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Flexural Behaviour of Geopolymer Concrete Beams using Waste Glass as Coarse Aggregate

B. Parthiban, S. Thirugnanasambandam

Abstract— *Cement is an associate environmentally venture some material as a results of cement production is very energy and fuel intensive, making it the third ranking producer of inexperienced house gas emissions. Cement production is increasing by more or less 5 percent a year, making it one of the formost environmentally assist in making concrete a extremely eco-friendly material. The mixture of cement with totally different mixture materials is that the first reason that concrete cannot bear associate eco-friendly label. The heating and combination technique wants giant amounts of energy and emits atrocious amounts of inexperienced house gas in the atmosphere. Trying to combat the quality of green house gases discharged as a by-product of the concrete trade, in experienced innovators have fictional cement substitutes and totally different methods to form loads of earth–friendly product. Throughout this analysis, geopolymer concrete is utilized as an Eco-friendly concrete and recycled waste is used as another coarse mixture. **In geopolymer concrete preparation, NaOH of 8 molarity concentration is used. Beam size of 125 mm × 200 mm × 1100 mm are cast to study the flexural behaviour. The beams are designed as under reinforced sections. Totally six beams are cast for M 20, M 40 and M 60 grade with crushed stone as coarse aggregate and with recycled glass as coarse aggregate. Out of six beams, three beams are made with stone aggregate and another three beams are made with glass aggregate. Beams are tested under two point loading for flexure. The ultimate load carrying capability of all beams is obtained. The crack and deflections of the beams are studied. The experimental results are compared with finite element modeling using ANSYS software.***

Index Terms—Geopolymer Concrete (GPC), Fly Ash, Ground Granulated Blast Furnace Slag (GGBS), Recycled Waste Glass Coarse Aggregate (RWGCA), Flexural Behaviour, Ductility, ANSYS.

I. INTRODUCTION

Replacing energy consuming Portland cement with useful materials and minerals offers 2 distinct advantages to the surroundings and it considerable reduces the number of greenhouse gas free into the atmosphere and it minimizes large lowland disposal. During this analysis geopolymer concrete is employed rather than standard Portland cement [1]. Ash and Blast furnace slag is chosen because the basic material to be activated by the geopolymerization method to be the concrete binder. The supply material for geopolymers supported alumina-silicate ought to be wealth in silica(Si) and alumina(Al). During this analysis, hydrated oxide pellets (NaOH) and soluble glass (Na_2SiO_3) are used for creating base forming matter. However, concreting one ton of greenhouse gas is free to the surroundings throughout production of 1 ton of cement that contributes to the inexperienced house result and cement concrete deteriorates once exposed to the severe environment friendly.

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* Correspondence Author
B. Parthiban, Research Scholar, Civil and Structural Engineering, Annamalai University, Annamalai Nagar, India
S. Thirugnanasambandam, Professor, Civil and Structural Engineering, Annamalai University, Annamalai Nagar, India

The higher than factors are overcome by geopolymer concrete and it is energy economical and surroundings friendly. River sand and coarse mixture are obtained from natural resources. Crushed stone has currently become the foremost wide consumed natural resources on the earth once H_2O. Yet, once crushed stone mixture has been reworked into concrete, the parts are sure forever and not offered as resources [2]. Thus suggests that recycled waste glass is different material for coarse mixture in concrete and it become economically viable. During this analysis recycled waste glass is employed in white colour [3]. The glass is then crushed and liquefied, that is then screened into needed size for immediate use. The form of the recycled glass is made as angular shape and size is maintained eight metric linear unit up to sixteen mm for concrete production. Waste glass is not a bio-degradable material and this time it is drop on a land that becomes a extremely unsustainable choice. To seek out an improved answer to cut back the environmental problems caused by disposable of waste glass, it is used as coarse mixture in concrete [4]. In geopolymer concrete, cement is 100% replaced by ash and furnace slag. Recycled waste glass is potential to function as precursor material in geopolymer production where the superabundant quantity of amorphous oxide is in waste glass.

II. EXPERIMENTAL PROGRAM

A. Fly Ash

Low-calcium category F sort ash is employed for this study work and it's obtained from Tuticorin thermal power house, Tamil Nadu, India. Category F sort ash is prosperous quantity in silicon oxide and alumina (Al) and fewer than 100% of lime (C_aO). Category F sort ash is okay grained material of spherical and thus the particle size distribution tests discovered that eighty % of the ash are less than fifty microns. The specific gravity of class F ash is 2.40. The lighter in colour indicates lower carbon content presents within the ash.

