



ORIGINAL RESEARCH ARTICLE

INFLUENCE OF REINFORCEMENT RATIOS ON LOAD AND DEFLECTION OF REINFORCED GEOPOLYMER CONCRETE BEAMS

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ABSTRACT

In recognition of the adverse environmental impacts of the Portland cement manufacturing process, interest has shifted toward developing alternative cementing materials. This shift is also driven by the depletion of fossil fuel reserves, scarcity of raw materials, and the increasing demand for cement and concrete. However, geopolymer cement can serve as a substitute for Portland cement binder in structural concrete. In this research, Reinforced concrete geopolymer concrete beams were produced with metakaolin as the pozzolan. The concrete was produced with a cement made up of metakaolin as the silica and alumina precursor, while Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) serve as the activator solution. Singly reinforced concrete beams were produced at 1.24%, 1.96% and, 2.86% reinforcement ratios using 8, 10, and 12mm steel reinforcements respectively. The beams were tested according to BS EN 12390-5 (2000). The results showed that the dominant mode of failure of the beams is the diagonal tension shear failure. Additionally, the behavior of the reinforced geopolymer concrete (RGC) beams in deflection was found to be similar to conventional reinforced concrete (RC) beams. Furthermore, the load required for a deflection of 1mm when the reinforcement ratio is 1.24%, 1.96% and, 2.86% is respectively 14kN, 20kN, and 29kN. In addition, a load of 20kN lead to a deflection of 1.33mm, 1.00mm, and 0.65mm for reinforcement ratios of 1.24%, 1.96% and, 2.86% respectively. The maximum deflection at failure of the beam with a 1.24% reinforcement ratio was 3.58mm. The value dropped to 3.01mm and 2.62 mm at 1.96% and 2.86% reinforcement ratios respectively. This showed that similar to conventional concrete, RGC beams with higher reinforcement content have higher stiffness. This therefore showed that deflection assumptions and code recommendations for conventional concrete can be extended to reinforced geopolymer concrete beams (RGCB).

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1.0 Introduction

Portland cement is the main constituent of concrete. However, its production is responsible for approximately 5 to 8 % of the world's carbon dioxide (CO_2) emissions, thus, a greener building material needs to be developed as the binding agent (Lucy, 2018; and Barcello et al., 2020). Hardjito et al. (2004a) reported serious environmental degradation being faced by the world which is imperative to search for environmentally friendly materials in order to reduce CO_2 emission. Geopolymer cement on the other hand is environmentally friendly and can be deployed to produce a reinforced concrete (RC) structure or structural element, and for such structures, safety is the foremost design and construction parameter to be considered, the safety is conventionally ensured with codes of practice.

Geopolymers are synthesized by blending pozzolanic materials such as metakaolin, ground granulated blast-furnace slags (GGBS) and fly ash (FA). A strong alkaline solution such as sodium hydroxide (NaOH), potassium

hydroxide (KOH), and in most cases with soluble silicates such as sodium and potassium silicate are used for the synthesis. The alkaline solution dissolved the Al_2O_3 and SiO_2 species through geo-polymerization to set-up a three-dimensional amorphous alumina-silicate network. The strength of the final product is comparable to or more than that of OPC concrete (Ken *et al.*, 2015). They are sometimes called alkali-activated aluminosilicate binders.

Geopolymer concrete produced with the alkali-activated aluminosilicate binders has no code to be used in checking and controlling its behaviour. Hence, this research used the deflection code formulations for reinforced concrete. The deflection of conventional concrete structural members is usually controlled by assigning a cap to the span effective depth ratio Mosley *et al.* (2007), but there are equations in EC2 that specify limiting ratios for the span-effective depth of RC members. Additionally, EC2 limits deflection to a maximum of span/250 for beams, slabs, and cantilevers. Furthermore, it should be noted that according to Mosley *et al.* (2007), any deflection computed must be taken as an estimate because it does not perfectly describe what is happening in reality.

