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Research Article

Mathematical Formulation for Prediction of Structural Performance of Green Geopolymer Concrete Beams and Columns

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Abstract: . In order to minimise the environmental impact of the waste and its disposal processes and to reduce global warming by cement production, this study has focused on the demand. This research looked at how waste wood ash can be used to make geopolymer concrete beams and columns, which can be used to replace traditional reinforced concrete elements in the construction industry. Waste wood ash, a waste produced in the nearby hotel and manufacturing factories by burning the waste wood collected in the woodworking industry and throwing the ash to land causing considerable environmental pollution. Geopolymer is an innovative inorganically friendly, alkaline-based binding agent that stimulates the source material of aluminosilicate (such as metakaolin, fly ash and GGBS). For three types of concretes (30 percent WWA – 70 percent Fly ash Geo-polymer concrete, Fly ash Geo-polymer concrete, and Reinforced Cement Concrete), the mathematical formula for the behaviour of beams in deflection, ductility factor, flexural strength, and columns in load carrying ability, stress strain behaviour, and load-deflection behaviours were investigated in this study. The results showed that the inclusion of waste wood ash into geopolymer concrete contributed to the 42 and 28 percent increase of the capacity for beam and column. Furthermore, by replacing waste wood ash, the compotation of structural elements was improved in their rigidity and ductility. The derived mathematical equations were most suitable for the prediction of forecast.

Keywords: Reinforced Geopolymer Concrete; Waste Wood Ash; Load-Deflection Behaviour; Ductility; Stiffness**.**

1. Introduction

In the construction industry, Portland cement has been the largest resource for concrete production. In addition to the development of the country's infrastructure, the use of cement and the environmental degradation for the production of cement have been tremendously increased[1]. The most spectacular environmental pollutant, according to the environmental impact assessment, is cement production, which should be eliminated as soon as possible to save the environment [2]. Researchers focused on finding the alternate for cement in concrete industry to reduce the more critical environmental global warming. Davidovits[3] discovered an alternative binding material for portland cement made from industrial waste products such as fly ash, ground grain waste furnace slag, rice husk ash, palm oil fuel ash, metakaoline, silica fume, or bottom ash [4-8]. The production of geopolymer concrete using fly ash as a source material was a common practise in geopolymer technology [8-12]. Compared with ordinary Portland cement and Portland pozzolonic concrete[9], fly ash based GPC's performance was higher. The geopolymer concrete based on fly ash has a demand of 60 degrees Celsius high temperatures to cure, high alkaline dissolving activators and long setting time. Ground granulated blast furnace slag ash (GGBS) based geopolymer concrete was discovered as an alternative for the fly ash based GPC to eliminate the elevated temperature curing. Due to the presence of C-S-H cementitious gel, GGBS-based GPC set quickly [13]. The geopolymer, which was manufactured using rice husk ash and palm oil fuel ash, had a high silica content which required a large number of alkaline activators to perform a geopolymerization reaction. The use of metakaoline in geopolymer has been involved in the geopolymerization process requiring high alkaline solutions[14]. The above-mentioned problem indicates that alternative waste materials are required during the production of geopolymer cement, which can reduce the demand for alkaline solutions, temperature curing and normal setting.

Waste production has increased dramatically over the last few decades. The term "solid waste" refers to the heterogeneous mass of urban waste as well as the homogeneous deposition of agricultural, industrial, and mineral waste [15]. In previous research, the author discovered an alternative waste material for diluting the problems mentioned above in geopolymer concrete. The alternative material that can be obtained from any nearby hotel is waste wood ash. Waste wood ash was also a pollutant for the environment by throwing in the ground and causing a sinus when human beings smell it. Because of its smaller surface area, this ash is easily flyable in the wild. Wood ash has an alternating alkaline activator of 12% potassium oxide chemical compound [16]. The presence of K2O aids in reducing the amount of alkaline solution required for the geopolymerisation process. Waste wood ash is partly substituted for the processing of green geopolymer concrete to eliminate the need for a high alkaline solution, high temperature curing, and waste disposal into ample usable material.

