Braided composite rods to reinforce concrete subjected to aggressive environments

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Abstract

The current work is concerned with the development of braided composite rods for civil engineering applications, namely for concrete internal reinforcement, as a steel substitute. The research study aims at understanding the tensile behaviour of composite rods reinforced by a textile structure – braided structure with core reinforcement.

Seven types of braided composite rods were produced, varying the type of fibres used as a core reinforcement of a polyester braided structure. E-glass, carbon and HT polyethylene fibres were used in different combinations. The tensile properties of the braided reinforced composite rods were evaluated 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.

Keywords: braiding, composite, concrete, corrosion, fibres, steel

1. Introduction

The concrete construction industry deals every day with the deterioration of steel reinforced concrete structures. 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. Deterioration of concrete severely affects the service life, safety and maintenance costs of concrete structures. Moreover, reinforced and pre-stressed concrete structures are particularly vulnerable, especially those exposed to moist and aggressive environments. In this case, steel corrodes producing unsightly staining, cracking and spalling of the concrete due to the volume expansion of the iron as the oxide is formed.

Stainless steel, galvanizing, epoxy coating and other procedures are some of the techniques that have been developed to reduce steel corrosion, but none of the solutions seem to be viable as suitable solution to eliminate the corrosion problem. Therefore, fibre reinforced composite materials have recently received a great deal of attention by the civil engineering scientific community (Chaallal et al, 1996) (Micelli et al, 2004). The advantages of fibre reinforced composite materials over steel include the excellent corrosive resistance, among others. Many engineers consider fibre reinforced composite materials as one of the most innovative materials that may overcome the inherited deficiency of concrete structures reinforced by steel rebars, due to corrosion in aggressive environments.

Typically, fibre reinforced composite rods are produced by pultrusion, which is a well-known manufacturing method in fabricating fibre reinforced composites with a constant cross section. In pultrusion process, the longitudinal fibres are drawn through a resin bath and then passed through a die, which gives the composite its final shape (Kadioglu et al, 2005). Therefore, fibre reinforced composite rods present smooth surface and, when used as internal reinforcement for concrete, the bond at the interface between a composite rod and concrete is of paramount importance. The bond behaviour will have a direct influence on both the serviceability and ultimate limit of reinforced concrete elements. To improve bond behaviour composite rod-concrete, a surface treatment is required to introduce deformations on the rod surface, and two different approaches can be considered: deformation of the surface, due to the presence of ribs or indents or providing deformations in the outer resin layer, or surface treatments, such as sand blasting or epoxy-coated sand (Lees, 2001). Besides pultrusion, fibre reinforced composite rods can also be produced using braiding techniques (Soebroto et al, 1990). Braiding is a low cost technique allowing in-plane multiaxial orientation, conformability, excellent damage tolerance and allows core reinforcement. Moreover, braiding allows the production of ribbed structures and a wide range of mechanical properties may be improved when the core braided structures are reinforced with the appropriate type of fibers (Fangueiro et al, 2006).

2. Objectives and motivations

The main objective of this research work is the development of a corrosion free material for concrete internal reinforcement, in order to overcome the main disadvantage of steel, e. g. corrosion. Moreover, it is intended to produce composite rods with ribbed surface in a single step production process. Thus, using conventional textile techniques, composite rods willl be produced with a polymeric matrix reinforced by braided structures with different types of high performance fibres as axial reinforcement.

3. Experimental work

The objective of the experimental work presented in this paper, is the evaluation of the influence of the type of core reinforcement fibres on the tensile behaviour of braided composite rods – core reinforced braided structure impregnated by a polymeric matrix.

3.1 Braided composite rods production

3.1.1 Braiding technique

Braiding technique is one of the most ancient production processes of textile structures. Normally used for ropes and cables, braided structures are also very interesting for composite reinforcements due to their characteristics: in-plane multiaxial orientation, conformability, excellent damage tolerance and low cost (Fangueiro et al, 2004). The basic principle of braiding is the mutual intertwining of yarns (Fig. 1). Braids are fibrous structures resulting of the yarns crossing in diagonal direction and can be tubular or flat, namely if they have round/oval cross section or not.