In Nigeria, RC design is mostly performed using the British code (BS 8110) which was withdrawn and replaced by Eurocode 2 in March 2010 (Mensah, 2015 and Aderinwale and Chinwuba, 2023). This implies that although Nigeria still used British code; eventually, Eurocode 2 would replace BS8110 as the most used RC design code in Nigeria. In the absence of codes of practice for emerging construction materials like geopolymer concrete, the safety levels associated with existing codes on the construction material to be used for structural purposes need to be assessed.

Additionally, the vast majority of research, Abdullah *et al.* (2011), Abdul Rahim *et al.* (2014), Zhang *et al.* (2020) carried out on geopolymer concrete focused on fly-ash, not metakaolin especially metakaolin sourced from Nigerian which could be used to produce structural-grade geopolymer concrete. The researchers focused on mechanical and micro-structural properties of the geopolymer concrete (Compressive, tensile and flexural strengths and also the use of micro-imaging and analysis techniques). The researchers did not consider the probabilistic reliability assessment considering inherent uncertainties in the geopolymer concrete (GPC) mix parameters as well as in the design variables of geopolymer reinforced concrete beams. Bai *et al.* (2018) noted that material properties, dimensions, and loadings affect structural members during service which could lead to failure if not properly handled during the analysis, design, and construction stages.

Geopolymer concrete (GPC) and conventional Portland cement concrete differ mainly in their binder system, yet extensive research has established the behavior of reinforced conventional concrete in line with existing design codes. However, limited studies have been conducted on reinforced geopolymer concrete, particularly metakaolin-based, leaving a gap in understanding its structural performance. This is especially critical given the absence of well-developed code provisions for predicting serviceability behavior such as deflection in geopolymer concrete beams. Therefore, this study investigates the properties of singly reinforced metakaolin-based geopolymer concrete beams and compares their behavior with conventional concrete code formulations.

2. Materials and Method

2.1 Materials

The Metakaolin used in this study was obtained by beneficiation and calcination of kaolin clay sourced from Kankara kaolin clay deposits in Kankara Local Government Area of Katsina State. The treatment was carried out at the Chemical Engineering Department, Ahmadu Bello University (A.B.U), Zaria. Aggregates were sourced locally. The aggregate is graded and of a nominal maximum size of 20 mm. Sodium Silicate (Na_2SiO_3), is a commercially available laboratory-grade sodium silicate in the form of a liquid gel purchased from a local supplier at Sabon-gari Local Government market, Kaduna state. The liquid is a gelatinous liquid with a sum of SiO_2 and Na_2O of 98.1 %. Sodium Hydroxide (NaOH) is a laboratory grade NaOH purchased at Sabon-gari Local government general market, Kaduna State. X-ray Fluorescence Spectroscopy (XRF) test was performed to identify the oxide composition of the geopolymer material and was conducted in the Multi-user Laboratory, Chemistry Department, A.B.U, Zaria using (X-Supreme 8000 XRF, Oxford, UK) analyser. The Steel Reinforcement (8mm, 10mm and 12mm) bars were purchased without any physical defects that might affect the steel's mechanical properties in conformity with BS 4449 (1997). It was obtained from a local supplier along Kongo road Tudun-wada Zaria, Kaduna state. Clean water was used as recommended by BS EN 196-1 (1995) in all preliminary tests on materials. Preparation of the alkaline liquid solutions as well as casting

operation of the specimens were all done at the heavy-duty/concrete laboratory of the Department of Civil Engineering, A.B.U, Zaria.

2.2 Method

2.2.1 Metakaolin production process

The powdered kaolin clay was placed in a furnace manufactured by RK industries India. It was heated (Calcined) for 3 hours at 800°C to obtain the Metakaolin. The choice of the duration and temperature was done to obtain a highly reactive metakaolin based on reports by Moodi *et al.* (2011), and Keeratikan and Janjit (2018).

2.2.2 Reinforced concrete beams test

The behaviour of singly reinforced Geopolymer concrete beam was assessed at three (3) different reinforcement ratios.