B. Ground Granulated Blast Furnace Slag (GGBS)

GGBS are obtained from Toshaly cement non-public restricted, province , India, conformist to IS: 12089 (1987). GGBS is that the industrial by-product obtained from industry. During this geopolymer concrete production, the cement is substitute by ash and GGBS of equal amount. The specific gravity of GGBS is 2.90 and also colour is white. The advantage of GGBS using in geopolymer concrete production is to resist chemical attack and maintain glorious thermal properties.

C. Sodium Hydroxide Pellets (NaOH)

Sodium hydroxide is accessible in solid state by means of pellets. In line with the purity the value of the hydroxide is varied. Attention is incredibly a lot of required to arrange the hydroxide in water as a results of respectable heat is liberated by the reaction. Since our geopolymer concrete is homogeneous material and its main technique to activate the water glass.

This analysis ninety four to ninety six purity that is the lower value is to be counsealed for geopolymer concrete production.

D. Sodium Silicate Solution (Na_2SiO_3)

Water glass could be a generic name for chemical compounds like metallic element meta salt, metallic element orthosilicate and sodium pyrosilicate. These are usually colourless clear solids or white powders and soluble in wate in varied amounts. Water glass (Na_2SiO_3) is to boot spoken as liquid glass. Normally it's employed in the textile trade and soap producing industry. In business, the various grade of water glass are characterized by their weight magnitude relation. Water glass to hydroxide for this analysis is taken 2.5.

E. Alkaline Solution

Sodium bydroxide pellets (NaOH) of eight Molar (8M) is employed for geopolymer concrete production. If the mass of NaOH is forty, therefore on organize eight molar solutions, 320 grams of hydroxide pellets are dissolved in one metric capacity unit water. Caustic soda pellets (NaOH) with ninety eight purity and water glass (Na_2SiO_3) is employed for concrete production. The water glass with hydroxide quantitative relation by mass is taken as 2.5. The alkaline solution is ready before twenty four hours of concrete producing.

F. Fine Aggregate

River sand is employed as fine mixture. The specific gravity
of sand is 2.56 and also the fineness modulus is 2.13. It conforms to Zone III in the line with 383-1970.

G. Recycled Waste Glass Coarse Aggregate (RWGCA)

The recycled waste glass employed in this concrete production is in white colour and also the form of the glass combination is angular. The scale of the combination is eight millimeter to sixteen mm. Before utilization the waste glass is washed to get rid of the impurities. Once the glass is crushed, liquefied and screened into needed sizes to be used. The specific gravity of recycled waste glass coarse combination is 2.5. The sample of recycled waste glass with crushed stone aggregate is shown in Figure I. The physical properties and chemical constituents of recycled waste glass coarse combination are shown in Table 1and 2. The scanning microscope (SEM) pictures of recycled waste glass coarse combination are shown in Figure II and Figure III.

Figure I Recycled Glass Coarse Aggregate sample with Crushed Stone Aggregate

Table 1 Physical Properties of Recycled Waste Glass Fine Aggregate (RWGFA)

Physical Property	Test Result
Specific gravity	2.56
Size of the aggregate	3 mm and down 3 mm
Shape of the aggregate	angular

