Demonstration of the upgrading of long-fibre thermoplastic composites.

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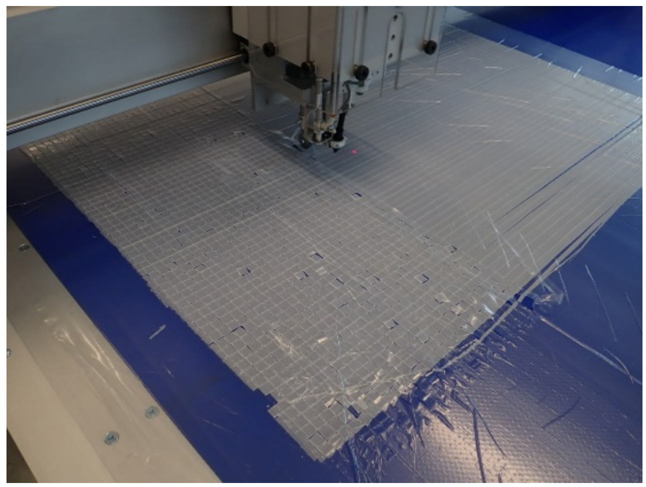
Objectives

The objective of this CDCQ-led project is to evaluate the upgrading of long-fibre thermoplastic composites. Two resins have been evaluated in this project: an acrylic resin (Elium Arkema) and polyamide resin 6 (PA6). Continuous fibre composites were manufactured with these matrices and subsequently revalued by the thermocompression and injection processes.

Manufacture of thermoplastic composite plates



Some thermoplastic composites are sold as thin tape. To evaluate the use of thin rolls or scraps by thermocompression molding, we made a thin plate with a single layer of Texonic TG10 fiberglass. The plate was produced by vacuum infusion with Arkema's Elium 190 acrylic resin. The plate was then cut into small 10 mm by 10 mm tiles on an automated cutting machine (Eastman Eagle S125). To test the recovery of parts or production losses, two series of thick plates were manufactured. The first series was produced by room temperature infusion with Texonic TG33 reinforcements and Elium 188O resin. The second series of plates was moulded using RTM by in situ polymerization at CDCQ with BASF PA6 and Texonic woven Johns Manville glass fibres.

Universal Test Compression Machine Moulding: Combining Manufacturing and Characterization

Compression moulding in composites is a set of closed mould processes using heated metal moulds. The moulding is carried out by inserting the material according to the desired quantities and then submitting it to a high pressure and temperature. Thermoplastic tiles melt and the pressure allows the material to flow into the mould. The mould is then cooled below the glass transition temperature of the resin to allow the part to be demoulded. The advantage of using a universal traction machine is that the conditions of the tests can be recorded and changed easily, so that the gap (opening of the mould), the temperature, the closing force applied throughout the moulding cycle can be known. These data make it possible to understand the behaviour of materials and to anticipate operating conditions in an industrial production context. Figure 2 shows the records obtained by the traction machine for the force applied and the displacement of the machine (closure of the mould).

