SOLUTION IMPREGNATION OF NATURAL FIBRES/ABS MATRIX COMPOSITES

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ABSTRACT
The aim to improve recyclability properties, exploit renewable sources, and decrease the cost of materials leads the composite community to investigate the properties of natural fibre/thermoplastic matrix composite materials. Two different types of composite materials have been produced impregnating filaments of two natural reinforcements (broom and hemp fibres) with a thermoplastic ABS matrix. Consolidation of the laminates has been achieved by hot press moulding at two different moulding temperatures. Quasi-static tensile and bending tests have been carried out on specimens of all the materials produced. The results show that a maximum increase of mechanical properties with respect to the pure matrix is obtained for the composite with hemp fibres, whose mechanical properties were twice as high as the those of the unreinforced ABS. However, a poor fibre-matrix adhesion and the uneven fibre distribution throughout the matrix remained critical issues for these composites. As a result, extensive fibre pull-out was found at the fracture surface of all the coupons tested.

Keywords: Broom, hemp, ABS resin, mechanical properties, manufacturing process

1. INTRODUCTION

In recent years, ecological awareness has considerably grown in the human society, raising the need for environmentally friendly materials and industrial processes. From the process point of view, the concept of "sustainable growth" is gradually leading to the development of industrial fabrication methods with low environmental impact and minimised waste [1]. From the material point of view, renewable sources have been selected for the development of fully recyclable plastics and composites of engineering interest [2-3]. Polymer matrix composites (PMC) such as carbon or glass fibre reinforced plastic are widely used as structural materials for their good mechanical properties. But these materials are difficult to be recycled because thermosetting matrices are generally used. Even for FRTP (using thermoplastics matrix) material recycling is not practicable today because of its high cost. Recently, wide attention has been gained by natural fibre-reinforced thermoplastic matrix composites, that combine good mechanical properties, low environmental impact and renewable sources.

Several studies have been conducted to evaluate the structure and the properties of the composites reinforced with natural fibres [4-5]. A limitation of using natural fibres for polymer reinforcement is the weak interfacial adhesion between the polar and hydrophilic natural fibre molecules on the one side and non-polar and hydrophobic plastics on the other[6]. Fibre-matrix adhesion, in these cases, often needs to be increased by means of fibre surface treatments [7]. In addition, high temperatures can also cause unwanted degradation of the fibre surface or even destroy the fibres [8]. Therefore, for thermoplastic matrices (most of which need to be processes at temperatures around 200°C or higher), uneven fibre dispersion and poor fibre wetting due to limited thermal stability during processing and inadequate compounding, which depend on the viscosity of the molten plastics, generate natural composites with poor mechanical properties [9]. Because of a low value of the processing temperature required, only the polypropylene could be used as a matrix for vegetable fibre composites [10], but also in this case the low fibre wettability and the high matrix viscosity do

not permit a proper impregnation of the fibres. An alternative method to reach a homogenous fibre impregnation provide the use of a suspension of matrix in a solvent, as reported by Lacroix *et al.* [11].
In this work a similar process to the one described in [11] was used with the aim to produce natural fibre composites using an ABS matrix and two different kinds of reinforcement, broom and hemp filaments. The processing route includes an impregnation step in a saturated ABS solution of acetone followed by drying at room temperature and hot press moulding. Tensile and flexural tests have been carried out to measure the mechanical properties of the unreinforced ABS matrix and of the different composites produced.

2. EXPERIMENTAL METHODS

The laminates have been manufactured using ABS matrix and natural broom and hemp fibres. The broom filaments were 50 to 100mm long, while all the hemp filaments were longer than 200mm.

(a) (b)

Figure 1. (a) Broom fibres; (b) hemp fibres.

Resin impregnation of the reinforcement has been carried out by dissolving the matrix in acetone. The solution had a resin-to-acetone ratio of one-to-two by weight. Plies of composite material have been produced by dipping the fibres in the solution and waiting for the evaporation of the solvent to be completed after 12 hours. The plies with hemp filaments have been realised with fibres oriented in one direction, while for the plies with broom filaments, fibre orientation was random. After the evaporation of the acetone the plies possessed a high porosity. The laminates have been obtained by consolidating several plies by hot-press moulding. The moulding operation lasted 30 minutes and two values of temperature of the plates have been employed in separate processes: 120 and 150°C. For moulding carried out at 150°C, shims of pre-set thickness have been inserted between the press plates. This was done to achieve a correct definition of the laminate thickness in conditions of very low viscosity of the resin. In fact, the liquid resin would flow away from the laminate almost completely when subjected to the moulding pressure at this temperature. Instead, for moulding carried out at 120°C, it has been possible to work by directly applying the pressure to the plies. At the end of each process, laminates with different thicknesses have been obtained. As a result, different materials have been manufactured, with different fibre volume fractions. In particular, every laminate contained 12g of natural filaments. At the end of the consolidation process, that involved some elimination of excess matrix, the laminates have been weighed to calculate to the real percentage of content of reinforcement. Table I lists the process parameters and the characteristics of the realised laminates.

