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Use of Fiber reinforced Polymer Rebars as internal reinforcement in structural members

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ABSTRACT

Fibre reinforced polymer (FRP) composites have been considerably used in diverse applications of engineering relatedaerospace, civil structural and automotive engineering industries.Recently, creation industrieshave also started using them. The main features of themare their excessive power to weight ratio, low unique weight, and corrosion and fatigue resistance. Due to above, they are chosen as an ideal choice for reinforcement in structural concrete that are exposed to extreme environments. Aramid, Carbon and Glass Fibers are also increasingly used in structural applications due to their blend of higher power and stiffness combined with sufficient resistance to creep and corrosion. In addition to the above, fibrous composites are used for outer and inner pre-stressing, strengthening composite plates, reinforcement in composite bars, and railway, marine product development engineering. This paper focusses on addressing the application of Aramid, Carbon and Glass Fiber used as reinforcements of rebar materials.

Keywords: corrosion, FRP rebars, Polymers, production, properties, and reinforcement.

1. INTRODUCTION

Civil engineering plays a crucial role in the development of materials engineering. This is due to the higher susceptibility to techno-material innovations, and development of modern technologies. Buildings, factories and structures are often built using polymer reinforcements and operated in severe environmental conditions, where reinforced concrete elements do not comply with the application environment. Fiber Reinforced Polymer (FRP) rebar reinforced with long fibers were used as an alternative to conventional reinforcing steel. Glass, carbon and aramid fibers were used as reinforced materials in the construction industry since late seventies. Low self-weight, high durability in aggressive environment along with very good strength, forced the development of applying the FRP rebar as the main reinforcement in concrete structures. The composite reinforcements are easy and rapid assembly under all weather conditions that made construction industry to use them. Therefore, FRP bars are made as alternative to steel reinforcement in concrete structures under extreme environmental conditions such as marine, parking, bridge decks, highways and structures that are highly susceptible to corrosion and magnetic fields.

2. CORROSION OF REINFORCEMENT

One of the major problems faced by structural engineersis the deterioration of concrete structures due to corrosion of steel reinforcement caused by exposure to aggressive environments. Deterioration due to corrosion reduces the durability and the service life of the structures and results in costly repair and safety hazards. To date, there has been considerable effort made on the development of techniques to avoid corrosion and to improve the durability of concrete structures. Corrosion of some of the structures shown in Fig.1.

Fig.1.Corrosion of Steel Reinforcement in Structures

Some of these techniques include replacement of the steel reinforcement with epoxy coated, galvanized or stainless steel bars; catholic protection of the reinforcement; grouting of prestressing tendons with cementations grout to provide alkali protection to the steel; and treatment of the concrete surface with silanes or siloxanes. However, none of these existing methods has proven to be fully effective in providing perfect protection for steel. Consequently, it appears that the only effective method to avoid corrosion is to remove the steel reinforcement from the concrete and replace it by non-corrosive materials. Recently, it has been proposed to use fiber reinforced plastic (FRP) reinforcement as a substitute for conventional steel reinforcement. So far, the use of this new type of reinforcement has shown a promising solution to durability problems caused by corrosion of steel.

3. TYPES OF REBARS

Fiber Reinforced Polymers made of fibers embedded in a polymeric resin have started replacing steel reinforcement for concrete structures. Based on the commercial viability, Aramid fiber reinforced polymer (AFRP), carbon fiber reinforced polyer (CFRP), and glass fibre reinforced polymer (GFRP) rods are largely used in the construction industry.

The FRP bars classified based on the their usage are as follows:

- GFRP(Glass Fiber Reinforced Polymers)
- CFRP (Carbon Fiber Reinforced Polymers)
- Polymer composites reinforced with aramid fibers
- Polymer composites reinforced with basalt fibers

3.1 Glass fiber reinforced polymers (GFRP)

Glass fibres are used in construction industry due to their low cost of manufacturing. But the disadvantages are, their low deformation modulus, low humidity and alkaline resistance, low long-term energy due to strain rupture. Aramid Fibres are used in places where higher alkaline resistance is needed. The following figure is corresponding to GFRP (Glass Fibre Bolstered Polymers) having AR glass in shown. Glass fibres of E and S glass are used in places requires alkaline proof.

