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Reliability Assessment of Natural Aggregate- Pulverized Glass Powder Concrete Beam Subjected to Shearing Forces

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ABSTRACT

Cement is the most expensive ingredient in the process of making concrete. Reducing the quantity of cement used in the production of concrete with Pulverized glass powder (PGP) will reduce the cost of concrete production and help tackle environmental, disposal and CO_2 emission challenges. The results of structural reliability assessment performed on Pulverized glass powder concrete produced using locally sourced Natural aggregate (NA) as coarse aggregate. Concrete cubes measuring 150 × 150 ×150 mm were cast, cured for 28 days and tested using the universal compressive testing machine. First order reliability method (FORM) was employed to determine the level of safety of the reinforced concrete beam. Result of sensitivity analysis under shearing forces shows the beam is structurally safe at a span of 3250 mm with Probability of failure (P_f) of 1.14×10^{-3}, Effective depth of 459 mm and corresponding Probability of failure (P_f) of 5.77×10^{-8} and an Area of Shear reinforcement (A_{sv}) of 201 mm^2 with Probability of failure (P_f) of 5.01×10^{-5}.

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1. Introduction

Concrete is a major material used in construction over the world. It is gotten by mixing cement, water and aggregates together in right proportions. Aggregates make up about 75% of total concrete mass as such are an extremely important factor in determining the quality of concrete [1].

The practice of exploring the potentials of incorporating agricultural and industrial wastes as suitable substitutes for conventional aggregates in the practice of producing concrete is gaining grounds; this is as a result of economic and environmental sustainability reasons [2]. Utilizing such wastes in concrete production is timely and justifiable especially for a developing Nation like Nigeria in which the cost of materials for construction keeps increasing [1,3].

[4] opined that incorporating local materials in the construction of Civil engineering structures has become a challenge which construction professionals are expected to rise up to because huge quantities of locally available raw materials which could be used in construction abound. Furthermore, using these locally sourced materials will go a long way in achieving industrialization and economic independence hence the growing interest in understanding the mechanical or structural properties of the concrete produced using these wastes.

According to [5] the cement Kiln emissions contributes substantially to environmental pollution. Several toxic metals are emitted in large volumes. Furthermore, noise emission is associated with virtually all the processes in cement manufacture. These highlighted environmental impacts seriously contribute to global warming, acidification and marine ecotoxicity.

Cement manufacturing plants use an extensive amount of raw materials processed at extreme conditions with very high temperatures. The high temperature processing (pyroprocessing) treats raw materials at high temperatures to result in solid-state reaction. Coal, fuel oil, natural gas, hazardous wastes, petroleum coke and basically anything combustible are used as fuel. In order to produce 1 ton of clinker, 1.52 tons of raw materials are used averagely. The 0.52 ton is usually converted to Carbon dioxide. This is a serious environmental problem because the increase in the amount of CO_2 in the atmosphere has direct consequences on the global warming phenomenon [5].

Cement is an essential component of construction and is key to the survival of the construction industry. Hence, there is no alternative to it as its production remains mandatory. Equally, controlling the amount of pollution emanating from the cement manufacturing industry is very important as such identifying various waste materials that can reduce the amount of cement used in construction is timely [6].

Modern structural engineering makes a case for the use of structural reliability and probabilistic methods in analyzing structural elements. This aids in achieving an economical, safe, elegant and functional structure which meets client specifications and request [7]. Reliability is the probability of a structure to perform adequately for the period in which it was designed for under operating conditions encountered. It is the ability of a structure to complete a predetermined function in a certain time frame under specified conditions [3]. It is a tool for predicting the level of safety and probability of failure of a structure during its service life. Figure 1 depict a typical reinforced concrete beam undergoing shear failure.

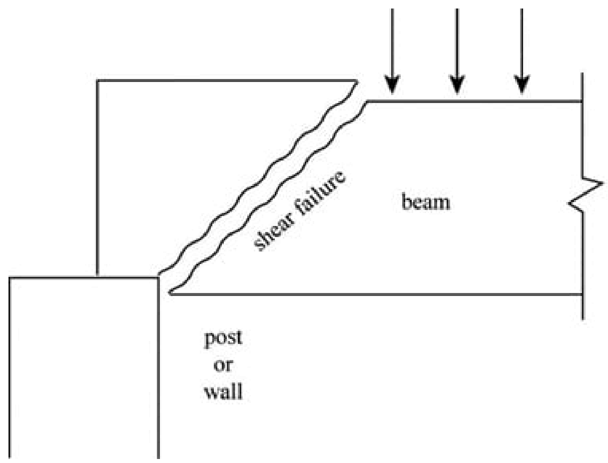

Fig. 1. Beam under shear mode of failure.