Table I. Process parameters and characteristics for the different laminates.

Laminate	Reinforcement type	Volume content (%)	Moulding temperature (°C)	Moulding pressure (MPa)
A	Unidirectional Hemp	20	150	N/A (shims)
B	Unidirectional Hemp	30	150	N/A (shims)
C	Unidirectional Hemp	40	150	N/A (shims)
D	Unidirectional Hemp	45	120	0.7
E	Random Broom	20	150	N/A (shims)
F	Random Broom	30	150	N/A (shims)
G	Random Broom	25	120	0.7
H	Random Broom	35	120	1

3. RESULTS AND DISCUSSION

From the laminates produced with the method described above, test specimens have been cut for tensile and bending tests performed according to the ASTM D3039 and D790M standards. Tensile tests were performed at a preliminary stage on individual hemp and broom filaments. The cross-sectional area of the single filaments has been calculated measuring the length and the weight of the fibre and assuming a density of $1.4gcm^{-3}$. Several test specimens have been made for each type of fibre, using a 100mm gauge length and adhesive paper end-tabs. A cross-head speed of 1mm/min was adopted for the tensile tests. The average values of the measured mechanical properties are listed in Table II.

Table II. Tensile properties of broom and hemp filaments.

Natural fibre	**E (GPa)**	**UTS (MPa)**
Hemp	50	620
Broom	20	270

Figures 2 and 3 show the average values of tensile and flexural strength and elastic moduli measured for pure ABS matrix specimens and specimens of the hemp filament composite laminates. A clear mechanical property increase is present, even for reinforcement contents as low as 20% by weight. With regard to the laminates obtained by hot-press moulding at 150°C, the mechanical properties increase as the fibre content increases. For the highest fibre contents, the composite material shows twice as high mechanical properties as the pure matrix.

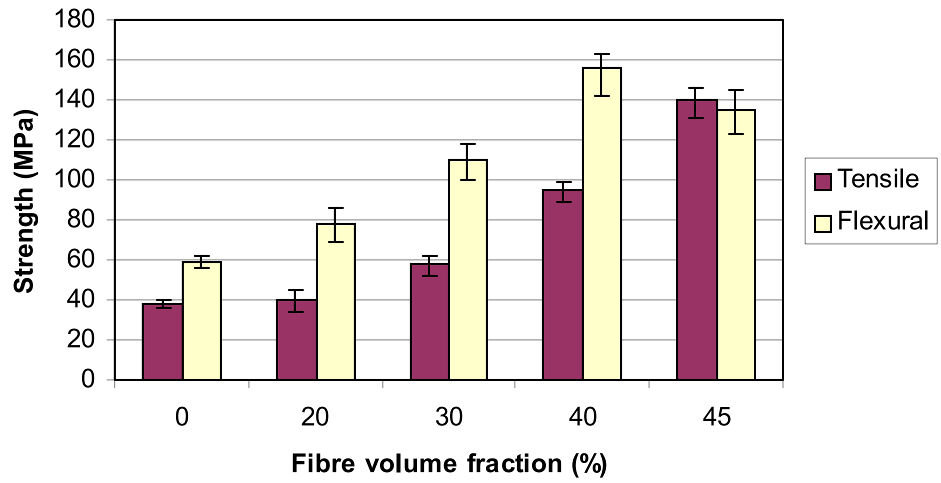

Figure 2. Tensile and flexural strength of hemp reinforced ABS specimens.