Table 2 Chemical Constituents of RWGFA

Constituent	SiO_2	$CaCO_3$	Na	MgO	Ca
In Percentage	78.8	5.44	8.39	1.84	5.53

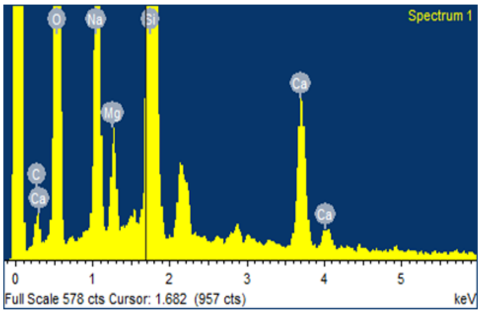

Figure II EDAX Images of RWGCA

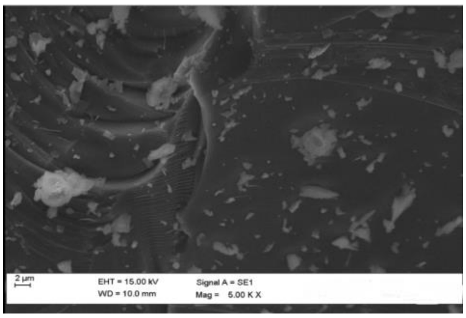

Figure III SEM Images of RWGCA

G. Chemical Admixtures

To maintain the slump and workability of the concrete, admixtures are used. Super softener Conplast SP 430 is employed during this concrete combine. The indefinite quantity of super softener is 0.7% to 1.2% mass of the binder employed for this concrete production.

G. Water

Locally available water that is free from organic impurities is employed for this concrete producing work.

H. Mixing, Casting and Curing

Geopolymer concrete is formed with same combine proportion employed in M twenty, M forty and M sixty grade standard cement concrete is intended for combine proportion by mix design IS code 10262-2009. The combination proportion M twenty, M forty and M sixty grade cement concrete is 1:2.75:3.36. 1:1.67:2.50 and 1:1.33:2.33 severally.

Water cement ratio is employed for M twenty, M forty and M sixty is employed 0.50, 0.39 and 0.35 severally. In geopolymer concrete preparation, NaOH of 8 M is employed in concrete combine.

The geopolymer concrete constitutents are ash, GGBS, sand, RWGCA, water and super plasticizer. Water glass with NaOH pellets ratio by mass is 2.5 has been used for concrete producing. Figure four shows the materials used for preparation of concrete. Crushed stone is employed for conventional geopolymer concrete and also the same mix is used for 100% replaced with RWGCA. The constituent of geopolymer combine is given Tale three.

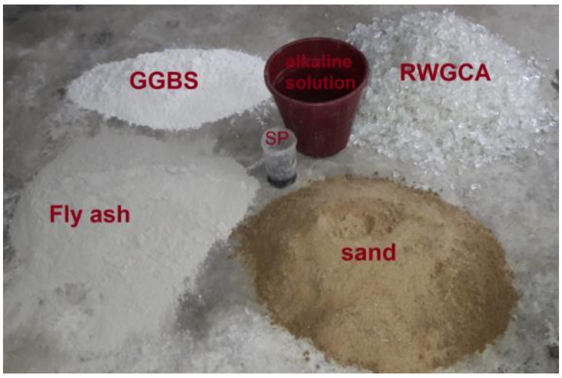

Figure IV RWGCA Geopolymer Concrete

Table 3 Constituents of Geopolymer Mix

Constituents	Quantity in m^3		
	M 20	M 40	M 60
Fly ash 50% + GGBS 50%	337.55	464.22	515.02
(Na_2SiO_3 + NaOH) / Fly Ash & GGBS	0.45	0.45	0.45
Na_2SiO_3 / NaOH	2.5	2.5	2.5
NaOH Pellets	13.89	19.1	21.19
Na_2SiO_3	108.5	149.21	165.54
Water	29.51	40.51	45.01
Fine Aggregate Sand	928.26	775.24	684.98
Coarse Aggregate (Gravel/RWGCA)	1134.17	1160.55	1200
SP	2.24	4.39	5.88

After seven and twenty eight days the cubes are tested. All above tests are carried out for conventional geopolymer concrete and glass aggregate concrete as per IS 516-1959.

III. TESTING PROCEDURE

A. Compressive Strength

For compression check, one thousand kN capability of compressive testing machine is employed to use the load. The load is step by step will increase till the cube is failure. The utmost load taken by every specimen throughout check is recorded. The average is that the compressive strength of the sample. Results of M twenty, M forty and M sixty grade geopolymer management concrete and recycled waste glass fine mixture (RWGCA) concrete are tabulated in Table four.

