FIBER REINFORCED POLYMER (FRP) COMPOSITES: EXPLORING THE POTENTIALS FOR REPAIRS OF DEFICIENT RC STRUCTURES IN NIGERIA

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ABSTRACT

As the use of Fibre Reinforced Polymer (FRP) composite material systems continues to rise all over the world, there is need to explore the possibilities of adopting this composite materials for the repairs and the restoration of deficient reinforced concrete structures in Nigeria. The fibre reinforced polymer [or fibre reinforced plastics (FRP)] composites is one of the innovative technologies that continues to win the attention of engineers in the recent times. The existence of deficient reinforced concrete structures in Nigeria is worrisome and has contributed to the numerous cases of building collapse with the disastrous consequences of deaths and economic waste. As Nigeria strives to improve standards on every side as to meet up with the Millennium Developmental Goals (MDGs), efforts must be geared towards reducing deaths in the country, especially in the building sector. For this, the need for researches into innovative methods of repairs and restoration remains very vital in the life of Nigeria. This article explores the potentials of externally bounded FRP composites and how it can be gainfully applied in Nigeria to strengthen our deficient RC structures and help the building industry to reduce the perennial and embarrassing cases of structural collapse. Results of laboratory tests were used to confirme the potentials of FRP composites in strengthening damaged beams.

KEYWORDS: FRP Composites, RC Structures, Structural defects, Repairs.

INTRODUCTION

While the need to renovate some aging infrastructures and historic buildings with lighter and environmentally friendly materials becomes increasingly evident in the advanced world, the need to restore recent structures is common in Nigeria. Cases of buildings resulting defective right from the very end of construction phase is very rampant in Nigeria. In the developed world, the necessity for rehabilitation in the characteristically conservative civil construction industry arises 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 remains a prominent issue to contend with (Ede, 2010). 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 (Täljsten, 2002; Schnerch and Rizkalla, 2004 and Goodman, 2005). Thus, rehabilitation instead of replacement often turns out to be a more economical solution.

In the recent years, the Fibre Reinforced Polymer (FRP) composites are becoming a popular material 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 FRP composites can be specifically designed by blending the best combination of material properties in response to specific necessities. As the costs of FRP materials and installation decrease, in addition to the numerous advantages when compared directly with steel plate, FRP is becoming increasingly popular in the field of civil engineering. Testimonies of the great potentials of the FRP composites can be found in numerous recent works (e.g. Pascale, and Bonfiglioli, 2001; Teng et. al., 2002; Bakis et. al., 2002; Quattlebaum et al., 2003; Ede et al., 2004, and Ede, 2008). In the following sections, more light will be shed on the great potentials of this composite material and why it will be very promising in helping the Nigerian building industries in restoration of deficient reinforced concrete structures. Laboratory tests results were used to confirm the potentials of FRP composites in strengthening damaged beams.

FIBER REINFORCED POLYMER (FRP) COMPOSITE SYSTEMS FOR STRENGTHENING CIVIL STRUCTURES: A GENERAL REVIEW

The use of Fibre Reinforced Polymer (FRP) composites in various engineering fields, e.g. aerospace, automotive and marine engineering applications has attained an advanced level while the use in civil structural applications is constantly increasing (Bakis et. al., 2002;). High quality manufacturing techniques, decreasing cost, advancement in methods of analysis, design and testing of FRP materials have all contributed to the diffused application of this innovative material in the construction industry. Due to their superior material properties: corrosion and weather resistance, high mechanical strength and low weight, ease of handling, good fatigue resistance, and versatility of size, shape or quality, they are finding a wide range of application in structural rehabilitations (Bakis et. al., 2002; Quattlebaum et al., 2003; and Ede, 2008).

From the majority of experimental works conducted on structures strengthened with various FRP technological systems, it has been established that the performance of these structures are controlled by the quality of the bond between the FRP and strengthened structure (Teng et. al., 2002). Therefore the most important issue for the repair of reinforced concrete structures is the efficiency of the bond between the FRP and concrete substrate.

