adopting the cube specimens of 1200mm in size for casting concrete Beams to do compression tests on the 3rd day, 7th day and 28th day.

3. TEST RESULT AND DISCUSSION

3.1 Test results

The recorded load deflection results were compared for the study of load-deflection behavior and the moment-curvature relationship of the control beam and retrofitted beam are shown in the following figures.

3.2 Preliminary test

Four numbers of cubes and four numbers of cylinders were cast for a preliminary study of concrete and four numbers cubes were cast for the study of geopolymer mortar. The test results are given in table1.

Table 1: Compressive strength of Specimens

S no.	Type of Specimen	Curing days Ambient Curing	Average compressive Strength in N/mm^2
1	Cube (Concrete)	7	38.2
2	Cylinder (Concrete)	7	37.6
3	Cubes (Mortar)	7	27.2

Table 2: Tensile Strength of Specimens

S no.	Type of Specimen	Curing days Ambient Curing	Average compressive Strength in N/mm^2
1	Cylinder (Concrete)	7	7.2
2	Cylinder (Mortar)	7	3.89

3.3 Charts

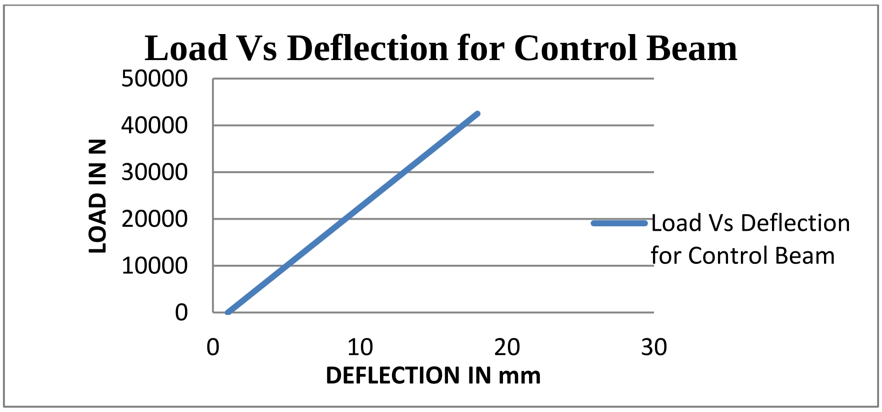

Fig. 1: Load vs. Deflection for Control Beam

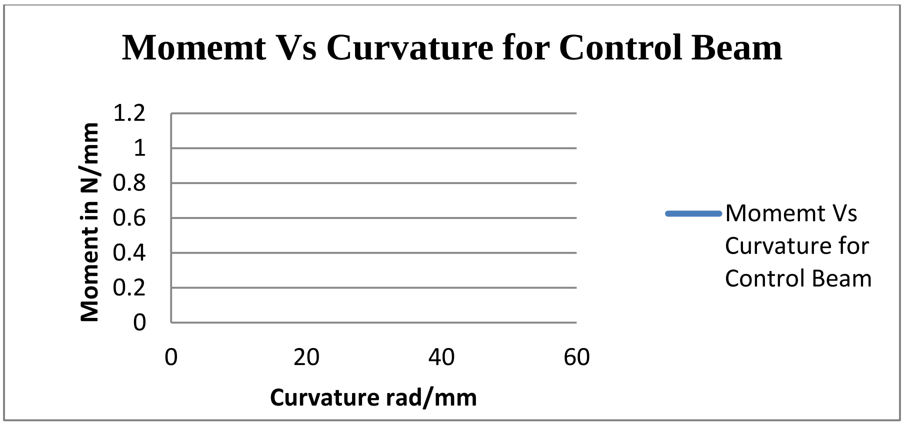

Fig. 2: Moment vs. Curvature for Control Beam

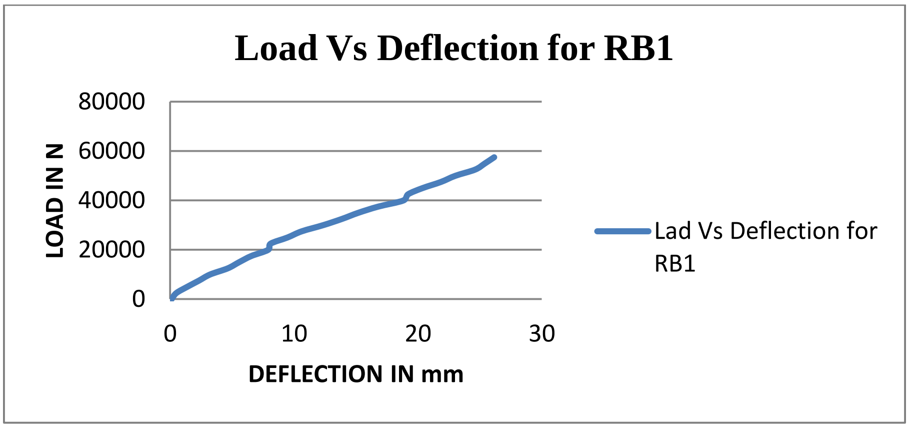

Fig. 3: Load vs. Deflection for RB1

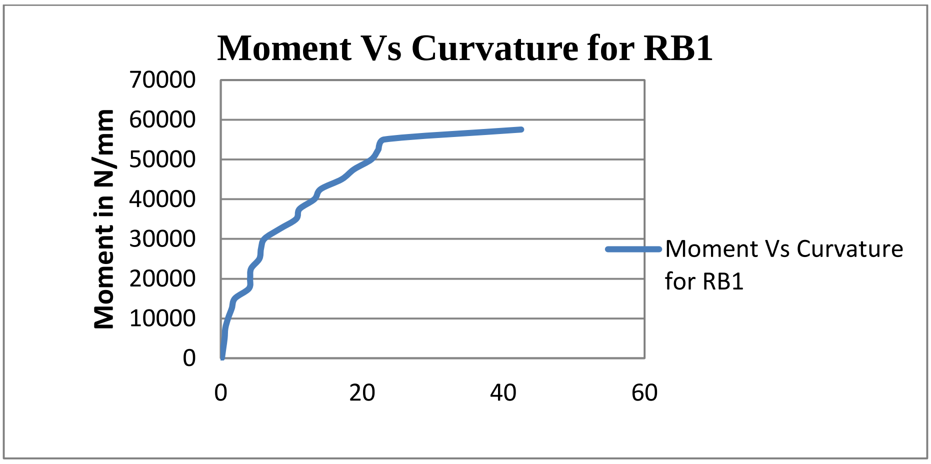

Fig. 4: Moment vs. Curvature for RB1

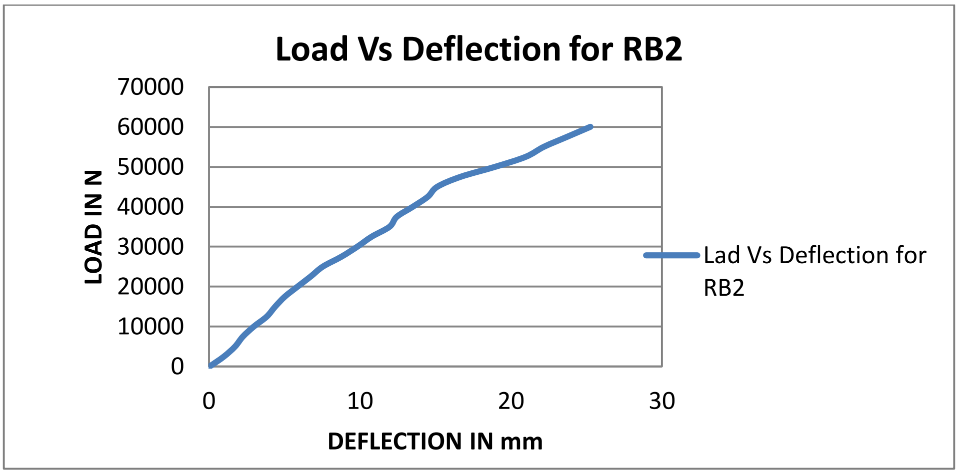

Fig. 5: Load vs. Deflection for RB2

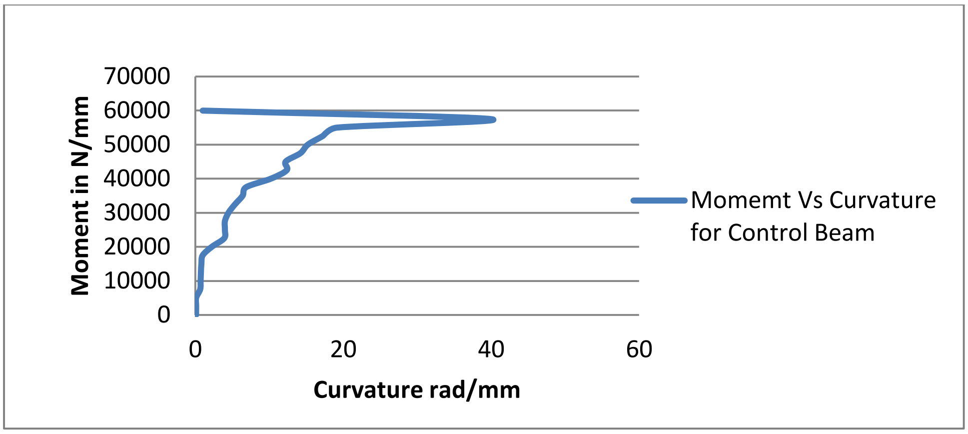

Fig. 6: Moment vs. Curvature for RB2

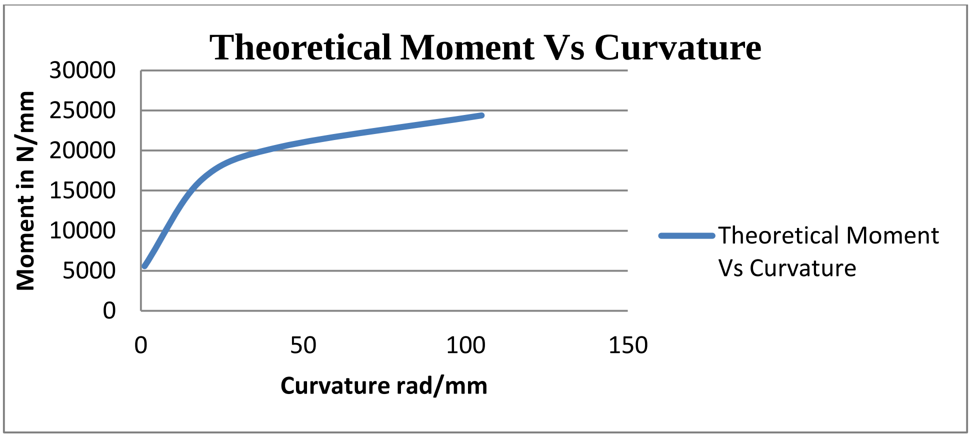

