Nigerian Research Journal of Engineering and Environmental Sciences 5(1) 2020 pp. 97-104

Nigerian Research Journal of Engineering and Environmental Sciences
Journal homepage: www.rjees.com

Original Research Article

Structural Stress Characteristics of Glass Fiber Reinforced Concrete Beam

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ARTICLE INFORMATION

Article history:
Received 05 Feb, 2020
Revised 31 Mar, 2020
Accepted 01 Apr, 2020
Available online 30 June, 2020

Keywords:
Nonmetallic
Glass fibre polymer
Conventional steel
Stress distribution
Flexural strength

ABSTRACT

The use of nonmetallic reinforcement in concrete structures because of the limitation of conventional steel due to corrosion and salt attacks has led to many research works all over the world. Materials such as glass fiber reinforce polymer (GFRP), carbon nanotubes (CN), fiber reinforced polymer (FRP), polyethylene terephthalate (PET) have been researched and many of these materials have performed well. The aim of this work was to determine the stress characteristics of glass fibre reinforced concrete beam. The flexural strength, bending stress, shear stress, deflection and stress distribution of the beams were determined. Conventional steel reinforced concrete beam and unreinforced beam were used as control in the experiment. The result generally showed that fibre reinforced concrete beam performed better than the unreinforced beam but was about eighteen percent less in performance when compared with the steel reinforced beam. Stress distribution in the fibre reinforced beam was very similar to that of steel reinforced beam, while distribution in the unreinforced beam showed a clustered stress at the mid span of the beam where there was maximum load.

1. INTRODUCTION

Concrete is the most used human-made material extensively applied in all of construction projects. Concrete has high strength when loaded in compression; however, when loaded in tension the strength is assumed to be zero in ultimate strength design (Qissab and Abass, 2016). Due to this weakness in tension, concrete has been reinforced with steel and sometimes wire mesh in reinforced concrete and wire strand in prestressed concrete.

Concrete with conventional reinforcement is susceptible to ageing and deterioration as a result of exposure, usage, salt attack and corrosion (Metha, 2000). The effects of these processes may accumulate within traditional concrete structures over time to cause failure under design conditions, or lead to repair (Atutis *et* *al.,* 2013). Because of these limitations, the use of nonmetallic materials as alternative reinforcement in concrete have been under research for some time now.

The use of carbon nanotubes was investigated by Qissab and Abass (2016), and in the study, a control beam was used with the conventional steel bar, while six other beams were reinforced with multiwall carbon nanotubes (MWCNTs) at different concentration of 0.03, 0.045 and 0.06% by weight. Mechanical test was carried out on the concrete samples, while ultrasonic pulse velocity test was used to evaluate the porosity of concrete nanocomposite. The work concluded that the use of MWCNT reduced the workability and porosity of concrete composite, while there was an improvement in the load carrying capacity and the deflection of concrete. The use of glass fibre reinforced polymer (GFRP) in concrete beams was investigated by Atutis *et al.* (2013). Flexural strength, deflection and crack test were conducted on both reinforced and prestressed concrete beams. The work concluded that for prestressed concrete, high strength GFRP rebar should be used effectively. Timinskas *et al.* (2013) investigated the accuracy of design methods for fibre reinforced polymers (FRP). The work inferred that current reinforced concrete design codes and recommendations are based on empirical and simplified methods of strain evaluation, which may be inadequate for design of structures with composite bars. Based on previous research on the advantage of FRP especially in concrete structures subjected to aggressive environment and to the positive effect on electromagnetic field, the application and design of concrete using FRP was reviewed by Gudonis *et al.* (2013). The review showed that the application of FRPs remain limited by the solution to simple structural problems that mainly appear due to the absence of design codes.

The review highlighted the main problems restricting the application of FRPs in building industry and revealed the problematic issues in relating to the material properties of FRP for the design of reinforced concrete. The paper concluded that attention should be given to the long-term mechanical process taking place in concrete elements with FRP reinforcement. The development of standard shape of internal FRP bars and anchoring measures for external reinforcement, and the development of standard design procedure for the application of unified internal and external reinforcements are still under investigation. Evbuomwam (2013 a,b) also worked on the behaviour of normal and high strength concrete beams reinforced with GFRP rods. Another of his work also examined the Flexural behavior of GFRP beams in composite action with concrete. The conclusion of both works encouraged the technology behind the use of GFRP as reinforcement in concrete.

