Structural Applications and Specifications Of Fiber-Reinforced Polymer (FRP) Composites In Australia And Philippines: A Review

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Abstract

Fiber-reinforced polymer (FRP) composites are considered viable alternatives due to their inherent advantages over traditional materials. Their advantages include light weight, high specific strength, high durability, corrosion resistance, chemical and environmental resistance, and low maintenance cost. This innovative material has been globally applied into civil infrastructure. In Australia, the applications include composite pile system and rehabilitation, marine structures, bridge structures and electrical cross-arms. On the other hand, strengthening of bridge and building structures are the common application of fiber composites in the Philippines. This paper presents the recent developments on the application of FRP composites in Australia and in the Philippines. Challenges in the implementation of this material are also presented. It is hoped that with the information revealed in this study, it will gain further application of this innovative material into civil infrastructure here in the Philippines.

Keywords: Fiber Composites; Civil Infrastructure; Construction; Bridge Structure.

1.0 Introduction

For the past decades, rapid improvements in the construction materials technology have prompted civil engineers and construction industry designers to attain notable achievements in safety and functionality of structures. These include the consideration and application of fiber-reinforced polymer (FRP) composite materials (or fiber composites) in civil engineering. Their application is of most importance in the renewal of constructed infrastructure facilities or rehabilitation of structures made from traditional materials such as concrete, steel, and timber, mainly due to their tailorable performance characteristics, ease of application, and low cycle costs. They are considered viable alternatives due to their inherent advantages over traditional materials. Their advantages include light weight, high specific strength, high durability, corrosion resistance, chemical and environmental resistance, and low maintenance cost (Sakr et al., 2005). On the other hand, there are also potential drawbacks of using FRP composite material. Their initial cost is generally expensive compared to traditional materials (Iskander and Hassan, 2002). Moreover, their performance is also a concern as composites have low bending and axial stiffness that may exhibit deformation more than that permitted by design codes. In spite of these shortcomings, however, their usage has been very substantial and is widely applied.

This paper discusses the recent developments on the application of fiber-reinforced polymer

(FRP) composites in Australia and in the Philippines. Challenges in the implementation of this innovative material are also presented. It is hoped that with the information revealed in the present study, it will gain further application of this innovative material into civil infrastructure here in the Philippines.

2.0 Methodology

Gathering of information to this purpose were made through available literatures. Furthermore, visiting of sites or projects that were adopting FRP composites were undertaken. Site visits to FRP-manufacturing industries or higher education institutions offering subjects or courses of FRP were also undertaken. The following are the identified agencies and companies that have been visited.

- Department of Public Works and Highways (Main Office), Structures and Bridge Division, Port Area, Manila, Metro Manila, Philippines.
- Department of Public Works and Highways (National Capital Region), Port Area, Manila, Metro Manila, Philippines.
- De La Salle University, Taft, Manila
- Sika Philippines Head Office and Manila Technical Center, Marcos Alvarez Ave. Talon Las Pinas City, Philippines
- Sika Philippines, Mantawi Ave., William Seno St.,Subang Daku,Mandaue City, Cebu
- Department of Public Works and Highways Regional Office No. VIII, Candahug, Palo Leyte.

3.0 Results and Discussions

Composite Specifications

Fiber Reinforcement (Synthetic) Materials

The primary function of the reinforcement in polymer matrix composites is to increase the strength and stiffness of the polymer. Particularly, it influences the tensile strength and modulus of the composite material. Glass, carbon and aramid fibers are the common reinforcements used in FRP composites for structural applications. Figure 1 shows comparison of the stress-strain curve of these fibers. Glass fiber is considered the most dominant reinforcement fiber of the current composites industry. Its combination of high strength and low cost make it an ideal choice in many structural situations. However, glass fibers have been noted to have poor long-term performance characteristics compared with other reinforcement options. Carbon fibers are high performance fibers suitable for primary load carrying applications. While the material price per kilogram for carbon fibers is currently significantly higher than for glass fiber reinforcement they exhibit superior structural performance. On the other hand, aramid reinforcements are noted to offer attractive characteristics in other areas such as impact and fire performance but are expensive compared to the other two fibers.

