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DESIGN OF POLYMER COMPOSITE PIPES PRODUCED BY FILAMENT WINDING TECHNOLOGY

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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. (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. Fiber – reinforced composite materials consist of fibers of high strength and modulus embedded in or bonded to a matrix with distinct interfaces between them. Many fiber-reinforced composites often a combination of strength and modulus that are either comparable to or better than many traditional metallic materials. 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.

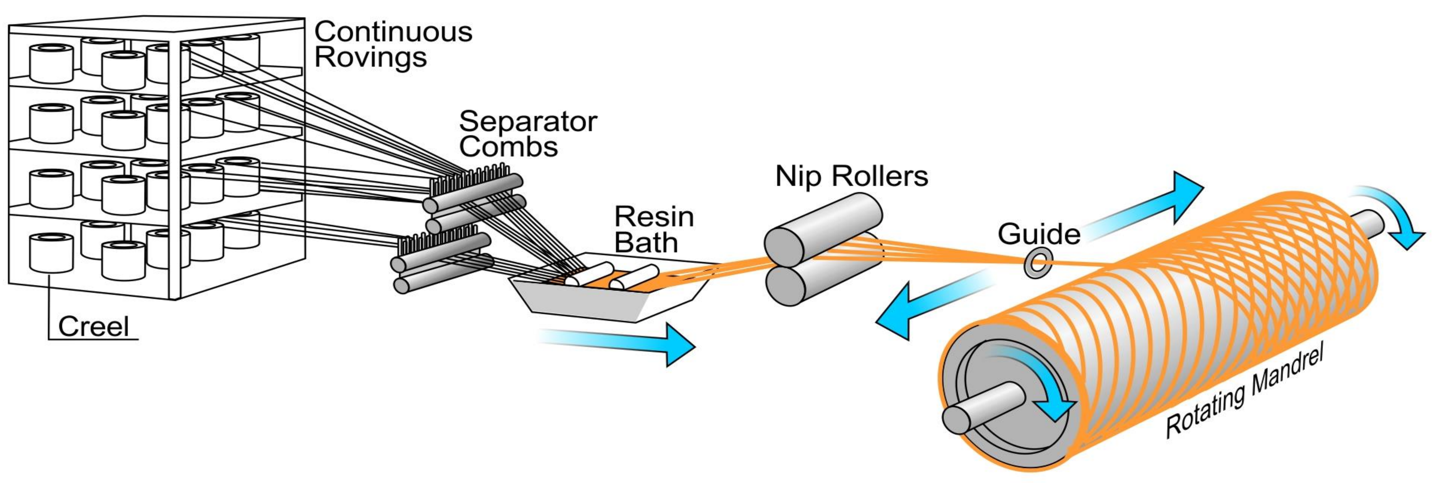


Figure 1. Schematic presentation of the filament winding technology

2. Preconditions and means for resolving the problem

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.

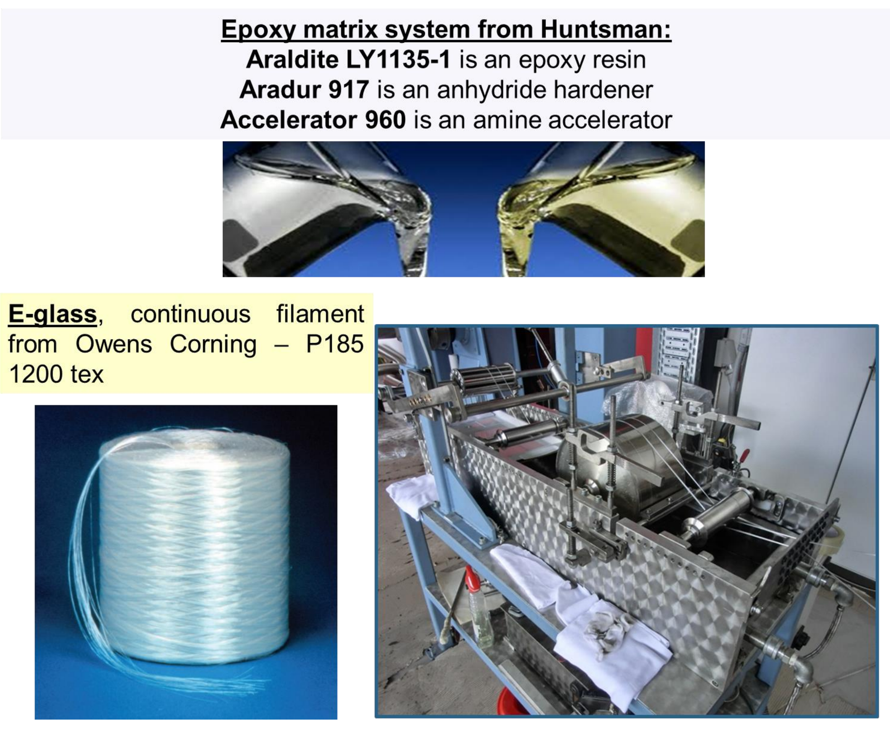


Figure 2. Materials and machine used for production of the composites

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 80°C 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 (^{0})** *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

