

MECHANICAL PROPERTIES OF FILAMENT WOUND PIPES: EFFECTS OF WINDING ANGLES

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Abstract: The aim of this study is to investigate the mechanical properties of continuous glass fiber reinforced composite tubes produced by filament winding technique with three different winding angles. With help of split-disk tests hoop tensile properties of selected specimens were determined, where reliable results were obtained with low standard deviations. It was observed that bigger winding angle lead to higher hoop tensile properties of filament wound tubular samples.

Also, the effect of reinforcement direction on the mechanical performances of these composites has been presented. Fiber fracture and fiber-matrix debonding is observed to be the dominant failure mechanisms by samples winded with bigger winding angles, whereas delamination in addition to these mechanisms is detected by samples with smaller winding angles. From received results it is concluded that, mechanical properties of composite specimens are depended from winding angles in filament winding technology.

With help of conducted SEM analysis good merger between glass fibers and the epoxy matrix was seen, but cracks within plies and broken fiber were noticed, due to the high fiber branching.

Key words: filament winding, split-disk test, composite pipes.

Introduction

Development of new composites and new applications of composites is accelerating due to the requirement of materials with unusual combination of properties that cannot be met by the conventional monolithic materials. Actually, composite materials are capable of covering this requirement in all means because of their heterogeneous nature. Properties of composites arise as a function of its constituent materials, their distribution, and the interaction among them and as a result an unusual combination of material properties can be obtained (Hastak at al., 2003; Sideridis and Papadopoulos, 2004).

From the wide family of composites, fiber reinforced composites have taken much attention due to their better mechanical properties. Composites produced by long fibers with high aspect ratio are called continuous fiber reinforced composites. A fibrous reinforcement is characterized by its length being much greater than its cross sectional dimension. These composites have found a wide range of application area due to their anisotropic nature, direction dependence of their properties results in much better design flexibility that cannot be obtained by monolithic materials or particle reinforced composites (Belingardi et al., 2006; Putic et al., 2007; Risteska et al., 2014).

Filament winding technique can be accepted as one of the most common production techniques, for the synthesis of polymer matrix composites. For the production of composite materials by the filament winding technology, a reinforcing agent in the form of continuous fibers (glass, carbon, aramid, etc.) and an im-

pregnation agent in the form of liquid resin (polyester, epoxy, etc.) are used. The basis of this technology includes winding of resin-impregnated fibers into a tool and hardening of the wound structure (Fig. 1) (Lee et al., 2005; ASTM, 2013; Dorigato and Pegoretti, 2014).

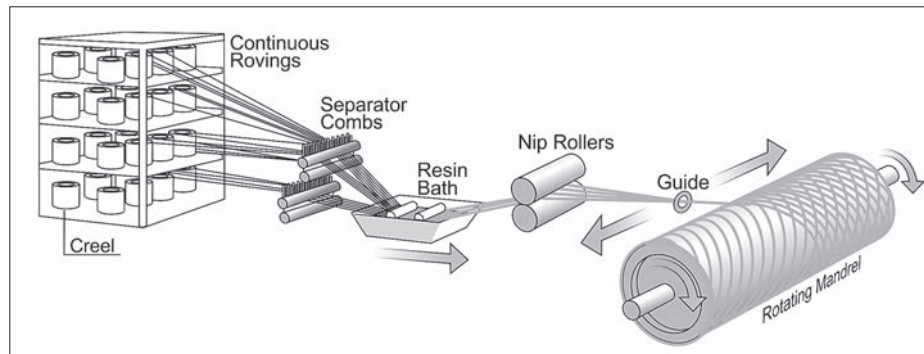


Figure 1. Schematic presentation of the filament winding technology

This technology enables the fiber to be placed into the direction of the load that may be expected during exploitation of construction elements. Owing to this unique capability, the mechanical properties of fibers in the longitudinal direction can be maximally exploited. Based on that, it is clear that the filament winding technology is used for creating new materials with distinct anisotropy according to the direction in which the fiber is placed. In other words, different directions result in a material with different mechanical properties (Davies and Hamada; 2001; Dong et al., 2012). Thus produced composite materials have the highest percent of fibers of all composite materials and small density. This fact is important for loaded elements of construction, which also need to have small mass. Three types of testing geometry are commonly used in testing of filament wound composite structures, namely; flat specimens (coupon specimens), ring specimens (Fig. 2), and tubular specimens. Axial (tension/compression), shear, and bending response of each testing geometry can be determined by applying a suitable loading to the specimen. In addition to these tests, internal pressure and torsion tests can be applied to the tubular specimens. Tests, involving biaxial/combined loading of test specimen can also be performed. For evaluation of the tensile properties of filament wound composite structures NOL-rings (split disk) test is usually used. Proposed ring shape of samples may be applied in axial tension test, internal pressure test, etc., as well as their combinations. Hoop tensile strength of specimens can be determined with help of split-disk test. Split-disk tests are very

