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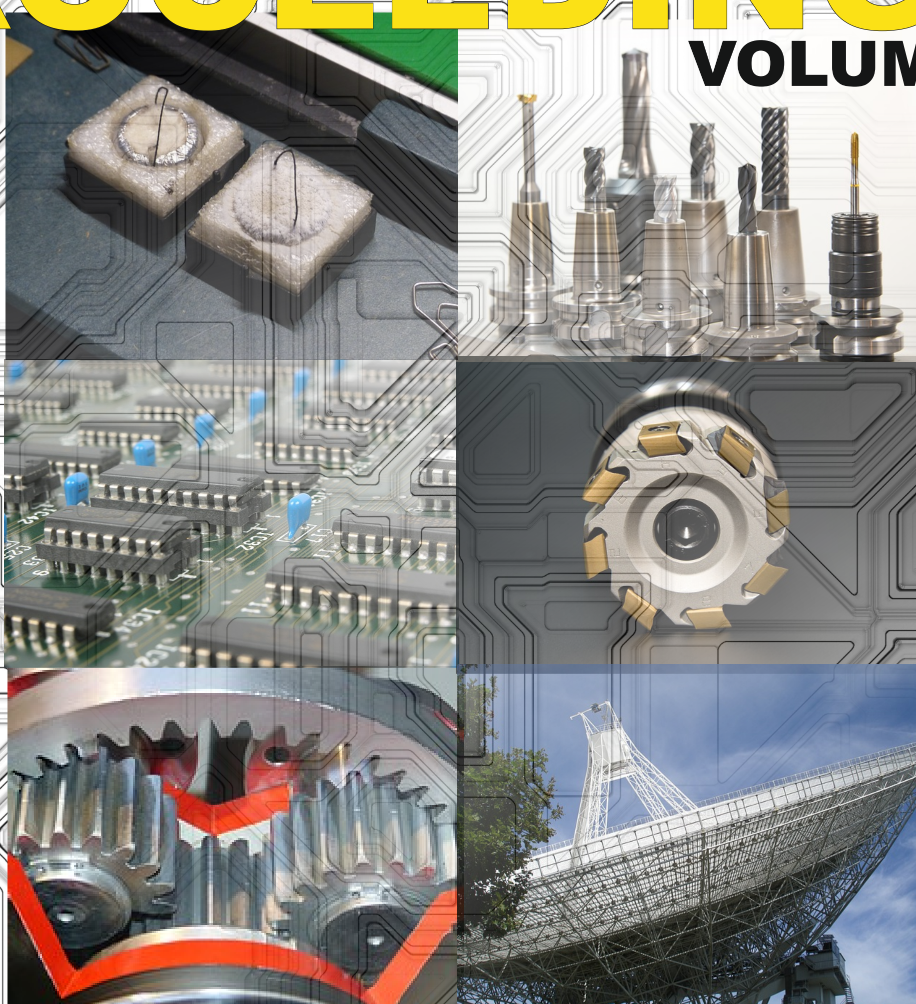

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CONTENTS

DESIGN OF POLYMER COMPOSITE PIPES PRODUCED BY FILAMENT WINDING TECHNOLOGY

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Abstract: *The aim of this study is to investigate the design of continuous fiber reinforced composite pipes, produced by filament winding technique. For this purpose, the full factorial experimental design was implemented. When designing filament winding composites three major factors are the most important: fiber orientation, fiber tension and velocity of the filament winding. The ultimate target is to achieve the composite pipes with good characteristics as bearing material for construction with the lowest possible weight. Preparation of the composites was done by applying the 2^3 full factorial experimental design. For the purposes of these investigation, eight test specimen configurations are made and on the basis that, test results should provide material properties useful in the design stage. The velocity of the filament winding was taken to be the first factor, the second – fiber tension and the third – winding angle. The first factor low and high levels were chosen to be 525 m/min and 21 m/min, respectively, for the second factor – 64 N and 110 N, respectively and for the third factor – 100 and 900, respectively.*
KEYWORDS: \ FILAMENT WINDING, GLASS FIBERS, EPOXY RESIN, COMPOSITE PIPES.

1. 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 (Krivokuća, M. et. al., 1999).

Properties of composites are strongly influenced by the properties of their constituent material, their distribution, and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents, or the constituents may interact in a synergistic way so as to provide properties in the composite that are not accounted for by a simple volume –fraction sum of the properties of the constituents (Roux, M, 2010).

