Flax/Acrordur® sandwich panel: an innovative eco-material for automotive applications

Currently, the automotive industry is greatly marked by the growing use of natural fibres. In particular, flax fibres are widely used as an eco-friendly reinforcement in various applications, combining higher specific properties than glass fibres with interesting cost and weight reductions [1] [2] [3]. In this context and according to new European environmental regulations, OEMs are looking for new alternatives in order to decrease the fuel consumption of vehicles.

To fulfil customer requirements, a new composite material named Flaxpreg (Figure 1) was developed by a consortium composed of Faurecia, PSA, LINEO NV and the University of Reims Champagne-Ardenne. This new bio-based sandwich material shows an extremely low weight (2kg/m²) and high mechanical properties. Its skins are made of three layers of an innovative flax fibre reinforcement impregnated with Acrordur® acrylic thermoset resin, stacked in a privileged direction according to the applied stress fields. Due to the use of flax fibres, this sandwich material has an excellent stiffness/weight ratio and a lower environmental impact. Acrordur® is a thermoset resin from the BASF Company essentially developed for natural fibres, which is widely used in the industry due to its excellent processability and good crosslinking properties, as well as its good thermo-mechanical properties when cured. A cardboard honeycomb is incorporated between the skins to provide a very good bending stiffness and high strength in the overall panel. This paper aims to determine the processing parameters of the sandwich skins in order to optimize the quality and properties of the final products. The mechanical characteristics of the flax laminates are governed by the properties of both the fibres and the resin matrix. In this paper, only the specific tensile properties of flax tape specimens and the Young’s modulus of derived flax/Acrordur® biocomposite are investigated, polyester acrylic resins being largely used and well-known in the industry. To this end, an automotive part prototype was prepared and subjected to flexural tests according to the customer’s specifications. Its mechanical behaviour was then modelled with the ABAQUS finite element analysis software.

Raw materials
Flax tape: a green reinforcement
The new bio-based flax/Acrordur® prepreg uses innovative, patented flax tapes [4] (Figure 2) composed of weight-controlled technical flax fibres arranged unidirectionally without any weft spinning (as observed in Figure 1). To maintain parallel cohesion of the fibres, a new process based on re-
activating the pectic cement by spraying a water mist over the surface of the fibre bundles is used. At first, flax is scutched: the bundles forming the flax stems are decorticated and separated, then the remaining shives and woody core of the stem are removed. Secondly, the scutched flax is hackled to obtain long technical flax fibres. These fibres are collected without any particular selection and transported to the flax tape processing line where the bundles are stretched, maintained in a unidirectional direction and sprayed with a water mist. This guarantees the cohesion of the flax tapes by binding all the fibres. Then, the sprayed flax tapes are dried in-line by an infrared oven. Finally, the reinforcements are air-cooled and ready for impregnation and packaging. As shown in Figure 2, the semi-finished products are completely free of twisting, crimping or weft spinning. Flax tape weights per unit area ranging from 50g/m² to 200g/m² are available.

**BASF Acrodur® resin**
A commercial polyester acrylic resin was chosen as a relevant material for a real industrial automotive process.

This resin offers good mechanical properties, a short crosslinking time, easy handling and cleaning, combined with a good “open” time. It is produced by dispersing a modified polycarboxylic acid and a polyol (cross-linking agent) to create a thermoset material (Figure 3). This formaldehyde-free binder is suitable for wood and vegetable fibres such as flax, sisal or jute. The original water content is 50% but the resin can be diluted for easier impregnation. Crosslinking at 160-180°C takes less than two minutes.

**Dry flax tape characterization**
The properties of the flax tape reinforcement are influenced by several processing factors such as the presence of tangle areas due to the flax fibre length and content, organization and distribution over the tape width. Moreover, it has been shown in literature that the characteristics of flax fibres also depend on their variable morphology, biochemical composition and biodegradability, and on the presence and location of defects in the stem [4] [5] [6]. In addition, their mechanical properties are affected by the damage sustained during processing and thus have considerable scatter [7]. Therefore, a simple and efficient method is needed to evaluate the specific modulus of flax tape. Conventional test methods are no longer relevant for the mechanical characterization of flax tape due to its structure and section discontinuity. To circumvent this issue, a new characterization protocol was established, mainly based on a statistical study, by analyzing the specific modulus (E/ρ) for each weight per unit area. In order to define the best test sample size for good repeatability of this modulus, different sample widths and lengths were investigated (Figure 4). The specific modulus value (E/ρ) is related to the flax tape density, which reflects not only the physical characteristics but also the quality of the tape. Quality is conditioned by several factors (fibre dispersion, fibre and...
Unidirectional Flax/Acrodur® composites