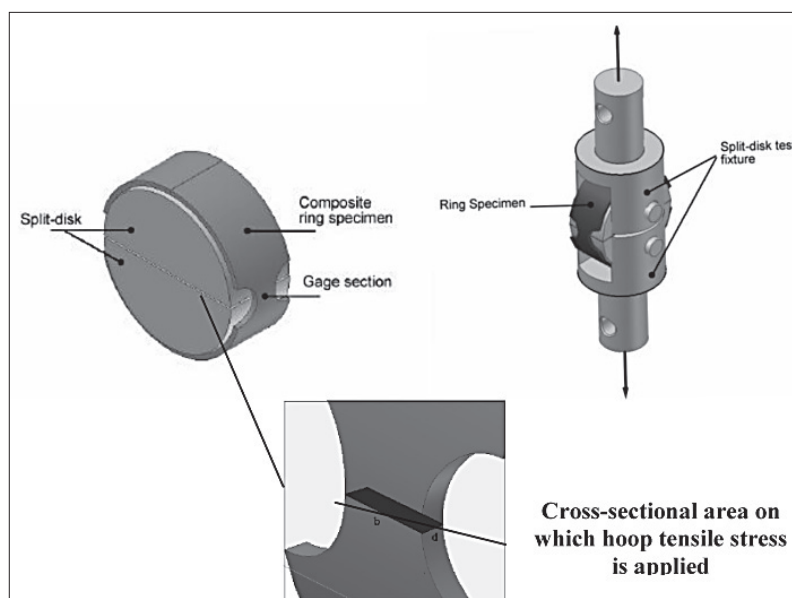


Figure 2. Split disk test specimen (NOL-ring) and test fixture

efficient in determine the performance of tubular structures which are usually used under internal pressure developing high hoop (Lee at al., 2005; Sudarisman and Davies, 2008; ASTM, 2013).

This research will present final properties of specimens, manufactured with conventional filament winding equipment.

Material and Methods

In this study for the production of the composite pipes 10 bobbins of E-glass fiber roving 185P with 1200tex from Owens Corning were used. The glass fibers were impregnated into epoxy resin system Araldite LY564/Aradur 917/Accelerator 960-1 from Huntsman. Samples with different winding designs were wound on iron mandrel with pins on the both sides with help of laboratory filament winding machine MAW FB 6/1 with six axes, roller type resin bath manufactured from Mikrosam A.D. Glass fibers with constant fibre tension 110 N pass through a resin bath and gets wet before winding operation. The velocity of the filament winding was 21 m/min. The composite tubes with three different winding angles: 10°, 45° and 90° of the continuous glass fiber were produced (Table 1). Winding angle is the angle between fiber and the line on surface of the mandrel, which is parallel to mandrel axis. Coupled helical winding of layers (± 0) are usually preferred, whereas hoop winding - winding angle, very close to 90° and winding with very low winding angle can also be used. By varying the winding angle with respect to the mandrel axis, directional strength can be obtained by considering the loads, which will operate on the finished product (Lee at al., 2005).

Table 1. Dimensions and winding angles of samples

Sample	Designation	Weight (g)	Width (mm)	Thickness (mm)	Winding angle (°)
1	1-1	52.80	14.06	3.64	90
	1-2	52.80	14.12	3.64	
	1-3	53.80	14.12	3.65	
2	2-1	42.20	13.97	3.18	10
	2-2	43.00	13.85	3.14	
	2-3	43.70	14.00	3.14	
3	3-1	53.60	14.01	3.18	45
	3-2	53.80	13.90	3.16	
	3-3	53.80	14.01	3.16	

Calculated mass ratio between fiber and resin of the produced composite pipes was 75:25 wt%. After winding samples were cured with industrial heater at 80°C and at 140°C, for four hours. After the curing operation, the removal of the mandrel from the specimens was performed.

