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José Barroso de Aguiar   Saíd Jalali   Aires Camões   Rui Miguel Ferreira

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Editors

José Barroso de Aguiar
Saíd Jalali
Aires Camões
Rui Miguel Ferreira

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Core reinforced braided composite armour as a substitute to steel in concrete reinforcement

R. Fangueiro[1], G. Sousa[2], M. de Araújo[3] and C. Gonilho Pereira[4]

Universidade do Minho, Departamento de Engenharia Têxtil
Azurém, P – 4800-058 Guimarães, Portugal

S. Jalali[5]

Universidade do Minho, Departamento de Engenharia Civil
Azurém, P – 4800-058 Guimarães, Portugal

ABSTRACT

This paper presents the work that is being done at the University of Minho concerning the development of braided rods for concrete reinforcement. Several samples of core reinforced braided fabrics have been produced varying the type of braided fabric (core reinforced and hybrid), the linear density of the core reinforcing yarns and the type of braiding structure (with or without ribs). The tensile properties of these samples were evaluated and the results are presented. The influence of each factor on the tensile properties of braided fabrics has also been analysed. Core reinforced braided composites rods were produced and tested to evaluate tensile and bending properties. The results obtained are presented and discussed. Reinforced concrete beams, with composite armour and steel armour, were produced and were subjected to bending test and the test results are presented. The adherence between composite rods and concrete was analysed as well.

1. INTRODUCTION

Concrete structures are subjected to repeated loading and to aggressive environmental agents which may lead to poor mechanical and durability performance of the structures with time. One of the most serious problems affecting concrete is corrosion of the steel reinforcement. As shown in Figure 1, corrosion may occur as a result of the reaction of lime present in hydrated cement with carbon dioxide or to the action of chlorides. In the first case, the lime reaction with the carbon dioxide, existing in the atmosphere, leads to a gradual decrease in concrete alkalinity. When the concrete cover pH is lower than 9 the compact oxide layer that protects the steel is destroyed, thus leading to the formation of

[1] Professor
[2] Researcher
[3] Full Professor
[4] Researcher
[5] Associate Professor

electrochemical reactions which are responsible for the corrosion of the steel. The chloride ion attack is mainly due to the migration of chloride ions existing in the vicinity of the structure. It is accepted that when the chloride ions reach a given critical concentration the potential for steel corrosion increases significantly. This fact is particularly hazardous in marine or structures in contact with de-icing salts.

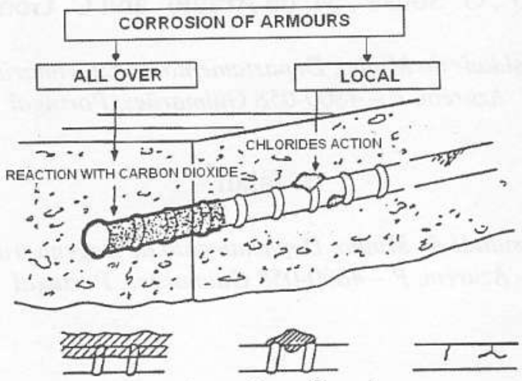

Figure 1 – Corrosion of steel armours

Composite materials are used in civil engineering as a substitute or as a reinforcement of conventional materials, like concrete and steel. The main reasons for the use of composite materials are corrosion resistance, low weight and nonmagnetic properties. In spite of these advantages, the lack of ductility and energy absorbing capabilities are a severe limitation of all these fiber systems if they are to be considered for earthquake resistant applications (Pastore 2004). The resistance to corrosion is one of the most important advantages when compared with steel. In the last years, several studies and applications have been developed using fibre reinforced polymers (FRP). Composite materials can be used in a structural way (as steel is used), as a concrete reinforcement and in rehabilitation of existing structures. The reinforcement of concrete can be done with composite materials reinforced by fibres or adding fibres and polymers to cement. Replacement of steel reinforcement in concrete structures with more corrosion resistant substitutes, such as composites, is rapidly becoming a more economical option for construction facilities worldwide. It's possible to use composite rods substituting ordinary steel armour in concrete reinforcement.