Apart from GFRP and FRP, there are other nonmetallic materials that had been used as reinforcement in concrete. Kim *et al.* (2016) used steel fibres in reinforced concrete beams. The flexural strength was predicted using the four-point loading method on eleven steel fibre reinforced concrete (SFRC). The test results confirmed that ultimate flexural strength increased with increasing fibre volume contents. Akinyele (2013) examined the effect of temperature on the behaviour of polymer reinforced concrete façade. The work subjected steel and polymer reinforced concrete façade to a temperature of over 50 ^{o}C and later to loading. The study concluded that steel is still the best reinforcing materials available, but its limitation under high temperature, corrosion, and chloride attacks has made other materials like GRFP, FRP, and polymers an attractive alternative.

The use of non-metallic materials as reinforcement or strength enhancers in concrete may not be popular due to factors like availability, financial cost, production of the material, and established standard codes of procedures. But some codes like the ACI and CAN/CSA codes for America and Canada allow the use of GFRP reinforcement for some concrete structures (CAN/CSA 2002; ACI 1996, 2011). Therefore, the aim of this research is to determine the structural stress generated and stress distribution in glass fibre reinforced concrete beams in relation to its flexural strength.

2. MATERIALS AND METHODS

2.1. Materials

The beams that were used in this research were of dimensional size 150 x 150 x 500 mm, which was divided in to three types. Beam B1 was reinforced with the conventional steel reinforcement of 10 mm diameter, B2 was reinforced with the glass fiber polymer (GFP), while B3 was not reinforced with any material as it was a plain concrete beam. Eighteen (18) beams were cast during the experiment, with each sample type having six numbers. The glass fibers used are of Cem-FIL Anti-Crack HD with modulus of elasticity 72 GPa, filament diameter 14 microns, specific gravity 2.68, length, aspect ratio of 857.1, tensile strength 2500 Mpa, elongation breaks 3.6%, density 2780 kg/m^3 and with a white color. Plate 1 showed the glass fibres being mixed with concrete. The glass fibre was obtained from a glass manufacturing industry in Lagos, Nigeria. Limestone Portland cement of grade 42.5R available in local markets was used in the investigation. The cement used has been tested for various proportions and found to conform to various specifications of BS: 12-1978 (BS 1978). The specific gravity was 3.02 and the fineness was 3200 cm^2/gm. Crushed angular granite from a local quarry was used as coarse aggregate. The size of the aggregate used was 20 mm downsize and 12.5 mm down angular type coarse aggregate. Grading of the sand was such that a mortar of specified proportions was produced with a uniform distribution of the aggregate, which had a high density and good workability, and which was worked into position without segregation and without use of high water content. The fineness of the sand was such that 100% of it passed standard sieve.

Plate 1: Glass fibres mixed with concrete

2.2. Methods

2.2.1. Casting of beams

The casting was carried out using metal molds which was primed with oil for easy demolding process. All the samples were cured in water at a temperature of 23 $\pm$ 2 ^{o}C for seven and twenty-eight days.

2.2.2. Mechanical tests

Flexural test was carried out on the concrete beams after 7 and 28 days of curing. This test determined the bending (flexural) strength of the concrete beams. The test was based on BS 1881 part 118 (BS 1983), where the beams were placed under the universal testing machine and subjected to a central point loading (Plate 2). The beams were subjected to continuous loading till failure occurred. The flexural strength of the beam was expressed as the modulus of rupture (f) which equals the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen, in cm, *f* was calculated to the nearest 0.1 N/mm^2 as follows:

$$f = Pl/bd^2 \quad (1)$$

Where *P* is the applied external force, *L* is the beam span, *b* is the width of beam and *d* is the beam depth.

During loading of any structure, internal stresses are developed due to the application of external load on the structure. These are the stress that tend to resist the external load and are developed at both the compressive and tensile area of the beam but almost at zero in the neutral axis. The distribution of these stresses increased from the neutral axis towards the surface of the structure. The bending and shear stresses are developed to resist forces due to bending moments and shear force. These values were determined at failure load using the following established stress equations for a rectangular section subjected to pure bending.

$$\sigma = Mx / I \quad (2)$$

$$\tau_{xy} = Fay/Ib \quad (3)$$

Equation 2 is the bending stress, while Equation 3 is for the shear stresses in the beam structure. Where *Mx* is the bending moment along the *x* axis, *I* is the second moment of area about neutral plane, *F* is the shear force, *a* is the area under consideration, *y* is the distance from neutral axis, while b is the breadth of the beam.