Material properties for the beams

The beam size and section property were chosen based on the size of available equipment required in the laboratory to produce the beams. However, the dimensions of the beams satisfy BS EN 12390-1 (2000). The nominal size of prism is resented in Figure 1. Also, reinforced geopolymer concrete beams with dimensions of 450mm x 100mm x 100 mm cross-sectional area were produced. The geopolymer concrete mix material, that is the proportion used was as established during mix design (Table 1). The mix produced for casting the beams achieved an average compressive strength of 32.8 N/mm² (as an average of three cubes). The specimens were allowed a resting period of 24 hrs under ambient temperature in the moulds after casting. Then, it's de-moulded weighed was wrapped in a polyethylene bag as recommended by Sameer (2015), and Jacob (2017) to prevent excessive evaporation. It was then placed in an oven and heated to cure for 24 hours at 60oC. The specimens were removed and weighed again and kept under ambient temperature until the day of testing. The choice of curing temperature and duration was as recommended by Heah *et al.* (2011), and Abdul Rahim *et al.* (2014). Plate VII shows a sample of wrapped geopolymer concrete cubes in an oven being prepared for heat curing.

Nine Metakaolin-based Reinforced Geopolymer Concrete Beams (RGCB) were produced where each set (three beams) were reinforced with two (2) 8mm, 10mm, and 12mm steel bars respectively and placed horizontally. It was Singly reinforced at at the bottom. A concrete cover of 15 mm was then provided. Plate I and II show the cast geopolymer RC beams containing the fresh concrete and the hardened de-molded beams.

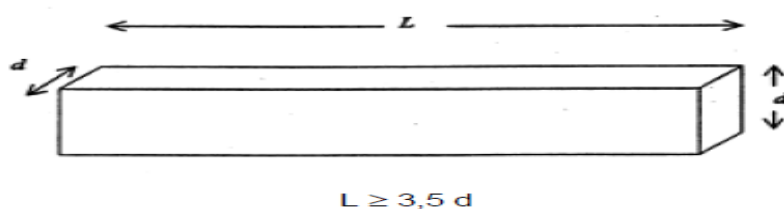


Figure 1: Nominal sizes of prisms (BS EN 12390-1:2000)

Table 1: Geoloymer mix design use for the production of reinforced concrete beam

S/No	Mc (Kg/m ³)	ALR (ALm)	Alr	Fa (Kg/m ³)	Ca (Kg/m ³)	Wc (Kg/m ³)	Slump (mm)	f _{ck} (N/mm ²)	
								Target	Acquired
I	400	0.9	3	546.7	1093.3	60	85	25	31.33

Beams bending test set-up

The test was conducted in the Strength of materials laboratory of the Mechanical Engineering Department, A.B.U Zaria. A universal testing machine model T42B3 produced by Saml-Denison and Sons Ltd Leeds England was used as the loading equipment. The loading capacity of the machine is 500kN and was set to a maximum of 100kN for this particular test. The test was conducted according to BS EN 12390 -5 (2009). One loading roller was positioned at the centre and then used. The beam was simply supported over two steel rollers (centre-point test). This is to ensure even distribution of the load between the rollers as required by the code

(Figures 2 and 3). A dial Gauge was placed at the bottom to measure the mid-span deflection (displacement). The machine was set to move at an average speed of 20mm/minute (0.33mm/sec). Readings were taken at 2 kN intervals simultaneously with the corresponding deflection reading until failure of the specimen. The test was conducted in triplicate.



Plate 1: Casting of the reinforced Metakaolin-based geopolymer concrete beams

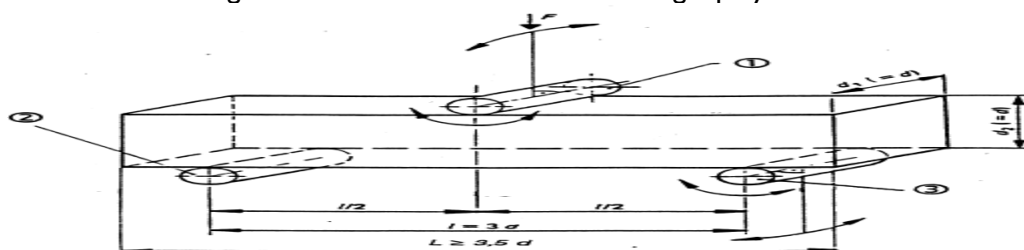


Figure 2: Centre point set up (BS EN 12390-5:2000)



