PRODUCTION OF GF/PP WOVEN FABRICS FROM POWDER COATED THERMOPLASTIC MATRIX TOWPREGS

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ABSTRACT

In the present work, glass fibre polypropylene (GF/PP) woven fabrics were manufactured from cost-effective flexible thermoplastic towpregs produced by a developed dry coating process [1, 2]. The article describes the modifications made on the developed coating line to allow producing thermoplastic towpregs able for being woven in textile equipments. The produced fabrics were observed under optical microscopy and submitted to tests in order to evaluate their textile properties, glass fibre content and flexibility. Finally, composites processed by compression moulding from those fabrics were submitted to mechanical testing in order to assess their performance.

1. INTRODUCTION

Composites laminates made from unidirectional fibre reinforced thermoplastic matrix plies have been successfully employed in the aircraft, military and aerospace industries [3]. They have shown to have excellent toughness, durability and damping properties and to possess possibilities of reshaping and reparability [3-5]. However, there are few applications of woven textile thermoplastic prepregs in composite laminates. The development of these products, which can be easily shaped into complex forms, can reduce the production cycle-time usually needed on large-scale consumption products. Furthermore, the woven textile thermoplastic prepregs exhibit much higher mechanical properties in the two directions of reinforcement than those presented by other commonly used materials, such as the GMTs and LFTs.

In the present work, a developed dry coating process [1, 2] was used and adapted to produce cost-effective and flexible glass fibre polypropylene (GF/PP) towpregs for being woven into fabrics that were observed under microscope and submitted to tests in order to evaluate their textile properties, glass fibre content and flexibility. Finally, in order to assess the mechanical behaviour of composites consolidated from the manufactured fabrics their tensile and flexure properties were experimentally determined.

2. EXPERIMENTAL

2.1. Raw materials

A polypropylene powder ICORENE 9184B P (supplied by ICO Polymers France) and an S glass fibre 675 Tex 933 S-2 roving (supplied by Advanced Glassfiber Yarns - AGY, France) were used to produce the studied towpregs. Table 1 summarises the raw materials properties. The mechanical properties presented of the PP were obtained in an earlier work [1].

The use of a low linear density roving allowed to promote the towpreg flexibility, which facilitates woven fabrics manufacturing.

Table 1. Raw materials properties

Property	Units	Glass fibres	PP
Density	Mg/m^3	2.56	0.91
Tensile modulus	GPa	70	0.978
Poisson ratio	-	0.26	0.21
Tensile strength	MPa	2000	19
Fibre diameter	μm	9	-
Powder particle size	μm	-	398
Linear roving weight	Tex	675	-

2.2. Powder coating line

Figure 1 schematically shows the powder-coating equipment used to produce the towpregs [1, 2, 6].

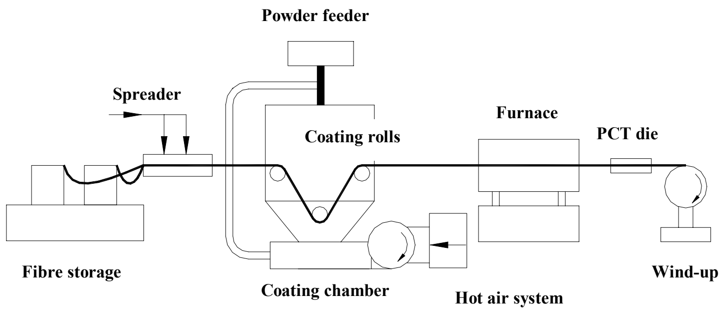


Fig. 1. Schematic diagram of the powder-coating line

In order to efficiently separate the filaments from the low linear density glass yarn a smaller pneumatic spreader (see Figure 2) had to be designed and mounted in the previously developed coating line.

