Pseudo-Ductile Braided Composite Rods (BCRs) Produced by *Braidtrusion*

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Abstract
Braided composite rods (BCRs) are being successfully used as replacement of steel for strengthening of beams, columns, bridges and other civil engineering structures. In this research work, braided composite rods were produced through "braidtrusion" process reinforced with glass, glass/steel and basalt/steel hybrid fibres. Tensile testing have been conducted to evaluate the Pseudo-ductile behaviour. The results show that compared to 100% glass fibre BCRs, BCRs which has glass/steel or basalt/steel hybrid modified the tensile behaviour from linear (fragile) to non-linear (ductile).

1. Introduction

Fibre reinforced polymer composites (FRP or FRPC) have been used widely in many industrial applications such as aerospace, marine, automobile, etc. due to their improved engineering properties like low-density, high stiffness and specific strength, high fatigue endurance, high damping characteristics, low thermal co-efficient, corrosion resistance, easy handling and maintenance, etc. [1-4]. Recently, composites have been applied predominantly in civil engineering area to replace conventional materials (steel and concrete) or ceramic based composites to enhance mechanical properties (flexural resistance, shear strength, bending property, confinement, etc.) of structural elements. Nowadays, research is being carried out to use FRPs in structural elements to enhance their resistance against blast, earthquake, impact loads caused by various explosions [5]. Capacity to absorb energy is one of the critical requirements for these applications and, therefore, developing strengthening materials possessing high ductility is primary.

Braided composite rods (BCRs) are widely used in civil engineering as a strengthening materials for beams, columns, bridges, etc. Braiding technology is a low cost and well established technology in which intertwining of three or more strands of yarns forms tubular fabric structures with different combinations of linear or twisted core (axial) materials. Impregnation of axial fibres with polymeric matrix (thermoset or thermoplastic) before introducing into the braided structure and subsequent curing forms composite materials with braided architecture or BCR. The load-deformation behavior of braided structures of composites can be tailored by choosing suitable fibers for the sheath and core components. The most commonly used core fibers for civil applications are glass, basalt, carbon, etc. BCRs offer several advantages over the other types of FRP rods such as simple and economical manufacturing process, tailorable mechanical properties and good bonding behaviour with cementitious matrices [6-8]. BCRs have been already demonstrated to possess high potential for application in concrete reinforcement and monitoring [9, 10], masonry wall strengthening [11] and reinforcement of soils for geo-technical applications [12].

Generally, BCRs comprise of glass, carbon and other advanced technical fibres in the core exhibits sudden breakage, i.e. fragile behaviour under tensile load, which is the biggest disadvantage when compared steel (shows ductile behaviour). So it is necessary to impart ductility to the BCRs in order to detect the damage before the structure collapses and carry out necessary maintenance work (replacement of composites).

Incorporation of Pseudo-ductility in BCRs, i.e. material having ductile behaviour, deforming in the plastic zone. In other words, conversion of materials from fragile into ductile in stress-strain curve. It means providing yielding zone before the breaking point. There are ways to incorporate pseudo-ductility in composite materials: 1) Introduction of fibrous materials with intrinsic ductile behaviour; and 2) Using of different fibres which has distinct Young's modulus. For example the sress-strain behaviour of hybrid braided composite rods is shown in Figure 1 and it exhibits different peak load with higher strain level. The peak forces obtained depends on strength of reinforced fibres.

In this research work, BCRs were developed with different types of core fibres with thermosetting polymer matrix as adhesive. The core fibres are passed through polymer matrix before being braided with filaments (as sheath). This technique of producing BCRs is known as “Braidtrusion”. This technique produces composite rods with uniform geometry and sufficient roughness, which gives good adherence to concrete. The ductility of the developed samples measured through tensile testing as per standard. The level of improvements in the ductility will be compared with control samples.