Fiber – reinforced composite materials consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interfaces between them. In this form, both fibers and matrix retain their physical and chemical identities, yet they produce a combination of properties that cannot be achieved with either of the constituents acting alone. In general, fibers are the principal load-carrying members, while the surrounding matrix keeps them in the desired location and orientation, acts as a load transfer medium between them and protects them from environmental damages due to elevated temperatures and humidity, for example (Dorigato A., Pegoretti A., 2014).

Many fiber-reinforced composites often a combination of strength and modulus that are either comparable to or better than many traditional metallic materials. Because of their low density, the strength-weight ratios and modulus weight ratios of these composite materials are markedly superior to those of metallic materials. In addition, fatigue strength as well as fatigue damage tolerance of many composite materials are excellent. For these reasons, fiber reinforced composites have emerged as a major class of structural materials and are either used or being considered for use as substitution for metals in many weight-critical components in aerospace, automotive, and other industries. Filament winding technique is a very important and widely used technique for production of fiber reinforced composites (Mallick, P.K, 2007).

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 impregnation 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 (Figure 1).

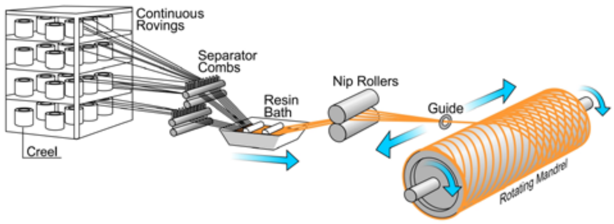

Figure 1. *Schematic presentation of the filament winding technology*

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 (Belingardi, G. et al., 2006).

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.

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.

2. Preconditions and means for resolving the problem

a. Experimental stand

For the production of the composites 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.

The preparation of the composites was done by applying the 2^3 full factorial experimental design. For the purposes of these investigation, eight test specimen configurations are made and on the basis that, test results should provide material properties useful in the design stage. The velocity of the filament winding was taken to be the first factor, the second – fiber tension and the third – winding angle. The first factor low and high levels were chosen to be 5,25 m/min and 21 m/min, respectively, for the second factor – 64 N and 110 N, respectively and for the third factor – 100 and 900, respectively (Table 1).

Samples with different winding designs were winded 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. Fibers pass through a resin bath after tensioning system and gets wet before winding operation.

After winding samples were cured with industrial heater at 80oC and at 140°C, for four hours.

Table 1. *Full factorial experimental design - 2^3*

No. exp.	Matrix of full factorial experimental design							Characteristics (conditions of the experiment)		
	X_1	X_2	X_3	$X_1 X_2$	$X_1 X_3$	$X_2 X_3$	$X_1 X_2 X_3$	**X_1 (m/min)** *velocity of the filament winding*	**X_2 (N)** *fiber tension*	**X_3 (°)** *winding angle*
1	-1	-1	-1	+1	+1	+1	-1	5,25	64	10
2	+1	-1	-1	-1	-1	+1	+1	21	64	10
3	-1	+1	-1	-1	+1	-1	+1	5,25	110	10
4	+1	+1	-1	+1	-1	-1	-1	21	110	10
5	-1	-1	+1	+1	-1	-1	+1	5,25	64	90
6	+1	-1	+1	-1	+1	-1	-1	21	64	90
7	-1	+1	+1	-1	-1	+1	-1	5,25	110	90
8	+1	+1	+1	+1	+1	+1	+1	21	110	90

Primary level	$X_1 = 13{,}125$	$X_2 = 87$	$X_3 = 50$
Interval of variation	7,875	23	40
Lower level	5,25	64	10
Upper level	21	110	90

3. Results and discussion

Tensioning system is an important part of filament winding. This importance gets critical when winding at high angles. Since tension changes the friction force between fiber and the mandrel, it should be kept at a certain value during winding operation (Jones, R. M., 1998).

Fiber tension also affects the volumetric ratio of composite at a given point. Excessive resin, due to a low tension, can result in decreased mechanical properties (Putic, S., et. al., 2007). Therefore, tensioning systems should be capable of rewinding a certain value of fiber. This condition occurs when fiber band reverses at the end of tube, while winding at low angles.

Wetting can be done by two commonly used bathing type: drum bath and dip bath.

Drum bath provide: less fiber damage than dip bath, this is especially important when using carbon fibers, drum baths can be heated for a better wetting action, lowering resin viscosity, reducing fiber speed, increasing fiber path on the drum are other methods used for better wetting action.

Dip bath provides: a better wetting action, resin can be heated during the travel of fiber through a dip bath, non-rotating surfaces are used for guidance, non-rotating surfaces provide good wetting, dip baths are used with aramid or glass fibers. Each layer of reinforcement can vary in winding tension, winding angle, or resin content.