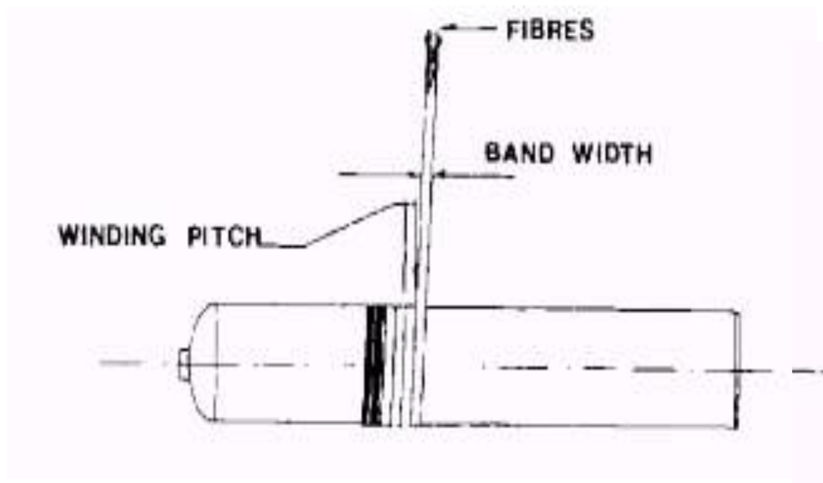
3. Results and discussion

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.

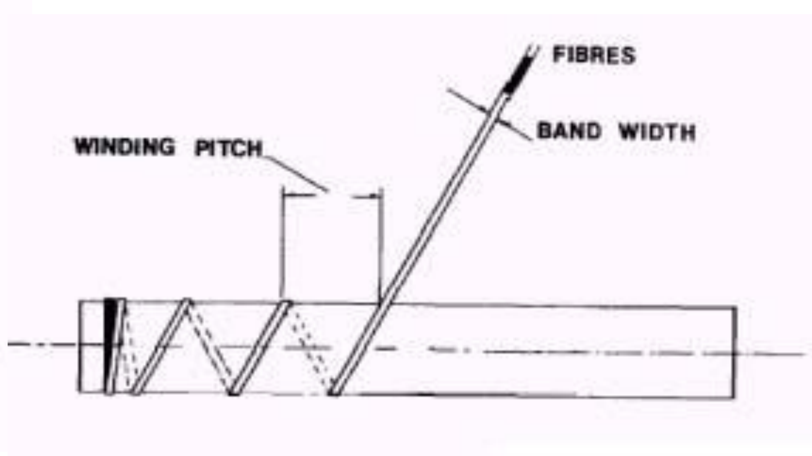
Wetting can be done by two commonly used bathing type: drum bath and dip bath. In filament winding, one can vary winding tension, winding angle and/or resin content in each layer of reinforcement until desired thickness and strength of the composite are achieved.

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 (figure 3):

1) Hoop Winding:



2) Helical Winding:



3) Polar Winding:

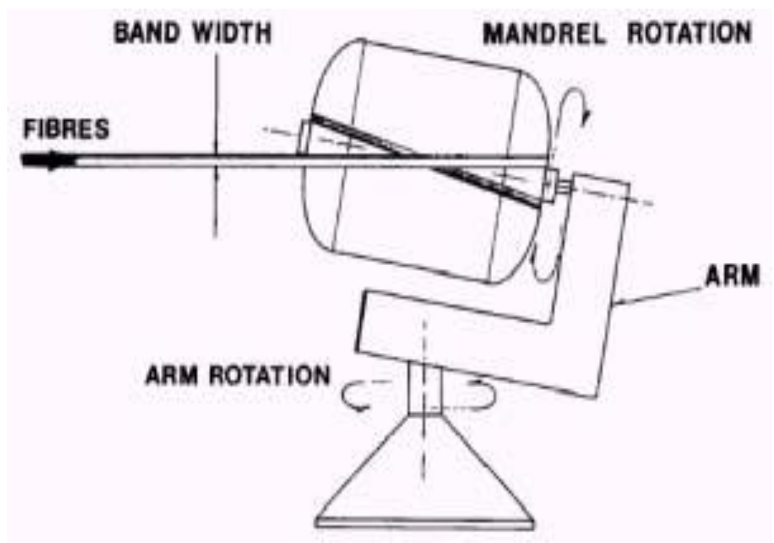


Figure 3. Presentation of hoop, helical and polar winding of layer

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 4. Produced glass fiber/epoxy resin filament wound composite pipes

3. 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 - 23 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 – 100 and 900, 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 4.