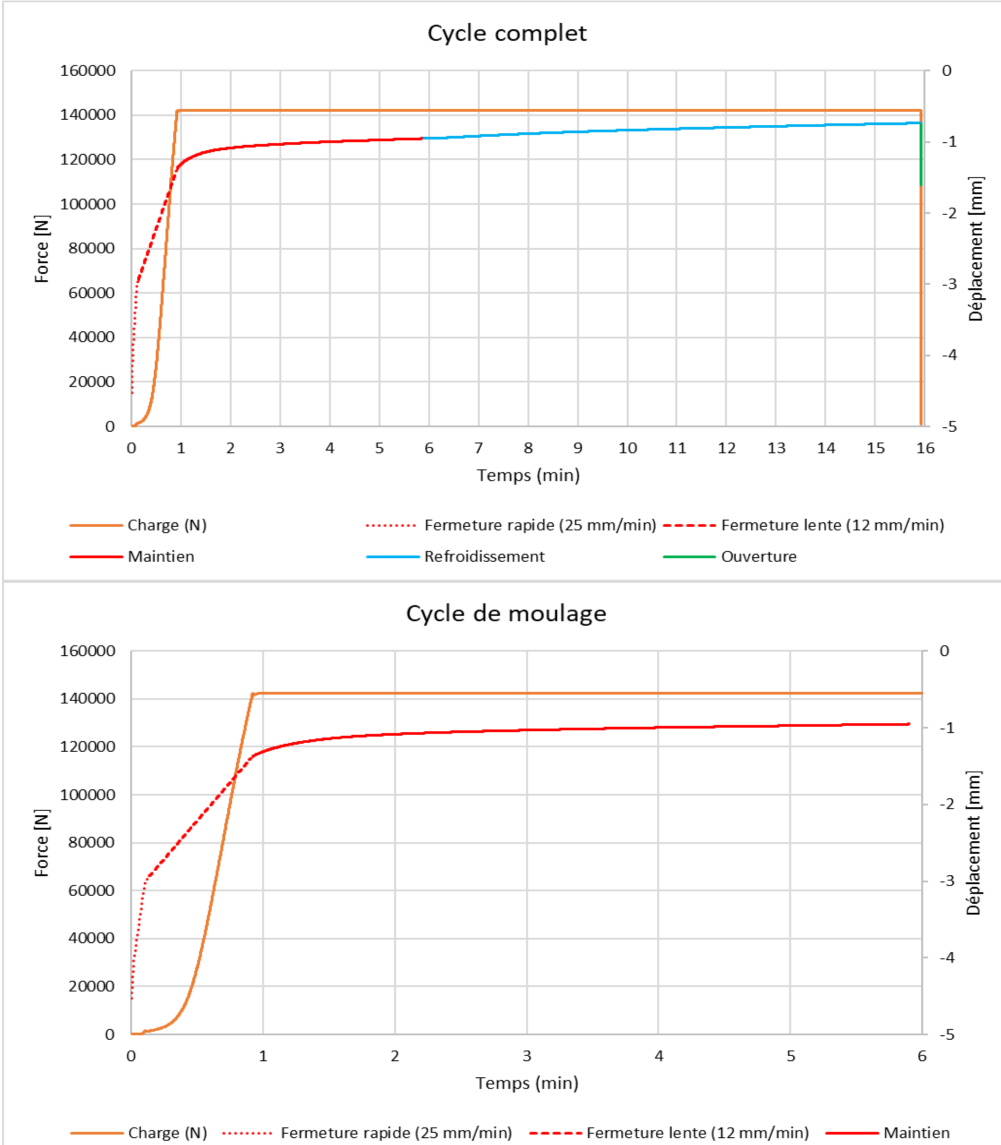


Figure 2 – Acrylic Tile Force and Displacement Data on Test Machine. 205°C Temperature

The cycle can be divided into 4 steps:

1. Closure of the mould, preheated to 205 C, by a fast approach (~6 seconds, dotted red curve).
2. Slow progressive closure to a maximum compressive force of 140kN (for pressure on 2000PSI material) (~1 minute, dashed red curve).
3. Pressure is maintained to melt the resin and allow the material to flow for 5 minutes, (solid red curve).
4. Pressure is maintained and the mould cooling cycle begins with 10-minute cooling air channels (blue curve)

This manufacturing cycle makes it possible to completely melt the composite tiles (TG10) and to fluidize the resin to allow the filling of ribs in the mould with the fibers and the resin (figure 3).