The Natural aggregate (NA) used as coarse aggregate for concrete production was sourced from Bida environs, it is brownish red in color. This aggregate is conveniently employed for mass concrete production with its suitability for use in reinforced concrete elements still being investigated [1] performed reliability analysis on this NA, the research used washed and unwashed NA. currently no research exists on structural reliability conducted utilizing this NA and pulverized glass powder hence this research is timely and justifiable.

2. Research significance

Cement is a very vital constituent in the process of producing concrete. The industry is a leading source of carbon dioxide emissions along with burning of fossil fuels and deforestation. Emission of these gases into the atmosphere results in global warming with CO_2 contributing about 65% to global warming. The cement industry worldwide is believed to be the source of about 7% of the entire greenhouse gas emissions on planet earth. Sequel to this premise, there exist an urgent need to identify alternative binders to make concrete. This reality has resulted in extensive research into the possibility of using waste materials and industrial by-products as partial cement replacement in concrete production [8].

3. Methods

Ordinary Portland cement (OPC) was used in the production of concrete, OPC was purchased from local cement retailer in Minna, Niger state. It conformed to guidelines in [9]. The fine aggregate was gotten from a river in Chanchaga Minna, Niger state. It conformed to requirements for fine aggregate used for concrete production as stated in [10]. Clean portable drinkable water from the civil engineering departmental laboratory of the Federal University of Technology Minna, Nigeria was used for producing concrete, the water met requirements stipulated in [11,12]. The coarse aggregate (NA) conformed to guidelines in [10] it is specifically situated on Longitude 5°N 52'E and latitude 9°N 55'E while the waste glass was collected from a local glass/aluminum retailers shop in Minna and transported to civil engineering laboratory where it was further processed into the pulverized glass. The NA and Pulverized glass are depicted in Figures 2 and 3 respectively.

Fig. 2. Natural aggregate.

Fig. 3. Pulverized glass powder.

First order reliability method (FORM) was the method employed in conducting the reliability assessment of the beam. FORM was first reported in literature by [5], it is sometimes referred to as Mean value first order second moment method (MVFOSM). The mean and standard deviations of the variables are utilized here, all variables are assumed to be normally distributed. It is particularly useful in analysis of structural reliability limit states to determine the probability of failure (P_f) measured by the reliability index (β). It uses limit state equations as a tool for measuring the level of reliability [1,3,13].

The performance function for a reinforced concrete beam undergoing shear failure is given thus:

$$g_1 = S_u - R_v \tag{1}$$

Equation (1) can further be transformed into (2):

$$g_1 = \frac{\mathrm{Asv}}{\mathrm{Sv}} \times 0.87\mathrm{fyd} + bV_c\,\mathrm{d} - \frac{1}{2}wL \tag{2}$$

where S_u is the shear force at the end of the beam and R_v is the shear resistance of the beam.

Table 1
Input parameters for Shear mode of failure.

Parameter	Mean	C.O.V	STD
Area of Shear reinforcement, A_{sv} (mm^2)	101	0.04	4.04
Width of beam, b (mm)	225	0.1	22.5
Span of Beam L, (mm)	4000	0.1	400
Dead load, DL (kN/m)	17.70	0.2	3.54
Live load, LL (kN/m)	3.33	0.2	0.67
Shear reinforcement spacing, S_v	447	0.04	17.88
Effective depth of Beam, d (mm)	359	0.1	35.9
Yield Strength of Steel, f_y (N/mm^2)	460	0.05	23

C.O.V: Coefficient of variation
STD: Standard deviation
All input parameters are assumed to be normally distributed

4. Results

Figure 4 presents the result of the compressive strength test performed on the pulverized glass concrete. The figure reveals a steady decline in the compressive strength values with successive increase in the pulverized glass (PG) content. The 5 percent PG content with compressive strength value of 18.70 N/mm^2 was chosen and used for reliability studies in this research.

