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Flexural Behaviour of Reinforced Geopolymer CONCRETE Beams with Glass Fibres

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Abstract: ***Geopolymer concrete is a concrete with an inorganic alumina-silicate binder mechanism correlated to the hydrated calcium silicate binder mechanism of concrete. It possesses the benefits of expeditious strength gain, excellent mechanical and durability properties, avoiding of water curing. In addition to these features they are eco-friendly and capable of being sustained alternative to the ordinary Portland cement but it exhibits the failure behaviour analogous to brittle solids. This inhibition may be overcome by fibre reinforcement to enhance their flexural strength. This paper demonstrating the experimental investigations conducted on Flexural behaviour of reinforced geopolymer concrete (GPC) and reinforced normally vibrated concrete (NVC) beams . A total of twelve beams were cast , in which six beams were of GPC beams and six beams were of NVC beams with varying percentages of glass fibres from 0,0.5,1,1.5,2 and 2.5 by weigh fraction of binder. This paper depicts the Load – deflection behaviour and Moment – Curvature behaviour of beam specimens.***

Keywords : ***Flexural behaviour, Glass fibres, Load – deflection behaviour, Moment – Curvature behaviour, GPC and NVC***

I. INTRODUCTION

Concrete is one of the most extensively used construction material it is mostly accompanied with Portland cement as the predominant constituent for producing concrete, OPC is traditionally used as the leading binder to produce concrete. However, Portland cements are highly internal-energy-demanding and cause the giving off of green house gas, CO_2 during their production. Cement production is also highly energy- demanding next to steel and aluminium. On the other hand, coal burning power generation plants generate massive quantities of fly ash. Most of the fly ash is not completely used, and a large part of it is disposed in landfills which affects aquifers and surface bodies of fresh water. In order to address environmental the effects there is a demand for development of substitute concretes. In such case, geopolymer concrete (GPCs) can be considered as potential substitute material for conventional concrete.

B. Vijaya Rangan et al had conducted the investigations on reinforced geopolymer concrete columns and beams to make evidence of geopolymer concrete usage in constructing of structural members and concluded that the behaviour of these members is similar to the reinforced conventional cement concrete members and shown good acid resistance, excellent resistance to sulphate attack, suffers very little drying shrinkage and undergoes low creep.[1].

Mohd Mustafa Al Bakri Abdullah et al had conducted a review on mechanism and chemical reaction involved in fly ash geopolymer cement and concluded that a wide range of research has already been carried out. The deserved name for these binders is alkali-activated binders for the general case even though the term geopolymer is. And most of the authors agreed that the mechanism comprises in three sequential manners such as dissolution, orientation and hardening [2].

Aanal Shah had conducted the experimental investigations to study the effect of replacement of fly ash by GGBS up to 50 % on compressive strength and durability of specimens. And concluded that the replacement of fly ash with 30% of GGBS gave the best results. [3].

James Aldred had observed that GPC has the low shrinkage and heat of hydration as well as the high tensile strength means that the material may have technical benefits over conventional concrete, especially in structural elements subject to external restraint [4].

Kim Hung Mo et al had conducted a review on the behaviour of structural elements such as beams, columns, slabs and panels which are of geopolymer concrete and concluded that there is no detrimental effect of using geopolymer concrete as structural member in terms of its load-carrying capacity, and standard codes of practice could be used to safely design the geopolymer concrete members as the behaviour and failure mode of structural elements is similar to that of traditional concrete members [5].

Faiz U.A. Shaikh had conducted the experimental investigations by inducing chloride to the reinforced ordinary Portland cement concrete and reinforced geopolymer concrete specimens. In case of a geopolymer concrete specimens of varying concentration of NaoH 14 molar and 16 molar with sodium silicate to sodium hydroxide ratio from 2.5,3.0,3.5.where these specimens are placed in

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sodium chloride salt solution for 4 days and then shifted these specimens to atmospheric condition for 3 days as a part dry cycle and then by conducting half cell potential method as per ASTM C-876 he concluded that geopolymer concrete specimens are excelling corrosion resistance than ordinary Portland cement concrete specimens and the performance of GPC specimens will be better if the concentration of NaoH and the content of Na_2SiO_3 is more [6].

P. Nath et al had conducted the experimental investigation on eight geopolymer concrete mixes with differing percentages of fly ash and GGBS ,varying solution to binder ratio from 0.35 to 0.45 and different sodium silicate to sodium hydroxide ratios and concluded that incorporation of slag in the fly ash based GPC decreases the setting time and increases the compressive strength, as the solution to binder ratio increases from 0.35 to 0.45 the strength of concrete is decreased and setting time increased [7].

R. B. Khadiranaikar et al had conducted the experimental investigations on the reinforced geopolymer concrete beam specimens with strength of concrete M 30, M 40 and M 50 ,12 molar NaOH solution and sodium silicate to sodium hydroxide ratio of 2.5 .And concluded that load deflection behaviour of OPC and GPC beams are similar, provisions made in IS 456 -2000 has good agreement in the design of geopolymer concrete beams [8].

Dattatreya J K et al had conducted the experimental investigations on 18 beams of which 3 beams are of OPC beams and 6 beams are of GPC beams with variation of strength from 17 to 63 N/mm^2 along with these differing the percentages of fly ash ,ggbs are considered. And concluded that load deflection features of GPC and OPC beams are same, observed that ultimate moment resistance capacity is more in case of GPC beams than that of OPC beams[9].

C. K. Madheswaran et al had conducted the experimental investigations on OPCC and GPC beams with varying of shear span to depth ratios of 1.5 and 2 ,with differing proportions of solutions in GPC mixes and concluded that load deflection behaviour is similar in case of GPC and OPC beams, there was a good compatibility between experimental analytically predicted values of deflection[10].

D. Annapurna et al had described the experimental work and analytical modelling using FEM analysis in ANSYS software to simulate the behaviour of GPC beams subjected to flexure and concluded that at various stages of cracking overestimates the deflection by 6% to 14% so, which enables to use the theoretical model to predict deflections [11].

Ruby Abraham et al had carried experimental work 12 GPC beams and 8 OPC beams with percentage of steel 0.55%, 0.83%, 1.02% and 1.3%.and concluded that GPC beams exhibited more number if narrow cracks with a closer spacing than that of OPC beams so, holds good regarding serviceability aspect and relatively better energy absorption capacity than OPC beams [12].

S. Kumaravel et al had experimental investigations on reinforced OPC and GPC beams and concluded that the ultimate load capacity of GPC beams is 16.27% higher than that of RCC beams [13].

Y. D. Deore et al had investigated the fracture behaviour of geopolymer concrete with respect to its compressive strength and concluded that with the adding of Glass fibres and Carbon Fibres in geopolymer concrete reduces the workability of concrete mixes, Glass fibres given higher strength in cracking propagation as compared with respect to the Carbon fibres [14].

Shrikant Harle et al had carried experimental work on conventional concrete and geopolymer concrete with glass fibres and concluded that compressive strength ,split tensile strength is more in case of conventional concrete where as flexural strength is observed as more in case of geopolymer concrete with glass fibres[15].