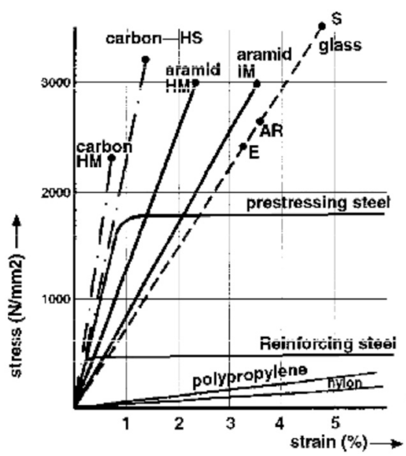

Figure 1. *Tensile stress-strain behavior of various reinforcing fibers (ACI 440R, 2002)*

Thickness of Laminates of FRP Composites

The most common form of fiber-reinforced composite used in structural applications is called a laminate. Laminates are made by stacking a number of thin layers (laminate) of fibers and matrix and consolidating them into the desired thickness and number of layers. Fiber 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. When subjected to compression, tension and flexure tests polymeric composites are susceptible to mechanical damages that can lead to interlayer delamination. Babukiran and Harish (2014) investigated the influence of specimen thickness on the flexural properties of laminated composites. They found that the increase in thickness of the laminates decreases the flexural properties of the material including the flexural strength and flexural modulus due to delamination. The effect of the thickness of the laminate on the strength was also reported by Banakar et al., (2012) whereby the Increase in thickness of laminate tends to decrease its tensile strength.

Fiber Orientations

ACI 440R (2002) outlined different fiber orientations and their effects on the strength of composite materials. Accordingly, a unidirectional or one-dimensional fiber arrangement is anisotropic. This fiber orientation results in a maximum strength and modulus in the direction of the fiber axis. A planar arrangement of fibers is two-dimensional and has different strengths at all angles of fiber orientation. A three dimensional array is isotropic but has substantially reduced strengths over the one-dimensional arrangement. Mechanical properties in any one direction are proportional to the amount of fiber by volume oriented in that direction as shown in Figure 2.

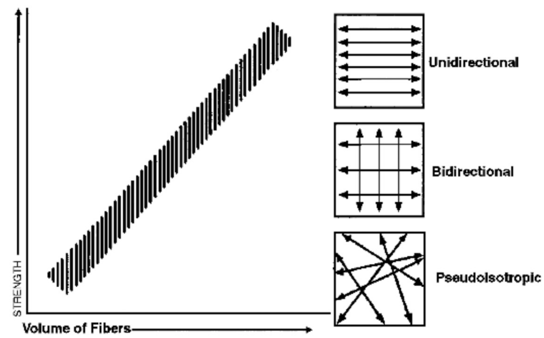

Figure 2. *Strength relation to fiber orientation (ACI 440R, 2002)*

Number of Plies (Layers)

Laminated composites are susceptible to mechanical damages when they are subjected to efforts of tension, flexural, and impact, which can lead to material failure. However, if the load direction is variable and not parallel to the fibers, it becomes more important to investigate the laminate mechanical behavior particularly on the number of layers of laminate or plies. Rahmani et al. (2014) investigated the effect of number of laminates on mechanical properties of laminated composites. They observed that the tensile and flexural properties of the composites made with five-ply were slightly higher than three-ply composites of same total laminate thickness. They highlighted that this may be due to the bond line defects, which adversely influence the mechanical properties of the laminated composites.

