International Journal of Innovative Research in Engineering & Management (IJIREM)
ISSN: 2350-0557, Volume-9, Issue-2, April 2022
https://doi.org/10.55524/ijirem.2022.9.2.88
Article ID IJIR-2291, Pages 562-567
www.ijirem.org

A Critical Review On Fiber Reinforced Polymer Composites In Strengthening Reinforced Concrete Structure

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ABSTRACT- Fibre reinforced polymer (FRP) composites still give designers the ability to deliver innovativeand intelligent solutions to beat the ever-growing aging problems in the infrastructure. Since it's been over50 years since the introduction of FRP materials to the development business, this paper presents a progressivereview of historic and up-to-datedevelopments of FRP in strengthening and rehabilitation engineeringapplications. This review highlights a fewof the classic and modern experimental, numerical, and analyticalstudies related to the mixing of FRPs into buildings, among different structures. The discussion representedherein aims at covering the application of FRP systems in concrete structural members and conjointly highlightsthe performance of FRPs (including bonding agents) beneath extreme conditions like elevated temperature,saline atmosphere, and cycles of physical change and thawing. This paper conjointly presents a collective perspective onseveral limitations, challenges, and analysis desires related to flourishing, property, and sturdy implementation of FRPs in civil infrastructure.

KEYWORDS- Concrete, fiber, polymer, reinforced, strengthening.

I. INTRODUCTION

Fiber-reinforced polymers (FRP) belong to a category of materials observed as composites. Composites are manufactured to enhance the property of a material by the combination of two or more parent materials [1, 2, 3]. In general, Fibre Reinforced Polymer materials are comprised of high-strength continuous fibers embedded in a polymer matrix.The embedded fibers represent the most reinforcing elements, whereas the polymer matrix acts as a binder that protects fibers and facilitates transferring masses to-and-between these fibers.E-, S-, and Z-glass fibers, aramid fibers, and carbon fibers (ultra-high modulus, high modulus, and high-strength) are the three main types of fibers used in the construction industry [1, 2, 3].

On the other hand, the polymer resins or matrices are divided into two groups i.e., Thermosetting and Thermoplastics.Thermosetting matrices or resins are further divided into vinyl esters, epoxies, and polyesters. These matrices are cross-linked polymers that are made by either addition or condensation polymerization. These types of matrices are made under the influence of heat and once they are formed, they don’t melt and soften upon heating. They don’t even melt or soften by dissolving in solvents.

Due to the improved mechanical performance of thermosetting resins, they are more prominently used and they have better properties of impregnating and adhesion. Thermoplastics are more expensive and sensitive to the conditions of their surroundings than thermoplastics and examples of such thermosetting resins arepolyethylene, polyvinyl chloride, polypropylene, and, polyurethane.Generally,resins can be made of polymers, metals, or ceramics. The polymer matrix is the most common material due to its easy process ofmanufacturing and relatively inexpensive production process. Thecombination of matrices with fibershas led to the development of variousclassic FRP materials such as carbon FRP (CFRP), glass FRP (GFRP),aramid FRP (AFRP), basalt FRP (BFRP), and some newlydevelopedpolyethylene naphtha late (PEN) and polyethylene terephthalate (PET)composites[4]. Depending on the type of fiber and polymer matrix,thebehavior of FRP materials can significantly vary, especially their mechanical properties.

The improvements in the properties of FRP materials i.e.,corrosion resistance characteristics, environmental durability,and inherent tailor ability,due to these the applications of FRP are growing and becoming helpful in the reconstruction of existing buildings and into the strengthening oflarge infrastructure and also in the construction of new facilities.There are many examples of the applications of FRP materials which further ranges from retrofittingof reinforced and unreinforced masonry and also in the rehabilitation ofunique structures for example-chimneys and historical monuments [1,2,3].The construction sector has become the largest consumer of polymer composites in recent years worldwide.As explained in the above applications, FRPs are usedas externally bonded systems. This is to enhance theaxial sectional capacity of reinforced concrete andto provide additional strength to the structures.

There are two types ofstrengthening systems i.e.,the first employs FRP plates andthe second utilizes near-surface mounted (NSM) bars.If we compare both of these then the FRP products are applied to concrete surfaces onlyafter preparing the external surface of the concrete by grinding, sandblasting or high-pressure water jetting and this method is quick to apply and easy for external strengthening.Although externally bonded steel systems were developed in the early 1940s to strengthen bridge girders, the introduction of FRP materialsshowed very much improvement because of the vast properties of FRP’s [5].