The behaviour of geopolymer concrete in ductility, energy absorption and impact resistance was assessed and found that the performances were less compared to conventional concrete. Incorporation of discrete fibres such as polypropylene, polyester, sisal, steel, coir and rubber could enhance the behaviour of GPC in ductile, impact resistance and energy absorption [17]. Each behaviour of Geopolymer was found by the suitable standard procedures defined by the ASTM and IS standards. Prediction of strength using standard test procedures were not difficult with the casting of different size and shape of specimens [18]. Analytical investigations were developed in now a day for the prediction of concrete behaviour in future ages. [19]. However, analytical investigations were in the need of skilled knowledge for using the software packages [20]. Hence prediction of concrete behaviour without casting the specimen and software packages has to be concentrated [21]. This study aims to involve the creation of mathematical equations and regression analysis equations for the prediction of behaviour of concrete in future forecast.

For a variety of applications, geopolymer concrete is becoming more popular in industry and research. A great deal of research is currently being done in Australia, the USA and Spain. Various researchers have suggested acceptable material sources for the production, manufacture, mix design, mechanical properties, and toughness of Geopolymer concrete [22–24]. Alumina and silica were used as the inorganic binder, which offered greater stability in the end. While geopolymers need reinforcement, they are often used in construction engineering. As a result, the behaviour of geopolymers in reinforced concrete was investigated [25, 26]. The analytical method used for standard OPC columns is generalised for GPC columns to account for the proper geopolymer-concrete stress-strain relationship. The analysis of GPC columns is based on Popovics' stress-stress relationship, as revised by Thorenfeldt et al.

The aim of this research is to concentrate on the efficiency of reinforced green geopolymer concrete beams and columns that are cured at room temperature. Two geopolymer concrete mixtures and OPC mixtures were used to cast a total of nine beams and nine columns. Analyzes have also been carried out on flexural strength, ductility factor and beam deflection. Meanwhile, this study looked at the performance of columns in terms of load carrying capacity, stress strain behaviour, and deflection at various levels.

2. Materials and test methods

2.1. Materials

2.1.1. Fly Ash (FA)

For the manufacture of geopolymer concrete, Fly Ash is used in this analysis as the raw material. It is tested to identify physical characteristics such as setting time, fineness, Sp. gravity and consistency as per IS code provisions. The fly ash acquired by thermal energy plant is selected through the 90 microne sieve. Table 1 shows the physical characteristics of fly ash. X-Ray diffration analyser analyses the chemical compounds in the FA and are presented in Table 1.

2.1.2. Ordinary Portland cement (OPC)

In this study, the grade 53 OPC was procured from local suppliers with a specific gravity of 3.15 used for conventional concrete production. Table 2 lists the chemical compositions.

2.1.3. Wood Waste Ash (WWA)

Waste wood ash is a residual ash generated from neighbouring hotels that is used to manufacture food by consuming wood waste from the local wood industry [16]. Ash wastes are tested to IS standards and listed in Table 1. Physical characteristics The X-ray diffraction analyzer listed in table 1 analyses chemical compounds presented in the ash of wood waste.

Table 1: Chemical composition of OPC, Fly Ash and Waste Wood Ash

Oxide	OPC	FA	WWA
CaO	62.9	4.8	3.72
SiO_2	25.11	24.3	8.23
Al_2O_3	6.75	17.4	2.6
K_2O	0.52	0.89	14.3
P_2O_5	1.4	-	3.03
TiO_2	0.36	0.99	-
Fe_2O_3	3.18	1.79	-
MgO	2.14	6.75	3.02

2.1.4. Aggregates

Natural river sand of size 1.18mm was used in this study as a fine aggregate material [28]. The physical characterstics of fine aggregate are tabulated in Table 2. The coarse aggregate procured from granite industries of size 10mm is used in this study. The physical characteristics are tested and tabulated in Table 2.

Table 2: Properties of Aggregates

Properties	Fine Aggregates	Coarse Aggregates
Specific Gravity	2.61	2.64
Fineness modulus	2.92	7.5
Water Absorption (%)	0.93	0.72
Size (mm)	1.18	10

2.1.5. Activator solution

Diverse alkaline activators were used, with the majority of recent studies showing that sodium silicate (Na2O.SiO2) [29] combined with sodium hydroxide provides strong power. For the dissolution of aluminium and silicate from alumino silicate source materials such as fly ash and waste wood ash, sodium based activators are used [30]. Sodium silicate and sodium hydroxide have a specific gravity of 1.59 and 1.45. The silica modulus (the ratio between SiO2 and Na2O) was found to be 2.5. The ratio of sodium hydroxide to sodium silicate is 1:2.5. Sodium hydroxide molarity is considered as 10M and 0.45 with the proportion of alkaline activator to binder.