Fiber Surface Treatments

The properties of a composite material depend on the behavior of its constituent parts as well as that of the interfaces between reinforcement and matrix. The surface is an important region that plays a contributing role in the interfacial behavior with the polymer matrix. Their interfacial characteristics can be chemically or physically altered by fiber surface-treatment. Appropriate surface-treatment may modify the fiber surface by increasing the surface area and/or by increasing oxygen containing functional groups on the surface that may provide some chemical interactions between the fibers and the matrix resin. Several studies have been conducted on the effect of surface coating of fibers on the behaviour of composites. Cho et al. (2004) investigated the effects of fiber surface-treatment and sizing on the dynamic mechanical properties of unidirectional and 2-directional carbon fiber composites by means of dynamic mechanical analysis. The results indicated that different surface-treatment levels onto carbon fibers influenced the change of the stiffness and the interfacial adhesion of the composites. On the other hand, the effect of carbon powder surface treatment on carbon fiber-reinforced composite was characterized by Xu et al. (2016). Carbon cloth woven in twill structure was adopted and carbon powder surface treatment method was used for carbon cloth. Experimental results showed that the surface morphology of the composites is slightly changed and in this way the bonding between the carbon fiber and the matrix was improved. Sever et al. (2008) studied experimentally the influence of fiber surface treatments on mechanical behavior and fracture mechanism of glass fiber/epoxy composites using silane coating. They reported that silane coating on the heat cleaned glass fibers increased the interlaminar shear strength of the composite. However, the silane coating on the acid activated glass fibers did not improve the interlaminar shear strength of the composite.

Issues And Common Failure Type Of Frp Composites

Aside from the advantages of FRP composites over traditional construction materials, the following issues of this material still need to be addressed for its optimum use. These issues have been summarized in Table 1. The applications of FRP composites are relatively uneconomic when considered on a "first cost" basis. In rough terms it is expected to pay three times as much for glass FRP reinforcing bars, and up to 10 times as much for aramid fibre or carbon fibre for prestressing tendons compared with steel reinforcement (Burgoyne, 2009). Another issue on FRP composites is that it exhibited brittleness as failure type. Not only do the fibres have high strain capacities, but when they do fail they are brittle (Burgoyne, 2009). This behavior of material is should be overcome especially for seismically active region as failure of the structure may not show any warning prior to collapse. Brittle elements cannot be allowed to fail. A ductile structure taken close to failure can redistribute loads to other elements; in brittle structures they snap. Thus, we have to apply larger factors of safety to brittle materials because the consequence of overstressing is more severe. The resistance of fibers to corrosion has been mentioned as a benefit, but they are not perfect. The fibers do not rust, but glass and aramid can hydrolyse, especially in the presence of the high alkalinity in concrete (Burgoyne, 2009). This concern leads on the durability issue on the use of this material. The resins in FRPs are also liable to various mechanisms for degradation. Unlike corrosion in steel, it will not be apparent on the surface, which is a concern. The performance of FRP composites is also a concern as composites have low bending and axial stiffness that may exhibit deformation more than the settlement permitted by design codes (Guades et al., 2012). The typical failure type of FRP composites has been reported in literature. For instance, Lee and Haas (1999) investigated the compressive response of polymer matrix fiber reinforced unidirectional composites made of glass and carbon fibers using both experimental and analytical methods. The results showed that glass fiber composites demonstrate a splitting failure mode for a range of low fiber volume fractions and a simultaneous splitting/kink banding failure mode for high fiber volume fractions. On the other hand, carbon fiber composites show kink banding throughout the range of fiber volume fractions.

Table 1. *Summary of Issues and Types of Failure of FRP Composites*

Issues and Common Failure of FRP Composites	References
Relatively expensive than traditional construction material	Burgoyne (2009); Iskander and Hassan (2002)
FRP composite is a brittle material	Burgoyne (2009)
Durability issue since fibers (i.e. glass and aramid) hydrolysed especially in the presence of the high alkalinity in concrete	Burgoyne (2009)
FRP composites have low bending and axial stiffness	Guades et al. (2012)
Common failure mode of FRP composites is matrix cracking and fiber rupture	Lee and Haas (1999); Guades et al. (2014)

Application Of Fiber Composites In Australia

Fiber Composite Piles

Hollow FRP composite piles were adopted by Wagners Composite Fibre Technology (Wagners CFT) to shore up boardwalks located in New South Wales and Queensland (Figure 3). The 125 mm square (6.50 mm thick) pultruded tubes are made from E-glass fibers and vinyl ester resin. This 2,250 square meter project was WCFT's first use composite piles in the field where a total of 410 piles were driven to set the boardwalk structure in reclaimed soil and near the shore (Aravinthan and Manalo, 2012).

a. Jack Evans Boardwalk (NSW)

b. Mackay Bluewater Environmental Trail (QLD)

Figure 3. *Pultruded tubes as FRP composite piles*

Similarly, BAC Technologies Pty. Ltd used an innovative technique for the repair of damaged timber piles in Shorncliffe Pier in Brisbane (Figure 4). This project used 300 mm diameter hollow composite tubes with the aim of replacing the deteriorated upper portion of a pile in an existing bridge or pier by hollow FRP pipe pile without the need to remove or modify the bridge superstructure. The material behavior of this composite pile was investigated using structural (flexural and compressive) and impact driving tests and reported by Sirimanna (2011) and Guades et al. (2012).

