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FRP Composites and Their Using in the Construction of Bridges

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Abstract

Traditional material for concrete reinforcement is steel. In recent times, non-metallic fibres have been intensively investigated and some of them used for construction of bridges. FRP composites are durable materials which are different from the steel reinforcement for their resistance to the electrochemical corrosion. With respect to steel, different mechanical behavior of non-metallic reinforcement, however, involves some drawbacks - namely the lack of thermal compatibility between concrete and FRP reinforcement. FRP composites belong among anisotropic materials. Their properties depend on the type, volume and alignment of the fibres, the matrix type, form and quality of the construction. The analysis of causes of failures on German bridges shows that reinforcement corrosion initiated by chlorides makes up 2/3 of all the failures recorded in the bridge construction. Corrosion of the reinforcement initiated by chlorides is the main cause of the loss of serviceability of bridge structures. In such an environment, fibre-reinforced polymer (FRP) reinforcement can fully replace the traditional steel reinforcement. The paper presents the mechanical properties and durability of different types of the FRP rebar’s and their use in construction of bridges.

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Keywords: FRP composites; serviceability of bridge structures; properties of FRP composites;

1. Introduction

Fibre-reinforced polymer (FRP) materials have emerged as an alternative material for producing reinforcing bars for concrete structures. FRP composites are alternative to steel reinforcement especially in aggressive environments, mainly due to their high corrosion resistance. The advantages of FRP fibres are high strength and lightweight,

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corrosion resistance, dimensional stability, low thermal conductivity, no conductivity, electromagnetic transparency, impact resistance and low lifecycle costs.

The disadvantages of the FRP composites are high initial costs, their susceptibility to mechanical damage and fire, inability to bend in the field, longer load transfer lengths, poor shear strength and low strain to failure. Due to other differences in the physical and mechanical behaviour of the FRP materials versus steel, unique guidance on the construction of concrete structures reinforced with FRP bars is needed. [3]

FRP composites are the combination of polymeric resins, acting as matrices or binders, with strong and stiff fibre assemblies which act as the reinforcing phase. [5]

2. FRP Composites

The composites consist of two components: fibres and matrix. The fibres create 30% to 70% from the volume of the composite and 50% of its weight. The main functions of fibres are to carry the load and provide stiffness, strength, thermal stability and other structural properties to the FRP. [5] The fibres in FRP composites must have high modulus of elasticity, high ultimate strength, low variation of strength among fibres, high stability of their strength during handing and high uniformity of diameter and surface dimension among fibres. The matrix ensures the position and alignment of the fibres, protection from damage during manufacture and manipulation, durability of the composite as well as the protection from influence of environment. It is also responsible for the distribution of the loads on the individual fibres [2]. There are more types of fibres dominating in civil engineering structures: carbon (CFRP), glass (GFRP), aramid (AFRP) or basalt (BFRP) fibres.

Table 1 Properties of various kinds of fibres.

Properties	Carbon fibres		Glass fibres		Aramid fibres		Basalt fibres	Steel
	HS (High Strength)	HM (High Modulus)	E-glass	S-glass	Kevlar 29	Kevlar 49		
Density ρ [kg/m^3]	1800	1900	2540	2530	1440	1440	2700	7850
Modulus of elasticity E [GPa]	230	370	72	89	83	124	90	200
Tensile strength [MPa]	2480	1790	3400	4600	2920	3600	4000	500
Extension [%]	11.00	0.50	2.12	1.93	3.50	2.90	2.25	2.50

Fig. 1 shows the stress-strain relation of the various kinds of the FRP composites in comparison with steel reinforcement.

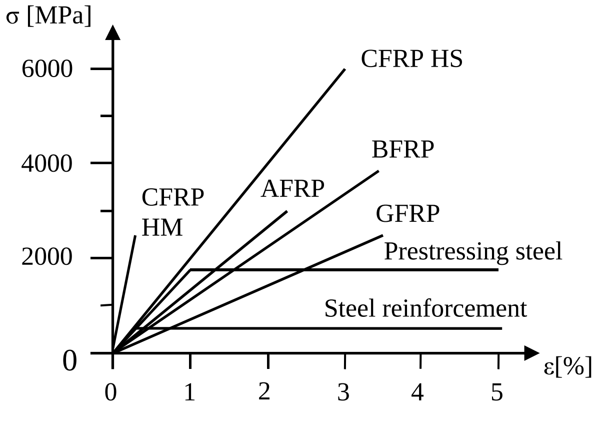

Fig. 1 Stress-strain diagram for the steel and FRP materials [1].

2.1. Carbon fibre

Carbon is produced from a petroleum pitch, rayon, or polyacrylonitrile (PAN) precursor filaments. PAN- based one is used in CFRP for structural reinforcement and strengthening due to its resulting high quality and strength characteristics. The carbon fibres have a high tensile strength and modulus of elasticity. They are not susceptible to aggressive environment and high temperatures. There are two types of carbon fibres: fibres with high tensile strength (HS) and fibres with high modulus of elasticity (HM). The main disadvantage of carbon fibres is their higher price. They tend to be 10 to 30 times more expensive then the fibres form glass.

2.2. Glass fibre

Glass fibre is by far the most predominant fibre used in the reinforced polymer industry and among the most versatile. In reinforced concrete structures there are used many varieties of glass fibres:

- *AR-glass* – Alkali resistant glass made with zirconium silicates. It is resistant to the alkaline environment found in concrete but have much higher cost. Used in Portland cement substrates.
- *E-glass* – Alkali free, highly electrically resistive glass made with alumina-calcium borosilicates. E-glass is known in the industry as a general-purpose fibre for its strength and electrical resistance. It is the most commonly used fibre in the FRP composite industry.
- *S-glass* – High strength glass made with magnesium aluminosilicates. Used where high strength, high stiffness, extreme temperature resistance, and corrosive resistance is needed.

