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REPAIR OF FLEXURAL DAMAGED REINFORCED CONCRETE BEAMS USING EMBEDDED BAMBOO REINFORCED EPOXY COMPOSITE

Samson Olalekan Odeyemi[a*], Rasheed Abdulwahab[a], Sefiu Adekunle Bello[b], Ahmed Olatunbosun Omoniyi[a], Adewale George Adeniyi[c]

[a]Department of Civil & Environmental Engineering, Kwara State University, Malete, Nigeria
[b]Department of Material Science & Engineering, Kwara State University, Malete, Kwara State, Nigeria
[c]Department of Chemical Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria

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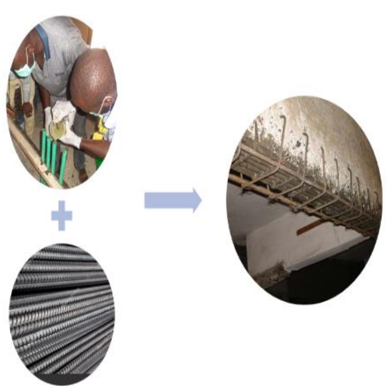
*Corresponding author
samson.odeyemi@kwasu.edu.ng

Graphical abstract



Abstract

In recent years, repair and retrofit of existing structures such as buildings and bridges have been among the most important challenges in Civil Engineering. Strengthening reinforced concrete (RC) members with steel plates is a conventional method that has been adopted for decades. The corrosive nature of steel plates, its weight and the need for many anchor bolts for attachment makes it inefficient for retrofitting damaged structures. Thus, there is a need to source for an alternative material which does not corrode and still be used in the strengthening of reinforced concrete. Bamboo Reinforced Epoxy Composite (BREC) was used to repair five (5) damaged reinforced concrete beams in this research. Two of the beams were preloaded to 40 % and 60 % of the ultimate load before strengthening with BREC and all the beams were loaded to failure. The RC beams implanted with BREC rods experienced a rise in their load carrying capacity when tested. Beams preloaded up to 40 % and 60 % had an increase in flexural strength of 33.7 % and 39.3 % respectively when compared with beams reinforced with steel reinforcements. BREC rods in concrete is an effective method in increasing the flexural strength of RC beams.

Keywords: Concrete, Beams, Bamboo, Bamboo Fibre Epoxy Composite, Flexural strength

1.0 INTRODUCTION

Repair and retrofit of existing structures such as buildings and bridges, have been among the most important challenges in Civil Engineering. Structures are strengthened to upgrade their resistance to bear underestimated loads, increase their load carrying capacity for higher limit loads, prevent premature failure as a result of insufficient detailing, restoration of lost strength caused by corrosion and degradation from aging [1]. Several works have been carried out to find ways of improving the structural performance of old or damaged RC members in shear and flexure. The most popular of the methods of strengthening is the external bonded reinforcement method [2]. This method, as reported in some published articles, adopts the attachment of carbon fibre reinforced polymer (CFRP), steel plates, Aramid fibre reinforced polymer (AFRP) and Glass fibre reinforced polymer (GFRP) to RC members to carry the tensile stresses [3-7]. This present study reveals the production of BREC and its application as an attachment in RC members to bear service loads and elongate the service life of RC members.

Strengthening RC members by using steel plates is the most recent method which has been adopted for years [8]. This method has been found to improve the flexural strength and shear resistance of concrete structures. Really, fasteners have proven to be advantageous for improving the ductility of structures. However, steel plates need several anchor bolts for attachment, they are heavy, and need regular maintenance to stop corrosion. For these reasons, the use of steel plates in strengthening RC members has reduced. Since the 1990s, Fibre Reinforced polymers (FRPs) such as glass fibre, carbon fibre, chopped glass and carbon fibre have replaced steel plates as the preferred method of external bonded reinforcement for ease of handling due to their light weight, their high strength-to weight ratio and their resistance to corrosion [3].

In the developed world, the necessity for rehabilitation in the characteristically conservative Civil construction industries arise from deterioration/aging of structures, adaptation of existing structures to new design standards, mistakes in design/construction, accidental overloading, and a change in the functionality requirements of the structure. Apart from these generally known causes of structural distress, the “Nigerian factor” of lack of regular maintenance of infrastructures remains a prominent issue to contend with [9]. All these factors contributing to the rampant cases of defective reinforced concrete structures in Nigeria eventually lead to collapses with the accompanying adverse effects. It has been verified that when the defects in structures are not excessive, repairs instead of complete substitution can be a viable solution. Based on the amount of capital invested in building many structures, it is often uneconomical to simply replace them with a new one without considering the available options. Thus, rehabilitation instead of replacement often turns out to be a more economical solution [8].

