Tensile properties of braided composite rods

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ABSTRACT: The current work is concerning the development of braided reinforced composite rods for civil engineering applications, namely for concrete internal reinforcement. The research study aims to understand the mechanical behaviour of braided reinforced composite rods produced from an innovative technique. Seven types of braided reinforced composite rods were produced, varying the type of fibres used as a core reinforcement of a polyester braided fabric. E-glass, carbon, HT polyethylene fibres were used in different combinations. The mechanical properties of the braided reinforced composite rods were evaluated under tensile in order to identify the type(s) of fibre(s) to be used as core reinforcement. Results are compared to those of conventional materials used for concrete reinforcement, such as steel.

1 INTRODUCTION

The concrete construction industry deals every day with the deterioration of concrete structures. Nowadays a large number of bridges, buildings and other structural elements require rehabilitation and repair and its maintenance have become an increasingly serious problem. Concrete structures when subjected to repeated loading and to aggressive environmental agents present a decrease in terms of mechanical properties and durability performance. Corrosion of steel is one of the most serious problems of concrete structures.

Several techniques have been developed to reduce corrosion of steel but none seems to be a suitable solution for the corrosion problem. Therefore, the use of fibre reinforced composite rods as concrete reinforcement material seems to be an effective solution to overcome durability problems of traditional steel reinforced concrete structures. The main advantages of fibre reinforced composite materials over steel include the excellent corrosive resistance, mechanical properties similar to steel, high strength-to-weight ratio and excellent fatigue resistance, among others (Alsayed et al (2000), Lees (2001)). Thus, the replacement of steel rebars with fibre reinforced composite rods is gaining popularity worldwide.

Typically, fiber reinforced composite rods are produced by pultrusion, although, besides this technique, fiber reinforced composite rods can also be produced using braiding techniques (Kadioglu et al (2005), Saikia et al (2005)). Braiding is a conventional textile technique known as the technique used to produce ropes. It is a low cost technique that allows in-plane multiaxial orientation, conformability, excellent damage tolerance and core reinforcement (Soebroto et al (1990)). Moreover, braiding allows the production of ribbed structures and a wide range of mechanical properties may be improved when the core braided fabrics are reinforced with the appropriate type of fibres (Fangueiro et al (2004), (2005), (2006)).

2 OBJECTIVES, EXPERIMENTAL WORK AND RESULTS

2.1 *Objectives*

The current research work deals with the development of braided reinforced FRP rods for civil engineering applications, namely to reinforce concrete structures as a substitute of steel rebars. The mechanical properties of fiber reinforced composite rods, produced by braiding technology, are influenced by the type of fibre used as braided fabric core reinforcement, among other parameters. The objective of this experimental work is to evaluate the influence of the type of core reinforcement fibres on the mechanical performance of braided reinforced composite rods. Several samples of braided reinforced composite rods were produced using polyester fibres, for the production of braided fabric, E-glass, carbon and HT polyethylene fibres, as braided fabric core reinforcements, and polyester resin as polymeric matrix.

2.2 *Experimental work and results obtained*

Braided reinforced composite rods were produced on a vertical braiding machine incorporating an impregnation system specially developed for this purpose. The production process is explained elsewhere (Fangueiro (2004)). Seven different braided reinforced composite rods were produced using a lab scale equipment, specially developed for this purpose, maintaining the braided fabric structure and varying the type of core reinforcement fibre, according to Table 1. FRP rods were reinforced with a single type of reinforcement fibres as well as with two and three types of fibres, varying the percentage of each type. The objective was to identify the influence of the fiber type and the amount on the mechanical behavior of the fiber reinforced composite rod. Table 1 presents the percentage of each type of fibre used as core reinforcement over the total linear density of the core reinforcement, the rod diameter and the fibre volume fraction of the reinforcement fibres.

In order to evaluate the volume fraction of the different braided composite rods produced, tests were conducted according to the Portuguese Standard NP 2216/1988 (determination of mass loss by calcinations of glass fibre reinforced plastics).