Table 4 Mechanical Strength of Various Grades

Mix	Code	Mechanical Strength (MPa)	
		7 days	28 days
M 20	GPC	19.00	29.00
	RWGCA	19.70	30.00
M 40	GPC	39.82	48.50
	RWGCA	40.60	48.80
M 60	GPC	56.80	70.10
	RWGCA	56.92	70.56

B. Flexural Test on GPC Beams and RWGCA Beams

Flexural behaviour is studied beneath beams of size one hundred twenty five millmetre x two hundred mm x 1100 mm [5] [6]. The beams are designed as beneath strengthened sections. 3 beams are created with standard GPC concrete and remaining three beams are made with RWGCA in concrete. To get flexural behaviour of concrete in varied grade mixture of M twenty, M forty and M sixty. The combination proportion and beam reinforcement details are tabulated in Table Five. The take a look at specimen is mounted in an exceedingly beam testing frame of two hundred kN capability. The beams are merely supported over a span of one thousand millimetre and subjected to 2 focused hundred are applied through a spreader beam placed symmetrically on the span. The space between the load points is 333.33 mm. The load is applied on 2 points every 166.67 millimetre faraway from the centre of the beam towards the support. To live the deflection, dial gauges of zero.001 millimeter least count is employed. 3 dial gauges are accustomed live the directions in middle span and below the load point. Load is given at the interval of each 0.5 Ton. Mechanical dial gauge is placed at centre to live the deflection throughout the time of final stage. Crack dimension, nature of crack are monitored throughout beam testing. Initial crack load is obtained by visual examination. Loading have continuing up to the final word stage and every one the measurements are recorded. Testing of beam beneath 2 points loading is shown in Figure five. The flexural take a look at results of M twenty, M forty and M sixty cement concrete beams RWGFA concrete beams are tabulated in Table five.

Figure V Flexural Test on Beam Specimen

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Table 5 Test Result of GPC and RWGCA Beams

Grade	Beam Code	1st Crack Load (kN)	Service Load (kN)	Yield Load (kN)	Ultimate Load (kN)	Max. Deflection (mm)
M 20	GPCB	50.00	83.33	120.00	125.00	18.00
	GPCGCAB	40.00	86.00	127.00	129.00	18.00
M 40	GPCB	45.00	93.33	135.00	140.00	22.00
	GPCGCAB	40.00	98.33	146.00	147.50	22.00
M 60	GPCB	55.00	101.67	150.0	152.50	27.00
	GPCGCAB	55.00	102.66	152.00	154.00	23.50

The load deflection behaviour for M 20, M 40 and M 60 grade mix geopolymer concrete beams and RWGCA concrete beams are shown in Figure 6 to 11.

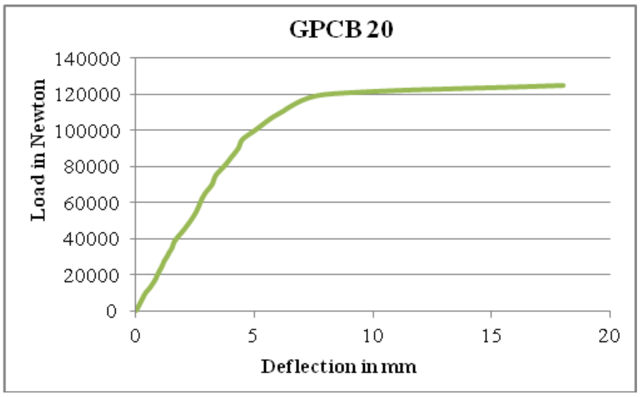

Figure VI Geopolymer Beam M 20 (GPCB)

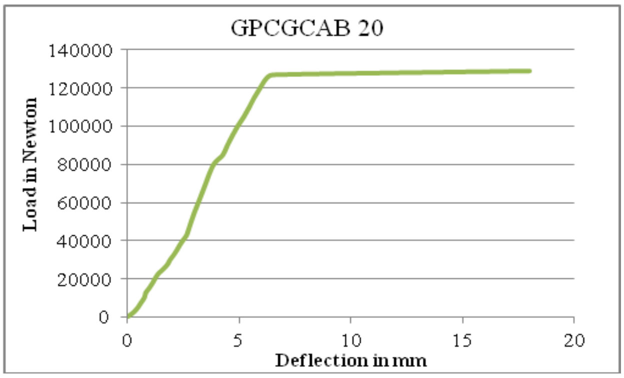

Figure VII Geopolymer Beam M 20 (GPCGCAB)