Fibre Reinforced Polymeric Composites (FRPCs) are becoming popular materials for a wide range of structural rehabilitation due to their superior material properties including corrosion and weather resistance, high mechanical strength and low weight, ease of handling, good fatigue resistance, and versatility of size, shape or quality. Unlike most of the traditional building materials, the FRPCs can be specifically designed by blending the best combination of material properties in response to specific necessities. As the costs of FRPC materials and installation decrease, in addition to the numerous advantages when compared directly with steel plate, FRPCs are becoming increasingly popular in the field of civil engineering. Testimonies of the great potentials of the FRPCs can be found in numerous recent publications such as [8-9].

Bamboo is a plant that is abundant in the tropical countries. It is made up of cellulose fibres surrounded in a lignin matrix. It has neither rays nor knots, and this gives it an evenly distributed stress throughout its length. Bamboo’s specific gravity varies between 0.4 and 0.8. The cellulose fibres in bamboo gives it the tensile flexural strength and rigidity it possesses. It is one of the oldest materials used for building by man [10]. Its use cuts across household products and industrial applications as a result of improved timber processing technology and enlarged market demand. Bamboo is being used in building construction as props, fences, trusses, scaffolds, rafters and purlins. Though, Bamboo has been employed in building material for thousands of years, its latent contribution to sustainable natural resource management has just been recently recognized [11].

Therefore, this research is aimed at repairing flexural damaged reinforced concrete beams using embedded BREC.

2.0 METHODOLOGY

Five (5) reinforced concrete beams were tested using a three-point loading test. Enhancement in the load carrying capacity of the damaged concrete beams in flexure due to preloading was taken note of. Two preloading levels were considered, 40% and 60% of the ultimate load. All beams have a cross section of 100mm by 150mm with a total length of one meter (1m) and all were designed to fail in flexure.

Epoxy resin (MAX 1618A) and hardener (MAX 1618B) were obtained from Polymer Composite Institute, Ontario, Canada through a local vender (Tony Chemicals, Ojota), Lagos, Nigeria. The bamboo used was cut from Bamboo Plantation, Kwara State University, Malete, Nigeria. The bamboo was treated by boiling in a mixture of water and neem’s leave extract and sundried for 8 hours per day at an average temperature of 25 ˚C. The sun drying was done for a period of four (4) months to reduce bacteria activities that may lead to decomposition of the bamboo. The bamboo log was then sliced into 4mm diametric 1000 mm long rods used as reinforcement for developing epoxy/bamboo composite. In producing epoxy/bamboo reinforced plastic, one-metric long poly vinyl chloride pipe with diameter of 21 mm were used as a mould material. Each pipe was bisected vertically into a pair of semicircular pipes to form front and rear mould parts which were later assembled using layers of sellotape and then positioned vertically upward using a support. Essence of this is for an easy removal of the reinforced plastics from the pipe/mould after production. The bottom part of each mould was blocked by many layers of the sellotape wrapped around the pipe to form closed circular base for the mould.

In the typical production of epoxy/bamboo composite, three pieces of 4mm diametric bamboo rods were positioned vertically upward at the centre of the pipe to form a triangular network. Then, about 500 cm^3 of curative (MAX 1618B) was added to 1000 cm^3 of epoxy prepolymer (MAX 1618A) in a container, equal to volume of hardener/epoxy mixing ratio of 1:2. The mixture was stirred manually for 10 minutes, after which the epoxy mixture was degassed using Shel Lab oven at 15-20 mmHg for 5 minutes. After then the degassed epoxy mixture was gently stirred again until curing began, indicated by thickening of the epoxy mixture. The epoxy mixture was poured into the moulds until the moulds were filled up as shown in Figure 1. Each mould was topped up at intervals due to leakages from sealed sides and bottom till the epoxy blend became too viscous to allow for further flow. Epoxy polymer without reinforcement was also produced. The epoxy composite blend was left at room temperature until the curing completed after 96 hours (4 days). The sellotape was removed, the pipe moulds were carefully opened at the sealed sides for removing the epoxy/bamboo composites.

Figure 1 Pouring of the mixed Epoxy mixture into moulds

2.1 Beam Specification

The beam specifications are shown in Table 1. The beams are of an average compressive strength of 22 N/mm^2.

2.2 Reinforcement Details

The reinforcement details are shown in Figure 2. The stirrups are 8 mm in diameter with a tensile strength of 589 N/mm^2. The tensile reinforcements are 12mm in diameter with a tensile strength of 611 N/mm^2 while the BREC 21 mm in diameter with a tensile strength of 20.45 N/mm^2.