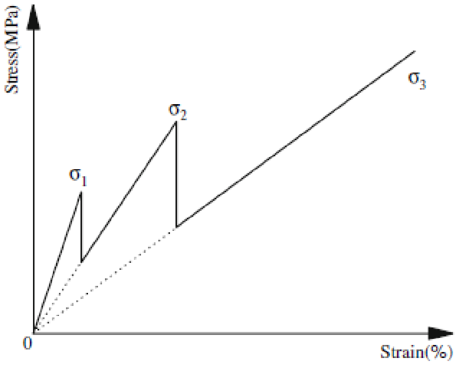


Figure 1. Theoric stress–strain curve of an hybrid reinforcement rod

2. Materials and Methods

2.1. Materials

For the production of braided composite rods, basalt fibre roving with linear density of 4800 tex and glass fibre roving with linear density of 1200 tex, 4800 tex, and 9600 tex was purchased from Owens Corning, France. The steel wire rope used in this work was purchased from Ferreira e Martins, Portugal. The epoxy resin used in the braidtrusion process was supplied by Sika, Germany, in three components: Biresin CR141 (epoxy resin, translucent), Biresin CH141 (hardener, carboxylic acid anhydirde, transparent) and Biresin CA141 (accelerator, amine, amber). The resin, hardener and accelerator components were mixed in a weight ratio of 100:90:2 prior to application. The important characteristics of fibre and resin system are listed in Table 1.

Table 1. Physical properties of core fibres and resin.

S. No.	*Properties*	*Steel*	*Glass*	*Basalt*	Epoxy
1	*Density* (g/cm^3)	7.86	2.62	2.70	1.20
2	*Filament diameter* (mm)	2-2.5	--	--	--
3	*Tensile strength* (MPa)	1055	3100 – 3800	4840	78
4	*Tensile modulus* (GPa)	210	80 – 81	89	3.2
5	*Elongation (%)*	21.0	4.0	3.2	3.3

2.2. Production of braided composite rods

Braided composite rods were produced in a horizontal braiding machine (see Figure 2) using polyester multi-filament yarns (with linear density of 110 tex) in the sheath, glass, basalt/steel and glass/steel as the core material. During the braiding process, 36 polyester filament bobbins were used to supply the sheath yarns, which were then braided around the core fibres [6-8]. The schematic diagram of braided composite rods cross-section are shown in Figure 3.

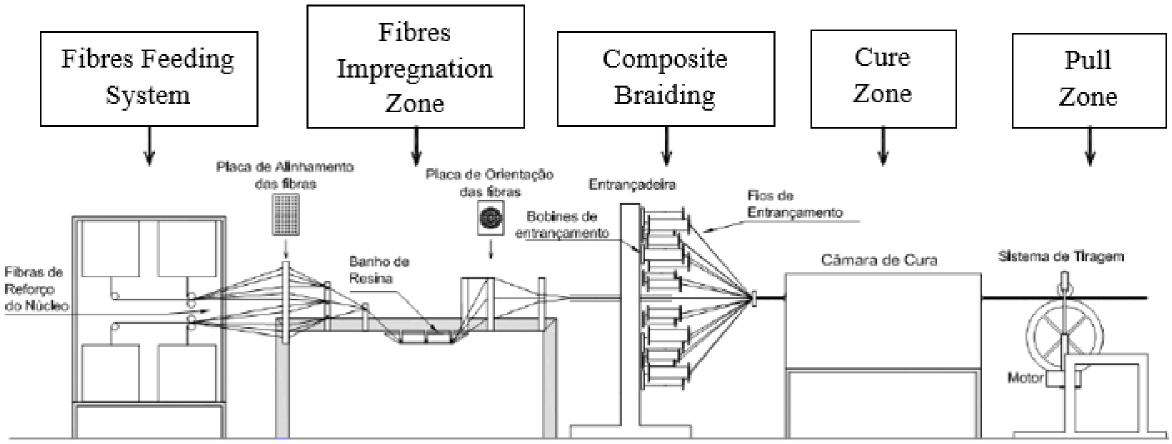


Figure 2. Schematic diagram of horizontal braiding machine.