Plate 2: Flexural test of beam

3. RESULTS AND DISCUSSION

3.1. Flexural Strength Test

The results in Figure 1 showed the reaction of beams to the externally applied load. Beam B_1 had the highest flexural strength both at the 7 and 28-day test, of 54.24 N/mm^2 and 75.21 N/mm^2 respectively. Beam B_2 had values of 50.33 N/mm^2 and 58.63 N/mm^2 at 7 and 28 days. The difference in the values between the two beam types is about 18%, while the plain beam B_3 had values of 9.12 and 15.68 N/mm^2 at 7 and 28 days, respectively. These values were about 78% less than the beam containing GFP. It can be observed that Beam B_2 that contain glass fibre performed better than B_3, this can be attributed to the role played by the glass fibre within the concrete matrix. The fibre acted like a filler, by filling up voids within the concrete, it also allowed proper bonding in concrete. During the loading of the beam, the glass fibre contributed to the internal stresses developed, this is because when a simply supported beam is subjected to external point load at the mid span, internal tensile and compressive stresses are developed to resist the external load and to keep the concrete material at equilibrium.

The more applied external load, the higher will be the stresses developed within the concrete. If more loads are continually applied to the beam, tensional reinforcement will be required in the beam to assist the tensile stresses in the resistance of the external load, since concrete is weak in tension but strong in compression. The glass fibre also played the role of a reinforcement in Beam B_2. At a stage during the loading, the yield point of the reinforced concrete beam will be attained; before this stage the concrete is believed to be within its elastic limit. If the loading continues beyond the elastic limit, the plastics phase will set in, which is a point of no return. When the load is removed at this point, the concrete will not return to its initial stage because it has yielded.

The effect of both the tensile stress and reinforcement will not be able to resist this load any more, tensional cracks are developed, and the beam will eventually rupture and fail. The nature of concrete is that it is a ductile material, and can be classified as an elastoplastic material, such material behave in an elastic manner until the elastic limit is reached after which they behave plastically. The flexural strength result had revealed that steel reinforced beam B_1 has the highest resistance to loading and modulus of rupture, this is because of the conventional steel reinforcement used in the beam, while beam B_2 was next and B_3 had the least resistance to external loads. The result obtained from this work is similar to the work of Akinyele *et al.* (2019) where polyethylene terephthalate (PET) reinforcement was used in concrete beam. The researched revealed that PET reinforcement performed better than the beam sample without reinforcement, but lower than the sample that contains the conventional reinforcement.

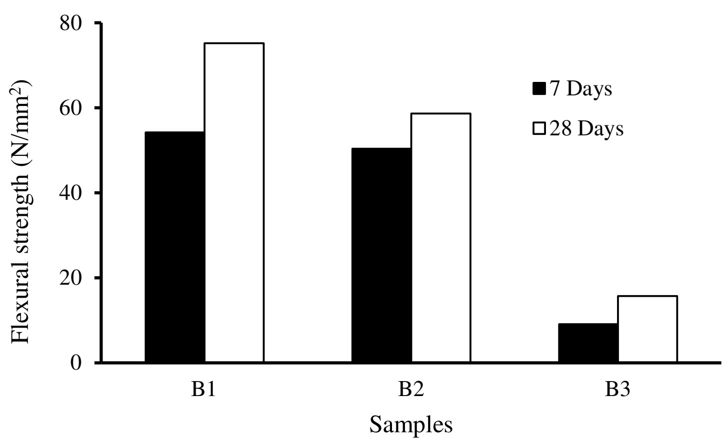

Figure 1: Flexural strength test result

3.2. Stress Distributions in Beams

At sections of beam, there is a variation of direct stress throughout the depth of any section. The upper fibres which are stretched longitudinally contract (compression), while the lower fiber extends laterally (tension).

Thus, the whole section of the beam is distorted. The distortion in the beam section is as a result of bending and shearing stresses. The amount of bending and shear stresses generated within the reinforced concrete beams are shown in Table 1. The bending stress of 14.25 N/mm^2, 11.73 N/mm^2 and 3.13 N/mm^2 were for obtained for beams B_1, B_2 and B_3 respectively, while the shear stresses for B_1, B_2 and B_3 were 1.43 N/mm^2, 1.7 N/mm^2 and 0.33 N/mm^2 respectively. These stresses were generated because of reaction within the concrete particles in response to the external load. Concrete being a homogeneous material will require a lot of interfacial forces (Van der Waals forces), to hold itself together against an external force. The bending stress is generated due to pure bending in the concrete beam and showed the amount of material resistance to bending. The value obtained for each beam is due to the type and amount of reinforcement within the concrete matrix.

Beam B1 had the highest value due to the presence of steel reinforcement that provided additional strength to the concrete. Beam B_2 had the next higher stress value because of the presence of glass fiber polymer (GFP). The GFP mixed with the concrete matrix and increased the bonding within the homogeneous concrete material, although the stresses generated were less than steel reinforced concrete beams due to its low mechanical properties, but it performed better than B_3 which happened to be a plain concrete. The shear stress showed the amount of material resistance to shear force before the cracking of concrete.