2.1.6. Reinforcing steel

In the shear and longitudinal reinforcement section, twisted steel bar of 12mm dia were utilized. The same dia of 12mm was provided for column reinforcement. Stirrups are made with 8mm dia steel bars and provided in both column and beam for stiffening the main reinforcement. Average strength were consolidated by testing of three specimens. The different characteristics of steel bars are illustrated in Table 3.

Table 3: Reinforced steel properties

Bar Size (mm)	12	8
Ultimate Strength fu (MPa)	808	682
Yield Strength fy (Mpa)	682	552
Bearing Strength fb (MPa)	576	405
Elongation %	25.5	22

3. Mix proportioning and methods

Sodium silicate and hydroxide are formulated individually, mixed, and poured into a mould during the casting process. To prevent the pre-heat formed when sodium hydroxide reacts with water, the solution should be formulated the day before it is used. Enable the solution to cool for 24 hours after it has been prepared.

The RCC cement mixing ratio is 1:1.5:3, with a water cement ratio of 0.4, as defined under IS100262-2019[31]. In compliance with the modified Indian guidelines for geopolymer concrete, the ratio of the mixture to the concrete is determined by geopolymer[32]. The proportions of the blend are 1:1.06:2.56. The use of 30percent WWA instead of FA resulted in improving the mortar's mechanical properties [16]. Three material combinations are selected and compared to build columns and beams (100 percent FA, 30 percent WWA-70 percent FA and RCC). The quantity materials needed for casting were proposed in Table 5.

Table 5: Mix Proportion in kg/m3for Beam and Column

Mix ID	CC	FA-GPC	WA-FA-GPC
% of OPC	100	-	-
% of FA	-	100	70
% of WWA	-	-	30
OPC	350	-	-
Fly Ash	-	550	385
WWA	-	-	97
M-Sand	525	668.45	668.45

Coarse Aggregate	1350	993.9	993.9

3.1. Specimen details and testing

The size and reinforcement details of the geopolymer beam and column were illustrated in Fig 1 and 2. In the case of a universal 1000 kN test machine, as demonstrated in Figure 3, the beams were repetitively tested. The loads on both sides of the mid - span are evenly applied at 400 mm. The Loading Frame Test unit was used to observe the effects with the test columns at a capacity of 2000 kN. Deflection in the centre of the columns is controlled by LVDTs located in the centre of each column. For each sample, the values are recorded, and the mean values are calculated.