Textile materials are also widely used in civil engineering structures and it is possible to adapt some textile production techniques to produce new composite materials with structural function.

Braiding technique is probably the most ancient production process for textile structures. Normally used for ropes and cables, braided fabrics are also very interesting for composite reinforcements due to their characteristics: in-plane multiaxial orientation, conformability, excellent damage tolerance and cost. The braiding technique can produce a wide range of preforms for composite reinforcements, however, the number of yarn bobbins in the braiding machine limits the dimensions of the fabric.

2. STUDY ON THE MECHANICAL BEHAVIOUR OF BRAIDED FABRICS

In order to evaluate the mechanical behaviour of braided fabrics when subjected to tensile stress, different types of fabrics have been produced, i.e, core reinforcement braided fabrics with and without ribs (core yarns reinforcing axially the braided fabric) and hybrid braided fabrics (combining different materials and without core reinforcement). Some characteristics of the materials used are summarized in Table 1.

Table1 – Types of fabrics produced.

	Ribs	Material	Yarn Count (Tex)
Braided fabric	Without	E Glass	204 Tex
Core reinforcement		E Glass	6-12 rovings, 900 Tex each
Braided fabric	With	E Glass	204 Tex
Core reinforcement		E Glass	12 rovings, 900 Tex each
Braided fabric	With	E Glass	204 Tex
Core reinforcement		E Glass	12 rovings, 900 Tex each
		Carbon	200 Tex

Braided fabrics were produced on a vertical braiding machine and the geometrical and dimensional parameters of each material produced have been evaluated. The obtained results are shown in Table 2 according to Figure 2.

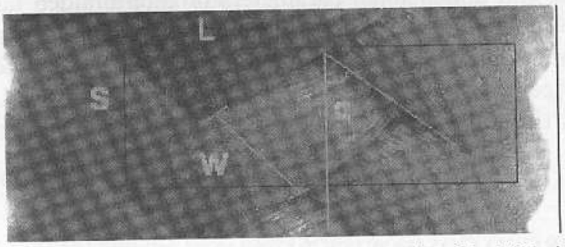

Figure 2 – Geometrical parameters of braided fabrics

Table 2 – Geometrical and dimensional parameters of each braided fabric tested.

Braided fabric	α (°)	L (mm)	W (mm)	S (mm)	Mass (g/m)	Thickness (mm)	Area (mm^2)
Glass (6 rovings of glass)	45,3	1,59	0,72	1,01	10,43	2,61	5,35
Glass (7 rovings of glass)	45,2	1,68	0,72	1,01	11,28	2,72	5,81
Glass (8 rovings of glass)	44,8	1,77	0,73	1,01	12,27	2,82	6,24
Glass (9 rovings of glass)	45,0	1,85	0,73	1,03	13,27	2,93	6,74
Glass (10 rovings of glass)	44,8	1,95	0,75	1,05	14,31	3,08	7,45
Glass (11 rovings of glass)	48,2	2,07	0,7	1,08	15,39	3,16	7,84
Glass (12 rovings of glass)	45,0	2,22	0,78	1,11	16,51	3,28	8,45
Glass (12 rovings of glass) with ribs	46,1	2,55	0,82	1,12	17,78	3,45	9,34
Glass (12 rovings of glass and 1 roving of carbon)	48,5	2,55	0,82	1,12	17,93	3,46	9,40

2.3 Mechanical properties

Each type of braided fabric has been tested on a Hounsfield H100 KS tensile machine according to standard ISO 2062, using a cross-head speed of 100 m/min. Due to brittleness of glass fiber, samples have been impregnated with polyester resin in the jaws contact area. The results are presented in Table 3.

Table 3 – Mechanical properties of each braided fabric tested.