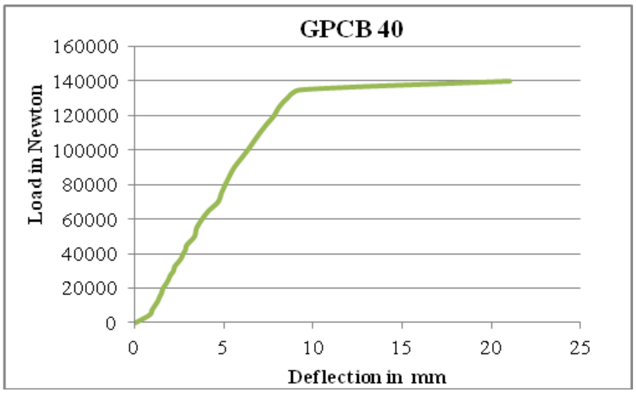

Figure VIII Geopolymer Beam M 40 (GPCB)

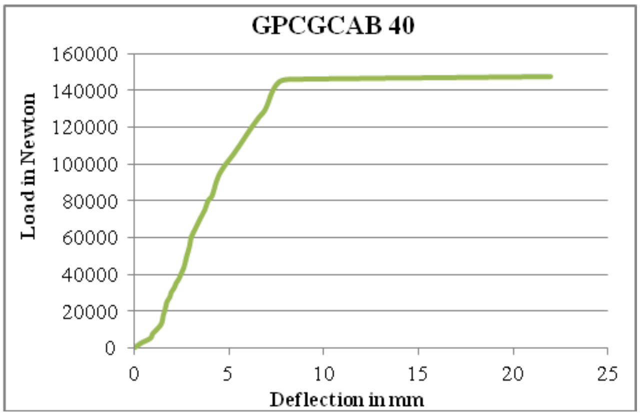

Figure XI Geopolymer Beam M 40 (GPCCB)

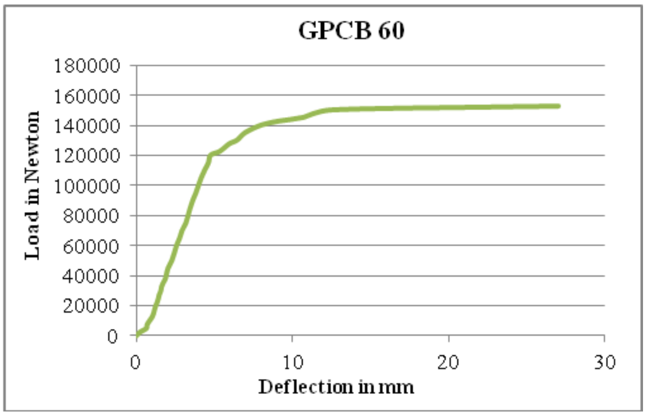

Figure X Geopolymer Beam M 60 (GPCB)

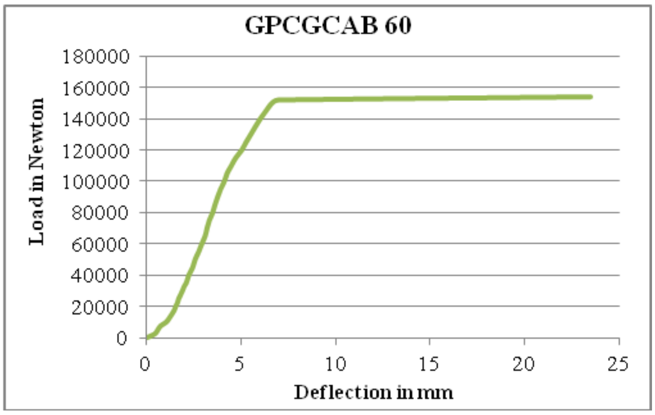

Figure XI Geopolymer Beam M 40 (GPCCB)

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C. Crack Patterns of GPC and RWGCA Beam

