PROCESSING OF CONTINUOUS FIBRE REINFORCED THERMOPLASTICS

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Abstract
Towpregs based on different fibres and thermoplastic matrices were processed for highly demanding and more commercial applications by different composite processing technologies. In the technologies used, compression moulding and pultrusion, the final composite processing parameters were studied in order to obtain composites with adequate properties at industrial compatible production rates. The produced towpregs were tested to verify its polymer content and degree of impregnation. The obtained results have shown that the coating line enabled to produce, with efficiency and industrial scale speed rates, thermoplastic matrix towpregs that may be used to manufacture composites for advanced and larger volume commercial markets.

1 Introduction
This work establishes process windows for efficient continuous dry production of thermoplastic matrix fibre reinforced raw materials on a developed coating line equipment [1-3]. Different thermoplastic matrices were used to coat raw materials for highly demanding markets (e.g., carbon fibre reinforced Primospire® towpreg) [4] and for more commercial applications (e.g., glass fibre reinforced polypropylene and polyvinyl chloride towpregs). Also, long fiber-reinforced composites (LFTs) were produced from chopped towpregs [5].

2 Experimental
2.1 Powder coating line
The prototype powder coating equipment used in this work to produce glass and carbon fibre reinforced towpregs is schematically depicted in Figure 1. It consists of six main parts: a wind-off system, a fibres spreader unit, a heating section, a coating section, a consolidation unit and a wind-up section.
In order to produce the desired amounts of pre-impregnated material, the process starts by winding-off fibres from their tows. In the next stage, the fibres pass through a pneumatic spreader and are heated in a convection oven. Immediately after, the heated fibres pass into a vibrating bath of polymer powder and therefore being coated. A gravity system keeps constant the amount of polymer powder. The oven of the consolidation unit allows softening

the polymer powder, promoting its adhesion to the fibre surface. Finally, the thermoplastic matrix towpreg is cooled down and wound-up on the final spool.

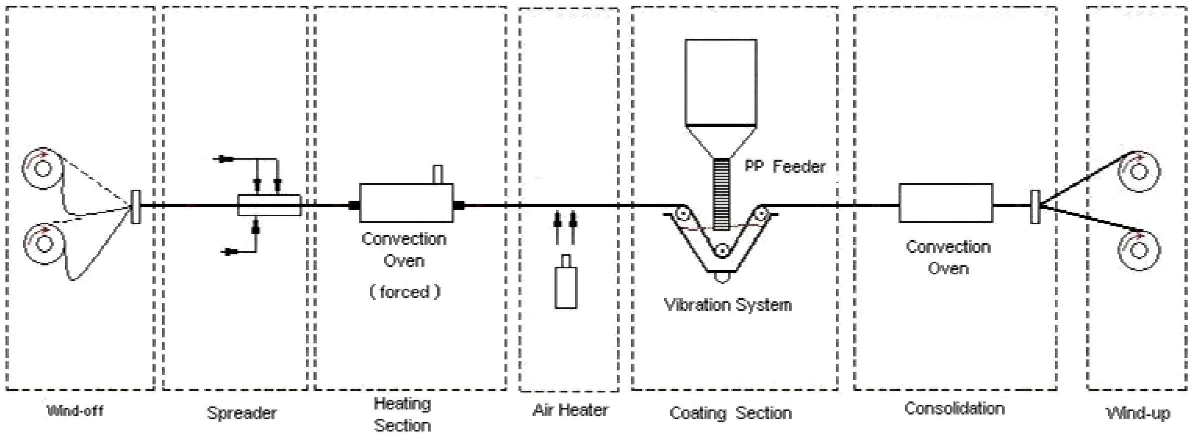

Figure 1. Schematic diagram of the powder-coating line set-up

2.2 Raw Materials

2400 Tex type E glass fibre rovings, from Owens Corning, polypropylene, from ICO Polymers France (Icorene 9184B P), and polyvinyl chloride, supplied by CIRES (PVC - PREVINIL AG 736), powders were used to produce GF/PP and GF/PVC towpregs to be applied in common composite engineering parts. Table 1 summarises the most relevant properties of these materials.