Braided fabric	Stress (MPa)			Extension (%)		
	Mean	Stand. Dev.	C. V.	Mean	Stand. Dev.	C. V.
Glass (6 rovings of glass)	336,53	28,86	8,58	2,75	0,33	11,82
Glass (7 rovings of glass)	356,83	17,75	4,97	2,72	0,17	6,11
Glass (8 rovings of glass)	391,47	26,67	6,81	3,16	0,15	4,74
Glass (9 rovings of glass)	413,70	22,74	5,50	3,26	0,21	6,28
Glass (10 rovings of glass)	444,93	5,74	1,29	3,79	0,31	8,11
Glass (11 rovings of glass)	454,16	14,15	3,12	3,93	0,50	12,71
Glass (12 rovings of glass)	477,07	25,04	5,25	4,18	0,28	6,66
Glass (12 rovings of glass) with ribs	522,65	15,88	3,04	4,00	0,15	3,74
Glass (12 rovings of glass and 1 roving of carbon)	429,96	8,99	2,09	5,15	0,63	12,15

The geometrical and dimensional parameters of each braided fabric are different and as the number of core rovings increase, the maximum load supported and the extension are also increasing. Core reinforced braided fabric with ribs presents an increase of 10% on the supported load and a decrease of 4% on the extension when compared with core reinforced braided fabric without ribs. The presence of carbon fiber reviled a decrease on mechanical properties.

3. BRAIDED REINFORCED COMPOSITE RODS

Braided reinforced composite rods have been produced and tested. Table 4 presents some characteristics of the rods produced. Moreover, the adhesion between concrete and composite rods has also been evaluated and discussed.

Table 4 – Types of composite rods produced.

Braided fabric	Ribs	Material	Yarn Count (Tex)
Core reinforcement	With	E Glass	204 Tex
		E Glass	12 rovings, 900 Tex each
Core reinforcement	With	E Glass	204 Tex
		E Glass	12 rovings, 900 Tex each
		Carbon	200 Tex

3.1 Production

The samples have been produced on a conventional braiding machine specially adapted to impregnate simultaneously the braided fabrics. In order to increase roughness of the braided reinforced composite material rods, and then its adhesion to the concrete, braided fabrics have been produced as a ribbed structure, as shown in Figure 3. This ribbed structure is provided by thicker yarns that are used in the braiding machine in a combination of 7 standard to 1 thicker yarn. For a stronger effect on roughness the number of thicker yarns could be increased during braiding the process.

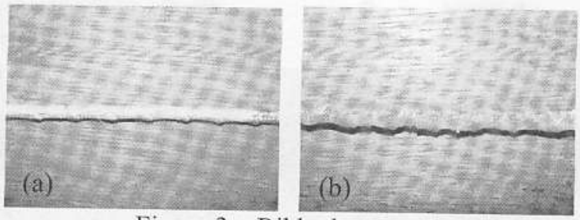

Figure 3 – Ribbed structure
(a) braided fabric (b) braided reinforced composite rod

The glass braided fabrics have been produced and simultaneously impregnated with a polyester thermosetting resin, with the reference Quires 272 THV, according to the following percentages: Resin 272 THV + 0.3% of CO accelerator + 2% of Butanox M60 catalyser. The characteristics of the composite material rods produced are shown in Table 5.

Table 5 – Characteristics of the composite material rods.

Braided fabric type	Fibre type	Fiber volume fraction (%)	Resin volume fraction (%)
Core reinforced	Braiding yarns: 204 tex, E glass fiber and 900 tex, E glass fiber Core reinforcement: 12 E glass fiber 900 tex rovings	44,45	55,55
Core reinforced	Braiding yarns: 204 tex, E glass fiber and 900 tex, E glass fiber Core reinforcement: 12 E glass fiber 900 tex rovings and carbon fiber 200 tex roving		

3.2 Mechanical properties

For the evaluation of the tensile properties of the braided reinforced composite rods produced, experimental work has been undertaken using a HOUNSFIELD universal tensile tester, according to NP 2257 standard, at a cross-head speed of 1 mm/min. The results obtained are shown in Table 6 while Figure 4 shows the typical stress-strain curve.

Table 6 – Tensile properties of composite reinforced rods (mean value of 10 tests).