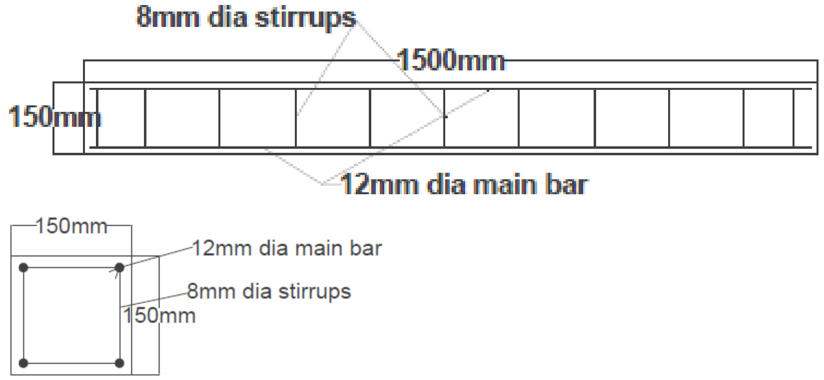


Fig. 1: Beam's cross-section and reinforcement details

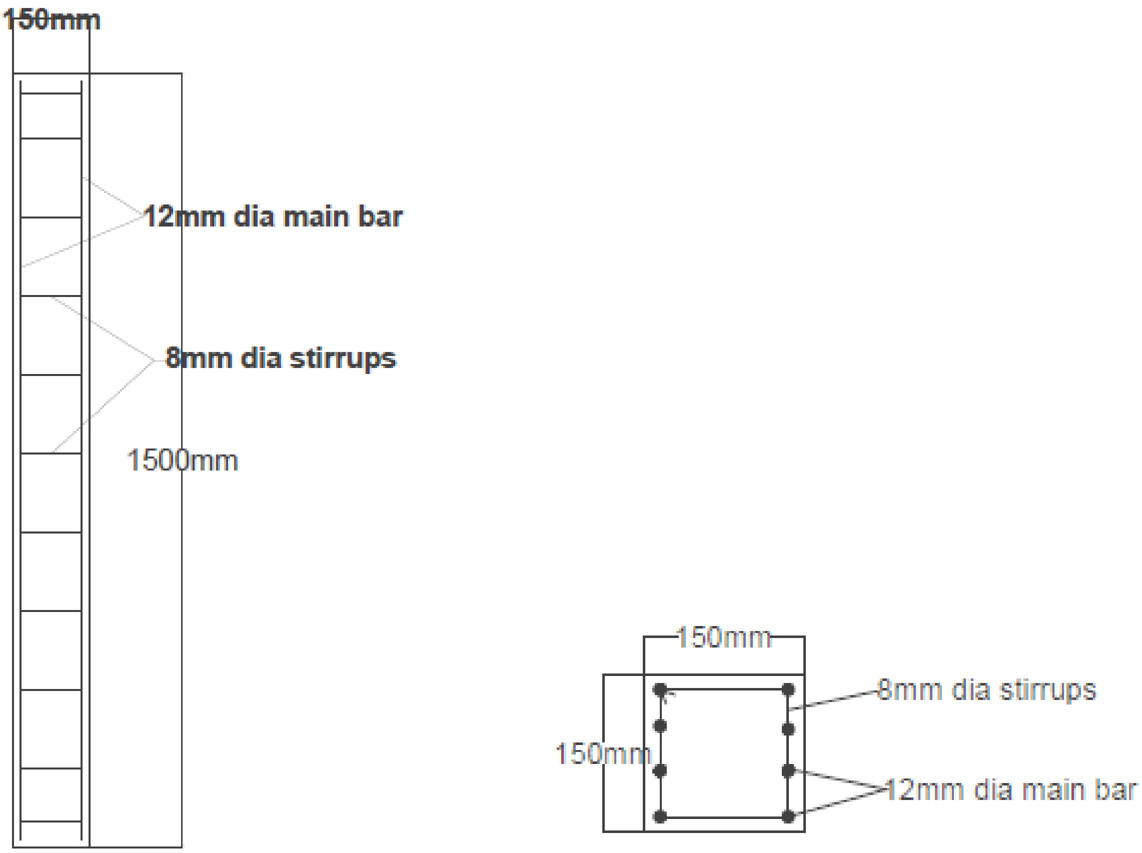


Fig. 2: Column's cross-section and reinforcement details

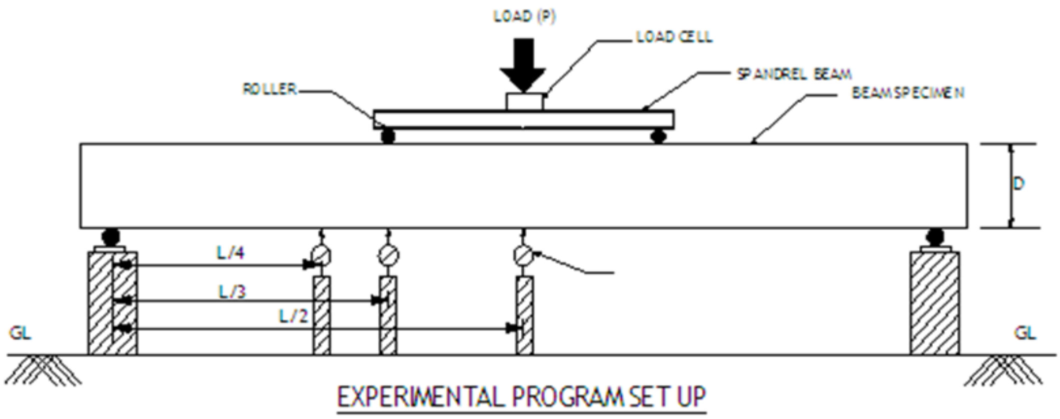


Fig. 3: Beam loading setup

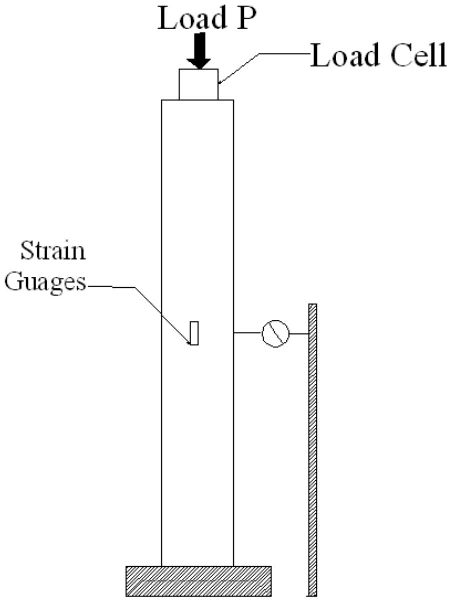


Fig. 4: Column loading setup

4. Results and discussion

4.1. Load carrying capacity for beams

Fig 5 illustrates the load carrying ability of beams that are tested under UTM. In comparison with control beams and FA based GPC beams, the maximum load in all parameter such as breaking load, ultimate load and yield load were observed with the specimen made with WWA. It proves that addition of waste wood ash helped in enhancing the behaviour of beams in all aspects. The range of ultimate loads of all beams are lies between 65 to 87KN. The strength enhancement was 41.23percent in the FA-WA-GPC [25].

The Mathematical equation for the future forecast of each load carrying capacity factors such as ultimate load, breaking load and first crack load was formulated. For prediction of ultimate load of GPC specimens, the