2nd International Conference on Current Research Trends in Engineering and Technology

© 2018 IJSRSET | Volume 4 | Issue 5 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section: Engineering and Technology

Use of Polymer Composite in Bridge Rehabilitation

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ABSTRACT

The need for innovative construction techniques and sustainable construction materials has completely reshaped the construction industry. Following the need for high-performance and environmentally-protected construction materials, FRP composites have gained gradual but wide acceptance from civil engineers around the world. Properties like high tensile strength, ease of installation, low maintenance cost, and resistance against harsh environmental conditions give FRP composites a clear advantage over traditional construction materials. The application of fiber reinforced polymer in civil construction ranges from rehabilitation of existing reinforced concrete (RC) to building new projects.

Keywords : High Tensile Strength, Weight Ratio, Beam Strengthening, fiber reinforcement.

I. INTRODUCTION

As a result of extensive research investigating the applicability of FRP composites in the bridge construction, advanced composite materials, especially GFRP rebar, is now being increasingly used to construct the new bridges and strengthen the existing structurally deficient bridge structures in North America. Why should traditional materials be replaced with FRP composites? Concrete provides a solid cover for steel reinforcement, however, despite the cover, severe environmental conditions can cause the formation of hydrated ferrous oxide that can lead to the deterioration of concrete members. FRP composites provide complete Protection against the environment and concrete degradation and this is exactly why the focus of civil engineers have shifted from steel to fiberglass bars over the past few years. It is in the interest of a country to build bridges that can offer an exceptionally long service life with very low maintenance cost. Since FRP composites are corrosion resistance, they can be used to replace steel reinforcement in the forms of rebar for shear and flexural reinforcements, and tendon for pre-stressing or post-tensioning. FRP rebar and tendon can be manufactured in multidimensional or one-dimensional forms depending on the nature of application. Fiber reinforced polymers was first introduced to civil engineering as a replacement of steel materials to strengthen and retrofit existing bridge structures using externally bonded FRP composites. In the strengthening and retrofitting application of FRP composites, sheets and strips are employed to increase the efficiency and strength of an underperforming or deteriorated bridge. These techniques have been used for improving both shear and flexural capacity of concrete members. So far as seismic retrofitting of reinforced concrete is concerned, FRP composites can be used in the form of wrapped column. Traffic disruption is the biggest hurdle that engineers face while carrying out seismic retrofitting of bridges. One of the advantages of fiberglass rehabilitation material is that they are easy and quick to install without disrupting the flow of traffic. The use of these corrosion-free and modern construction materials can save governments billions of dollars annually and can help build a sustainable bridge infrastructure.

II. METHODS & MATERIALS

Materials:

Types of fiber reinforcement:

There are many different types of fibers that can be used to reinforce polymer matrix composites. The most common are carbon fibers (AS4, IM7, etc.) and fiberglass (S-glass, E-glass, etc.). As with the matrix, the fiber chosen will be determined by the end application.

Carbon (Graphite) Fibers

Carbon fibers are conductive, have an excellent combination of high modulus and high tensile strength, have a very low (slightly negative) CTE and offer good resistance to high temperatures. Carbon fibers are frequently categorized using tensile modulus. There are five categories of carbon fibers generally used in composites; low modulus, standard modulus, intermediate modulus, high modulus and ultra-high modulus. The exact cut-off for these categories will vary depending on the reference consulted, but in general, low modulus fibers have a tensile modulus of less than 30Msi and ultra-high modulus fibers have tensile modulus greater than 75Msi. As a point of comparison, steel has a tensile modulus of 29Msi. As the modulus increases, the fibers tend to get more brittle, more expensive and harder to handle. Further, the tensile strength of the fibers generally increases as the modulus increases from low to intermediate, but then tends to fall off in the high and ultra-high modulus fibers. I.e. the tensile strength of carbon fibers tends to be the greatest for the intermediate modulus fibers. For these reasons, standard and intermediate modulus fibers tend to give the best overall performance, unless the application is very stiffness oriented. This is illustrated even more clearly when fiber price and availability is also taken into consideration.

Fig.1 mounting plate made from carbon fiber reinforced composite. The carbon fiber was chosen for its very low CTE and high strength.

Fiberglass

Fiberglass is, as its name implies, glass that has been spun into the form of fibers. Fiberglass is not as strong or stiff as carbon fibers, but it has characteristics that make it desirable in many applications. Fiberglass is non-conductive (i.e. an insulator) and it is generally invisible to most types of transmissions. This makes it a good choice when dealing with electrical or broadcast applications. There are five major types of fiberglass. A-glass (alkali glass) which has good chemical resistance, but lower electrical properties. C-glass (chemical glass) which has very high chemical resistance. E-glass (electrical glass) which is an excellent insulator and resists attacks from water. S-Glass (structural glass) which is optimized for mechanical properties. D-glass (dielectric glass) which has the best electrical properties but lacks in mechanical properties when compared to E and S glass. E-glass and S-glass are, by far, the most common types found in composites. These types have good combinations of chemical resistance, mechanical properties and insulating properties. Of the two, E-glass offers the more attractive economics, and S-glass offers better mechanical performance.