Preparation and characterization of composite samples

Unidirectional (UD) prepregs were prepared using the compression moulding process (3 min, 200 bars, 190°C), with two impregnation techniques such as spraying (expected for industrial production) and roll coating (used for prototyping) (Figure 6). Four parameters were investigated: impregnation over one or both sides, variation of resin concentration, resin weight in the prepreg and drying cycle. A wetting agent is commonly applied on the flax tape to modify its surface tension and enhance its impregnability before adding the resin. The moisture content of the prepregs plays a key role. Due to the high curing temperature, vapour is released and may create blisters and voids in the final composite. An optimal fibre/resin ratio and process (wedge) were identified to avoid blisters and thus control the quality of the laminates in terms of density, visual aspect and mechanical properties (Figure 7). Tensile tests were carried out on laminate samples following the ISO 527 standard.

The experimental setup used an Instron 33R 4204 testing machine equipped with a 50kN load cell and coupled to a stereovision apparatus for the experimental kinematics full-field measurements (Figure 8).

The results show that the tensile modulus increases proportionally with the density (Figure 9 (b)). For optimal densities close to 0.9 ± 0.04g/cm³, the tensile modulus values reach 18 ±1GPa (calculated on the slope over 0.2% of strain). The density cannot be increased beyond 0.9g/cm³ because the over-compacting leads to delamination and blistering. This could be related to the water contained in flax fibres and released during the Acrodur® crosslinking reaction. Manual impregnation of the flax tape using the roll coating method results in high prepreg quality in terms of matrix distribution over the reinforcement. Microscopic observations show that the Acrodur® resin fills the
The DMA results are illustrated in Figure 11. At lower temperatures (-40°C to 25°C), the mechanical properties of the composite were not affected. The increase in temperature enhanced the storage modulus of the composite by evaporation of the contained moisture. The glass transition temperature (close to 75°C) can be obtained from both the loss modulus and tanδ curves. It is associated to the crosslinking density of the composite. The higher storage modulus above Tg reflects the higher performance level of the composite at high temperature. Tanδ also shows the damping capacity of this green composite – a sensible change in the damping factor is observed when the temperature increases. This factor is close to 1.9% and 2.6% respectively at 25°C and 80°C, which is excellent (as compared to 0.10-0.15% for common glass/epoxy or carbon/epoxy composites).

**Flexural test on a prototype automotive part**

Considering the optimal process parameters, a Flaxpreg sandwich panel was prepared in a one-shot process.
and used to produce a real automotive trunk load floor (Figure 11). According to the customer’s specifications, this luggage board was subjected to flexural and creeping tests. The results show that the Flaxpreg biomaterial can withstand 100kg for 4 hours at ambient temperature, and 2 hours at high temperature, thanks to the high thermal stability of Acrodur and the good specific mechanical properties of the almost continuous flax fibres. At high temperature, the measured deflection is close to 13.5 mm, a value in accordance with the specifications.

**Flaxpreg behaviour modelling**

To simulate the flexural behaviour of automotive parts, a finite element analysis of the Flaxpreg sandwich panel was conducted using the ABAQUS software. The difficulty was the high computation time due to the complex 3D geometry of honeycomb cardboard. Therefore, an analytical model was developed to replace the spacer structure by a homogenous solid part with equivalent mechanical behaviour (Figure 13). To check its efficiency in terms of behaviour and deflection, two simulations were conducted and compared to the real flexural test:

- Simulation test with a fully discretized honeycomb spacer: the skins and the 3D spacer parts were generated using shell elements according to the laminates’ stacking sequence 

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Table 2: Deflections obtained with simulations and experimental tests

- Simulation test with a homogenized honeycomb spacer: in this case, the composite laminate parts were represented by shell elements too but the honeycomb spacer was replaced by a homogenous deformable solid whose properties were calculated by the developed analytical method.

The resulting deflections are summarized in Table 2 below, which shows that the homogenous model developed gives accurate results compared to both numerical and experimental results. According to the specifications, the model can be used to simulate several mechanical tests such as compression and flexural tests using a simplified structure with little CPU time. Figure 14 presents the iso-values of vertical displacement recorded during the simulation of the flexural tests.

**Conclusions**

The Flaxpreg project follows the triple objective of drastically reducing weight, using renewable resources and being able to process the resulting composite with cycle times and material costs meeting the constraints of automotive mass production. These first results show that the flax tape reinforced Acrodur® biocomposite has the potential to be integrated in automotive applications thanks to its high stiffness/weight ratio and its environmental advantages. The characterization tests provide good thermo-mechanical properties that remain almost unchanged over a wide
temperature range. Furthermore, Flaxpreg presents a low density which offers a good trade-off for semi-structural automotive applications. The use of a thermoset resin blended with long flax fibres (dm) confirms that a potential weight reduction of 35% to 50% can be achieved at the same level of performance compared to the Baypreg technology.

More information: www.