Figure 4. *Hollow FRP pipe piles (Courtesy of BAC Tech. Pty. Ltd., Queensland, Australia)*

Boardwalks and Pedestrian Bridges

The Jack Evans boardwalk was commissioned by the Tweed Shire Council (New South Wales) to Wagners CFT to take advantage of the scenic views of the Jack Evans Boat Harbor. A 125 and 100 mm square pultruded FRP tubes where used to construct this project. The timber decking and cladding was kept to enhance the aesthetic appeal of the project and so that the boardwalk would blend in with the surrounding structures perfectly. Similarly, the 125 mm and 100 mm square pultruded FRP tubes where also adopted in the Mackay Bluewater Environmental Trail. Fiber composite solution was used since the area is subject to regular cycles of submersion. This project is 4 km long and is located on an environmentally sensitive tidal belt of the Pioneer River just north of the Mackay Central Business District. (Aravinthan and Manalo, 2012). On the other hand, fiber composite materials were used by WCFT in the construction of Bowman Parade Pedestrian Bridge. This pedestrian bridge is a 3 span, 30 meter structure and is made up of pultruded composite sections for the main structure and glue-laminated composite sandwich panels for the deck (Aravinthan and Manalo, 2012). Another application of fiber composites in bridge structure is the Gosnells pedestrian bridge (Figure 5) and is designed to resist various flooding-related load cases (www.compositesaustralia.com.au). Located in the Centennial Pioneer Park in Perth, the 21m single span bridge is used by hundreds of pedestrians and cyclists a day as a link between residential areas and Albany Highway. The bridge structure is a hollow, U-shaped box made of e-glass skins over structural cores infused with fire retardant vinyl ester resin. Carbon capping tapes running the length of the bridge add the strength and stiffness required for the long bridge span.

Figure 5. *Gosnells pedestrian bridge (www.compositesaustralia.com.au)*

Electrical Transmission Application

Fiber composite tubes were also applied as power pole cross-arms (Guades et al., 2014). Aside from the beneficial properties of fiber composites mentioned earlier, these 100 mm square FRP cross-arms provide additional protective layer of insulation and do not sustain a flame thereby virtually eliminating pole top fires making them suitable as structural component in electrical poles (http://www.wagnerscft.com.au). The structural and impact behavior of this square FRP tube has been extensively characterized by Guades et al. (2013a), Guades et al. (2013b), Guades and Aravinthan (2013), Guades et al. (2014).

Fiber Composite Bridges

The pioneering application of fiber composites in a highway bridge in Australia happened during the reconstruction of Taromeo Creek Bridge at Blackbutt, Queensland by the Wagners CFT in 2005 (Aravinthan and Manalo, 2012). The highway bridge, which was constructed using fiber composite girders and reinforced concrete deck slab, is of two spans, 10m and 12m, and replaced an existing timber bridge. The box girder is 350mm deep formed using glass-reinforced isophthalic-polyester pultruded profiles. Another project that utilized the fiber composite bridge girder is its application in Manly Road Bridge in Brisbane designed and developed by Wagners CFT. The I-girder is made up of 125x125x6.5mm pultruded section and 300x6 mm flat laminates bonded with rubber toughened epoxy adhesive. This I-girder was also adopted in road bridge replacement in Hawkesbury Council, Queensland (Aravinthan and Manalo, 2012).

