Effect of Layer and Angle on Mechanical Properties of Polyester Braided Composite Rods

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Abstract:
Fiber-reinforced polymers (FRPs) with their lightweight and very good mechanical properties have opened up the possibility to replace the steel bars used in civil structures which are being limited due to their corrosion vulnerability. The fibre-matrix system called braided composite rods (BCRs) can also make an impact in the civil industry with their inherent strength approachable structure and corrosion-resistant nature. In the present study, biaxial braided ropes were prepared on a braiding machine with a braid over braid method using high-tenacity multifilament polyester yarns. Prepared ropes were converted to BCRs by permeating and curing the resin solution through the braided ropes. Six different braided ropes were prepared with varying braid angles and the number of layers. Prepared BCRs were evaluated for their mechanical properties like tensile strength, flexural strength, and compressive strength. Interpretation of the results was carried out based on the effect of layers and braid angle on the mechanical properties. Developed BCRs may offer a suitable replacement for conventional building materials due to their less susceptibility to corrosion, catastrophic falls, good mechanical performance, and lightweight nature along with its at par mechanical properties..

Keywords: *Biaxial braided rope, Braid over braid, braided composite rods (BCRs), Corrosion resistant, Fibre-reinforced composites (FRCs)*

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1. Introduction

Fibre-reinforced composites (FRCs) are a type of engineered material, which exhibit high strength/weight and modulus/weight ratios than some metallic materials. FRCs with the highest specific properties typically have continuous fibre reinforcement embedded in a polymer matrix [1,2]. FRCs can be used to manufacture highway structures like guardrails, signboards, drainage systems, and bridge decks, along with auto skyways, utility poles, and pipelines for gas, water, and sewage [3,4]. Apart from this, it can also offer corrosion-resistant lightweight building materials [5]. Braided composite rods (BCRs) are one of the products which can be utilized as a replacement for iron/steel bars to obtain sustainable building materials [6].

Braiding is the method of interlacing three or more yarns or bias-cut cloth strips in such a way that they cross one another and are laid together in diagonal formation, forming a narrow strip of flat or tubular fabric [7,8]. A braided structure gives much better axial strength to the fabric which leads to better performance in the composite application [9]. Braided composites are specially designed to achieve extra strength, functionality, and durability [10]. Unlike other composites, in braided composites braids are used as a reinforcement material rather than fibres. In various studies, glass, carbon, polyethylene, and sisal fibers are taken for braid composite and have achieved good mechanical properties [11]. Generally, all kinds of yarn can be converted into a composite structure by treating it with a different matrix-like, like epoxy, polyester, vinyl ester, etc [12]. However, to attain the high tensile strength of a composite structure, the strength of reinforcement material and type plays a major role [13]. A single yarn cannot provide such tensile strength after becoming a composite. While the single yarns converted into braided ropes can offer exclusive properties which can further be emphasized by matrix when formed into braided composite rods.

The braiding process competes well with the filament winding, pultrusion, and tape lay-up [14,15]. Braiding compares favorably in terms of the structural integrity of components, design flexibility, damage tolerance, repair ability, and low manufacturing cost [10,16]. Many researchers have addressed several parameters which can affect the performance of braided ropes like braid geometry, crimp angle braid angle, etc [17–20]. However, none of the work reports the effect of layers along with their changing braid angle, which is of utmost importance since BCRs of different diameters are being subjected to varied loads in different directions.

Looking at the scope, this study aims to determine the effects of braid angle along with the increasing number of layers on the braided composite structure. Attainment for the high strength requirement of BCRs was achieved with special high-tenacity multifilament polyester yarn of high denier. Braided ropes were prepared from these yarns with the braid over braid method which was further treated with the matrix material to form BCRs. These rods were exclusively evaluated based on their tensile, bending, and flexural properties. Prepared BCRs can be utilized as a reinforcement material in concrete members to avail improved lifespan by using corrosion-resistant and high specific strength instead of conventional steel rebars. This may give a new dimension to solid biaxial braided rods.