Plate 2: Laboratory Beam Test set up

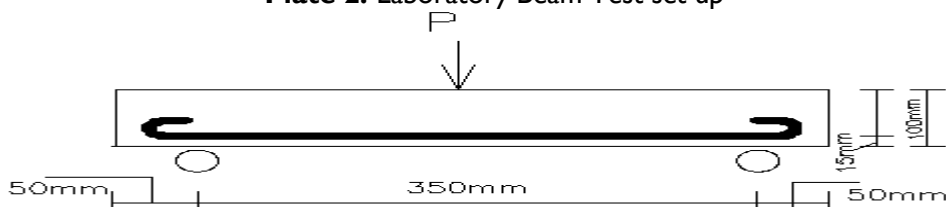


Figure 3: Loading and reinforcement detail of the RGCB

Reinforcement details for the sets of metakaolin-based geopolymer reinforced concrete beams are provided in Table 2

Table 2: Beam Dimension and Reinforcement Details

Beam	Dimension (mm)	Effective depth (mm)	Tensile reinforcement diameter(mm) and Area (mm ²)	Reinforcement ratio (%)
RGCB08	450×100×100	81	2Y8 (100.53)	1.24
RGCB10	450×100×100	80	2 Y10 (157.08)	1.96
RGCB12	450×100×100	79	2Y12 (226.19)	2.86

The tension reinforcements fall within the EC 2 limit of $0.13\% \leq \rho \leq 4\%$

Theoretical beam capacities based on Eurocode 2 formulations

The limiting deflection based on Eurocode's requirements according to Eurocode 2 is span/250 and the limiting span effective depth ratio is in equation (1):

$$\frac{l}{d} = K \left[11 + \frac{1.5\sqrt{f_{ck}}}{\rho - \rho'} \rho_0 + \frac{\sqrt{f_{ck}}}{12} \sqrt{\frac{\rho^1}{\rho_0}} \right] \text{ where } \rho > \rho_0 \quad (1)$$

ρ^1 = Compression reinforcement (Zero in this case), ρ^0 = Reference reinforcement ratio = $10^{-3} \sqrt{f_{ck}}$, $K = 1$ for simply supported beam

The deflection expressions captured on equation (1) was used to compute the deflection presented in the result

3. Results and Discussion

3.1 Reinforced Metakaolin-Based RGCB

The reinforced metakaolin-based geopolymer concrete beams produced using the established mix design and tested were analysed based on the type of failure experienced. It was observed that the failure was diagonal tension shear failure (Plate III) based on Clause 6.2.2 and also according to Zhang et al, (2024), and the relationship between load and deflection.

3.2 Failure Pattern of the Metakaolin Based RGCB

The behaviour of singly RGCB was studied at varying reinforcement ratios. The failure pattern of the beams was found to be the same for all the beams (Plate III). Similar to conventional cement reinforced concrete, the major failure mode for all the beams was a tensile shear failure. The failure is indicated by a diagonal tension failure (Lines 2 and 1) at an approximate angle of 45° , and the cracks developed were as a result of a tensile failure of the concrete. With an increase in loading, an inclined crack rapidly developed from the edge of the support to the point of load application leading to the splitting of the beam into two (diagonal tension failure). The cracks propagated from the tension face towards the compression face. The cracks appeared at the support and propagated diagonally towards the point of load application along the line of load action on either side of the beam. A vertical crack (Line 3) at the bottom was as a result of the concrete flexural failure. The crack propagated vertically, but the beams failed in diagonal tension before the vertical crack reaches the top fibre of the tension face at a point from whence the concrete flexural tensile capacity is exceeded. Additionally, the propagation of the vertical crack propagation might have been obstructed by the diagonal cracks. A similar diagonal tension failure mode was observed for all the specimens irrespective of the reinforcement ratio, the same failure mode was observed by Ikponmwoosa and Ehikhuenmen (2018).