In the past, the bonding of steel plates to deficient reinforced concrete (RC) structures has been the most popular method for strengthening RC structures. Epoxy bonded steel plates have proved to increase the strength and stiffness of existing structures and also to reduce flexural crack widths in the underlying concrete (Oehlers, 1992). This technique is simple, cost-effective and efficient for strength, stiffness and ductility enhancement, but it suffers from deterioration of the bond at the steel-concrete interface caused by corrosion of steel. Other problems include difficulty in manipulating the heavy steel plates at the construction site, need for scaffolding, and limited delivery lengths for long elements, increase in dead loads and the cross-sectional dimensions of the structure, intensive labour and down time. All these pose significant problems for the efficiency of this method (Stallings et al., 2000). In the recent years, the use of fibre reinforced polymer composite plates or sheets to replace steel plates in structural strengthening has become very common.

The Fibre Reinforce Polymer (FRP) has gradually taking the place of steel plates in some field of structural rehabilitation. In fact, FRP sheets may be wrapped around structural elements, resulting in considerable increases in strength and ductility without excessive stiffness change. Furthermore, FRP wrappings may be tailored to meet specific structural requirements by adjusting the placement of fibres in various directions or stacking more layers together (ACI Committee 440 report, 2002).

Today, FRP is virtually used in almost all fields of applications and in particular in the following fields: aerospace/military, automotive, building/construction/ infrastructure, industrial plants/chemical processing, oil & gas/ petrochemical, electrical and household applications. The major advantages are high mechanical strength, low weight, corrosion and weather resistance, good fatigue properties, high impact strength, high insulation values, very low maintenance cost, resistance to water, frost and salt, easy integration of lighting, cables and conduits

Evolution of Fibre reinforced polymer (FRP) composite materials for civil constructions

Over the past sixty years, rapid advances in construction materials technology have enabled impressive gains in the safety, economy and reliability of civil structures built to serve mankind. This has been in tone with the other advances made to improve human health and general standards of living. The fibre reinforced polymer [or fibre reinforced plastics (FRP)] composites is one of these new technologies that continue to win the attention of engineers engaged in civil constructions in the recent years. Historically, the fibre reinforced composites materials have been in use since the 1940s in the form of glass fibres embedded in polymeric resins made available from the petrochemical industries. The combination of high-strength, high-stiffness and low-density/ light-weight structural fibres with environmentally resistant polymers resulted in composite materials with mechanical properties and durability better than either of the constituents alone (Nanni, 1996).

At first, FRP composites made with high performance fibres such as boron, carbon and aramid were too expensive to make much impact beyond niche applications in the high value added technological fields (e.g. aerospace and defence industries).

As the cost of FRP material continues to decrease and with the aid of intensive research and demonstration, projects on FRP civil structural applications have become common. After over 50 years of service experience, this technology is now finding wider acceptance in the characteristically conservative civil construction industry (Bakis et. al., 2002).

The range of strengthening and retrofit has passed from RC structures to masonry, timber, metal and aluminium structures. The type of structural elements strengthened include beams, slabs, columns, shear walls, joints, chimneys, vaults, domes and trusses. An extensive detailing on FRP civil applications can be found in the literature (e.g. Crivelli Visconti, 1975; Nanni, 1995; Teng et.al., 2002; Bakis et. al., 2002 and Ede, 2008).

The most common FRP products for civil structural applications are internal reinforcing bars, pre-stressing tendons/anchor systems, and externally bonded plates, sheets, shells and tapes.

FRP Composite Materials Technology

The term *composite* can be applied to any combination of two or more separate materials having an identifiable interface between them. FRP composites for structural strengthening are produced by embedding continuous fibres in a resin matrix which binds them together. The fibres are the load carrying elements and have highly oriented-defect free micro structures. The resin matrix binds the fibres together, protects fibres from the environment, provides stability to the fibres and acts as a medium to transfer stresses between adjacent fibres (Karbhari and Zhao, 2000). The main material properties include anisotropy, linear elasticity to failure, high tensile strength/modulus in the direction of the fibres, and generally limited compressive properties (Nanni, 1995).