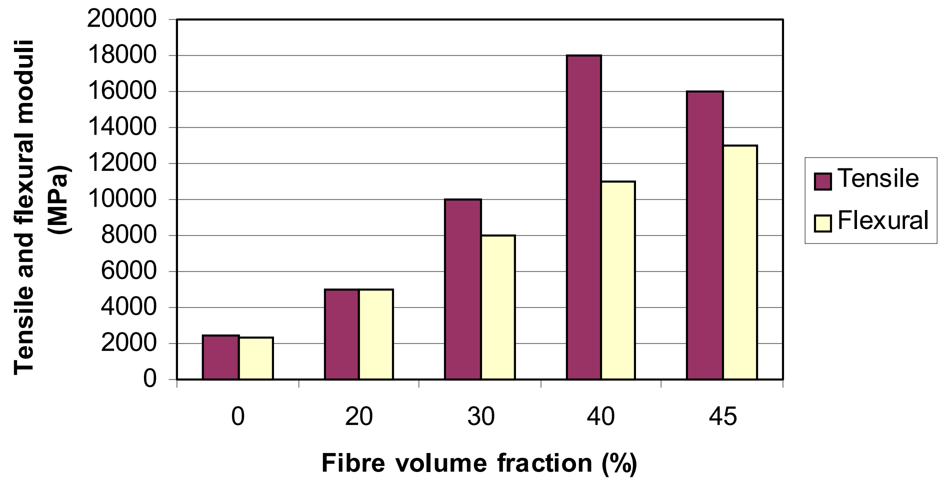

Figure 3. Tensile and flexural moduli of hemp reinforced ABS.

Hot-press moulding at 120°C yielded higher fibre volume fraction laminates with respect to moulding at 150°C. This resulted in higher tensile properties of these laminates, whilst the bending performance resulted to be rather low. The latter is explained by considering that the low processing temperature hindered the establishment of a proper adhesion between different plies of the laminate. The resulting delaminations under bending produced low values of the flexural properties measured for the material. Figure 4 shows tensile stress-strain curves for the hemp fibre composites. A difference between the composites and the pure matrix can be noticed. The matrix has the highest elongation to break, but the lowest strength.

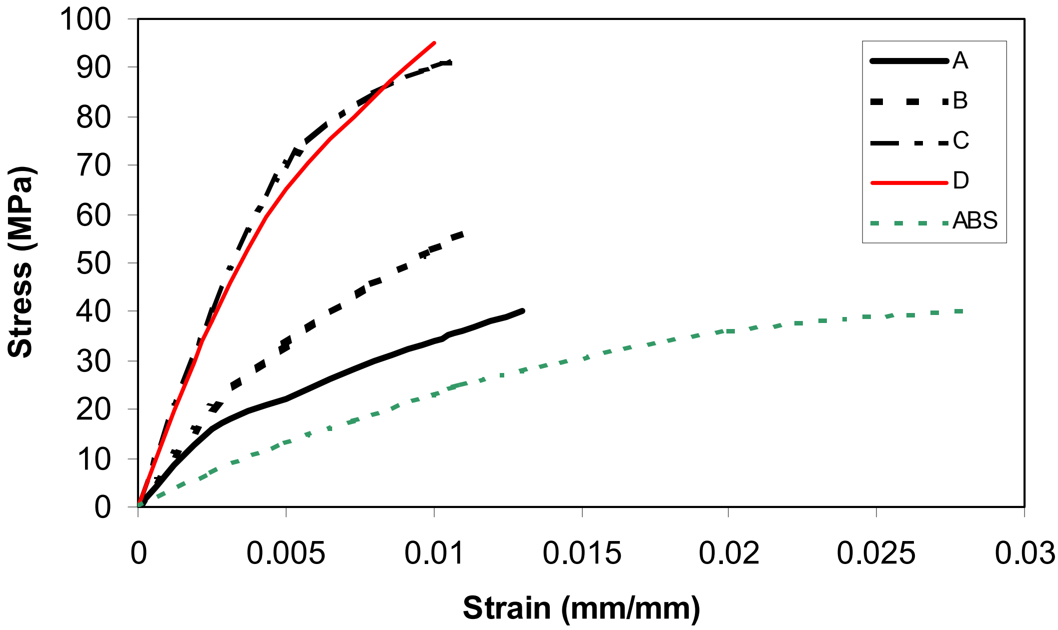

Figure 4. Experimental stress-strain curves of tensile test for ABS and unidirectional hemp reinforced ABS.

Figures 5 and 6 show the values of mechanical properties for the random oriented broom fibre reinforced ABS. The values refer to both tensile and three-point bending tests. The tensile strength of the polymer is not improved by the presence of the reinforcing filaments. Indeed, for these laminates, by increasing the reinforcement content, the probability of having filaments transversely oriented to the applied load direction is increased. As a result, the tensile response is degraded accordingly. On the other hand, though, the flexural performance of the pure matrix is enhanced with the vegetable reinforcement. In general, laminates manufactured by press moulding at 150°C show better properties than laminates moulded at 120°C. The tensile stress-strain plots, reported in Figure 7, show a higher elongation-to-break for the pure matrix, which also has the smallest Young's modulus.