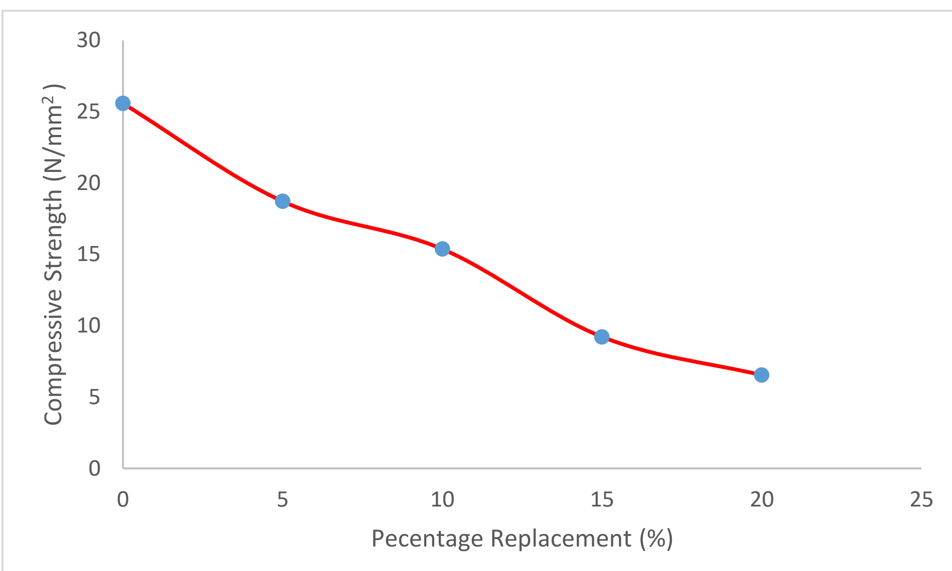

Fig. 4. Compressive strength values for various Pulverized glass content.

Figure 5 presents the result of the sensitivity analysis conducted on the span of the Pulverized glass powder (PGP) concrete beam under shearing forces. An increase in the beam span returned lower values of safety indices, these values were lower than the 3.0 target reliability (β_T). A decrease in the span however resulted in higher safety indices. The decrease is attributed to the fact that an increase in the beam span results in increased bending moments which is a major causation factor in beam bending. The beam was adjudged to be safe at a span of 3250 mm with reliability index of 3.05 and probability of failure (P_f) of 1.14×10^{-3}.

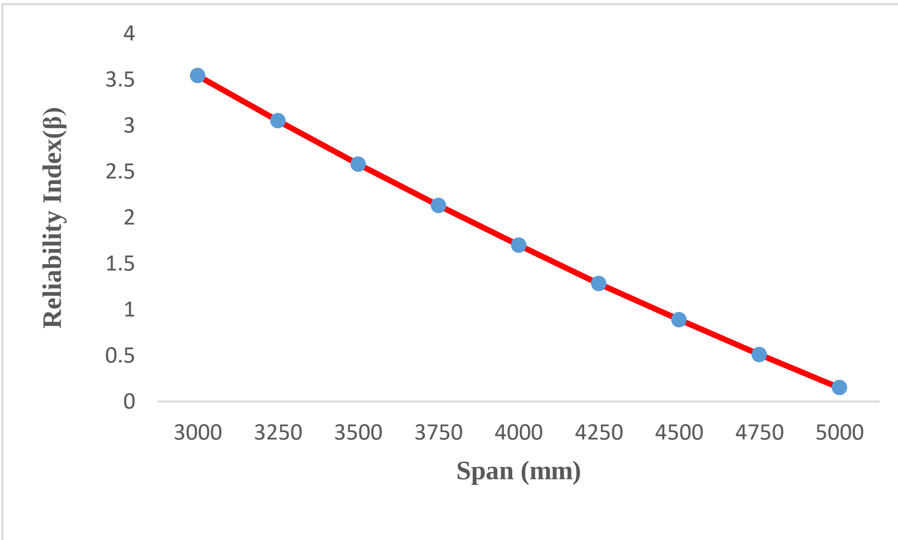

Fig. 5. Reliability Index-Span Relation for the beam.

The relationship between the Effective depth of the beam and reliability index is presented on Figure 6. An increase in Effective depth resulted in higher reliability index values. The beam was determined to be safe at an Effective depth of 459 mm with reliability index of 3.29 and P_f of 5.77×10^{-8}.