Failure pattern of beams are ascertained rigorously. The flexure zone the cracks are developed once the load is applied. If the load is redoubled the present cracks in flexure zones are widened and therefore the new cracks are created on the span. As a result of the shear force, range of flexural cracks at intervals the shear span was inclined cracks. All the cracks corresponded to flexural cracks with a range varied between eleven and twenty six cracks and spacing go between twenty mm to a hundred and forty millimeter. The most load to yield load quantitative relation (pu /py) ranges between 1.02 and 1.06. The cracks at middle span opened wide getting ready to failure. Throughout peak load, the beams deflected significantly, thus indicating that the tensile steel ought to have yielded at failure. Once the compression zone is crushed, the final word failure of the beam occurred within the interior of buckling of steel bars. The failure mode altogether beams are that typical failure of an under-reinforced concrete beams. Throughout the take a look at, the crack patterns are measured with crack deflection magnifier and therefore the pattern of cracks are analyzed. Throughout the take a look at the crack dimension is marked each twenty five kN. The dimension of crack is mostly redoubled at tension zone and therefore the cracks are perpendicular to the beam axis. Altogether the beams, principally vertical cracks are seem in bending zone and inclined cracks are appeared in shear zone. The crack patterns of M twenty, M forty and M sixty grade combine geopolymer concrete beams and RWGCA beams are shown in Figure 12 to17.

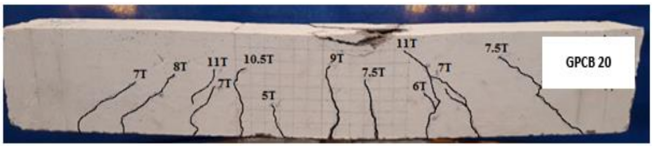

Figure XII Crack Patterns of M 20 GPC Beam

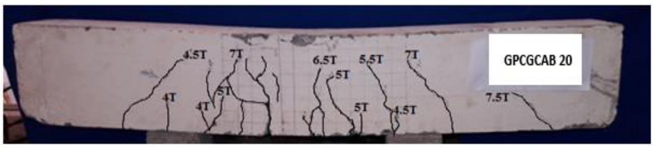

Figure XIII Crack Patterns of M 20 GPCGCA Beam

Figure XIV Crack Patterns of M 40 GPC Beam

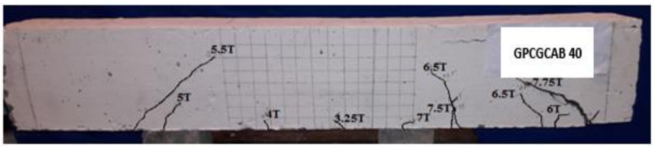

Figure XV Crack Patterns of M 40 GPCGCA Beam

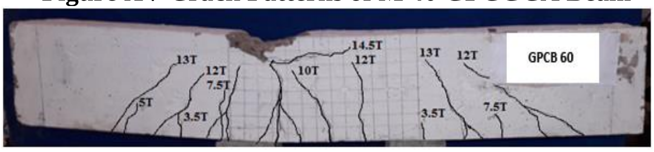

Figure XVI Crack Patterns of M 60 GPC Beam

Figure XVII Crack Patterns of M 60 GPCGCA Beam

D. Ductility Behaviour of GPC and RWGCA Beams

The displacement ductility characteristics of M twenty, M forty and M sixty grade geopolymer concrete and RWGCA geopolymer concrete beams results are shown in Table 6.

Table 6 Ductility Displacement of CC and RWGCA Beams

Grade	Beam Code	Minimum Deflection (milli metre)	Maximum Deflection (milli metre)	Ductility Ratio
M 20	GPCB	7.96	18.00	2.26
	GPCGCAB	6.50	18.00	2.77
M 40	GPCB	9.26	22.00	2.38
	GPCGCAB	8.12	22.00	2.70
M 60	GPCB	12.55	27.00	2.15
	GPCGCAB	6.94	23.50	3.39

D. ANSYS Modeling of Beams

FEA software system package ANSYS is adopted for predicting the load displacement response of geopolymer beam and RWGCA beams. The obligatory half divisions are noted and modeling is usually performed by mapped meshing (or) free meshing. The reinforcement model is meshed victimization line components therefore the nodes of the road elements come exactly over the node of the solid elements that are unified so every rebar parts and to boot the concrete parts share identical node. For beam generation total mesh model outlined 4666 nodes and 3380 parts are needed. These
nodes and parts follows a procedure of concrete mapped mesh modeling within which meshes are generated in even order. Free mesh modeling is that the one within which the meshes are generated in random. The meshing concrete is shown in Figure eighteen and also the meshing reinforcement is shown in Figure nineteen.