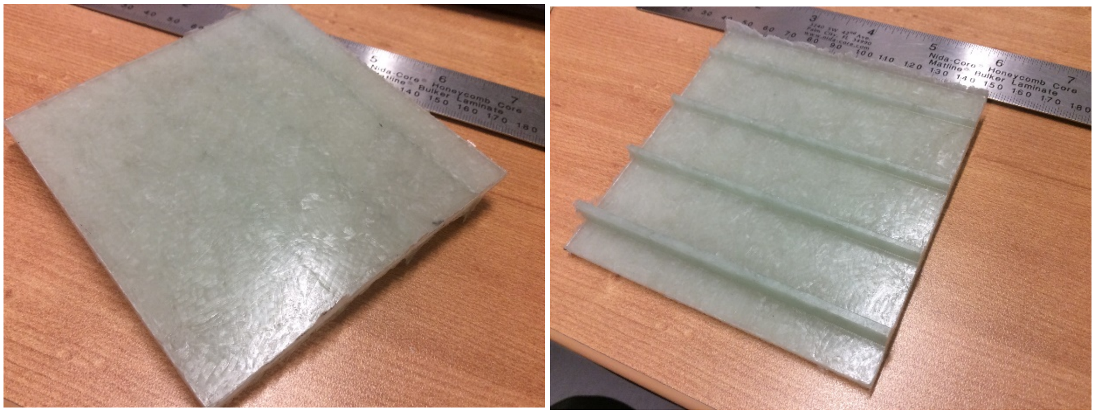


Figure 3 - Cast Plate with Universal Traction Machine

A similar cycle was used to cast a large plate on a hydraulic press (100-ton Carver with heating plates). The produced plate was used to perform tensile characterization tests according to ASTM D3039 (Figure 4).

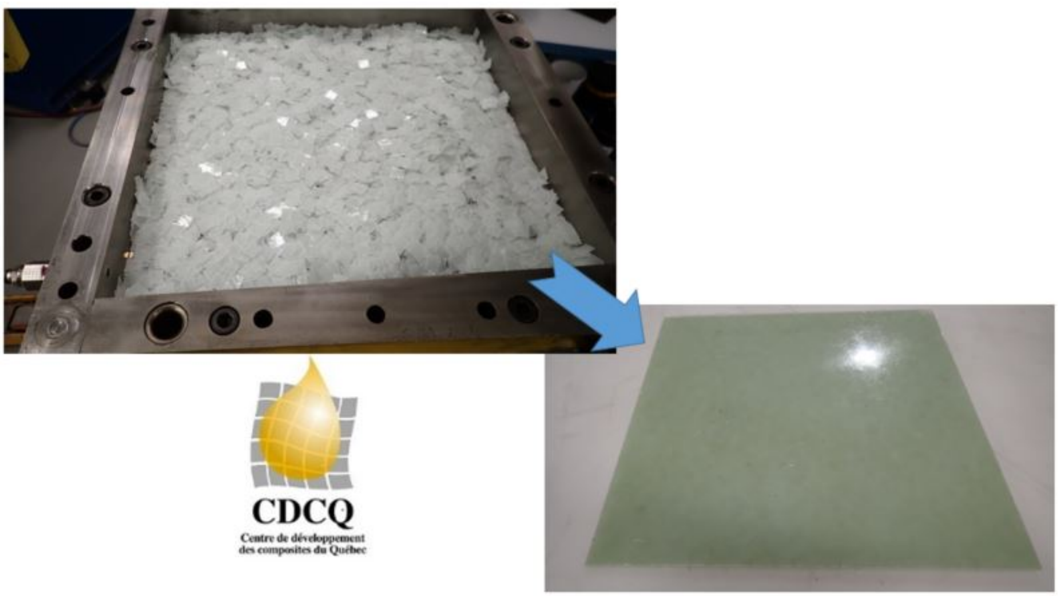


Figure 4 – TG 10 Tile Press Molding

Injection testing

The tests for the reclamation of moulded plates were carried out by the CCTT specialized in thermoplastics Coalia at Thetford Mines. The plates were granulated with a Cumberland granulator with a 3/16 inch grid. To reduce the rate of reinforcement and facilitate injection, the granules were mixed with virgin plastic pellets at a rate of 1:1. Thus, the mass reinforcement rate has been reduced from 60% to about 30%. PA6 being more ductile the aggregate produced by grinding is finer than that of the acrylic resin which being more fragile, bursts into larger pieces.