equation is formed as y = 65.372x0.269. For prediction of yield load of GPC specimens, the equation is formed as y = 56.017x0.1217. The equation for prediction of first crack load is formed as y = 21.636x0.3303.

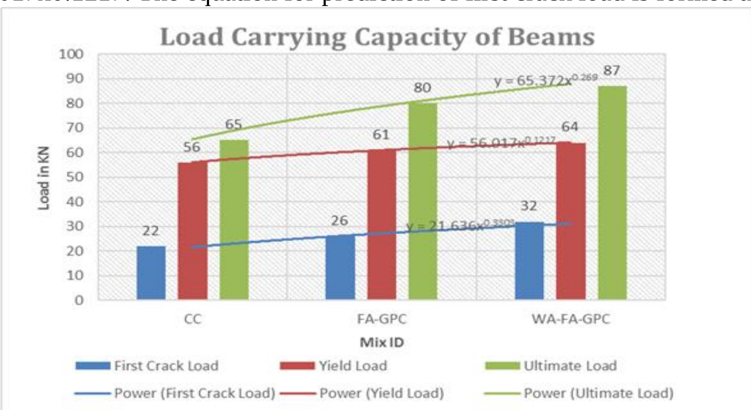


Fig. 5: Load carrying by beams at various level

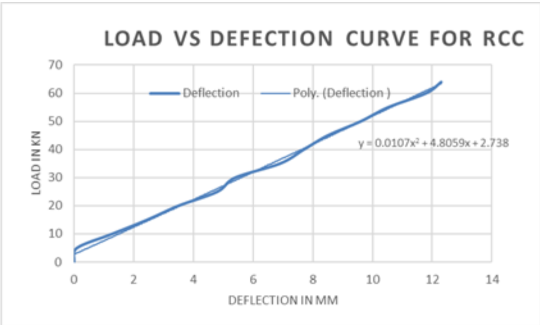
4.2. Deflection behaviour for beams

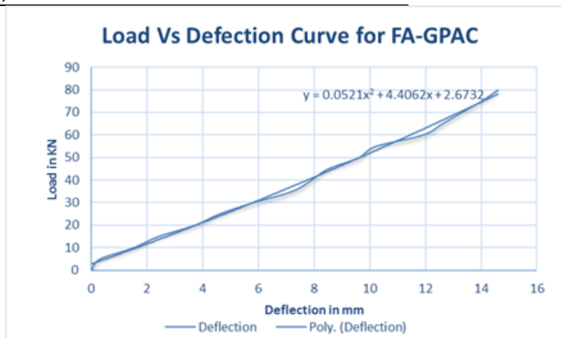
Deflection of beams were measured using LVDT by significantly increasing the applied load up to failure. From the measured deflection of beam under each load are directed in to graph and the regression model analysis was performed to predict the future forecast equation. This was performed for each specimen and the regression model equation was formed. The relationship between the experimental midspan load deflection and the expected ACI 318-11 value [34] is illustrated in Table 6. The quantitative exceedances of the predicted values are greater than the experimental values. The ratio span-deflection of the assessed beams was observed to be within the permissible of ACI was suggested [35].