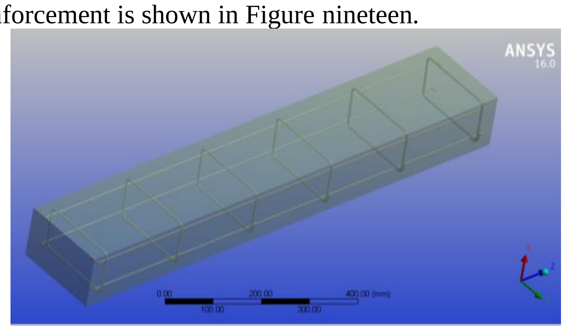

Figure XVIII Meshing Concrete

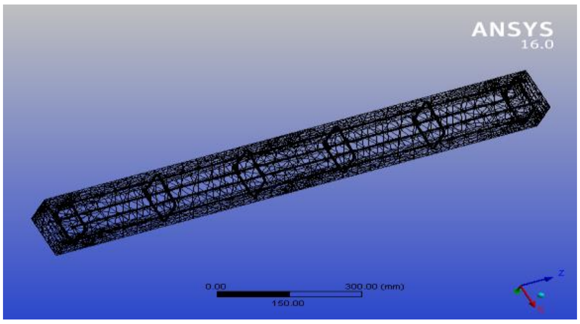

Figure XIX Meshing Reinforcement

The comparison of final load and alsothe experimental and numerical (ANSYS) results are tabulated in Table seven. A typical deflected form of M twenty, M forty and M sixty grade combine geopolymer concrete are shown in Figure twenty to twenty