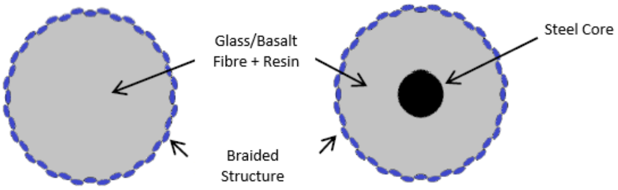


Figure 3. Schematic diagram of BCRs cross-section.

2.3. Samples detail

Four different BCRs were produced using polyester fibres for the braided structure production, E-glass, Basalt and Steel as core reinforcement, and epoxy resin was used as adhesive to bind both sheath and core.

BCRs were produced maintaining the braided structure geometry and diameter (4 mm) of the BCR by varying the type of core reinforcement fibre, according to Table 2. The weight percentage of core fibre in the produced BCRs is around 60%. Braided composite rods were reinforced with a single type of reinforcement fibres as well as with two types of fibres, varying the percentage of each one. The aim was to evaluate the influence of the type of fiber and its quantity on the mechanical behavior of the braided composite rods.

Table 2. Produced BCR samples wit theoretical composition in percentage of fibres.

S. No	*BCR type*	*Fibre proportion*
1	GF	100% Glass
2	GF+S→2.0mm Ø	70% Glass + 30% Steel
3	GF+S→2.5mm Ø	60% Glass + 40% Steel
4	BF+S→2.5mm Ø	60% Basalt + 40% Steel

2.4. Evaluation of tensile behaviour

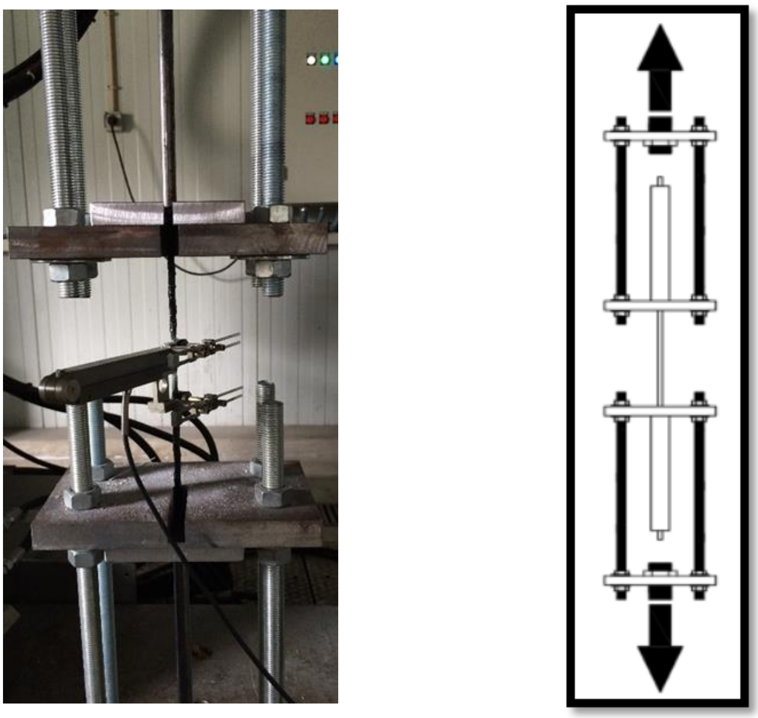
In order to evaluate the ductility of the different BCRs produced, tensile tests were carried in Universal Tensile testing machine according to ASTM D 3916-94, with a crosshead speed of 2 mm/min. The test set-up is shown in Figure 4.

3. Results and Discussion

Tensile test results of BCRs produced in this work is given in Table 3 and tensile behaviour of the BCRs is shown in Figure 5. The results show that the hybrid glass/steel anda basalt/steel BCR exhibited high elongation than 100% glass BCR due to inclusion of steel and tensile strength decreases with increase of steel fibre proportion in BCRs. For glass/steel hybrid BCR which has 30% steel showed high tensile strength and low elongation compared to BCR with 40% steel. This may be attributed to steel diameter, i.e. to achieve 40% of steel proportion, higher diameter steel was used compared to 30% of steel proportion. This results decrease of tensile properties but higher elongation.