Performance of composite materials depends upon the materials of which they are constructed, the arrangement of the primary load bearing reinforcing fibres and the interaction between these materials. FRP composites have better mechanical properties than their constituent materials because the fibres and matrix interact to re-distribute the stresses caused by the external loads and the fibres are better protected from mechanical damage (Nanni, 1996).

Two common methods have been adopted for producing FRP composites used in strengthening RC structures: wet-lay-up method and automated production methods. Wet-lay-up method is commonly used and involves the in situ application of resin to either woven fabric or uni-directional tow sheets. The second method is the automated production of FRP composites of various forms, including pultrusion for plates used in flexural strengthening and filament winding for shells for column strengthening. This prefabrication method allows for better quality control. Standard pultruted shapes are angles, tubes, and channel and *I* sections.

In all FRP structural applications, reference is normally made to FRP systems since FRP composite materials are generally supplied as a package with instructions for the end users. Such instructions should be closely followed as to optimize the expected result of the applications.

FRP Forms and Properties

The most common form of FRP composite used in structural applications is called laminate. Laminates are made by stacking a number of thin layers (laminae) and consolidating them into the desired thickness. Fibre orientation in each layer as well as the stacking sequence of the various layers can be controlled to generate a range of physical and mechanical properties.

The mechanical properties of FRP composites depend on the direction of the fibres and on the volume of fibre adopted. The composites have a very high resistance in the direction of the fibres and much less in the perpendicular direction.

The function of the fibres is to support the applied stress. The name of a composite material derives from the type of the fibres adopted. The most commonly used composite materials for structural strengthening are carbon fibre-reinforced polymer (CFRP), glass fibre-reinforced polymer (GFRP) and aramid fibre-reinforced polymer (AFRP). The glass fibres have been the predominant composite material adopted for civil engineering applications because of an economical balance and specific strength properties.

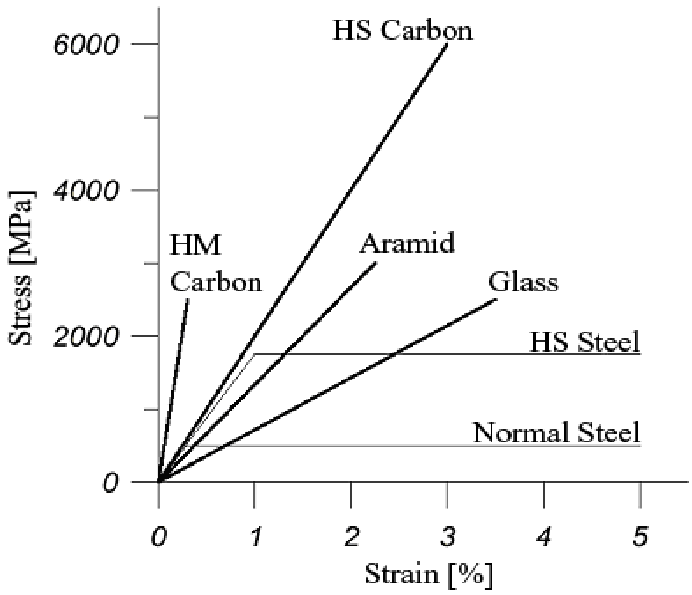

Figure 1: Stress-Strain in different FRP composites and steel [Source: Nanni, 1996].

The polymeric resin performs the following major functions: binds the fibres together (matrix), transfers loads to fibres and protects fibres from environmental and mechanical damage. The same polymeric resin is the adhesive used in bonding the FRP composite material to the strengthened structure. Resins usually determine the FRP composite temperature limitations and environmental resistance. There are two major groups of resins: thermoplastics (soften upon heating and harden upon cooling) and thermo-sets (undergo irreversible chemical change when set). Epoxy resin and vinyl ester resin are the most common types of thermo-set resins adopted in civil applications.