2.3 Beam Descriptions

Five (5) RC beams were cast and designated B_1, B_2, B_3, B_4 and B_5 respectively. B_1 was the control beam having only steel reinforcements. Samples of B1 were loaded to failure after 28 days of curing to obtain the ultimate load capacity of the beams. This was found to be 24,128 kN as shown in Table 2. B_2 was also a control beam with steel reinforcement and a BREC rod. B_3 had its concrete cover removed after 28 days and embedded with BREC without preloading. B_4 and B_5 had their covers removed and embedded with BREC after being preloaded to 40 % and 60 % of the ultimate strength.

Beam strengthening was carried out by taking away the whole concrete cover without affecting the steel reinforcement and steel stirrups at different loading 0 %, 40 % and 60 % of the ultimate load capacity, for B_3, B_4 and B_5 respectively. The BREC rod was inserted through the stirrups as shown in Figure 3. The old and new concrete were bonded with a bonding epoxy material to enhance the bond between the two materials. Finally, the concrete cover was re-cast and the beams were returned to their original shape and tested for flexure at the Department of Agriculture and Biosystems Engineering, University of Ilorin using a Universal Testing Machine with a capacity of 300 kN.

Table 1 Beam description

Beam No.	Specimen	Specification
B_1	C-S-0 %	Control beam having only steel reinforcements
B_2	C-B-0 %	Control beam with steel reinforcement in addition to BFEC rod
B_3	S-B-0 %	Strengthened beam with BFEC rod without preloading
B_4	P-S-40 %	Preloading RC beam 40% of ultimate load then strengthened with BFEC rod
B_5	P-S-60 %	Preloading RC beam 60% of ultimate load then strengthened with BFEC rod

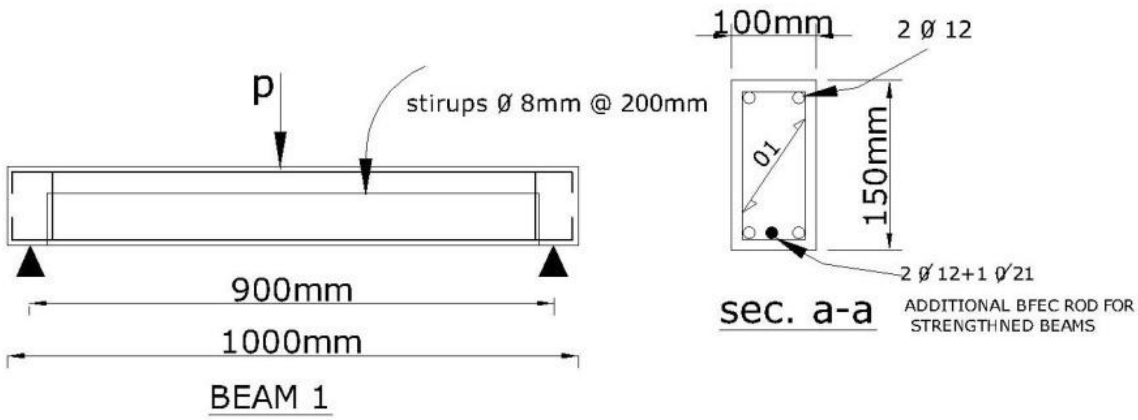


Figure 2 Reinforcement details

Figure 3 Embedding BFEC Rod before re-casting

3.0 RESULTS AND DISCUSSION

The results from the flexural test carried out on the samples are shown in Table 2. The strengthening of the beams using BREC rod increased the flexural strength of the beams tested as shown in Table 2. The flexural strength for beam B3 increased by 21.2% compared to the control beam without strengthening (B_1). Beams B_4 and B_5 also show an increment in their flexural strength by 33.7 % and 39.3 %, respectively. The force against deflection curve for each of the beams tested is shown in Figure 4.

Table 2 Flexural test results of beam specimen

Beam No.	Specimen	Force at Break (N)	Force at Peak (N)	Stress at Break (N/mm²)	Stress at Peak (N/mm²)	% Change in Stress to the Un-Strengthened Beam
B_1	C-S-0 %	15,942.000	24,128.000	10.628	16.085	0
B_2	C-B-0 %	16,093.000	25,028.000	10.186	10.729	4.1
B_3	S-B-0 %	25,677.000	29,233.000	17.118	19.489	21.2
B_4	P-S-40 %	31,139.999	32,259.88	20.760	21.507	33.7
B_5	P-S-60 %	26,434.999	33,610.001	17.623	22.407	39.3