Plate 3: Sample of the failure configuration of the geopolymer beam

3.3 Reinforcement Influence on the Load-deflection Curves

It is a known fact that the load-deflection curve is an important factor used for the evaluation of the mechanical behaviour of simply supported RC beams. Figure 4 shows the load-deflection curve for the three RGCB with reinforcement ratios 1.24%, 1.96%, and 2.86% respectively representing two 8mm, 10mm, and 12mm diameter tensile reinforcement bars placed at the bottom. A linear load-deflection curve was observed at the beginning of the loading since the concrete and steel were within the elastic region (load is directly proportional to deflection) which gradually became non-linear as the load increase after cracks have developed as reported by Shiyun et al. (2012) due to a gradual loss of stiffness of the beam with an increase in load caused by the failure of concrete in tension. As the load increases, the cracks become more pronounced. Once the tensile steel yields, the stiffness decreases further, leading to a rapid increase in mid-span deflection. Eventually, the load-deflection curve levels off and flattens, culminating in the beam's failure by diagonal tension (shear failure). Similar failure behavior has been reported Shiyun et al. (2012) and Jongho et al. (2017), for Portland cement concrete.

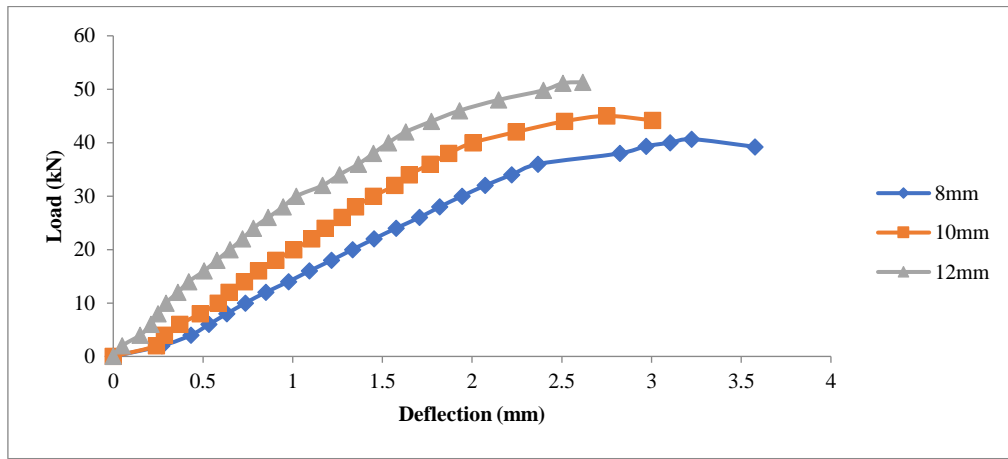


Figure 4: Mid-span load-deflection curves for the three reinforcement diameters

Comparing the three curves, it can be deduced that the reinforcement amount (ratio) plays a role in RGCB deflection. The load required for a deflection of 1mm when the reinforcement ratio is 1.24%, 1.96% and, 2.86% is 14kN, 20kN, and 29kN respectively. Similarly, a load of 20kN lead to a deflection of 1.33mm, 1.00mm, and 0.65mm for reinforcement ratios of 1.24%, 1.96% and, 2.86% respectively. This behaviour is in concurrence with conventional reinforced concrete beams, and the trend agrees with Langni *et al.* (2017) who reported an increase in failure load and decrease in deflection of beams with an increase in the amount of reinforcement.

Furthermore, Figures 5 and 6 illustrate that as the reinforcement ratio increases, the failure load also increases, while deflection decreases. Specifically, the failure load at a 1.24% reinforcement ratio was 39.23 kN, which then rose to 44.20 kN (an 11.7% increase) at 1.96% and further to 51.33 kN (a 29.7% increase) at 2.86% reinforcement ratios. Conversely, the maximum deflection at failure for the beam with a 1.24% reinforcement ratio was 3.58 mm, decreasing to 3.01 mm (a 15.9% reduction) and 2.62 mm (a 26.8% reduction) at 1.96% and 2.86% reinforcement ratios, respectively. These results indicate that RGC beams with higher reinforcement content exhibit greater stiffness, similar to conventional concrete. Consequently, deflection assumptions and code recommendations established for conventional concrete could be considered applicable for geopolymer reinforced concrete beams (RGCB).