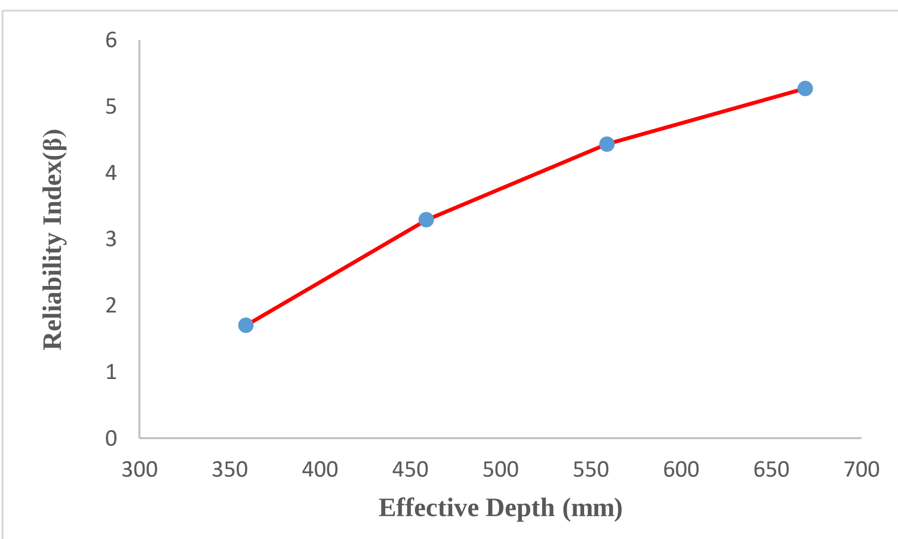

Fig. 6. Reliability Index-Effective depth for beam.

The result of sensitivity analysis conducted on the PGP concrete beam varying the Area of shear reinforcement (A_{sv}) is presented on Figure 7. An increase in the A_{sv} returned higher reliability indices. The PGP concrete beam was adjudged to be structurally safe at A_{sv} of 201 mm^2 with reliability index value of 3.89 and Probability of Failure (P_f) of 5.01×10^{-5}.

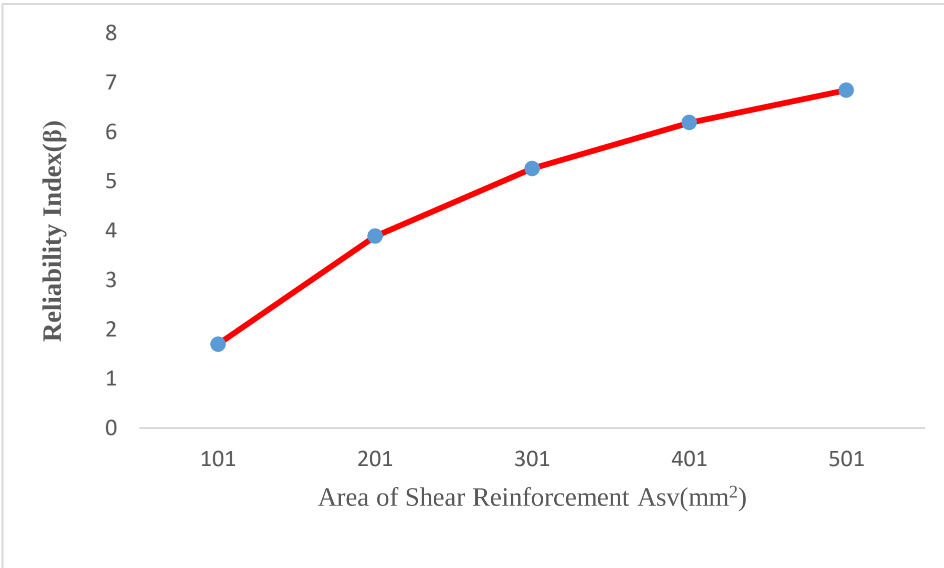

Fig. 7. Reliability Index-Area of Shear reinforcement Relation for beam.

5. Conclusions

This research examined the structural reliability of reinforced concrete beam produced with locally available coarse aggregate and pulverized glass powder as partial replacement for cement. The result showed 5% pulverized glass content returned a 28 days compressive strength of 18.70 N/mm^2. Sensitivity analysis performed revealed that:

The reinforced PGP concrete beam subjected to shearing forces is structurally safe at a span of 3250 mm, Effective depth of 459 mm and Area of shear reinforcement of 201 mm^2 with probabilities of failures of 1.14×10^{-3}, 5.77×10^{-8} and 5.01×10^{-5} respectively. The beam span and depth are critical factors to be put into consideration when designing reinforced concrete beams using PGP.

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Conflicts of interest

The authors declare no conflict of interest.

Authors contribution statement

DNK: Conceptualization; SSK: Data curation; SSK: Formal analysis; HAM: Investigation; FA, DNK: Methodology; SSK: Project administration; HAM: Resources; DNK: Software; DNK: Supervision; DNK: Validation; DNK: Visualization; DNK, SSK: Roles/Writing – original draft; DNK, SSK, HAM: Writing – review & editing.

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