Concrete infrastructures are subjected to different types of loading and hazards. Thus, the performance of FRP strengthening systems under uniqueload types including static, cyclic (fatigue/seismic), impact, blast, and fire, etc. was investigated by the researchers. Some of the recently developed fiber-reinforced polymer systems include sprayed FRP systems [6], fire-resistant FRP material [7], andextra-ductile FRP products [4]. The American Concrete Institute (ACI) published its firstdesign provisions for FRP reinforced concrete in 2001 [8], ACI 440.1R- 01, and has been expanded and revised since then. Other design provisionswere also developed such as International Federation for StructuralConcrete (FIB) in 2001 [9], and Japanese code (BRI) in 1995 [10], etc. Due to the widespread of these codes, the integration of FRP materials isnow more natural (and frequent) in infrastructure construction projects.

It is observed from the above review that the application of FRP material has been growing rapidly which solidifies the fact that it is going to be an integral part of the modern construction industry. In this paper, the performance of FRP strengthened concrete members under different environmental conditions isdiscussed.After that, there are some discussions on the number of challenges, drawbacks, and research that needs to associate with the proper implementation of FRPs is presented.

II. TYPES OF FRP STRENGTHENING SYSTEMS AND PRODUCTS

FRP materials are made in a variety of products, and they are mainly classified into two groups is constant cross-sectioned and pultruded sections. Constant cross-sectioned FRP composite structural shapes are mainly produced to be used in the construction industry, buildings, and bridge applications. Pultruded sections are mainly used for highway bridge decks and pedestrian passes. FRP products developed for the use in new structures and to provide strengthening and retrofitting for existing structures. FRP reinforcements can be divided into three primary products for new structures

- FRP bars to be used as internal reinforcement
- FRP tendons for the prestressed concrete members
- Stay-in-place FRP formwork for RC members [3].

FRP materials are also used in retrofitting. It is the process in which load-bearing elements in the existing structure are repaired and provide strength to them. Applications of retrofitting are classified into two types. The first one is called strengthening. In strengthening, the structure’s initial strength or ductility needs to be upgraded to account for new services or levels of loading. The second type of FRP retrofitting is called repairing. In this case, Fiber-reinforced polymers are used to repair an existing structure to bring its load-carrying capacity, ductility, or stability back to the level for which it was designed.

The most commonly used Fibre Reinforced Polymers (FRPs) products (Table1, 2 and 3) are manufactured as prefabricated plates, bars, sheets, and anchorages. It should be noted that prefabricated FRP elements are difficult to bend or use as internal reinforcement (stirrups) because they are typically stir. On the other hand, Fibre Reinforced Polymers fabric is available in continuous unidirectional or bidirectional sheets supplied that can be easily tailored to fit any geometry and wrapped around complex profiles.

Table 1. Properties of typical commercially produced FRP products (Plates/Strips)

FRP Plates/Strips						
	Standard Modulus Carbon-reinforced	High-Modulus Carbon reinforced	GFRP	Carbon-reinforced Vinyl ester	Hybrid FRP plate	BFRP
Fiber volume	65–70	65-70	65-70	60	NA	68.7
Fiber architecture	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional
Thickness (mm)	1.2-1.9	1.2	1.4-1.9	2	3.65	1.27
Tensile strength (MPa)	2690-2800	1290	900	2070	376	1417
Tensile modulus (GPa)	155-165	300	41	131	24.4	59.2

Table 2. Properties of typical commercially produced FRP products (FRP Bars)

FRP Bars						
	Glass-reinforcedVinylester (13 mm diam.)	Glass-reinforcedVinylester (25 mm diam.)	Carbon-reinforcedVinylester (13 mm diam.)	Carbon-reinforcedVinylester (13 mm diam.)	AFRP (38 mm diam.)	BFRP (18 mm)
Fiber volume	50-60	50-60	50-60	50-60	NA	NA
Fiber architecture	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional	Unidirectional
Tensile strength (MPa)	620-690	551	2070	2255	1448	676
Tensile modulus (GPa)	41-42	41	124	145	70.3	35.2

Table 3. Properties of typical commercially produced FRP products (FRP sheets and Fabrics)

FRP sheets and Fabrics						
	Standard Modulus Carbon Fiber Tow Sheet	High Modulus Carbon Fiber Tow Sheet	Glass fiber (Unidirectional)	Basalt fiber* (Unidirectional)	PET900 (Unidirectional)	PEN900 (Unidirectional)
Thickness (mm)	0.165-0.330	0.165	0.356	0.17	1.262	1.273
Fiber tensile strength (MPa)	3790	3520	1520-3240	2100	740	790
Tensile modulus (GPa)	230	370	72	91	10	15
Strain at rupture (%)	1.2-1.5	1.0-1.5	3.5	2.4	7	5