The regression model equation for the control specimen was found as y = 0.0107x2 + 4.8059x + 2.738 with the mean square value of 1. For the specimen with FA based GPC, it was revealed as y = 0.0521x2 + 4.4062x + 2.6732 with the same mean square value. At the same way, the regression equation for the specimen with 30 percent WWA was determined as y = 0.0229x2 + 4.6586x + 2.9253. Where the relation between load(y) and deflection (x) is formed as the regression equation for all specimens

Table 6: Analytical and Empirical test results of beam

Mix		RCC	FA-GPC	WA-FA-GPC
Analytical	Load (KN)	65	80	87
	Deflection (mm)	11.9	13.8	17
Empirical	Load (KN)	59	75	82
	Deflection (mm)	10.9	12	14.9
Analytical/Empirical	Load (KN)	1.07	1.08	1.05
	Deflection (mm)	1.1	1.13	1.14





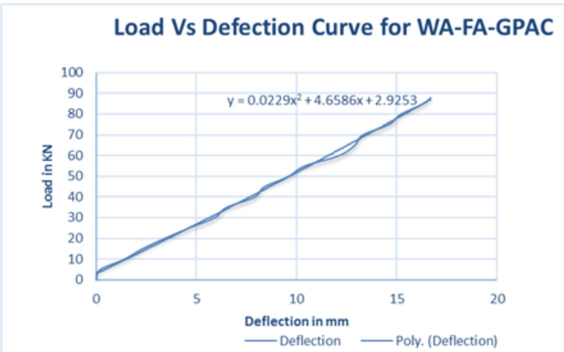


Fig. 6: Load Deflection curve for all beams

4.3. Ductility behaviour for beams

Ductility factors of each beam specimens were illustrated in Fig. 7. The relation between ultimate displacement to yield displacement was noted as ductility factor. This is due to the creation of a small crack and the spread in size as the load effect on the steel after a rapid decrease in stiffness [33]. The mathematical equation for ductility factor of all beams were found to be y = 1.1497x0.0988. The equation for ultimate and yield deflection of each beam was calculated as y = 1.1497x0.0988 and y = 10.107x0.2475.

The relation between ultimate deflection (y) and various types of specimens (x) is obtained as the regression equation of y = 2.75x + 8.9667, R^2 = 0.9999 and for regression relation between yield deflection(y) to the various mix proportions(x) was formed as y = 1.7x + 8.4, R^2 = 0.9601.