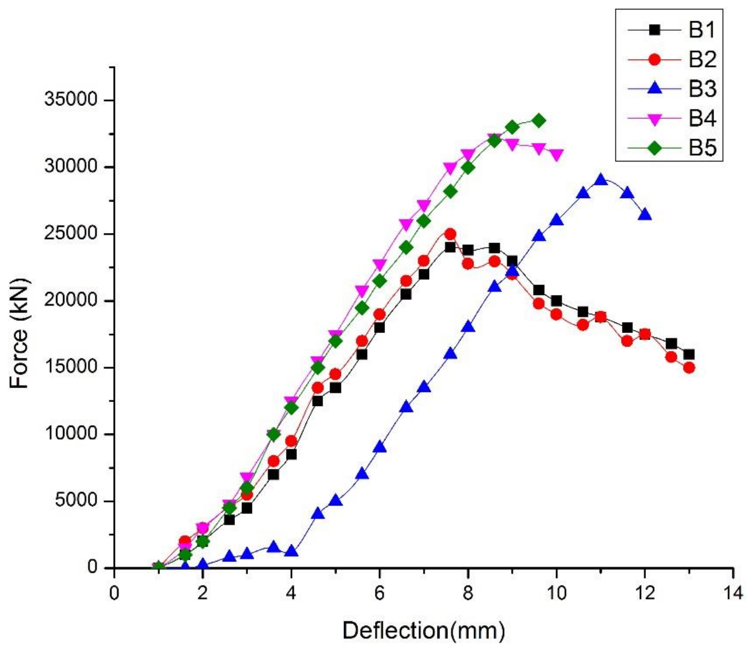


Figure 4 Load against deflection for all tested beams

4.0 CONCLUSIONS

The following conclusions are drawn from the study:

1. Embedding BREC rod in reinforced concrete beams increased their flexural strength. The load carrying capacity of beam with BREC without preloading (B_3), beam with BREC preloaded to 40 % of the ultimate load (B_4) and beam with BREC preloaded to 60 % of the ultimate load (B_5) increased by 21.2 %, 33.7 % and 39.3 %, respectively.
2. Using embedded BREC rod is thus an effective method to improve the flexural strength of RC beams. Inserting it through the stirrups is an effective method of repairing beams especially in corroded steel RC beams since it increases the beam capacity after repairing. This will be easy in construction as concrete covers in most damaged beams has already been removed.

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References

[1] R. Kishore, N. Zia Nasiry, and A. Muslim Rujhan, 2016. "Strengthening of Reinforced Concrete Beams Using CFRP Laminates," *Asian Journal of Civil Engineering.* 17(2):. 159–167

[2] A. M. Morsy, E. M. El-Tony, and M. El-Naggar, 2015. “Flexural repair/strengthening of pre-damaged R.C. beams using embedded CFRP rods. *Alexandria Engineering Journal.* 54: 1175–117,

[3] L. De Lorenzis and A. Nanni, 2001. “Shear strengthening of reinforced concrete beams with NSM fiber reinforced polymer rods,” *ACI Structural Journal.* 98(1): 60–68,

[4] H. Nordin, B. Taljsten, and A. Carolin, 2001. “Concrete beams strengthened with pre-stressed near surface mounted reinforcement,” in *Proceeding of International Conference on FRP Composites in Civil Engineering (CICE)*,

[5] R. Kotynia, 2005. “Strengthening of reinforced concrete structures with near surface mounted FRP reinforcement,” in *Proceeding 5th International Conference AMCM (CD-ROM), Glivice – Ustrum, Poland*

[6] R. EI-Hacha and S. H. Rizkalla, 2004. “Near-surface mounted fibre reinforced polymer reinforcements for flexural strengthening of concrete structures,” *ACI Structural Journal*. 101(5): 717-726

[7] R. Capozucca, 2009. “Assessment of RC Beams Strengthened with Near Surface Mounted CFRP Rods by Static and Dynamic Tests, Struct. Section of Dept. DACS, Università Politecnica delle Marche, Italy

[8] K. N. Hong, C. G. Cho, S. H. Lee, and Y. Park, “Flexural Behavior of RC Members Using Externally Bonded Aluminum-Glass Fibre Composite Beams,” *Polymers (Basel).* 6(3):. 667–685, 2014.

[9] A. N. Ede, 2010. “Structural Stability in Nigeria and Worsening Environmental Disorder: The Way Forward,” in *The West Africa Built Environment Research Conference*. 489–498.

[10] F. R. Falayi and B. O. Soyoye, 2014. “The Influence of Age and Location on Selected Physical and Mechanical Properties of Bamboo (Phyllostachys Pubesces),” *Int. J. Res. Agric. For.* 1(1): 44–54,

[11] K. Hinkelmann, 1997. “Selected SAS Documentation for STAT 5615/5616: Statistics in Research. Department of Statistics, Virginia Tech,”