In addition to this, fiber composites are also used to strengthen bridges as they offer a flexible solution to solve structural issues that may arise as a result of increased traffic loads, continuous aging of the structure, and inadequate design. The pre-stressed piles concrete piles in Houghton Highway in Redcliffe, Queensland were repaired with glass and carbon fiber wraps Accordingly, a total of 500 damaged piles where rehabilitated to prevent the propagation of vertical cracking on the piles due to alkali-silica reaction. Similarly, the West Gate Bridge was strengthened using fiber composites to accommodate the construction of additional traffic lanes. The project involved wide use of carbon fiber laminate and fabric strengthening to both the underside and top side of the bridge deck including the central spine girder, the cantilever bridge deck support beams and the bridge deck infill panels. Carbon fiber fabric composite was used to strengthen the beams of the Little River Bridge (www.vicphysics.org). This 84 year old bridge (Figure 6) is a 4 span continuous structure on the Princes Freeway (National Highway 1) between the cities of Melbourne and Geelong in Australia. The beams of this bridge required strengthening for positive moment as part of the upgrading and widening of the road to a 6 lane freeway.

Figure 6. *Strengthened Little River Bridge (www.vicphysics.org)*

Marine and Floating Structures

Wagners CFT designed and constructed the Cameron Rocks fishing platform located in northern bank of the Brisbane River. The platform was constructed with composite supports fixed to the existing concrete piles with a completely composite substructure to ensure long life in the highly corrosive marine "splash" zone (Aravinthan and Manalo, 2012). The decking adopted fiber composites to increase the overall resilience and maintenance return of this structure. On the other hand, the Center of Excellence in Engineered Fiber Composites (CEEFC) of the University of Southern Queensland developed and built a new type of fiber composite waler. This 800m long floating riverwalk project consumed over 100 tons of structural composites through fabrication of 550 3m long beams, several 12m beams and a 16m truss (Aravinthan and Manalo, 2012).

Fiber Composites Railway Sleepers

Fiber composites had been trialled on an actual railway bridge in Australia to replace deteriorated timber sleepers in Australia (Manalo, 2013). The composite railway turnout sleeper is produced by gluing layers of fiber composite sandwich structure together in flatwise (horizontal) and in edgewise (vertical) orientations which was developed by CarbonLOC Pty. Ltd. Accordingly, fiber composite sleepers are performing to expectations and estimated that its serviceable life should be well in excess of 50 years.

Application Of Fiber Composites In The Philippines

The application of fiber composites in civil infrastructure in the Philippines context is considered to be in its infancy and no comprehensive documentation has been established. As a result, the author conducted an investigation to establish a database of the current application of fiber composites that will serve as benchmark for future research studies. Gathering of information to this purpose was done by visiting project sites, FRP-manufacturing industries, DPWH, and other FRP-concerned government and private agencies. Unlike in Australia, rehabilitation and strengthening of civil infrastructure is the most common application of fiber composites in the Philippines with not much on new structure. In this study, few of these applications with brief information and corresponding documentary pictures are presented. The author believed that this information can already describe the entire process of the retrofitting technique. However, a summary of the entire applications of FRP composites based from the documentation of the author is reported in the corresponding tables.

Rehabilitation and Strengthening of Bridge Structures

Carbon FRP sheet and plate were used to strengthen the the 270m Bago Bridge (Figure 7) in Bago City, Negros Occidental to increase the traffic loads (www.sika.com). A 0.12 mm woven Carbon high strength fabrics impregnated by structural epoxy resin were used on the bridge girder whilst a 100 mm width x 1.2 mm thick Carbon FRP plates were adopted on the bridge slab. The increase of the load is primarily related to the main crop in the island, the sugar crane, which is quite heavy if mobilized by truck. Old Bago Bridge was used to be a steel span, 200 meters long and 12 meters above the water, traversing the wide river of Bago between the Poblacion and the Bago Ma-ao crossing.

Figure 7. *Strengthened Bago Bridge in Negros Occidental (Courtesy of SIKA Philippines)*

Fiber composites were also used to retrofit the bridge girder of Cabug Bridge along Medina By-Pass Road in Misamis Oriental. This bridge is 30m long and made from reinforced concrete. A 0.12 mm woven Carbon high strength fabrics impregnated by structural epoxy resin were used in this project. Just like the previous bridge application, rehabilitation is undertaken due to additional traffic load and to increase the integrity of the structure. On the other hand, fiber composite was adopted to rehabilitate the Cagbayok Bridge (Figure 8) along Maharlika Highway (Surigao-Agusan Section) in Misamis Oriental. The structural member of this bridge particularly the pier suffered severe damage and needs immediate repair. This particular project used a 0.12 mm thick carbon FRP sheet with epoxy resin wrap around the damage square reinforced concrete column. Prior to wrapping of the composite sheet, the damage portion of the structural member was treated, cleaned and later applied by an epoxy grout.