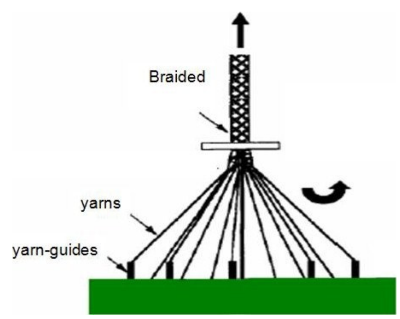

Fig. 1 Braiding machine.

3.1.2 Core reinforced braided structure

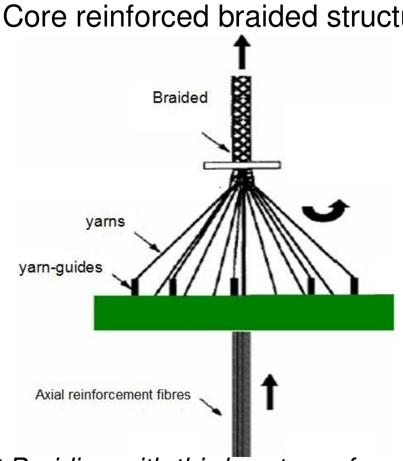

Fig. 2 Braiding with third system of yarns

Core reinforced braided structures are braided tubular structures presenting, beside two systems of yarns moving helically, a third one that introduces yarns on the braid axial direction (Fig. 2). This third system of yarns may be composed by different types of fibres, namely natural or man-made. Moreover the use of combination of different types of fibres to reinforce braided structures is also a possibility. The axial reinforcement fibres are responsible for the mechanical performance of core reinforced braided structures. The influence of the braided structure itself is rather poor.

3.1.3 Braided composite rod.

Braided composites rods are produced in a conventional braiding machine with minor modifications, developed by the Fibrous materials Research Group, at University of Minho.

The braiding machine has integrated an impregnation device that allows the impregnation of the axial reinforcement fibres in a polymeric matrix, in the instant immediately before to the braiding process (Fig. 3). Therefore, it is guarantee that the impregnation of the axial reinforced braided structure occurs from the inside to the outside of the structure. Moreover, the ribbed braided structure is obtained when yarns with signinficantly different linear densities are used in the production of the braided structure.

Hence, using braiding technology with minor adaptations, ribbed composite rods may be produced in a single step.

Due to braiding technology capabilities, braided composite rods may be produced with different types of fibres. Varying the type of fibers used and their quantity and varying the type of polymeric matrix used, different composite rods may be obtained with specific mechanical, physical and chemical properties for different applications.

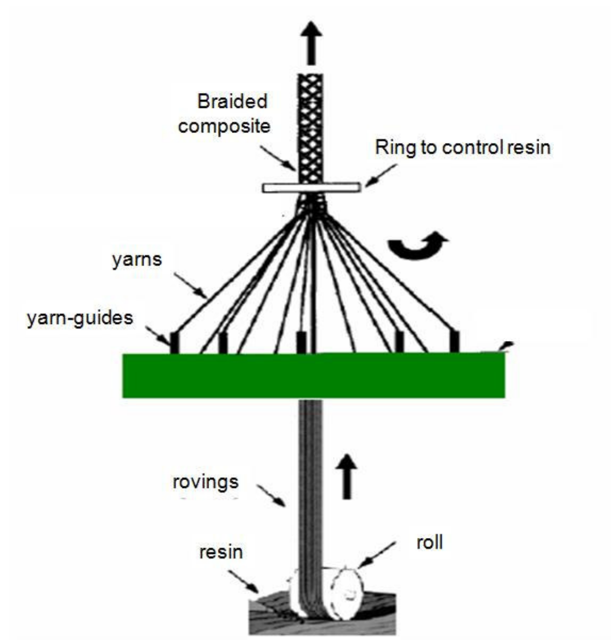

Fig. 3 Braiding with third system of yarns impregnated in resin

3.2 Raw materials

Seven different braided composite rods were produced using polyester fibres for the braided structure production, e-glass, carbon and HT polyethylene fibres as braided structure core reinforcement, and a polyester resin was used for the core reinforced braided structure impregnation.