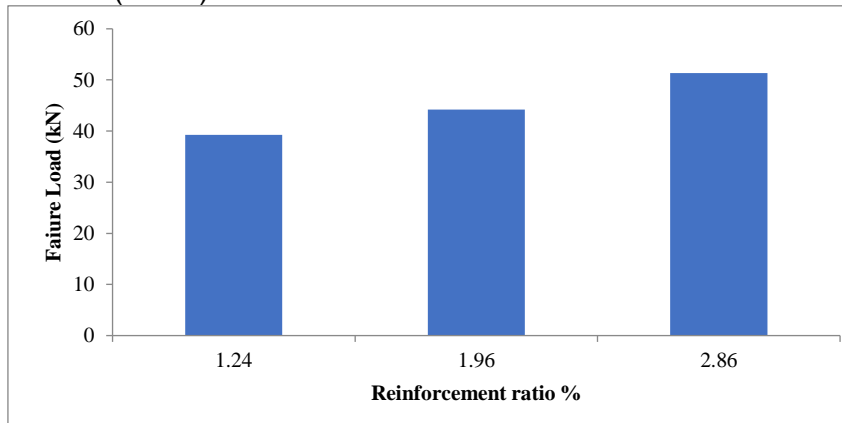


Figure 5: Failure load against the reinforcement ratio

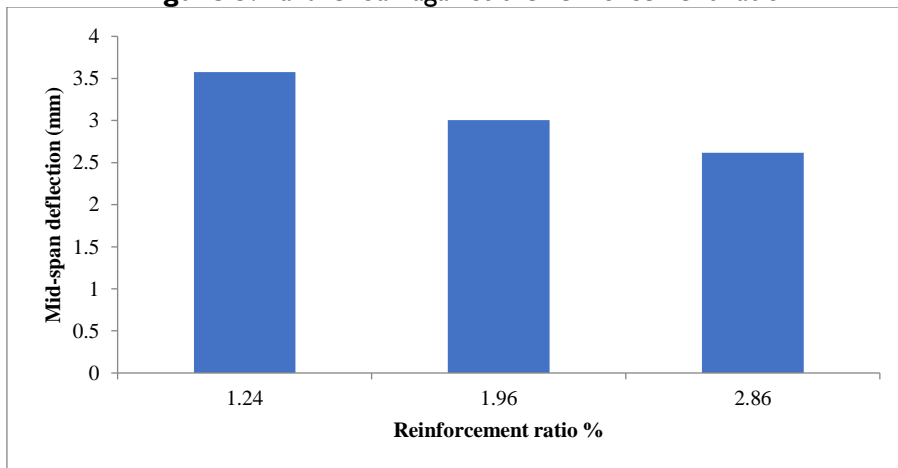


Figure 6: Maximum deflection against the reinforcement ratio

3.4 Deflection Analysis

Deflection is generally controlled by limiting the span effective ratio Mosley *et al.*, (2007), and the maximum limit is span/250. The limiting deflection value of 1.4 mm was reached when the applied load was approximately at 21, 29 and, 37kN load for RGCB08, RGCB10 and, RGCB12 respectively. The limit is reached before the yield load of 36 kN, 40 kN, and 43 kN of the beams respectively. It is noteworthy that limiting deflections for a simply supported beam to span/250 is actually a good practice and works well for Simply supported RGCB.

Table 3: Ultimate and limiting deflection of the RGCB

Beam	Ultimate deflection (mm)	Limiting deflection (L/250) (mm)
RGCB08	3.577	1.4
RGCB10	3.005	1.4
RGCB12	2.617	1.4

In Table 3, a comparison of the ultimate deflection at failure and the limiting deflection of span/250 was made. The ultimate deflections can be seen to be far greater than the limiting deflections since the values are at the ultimate limit state as reported by Jongho *et al.* (2017) who mentioned that code deflection expressions underestimate values from experimental results.