Figure 8. *Column before and after Carbon FRP application (Courtesy of SIKA Philippines)*

In a similar way, fiber composites were used to strengthen Tibsok Bridge in Bacolod City. Retrofitting of this structure was undertaken as a result of the significant damage of the bridge pier. Before the fiber composites were applied, the damage surface was dressed by chipping in few mm of outer layer of the perimeter column and a de-rusting chemical was spread-over to remove the corrosive element from the reinforcing bars. A single layer of carbon FRP sheet impregnated by epoxy was then wrapped around the treated column (Figure 9).

Figure 9. *Column before and after Carbon FRP application (Courtesy of SIKA Philippines)*

Fiber composites were adopted to strengthen the Magallanes Interchange in Makati City. This project involved the retrofitting of the deck slab (soffit) of the second-level Interchange and the inner lane of the third-level flyover (Pasay Bound). This process includes the use of carbon FRP sheets with epoxy mortar applied on the top layer of the slab. On the other hand, glass fibers were embedded in the bottom layer of the deck slab. Accordingly, the completion of the1,809m long project will restore the structural integrity of the bridges for the safety of the travelling public.

It can be observed that numbers of applications of fiber composites in bridge structures as manifested in the above projects are already been implemented. Moreover, additional case studies and its applications are summarized in Table 2. As can be seen in the table, the applications of fiber composites spread across the country. Most of the rehabilitation projects involved the use of carbon FRP plates and sheets whilst others are using glass fiber as reinforcement.

Table 2. *Summary of Fiber Composites Application in Bridge Structures*

Name of Bridge	Location	Material Used/No of Layers	Structural member being applied
Bago Bridge[a]	Bago City, Negros Occidental	Carbon FRP Sheet & Plate/ 2	Girder/Beam
Cabug Bridge[a]	Medina, Misamis Oriental	Carbon FRP Sheet/2	Girder/Beam
Pongtod Bridge[a]	Mainit, Surigao del Norte	Carbon FRP Sheet/1`	Girder/Beam