II. EXPERIMENTAL PROGRAMME

The experimental program consists of procurement of materials, testing of materials for physical properties, casting and testing of 12 reinforced concrete beams of which six beams are of Geopolymer concrete and six beams are of normally vibrated cement concrete with varying percentages of glass fibres from 0, 0.5, 1, 1.5,2 and 2.5 by weight fraction of binder respectively by permaintaining constant grade of concrete as M 25 and constant percentage of steel.

A. *Specimen details*

All the beams were designed in accordance with the IS 456-2000 codal provisions. The dimensions of beam specimens were 120 mm X 180 mm X 1350 mm. For all the beams, two 10 mm diameter bars were provided on the tension side, two 8 mm diameter bars were provided on the compression side and 2-legged vertical stirrups of 6 mm diameter bars @ 120 mm c/c were used as shear reinforcement.

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Fig 1- Casting of Specimen

B. Materials used

1) *Fly Ash :* Fly ash is a by-product from pulverized coal in electric power generating plants. For the present work fly ash used was confirming to class F, obtained from Rayalaseema thermal power plant (RTPP), kadapa, Andhra Pradesh
2) *Ground granulated blast slag (GGBS):* Ground Granulated Blast Furnace slag (GGBS) is the granular material shaped when liquid iron blast furnace slag (a by-result of iron and steel making) is quickly chilled (extinguished) by inundation in water. For the present investigation GGBS was obtained from JSW cements Ltd, Bilakalaguduru village, gadivemula mandal, Kurnool district, Andhra Pradesh.
3) *Alkaline liquid:* In present investigation, a combination of sodium hydroxide solution and sodium silicate solution were used as alkaline activators for Geopolymerization. Sodium hydroxide is available in the market as flakes or pellets form. For the present study, sodium hydroxide pellets were dissolved in water to make sodium hydroxide solution with a concentration of 10M it consists of 10x40 = 400 grams of sodium hydroxide solids (in pellet form) per litre volume of water .This solution was prepared one day before the casting of concrete to allow the exothermic process and to reduce heat .Sodium silicate is available in the market as liquid gel form and hence it can be used as 2.5 times that of NaoH.
4) *Aggregates:* The coarse aggregate used in this investigation was of two sizes namely 20mm and 10mm nominal size. The granite crushed angular shaped coarse aggregate was obtained from the local crushing plants. It has a specific gravity of 2.76 whereas, locally available sand was used as fine aggregate it has a specific gravity of 2.63 and conforming to grading zone – II
5) *Cement:* available ordinary Portland cement (OPC) of 53 grade, ZUARI brand has been used in this investigation for NVC mixes. The cement used was fresh and free from lumps. The cement thus procured has a specific gravity of 3.13, fineness of 2%, consistency of 33% and compressive strength of 54.7 MPa.
6) *Steel:* Steel of Fe 500 grade has been used in the present work..
7) *Glass fibres:* Glass fibres are characteristic for their high strength, good temperature resistance, and corrosion resistance. The glass fibre has a length of 12 mm, diameter of 14 microns, aspect ratio of 857, tensile strength of 1700MPa .For the present work glass fibres was obtained from Buddha building technology, Shree Shashwat, Hatkesh, MiraBhaynder Road, Mira Road (East), Thane, Maharashtra.

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Fig 2 – Glass fibres

C. Mix Proportions

1) *Normally Vibrated Concrete* : The mix proportions for M 25 grade of concrete were obtained in accordance with the IS 10262:2009 guidelines.

Table 1: Mix Proportions of NVC

Specimen ID	Cement (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Water (kg/m^3)	Glass fibres (kg/m^3) (by weight of cement)
NVCG0	383.16	1174.76	686.12	191.58	0
NVCG0.5	383.16	1174.76	686.12	191.58	1.92
NVCG1	383.16	1174.76	686.12	191.58	3.83
NVCG1.5	383.16	1174.76	686.12	191.58	5.75
NVCG2	383.16	1174.76	686.12	191.58	7.66
NVCG2.5	383.16	1174.76	686.12	191.58	9.58

2) *Geopolymer concrete:* For the purpose of mix proportioning the following were considered:

a) The density of geopolymer concrete as 2400 kg/m^3.

b) The mass of coarse aggregate and fine aggregate together are taken as 75% of entire concrete by mass.

c) The mass of fine aggregate is taken as 30% of the total aggregates.

3) Design procedure of M 25 grade GP

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a) Density of GPC =2400 kg/m
b) Mass of combined aggregate =0.75*2400 =1800 kg/m
c) Mass of alkaline liquid and binder =2400-1800=600 kg/m
d) The ratio of alkaline liquid to binder ratio =0.4
e) Mass of binder = 600/(1+0.45) =413.79 kg/m^3
f) Mass of Fly ash (70%) =0.70*413.79 = 289.66 kg/m^3
g) Mass of GGBS (30%) =0.30*413.79 = 124.14 kg/m
h) Mass of Alkaline liquid = 600-413.79 = 186.21 kg/m^3
i) Let the ratio of Sodium silicate solution to Sodium hydroxide solution =2.5
j) Mass of Sodium hydroxide solution = 186.21/(1+2.5) = 53.2 kg/m3 \
k) Mass of Sodium silicate solution = 186.21-53.2 = 133.01 kg/m^3

Table 2: Mix Proportions of GPC

Specimen ID	Fly ash (kg/m^3)	GGBS (kg/m3)	NaOH Solution (kg/m^3)	Na_2SiO_3 Solution (kg/m^3)	Coarse aggregate (kg/m^3)		Fine aggregate (kg/m^3)	Glass fibres (kg/m^3)
					10mm	20mm		
GPCG0	289.6	124.1	53.2	133.01	882	378	540	0
GPCG0.5	289.6	124.1	53.2	133.01	882	378	540	2.07
GPCG1	289.6	124.1	53.2	133.01	882	378	540	4.14
GPCG1.5	289.6	124.1	53.2	133.01	882	378	540	6.21
GPCG2	289.6	124.1	53.2	133.01	882	378	540	8.27
GPCG2.5	289.6	124.1	53.2	133.01	882	378	540	10.34

D. Testing of specimens

All the specimens were coated with lime water in order to view the cracks. The beam specimens were kept under loading frame with simply supported conditions at the both ends and two point static loading was applied. The effective span of the beam is 1200mm. A 1000KN servo-controlled hydraulic actuator was used to apply the loads. Then, the LVDT is placed at the mid-span of the beam to measure the deflection. All the test specimens are tested to increment loadings, after applying each increment of load, load, deflection are automatically recorded in the system.