Property	**Units**	**Glass fibres**	**Polypropylene**	**PVC**
Density	Mg/m^3	2.56	0.91	1.4
Tensile strength	MPa	3500	30	55
Tensile modulus	GPa	76	1.3	3.0
Average powder particle size	μm	-	440	150
Linear roving weight	Tex	2400	-	-

Table 1. Properties of raw materials used in towpregs for common applications

To produce towpregs for highly demanding advanced markets a new polymer developed by Solvay Advanced Polymers (PRIMOSPIRE® PR 120) and carbon fibre tows from TORAYCA (760 Tex M30SC) were used. Table 2 presents the most relevant properties determined on these raw materials.

Property	**Units**	**Carbon fibres**	**Primospire®**
Density	Mg/m^3	1.73	1.21
Tensile strength	MPa	2833	104.3
Tensile modulus	GPa	200	8.0
Average powder particle size	μm	-	139.4
Linear roving weight	Tex	760	-

Table 2. Properties of raw materials used in towpregs for advanced applications

It was determined that production rate speeds between 2.0 and 6.0 m/min may be used to produce GF/PP and GF/PVC towpregs with polymer mass contents compatible with the major

common commercial engineering applications. Enough amount of Primospire® was obtained for production speeds until 4 m/min in the case of these advanced market towpregs.
Typical temperatures of 315º C, 400ºC and 620ºC were used in the coating line initial convection oven in the above experiments made with towpregs using the PP, PVC and Primospire® as thermoplastic matrices, respectively.

2.3 Compression moulding consolidation

A technique described elsewhere [6] was used to produce unidirectional fibre reinforced laminate plates with 100×100×4 mm directly from the towpregs. First, the towpreg were wound over a plate with appropriate dimensions and the resultant pre-form then conveniently placed in the cavity of a heated mould. A 400 kN SATIM hot platen press was used to obtain the desired consolidation pressure. After heating the cavity, pressure was applied and, finally, the mould was cooled down to room temperature and the final composite laminate plate removed.

2.4 Flexural Properties of the composite plates

Accordingly to ISO 178 standard, three-point bending tests in fibre direction were made on five $100 \times 15 \times 4$ (mm) specimens obtained from the composites plates processed by compression moulding using an universal INSTRON 4505 testing machine. The tests were performed at 2 mm/min cross head speed using a distance between supports of 80 mm. The fibre mass fraction was also determined according to EN 60.
Table 3 summarizes the experimental results obtained for the different materials used in this work.

Property	Units	GF/PP	GF/PVC	CF/Primospire
Flexural strength	MPa	66.3±9.4	62.2±6.9	124.3±15.0
Flexural modulus	GPa	24.7±2.6	17.6±0.9	30.0±5.0
Fibre mass fraction	%	85.6±1.6	57.7±1.1	59.7±0.3

Table 3. Properties of composite plates made from towpreg

As may be seen, flexural properties compatible with the applications envisaged for the composites processed from the produced towpregs were obtained in this work. Better properties may be certainly obtained through the improvement of fibre/matrix adhesion, polymer powder distribution and fibre alignment.

2.5 Pultrusion

A pultrusion head was purposely designed to adapt a conventional pultrusion line built for thermoset matrix composites to the production of continuous profiles made from thermoplastic matrix towpregs. A model describing the consolidation of the towpregs was used in the design [7]. This pultrusion head, shown in Figure 2, includes three main parts: a pre-heating furnace, a pressurisation and consolidation die and a cooling die.