Table 6 is the actual L/d, Limiting L/d, and the beams limiting lengths based on the limiting L/d and beams effective depth. All beams satisfy the L/d limits (Based on EC2). It was observed that the beams can accommodate more than twice their experimental lengths without exceeding the limits. Moreover, a decrease in beams limiting length could be observed with an increase in reinforcement ratio. It was observed that a 17.1% decrease in limiting length was observed with RGCB12 when compared with RGCB08.

Table 6: Limiting EC2 L/d compared with Actual L/d

Beam	Reinforcement ratio (%)	L/d Actual	L/d Limiting	Limiting Length(mm)
RGCB08	1.24	4.32	14.97	1213
RGCB10	1.96	4.37	13.51	1081
RGCB12	2.86	4.43	12.72	1005

This decreases results from the formulation of EC2 for limiting L/d. The formulation might have taken into cognizance the fact that an increase in steel area increases the stiffness, which reduces beam deformation. For safety reasons, noticeable deformation is required to allow for ample warning before failure. In other words, the expression might have been formulated to reduce the length of the beam as the steel area increases so that the effect of beam length on beam deformation—an effect that, when coupled with a high reinforcement area, would lead to beam compressive strut failure curtailed.

4. Conclusion

The following conclusions were drawn from the results of the study:

- i. The dominant mode of failure of the beams is the diagonal tension shear failure.
- ii. Additionally, the behaviors of the RGC beams in deflection was found to agree with reports on conventional RC beams in terms of resistance to loading and effect of reinforcement ratio.
- iii. The load required for a deflection of 1mm when the reinforcement ratio is 1.24%, 1.96% and, 2.86% is respectively 14kN, 20kN, and 29kN; similarly, a load of 20kN lead to a deflection of 1.33mm, 1.00mm, and 0.65mm for reinforcement ratios of 1.24%, 1.96% and, 2.86% respectively
- iv. The maximum deflection at the failure of the beam with a 1.24% reinforcement ratio was 3.58mm which dropped to 3.01 and 2.62mm (by 15.9% and 26.8%) at 1.96% and 2.86% reinforcement ratios respectively, this showed that RGC beams with higher reinforcement content have higher stiffness similar to conventional concrete, and deflection assumptions and code recommendations for conventional concrete could be used for RGCB).
- v. It is recommended that Eurocode 2 formulations for conventional concrete can be employed for the analysis and design of safe Metakaolin-based geopolymer concrete structural members.

References

Abdul Rahim, RH., Azizli, KAZ. Man, T., Rahmiati and Nuruddin. MF. 2014. Effect of Sodium Hydroxide Concentration on the Mechanical Property of Non-Sodium Silicate Fly Ash Based Geopolymer. *Journal of Applied Sciences*, 14: 3381-3384.

Abdullah, MMA., Hussin, K., Bnhussain, M. 2011. Ismail, K.N.; Ibrahim, W.M.W. Mechanism and Chemical Reaction of Fly Ash Geopolymer Cement—A Review. *Asian J. Sci. Res.*; 2011; 1, pp. 247-253.

Aderinwale, A. and Chinwuba A. 2023. Review of BS 8110, EC2, and the Improved EC2 shear resistance models for stirrup in reinforced concrete beams. *Res. Eng. Struct. Mater.*; 9(2): 351-362. <http://dx.doi.org/10.17515/resm2023.497ma0810>

Bai, L., Jiang, F., and Fan, B. 2018. Reliability Analysis of Reinforced Concrete Columns after High Temperature under Comprehensive Considering Failure Paths. *Journal of Nanoscience and Nanotechnology Applications. Scholarena*, 2(2): 1-10

Barcello, L., John, K., Guther, W., Ellis, MG. 2020. Cement and Carbon Emissions. *Materials and Structures*, 47(6): 1055-1065. Doi:10.1617/511527-013-0114-5

BS EN 196-1 1995. Method of Testing Cement: Determination of Strength. British Standards Institutions London

BS 4449 1997. Carbon Steel Bars for the Reinforcement of concrete. British Standards Institutions London.