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Fig 3 – Test setup for two point static loading

III. RESULTS AND DISCUSSIONS

Table 3 – Test results of reinforced NVC and GPC beams

Specimen ID	Ultimate load(KN)	Deflection(mm)	Moment of resistance(KNM)	Curvature (1/m*1000)	Energy absorption (J)
NVCG0	53.5	3.60	11.64	25.53	121.7
NVCG0.5	55.1	7.21	11.98	51.13	265.3
NVCG1	56.9	5.21	12.38	36.95	219.7
NVCG1.5	57.2	3.91	12.44	27.73	124.4
NVCG2	62.4	8.76	13.57	62.12	367.9
NVCG2.5	57	6.83	12.40	48.44	285
GPCG0	55.6	8.57	12.09	60.78	375.9
GPCG0.5	60.5	7.43	13.16	52.69	343.8
GPCG1	62	7.51	13.49	53.26	331.1
GPCG1.5	63.6	8.02	13.83	56.80	322.5
GPCG2	65.4	6.94	14.16	49.22	319.7
GPCG2.5	67.1	5.69	14.59	40.35	269.7

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A. Load deflection behaviour

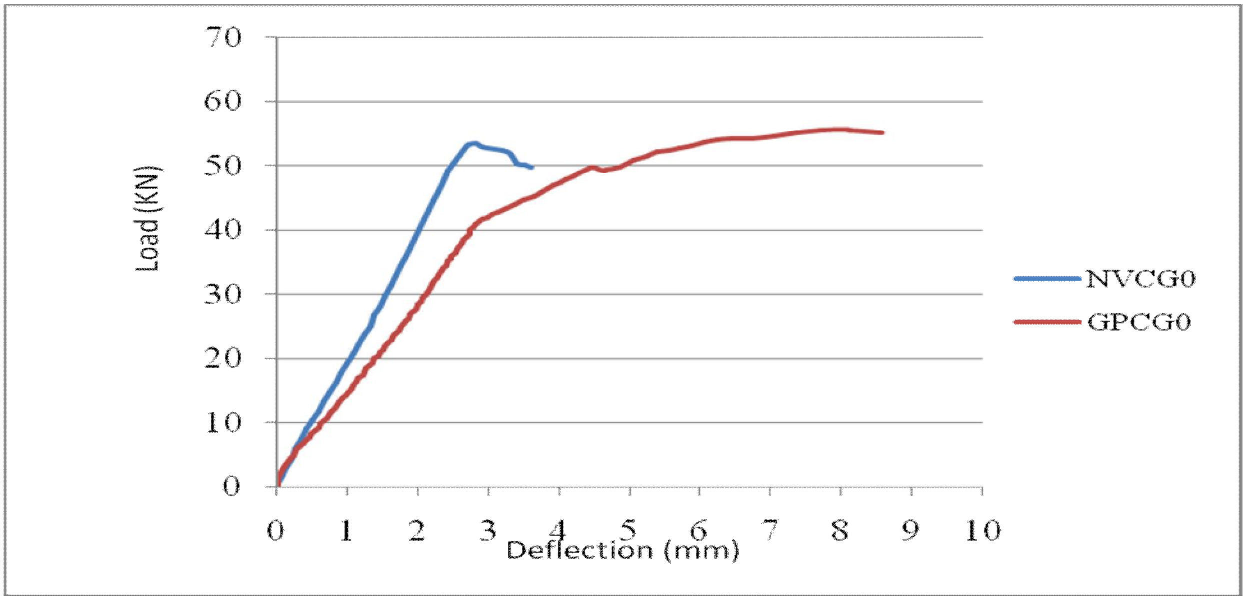

Fig 4 – A Relation between load - deflection behaviour of reinforced NVC and GPC beams with 0% of glass fibres
From the above behaviour it was observed that,

GPCGO beam has a ability to carry 2.1 KN more than that of NVCG0 beam
VCG0 beam has a energy absorption of 121.7 J and GPCG0 beam has a energy absorption of 375.9 J

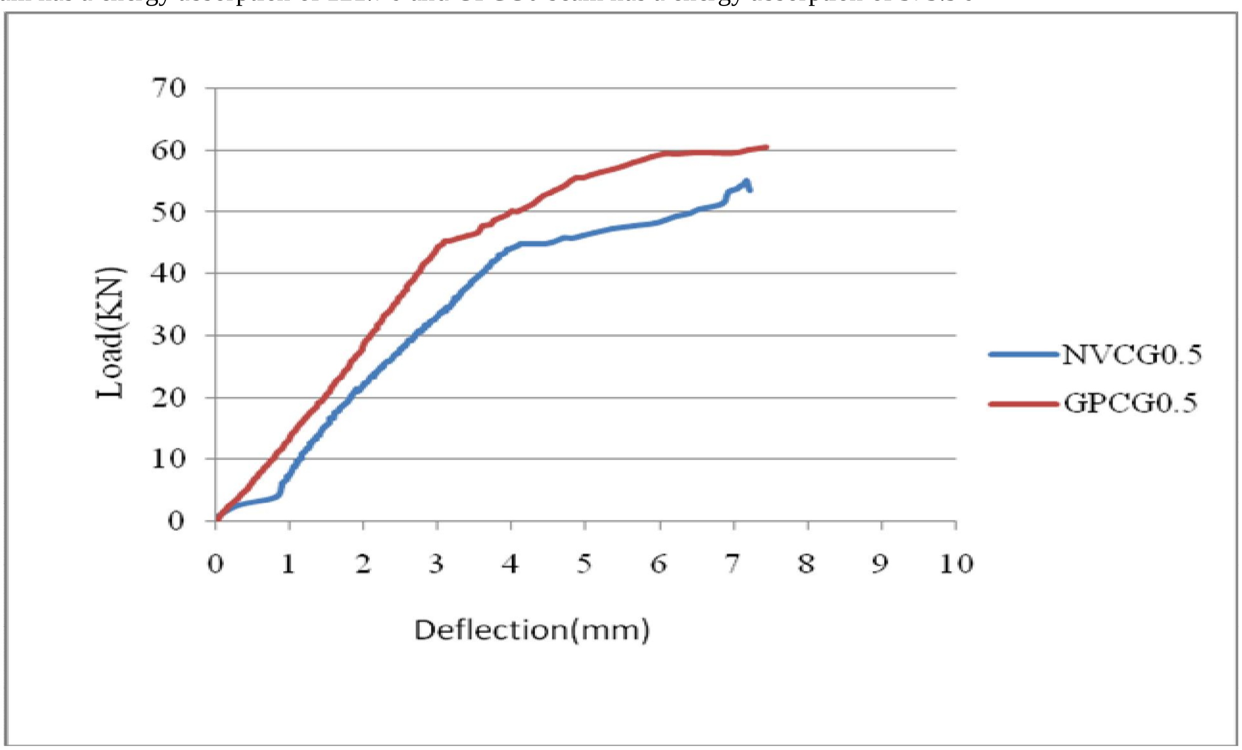

Fig 5 - A Relation between load -deflection behaviour of reinforced NVC and GPC beams with 0.5 % of glass fibres
From the above behaviour it was observed that,

GPCG0.5 beam has a ability to carry 5.4 KN more than that of NVCG0.5 beam
NVCG0.5 beam has a energy absorption of 265.3 J and GPCG0.5 beam has a energy absorption of 343.8 J