2. Materials and Methods

2.1 Materials

High-tenacity multifilament polyester yarn of 6000 denier was purchased from Reliance Industries Ltd., Vapi, India having a tenacity of 33.36 g/Tex for the preparation of braids. Epoxy resin and hardener were purchased from Composite Tomorrow, Vadodara, India, and were used without any modification.

2.1.1 Preparation of Biaxial Braided Composite Rods

Circular braided ropes were prepared on a Bharat and Brothers (B&B) braiding machine comprised of 16 carriers that work on a maypole principle. Six samples were prepared by employing two braid angles and three layers using the braid over braid method. Braid angles for the base braid or first braid layer were set by varying the take-up speed of the machine. An increase in the take-up speed will lead to a lower braid angle and vice versa. Further, for the preparation of the second and third layers over the first layer of braided rope, the take-up speed of the machine was kept constant. This was done to keep the braid angle constant within all layers of the braided rope. BCRs were prepared by impregnating the solutions of resin and hardener into the braided ropes by keeping the ratio of CTE556 (Epoxy resin): CTAH951 (hardener) at 10:1. **Table 1** shows the sample abbreviations and the parameters for each sample.

Table 1: Sample Description

Braid Angle on Machine	Sample Code					
A - 33°	**First Layer**		**Second Layer**		**Third Layer**	
	BCR A1		**BCR A2**		**BCR A3**	
	Diameter (mm)	Angle achieved	Diameter (mm)	Angle achieved	Diameter (mm)	Angle achieved
	5.5	33°	7.0	43°	8.5	53°
B - 38°	**First Layer**		**Second Layer**		**Third Layer**	
	BCR B1		**BCR B2**		**BCR B3**	
	Diameter (mm)	Angle achieved	Diameter (mm)	Angle achieved	Diameter (mm)	Angle achieved
	6.0	38°	7.0	41°	8.5	47°

2.2.2 Test Standards

- Tensile test was performed on a universal testing machine (UTM) STS 481 using ASTM standard D 638 with an extension rate of 5 mm/min.
- Test for flexural strength was carried out on a UTM STS 481 in accordance with ASTM standard D 790.
- Compressive strength was characterized on Instron compressive test machine using ASTM standard D 695.

3. Results and Discussion

Braided composite rods were characterized for their mechanical properties such as tensile, bending, and flexural rigidity using ASTM standards at Ahmedabad Textile Industry’s Research Association (ATIRA). All BCRs were studied for the effect of the number of layers and braid angle on their mechanical properties. **Fig.1** shows the technique for the measurement of the braid angle from the braid axis [21] and the results of the tests have been reported in **Table 2.** As shown in **Table 1**, it should be noted that although no variations were kept for the setting of the braid angle while producing the second and third layers, but higher braid angles were obtained for each layer due to the larger base obtained thanks to braid-over-braid manufacturing technique.

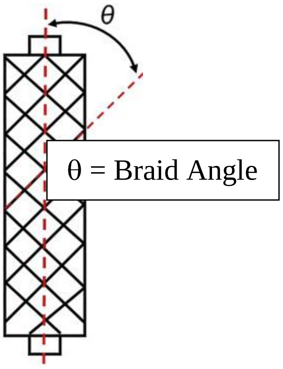

Figure 1- Braid angle measurement

3.1 Tensile Strength

Tensile strength of each BCR obtained from the tensile test has been reported in **Table 2.** It can be observed that the tensile strength of BCR A1 is slightly higher than BCR B1. This shall be due to higher braid angle of BCR B1. Studies state that high strength in the yarn is obtained when fibres/filaments are aligned in direction of loading [22]. However, in the case of a high braid angle, the filaments are away from the yarn axis which may have led to lesser strength.