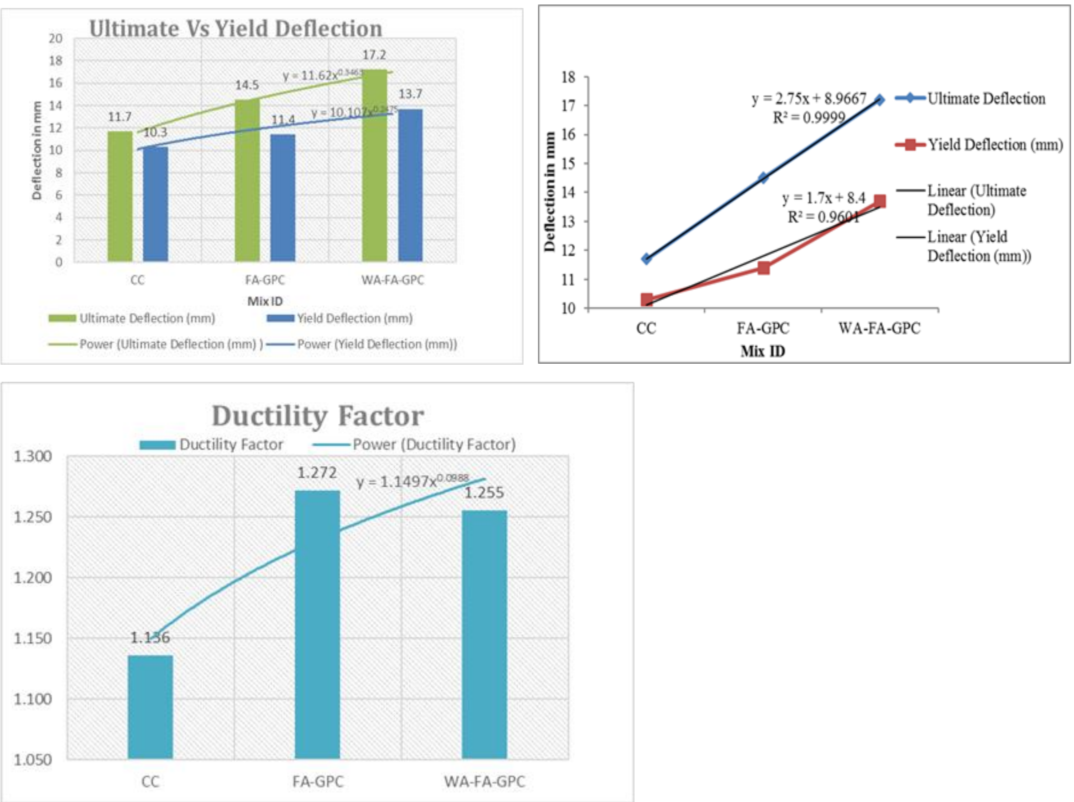


Fig. 7: Yield Deflection, Ultimate Deflection and Ductility Factor for all beams

4.4. Stiffness degradation for beams

Stiffness can be determined by comparing the ratio of a certain load to its corresponding deflection [30]. The stiffness deterioration curve is shown in the Fig. 8. The mathematical equation for ultimate stiffness degradation of all beams were found to be y = 5.0701x0.0462. Whereas for the yield stiffness degradation equation was formed as y = 4.9511x0.0219.

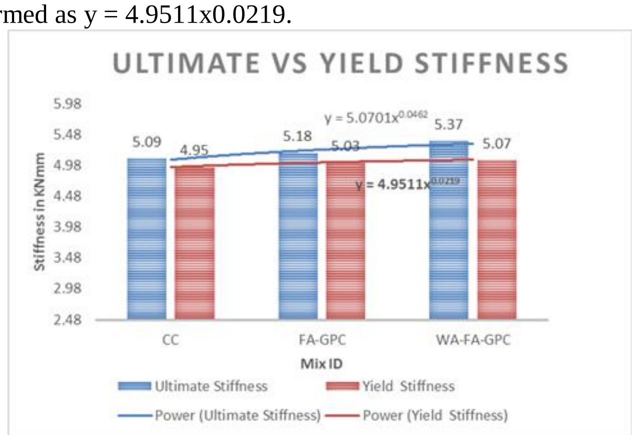


Fig. 8: Stiffness for all beams

4.5. Load carrying capacity for columns

Table 7 shows load carrying capacity of columns. The results and predictions are compared in Figure. 9. A theoretical outcome and an actual outcome have a high relationship factor [36]. The mathematical equation for theoretical prediction of loads of all columns were found to be y = 577.92x0.2061. The equation for experimental prediction of loads of all columns were also formed as y = 564.15x0.1996. By the same way the equation for yield load of all column specimens was

Table 7: Analytical and Empirical test results of columns

Mix		RCC	FA-GPC	WA-FA-GPC
Analytical	Load (KN)	585	645	740
	Deflection (mm)	6.8	7.4	8.8
Empirical	Load (KN)	570	630	715

	Deflection (mm)	6.3	7.2	8.5
Analytical/Empirical	Load (KN)	1.026	1.024	1.021
	Deflection (mm)	1.06	1.04	1.02

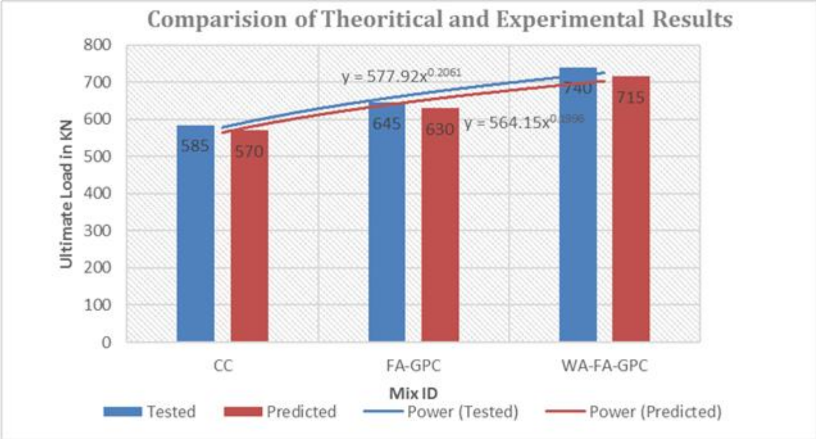


Fig. 9: Comparison between Theoretical and Experimental Load for columns

Table 7 displays the load-deflection values of the columns. Fig. 10 illustrates the curve for load-deflection. By adding WWA, the column deflection increases. The regression model equation for the control specimen was found as y = -12.322x2 + 146.9x + 39.552 with the mean square value of 1. For the specimen with FA based GPC, it was revealed as y = -4.7834x2 + 100.72x + 55.789 with the same mean square value. At the same way, the regression equation for the specimen with 30 percent WWA was determined as y = -2.3971x2 + 84.099x + 54.499. Where the relation between load(y) and deflection (x) is formed as the regression equation for all specimens