In filament winding, one can vary winding tension, winding angle and/or resin content in each layer of reinforcement until desired thickness and strength of the composite are achieved. The properties of the finished composite can be varied by the type of winding pattern selected (Babu, M., et al., 2009). Three basic filament winding patterns are:

1) Hoop Winding: It is known as girth or circumferential winding. Strictly speaking, hoop winding is a high angle helical winding that approaches an angle of 90 degrees. Each full rotation of the mandrel advances the band delivery by one full bandwidth (Figure 2).

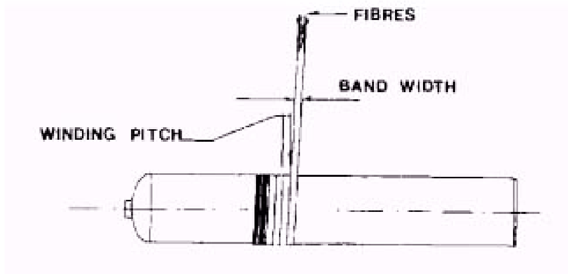

Figure 2. *Presentation of hoop winding of layers*

2) Helical Winding: In helical winding, mandrel rotates at a constant speed while the fiber feed carriage transverses back and forth at a speed regulated to generate the desired helical angles (Figure 3).

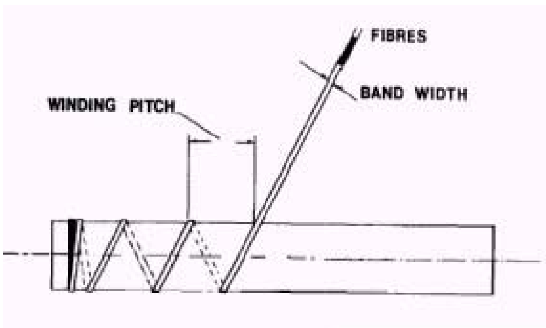

Figure 3. Presentation of coupled helical winding of layers

3) Polar Winding: In polar winding, the fiber passes tangentially to the polar opening at one end of the chamber, reverses direction, and passes tangentially to the opposite side of the polar opening at the other end (Figure

4).

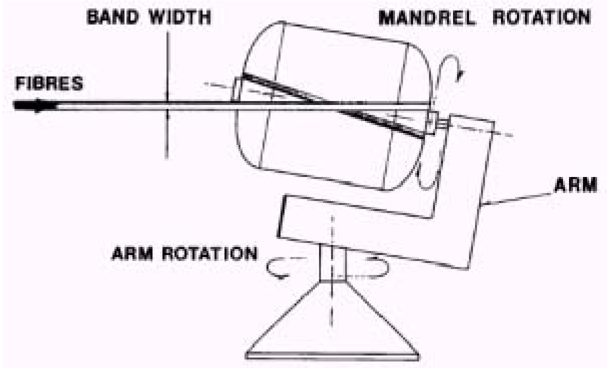

Figure 4. Presentation of polar winding of layers

In other words, fibers are wrapped from pole to pole, as the mandrel arm rotates about the longitudinal axis as shown in Figure 2. It is used to wind almost axial fibers on domed end type of pressure vessels. On vessels with parallel sides, a subsequent circumferential winding would be done.

In the above three, helical winding has great versatility. Coupled helical winding of layers (±Ө) are usually preferred, whereas hoop winding - winding angle, very close to 90° can also be used. Very low winding angle values need some arrangements at the ends of the mandrel, such as pins, etc. 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. Almost any combination of diameter and length may be wound by trading off wind angle and circuits to close the patterns. Usually, all composite tubes and pressure vessels are produced by means of helical winding.

Filament winding is a manufacturing process which can offer:

• A high degree of automation;

• Relatively high processing speeds (> 50 m/min winding speed);

• An ability to fabricate composites with relatively high fibre volume fractions (~ 70%).

The main limitation of filament winding technique is the difficulty in production of complex shapes due to the requirement of very complex mandrel designs. In addition, production of reverse curvature parts is not possible by using this technique.

Figure 5. Produced glass fiber/epoxy resin filament wound composite pipes

4. Conclusion

The glass fiber/epoxy resin composite pipes were produced by using of filament winding technology. For the designing of the filament winding composite pipes the full factorial experimental design - 2^3 was applied. Base on that eight test specimen configurations were made. Three major factors were taken and two levels of variation. The first factor low and high levels were chosen to be 5,25 m/min and 21 m/min, respectively, for the second factor – 64 N and 110 N, respectively and for the third factor – 10^0 and 90^0, respectively. The effect of a filament-winding processing variables on longitudinal and hoop tensile and bending properties of the prepared composites further will be investigated. The produced filament wound composite pipes are shown on figure 5.

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