Braided composite rods were produced maintaing the braided structure geometry and linear density and varying the type of core reinforcement fibre, according to Table 1.

Braided compoiste 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 one. The objective was to evaluate the influence of the type of fiber and its quantity on the mechanical behavior of the braided composite rods. Table 1 presents the percentage of each type of fibre used as core reinforcement over the total linear density of the core reinforcement.

Table 1. Braided composite rods composition

Rod type	Type of core reinforcement fibre		
	E-Glass fibre [%]	Carbon fibre [%]	HT polyethylene fibre [%]
1	100	-	-
2	77	23	-
3	53	47	-
4	-	100	-
5	50	45	5
6	52	45	3
7	75	22	3

The type and the amount of fibre were chosen to compare the tensile behavior of composite rods, as showed in Table 1. Comparison between braided reinforced braided 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.

3.3 Properties evaluation

3.3.1 Braided composite rods physical evaluation

Table 2 presents the rod diameter and the fibre mass fraction of the reinforcement fibres of each rod produced.

In order to evaluate the mass 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 2. Braided reinforced rods physical properties

Rod type	Rod diameter [mm]	Mass fraction (reinforcement fibres) [%]
1	5,50	40,6
2	5,27	35,3
3	5,75	31,8
4	6,40	33,3
5	6,00	35,6
6	5,98	32,7
7	5,78	33,7

Rods diameter varies from 5.27 to 6.40mm and the mass fraction of the core reinforcement fibres ranges from 31.8 and 40.6 %.

According to Fig. 4, 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.

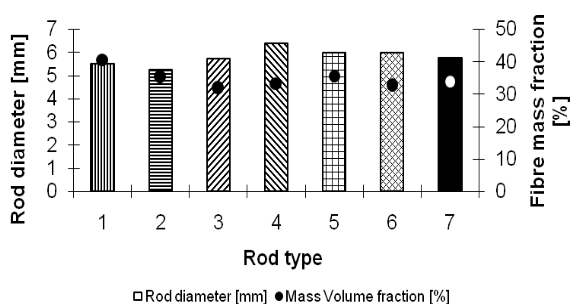

Fig. 4 Relationship between rod diameter and fibre mass fraction

3.3.2 Braided composite rods tensile evaluation

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 3 presents the average values of the tensile test results obtained for each rod type.

Table 3. 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 braided composite rods type 2 (77% E-glass fibre, 23% carbon fibre) present the highest tensile strength. Composite rods type 3 and type 4, when compared with rod 2, presents a decrease of tensile strength of about 3%. Composite rod type 1 presents the lowest tensile strength (Fig. 5).

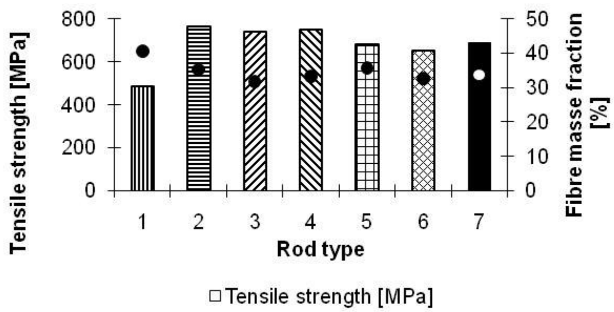

Fig. 5 Influence of core reinforcement fibre type in braided composite rods tensile strength.

Braided reinforced rod 1 presents the highest extension at failure. The composite rod 6 presents the lowest extension at failure (Fig. 6).