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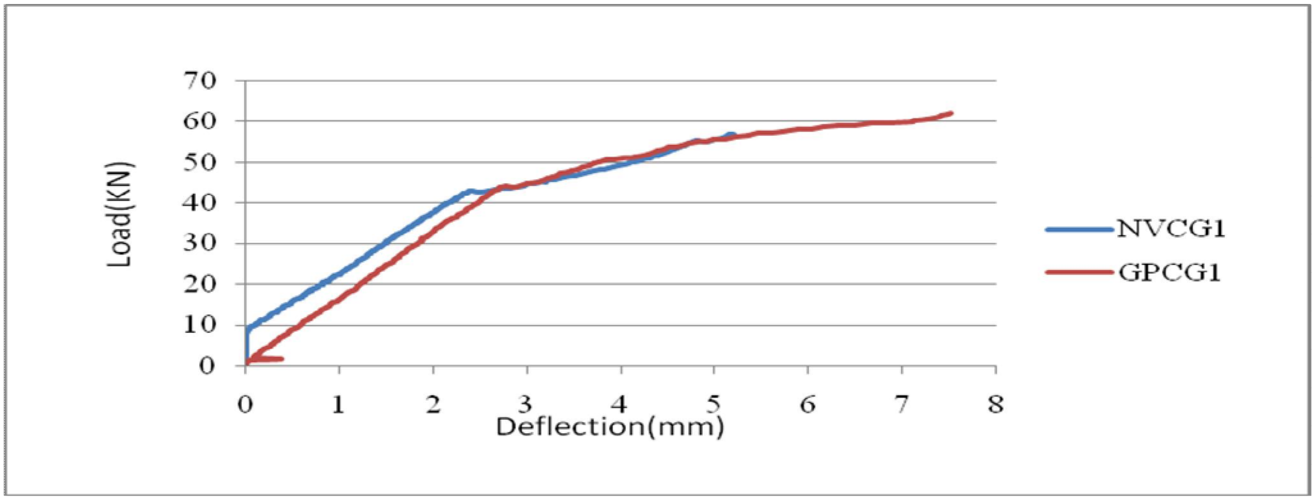

Fig 6- A Relation between load -deflection behaviour of reinforced NVC and GPC beams with 1 % of glass fibres

From the above behaviour it was observed that,

GPCG1 beam has a ability to carry 5.1 KN more than that of NVCG1 beam
NVCG1 beam has a energy absorption of 219.7 J and GPCG1 beam has a energy absorption of 331.1 J

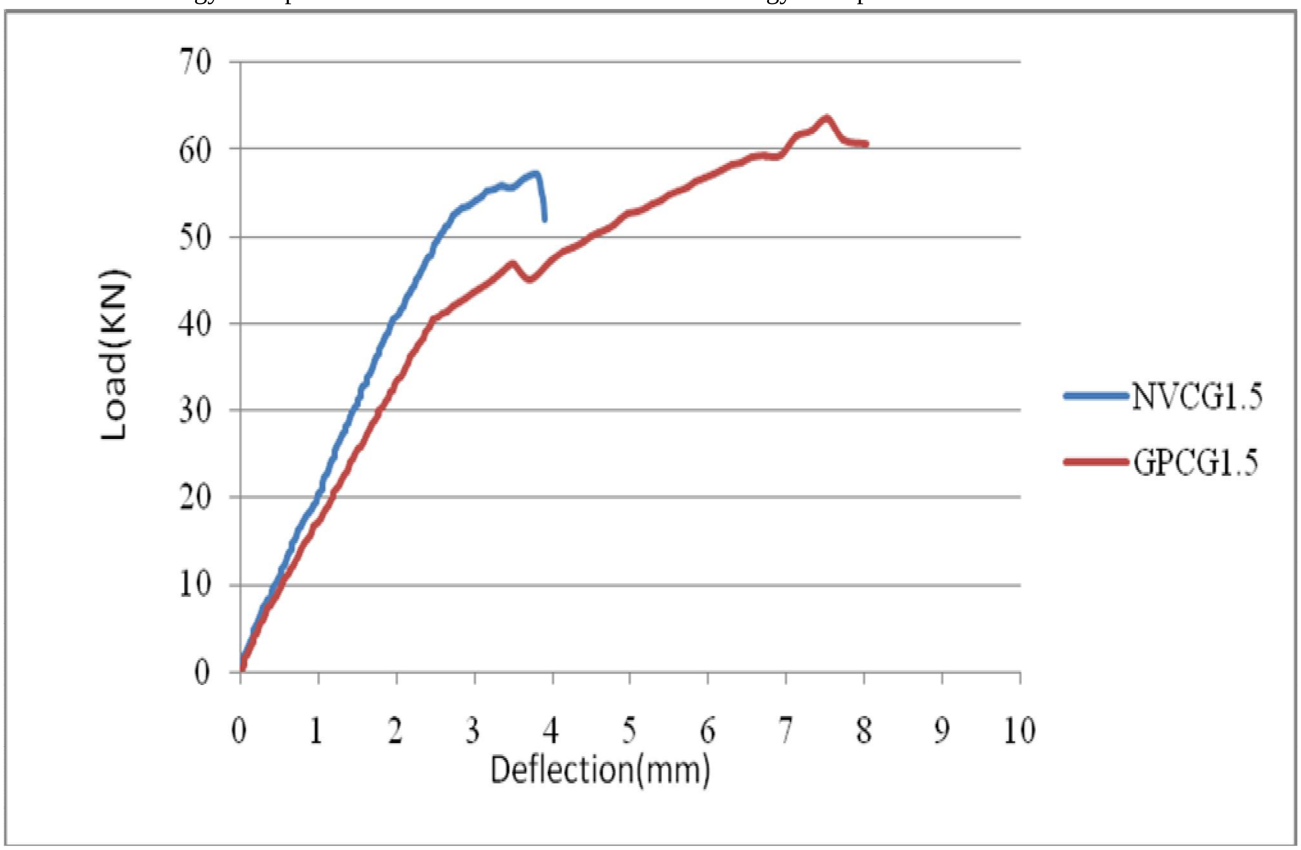

Fig 7 – A Relation between load- deflection behaviour of reinforced NVC and GPC beams with 1.5 % of glass fibres

From the above behaviour it was observed that,

GPCG1.5 beam has a ability to carry 6.4 KN more than that of NVCG1.5 beam
NVCG1.5 beam has a energy absorption of 124.4 J and GPCG1.5 beam has a energy absorption of 322.5 J