Fig 2. GFRP Rebars

3.2 Carbon fiber reinforced polymers (CFRP)

Carbon fibres are having high deformation modulus, and fatigue resistance. It is not advisable to soak them in water due to their electrical conductivity. The manufacturing cost of such fibres are high due to their higher power consumption while manufacturing. They display a behaviour of anisotropic – the properties are not uniform in different planes. They are prone to galvanic corrosion while direct contact with metal. CFRP reinforced with graphite and carbon fibres are shown in the figure 3 below:

Fig3. CFRP Rebars

3.3 Aramid fiber reinforced polymers (AFRP)

Aramid fibres have very high strength against static loading. Their use is restricted to due to the reduction of creep properties. (Reduced strength while subjected to loads for a long period of time) and sensitivity to ultra violet radiations. It is tough to reduce them during processing too. The examples are aramid fibres kelvar 29, kelvar 49, kelvar 149, Technora H and SVM as shown in figure 4.

Fig.4. AFRP Rebars

3.4 Basalt fiber reinforced polymers (BFRP)

Basalt fibres are having high resistance to high temperature coupled with the application of high loads. They display good sturdiness. They have the properties of resistance to the following: acids, corrosion, radiation and UV. They have superior electro-magnetic properties and vibration resistance.

Fig.5.BFRP Rebars

3.5 Applications of FRP Rebars

- Waste Water Treatment Facilities
- Swimming Pools
- Sequential Excavation or Tunneling
- Deep Foundation Tunnel Boring Machine
- Temporary Reinforcement
- Rock Bolts
- Historic Preservation - Restoration & Pinning of Stone Elements
- Architecture Concrete Elements
- Bridges & Railings
- Median Barriers
- Parking Structures
- Approach Slabs
- Continuously Reinforced Concrete Paving
- Precast Elements
- Salt Storage Facilities
- Strengthening for Clay & Concrete Masonry
- Coastal Construction exposed to Salt Spray
- Sea Walls, Wharfs & Dry Docks
- Desalinization Intakes
- Port Aprons
- Light & Heavy Rail
- High Voltage Substations
- Radio Frequency Sensitive Areas
- Cable Ducts & Banks
- Hospital MRI Areas
- Aluminum Smelters & Steel Mills
- High Speed Highway Tolling Zones
- Airport Radio & Compass Calibration Pads

4. MANUFACTURING PROCESS

Pultrusion is a continuous, automated process that is cost effective for high volume production of parts with uniform cross-section. Due to uniformity in resin dispersion, fibre distribution and alignment, excellent composite structural materials can be fabricated by pultrusion. Modular bridge construction, telecommunication towers, post strengthening of building and infrastructure are done using composites.

In this process, shapes are created by pulling rovings through a heated die having the shape of the fibre. Since, it is used manufacture uniform cross sections, I beams, and boxes, channels, tubes and similar structural components are made by them. The parts used for special application in aircraft industry is manufactured using carbon fibres.

A typical continuous Pultrusion process is shown in Fig.6.

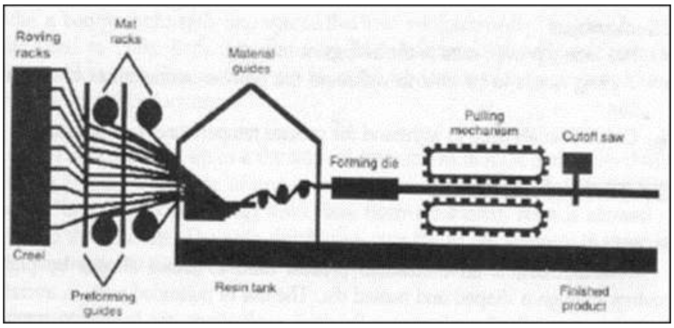

Fig.6. Typical continuous Pultrusion process

Pultrusion products are classified in to two. One is solid rod and bar stock produced from axial fibre glass reinforcements and polyester resins. The parts that require high axial tensile strength such as fishing rods and electrical insulators are made using them. Second is of structural profiles using combination of axial fibres and multi-directional fibre mats. The anisotropic behaviour helped them to meet the different strength requirements in transverse and longitudinal directions.