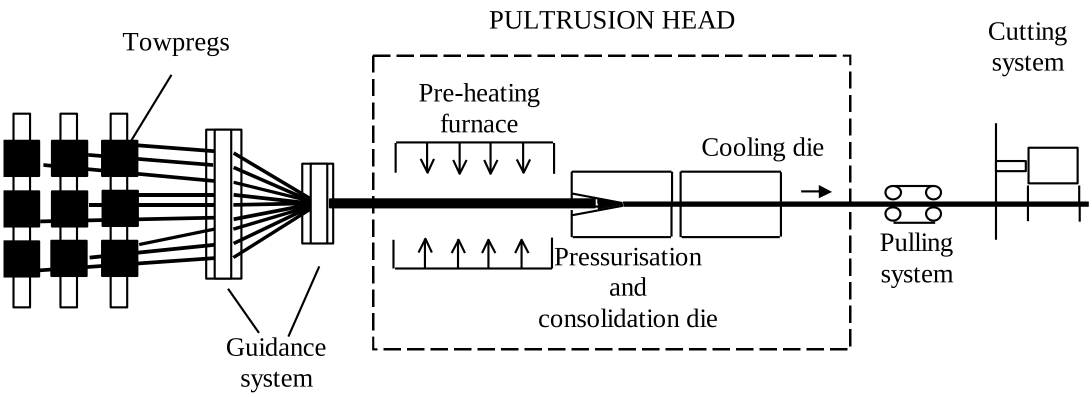

Figure 2. Schematic diagram of the pultrusion line

The towpregs are guided into the pre-heating furnace where the material is heated up to the required temperature. In the entering zone of the pultrusion die, the material is heated up and consolidated, and then cooled down to achieve the desired shape. After reaching the solid state the material is cut into specified lengths. Figure 3 shows an U-shape profile, with a 24 × 4 (mm) cross-section and 2 mm thickness that was produced using this technique.

Figure 3 – U-Shape pultruded profile

The 4.8 kW pre-heating furnace was built with a 70 × 84 × 625 (mm) heating chamber that can be opened to facilitate the passage of the towpreg at the start-up. Two type-K thermocouples and controllers were mounted in the furnace to enable the control of the temperatures in its entry and exit zones.
To produce the abovementioned profile, the pressurisation and consolidation die and the cooling die were designed with an overall length of 400 mm using the methodology proposed by Astrom et al. [8]. Table 4 shows typical operating conditions of the pultrusion line.

Variable	**Units**	**Value**
Pultrusion pull speed	m/min	0.5-0.8
Pre-heating furnace temperature	ºC	400
Pressurisation and consolidation die temperature	ºC	330
Cooling die temperature	ºC	60

Table 4. Typical pultrusion operational conditions

Using these conditions, it was possible to obtain profiles with well-defined forms and smooth surfaces.

2.6 Long chopped fibre-reinforced composites

Long Fibre Thermoplastic (LFT) technology, a recent technique that allows for the production of complex shape composite structures from towpregs in very short production cycles, has also been used in the present work. With this technology a compound is obtained by mixing towpregs, cut with a desired length, at very low shear rates to retain fibre length, in a low-cost equipment. Further details on the equipment, that was developed by the Centre of Lightweight Structures (TUD-TNO, Delft, the Netherlands), can be found in reference 5. After melting and mixing the towpregs, the compound is ejected and immediately compression moulded, in a mould at 80°C and at a pressure of 200 bars, at much higher production rates than in traditional systems. Figure 4 shows some plates manufactures from GF/PP towpregs.

Figure 4. Long chopped fibre reinforced composite plates.

3 Conclusions

Towpregs based on different fibres and thermoplastic matrices were easily produced in a developed coating line to be processed into composites for highly demanding and more commercial applications by different composite technologies. In the technologies used, compression moulding and pultrusion, the final composite processing parameters were studied in order to obtain composites with adequate properties at industrial compatible production rates. The produced towpregs were also tested to verify their quality, polymer content and degree of impregnation.

The obtained results have shown that the coating line enabled to produce, in efficient conditions and industrial scale speed rates, low cost thermoplastic matrix towpregs for being used in the fabrication of composites not only for large volume commercial but also for more stringent advanced markets.

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