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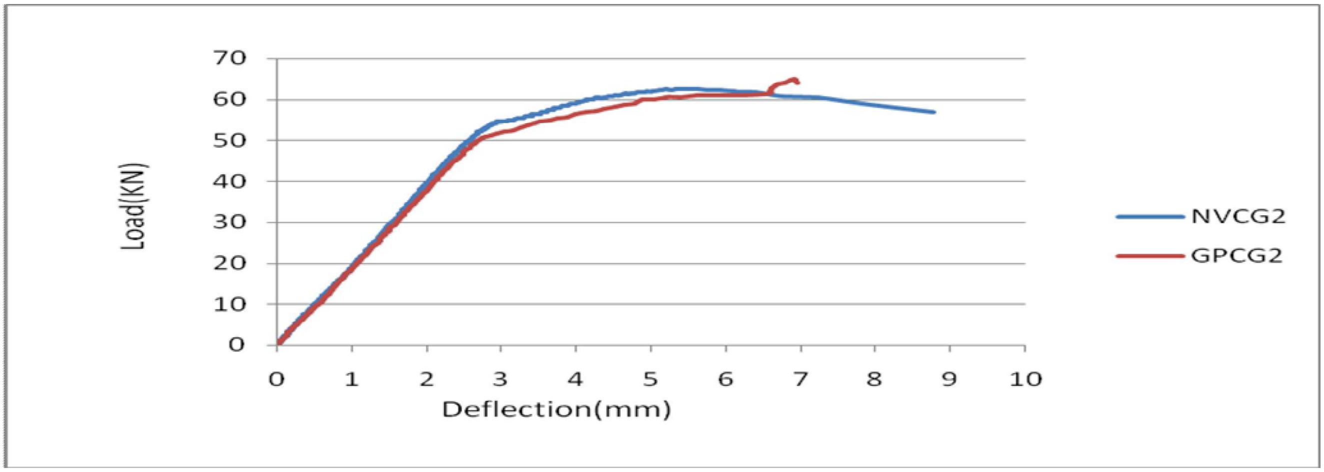

Fig 8 A Relation between load -deflection behaviour of reinforced NVC and GPC beams with 2 % of glass fibres
From the above behaviour it was observed that,

GPCG2 beam has a ability to carry 3 KN more than that of NVCG2 beam
NVCG2 beam has a energy absorption of 367.9 J and GPCG2 beam has a energy absorption of 319.7

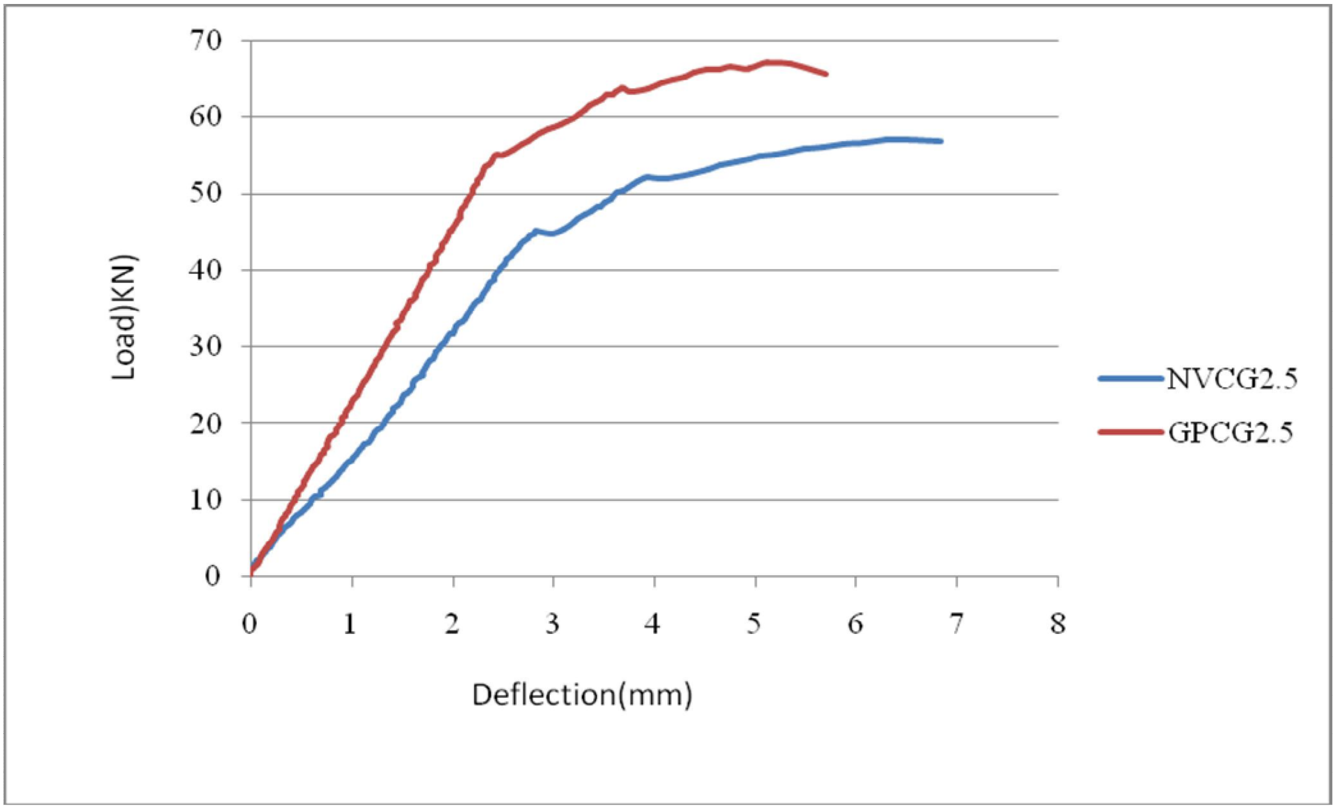

Fig 9 – A Relation between load- deflection behaviour of reinforced NVC and GPC beams with 2.5 % of glass fibres
From the above behaviour it was observed that,

GPCG2.5 beam has a ability to carry 10.1 KN more than that of NVCG2.5 beam
NVCG2.5 beam has a energy absorption of 285 J and GPCG2.5 beam has a energy absorption of 269.7

B. Moment – Curvature behaviour

Moment- curvature relations are drawn by using the data of load –deflection curves.

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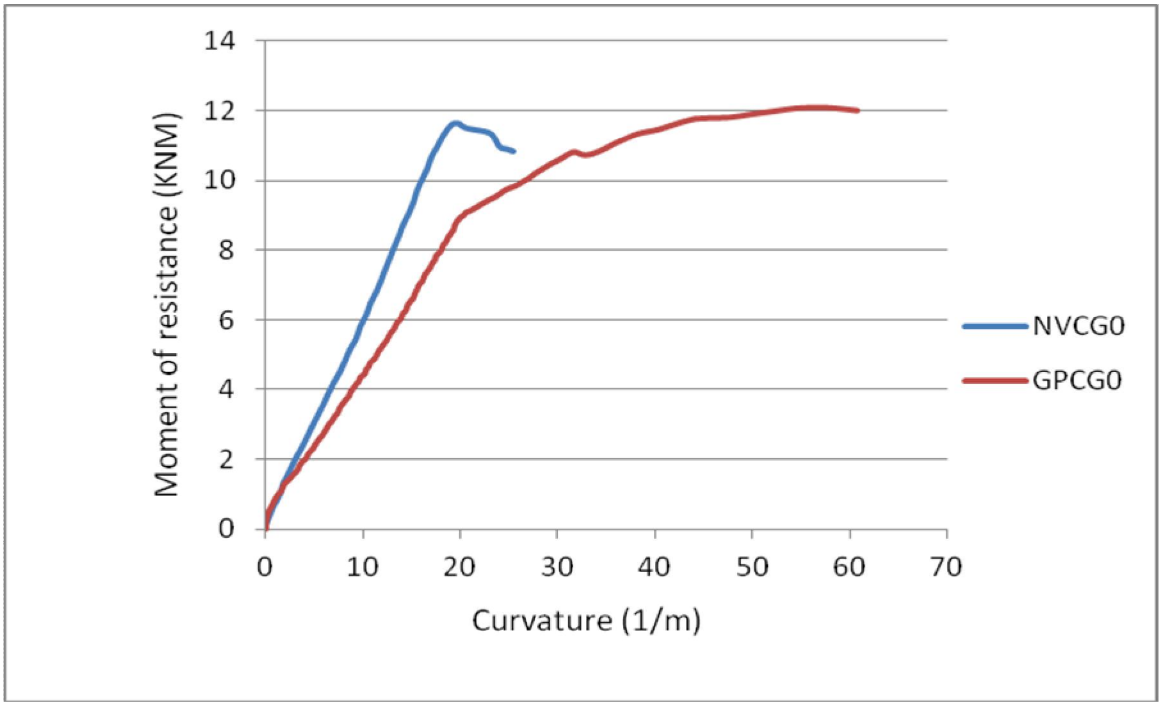