More than 90% of all pultruded products are fibre glass reinforced polyester. For getting improved corrosion resistance, vinyl ester resins are used. When better corrosion resistance is required, vinyl ester resins are used. Epoxy resin is used to have superior mechanical and electrical properties. Higher temperature resistance and superior mechanical properties generally dictate the use of epoxy resins reinforced with aramid or carbon fibres.

5. MECHANICAL PROPERTIES OF FRP

The physical and mechanical characteristics of FRP rebars are directly related to the type of fibres used, and the direction of fibre orientation. It is can be expressed as the percentage of fibre content in theentire volume of the composite and the diameter ofthe rebar. The polymer matrix type and method of production also plays a significant role in deciding the physical and mechanical properties of the FRP rebars.

FRP bars are having density almost four times lower than the reinforced steel concrete that brought their dead load as very low. Basalt fibres are having high density compare to the rest of the three. Carbon fibres are having higher tensile strength to weight ratio compared with steel bars. The strength properties of the FRP bars in tension is found and plotted as linear elastic until rupture. They don't undergo any plastic deformation, therefore, the destruction takes place suddenly, without any prior indications. Further to the above, the tensile strength of the reinforced while compared to FRP bars, are considerably lower, whereas the tensile modulus is relatively low except the ones with carbon reinforcements.

6. SERVICEABILITY OF FRP

The transfer of load from concrete to reinforcement that develop the required stress in the reinforcement and bring it to an equilibrium mainly depends on the bonding characteristics. It also influences the service limits such as deflection, crack width and crack spacing in fibre reinforced concrete. Since, FRP bars are anisotropic, their loading carrying capacity mainly depends on the fibre orientation. Factors such as type and volume of fiber and resin, fiber orientation and quality control during the manufacturing play a major role in deciding the mechanical characteristics. In the case of Carbon FRP rebar when comparing a steel bar of 11.3 mm diameter with CFRP rebar with similar diameter of about 9.5 mm, the results shows that the tensile stress- strain curves of the CFRP bar are linear up to failure (All FRP bars are linear elastic to failure). The ultimate tensile strength is at least 1500 MPa 3 times that of steel rebar. The modulus of elasticity of the CFRP bar is 128 GPa, about 65% that of steel. The CFRP bar exhibited almost the same bond strength to concrete as 11.3 mm diameter steel bar As for Glass FRP bar tensile strength of 9 mm GFRP bar is 760 MPa, and the Modulus of Elasticity is 40.8 GPa, much lower than that of steel.

7. RESULTS AND DISCUSSIONS

In order to eliminate the typical defects and disadvantages of conventional reinforced concrete the FRP rebar are increasingly investigated and used in the construction industry. The reason is multitude of very good physical and mechanical properties of this material, such as high tensile strength and resistance to corrosion, low density, and electromagnetic, electrical and electro-static neutrality. All of these properties are related to the internal structure of the rebar. It consists of embedded continuous long fibers (carbon, glass, basalt, aramid), which act as internal reinforcement of the composite and matrix (thermosetting or thermoplastic resins), which provide not only the proper separation of reinforcing fibers and protection from damage, but also the proper transmission of stresses on the fibers.

The properties of the FRP rebar depends on the type of fibre, content of fibre in volume, direction of the fibre, and the method of fabrication. Due to the low weight of fibres compared to steel, the density and self-weight is very low. There difference in density values among the different fibres. For example, basalt fibre while reinforced produces higher density that leads to high self-weight. On the other hand, the largest tensile strength/density ratio is a characteristics of the CFRP bars (approx. 22 times more than reinforcing steel). In comparison to the reinforcing steel, the tensile strength of the FRP bars are very high and has linear elastic characteristics until rupture. Moreover, with exception of the CFRP bars, the tensile modulus is relatively low.

In general, FRP reinforcing elements provide durable structures that are free of deterioration caused by corrosion of steel. FRP rebars have the major advantages over steel of being impermeable to effects of sodium chloride. In addition, their light weight makes handling much easier, while the high strength-to-weight ratio of FRP is most significant when spans become very long.

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