III. APPLICATIONS OF FRP IN REINFORCED CONCRETE STRUCTURES

- Fiber-reinforced polymer is mainly used in commercial structures as well as in the public sector
- It is most economical than the other strengthening methods.
- It increases the load capacity of the structures
- It may make the structures earthquake resistant as it increases the seismic strengthening
- We can use it as repairing material in an old structure.
- It increases the shear strengthening of the building.
- It has good ductility.
- FRP has some defect remedies like layout errors, if the strength of concrete is poor then it will not work properly.
- It can be used in buildings, bridges, tanks, underwater, etc.
- It can be used on concrete, timber, masonry.
- It is also fire resistant and has excellent fatigue behavior
- Flexure strength of beams is also improved by providing FRP composites to their tension zone by using epoxy. We can apply both FRP strips and sheets.
- By providing FRP insides of the beam, bonding between U jackets covering both sides and the tension face of the beam, wrapping around the whole section of the beam increases the shear strength of the beam.

IV. PERFORMANCE OF CONCRETE STRUCTURE UNDER VARIOUS ENVIRONMENTAL CONDITIONS

While the FPR material behaves adequately in most situations, the fact remains that the composites can be afflicted considerably by the surrounding environment.This section reviews selectively experimental and numerical studies in which FRP lay Strengthening system was subjected to harsh conditions such as high temperature (fire), saline conditions, cycles of freeze and thaw. It should be noted that due to the increased use of FRP in strengthening RC structures Mostly reported studies were checking the performance of FRP material and FRP-strengthened concrete structures under extreme effects. To find out more about these effects, the reader is encouraged to review these relevant studies [11, 12, 13, 14].

A. Elevated temperatures

In the early years, FRP systems were used in most of the Bridges where fire safety, generally primary design, was not considered.However, FRP systems are being widely prevented due to concerns involving FRP performance at an elevated temperature in the case of buildings[15,16,17].These concerns are referred to by the fact that not only that strength,excessive assets get degenerated at moderate temperaturesbut this leads to a fast and significant decline in the bond between the FRP and concrete surfaces, which is vital for sustaining the effectiveness of strengthening systems.This is caused due to the low glass transition of the epoxy adhesive that ranges between 65 and 120 °C.Moreover, the organic matrix of FRPS gets disintegrated when exposed to temperature ranges between 300 and 500°C, releasing heat, smoke, and toxic gases.

Although research on the performance of FRP strength concrete members on fire contact is quite lacking and needs more investigation also. Some FRP studies have been carried out on the fire exposure of the FRP strengthened concrete beams. A researcher, who firstly conduct a test on fire, in which he observed that the unprotected FRP strong beam can attain a fire of 81 minutes endurance [18]. This is opposite to a uniform beam having a protected FRP system which will attain fire endurance of 146 min. It was also tested, in a similar fire test program, with calcium silicate boards [19]. In this study, several parameters were researched that is length, location, and bonding method including board thickness. It was observed that u-shaped fires used on the bases and sides of the beams can be achieved the best fire endurance through secure systems.The investigation also revealed that FRP startsdeboning at a temperature is close to a transient glass temperature of 55-60 °C.

A more recent study was undertaken in which he concluded that a properly insulated system can maintain FRP and promote steel material below critical temperature value maintaining structural integrity it was also concluded that a layer of VG (vermiculite gypsum) insulation can keep the beam secure during the fire and fire can attain endurance of more than 4 hours [20].

B. Saline environment

Infrastructures with high humidity and moisture content (Marine environment) often experience steel and/or steel strengthening corrosion. Steel corrosion (i.e., flange) gives rise to many distortions, reductions in cross-sectional area, including swelling timber, concrete, and masonry cracks [1,2]. As a result of such defects, these structures need to be retrofitted.

Recent tests have shown that the strength of FRP reinforcement from the resin properties is considerably reduced - particularly GFRP material. Unlike glass fibers, carbon fibers cannot absorb liquids and thus are resistant to acid, alkali, and organic solvents [21].GFRP lamination, on the other hand, has its high absorption capabilities and the epoxies absorb 1% of the moisture from the weight and 7% of it. Other studies undertaken showed that CFRP is durable in usual environments in comparison to GFRP and AFRP materials [21]. A 36% decreases in ultimate strength was observed for glass fiber reinforced polymer retrofitted samples which were subjected to 100 wet/dry cycles, while 19% reduction for Carbon fiber reinforced polymer-bondedspecimen [22].On another hand, exposing concrete specimen to saltwater immersion concrete equipment improved due to over curing of concrete however, these specimens achieved higher slips under applied loading [23].