Fig.2 Fiberglass reinforced composite insulating sleeve. In this case the fiber was chosen for its insulating properties and strength to transfer loads between metal components.

Other fibers

While carbon fibers and fiberglass are the most common reinforcements in thermoplastic composites, there are other options. Aramid fibers (such as Kevlar ® and Twaron ®) and boron fibers have been used in composites and offer some beneficial properties (excellent toughness and compressive strength, respectively). However they have characteristics that have limited their use (susceptibility to light/difficulty machining and brittleness, respectively). Still others include ceramic fibers like SiC or aluminum oxide. These may be attractive for their compression, insulating, or high-temperature properties. Automated Dynamics’ staff can assist with the selection of the best fiber for your application based on program needs, availability, economics, and other considerations.

Methods:

Manual and semi-automated methods

Manual processes include methods such as hand lay-up and spray-up. Hand lay-up or wet lay-up process is one of the oldest composite manufacturing technologies. It is labour intensive method, in which liquid resin is applied to the mould and fiber reinforcement is placed manually on top. Metal laminating roller is used to impregnate the fiber with resin and remove any trapped air. Several steps are repeated until a suitable thickness is reached. Several limitations of hand lay-up include inconsistency in quality of produced parts, low fiber volume fraction, and environmental and health concern of styrene emission.

Spray-up process is similar to hand lay-up process, but much faster and less expensive. In this process, a spray gun is used to apply resin and chopped reinforcements to the mould. Glass fibres chopped to a length of 10 to 40 mm are usually used as reinforcement. It is more suitable for manufacturing non-structural parts that do not require high strength. However, it is very difficult to control the fiber volume fraction and thickness, and it is very dependent on highly skilled operator. Therefore, this process is not appropriate for parts that require dimensional accuracy. One of the semi-automated processes is resin infusion under flexible tooling process. This method is mainly used to retrofit CFRP to steel, cast iron, and concrete bridges. In this method, fibres are performed in a mould and transported to site. The preform is then attached to structure being retrofitted and enveloped by vacuum bagging system, together with a resin supply. Resin is then injected into the preform, forming both composite material and adhesive bond between the composite and the structure. This process yields high fiber volume fraction as high as 55%.

Fully-automated methods

Pultrusion

Pultrusion is a process enabling continual production of FRP profiles with constant cross sections and material properties manufactured for specific purposes. According to sources, so far it´s the only known method that ensures sufficiently consistent quality. The process in its basic form has been used for almost 60 year. Pultrusion is done by continual pulling reinforced material through a guide where the fibres are placed precisely in required relation to the profile cross section, then, leading the fibres through processing equipment and impregnating them with the matrix material, pulling the combined mixture through the heated equipment and curing the profile into its final geometry. The fully cured profile is pulled forward to a floating suspended saw which cuts it into defined lengths. The type and number of continuous fibres, as well as the type and dimensions of complex weaves and mats are arranged in a way that enables visual checking when the fibres and mats are positioned in a profile. Precise positioning of fibres and mats in relation to the cross section of a profile is crucial to the properties and quality of the finished product. When the reinforcement is pulled into the processing equipment, the matrix is added by injection. Pultrusion by injection is advantageous in controlling and checking the reinforcement, it speeds changing from one profile to another, and eases matrix changes during a process. The degree of impregnation of the fibres is another decisive factor for the properties of the finished product. In traditional pultrusion, reinforcement is led through an open vat containing the matrix. However, the injection method is a fully enclosed process which keeps evaporation of solvents at a minimum. After the fibres are impregnated with the injected matrix, the entire product moves forward to the next zone in the process where heating takes place and where curing of the profile is accelerated. The final curing takes place in the last section of the processing equipment. As profile is thus fully cured and stable in form when it leaves the processing equipment. The pulling power that overcomes friction in the processing equipment - and thus driving force in the process - is provided by pullers placed outside the processing equipment. Pulling can be done by either belts or reciprocal pullers. During the last phase of the process, the profiles are shortened by a saw mounted to move at the same speed as the profile being pulled out of the equipment. This ensures a continual process.

Filament winding

Filament winding is a process in which resin-impregnated fibres are wound over a rotating mandrel at the desired angle. Therefore, starting materials for this process are continuous glass, carbon or aramid fibres. Liquid thermoset resins used in this process are epoxy, polyester and vinylester. The composite unit is then removed from the mandrel and cured by being placed in an oven enclosure at 60°C for 8 hours. This manufacturing process is commonly used to fabricate tubular structures and pipes. It is a low-cost process because low-cost materials and tooling are used. However, it is limited to producing closed and convex structures and gives comparatively low volume fraction of fibres.