Table 1. Braided reinforced FRP rods characteristics

Rod type	Type of core reinforcement fibre			Rod diameter [mm]	Volume fraction (reinforcement fibres) [%]
	E-Glass fibre [%]	Carbon fibre [%]	HT polyethylene fibre [%]		
1	100	-	-	5,50	40,6
2	77	23	-	5,27	35,3
3	53	47	-	5,75	31,8
4	-	100	-	6,40	33,3
5	50	45	5	6,00	35,6
6	52	45	3	5,98	32,7
7	75	22	3	5,78	33,7

The type and the amount of fibre were chosen to compare the tensile behavior of composite rods. Comparison between braided reinforced composite rods 1, 2, 3 and 4 allows the identification of the influence of the quantity of E-glass and carbon fibres on the rod tensile behavior. Comparison between rods 2 and 7 enables the identification of the influence of HT-polyethylene fibre on the rods behavior. The influence of HT-polyethylene fibre amount can be assessed by the comparison of rods 3, 5 and 6.

The rods diameter varies from 5,27 to 6,40mm and the volume fraction of the core reinforcement fibres ranges from 31,8 and 40,6 %. There is no relationship between the rod diameter variation and the volume fraction of the core reinforcement fibres. Therefore, the resin content varies from rod to rod.

During the curing period of the polyester resin, the core reinforcement fibres were subjected to a pre-load of 100N. In order to evaluate the mechanical performance of the different braided reinforced composite rods produced, tensile tests were carried out according to ASTM D 3916-94 standard, with a crosshead speed of 5 mm/min. A post-load of 50KN was applied to the rods prior to performing the tensile tests. Table 2 presents the average values of the tensile test results obtained for each rod type.

Table 2. Tensile test results obtained for the different braided reinforced composite rods (C.V. – Coef. Variation)

Rod Type	**Tensile strength [MPa]**	C.V. [%]	**Extension at failure**	C.V. [%]	**Tensile strength at 0.2% [MPa]**	C.V. [%]	**Modulus of Elasticity [GPa]**	C.V. [%]
1	485,35	60,69	0,01701	38,61	110,73	0,08	55,36	0,08
2	766,70	11,95	0,01416	12,32	157,05	3,16	78,52	3,16
3	740,41	13,44	0,01178	8,40	148,96	3,88	74,48	3,88
4	747,77	14,11	0,01183	57,36	192,58	2,67	96,29	2,67
5	679,45	9,43	0,01105	4,08	167,84	15,74	83,92	15,74
6	652,77	11,50	0,01098	12,61	162,17	3,52	81,09	3,52
7	690,99	4,44	0,01438	7,95	146,40	7,92	73,20	7,92

Analysing the tensile strength, it can be concluded that composite rods type n.º 2 (77% E-glass fibre, 23% carbon fibre) present the highest tensile strength. Composite rods type n.º 3 and type n.º 4, when compared with rod n.º 2, presents a decrease of tensile strength of about 3%. Composite rod type n.º 1 presents the lowest tensile strength (Figure 1).

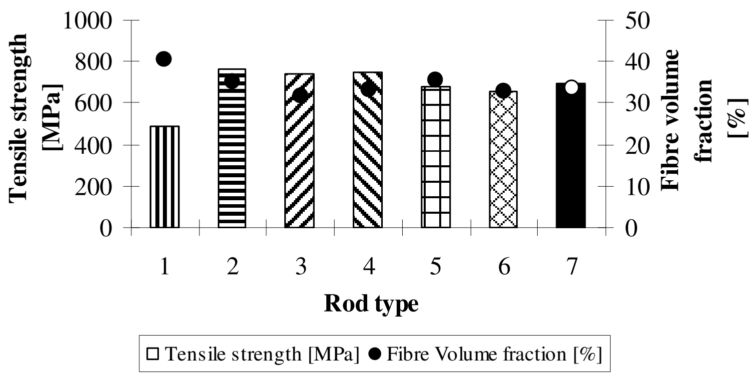

Figure 1. Influence of core reinforcement fibre type in braided reinforced composite rods tensile strength.

Braided reinforced composite rod n.º 1 (100% E-glass fibre) presents the highest extension at failure. The composite rod type n.º 6 (52% E-glass fibre, 46% carbon fibre, 3% HT polyethylene fibre) presents the lowest extension at failure (Figure 2).

The yield point was defined as the stress at 0.2% strain. Figure 3 presents the tensile stress obtained, for each FRP rod, at an extension of 0.002. Composite rod n.º 4 (100% carbon fibre) presents the highest yield point, while 100% E-glass reinforced composite rod (rod n.º 1) presents the lowest one.