Effect of fully or partially immersion of GFRP bars-strengthened specimen tap-water and seawater [24].The conclusion shows that there is a significant loss in the tensile strength of the GFRP bars when subjected to constant stress to considered risky situations.Porter et al.'s two test programs were conducted to check the longterm strength of GFRP composite through the process of accelerated aging[25,26].The results of these tests determine the strength reduction in the range of 34-71% of initial strength.Sultan et al. reported 50-60% of this strength loss in hand laid up GFRP sheets and bars for 10-15 years respectively.

C. Cycles of freeze /thaw

Degradation of fiber-reinforced polymers is progressively caused due to freeze-thaw cycles.This may cause a sustained reduction in the capacity to lift loads and hence the service performance of strength and retrofitted structural elements needs to be evaluated.

The adverse effects of the freeze-thaw cycle have been studied recently based on the number of researchers [27]. The impact of a freeze-thaw cycle on CFRP concrete interface fracture properties using direct shear tests [28]. CFRP material has much higher durability than either GFRP or AFRP. These authors monitored the tension transfer between FRP and concrete through the digital image correlation (DIC) method and reported a 17% reduction in ultimate load due to the freeze-thaw cycle.

Other studies have shown that even after being exposed to the freeze and thaw cycle, the members of the FRP have not changed. The ultimate strength of bonding between symbolic FRP and concrete has not been affected, but the manner of failure was converted by shear concrete and adhesive failure after freeze and thaw cycles. A single power of performing a single lap shear exhibits ultimate strength up to 54% after freeze-thaw exposure and failure mode changes from concrete shear failure to adhesive failure [29, 30].

The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction [31].

V. CHALLENGES AND FUTURE RESEARCH NEEDS

The above literature review indicates that FRPS has great potential for constant integration in civil engineering applications These materials have better properties and can thus be employed in various constructions. The simplest way to enhance any construction material, such as FRP, is to improve its inherent material properties.A systematic and comprehensive study of accelerated environmental influences on the propagation of moisture in FRP concrete bond, chloride, and salinity effect is required, instead of improving the built-in content properties of the composite.The durability and sustainability of FRP systems are pressing issue that guarantees further investigation.Testing may be done through experiments that determine the basis of statistical analysis and analysis models.The results of these studies could provide raw data to achieve and calibrate the design expression which was then used in codes and standards for design and analysis purposes.

Furthermore, it would be certainly trickled to analyze and test some early FRP-strengthened/reinforced construction to research long time performance of such structures.This can significantly increase the viability of experimental tests and give them a better link to on-site applications.Fortunately, recent advances in technology have developed several types of sensing devices which can be installed in new FRP-strengthened/reinforced constructions. With the help of such devices, real-time monitoring of or structural/physical/chemical facilities can be accessible to researchers and designers are to understand the better performance of such structures during their service life.Modern FRP systems, such as Fibre Reinforced Cementitious Matrix (FRCM), FRP anchors, etc, be approachable and widely accepted.The orderly and collaborative investigationthat covered aspects ofperformance, manufacturing, and durability of these systems is warranted.

VI. SUMMARY AND CONCLUSION

This literature review represents that FRPs providebetter potential for continual integration into the strengthening of reinforced structures. These materials also provide superior properties which can be used in a variety of construction applications and have revolutionizedthe construction design of modern RC structures.Unfortunately, like several alternative construction materials, FRP composites have limitations that hinder designers from utilizing these systems to their full potential.As mentioned earlier, a companion study highlights a number of these limitations and associated challenges specifically regarding the performance of FRP materials and FRP strengthening systems once subjected to fatigue, seismic and impact loading moreover as once exposed to extreme conditions like elevated temperature, saline setting, and cycles of temperature reduction and thawing.

This paper represents a literature review on some of the pastand recent studies related to the FRP strengthening systems in concrete structures. The outcomes of this review paper can be summarized in the followingpoints

- The major contribution of fiber-reinforced polymer composites is their potential to increase the service life of existing structures.
- Performance of fiber reinforced polymer-strengthened or reinforced structures is restricted bythe performance of FRP materials and systems under surroundingloading and environmental conditions.
- The execution of new technologies (such as sensing devices)can provide better awareness ofthelong-term behavior of fiber-reinforcedpolymer-strengthened concrete structures.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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