Mabuhay Bridge[a]	Sison, Surigao del Norte	Carbon FRP Sheet/1	Girder/Beam
Cagbayok Bridge[a]	Surigao City, Surigao del Norte	Carbon FRP Sheet/2	Pier/Column
Migcanaway Bridge[a]	Tangub City, Misamis Occidental	Carbon FRP Sheet/1	Girder/Beam
Colupan Bridge[a]	Sinacaban, Misamis Occidental	Carbon FRP Sheet/1	Girder/Beam
Tubod Bridge[a]	Iligan City, Misamis Occidental	Carbon FRP Sheet/1	Girder/Beam
Kiling Bridge[a]	Tanauan, Leyte	Carbon FRP Sheet/1	Girder/Beam
Tago-San Miguel[a] Bridge	San Miguel, Surigao del Sur	Carbon FRP Sheet/1	Girder/Beam
Buruon Bridge[a]	Iligan City, Misamis Occidental	Carbon FRP Sheet/1	Girder/Beam
Limbuhan Bridge[a]	Bislig, Tanauan, Leyte	Carbon FRP Sheet/1	Girder/Beam
Das-ay Bridge[a]	Hinunangan, Southern Leyte	Carbon FRP Sheet/1	Girder/Beam
Talisayan Bridge[a]	Palale, Mac Arthur, Leyte	Carbon FRP Sheet/2	Girder/Beam
Labiranan Bridge[a]	San Jose, Dulag, Leyte	Carbon FRP Sheet/2	Girder/Beam
Digahungan Bridge[a]	Tanauan, Leyte	Carbon FRP Sheet/1	Girder/Beam
Bagahupi Bridge[a]	Babatngon, Leyte	Carbon FRP Sheet/1	Pier/Column
Magsaysay Bridge[a]	Butuan City, Agusan del Norte	Carbon FRP Sheet/1	Girder/Beam
Argao Bridge[a]	Argao Cebu	Carbon FRP Sheet/1	Pier/Column
Maabon Bridge[a]	Inobaan, Negros Occidental	Carbon FRP Sheet/1	Pier/Column
Langub Bridge[a]	Murcia, Negros Occidental	Carbon FRP Sheet/1	Pier/Column
Caticlan Bridge[a]	Caticlan, Panay Island	Carbon FRP Sheet and Plate/2	Girder/Beam
Tibsok Bridge[a]	Negros Occidental	Carbon FRP Sheet/2	Pier/Column
Montinola Bridge[a]	Iloilo City, Panay Island	Carbon FRP Sheet/Plate/2	Girder/Beam
Mambuloc Bridge[a]	Bacolod City, Negros Oriental	Carbon FRP Sheet/2	Girder/Beam
Himamaylan Bridge[a]	Himamaylan City, Negros Occidental	Carbon FRP Sheet/2	Girder/Beam
Caraguit Bridge[a]	Negros Occidental	Carbon FRP Sheet/2	Girder/Beam
Caradio-an Bridge[a]	Negros Occidental	Carbon FRP Sheet/2	Girder/Beam
Calatrava Bridge[a]	Negros Occidental	Carbon FRP Sheet	Slab
Binalbagan Bridge[a]	Negros Occidental	Carbon FRP Sheet/2	Girder/Beam
Tuyoman Bridge[a]	Negros Occidental	Carbon FRP Sheet/1	Girder/Beam
Omanod Bridge[a]	Sta. Catalina, Negros Oriental	Carbon FRP Sheet/2	Girder/Beam
Tangub Bridge[a]	Bacolod City, Negros Oriental	Carbon FRP Sheet/2	Girder/Girder
Luka Bridge[a]	Oslob Cebu	Carbon FRP Sheet/3	Girder/Beam
Balangiga Bridge[b]	Balangiga, Eastern Samar	Carbon FRP Sheet/ 1	Girder/Beam/ Slab
San Joaquin Bridge[b]	Palo, Leyte	Carbon FRP Sheet/2	Girder/Beam/ Slab
Bao Bridge[b]	Ormoc City	Carbon FRP Sheet/1-2	Girder/Beam/ Slab
Layog Bridge[b]	Sulat, Eastern Samar	Carbon FRP Sheet/ 1	Girder/Beam/ Slab
Catbalogan Diversion Bridge[b]	Catbalogan City, Samar	Carbon FRP Sheet/ 2	Girder/Beam/ Slab
Magallanes Interchange [c]	Makati City	Carbon FRP Sheet and Glass fibers/ 1	Slab

Reference: a = SIKA Philippines Inc, b = DPWH RO8, c = DPWH NCR

Rehabilitation and Strengthening of Building Structures

Carbon Fiber composite was adopted to rehabilitate the Corazon Locsin Montelibano Memorial Regional Hospital (Figure 10) in Bacolod City (www.sika.com). This government controlled and owned health care facility caters to at least 400 beds for indigent patients. Carbon FRP plates were used to strengthen the damage concrete slabs due to excessive structural cracks. Approximately 70 mm of the surface plaster and topping were stripped off from the suspended slab and the structural cracks of the slab were treated by injecting epoxy grout prior to the application of the 50 mm width x 1.2 mm thick Carbon FRP plates. Concrete mortar and topping was applied to overlay and protect these plates, as well for aesthetic purposes.

Figure 10. *Strengthening of Montelibano Hospital (Courtesy of SIKA Philippines)*

Similarly, The Malacanang Guest House in Manila was retrofitted using fiber composite materials. This project involved the strengthening of structural columns, beams, and walls. Carbon FRP plates were adopted in the wall (Figure 11), whilst Carbon sheets impregnated by epoxy resin were used for the concrete beams. Unlike the two structural members, combinations of Carbon and glass fiber sheets were used to strengthen the concrete column (Figure 11). Glass fiber was wrapped on the upper portion of the column whilst Carbon fiber on the lower part. In general, 1-2 layers of FRP sheets were applied in this project.