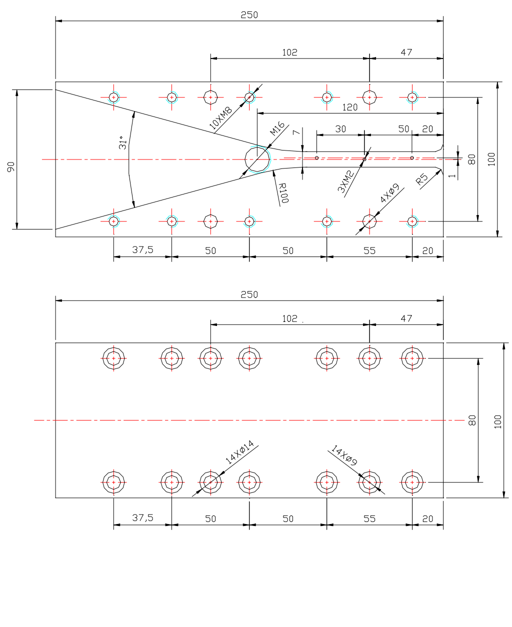


Fig. 2. New pneumatic spreader

The typical coating line operational conditions used to produce GF/PP towpregs are summarised in Table 2.

Table 2. Typical coating line operational conditions

Variable	Units	Value
Linear fiber pull speed	m/min	0.7-1.2
PP Powder feeder	g/min	11.8
Fan speed	rpm	825
Furnace temperature	ºC	240
Coating Chamber temperature	ºC	50
Spreader pressure	kPa	500

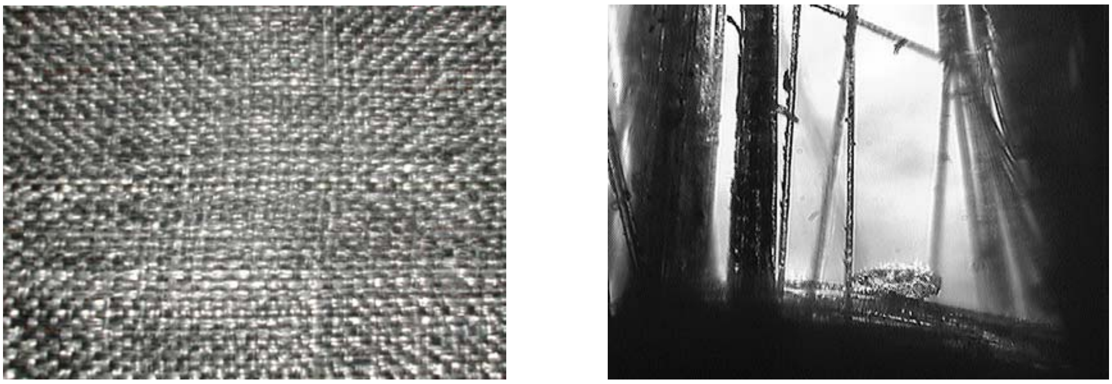
Using the operational conditions shown in Table 2, GF/PP towpregs having fibre mass fractions between 80% and 85% were produced in the coating line.

2.3. Woven fabrics manufacture

Due to the small amount of towpreg produced, was not possible to prepare a warp beam to be processed in an industrial weaving machine. Therefore, a manual weaving loom has been used for the production of plain woven fabrics from the produced GF/PP towpregs, as shown in Figure 3.

Fig. 3. Manual weaving loom

The produced fabrics were observed under optical microscopy and submitted to tests in order to evaluate their textile properties, glass fibre content and flexibility.
As can be seen in Figure 4, it was possible to manufacture fabrics with fairly good appearance.



(a) (b)

Fig. 4. Produced GF/PP woven fabrics: a) normal view; b) observed under optical microscopy

The dimensional properties of the produced woven fabrics were evaluated according to NP EN 4105/91, NP EN 4115/91, NP EN 12127 and NP EN 4114/91 standards. Moreover, the woven fabrics flexural properties were determined according to ISO 178 standard. Table 3 summarises the results obtained.

Table 3. Properties of the woven fabrics

Woven fabric specifications	
Type of woven structure	Plain
Type of fiber	S glass
Weight (gr/m^2)	605
Fiber mass (%)	84.1
Warp:	
Linear density of the yarn (Tex) (before coating)	660
Linear density of the yarn (Tex) (after coating)	788
Density (yarns/cm)	4.5
Crimp (%)	1.1
Weft:	
Linear density of the yarn (Tex) (before coating)	660
Linear density of the yarn (Tex) (after coating)	778
Density (yarns/cm)	4.5
Crimp (%)	2
Flexural properties	
Flexural modulus (MPa)	0.0401
Flexural stress at max. (MPa)	0.0322
Deformation at max. (mm)	10.61

2.4. Compression moulding

In order to process 2 mm thickness composite plates by compression moulding, 100 × 100 (mm) woven fabric layers were cut and stacked-up into a electrically heated and water-cooled mould cavity. Before compression, equal amounts of PP powder were placed between the fabric layers in order to obtain glass mass fractions of approximately 70% in the final composites. Finally, the laminate was consolidated using a 400 kN SATIM press.