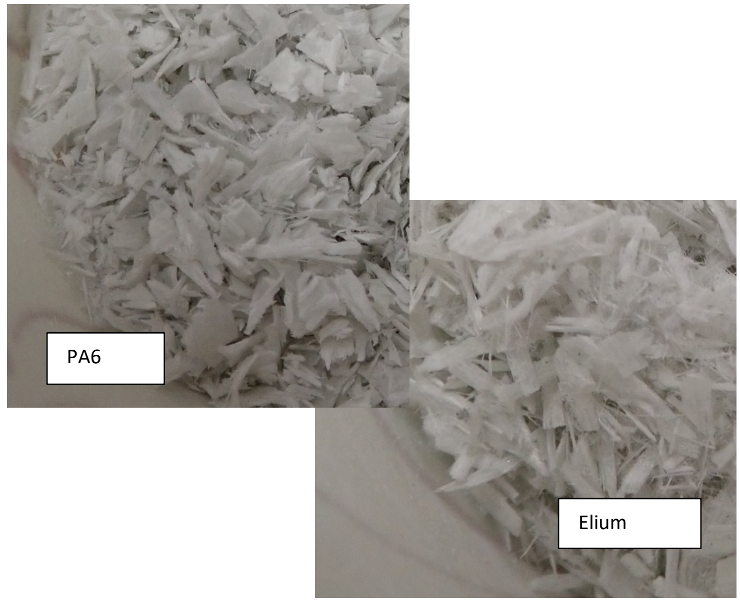


Figure 5 – Recycled Pellets

The virgin resin and recycled granules mixture was injected onto a 66-ton ARBURG press into a traction coupons mould according to ASTM D638.

Low fiber length for PA6 allows for a better surface finish on injected coupons

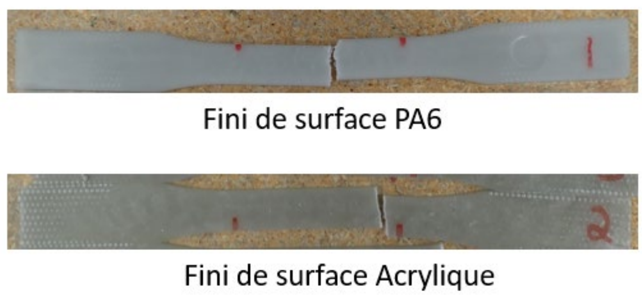


Figure 6 - Surface Finish

Pyrolysis tests were carried out on the stress coupons to assess the length of the fibres obtained after grinding and injection. Glass fibers in a PA6 matrix (BASF) have a length of about 1 mm, while those in acrylic resin (Elium 1880) have a length of 5 to 10mm.

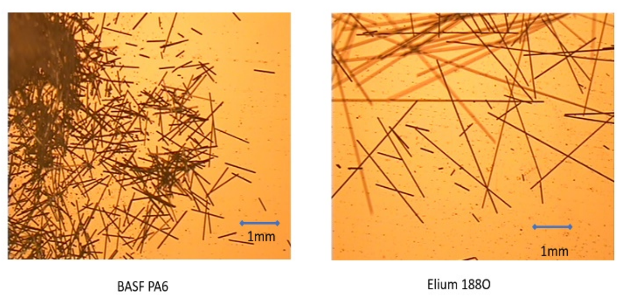


Figure 7 - Length of glass fibres in recycling

Pellet compression moulding tests without the addition of virgin resin.

The compression moulding of Elium composite granules was successfully completed without the addition of virgin resin (Figure 8). The pressure of 2000 psi is required to fill the mould, and there is some leakage of material in the space between the mould punch and the cavity.

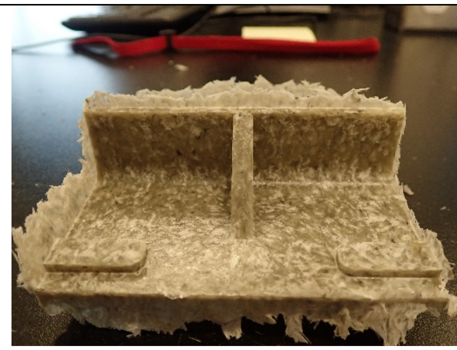


Figure 8 - Acrylic resin granules

However, the PA6 is not fluid enough and we have not been able to fill the ribs. It is also noted that the increase in the temperature of the mould did not sufficiently fluidize the load before observing the thermal degradation of the die (Figure 9, brown corners of the part).