Figure 11. *Strengthened wall and column (Courtesy of DPWH Central Office)*

Fiber composites were also used in rehabilitating school buildings. One of the school buildings of the University of San Carlos (North and Talamban Campuses) and the St. Therese College in Cebu City was rehabilitated using fiber composites to increase its loading capacity and structural integrity. The concrete columns were wrapped by a 0.12 mm thick woven Carbon high strength fabrics impregnated by structural epoxy resin. Fiber composites were also adopted to strengthen the De La Salle University Building in Taft, Manila (Figure 12). Strengthening of this structure was undertaken since this building is considered a historical trademark of the university. Carbon FRP sheets impregnated by epoxy resin were used to reinforced the structural members including concrete beams and columns.

Figure 12. *Strengthened De La Salle University Building*

The above documentation shows that several applications of fiber composites in building structures have already been in the existence. In addition to this, the author lists down the application of fiber composites and is summarized in Table 3. Carbon FRP sheets and plates are the most dominant material of choice in strengthening structural concrete members like beams, columns, walls, and slab.

Table 3. *Summary of Fiber Composites Application in Building Structures*

Name of Building	Location	Material Used/No of Layers	Structural member being applied
Montelibano Regional Hospital[a]	Bacolod City	Carbon FRP Plate/ 1	Slab
University of San Carlos - North[a]	Cebu City	Carbon FRP Sheet/3	Column
University of San Carlos - South[a]	Cebu City	Carbon FRP Sheet/2	Column
University of San Carlos - Montessori[a]	Cebu City	Carbon FRP Sheet/2	Column
Innodata BPO Building[a]	Cebu City	Carbon FRP Sheet/2	Column
LGC Building[a]	Cebu City	Carbon FRP Sheet and plate/ 1	Beam
Geo Transport RMC Facilities Building[a]	Cebu City	Carbon FRP Sheet and plate/ 1	Beam
St. Theresa's College[a]	Cebu City	Carbon FRP Sheet/2	Column
Malacanang Guest House[b]	Manila	Carbon FRP Sheet & Plate, Glass FRP Sheet/ 1-2	Column/beam/wall
De La Salle University Building	Manila	Carbon FRP Sheet/No Data	Column, beam

Reference: a = SIKA Philippines Inc, b = DPWH Central Office

Challenges And Issues

The existing applications of fiber composites presented in this paper demonstrate that this engineering material had been widely applied in Australia as compared in the Philippines. The application in the Philippines is scarce and is limited only in strengthening bridge and building structures. Several challenges and issues need to be addressed in order to advance the use of fiber composites in civil engineering applications in Philippine setting. For instance, there is a great challenge for the practicing engineers when there are no specific design standards and familiarity with the behavior of such new materials. Currently a standard for Carbon fiber in civil infrastructure use is prescribed by the DPWH (http://www.dpwh.gov.ph). The information provided in this guideline however may not be sufficient to define the overall characteristics of the fiber composites and their corresponding constituent materials. There is a lack of structural engineers who are competent to design and use fiber composite materials in the Philippines and there is a need to incorporate fiber composite subjects in postgraduate level courses particularly in advanced structural engineering. Another issue that needs attention is the availability of other fiber composite products (e.g., pultruded tubes or plates) that can be used in various civil infrastructure applications. This can be answered if there will be company that will do business in manufacturing fiber composite materials in the Philippines. Not only that this will answer the supply requirement of this material, but will also certainly reduce its market price.

4.0 Conclusion

This paper presented the advancement of fiber-reinforced polymer composites into civil infrastructure in Australia and in the Philippines. The notable advantages of fiber composites over traditional engineering materials provide the development of a more sustainable infrastructure. Unlike in Australia, the application of fiber composites in the Philippines is generally in the rehabilitation of either bridge or building structures. The most common constituent materials used in strengthening structural members are Carbon FRP sheet or plate paired with epoxy resin. The application of fiber composites in the Philippines is still in its infancy and issues such as the development of design guidelines, understanding of the behavior of this innovative material, and their availability need to be addressed. Addressing these concerns will surely make fiber composites more competitive with the traditional materials leading to their optimum use in civil infrastructure.

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