A lot of factors are to be considered before adopting a particular type of FRP for an application. The major factors considered include: the desired strength and stiffness of the FRP, the environment of applications and the economic constraint. Due to its superior stiffness, CFRP is often preferred for flexural retrofit over GFRP.

Typical FRP Products for Civil Structural Strengthening

Strengthening and retrofit techniques utilized for externally bonded FRP composites offer unique properties in terms of strength, lightness, chemical resistance and ease of application. These techniques are particularly most attractive for their fast execution and low labour costs. The major obstacle to a complete acceptance of these innovative materials in construction industry is the risk of fire and vandalism.

The most commonly adopted FRP forms used in externally bonded strengthening of civil structures are plates, sheets, shells and tapes. The thickness of an installed ply is in the range of 1 to 3mm. The process followed for the field installation of externally bonded FRP strengthening varies according to the type of application.

Externally-epoxy bonded applications follow the following general steps:

a) Concrete surface preparation (e.g., cleaning, sealing of cracks, rust proofing existing steel reinforcement, smoothing, etc.),
b) Application of primer coat,
c) Application of resin strand/s (undercoat) and adhesion of the FRP composite
d) Application of resin,
e) Curing and application of finish coat.

Most of the researches and applications on externally-epoxy bonded FRP applications are focused on structures subject to flexural, shear and normal stresses.

Common FRP structural shapes are shown in figures 2 and 3 below.

Figure 2: Bedford structural shapes [Source: Ede, 2008].

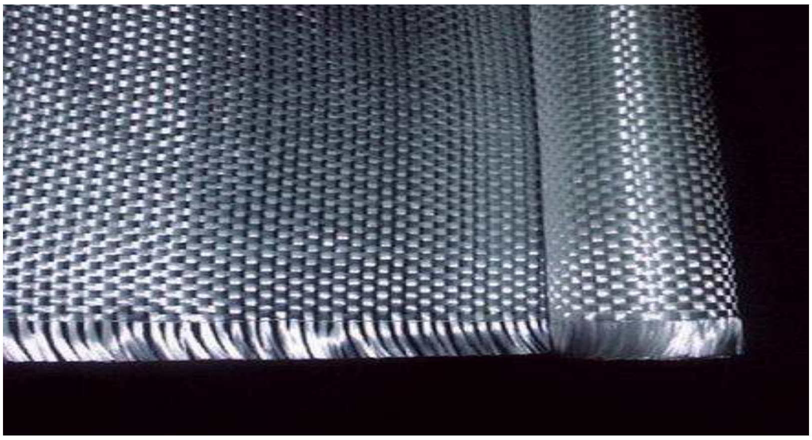

Figure 3: Fiberglass woven roving [Source: Ede, 2008].

TEST OF DAMAGED BEAM STRENGTHENED WITH CFRP COMPOSITE

For the verification of the potentials of FRP composite in damaged structure, laboratory tests were performed. An un-strengthened reinforce concrete beam and an FRP-strengthened reinforced concrete beam were tested. Four-point static loadings were applied to the beams to induce damage (1^{st} crack). After the appearance of the first crack, one of the beams was strengthened with CFRP and one was left un-strengthened. Successively, the two beams were subject to different cyclic loadings of 30K, 100K and 300K cycles. Dynamic tests were performed at the beginning of the process on each of the beams and then repeated after each static and cyclic test to ascertain the corresponding stiffness of the beams at each damage scenarios. Set of the laboratory test is shown in figure 4.