Figure 4 presents the results obtained for the modulus of elasticity, determined for a strain of 0.2%. 100% carbon fibre reinforced composite rod (rod n.º 4) presents the highest modulus of elasticity while 100% E-glass fibre reinforced composite rod (rod n.º 1) presents the lowest one.

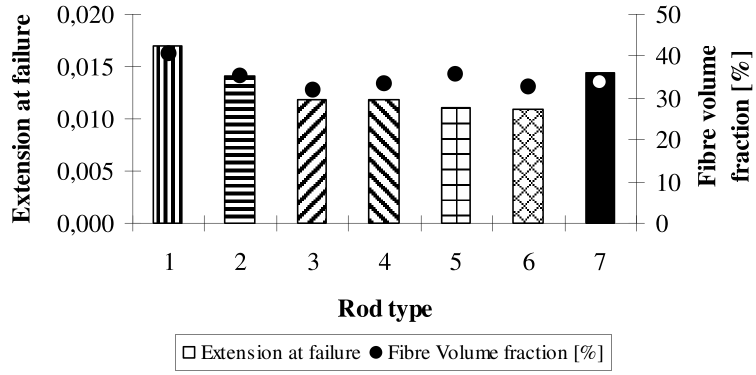

Figure 2. Influence of core reinforcement fibre type in braided reinforced composite rods extension at failure.

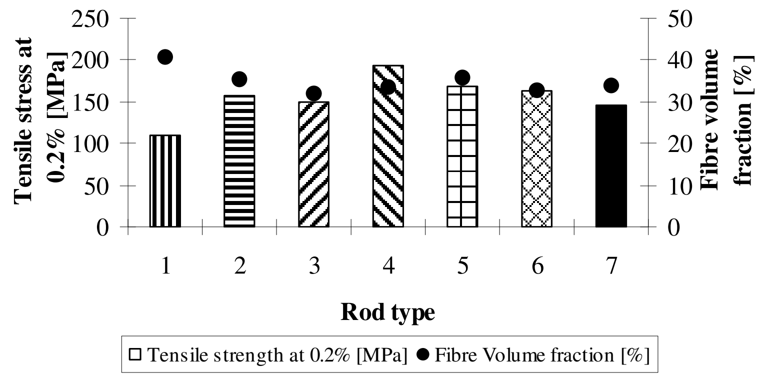

Figure 3. Influence of core reinforcement fibre type in braided reinforced composite rods yield point.

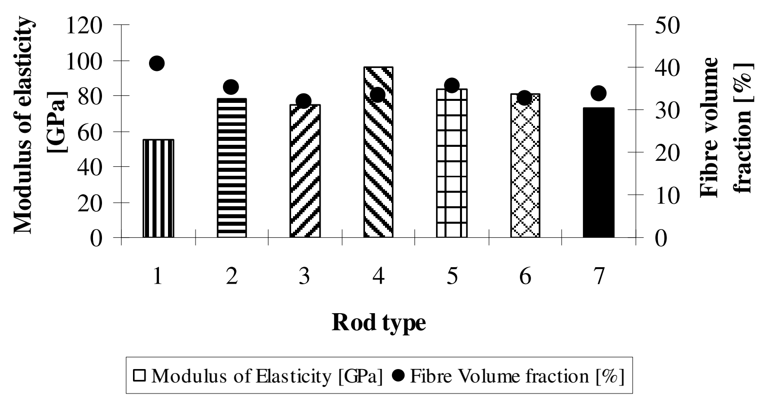

Figure 4. Influence of core reinforcement fibre type in braided reinforced composite modulus of elasticity.

2.3 *Braided reinforced FRP rod tensile performance ranking*

In order to identify the braided reinforced composite rod with the most interesting tensile performance, a classification criterion was defined. Thus, was established a score from 1 to 7, namely, for the worth and best tensile performance in each parameter evaluated – tensile strength, extension at failure, tensile strength at 0,2% strain and modulus of elasticity (Table 3). Therefore, the composite rod presenting tensile performance according to the objectives envisaged is the one that presents the highest total score. The composite rod presenting the smallest total score value is the one which tensile performance is less interesting, among the FRP rods produced. For instance, the best composite rod is the one that presents the highest tensile strength and tensile stress at 0,2%, lowest extension at failure and, consequently, the highest modulus of elasticity.