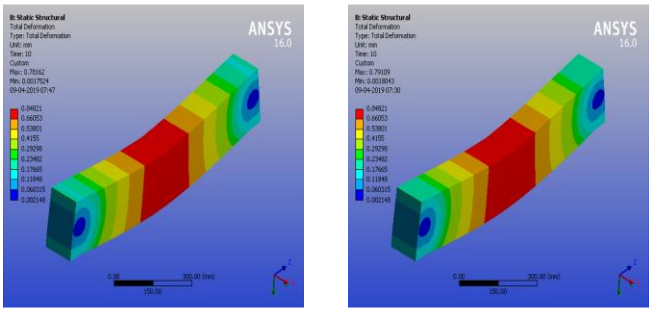

Figure XX Deflected Shape of M 20 GPC and M 20 RWGCA Beams

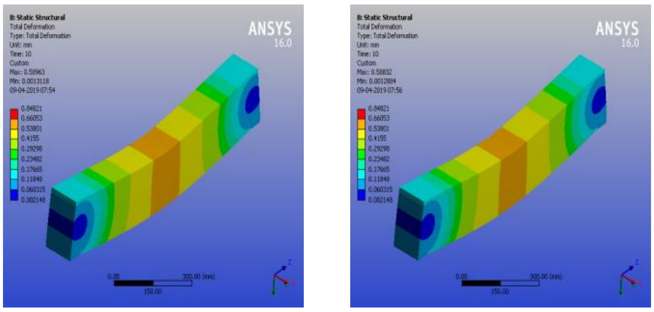

Figure XXI Deflected Shape of M 40 GPC and M 40 RWGCA Beams

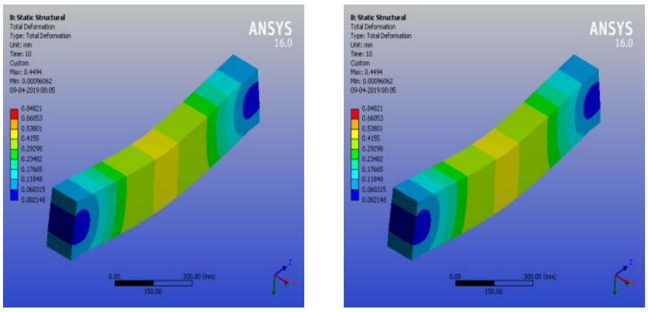

Figure XXII Deflected Shape of M 60 GPC and M 60 RWGCA Beams

IV. RESULTS AND DISCUSSIONS

The characteristic of recycled glass coarse mixture aren't significantly varied from crushed stone aggregate. The non absorption of water in glass combination and free from roughness, the mechanical property is increased and therefore the glass coarse combination shows additional cohesive then management combine concrete. The absorption of water will have an effect on the strength parameters. The upper water absorption results in lower strength. Recycled waste glass coarse combination absorbs minimum amount of water and therefore the lower workability and therefore the results of mechanical properties higher than the standard concrete. The
Mean of M twenty, M forty and M sixty grade combine geopolymer mix and RWGCA mix are obtained. The compressive strength of RWGCA geopolymer combine is slightly on the top of the conventional geopolymer concrete. Flexural behaviour of M twenty, M forty and M sixty geopolymer combine and RWGCA geopolymer mix are tabulated antecedently. The load deflection curve of geopolymer beams and RWGCA concrete beams are shown in Figures. The crack patterns of the geopolymer beams created with crushed stone aggregate and RWGCA made with glass aggregate are shown and also the failure patterns of RWGCA beams is analogous to geopolymer concrete. The comparison of load deflection curve for RWGCA and GPC beams are shown in Figure 23.

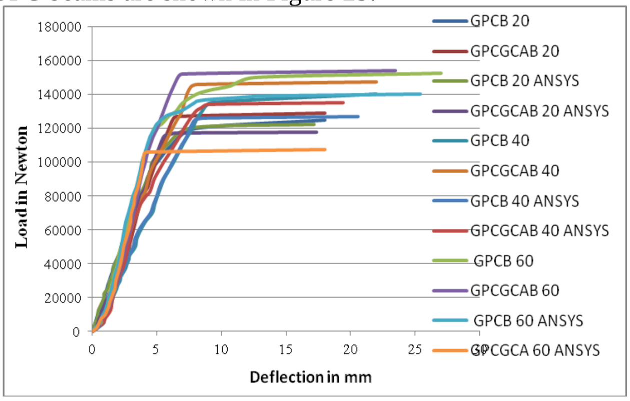

Figure XXIII Comparison of Load Deflection Curve for GPC and RWGCA Concrete Beams

Table 7 Summary of Test Results for GPC Beams and RWGCA Concrete Beams

GRADE	Beam Code	Yield Load (kN)		Maximum Load (kN)		Ultimate Deflection (mm)	
		Experimental	ANSYS	Experimental	ANSYS	Experimental	ANSYS
M 20	GPCB	120.0	118.00	125.0	122.0	18.00	17.20
	GPCGCAB	127.0	114.00	129.0	117.5	18.00	17.40
M 40	GPCB	135.0	125.90	140.0	126.9	22.00	20.60
	GPCGCAB	146.0	123.00	147.5	135.0	22.00	19.40
	GPCB	150.0	138.2	152.5	140.2	27.00	25.42

M 60	GPC GCA B	152.0	140.0	154.0	142.0	23.50	20.50

V. CONCLUSION

The following determinations are drawn from the take a look at results. Recycled waste glass coarse combination (RWGCA) is effectively used rather than typical crushed stone in geopolymer concrete. M twenty, M forty and M sixty grade geopolymer beams of flexural behaviour are compared with glass coarse combination geopolymer beams. The maximum load carrying capacity of RWGCA beams is 2% to 5% higher than the conventional geopolymer beams. The amount of cracks and dimension of cracks of RWGCA geopolymer beams don't seem to be abundant distinction compared with typical geopolymer beam. The deflected form of geopolymer beams and RWGCA beams are compared with ANSYS modeling. The deflected form and also the deflection behaviours are the same as that of the beams tested through experiment.

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AUTHORS PROFILE

B. Parthiban received his Bachelor Degree and Master Degree in Department of Civil & Strutural Engineering, Annamalai University. At present, he is pursuing Doctoral Degreee in Structural Engineering in Annamalai University. He had published Nine research papers in UGC Approved Journals. He had presented Two papers in National Conference and Two papers in International Conference. Also, he is doing construction work with architectural designs and detailing.
E mail: balaparthi@gmail.com

Dr.S.Thirugnanasambandam is presently working as Professor in Annamalai University. He had completed his Master Degree and Doctoral Degree in Annamalai University. He is working in the Department of Civil and Structural Engineering since 1999. Four of his scholars awarded Ph.D., degree and presently guiding seven Ph.D., Scholars. He had published 74 research papers and attended many National and International Conference. His areas of interest are damage assessment and repair of structures. Also, he is familiar in development of Geopolymer Concrete Products.
E mail: agstsai@gmail.com