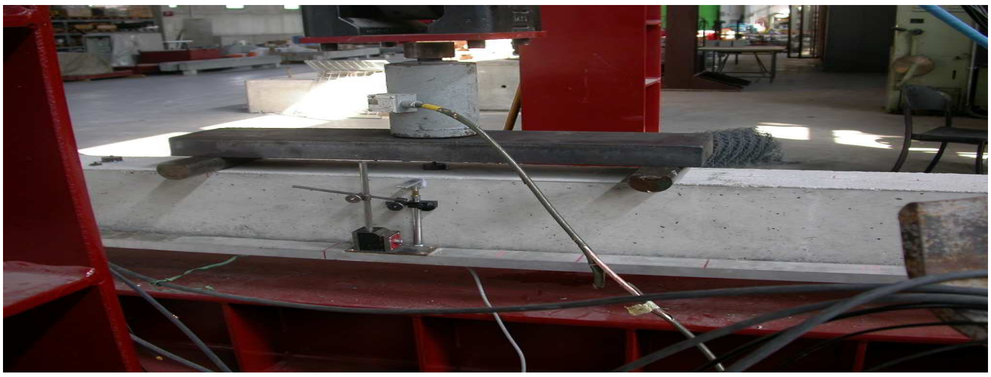

Figure 4: Setup of four point static loadings [Source: Ede, 2008].

TEST RESULTS

Figure 5 displays the variation of stiffness for the un-strengthened and strengthened beams starting from the cracked stage. The recovery of the strengthened beam over the un-strengthened can be neatly appreciated.

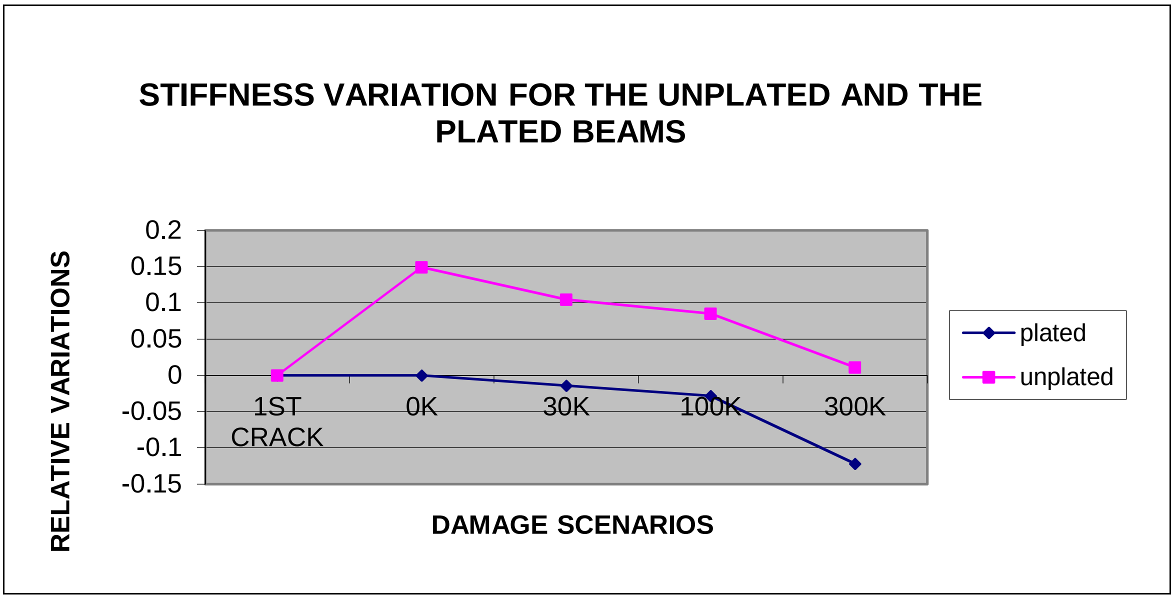

Figure 5: stiffness variations for the un-strengthened and strengthened beams

CONCLUSION

From the analysis, the enormous potential of the FRP composite have been exposed. It is very evident that the material will be of great benefit to the Nigerian construction industry especially for the repairs of common heavy concrete structures without overloading with excessive weights. The result of this laboratory test can be easily replicated in bigger life structures.

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