Figure 8 shows a image of the fracture region of a tensile (A) and a bending (B) specimen of hemp fibres reinforced ABS after testing. It is possible to notice the large fibre-matrix debonding occurred in the material at failure. Moreover, the filaments appear to be not perfectly aligned, which suggest the occurrence of some unwanted resin flow during the moulding process.

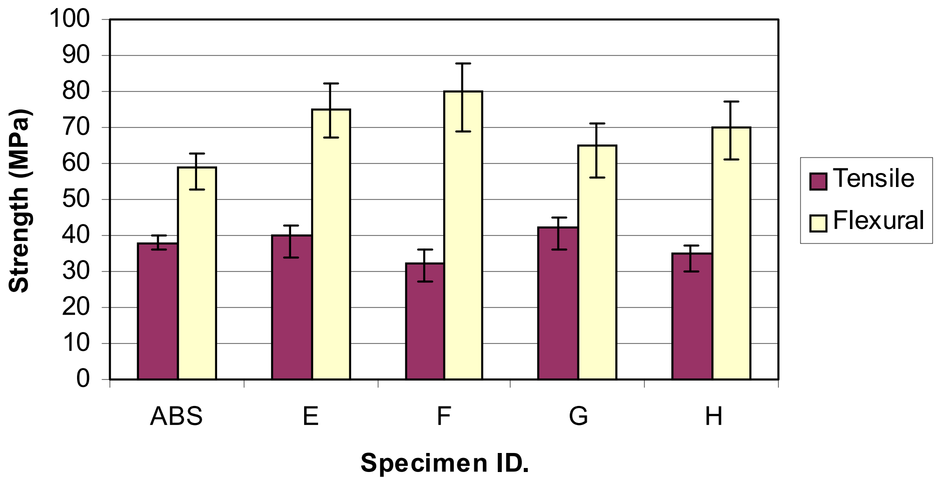

Figure 5. Tensile and flexural strength of broom reinforced ABS specimens.

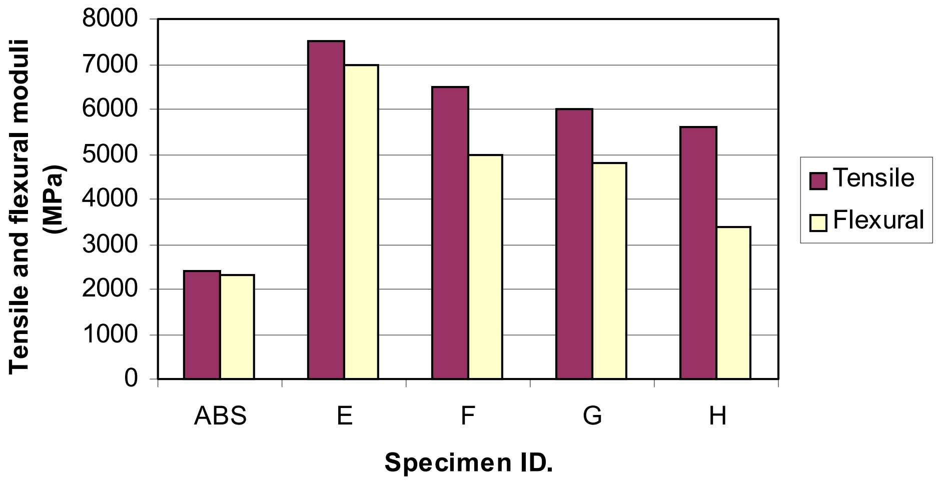

Figure 6. Tensile and flexural moduli of broom reinforced ABS specimens.

