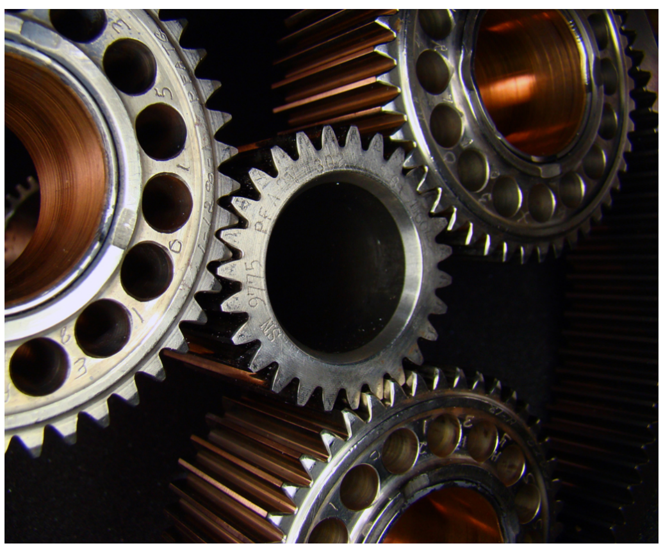
International journal for science, technics and innovations for the industry

MTM MACHINES TECHNOLOGIES MATERIALS

YEAR IX Issue 11 / 2015 ISSN 1313-0226



Published by
Scientific technical
Union of Mechanical Engineering

MACHINES, TECHNOLOGIES, MATERIALS

INTERNATIONAL JOURNAL

PUBLISHER

SCIENTIFIC TECHNICAL UNION OF MECHANICAL ENGINEERING

108, Rakovski Str., 1000 Sofia, Bulgaria
tel. (+359 2) 987 72 90,
tel./fax (+359 2) 986 22 40**,**
journal@mech-ing.com,
www.mech-ing.com/journal

ISSN 1313-0226
YEAR IX, ISSUE 11 / 2015

The current issue and the first issue of MTM journal and the conditions for publication can be find on www.mech-ing.com/journal

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HOOP TENSILE PROPERTIES OF FILAMENT WOUND PIPES

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Abstract: *In this study hoop tensile properties of continuous fiber reinforced composites pipes are investigated. The test pipes were manufactured of glass fiber and epoxy resin by filament winding method with three different winding angle configurations (10°, 45° and 90°). Three specimens from each model of filament wound pipes with help of split-disk tests were tested and the hoop tensile strengths and modulus of elasticity were determined. From received results it is concluded that, mechanical properties of composite specimens are depended from winding angles in filament winding technology, whereas that bigger winding angle lead to higher hoop tensile properties of filament-wound tubular samples. The optimal values for the hoop tensile strength are obtained for the samples winded with 45° winding angle.*

KEYWORDS: COMPOSITE PIPES, FILAMENT WINDING, SPLIT-DISK TEST, GLASS FIBERS, EPOXY RESIN

1. Introduction

Many of the modern industrial applications and technologies require materials with superior properties that cannot be met by conventional monolithic materials, such as metal alloys, ceramics and polymers. Because of their heterogeneous nature composite materials have several advantages over traditional engineering materials, which make them attractive for many industrial applications. 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. Composite materials have superior mechanical properties like high specific stiffness, high specific strength, high fatigue strength and good impact properties.

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. Fibers are the materials with very high aspect ratios; i.e. they have one very long dimension compared to the others. They have significantly more strength in the long direction than the other directions. These composites have found a wide range of application area due to their anisotropic nature, the direction dependence of their properties results in much better design flexibility that cannot be obtained by monolithic materials or particle reinforced composites.

Filament winding technique can be accepted as one of the most common production techniques, for the synthesis of polymer matrix composites (PMC).

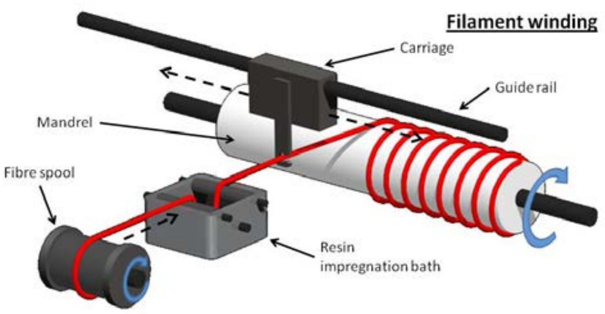

Figure 1. *Schematic presentation of the filament winding technology*

Filament winding is a process where the reinforcing agent in the form of continuous fibers (glass, carbon, aramid, etc.) is accurately positioned in the impregnation agent in the form of liquid resin (polyester, epoxy, etc.) to form a cylindrical shape. Figure 1 shows a filament winding process. A number of fiber rovings are pulled from a series of creels and tensioners that control the tension of the fibers into a liquid resin bath that contains the resin itself, the hardeners and the accelerators. At the end of the resin tank, the rovings are pulled through a wiping device where the excess resin is removed from the rovings. Once the rovings are thoroughly impregnated and wiped, they are collected together in a flat band, pass through the carriage and located on the mandrel. The traversing speed of carriage and the winding speed of the mandrel are controlled to generate the desired winding angle patterns. After the appropriate number of layers has been applied, curing is carried out in an oven or at room temperature, after which the mandrel is removed.

The filament winding method in general, has several advantages over other methods.