Braided fabric type	Fibre type	Final Strength (MPa)	Extension at maximum stress (%)	Young´s modulus (GPa)
Core reinforced	Braiding yarns: 204 tex, E glass fiber and 900 tex, E glass fiber Core reinforcement: 12 E glass fiber 900 tex rovings	437,20	6,18	12,88
Core reinforced	Braiding yarns: 204 tex, E glass fiber and 900 tex, E glass fiber Core reinforcement: 12 E glass fiber 900 tex rovings and carbon fiber 200 tex roving	593,95	8,89	9,60

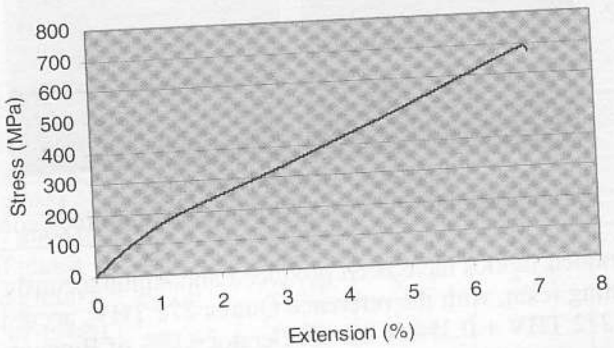

Figure 4 – Typical stress-strain curve for braided reinforced composite rods.

Bending properties were also evaluated on glass fibre composite rods, according to ISO 14125, using HOUNSFIELD H100 KS, at a cross-head speed of 1 mm/min and 100mm distance between supports. The results obtained are shown in Table 7.

Table 7 – Bending properties of composite reinforced rods (mean value of 5 tests).

Braided fabric type	Fibre type	Final Strength (MPa)	Deflection at maximum stress (mm)	Young´s modulus (GPa)
Core reinforced	Braiding yarns: 204 tex, E glass fiber and 900 tex, E glass fiber Core reinforcement: 12 E glass fiber 900 tex rovings	521,12	15,24	12,31

Analysing tensile properties, glass/carbon composite rod presents higher final strength when compared with glass composite rods. The strength increased 36% and the deformation at final strength had an increase of 44%. The Young's modulus decreased 25%.

When analysing bonding properties, it is concluded that the values of final strength and Young's modulus are not so different when compared with the results obtained with tensile test.

3.3 Adhesion to the Concrete

In order to evaluate the adherence between the braided composite rods and the concrete, 8 samples have been prepared, as shown in Figure 5. The samples have been tested on a universal tensile tester (Figure 6), at a cross-head speed of 0.1 mm/s, according to standard NP EN 10002-1 usually used for steel. The braided composite rods have completely adhered to the concrete up to the breaking point.

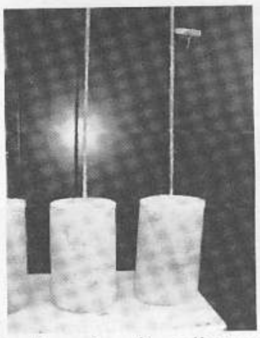

Figure 5 – Samples for adherence test

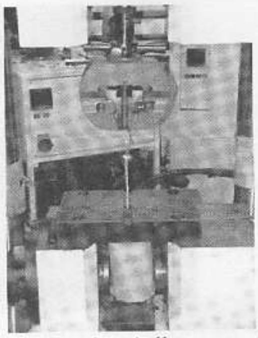

Figure 6 – Adherence test

4. CONCRETE BEAMS REINFORCED BY BRAIDED REINFORCED RODS

4.1 Samples preparation

Three concrete beams reinforced by an armour of braided composite rods (Figure 7) and three concrete beams reinforced by an armour of steel were prepared with the configuration presented in Figure 8. The dimensions of the beams are presented in Figure 9.

