FILAMENT WOUND PRODUCTS MADE WITH THERMOPLASTIC MATRIX TOWPREGS

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Abstract

Cost-effective glass-reinforced thermoplastic matrix towpregs produced by a powder coating line were used to manufacture composite pipes by filament winding. A conventional 6 axes filament-winding equipment was adapted for processing such structures. The influence of the filament winding speed and mandrel temperature on the composite final properties was studied in the present work. An optimized processing window was established by comparing the composite theoretical expected mechanical properties with the experimentally obtained ones. The final properties determined on the produced pipes and structures and the technological changes introduced to the conventional filament-winding equipment will be presented and discussed. Besides the processing description and conditions, it will be presented the relationship between processing conditions and mechanical properties.

1 Introduction

A purposely-built powder-coating process was used to produce thermoplastic matrix towpregs based on a polypropylene reinforced with continuous glass fiber (GF/PP) [1, 2]. A conventional filament winding equipment used to produce thermosetting matrix composites was modified to process the towpregs into 80 mm diameter pipes [3, 4] using a new developed heated mandrel. The concept can be seen in the schema shown in Figure 1.

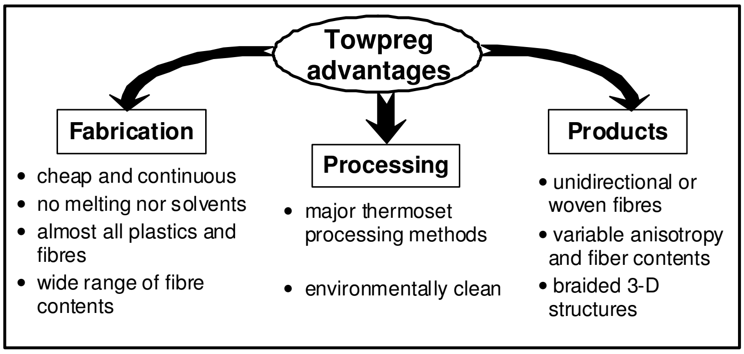


Figure 1. Schematic proposal of the work carried out

The influence of filament winding speed on the final composite properties was studied at different mandrel temperatures. This work discusses the results obtained and compares them with those already achieved using a mandrel at room temperature [4].

The results obtained from the interlaminar shear tests made to verify the consolidation quality proven that the pipe interlaminar shear strength is more sensitive to the mandrel temperature and winding speed than the tensile strength or the initial specific ring stiffness.

2 Experimental

2.1 Raw materials

A polypropylene powder (ICORENE 9184B P from ICO Polymers France) having a powder size between 60 and 850 (μm) and a 2400 Tex glass fibers (357D-AA from Owens Corning) were used to process towpregs in the powder-coating line. Table 1 shows the properties of the raw materials used in this work.

Property	Units	Glass fibres	Polypropylene
Density	Mg/m^3	2.56	0.91
Tensile strength	MPa	3500	30
Tensile modulus	GPa	76	1.3
Linear roving weight	Tex	2400	-

Table 1. Raw materials properties

2.2 Production of the GF/PP Towpregs

The GF/PP towpregs used in this work were produced using the typical powder coating line processing conditions shown in Table 2.

Variable	*Units*	Value
Linear fibre pull speed	m/min	2-6
Furnace temperature	ºC	400-420
Spreader pressure	kPa	500

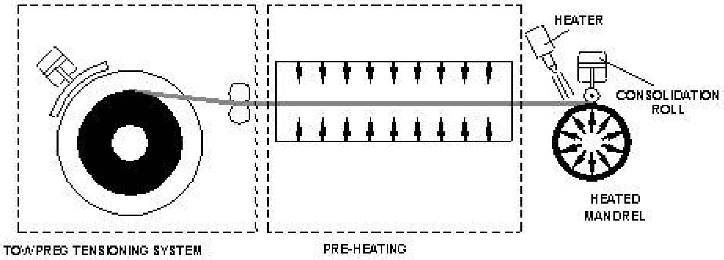
Table 2. Typical coating line operational conditions

2.2 Filament wound system

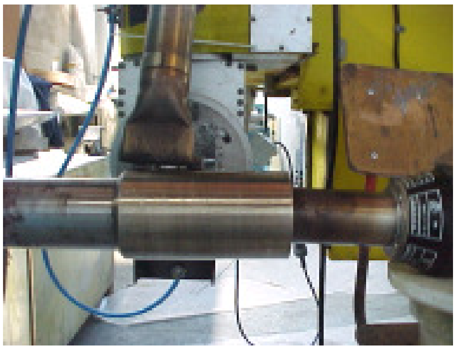
GF/PP pipes with dimensions of $\phi 80\times 4$ mm were processed from the towpregs on the modified CNC 6 axes conventional PULTREX machine shown in Figure 2.

As can be seen in the Figure 2, a pre-heating furnace, a hot-air heater and a 30 mm diameter consolidation roll were mounted in the machine. In respect to the system used in a previous work and described elsewhere [3, 4], a new mandrel internally heated by hot air was employed here. Furthermore, the mandrel and consolidation temperatures were measured and controlled by two thermocouples, one mounted in contact with the mandrel surface and the other near the consolidation roll contact area, respectively.

Using this system, the GF/PP composite pipes were made in the different filament winding conditions shown in Table 3. As can be seen, two different mandrel temperatures were used to produce the composite pipes at three different mandrel rotational speeds.



a) Schematic layout



b) Photograph showing a detail of the heated mandrel.