Table 2: Mechanical properties of braided composite rods

Braid Angle	Samples	Tensile Test		Flexural Test		Bending Test	
		Tensile Strength (Newton)	Tensile Stress (Mpa)	Flexural Strength (Newton)	Flexural Stress (Mpa)	Compressive Strength (Newton)	Compressive Stress (Mpa)
33°	BCR A1	4750	187.23	71.90	93.81	730	35.48
	BCR A2	7710	214.58	154.87	140.64	1360	32.66
	BCR A3	8530	146.33	206.53	124.71	3430	59.03
38°	BCR B1	4540	183.09	117.19	175.60	1400	47.28
	BCR B2	9170	238.95	219.45	188.94	1940	58.35
	BCR B3	14100	268.74	283.31	159.55	2860	52.77

Fig.2 shows the effect of layers on tensile strength for both braid angles. It can be seen that the tensile strength of BCRs increases with an increase in the number of layers. It is also observed that the percentage increase in tensile strength of BCR B-type rods is much higher than BCR A-type rods. This is attributed to a change in braid angle, as seen in **Table 1** braid angle of BCR B3 is 47° whereas the braid angle of BCR A3 is 53°, this leads to lesser strength.

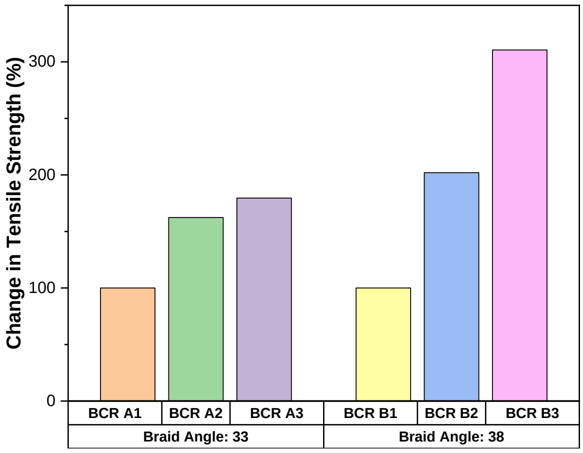

Figure 2 - Effect of layers on tensile strength

The values of tensile stress were also obtained as shown in **Table 2**, which shows that the tensile stress increases as the number of layers increases. However, BCR A3 shows a slight decrease in tensile stress compared to BCR A2. This can be due to a limited increase in tensile strength with respect to its diameter.

3.2 Flexural Strength

Flexural strength is the load applied in the perpendicular direction of the rod axis to measure static three-point flexural performance. Test results of flexural strength have been enumerated in **Table 2.** It can be observed that BCR B1 shows higher flexural strength than BCR A1. This may be due to the higher braid angle of BCR B1 [23]. **Fig.3** shows the percentage change in flexural strength while increasing the number of layers, as the number of layers increases the flexural strength of BCRs also increases. It can also be noted that the percentage increase in flexural strength of the BCR A type rod is quite higher than the BCR B type rod. This can be due to the higher outer braid angle obtained for BCR A-type rods [23]. Flexural stress also increases as the number of layers increases, however, decrement was observed for the third layer for both the base braid angle. This is due to a limited increase in flexural strength with respect to its diameter.