BS 4449 1997. Carbon Steel Bars for the Reinforcement of concrete. British Standards Institutions London.

BS EN12390-1 2000. Testing hardened concrete: Shape, dimensions and other requirements for specimens and moulds. British Standards Institutions London

Eurocode 2 2004. Design of concrete structures—Part 1-1: General rules and rules for buildings. London: British Standard Institution, 37.

Heah, CY. Kamarudin, H. Mustafa Al Bakri, AM. Binhussainb, M., Luqman, M. Khairul Nizar, I. Ruzaidi, CM. and Liew, YM. 2011. Effect of Curing Profile on Kaolin-based Geopolymers. *Proceedings of 2011 International Conference on Physics Science and Technology (ICPST 2011)*. 305-311

Ikponmwosa, EE., and Ehikhuenmen, SO. 2018. Flexural Behavior of Concrete Beams Containing Ceramic Waste As Replacement Of Coarse Aggregate. *ANNALS of faculty of Engineering Hunedoara-International Journal of Engineering Tome XVI Fascicule*.

Jacob, EA. 2017. Evaluation of the properties of Matakaolin based Geopolymer Concrete made with Recycled concrete Aggregate. Unpublished MSc Dissertation submitted to the Department of Building, Faculty of Environmental Design, Ahmadu Bello University, Zaria

Jongho, PI., Jinwoong, C., Yong, SP., and Sungnam, H. 2017. An Experimental and Analytical Study on the Deflection Behavior of Precast Concrete Beams with Joints. *Appl. Sci.*, 7, 1198.

Keeratikan, P, and Janjit, I. 2018. Characteristics of meta-kaolin geopolymer Bender-Element (BE) test. *Science Direct Materials Today Proceedings* 5, 5120–15125.

Ken, PW., Ramli M. and Ban, CC. 2015. An overview on the influence of various factors on the properties of geopolymer concrete derived from industrial by-products. *Journal of Construction and Building Materials*, 77. 370–395.

Langni, D., Jinchao, M., Jun, M., Risheng, L., and Xiaoxia, H. 2017. Research on Calculation Methods for Ductility of RC Beams with Near-Surface Mounted CFRP Plate Reinforcement. *2nd International Conference on Information Technology and Industrial Automation (ICITIA 2017)*.

Lucy, R. 2018. Climate Change: The massive CO₂ emitter you may not know about. Climate Change. www.bbc.com/news/science-environment-46455844

Mensah K. 2015. "Reliability Assessment of structural concrete with special reference to stirrup design", PhD Thesis, University of Stellenbosch, South Africa.

Moodi. FAA., Ramezaniapour, A. and Safavizadeh. S. 2011. Evaluation of the optimal process of thermal activation of kaolins. *Scientia Iranica* 18(4): 906-912

Mosley, WH., Bungey, JH., and Hulse, R. 2007. Reinforced Concrete Design (6th Ed). Palgrave Macmillan, New York.

Sameer UB. 2015. Effect of Alkali materials on Geopolymer concrete. *International Journal of Civil Engineering and Technology (IJCET)*. 6(1): 01-13.

Shiyun, X., Wenbo, C. and Haohao, P. 2012. Experiment of Reinforce Concrete Beams at Different Loading Rates. 15 World Conference on Earthquake Engineering (WCEE) LISBOA 2012

Zhang, L., Deng, B., He, B., Jiang, H., Xiao, J., Tian, Y., and Fang, J. 2024. Experimental investigation on shear behavior of non-stirrup UHPC beams under larger shear span–depth ratios. *Buildings*, 14(5), 1374.

Zhang, P., Gao, Z., Wang, J., Guo, J., Hu, S., and Ling, Y. 2020 Properties of fresh and hardened fly ash/slag based geopolymer concrete: A review. *J. Clean. Prod.* 270: 122389.