The basalt/steel BCR which has 40% of steel shows a high Young’s modulus, tensile strength and elongation when compared with glass/steel BCR with the same proportion of steel. This is justified by the intrinsic mechanical properties of basalt, that are better than glass fibre used in this work.

The tensile behaviour of the BCR with 100% glass is linear and inclusion of steel fibre modified linear behaviour into non-linear behaviour. BCRs with steel exhibited linear behaviour till around 0.5% to 1% then showed ductile behaviour up to failure.



(a) (b)

Figure 4. Tensile testing of braided composite rods. (a) Actual test set-up and (b) schematic diagram of test set-up.

Table 3. Tensile properties of BCR samples

S. No.	*BCR types*	*Tensile strength, MPa*	*Elongation at max. Load, %*	*Young's Modulus (GPa)*	*Percentage of elongation increased w.r.t 100% glass*
1	GF	1083.64 (1.6)	3.37 (9.2)	60.7 (0.01)	--
2	GF+S→2.0mm Ø	705.10 (10.4)	4.10 (14.9)	81.1 (3.18)	21.6
3	GF+S→2.5mm Ø	699.53 (0.2)	4.68 (2.3)	99.4 (2.45)	38.9
4	BF+S→2.5mm Ø	779.66 (6.0)	5.19 (8.1)	110.4 (1.14)	54.0

Note: The CV% values are given in the bracket.

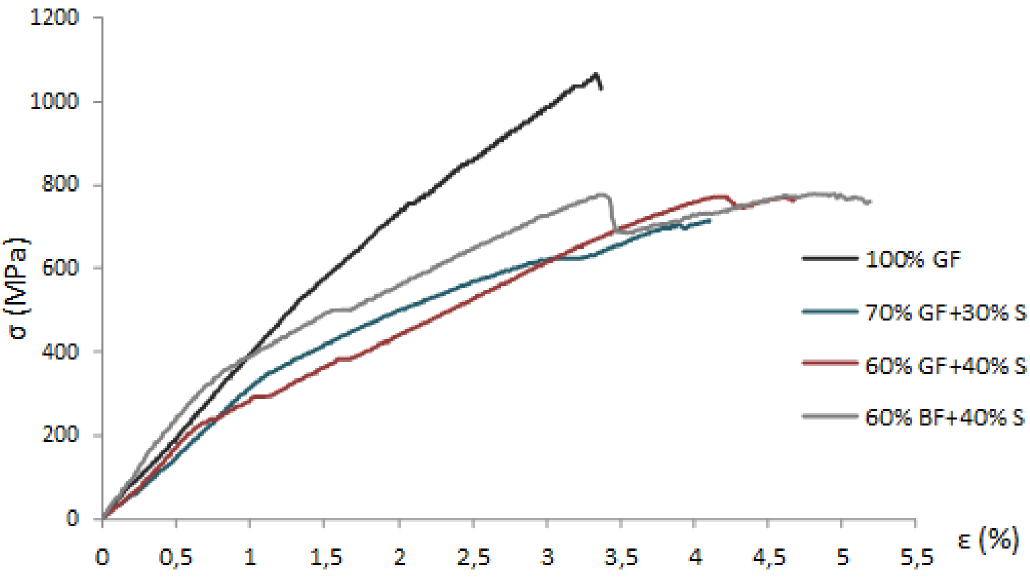


Figure 5. Tensile behaviour of the BCR samples.

4. Conclusion

In this research work, braided composites rods reinforced with 100% glass fibre, glass/steel and basalt/steel hybrid fibre produced using “braidtrusion” process. The results show that linear behaviour of 100% glass BCR under tensile load has been transformed into nonlinear behaviour, i.e. fragile material into ductile material. By using 30% and 40% of steel into glass fibre, the elongation increased around 22% and 40% compared to 100% glass BCR, respectively. In addition, the basalt/steel hybrid BCR exhibited higher tensile properties and elongation compared to glass/steel with same proportion of steel fibre (40%). This may be attributed to the fact of fibres inherent properties.

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