- It is highly repetitive and precise in fiber placement.
- It can use continuous fibers to cover the whole component area, which simplifies the fabrication process of many components and increases reliability and lowers the cost by reducing the number of joints.
- It is less labor intensive, which reduces the costs significantly.
- Large and thick walled structures can be built.

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.

Three types of testing geometry are commonly used in testing of filament-wound composite structures, namely; flat specimens (coupon specimens), ring specimens, 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. For evaluation of the tensile properties of filament wound composite structures 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 efficient in determine the performance of tubular structures which are usually used under internal pressure developing high hoop.

This research will present the hoop tensile properties of different models of specimens based on the different winding angle, manufactured with conventional filament winding equipment.

2. Preconditions and means for resolving the problem

a. Experimental stand

Samples with different winding designs were winded on iron mandrel with help of laboratory filament winding machine MAW FB 6/1 with six axes, roller type resin bath manufactured from Mikrosam A.D. The filament winding machine is given in Figure 2.

Figure 2. *Filament winding machine MAW FB 6/1*

The resin system employed in the fabrication of the pipes is Araldite LY564/Aradur 917/Accelerator 960-1 from Huntsman. This polymer system is suitable for filament winding, wet laminating, and pultrusion processes and it was recommended by the producer. The reinforcements employed in the fabrication of the pipes are 10 bobbins of E- glass fiber roving 185P with 1200 tex from Owens Corning. Glass fibers with constant fiber tension 110 N pass through a resin bath and gets wet before winding operation. The velocity of the filament winding was 21 m/min. During the manufacturing of the test pipes, three different winding angles are used, 10°, 45° and 90° (table 1).

Table 1: *Designation of models of samples*

Number of samples	**Characteristics (conditions of the experiment)**		
	X_1 (m/min) *velocity of the filament winding*	**X_2 (N)** *fiber tension*	**X3 (^{0})** *winding angle*
1	21	110	**10**
2	21	110	**45**
3	21	110	**90**

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 (± θ) 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.

low winding angle ($\theta = 10^0$)

helical winding ($\theta=45^0$)

hoop winding($\theta=90^0$)

Figure 3. Winding of impregnated glass fibers

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.

3. Results and discussion

For tensile tests three split-disk test specimens from each model of filament wound pipes was cut according to ASTM D2290. Tensile tests of split-disk samples were carried out at room temperature using universal testing machine Schenck with max load of 250 kN and loading speed of 5 mm/min. Width and thickness of each split-disk samples was measured with help of micrometer with reading to at least 0.0254mm. In this way prepared specimens were elongated till rupture with help of test fixture, made according to standard (Fig. 4).

Figure 4. *Split-disk test specimen and test fixture with specimen for hopp tensile testing*

Based on the obtained results, the general behavior of the specimens were determined. The results of the testing method of the split-ring specimens for determination of the hoop tensile strength are presented in Table 2.

Table 2: *Hoop tensile strength results of split-disk tests*

	Sample Designation	Weight (g)	Width (mm)	Thickness (mm)	F_{max} (N)	Tensile strength (MPa)	Winding angle (^{0})
1	1 -1	42,2	13,97	3,18	1600	18,00	10
	1-2	43,0	13,85	3,14	1250	14,34	
	1-3	43,7	14,00	3,14	1759	20,00	
2	2-1	53,6	14,01	3,18	25000	280,57	45
	2-2	53,8	13,9	3,16	24225	275,76	
	2-3	53,8	14,01	3,16	24400	275,57	
3	3-1	52,8	14,06	3,64	94500	923,24	90
	3-2	52,8	14,12	3,64	90250	877,97	
	3-3	53,8	14,12	3,65	93000	902,25	

The hoop tensile strength of the specimens were calculated by using the following equation:

$$\sigma = \frac{F_{max}}{2 \cdot A_m} \qquad (1)$$

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, mm^2 (Fig. 5).

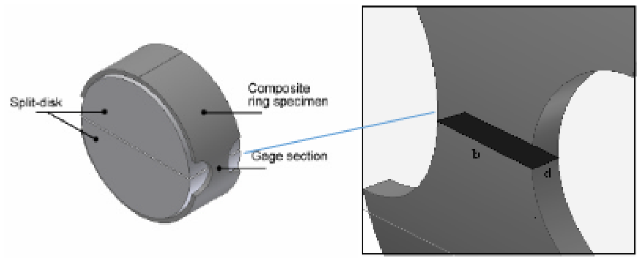

Figure 5. *Cross-sectional area on which hoop tensile stress is applied*

From the results shown in table 2 can be observed, that split-disk specimen 3 with tensile strength with average value of 901,15MPa had shown the best results and it was winded with angle 90^0. The specimen designated with 1 winded with angle 10^0 had shown much lower value up to 10 times lower than tensile strength from sample 3. From received results it can be concluded that mechanical properties of composite specimens depended from winding angles in filament winding technology, namely, the bigger winding angle lead to higher hoop tensile properties of filament-wound tubular samples. The optimal values for the hoop tensile strength are obtained for the samples winded with 45° winding angle.

4. Conclusion

Advantages of filament winding technique are high specific strength, specific modulus and fiber volume percentage of the finished products and high repeatability of the process. Production can be repeated successively, to obtain the same properties of the finished products.

The main limitation of filament winding technique is the difficulty in production of complex shapes due to the requirement of very complex mandrel designs. From results of the mechanical testing can be concluded, that the best results in tensile strength and break force were obtained from composite pipes winding with angle 90°. Change of winding angle will cause variation in the final mechanical results, whereas that bigger winding angle lead to higher hoop tensile properties of filament-wound tubular samples.

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