A cavity temperature of 230 ºC and a pressure of 15 MPa were applied during 10 min during consolidation. Finally, the mould was cooled down to room temperature and the final composite part removed (see Table 4).

Table 3. Compressing moulding processing conditions

Variable	Units	Value
Mould temperature	ºC	230
Pressure	MPa	15
Compression time	min	10

2.5 Final composites properties

Tensile specimens cut from the consolidated composites with dimensions of 100 × 15 mm were tensile tested in the fibre directions, at room temperature, using an Instron 4505 universal testing machine. The test was conducted at a crosshead speed of 1 mm/min. The elongation was determined by using a 10 mm Instron extensometer.

Three-point bending tests were also conducted in the same testing equipment on five 120 × 15 × 2 (mm) specimens according to ISO 178 at 2 mm/min using 100 mm span distance.

In all consolidated plates the glass fibre mass fractions were determined by burn-off tests according to ISO 1172. The obtained results are shown in Table 4.

Table 4. Properties of composites

Property		Units	Determined Values	
			Average	Stand. Dev.
Tensile modulus	Experimental	GPa	12.2	2.5
	Theoretical		18.9	-
Flexural modulus	Experimental		6.4	1.2
Fibre mass fraction	Experimental	%	73.3	2.4
Fibre volume fraction	Calculated		59.5	4.2

As can be seen in the above table, the composites processed from the woven fabrics presented stiffness values compatible with major commercial engineering applications. As Table 5 shows the composites processed from the woven fabrics present much better stiffness than other currently used composite materials, such as LFTs andGMTs.

Table 5. Comparison between traditional materials and composites tensile modulii

Material	Density (kg.m^{-3})	Tensile modulus	
		Value (GPa)	Specific value (MN.m/kg)
Composites made from the woven fabrics	1800	12.2	6.8
LFTs composites	1070	3.4	3.2
Mild Steel	7850	210	26.8
Stainless steel	7850	185	23.6
Aluminium (pure)	2700	70	25.9
Aluminium (Alloy)	2810	71	25.3
GMTs (20% fibre weight)	1030	3.4	3.3
Nylon 66 (PA)	1060	2.8	2.6
PEEK	1380	5.1	3.7

The tensile modulus experimentally obtained is only slightly under the theoretical value calculated from the fibre and matrix properties given by the manufacturers (see Table 1) using the rule of mixtures (ROM).

The composites tensile strength was not determined experimentally due to grip slippage.

The low fibre/matrix adhesion obtained in the composites seems to be major cause for the lower values of the flexural modulus obtained and for the interlaminar shear failure mode that was detected in the tested specimens. This reason made also impossible the determination of the composites flexural strength from these tests.
Presently, good results were already obtained in a work carried out to improve the fibre/matrix adhesion by mixing carboxylic-acid-anhydride-modified polypropylene with the standard polypropylene normally used as matrix in the towpreg coating line [7].

3. CONCLUSIONS

The following conclusions can be taken from the present work:

- the results have shown that the cost-efficient manufactured woven fabrics have a good potential for the application in large-scale commercial markets (e.g. automotive).
- furthermore, research must be carried out to evaluate the processability of GF/PP towpregs in an industrial weaving machine. Specially, the following subjects shall be carefully studied: i) the decrease in friction to enable continuous production of weaving fabrics from towpregs in industrial environment; ii) the feeding of warp yarns directly from a creel to avoid warp beam preparation; iii) the decrease of the amount of PP resulting from the direct contact between towpreg yarns and metallic parts of the textile equipment.
- The results obtained from the flexural tests suggest that further work shall be made to improve the fibre/matrix bonding in the composites.

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