Fig 10– Moment -Curvature behaviour of reinforced NVC and GPC beams with 0 % of glass fibres (Curvature: 1000/m)

From the above behaviour it was observed that,
GPCG0 beam has a 0.45 KNM more moment resistance capacity than that of NVCGO beam
NVCG0 beam has a curvature of 25.53 1/m whereas GPCGO has 60.78 1/m

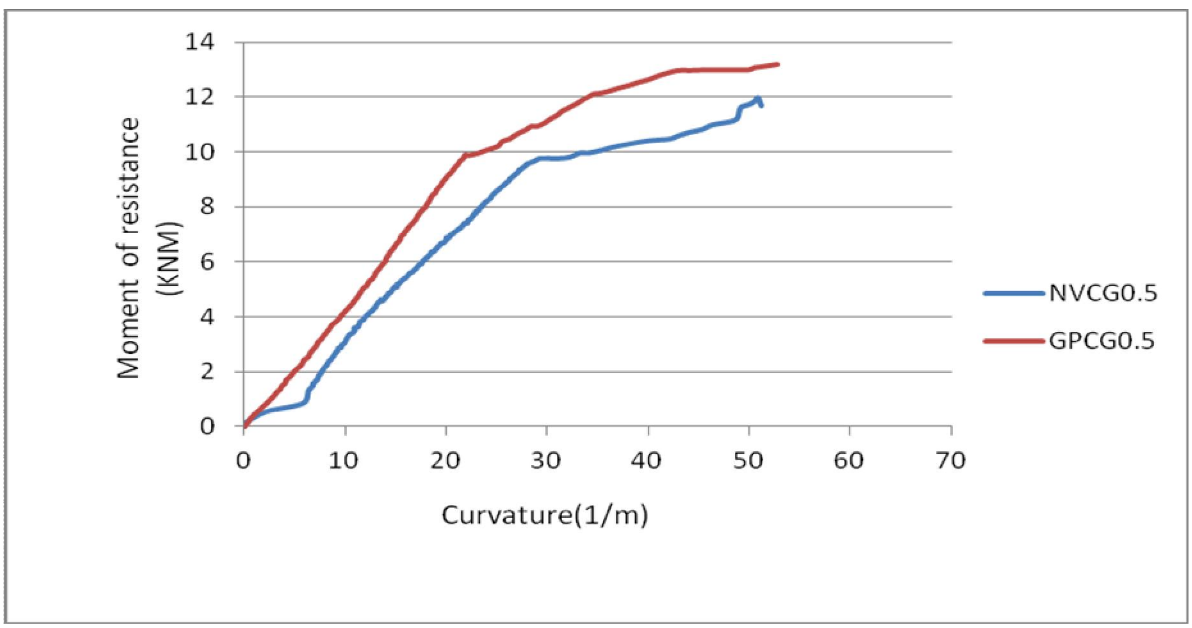

Fig 11 – Moment -Curvature behaviour of reinforced NVC and GPC beams with 0.5 % of glass fibres (Curvature: 1000/m)

From the above behaviour it was observed that,
GPCG0.5 beam has a 1.18 KNM more moment resistance capacity than that of NVCGO.5 beam
NVCG1 beam has a curvature of 51.13 1/m whereas GPCG1 has 52.691/m

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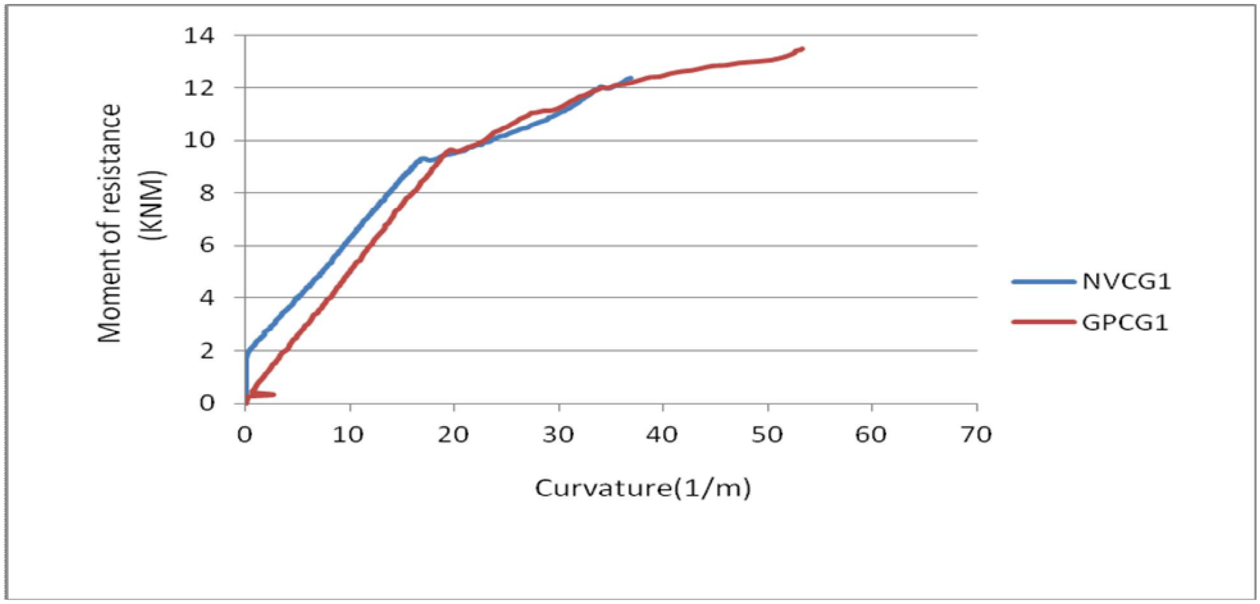

Fig 12 – Moment -Curvature behaviour of reinforced NVC and GPC beams with 1 % of glass fibres (Curvature: 1000/m)

From the above behaviour it was observed that,
GPCG1 beam has a 1.11 KNM more moment resistance capacity than that of NVCG1 beam
NVCG1 beam has a curvature of 36.95 1/m whereas GPCG1 has 53.26 1/m