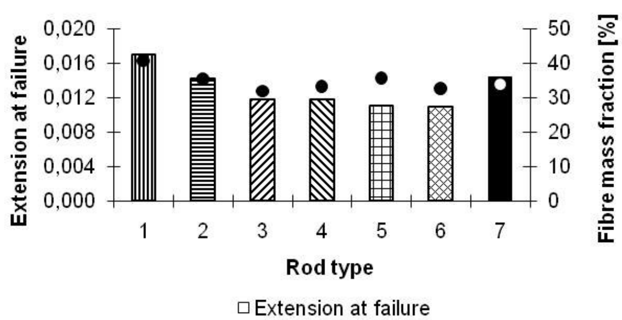

Fig. 6 Influence of core reinforcement fibre type in braided composite rods extension at failure.

The yield point was defined as the stress at 0.2% strain. Fig. 7 presents the tensile stress obtained, for each rod, at an extension of 0.002. Composite rod 4 (100% carbon fibre) presents the highest yield point, while 100% E-glass reinforced composite rod (1) presents the lowest one.

Fig. 8 presents the results obtained for the modulus of elasticity, determined for a strain of 0.2%. 100% carbon fibre reinforced composite rod (4) presents the highest modulus of elasticity while 100% E-glass fibre reinforced composite rod (1) presents the lowest one.

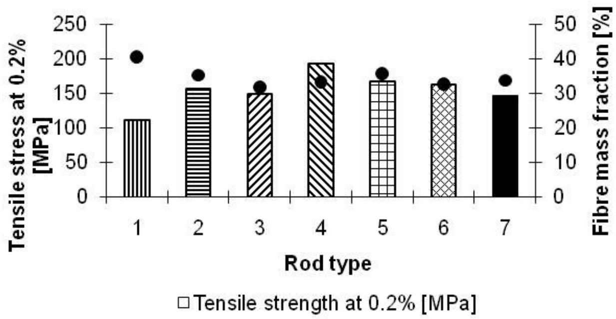

Fig. 7 Influence of core reinforcement fibre type in braided reinforced rods yield point.

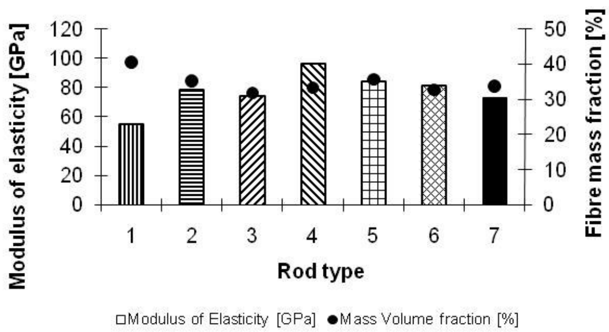

Fig. 8 Influence of core reinforcement fibre type in braided composite rod modulus of elasticity.

3.4 Braided composite rod and steel rebar comparison

Considerering the different composite rods tensile strength, extension at failure, tensile strength at 0,2% strain and modulus of elasticity, some conclusions can be withdrawl.

Braided composite rod 4 (100% carbon fibre) presents the most interesting tensile performance while braided composite rod 1 (100% E-glass fibre) presents the less interesting one, although rod 1 presents the highest reinforcement fibre mass fraction.

Composite rods 2 and 7, presenting the same amount of E-glass and carbon fibres, presents significantly different tensile behaviour, mainly due to the reinforcement fibre mass fraction. Although rod 7 presents also HT polyethylene fibres, its fibre mass fraction is lower than in rod 2.

For composite rods 3, 6 and 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 mass fraction, promotes an increasing of the rod tensile performance.

Although the tensile performance of the braided composite rods is influenced by the reinforcement fibre mass fraction, one can conclude that the type of reinforcement fibre has a significantly higher influence.

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.

Braided composite rod 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 braided 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).

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

4. Conclusions and Acknowledgements

The braided composite rods diameter varies due to the core reinforcement fibres used and to the resin mass fraction. There is no relationship between the rod diameter and the mass fraction of the reinforcement fibres. Braided 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.

Braided 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.

The braided 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 mass fraction in the tensile performance of the FRP rods. When compared to the steel rebars, composite rods present higher tensile strength. Even though the tensile strength of braided 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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