Fig. 7: Theoretical Moment vs. Curvature

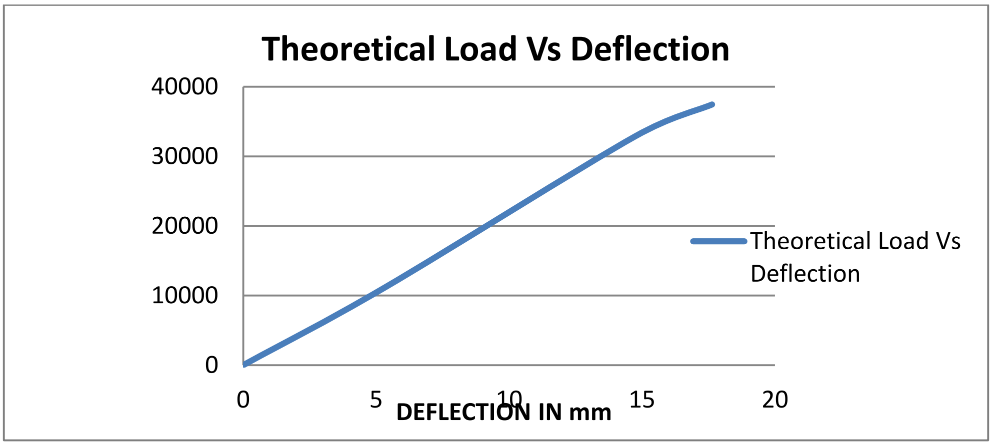

Fig. 8: Theoretical Load vs. Deflection

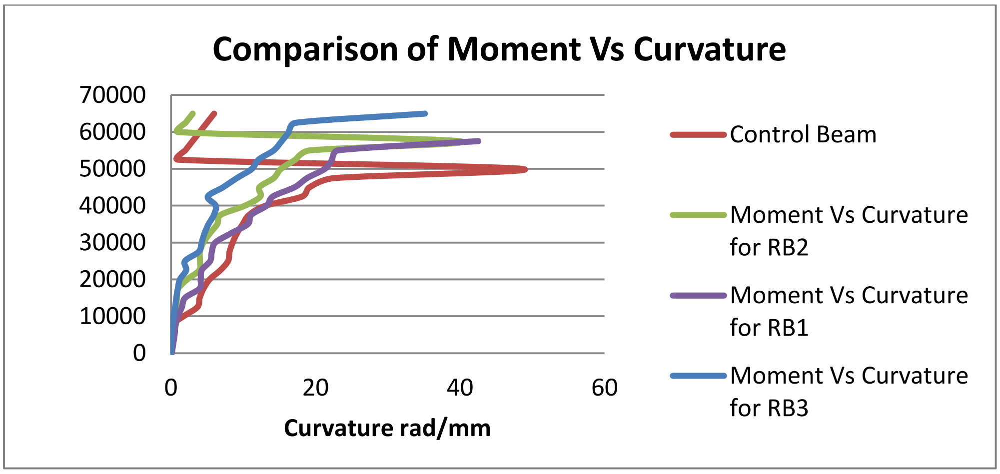

Fig. 9: Comparison of Moment vs. Curvature of control and Retrofitted beam

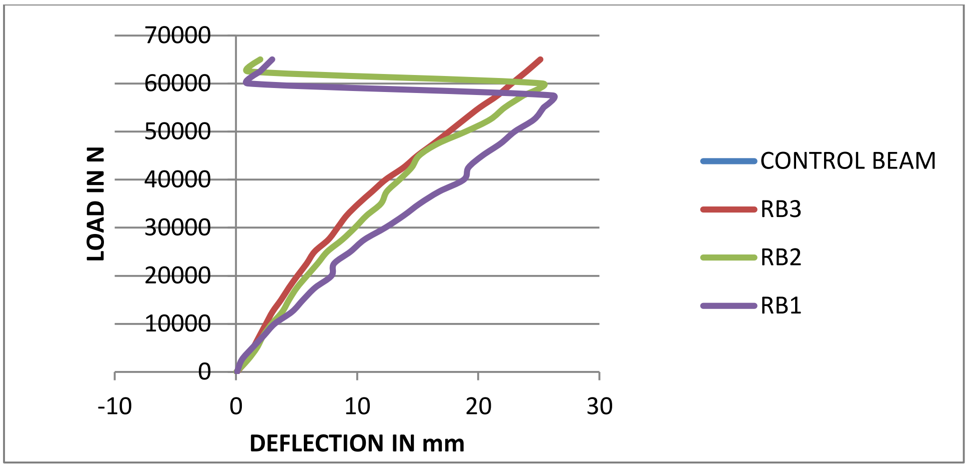

Fig. 10: Load vs. Deflection of control and Retrofitted beam

4. CONCLUSION

Based on the results and observation of the experimental investigations presented in this thesis regarding the effectiveness of the laminated Geopolymer Based Ferro cement in strengthening Geopolymer Reinforced concrete beams, the following conclusions are drawn.

(a) Partial replacement of Fly ash by GGBFS shows an increase in Strength and arrives at ambient curing avoiding heat curing techniques
(b) Increase in volume fraction in the Ferro cement increases the load carrying capacity of the beam significantly.
(c) Strengthening of uncracked Geopolymer RC beams exhibits an increase of 35 per cent in their ultimate load capacity when compared with that of the unstrengthened beam.
(d) All the strengthened beams showed a significant increase in ductility.
(e) All the strengthened beams exhibit smaller deflections and rebar strains at all load levels compared to the unstrengthen beam.
(f) The epoxy combination used for bonding the Geopolymer based Ferro cement laminates at the soffit of the beams ensure that the bond line does not break before failure and also participate fully n the structural resistance of the strengthened beams.

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