In this experimental study the investigation of the effect of winding angles on hoop tensile strength of glass fiber reinforced filament wound ring specimens was performed. For tensile tests each specimen was then cut to obtain three split-disk test specimens according to ASTM D2290. Tensile tests of NOL-ring samples were carried out at room temperature using universal testing machine Schenck with max load of 250 kN and loading speed of 5mm/min. Width and thickness of each NOL-ring specimen was measured with help of micrometer with reading to at least 0.0254 mm. In this way prepared specimens were elongated till rupture with help of test fixture, made according to standard. Dimensions and winding angles of tested samples are represented in Table 1.

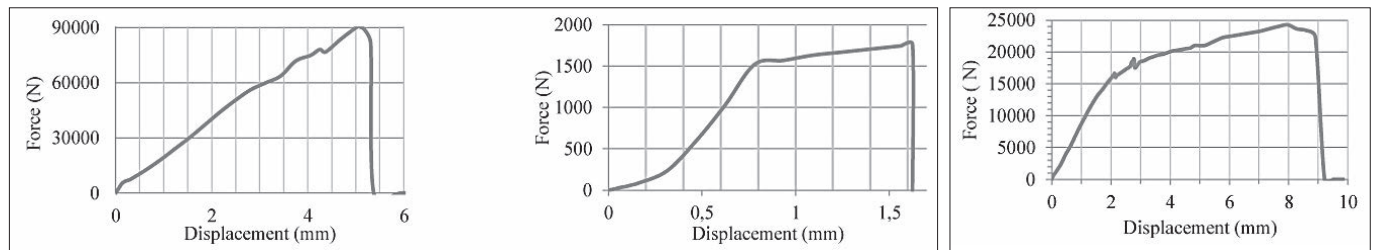
Fractured surfaces obtained from mechanical tests were examined at different magnification by using scanning electron microscope (SEM) from Tescan type VEGA3, in order to observe fracture behavior of the specimens, fibers orientation and crack interaction of these domains.

Results and Discussion

Determination of hoop tensile properties of filament wound composite tubular specimens by split-disk method is the main objective of this study. Tests were performed with specimens having 10°, 45° and 90° winding angles. Three specimens were tested from each testing group. Mainly, the ultimate hoop tensile strength of the specimens was determined. In addition, mean average of these results were calculated for each group, and with the aid of this data, the general behavior of the specimens were determined. The apparent hoop tensile strength of the specimens were calculated by using the following equation (Lee at al., 2005; ASTM, 2013):

$$\sigma = \frac{F_{\max}}{2 \cdot A_m} \tag{1}$$

In equation (1) σ is ultimate hoop tensile strength, MPa, F_{\max} is maximum load prior to failure recorded in Newton (N), whereas A_m is minimum cross-sectional area of the two reduced sections, d x b, mm².



a) Force and displacement of sample 1-2 b) Force and displacement of sample 2-3 c) Force and displacement of sample 3-2

Figure 3. Force and displacement graphs of split disk samples from universal tensile testing machine

Fig. 3 show a typical force-displacement diagram at ambient temperature for samples 1-2, 2-3 and 3-2. The tensile strength of composite rings were determined for three specimens for each experiment according to equation (1). The average values for each experiment are shown in Table 2.

From the results shown in Table 2 can be observed, that split-disk specimen 1 with tensile strength of 901.15 MPa had shown the best results. This sample 1 was winded with angle 90°. In contrary, specimen 2 winded with angle 10° had shown much lower value in tensile strength in comparison to sample 1. From received results it can be concluded that mechanical properties of composite specimens depend from winding angles in filament winding technology, namely, the bigger winding angle lead to higher hoop tensile properties of filament wound tubular samples.

Table 2. Hoop tensile strength results of split-disk tests

Sample Designation	F _{max} (N)	F _{max} average (N)	Tensile strength (MPa)	Tensile strength average (MPa)
1-1	94500		923.24	
1-2	90250	92583.33	877.97	901.15
1-3	93000		902.25	
2-1	1600		18.00	
2-2	1250	1536.25	14.34	27.45
2-3	1759		20.00	
3-1	25000		280.57	
3-2	24225	24541.67	275.76	277.3
3-3	24400		275.57	

Scanning electron microscopy (SEM) analyses were performed to see impregnation quality of glass fibers into the epoxy resin during filament winding process. In Fig. 4 are presented SEM analysis from longitudinal and cross section of split-disk specimens with different magnification after tensile testing. As seen from the photographs, failure of specimens occurred in the gage section whatever the winding angle is. For specimens, having 90° winding angle (Fig. 4a), fiber-matrix debonding, and parallel to the fibers and loading axis, was followed by rupture of fibers. For specimens made with $\pm 45^{\circ}$ winding angle (Fig. 4c), fiber-matrix debonding occurred more dominantly. Delamination of $\pm 45^{\circ}$ layers was also observed for these specimens. Finally, for 10° winding angle specimens (Fig. 4b), fiber breakage was very limited, and the specimen failed with the rupture of the matrix phase, which causes the formation of less macroscopic damage on the specimens, and low failure strength.