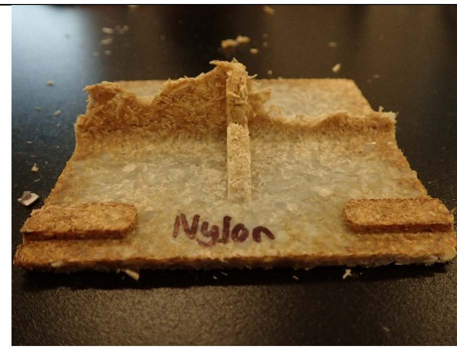


Figure 9 - PA6 resin granules

We tried to cast a simple shape (plate) with PA6 granules, this worked well, and we got a nice piece without overheated areas, figure 10.

Figure 10 - Recycled PA6 Plate Mold

Mechanical properties

The coupons were tested on an Instron 5985 universal traction machine at the CDCQ and compared to the original molded plates.

In the case of both resins, a reduction in the properties due to the reduction in the length of the fibres and the change in the proportions of the fibres aligned with the loading axis is noted during the stress tests. Initially, on woven reinforcements, 50% of the fibres are aligned with the direction of the test, while during the reshaping, the fibres are oriented randomly when moulded in the form of a plate (The evenly distributed material in the mould is shown in Figure 4). For the injection we also have a random dispersion, although a preferential reorientation of the fibres is generated during the injection of the specimens, the direction being according to the main axis.

Table 1 - Characterization Tests

	PA6/FV before	PA6/FV ground and then injected	Acrylique/ FV before	Acrylic/FV ground and then injected	Acrylic/FV remoulded by compression
ASTM Standard	D3039	D638	D3039	D638	D3039
Mass rate of reinforcement	60%	30%	65%	33%	65%
Volume rate of reinforcement	39%	15%	44%	17%	44%
Module (GPa)	**21.5**	**7.9**	**27.0**	**9.6**	**16.0**
Réduction	-	63%	-	65%	41%
Contrainte ultime (MPa)	**382**	**151**	**589**	**112**	**79**
Reduction	-	61%	-	81%	87%
% of deformation	**5.7**	**3.9**	**6.0**	**1.4**	**1.1**
Reduction	-	32%	-	77%	82%
Theoretical module (Vf Fct and Orientation) (GPa)		**5.1**		**6.2**	**18.0**

The remoulded plate: The volume reinforcement rate remains the same and the loss of module is only due to the orientation of the reinforcements; we initially had 50% of the fibers aligned with the test and following the reshaping we have 30% of the fibers that are aligned, which is confirmed by the tests (reduction of the module of 41%).

The ultimate stress is intimately related to the ability of the fibres to transfer loads. Initially, the fibers are continuous throughout the sample, which allows the transfer of the load through the entire composite. In the case of short fibres, the matrix must transfer the loads. The length and the fiber-matrix adhesion play a vital role. The ultimate stress reduction is in the order of 80% for acrylic and 60% for PA6. The sharp reduction in properties for acrylic deserves further analysis and testing to explain the cause.

The mechanical properties obtained in injection are comparable to the commercial materials available.

Conclusion

Tests to revalorize parts of thermoplastic composites show that it is possible to mould by compression without the addition of virgin resin. Additional work is required to find suitable moulding parameters for PA6 resin that would allow the resin to be fluidized sufficiently without degrading it to produce ribbed parts.

The tests also demonstrated that granulated composites can be used by injection moulding when mixed with virgin resins. The mechanical properties then obtained are comparable to those of commercial materials currently available at the same glass fibre ratio.

A universal traction machine can be used to manufacture thermoplastic composites and to acquire process data useful for the establishment of press production cycles.

Acknowlegments

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