The distribution of stresses within the beams showed that the stresses were highest at the mid span for each beam while very low at the support. However, beam B_3 had clustered stresses at the mid span and the reason for this cluster was because there was no reinforcement in the beam to help distribute the stresses like that of beams B_1 and B_2. The same condition applied to the deflections of beams as shown in Figures 2 to 4. The value of bending stress obtained for each beam in Table 1, correspond to the amount of stress distribution shown in Figures 2 to 4. Beam B_1 had the highest stress distribution when compared to B_2 and B_3. The deflection in beam B_1 was 0.03 mm at the mid span and 0.01 mm close to the support and 0.00 mm at the support. Beam B_2 had a maximum deflection of 0.02 mm at the mid span, it became 0.01mm prior to the support and 0.00 mm at the support. Beam B_3 had a maximum deflection of 0.01 mm at the mid span, showing that B_3 collapsed earlier when compared to the two other beams. It cannot resist the externally applied load due to the absence of reinforcement and GFP that would have allowed some stability before eventual failure.

The implication of all these results is that the GFP performed well in concrete as alternative reinforcement, although the value obtained is lower than that of steel reinforced concrete, but better when compared to beams without any form of reinforcement.

Table 1: Stress generated in beams

Beam types	Bending moment (kN/m)	Bending stress (N/mm^2)	Shear stress (N/mm^2)	Shear force (kN)
B_1	8.46	14.25	1.43	33.85
B_2	6.60	11.73	1.76	26.38
B_3	1.76	3.13	0.33	7.84

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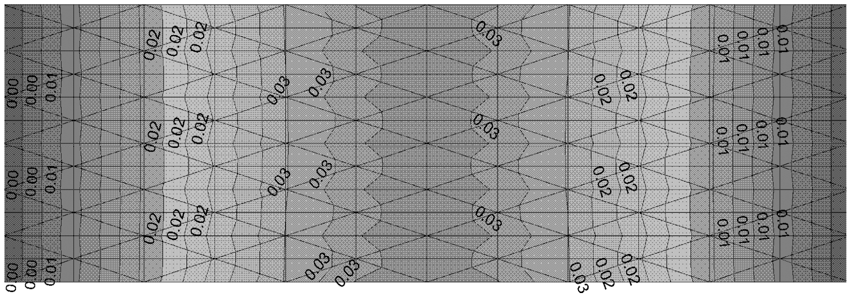

Figure 2: Stress distribution and deflection in beam B_1

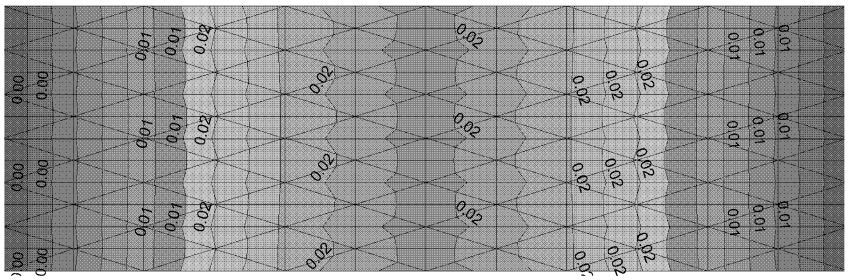

Figure 3: Stress distribution and deflection in beam B_2

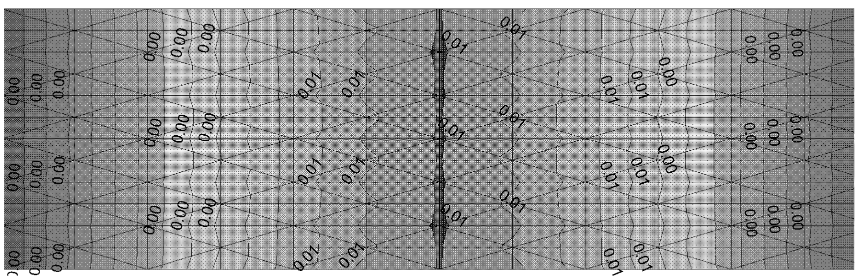

Figure 4: Stress distribution and deflection in beam B_3

4. CONCLUSION

This work has succeeded in examining the stresses generated and distributed in such beam when compared with the conventional steel reinforced beam. It can be concluded that the difference between the bending and shear stresses of GFP reinforced beam and steel reinforced beam is about eighteen percent. This is very small when compared to unreinforced concrete beam which is about seventy eight percent. Stress distribution pattern for both types of beam are very similar with little difference, while unreinforced beam has majority of its stresses clustering together at the mid span of the beam where the load is highest.

5. ACKNOWLEDGMENT

The authors acknowledged the contributions of the staff of the Department of Civil Engineering laboratories of both Federal University of Agriculture, Abeokuta, and Moshood Abiola Polytechnic, Abeokuta where all the experiments were performed.

6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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