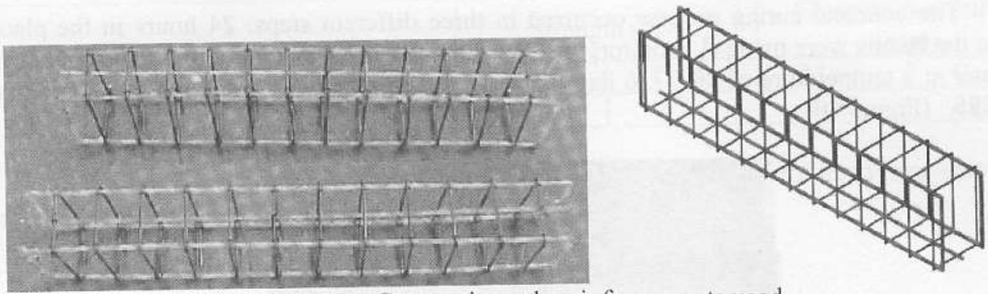

Figure 7 – Composite rods reinforcements used.

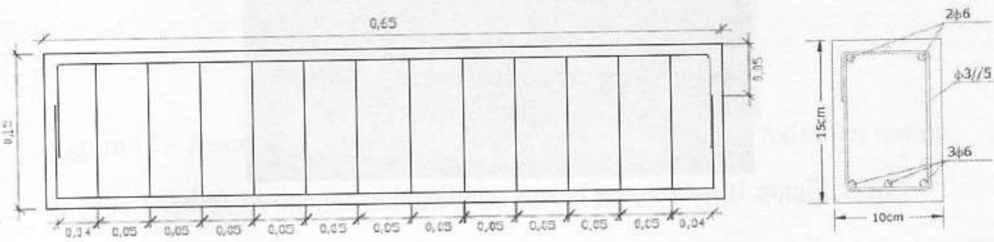

Figure 8 – Configuration of reinforcement used.

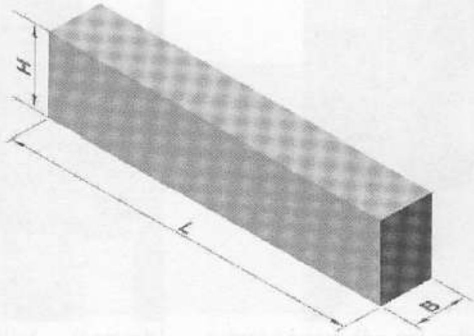

Figure 9 – Beam dimensions (B=10 cm; H=15 cm; L=65 cm)

Were produced 60 L of concrete according to the Table 8.

Table 8 – Constitutes and quantities of concrete.

Constitutes	Quantity per m^3 of concrete
Cement (CEM I 42,5R) [kg]	339,9
Sand [kg]	868,0
Aggregates [kg]	864,6
Water [L]	201,6

The concrete curing process occurred in three different steps: 24 hours in the place where the beams were made (Laboratory of Civil Engineering, University of Minho); 20 days in water at a temperature of 20 ºC; 6 days at a room temperature of 20ºC and 100% relative humidity. (Figure 10)

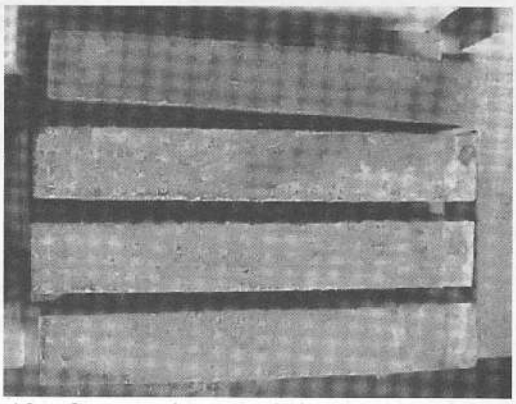

Figure 10 – Concrete beams reinforced by composite rods-

3.2 Testing and results

The beams were tested in bending in a hydraulic press with a speed of 10 µm/s. The displacements and the corresponding loads were registered (Figure 11).

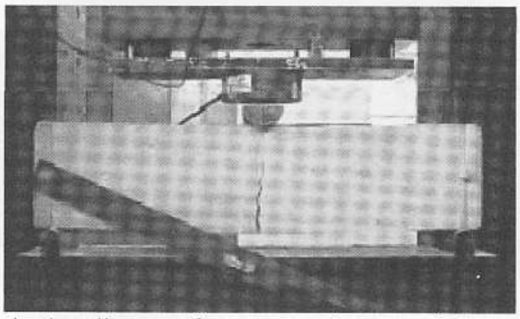

Figure 11 – Three point bending test for concrete beams reinforced by composite rods.