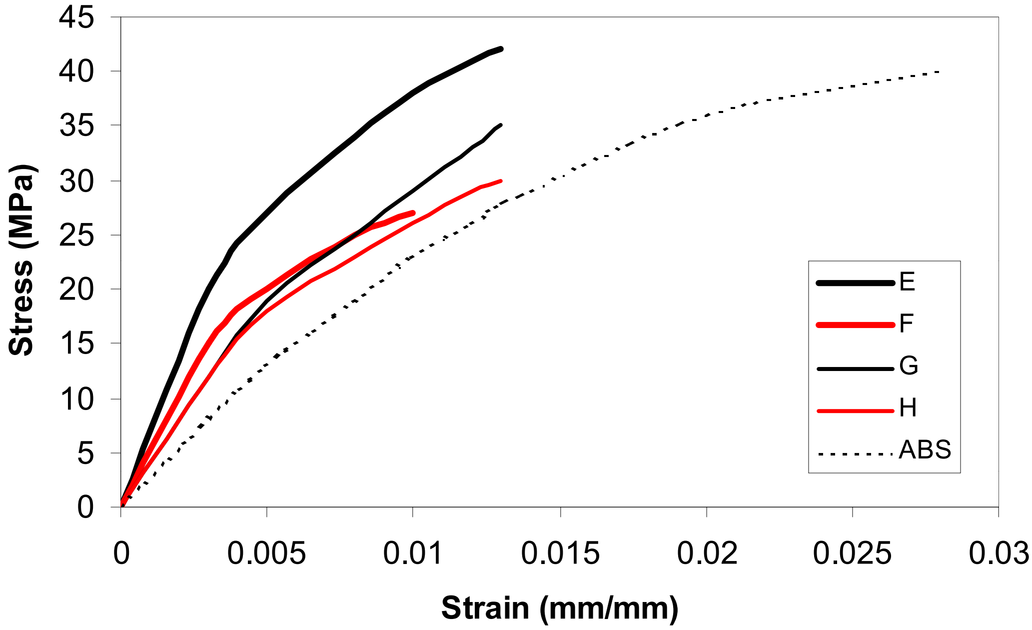

Figure 7. Experimental stress-strain curves of tensile test for ABS and random broom fibres reinforcing ABS.

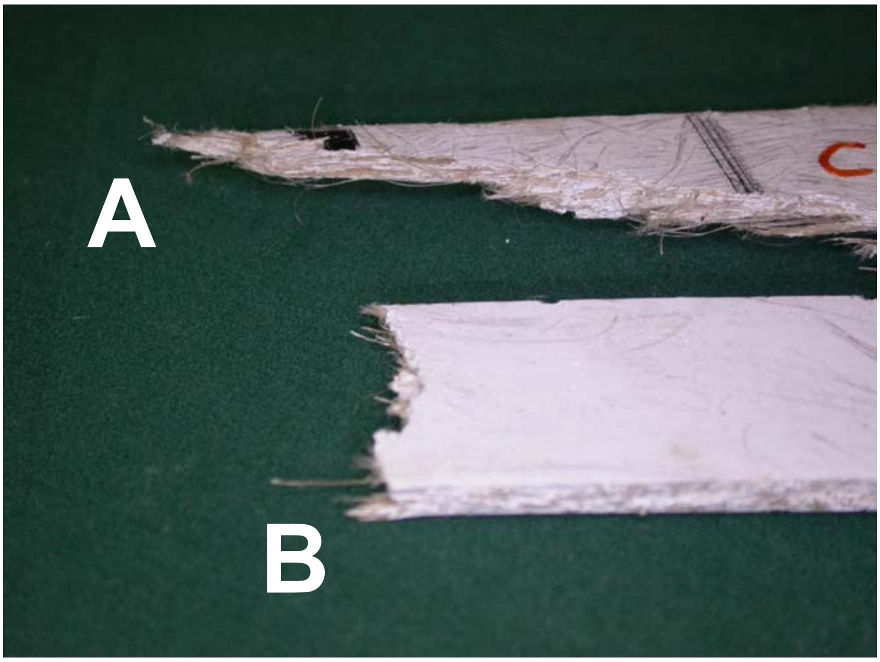

Figure 8. Image showing the fracture zone of hemp/ABS tensile (A) and bending (B) specimens.

4. CONCLUSIONS

The impregnation of natural fibres with an acetone solution of ABS resin leads to the realisation of plies from which it is possible to easily produce laminates through hot-press moulding. Processing temperatures of 120°C and 150°C have been experimented for the press moulding process. Laminates have been realised with unidirectionally oriented hemp fibres and randomly oriented broom fibres. For the laminates with hemp fibres the fibre volume percentage resulted to be equal to: 20-30-40-45%, while for the laminates with broom fibres, fibre percentages of 20 and 30% by weight were achieved. From the results of mechanical tests it has been noticed that the best results have been obtained with moulding temperatures of 150°C. Higher temperatures have not been employed, so as to avoid damaging the natural fibres. In terms of tensile performance, however, with unidirectional hemp fibres a clear increase of the reinforced matrix mechanical properties is achieved. With randomly oriented broom fibres an elastic modulus and flexural strength increase has been obtained, together with a decrease of the strain to failure. The best results have been obtained with a lower percentage of reinforcement. The fibre-matrix adhesion is very weak, however, and the zones of fracture of the test specimens are characterised by a remarkable debonding.

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