As shown in Table 3, braided reinforced composite rod n.º 4 (100% carbon fibre) presents the most interesting tensile performance while braided reinforced composite rod n.º 1 (100% E-glass fibre) presents the less interesting one, although rod n.º1 presents the highest reinforcement fibre volume fraction. Composite rods n.º 2 and n.º 7, presenting the same amount of E-glass and carbon fibres, presents significantly different tensile behaviour, mainly due to the reinforcement fibre volume fraction. Although rod n.º 7 presents also HT polyethylene fibres, its fibre volume fraction is lower than in rod n.º 2. For composite rods n.º 3, n.º 6 and n.º 5, with the same amount of E-glass and carbon fibres, the presence and increasing of HT polyethylene fibre, as well as the increase of the fibre volume fraction, promotes an increasing of the rod tensile performance. Although the tensile performance of the composite rods is influenced by the reinforcement fibre volume fraction, one can see in Figure 6 that the type of reinforcement fibre has a significantly higher influence.

Table 3. Braided reinforced composite rods score board.

Rod Type	**Tensile strength [MPa]**	**Extension at failure**	**Tensile stress at 0.2% strain [MPa]**	**Modulus of Elasticity [GPa]**	**Total Score**
1	1	1	1	1	4
2	7	3	4	4	18
3	5	5	3	3	16
4	6	4	7	7	24
5	3	6	6	6	21
6	2	7	5	5	19
7	4	2	2	2	10

When compared to the steel rebars currently used in the construction industry, composite rods reinforced by carbon, glass and polyethylene fibres present higher tensile strength (Table 4). Current Portuguese steel rebars, A235NL, A400NR/ER and A500NR/ER have values of tensile strength of 360 MPa, 460 MPa, and 550 MPa, respectively.

Table 4. Tensile test results obtained for the different braided reinforced composite rods

Rod Type	**Tensile strength [MPa]**	**Yield Stress [MPa]**	**Tensile strength at 0.2% [MPa]**	**Modulus of Elasticity [GPa]**
1	485,35		110,73	55,36
2	766,70		157,05	78,52
3	740,41		148,96	74,48
4	747,77		192,58	96,29
5	679,45		167,84	83,92
6	652,77		162,17	81,09
7	690,99		146,40	73,20
A 235 NL	360	235		210
A 400 NR/ER	460	400		210
A 500 NR/ER	550	500		210

A – Steel; N – Ribbed; L – Hot rolling; R – Cold rolling

Composite rod n.º 1 (100% glass fibre) is the only composite rod that presents tensile strength lower than 550MPa. Even though the tensile strength of E-glass, carbon and HT polyethylene fibre reinforced composite rods is higher than that of steel rebars. However, composite rods have a lower modulus of elasticity when compared to that of steel rebars, 210 GPa (Table 4).

3 CONCLUSIONS

The composite rods diameter varies due to the core reinforcement fibres used and to the resin volume fraction. There is no relationship between the rod diameter and the volume fraction of the reinforcement fibres. Composite rod, reinforced by 77% E-glass and 23% carbon fibres, presents the highest tensile strength. The lowest tensile strength is presented by the composite rod reinforced by 100% E-glass fibre. Analysing the extension at failure parameter, composite rod reinforced by 52% E-glass, 46% carbon and 3% HT polyethylene presents the lowest extension at failure. Once again, the composite rod reinforced by 100% E-glass fibre presents the highest value. Composite rod reinforced by 100% carbon fibre presents the highest yield stress and, therefore, the highest modulus of elasticity. Composite rod reinforced by 100% E-glass fibre presents the lowest values in both parameters. Based on the braided reinforced composite rod score board, the composite rods that present the best tensile performance are those who present the lowest amount of E-glass fibre. Among the rods with the same amount of E-glass and carbon fibres, the composite rod with highest percentage of HT polyethylene presents highest tensile performance. The type of reinforcement fibre used has higher influence than the fibre volume fraction in the tensile performance of the composite rods. When compared to the steel rebars, composite rods present higher tensile strength. Even though the tensile strength of composite rods is higher than that of steel rebars, composite rods have a lower modulus of elasticity when compared with the 210 GPa of steel rebars

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