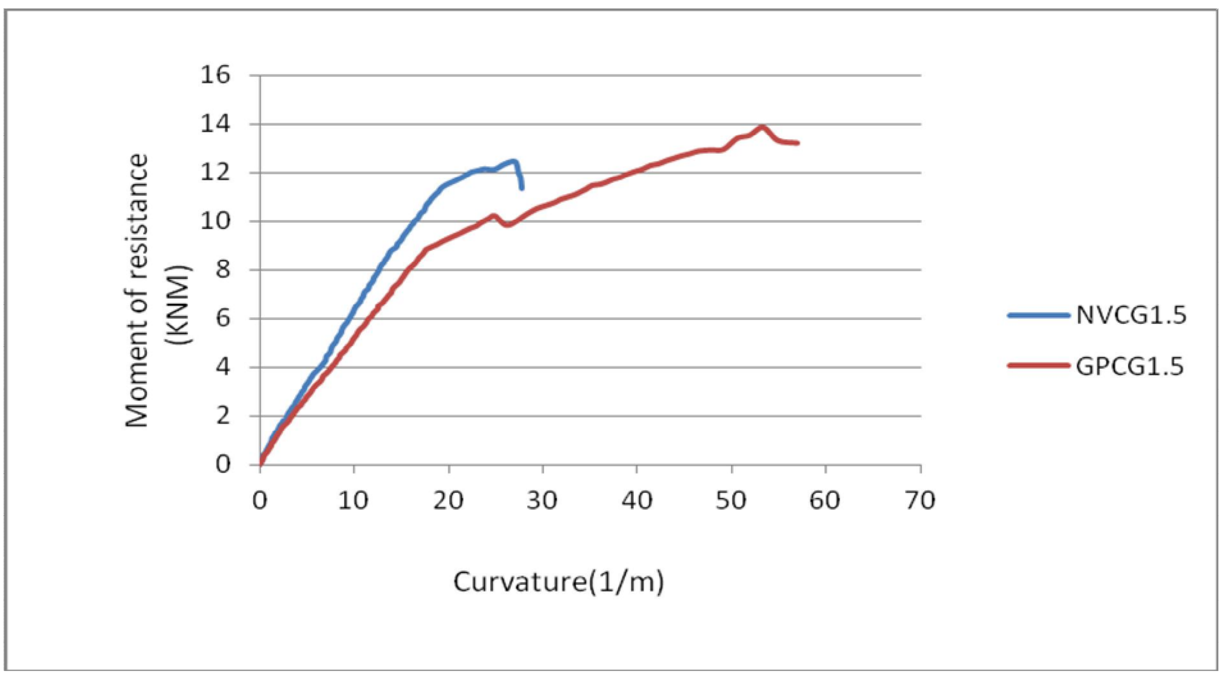

Fig 13 – Moment -Curvature behaviour of reinforced NVC and GPC beams with 1.5 % of glass fibres (Curvature: 1000/m)

From the above behaviour it was observed that,
GPCG1.5 beam has a 1.39 KNM more moment resistance capacity than that of NVCG1.5 beam
NVCG1.5 beam has a curvature of 27.73 1/m whereas GPCG1.5 has 56.80 1/m

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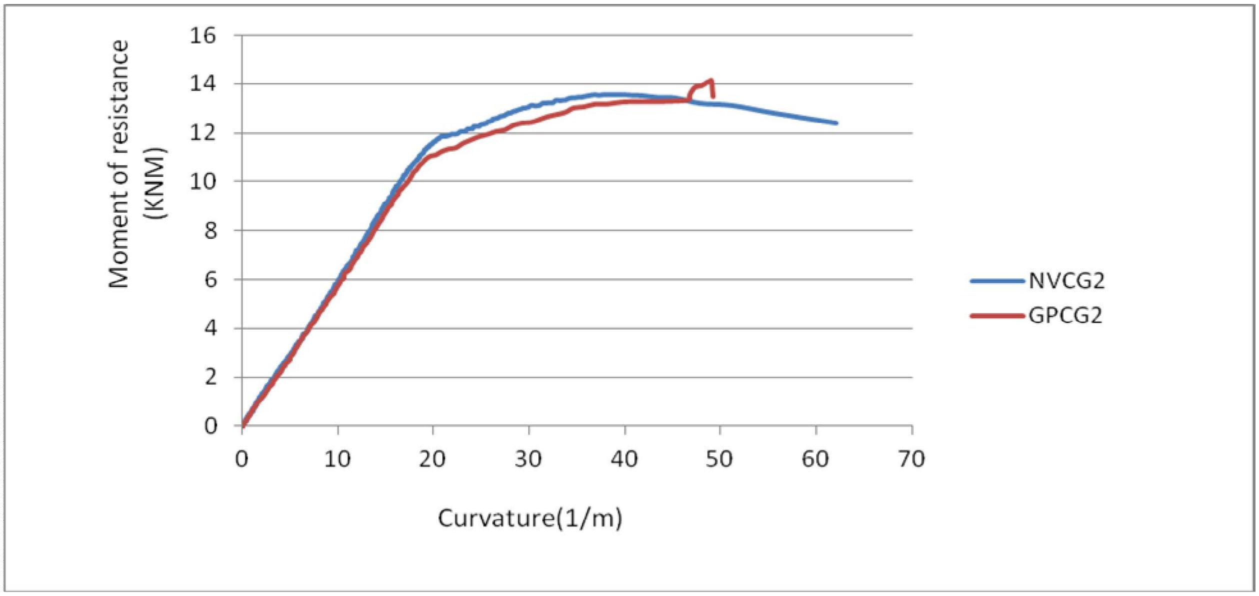

Fig 14 – Moment -Curvature behaviour of reinforced NVC and GPC beams with 2 % of glass fibres

(Curvature: 1000/m)

From the above behaviour it was observed that,

GPCG2 beam has a 0.59 KNM more moment resistance capacity than that of NVCG2 beam