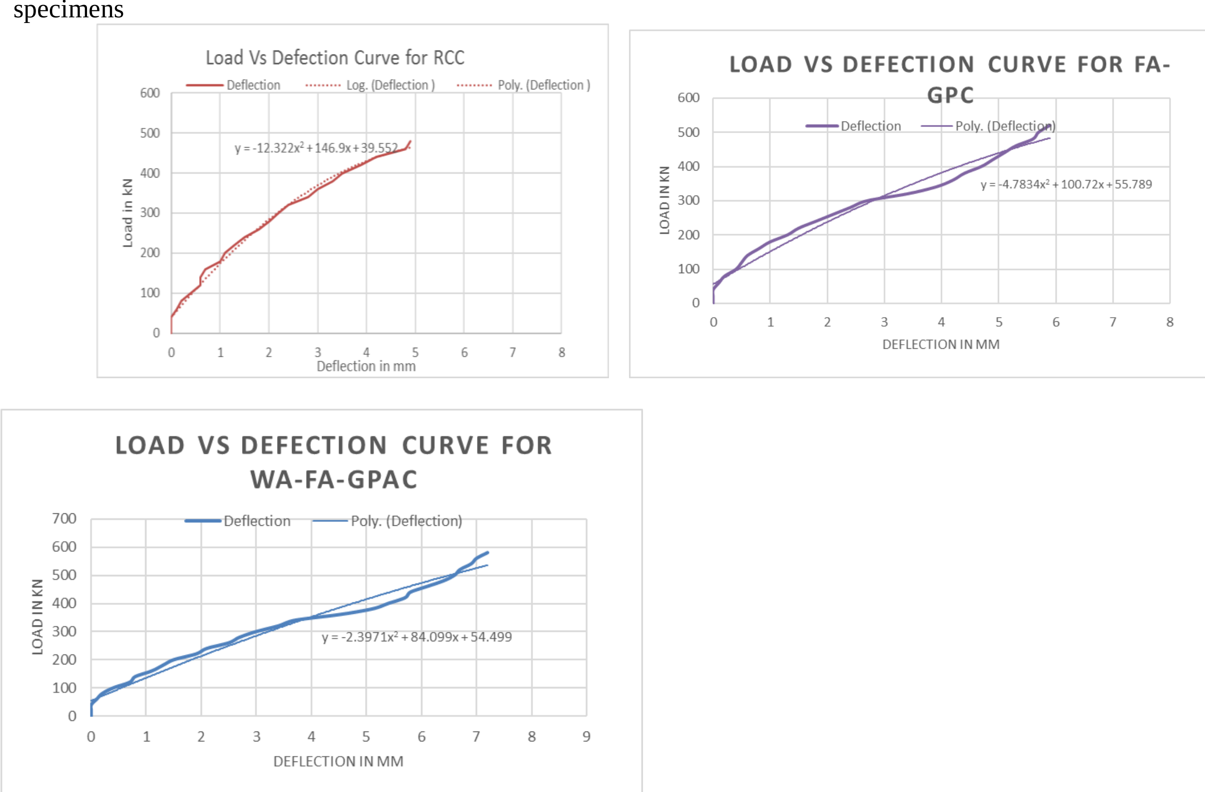


Fig. 10: Load- mid height deflection for all columns

5. Conclusion

This study looked at how well waste wood ash could be used to make environmental friendly geopolymer concrete beams and columns. An insight into several factors, including beam and column load carriage capacity, rigidity, ductility factor, and hardness index, has been analysed. The test and discussion results have led to a better performance in both beam and column applications of fly ash-based geopolymer concrete, partially replaced with waste wood ash, than conventional concrete beams and columns. At the same time mathematical formulation of different specimens in various factors were also assessed. The presence of waste wood ash increased the load carrying ability of geopolymer concrete beams by 41.23 percent over RCC and 12.21 percent over FA-GPC. The inclusion of WWA has led to the ultimate bending deflection and reduced stiffness in the initial stage. In the meantime, the inclusion of WWA in GPC could improve column loads by 28.23% above RCC and by 13% above GRGPC. The empirical findings were also analysed and compared to those of the experiments. The value difference was not more than 2%. WWA has assisted in reducing column deflection by utilising live load. The stiffness of the columns is increased by using waste wood ash materials. The empirical mathematic formulas have been developed for the prediction of future forecast of GPC beams and columns in various factors. Accordingly, geopolymer produced from waste wood ash could be the perfect solution for RCC construction in order to combat global warming issues.

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