Table 9 and 10 present the results obtained for each type of beam tested.

Table 9 - Bending test results for beams reinforced by steel (mean values of 3 tests).

Concrete reinforced with steel armour	Strength (kN)		Elongation at failure (mm)	
	Mean	C. V.	Mean	C.V.
	60,50	4,30	3,43	28,72

Table 10 - Bending test results for beams reinforced by composite rods (mean values of 3 tests).

Concrete reinforced with composite rods armour	Strength (kN)		Elongation at failure (mm)	
	Mean	C. V.	Mean	C. V.
	30,80	4,04	6,57	21,29

Figure 12 presents a beam after testing. The broken braided reinforced composite rods are shown.

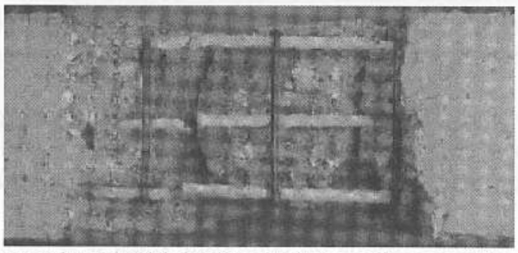

Figure 12 – Beam produced with braided reinforced composite rods after testing.

Figure 13 presents the load-deformation curves for each type of beam tested.

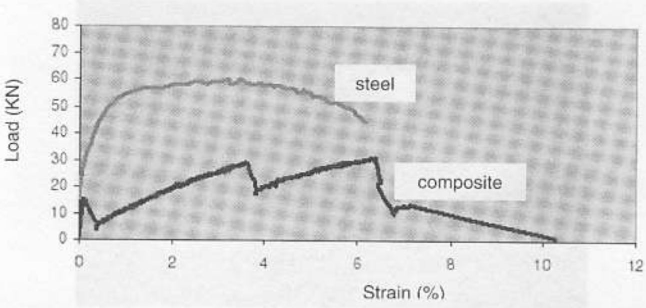

Figure 13 – Load-strain curves for concrete beams reinforced by composite rods and steel.

Analysing the results obtained and the correspondent load-extension curves it is possible to detect different performances between both types of beams tested. The steel reinforced beams carry twice as much load compared to composite reinforced beams. Moreover, strain values of the steel reinforced beams are lower than those obtained for beams reinforced by the composite rods.

In the load-strain curves obtained for the composite reinforced beams, three peaks are visible that correspond to the breaking point of each of the composite rods used. These peaks show that the rods in the reinforcement are not stressed simultaneously. Moreover, the first peak indicates that the reinforcement is not bearing the full load at the initial stage of testing. This behaviour is probably due to the rather loose state of the composite rods that are tensioned only after some considerable deformation of the beam.

4. CONCLUSIONS

In order to evaluate the mechanical behaviour of braided fabrics when subjected to tensile stress, core reinforced braided fabrics were subjected to tensile stress. Based on tensile test results, it can be concluded that as the number of core rovings increase, the maximum load supported increases also, as well the extension value. The results of tensile test shows that core reinforced braided fabric with ribs present higher final strength and lower extension at final strength.

Composite rods were subjected to tensile stress and bending. Based on tensile test results, it can be concluded that glass/carbon composite rod presents higher ultimate strength, higher deformation at ultimate strength and lower Young's modulus when compared with glass composite rods.

When analysing bonding results on composite rods, it is concluded that the values of final strength and Young's modulus are not so different when compared with the results obtained with tensile test.

Concrete beams reinforced by composite rods carried half load compared to steel reinforced beams and strain values are higher than those obtained for beams reinforced by steel rods.

The composite rods used to reinforce concrete beams were not stressed simultaneously, then the behaviour of concrete beam when subjected to bending present three peaks that correspond to the breaking point of each of the composite rods that were used.

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