NVCG2 beam has a curvature of 62.12 1/m whereas GPCG2 has 49.22 1/m

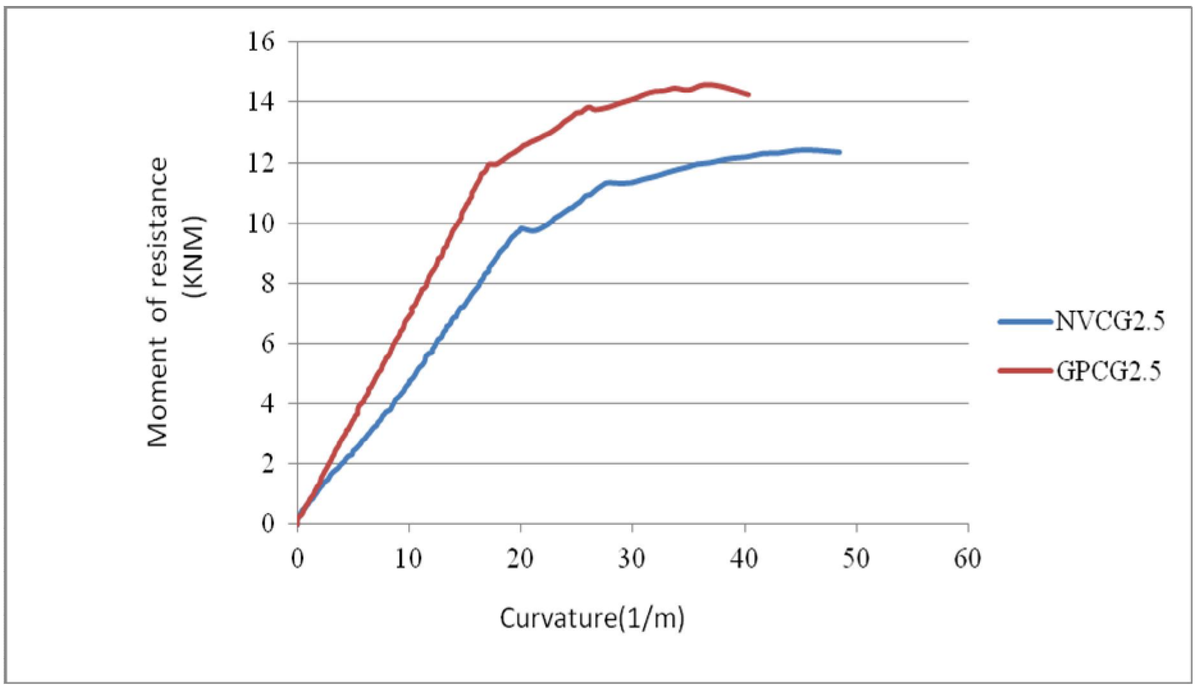

Fig 15 – Moment -Curvature behaviour of reinforced NVC and GPC beams with 2.5 % of glass fibres

(Curvature: 1000/m)

From the above behaviour it was observed that,

GPCG2.5 beam has a 2.19 KNM more moment resistance capacity than that of NVCG2.5 beam

NVCG2.5 beam has a curvature of 48.44 1/m whereas GPCG2.5 has 40.35 1/m

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C. Crack Pattern of beam Specimens

1) The crack pattern observed in the NVC and GPC beams were almost similar.

2) The failure mode of both NVC and GPC beams is flexure.

Fig 16 – Crack pattern of NVC beams with 0.5 %, 1% and 1.5% of glass fibres

Fig 17– Crack pattern of NVC beams with 2% and 2.5 % of glass fibres

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Fig 18 – Crack pattern of GPC beams with 0 %, 0.5% and1% of glass fibres

Fig 19 – Crack pattern of GPC beams with 1.5 % ,2% and 2.5% of glass fibres

IV. CONCLUSIONS

Based on the experimental investigations carried on the reinforced normally vibrated concrete beams and reinforced geopolymer concrete beams with glass fibres the following conclusions are drawn.

A. The Load carrying capacity of GPC beams are observed to be better than that of NVC beams

B. The Moment resistance capacity of GPC beams are found to be greater than that of NVC beams

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C. Energy absorption capacity of GPC beams are noticed to be abundant than that of NVC beams as a result of the more load sustaining capacity and the larger deflections undergone by the GPC beams, which shows better ductility

D. The mode of failure observed in all the beams is flexure by yielding of reinforcement in the tension zone

E. The crack pattern observed in the GPC and NVC beams are resembling the same.

F. The Geopolymer concrete were found to be excellent as structural members and could .be allocated as a competent material for substitution of ordinary Portland cement.

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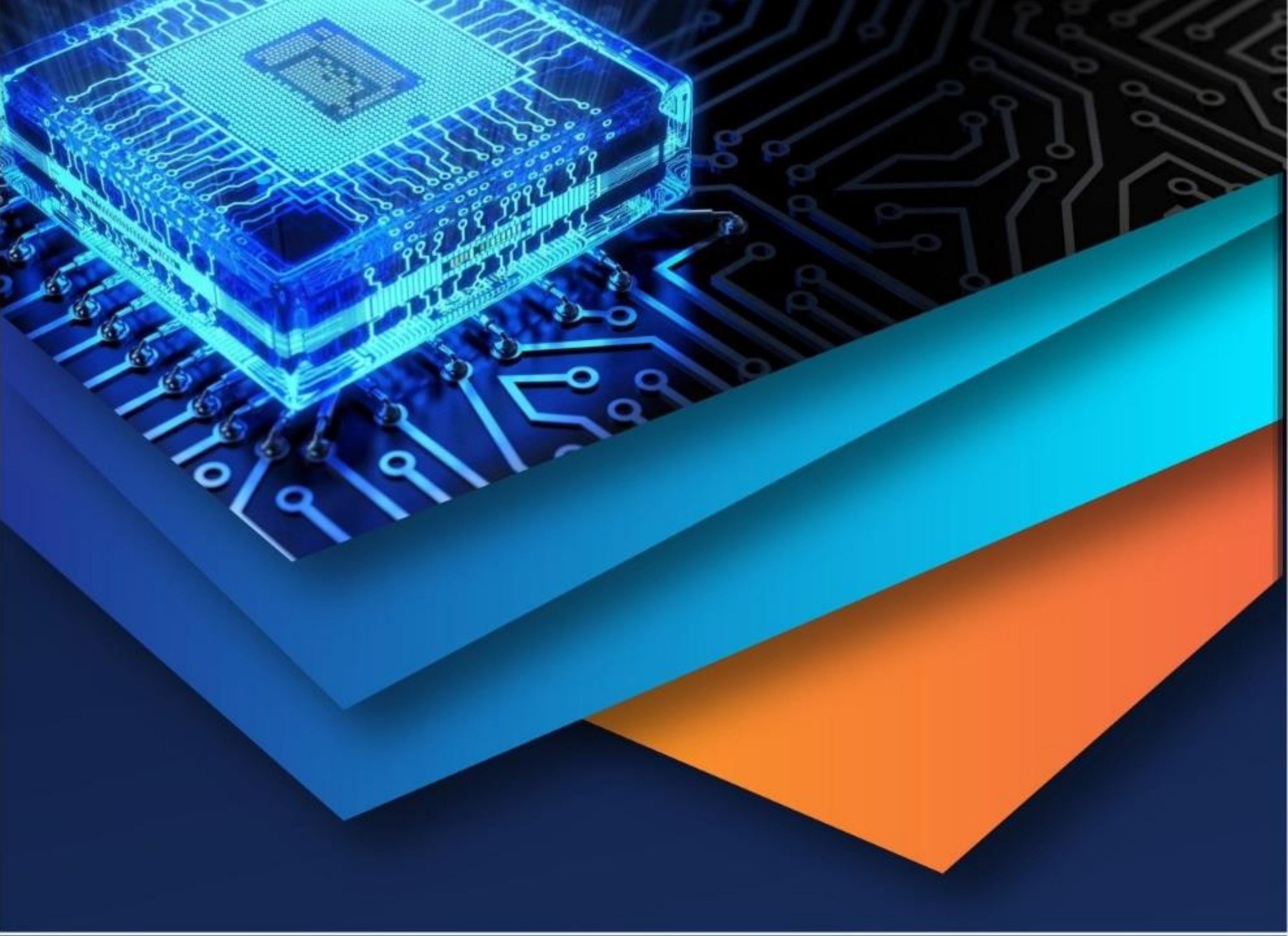

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