Figure 2. Filament winding system

Variable	Units	Values					
Mandrel rotational speed	rpm	6		8		10	
Mandrel temperature	ºC	150	200	150	200	150	200
Consolidation pressure	kPa	200					
Pre-heating temperature	ºC	260					
Consolidation temperature	ºC	300					
Tow tension	N	10					

Table 3. Filament winding operational conditions

2.3 Testing procedure

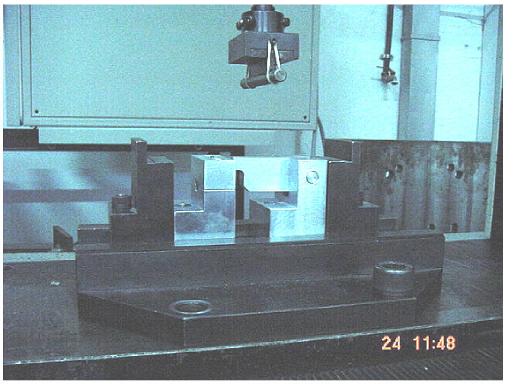
Each produced pipe was tested in order to determine the initial specific ring stiffness, apparent circumferential tensile strength and fiber mass fraction according to EN 1228, ASTM 2290 and EN 60, respectively.

Furthermore, specimens with dimensions of $12 \times 7 \times 4$ mm3 were cut from the filament wound pipes and submitted to interlaminar shear tests to evaluate the consolidation quality. In order to do this the interlaminar shear strength was determined in a new developed testing device (see Figure 2) based on the one described elsewhere [5]. After mounting this device in a universal testing machine Instron 4505, simple supported specimens were submitted to shear tests using a cross-head speed of 1 mm/min. The interlaminar shear strength, τ, was then calculated by:

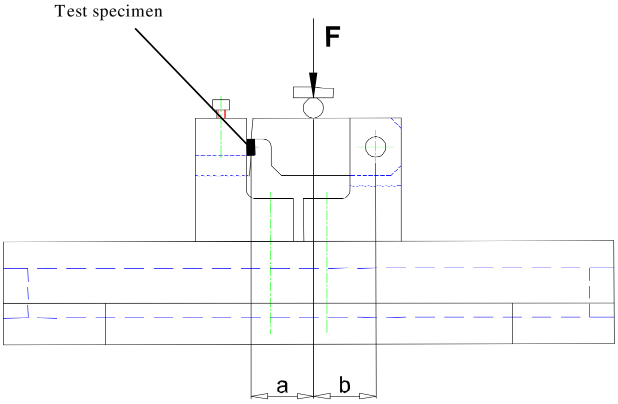
$$\tau = \frac{F \cdot b}{S \cdot (a+b)} \tag{1}$$

where:

F is the testing machine force
S is the specimen cross-section and,
a, b are the dimensions shown in Fig. 3



a) Photo of the device



a) Device drawing

Figure 3. Interlaminar shear testing device.

2.4 Results

Table 4 shows the dependence of the composites mechanical properties on the mandrel temperature and compares them with the theoretical expected ones calculated from the properties determined experimentally on the glass fibers and polypropylene [2] using the Classical Lamination Theory (CLT) and the micromechanical lamina approach [6,7].

Property		**Units**	**Mandrel temperature (ºC)**		
			150	200	Room Temperature
Tensile strength	Experimental	MPa	375.3 ± 53.9	281.9 ± 18.3	431.0 ± 37.6
	Theoretical		693.7 ± 229		
Interlaminar shear strength	Experimental	MPa	1.76 ± 0.51	2.28 ± 2.19	2.82 ± 1.06
	Theoretical		8.93 ± 0.37		
Circumferential modulus	Experimental	GPa	15.1 ± 0.52	15.4 ± 0.75	17.8 0.45
	Theoretical		37.3 ± 7.7		
Fiber mass fraction	Experimental	%	80.2 ± 1,5		
Fiber volume fraction	Calculated		59.0 ± 2,8		

Table 4. Mechanical properties determined on composites

As can be seen, the obtained mechanical properties are lower than the theoretical expected ones but already enough competitive for a large number of commercial applications of composite pipes/vessels. As the poorest values of the interlaminar shear strength suggest, this seems to be related with the difficulties found to consolidate well the composite pipe wall structure during the very short consolidation time achieved in the filament winding process.

In order to improve the composite consolidation the dependence of the interlaminar shear strength on the mandrel surface temperature and rotational speed was investigated. The results obtained are summarized in Table 5. It shows that the composite consolidation is deeply affected by both parameters under study. The highest interlaminar strength was achieved by combining a mandrel surface temperature of 200ºC with a 8 rpm rotational speed.

Property	**Units**		**Mandrel rotational speed (rpm)**					
			6		8		10	
Mandrel temperature	ºC		150	200	150	200	150	200
Interlaminar shear strength	MPa	Average	2.12	1.58	1.97	4.73	1.18	0.53
		St. Dev.	0.99	0.02	0.40	0.59	0.05	0.03

Table 5. Dependence of the interlaminar shear strength on the mandrel temperature and rotational speed

3 Conclusions

A new low-cost filament wound technology was developed to produce thermoplastic matrix composites with mechanical properties compatible with the major commercial applications. It was found that the mandrel surface temperature and rotational have a major role on the composite consolidation quality. This work shows that interlaminar shear tests can be used in the optimization of these parameters. Such optimization could be useful to enlarge the application of filament wound composite structures on more demanding markets.

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