E-glass is by far the most used and the least expensive one. Glass composites are used where higher stiffness of the carbon or aramid fibres is not required. [4]

2.3. Aramid fibres

Aramid is a synthetic fibre made from the polymer aromatic polyamide. Aramids are rapidly degraded by ultraviolet (UV) light and therefore they must be coated or painted. AFRP also absorb moisture. Strength and stiffness decreases with water contact or in high humidity environments. Impregnating the fibres in an epoxy or vinyl ester matrix will protect them from moisture infusion. Aramid fibres have the best tensile strength to the density ratio. Aramid fibres are of the lowest density, is about 40% lower than glass density. [4]

2.4. Basalt fibres

Basalt is a type of igneous rock formed by the rapid cooling of lava at the surface of the planet. The production of the basalt and the glass fibres is similar. Crushed basalt rock is the only raw material required for manufacturing the fibre. It is a continuous fibre produced through igneous basalt rock melt at about 1500 °C. Basalt fibre is a relative newcomer to fibre reinforced polymers and structural composites. It has a similar chemical composition as glass fibre but has better strength characteristics, and unlike most of the glass fibres, it is highly resistant to alkaline, acidic and salt attack, which is making it a good candidate for concrete, bridge and shoreline structures. Compared to carbon and aramid fibre, it has the features of wider application temperature range -269°C to +650°C, higher compression strength, and higher shear strength. The price of fibres made from basalt is higher than those made of E-glass, but less than S-glass, aramid or carbon fibre and as worldwide production increases, its cost of production should reduce further. Basalt fibres have high potential and are getting a lot of attention due to its high temperature and abrasion resistance. Compared to FRPs made from carbon, glass and aramid fibre, its use in the civil infrastructure market is very low. [4]

3. FRP Composites in the Construction of Bridges

Structural profiles used in bridge engineering are produced primarily in the pultrusion process. The forms are based on cross sections of steel profiles, although there are some innovative forms adapted to the properties of FRP composites [6].

In principle there are no limits for dimensions of the elements beyond those of a manufacturer. The only limitation independent of the manufacturer, dependent on material properties, is the thickness of the element. The process of curing the resin is exothermic and for large thicknesses problems might occur in discharging the produced heat, which in extreme cases can lead to spontaneous combustion. FRP in form of wires (in particular CFRP) are a material with very interesting properties for stay cables or tendons, like high tensile strength, high fatigue resistance as well as low weight and excellent chemical resistance. However, due to anisotropy of the material, there exists the problem of developing a method of anchoring the cables of the FRP in such a way that anchorage strength was comparable to the strength of anchored cable. [6]

4. Hybrid Bridge Structures

Hybrid Bridge Structures are presented on following Fig.2 and Fig.3.

Fig. 2. Hybrid bridge over A27 motorway near Utrecht, [7].

Fig. 3. King's Stormwater Channel Bridge, [8].

5. All-Composite Bridge Structures

Examples of All-Composite Bridge Structures are presented on following Fig. 4 to 9.

Fig. 4. Friedberg bridge over B3 highway, [9].

Fig. 5. Friedberg bridge over B3 highway, [10].

Fig. 6. West Mill bridge (Oxfordshire, 2002), [11].

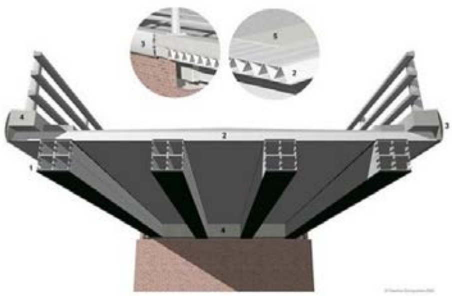

Fig. 7. West Mill bridge (Cross-section), [11].

Fig. 8. ApATeCh arched footbridge, [12].

Fig. 9. ApATeCh arched footbridge (Produced by vacuum infusion), [12].

6. Strengthening of Bridges with FRP Composites

FRP composites can also be used for the strengthening of old bridges. Many bridges in our country are in bad condition. They will undergo reconstruction and strengthening in the short time. The following figures (Fig. 10 to 12) present several examples of strengthening of bridges.

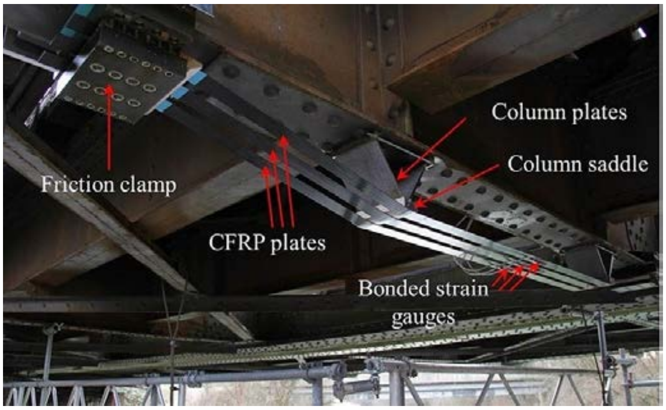

Fig. 10. Strengthening of a steel bridge by using CFRP strips, [13].

Fig. 11. Strengthening of a concrete bridge with CFRP strips, [14].

Fig. 12. Strengthening of a concrete bridge with the CFRP sheets, [15].

Conclusion

The steel reinforcement can be replaced by FRP composite reinforcement, especially in cases of concrete structures exposed to environments with the increased environmental burden. Serviceability limit state is the deciding criteria for the design of FRP reinforced structures. FRP composites are used in bridge engineering. FRP composites can be used for construction of new bridges, so also for strengthening the old (historical) bridges.

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