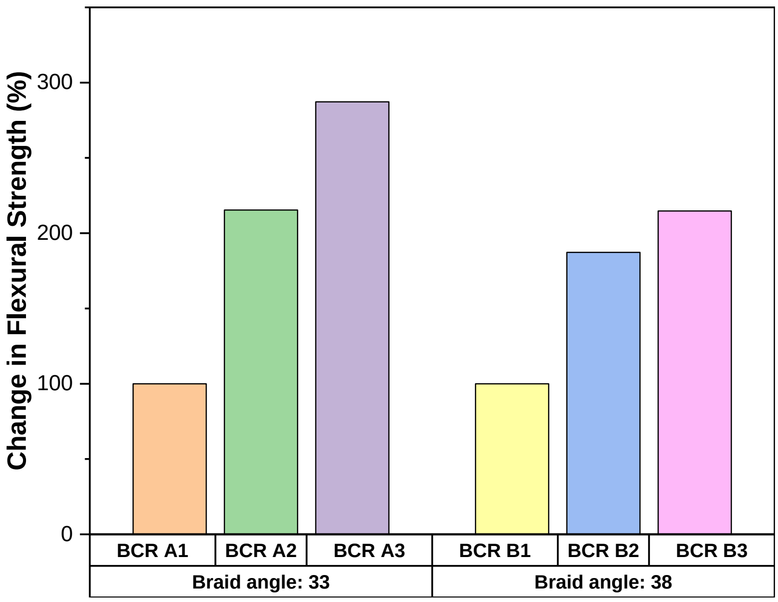

Figure 3 - Effect of layers on flexural strength

3.3 Compressive Strength

Compression strength is the ability of the material to withstand external forces that push on it. It is one of the most important parameters for the column structure as it is subjected to compressive load. Generally, the rope-like structure can support a large amount of tension but has virtually no compression strength. However, the compression strength measured for the BCRs shows good feasibility for the textile-based material to support the compression strength. The results of the compression test are reported in **Table 2.** The results show that the BCRs of a higher braid angle offer better compressive strength than a lower braid angle. This can be due to the specific structure of braiding that supports the compression load. **Fig.4** shows the effect of layers on compression strength which shows the increase in resistance to compression as the number of layers increases. The maximum compressive strength was achieved with the sample BCR A3, which can be attributed to the maximum braid angle. No specific trend was observed for the compressive stress. The maximum compressive stress was also obtained with BCR A3.

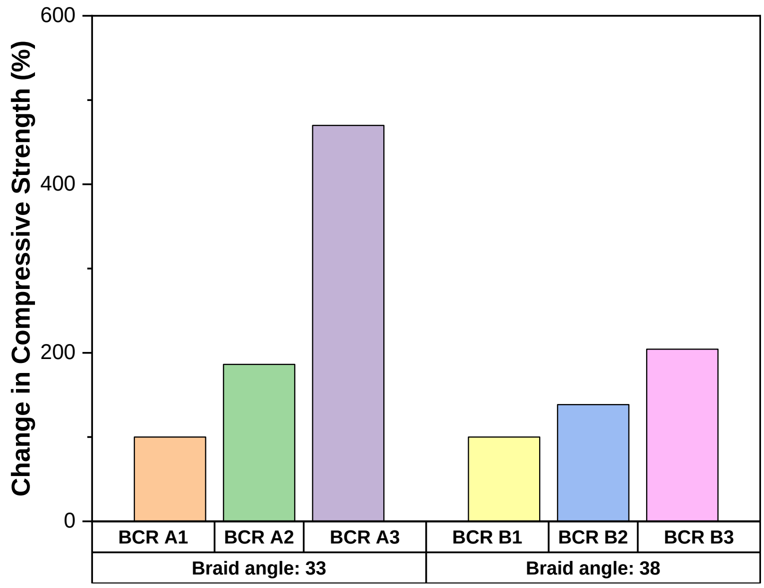

Figure 4 - Effect of layers on compressive strength

4. Conclusion

Braided composite rods (BCRs) were prepared by impregnating resin solution into the braided ropes with a specific ratio of resin to hardener of 10:1. Different braid angles and layers were involved to analyse the effect of layers along with the braid angle. Tensile strength, flexural strength, and compressive strength increase as the number of layers increases. BCRs of lower braid angle perform well in the tensile test. The flexural strength and compressive strength can be enhanced with the higher braid angle. Tensile stress and flexural stress also increase as the number of layers increases. However, as there was no marginal increase in the strength as compared to its diameter, tensile stress and flexural stress were decreased for the third layer. Compressive stress has not given a specific trend as the layers increase. The analysis also shows that controlling braid angle is easier in single layer than multi-layer braided ropes.

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