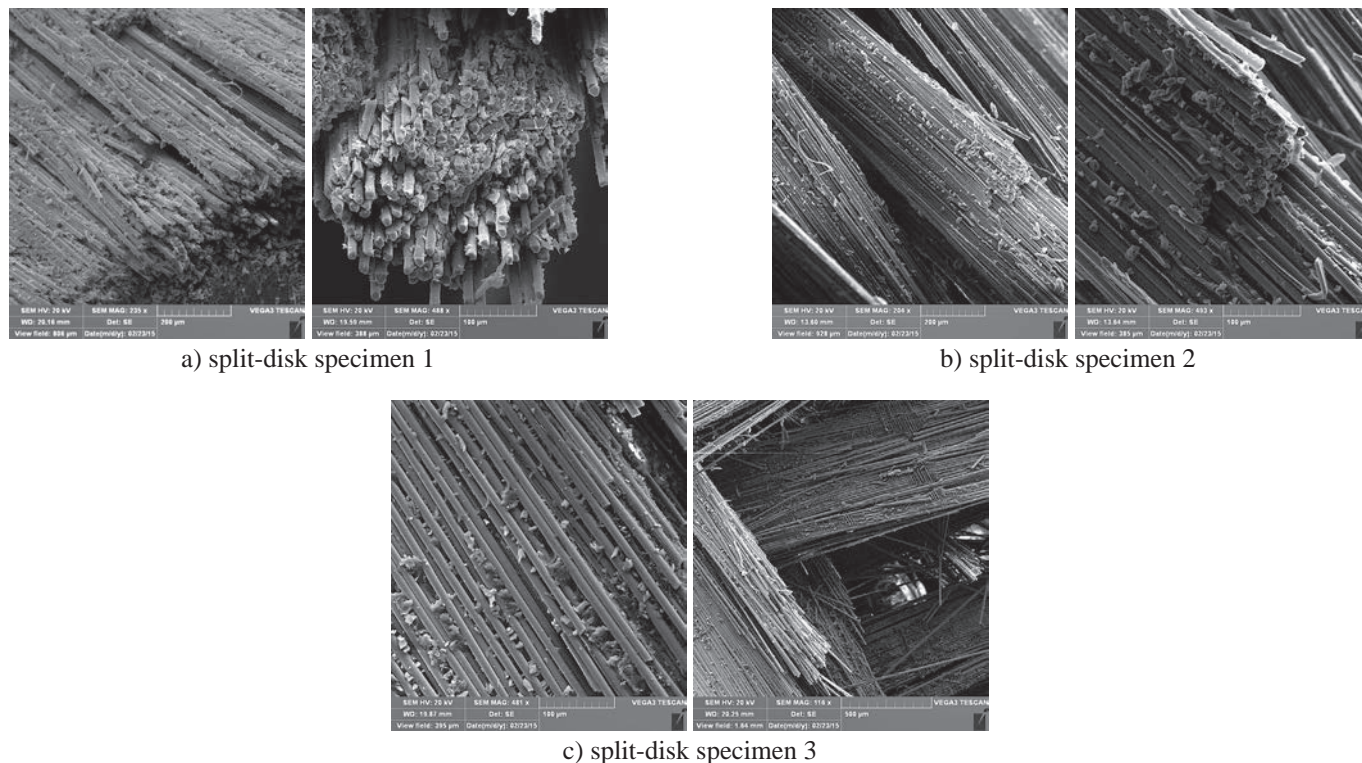


Figure 4. SEM photographs of failure section so split-disk specimens (deforming and breaking of fibers after testing)

Conclusions

The experimental procedure described in the present work is suitable to study the influence of the winding angles on mechanical properties of continuous glass fiber reinforced composite with split-disk specimens produced by filament winding technique.

From mechanical tests results can be concluded, that the best results in tensile strength and break force were obtained from composite pipes wound with angle 90° . Change in winding angle will cause variation in final mechanical results, whereas bigger winding angle lead to higher hoop tensile properties of filament wound tubular samples.

SEM analysis exhibit good merger between glass fibers and epoxy resin system in the split-disk specimens. Also, the breaking of the specimens took place at the reduced areas, as expected.

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