Resin transfer moulding

In resin transfer moulding, fabrics are laid up as a dry stack, sometimes prepressed to the mould shape, and held together by a binder. These preforms are then more easily laid into the mould tool. A second mould tool is then clamped over the first, and a pressurized mixture of thermoset resin, a catalyst, colour, filler, etc. is injected into the cavity using dispensing equipment to form structural parts. Once all the fabric is wet out, the resin inlets are closed, and the laminate is allowed to cure. Both injection and cure can take place at either ambient or elevated temperature. This method is suitable for manufacturing small- to medium-sized structures in small- to medium-volume qualities. Resin transfer moulding can produce complex parts at intermediate volumes rate, allowing limited production to run in a cost-effective way. Fibre volume fractions, as high as 65%, can be achieved by this method. However, resin transfer moulding has a number of limitations. These include the fact that tooling and equipment costs are much higher and complex than for hand lay-up and spray-up process, and the adherence to dimensional tolerances is lower than in pultrusion method. Resins must be low in viscosity, possibly compromising mechanical properties of the finished composite.

Resin transfer moulding includes numerous varieties which differ in the mechanics of how the resin is introduced to the reinforcement in the mould cavity. These variations include everything from vacuum infusion to vacuum assisted resin transfer moulding (VARTM).

III. RESULTS

Fiber reinforced polymer (FRP) composites have been in service as bridge decks or complete load bearing superstructures on U.S. public roads (or the complete load bearing superstructure) for over 13 years. The overwhelming majority of these bridges are performing well, although there have been a few instances where they have created problems for the bridge owner and were taken out of service.

All but a few FRP structures have been made of glass fiber (such as E-glass). Carbon, aramid and other fibers are available but in most instances, glass provides the best value for the dollar (i.e. ability to meet established design criteria for the least cost). Vinylester resin is the predominant choice for the matrix that binds the fibers together. It is cost effective, yet durable over the long run. Lower cost polyesters and more expensive epoxies have also been used but to a lesser extent.

Decks deployed to date have been made primarily by one of three manufacturing methods: hand lay-up, vacuum assisted resin transfer molding (VARTM), and pultrusion. Each of these methods has particular benefits. See table 1.

Table 1. Manufacturing Methods Used to Date (for bridge deck or superstructure)

Manufacturing Method Used	Number of Bridges
Pultrusion	56
VARTM	37
Hand Lay-up	18
Other (e.g. laminate)	10
Total	121

A very good application of FRP composites has been for hundreds of pedestrian bridges. These projects have benefited from the lightweight nature of composites and the ability to carry components into remote locations.

State Activity

FRP composite bridge deck and superstructure research has led to successful applications in niche areas such as rapid replacements for truss rehabilitation, temporary structures, movable bridges, pedestrian bridges and difficult access sites. Approximately two-thirds of the completed projects were done with special funding from FHWA (Federal Highway Administration) or another agency, designed to provide an incentive for owners to explore this new technology. Table 2 summarizes activity according to state.

Table 2. States with FRP Decks and Superstructures

State	Abrev.	#decks	#SS	TOTAL
Ohio	OH	22	3	25
West Virginia	WV	9	11	20
New York	NY	8	7	15
Pennsylvania	PA	7	1	8
Kansas	KS	6	1	7
Maine	ME	0	7	7
Delaware	DE	1	4	5
Virginia	VA	4	1	5
Maryland	MD	1	3	4
Iowa	IA	2	1	3
Missouri	MO	2	1	3
Oregon	OR	3	0	3
California	CA	1	1	2
Illinois	IL	1	1	2
North Carolina	NC	1	1	2
Washington	WA	2	0	2
Texas	TX	0	2	2
South Carolina	SC	1	0	1
Vermont	VT	1	0	1
Wisconsin	WI	1	0	1
Idaho	ID	0	1	1
New Jersey	NJ	0	1	1
Puerto Rico	PR	0	1	1
Total		73	48	121

IV. CONCLUSION

This paper attests to the many potential applications of FRP composite materials in construction, although the need for brevity prevents all topics from being fully addressed. It can be said that the amount of experience with various forms of FRP construction materials varies in accordance with the perceived near-term economic and safety benefits of the materials. In the case of externally bonded reinforcements, for example, the immediate cost and safety benefits are clear, and adoption of the material by industry is widespread. In other cases where FRP materials are considered to be primary load-bearing components of structures, field applications still maintain a research flavor while long-term experience with the material accumulates. A number of careful monitoring programs of structures with primary FRP reinforcement have been set up around the world and should provide this experience base in the coming years.

Standards and codes for FRP materials and their use in construction are either published or currently being written in Japan, Canada, the United States, and Europe. These official documents are typically similar in format to conventional standards and codes, which should ease their adoption by governing agencies and organizations. The most significant mechanical differences between FRP materials and conventional metallic materials are the higher strength, lower stiffness, and linear-elastic behavior to failure of the former. Other differences such as the thermal expansion coefficient, moisture absorption, and heat and fire resistance need to be considered as well.

The education and training of engineers, construction workers, inspectors, and owners of structures on the various relevant aspects of FRP technology and practice will be crucial in the successful application of FRP materials in construction. However, it should be emphasized that even with anticipated moderate decreases in the price of FRP materials, their use will be mainly restricted to those applications where their unique properties are crucially needed.

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