USE OF BANANA FIBER IN INJECTION – MOULDED PARTS FOR THE AUTOMOTIVE SECTOR

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Abstract
The use of natural fibers as reinforcement in plastic matrixes constitutes an issue of great importance in the industry, and also in the automotive industry. This paper focuses on results obtained in the analysis of window pillars for car's interiors produced by injection – molding of a composite of banana fiber. Banana fiber from Canary Islands were extracted and characterized in order to find if they are likely to be exploited to obtain a high quality fiber, with applications in the plastics industry, more specifically in the automotive industry, for production of parts for cars (window B – pillar in this paper). To accurate this fiber and the composite prepared accomplish with standards, several tests have been carried out to the fiber, the composite and the final part. Results show that banana fiber and its composites have a great potential to be used for the production of parts for the automotive industry.

1 Introduction
Glass and carbon fibers are the most common fibers employed in plastic materials, because of their good mechanical properties, such as strength and stiffness. Natural fibers can win the market currently dominated by synthetic fibers, due to their properties, their recyclability and their green origin. The increase in plastic wastes, including composites, is a serious trouble for the environment, due to their long period of life and their difficult recycling. An important issue concerning natural fibers is that the plants, producers of vegetal fibers, take carbon dioxide from the air, so that lifecycle of these materials are quite positive [1]. Especially because they are a biodegradable and renewable resource, its use should be encouraged, even more if the legal restrictions for environmental protection are taken in consideration, according to the existing EU legislation on recycling [2], which aims are to guarantee a higher level of recyclability in materials used in industrial productions; specifically, this rule [2] focuses on vehicles at the end of their lifetime. The interest of using natural fibers lies in their excellent mechanical properties, dimensional stability and some economic and ecologic advantages [3, 4], taking into consideration recycling and sustainability premises.

In the recent years the interest in using vegetable fibers, natural fibers in fact, as reinforcement in composite materials has been increased. Different authors have studied

different ways to reduce the amount of composites wastes and their impact in the environment, by substituting glass fiber with natural, renewable and biodegradable fibers. Some works with sisal, coir, flax, hemp or straw show have been carried out by several authors [3, 4], finding a number of applications in the furniture industry, production of panels, partitions for interior doors and wall coverings or automotive panels, among many other uses [4].

In 2005, 19 000 tonnes of natural fibers, excluding wood and cotton, were used in automotive composites [5]. Exotic natural fibers, such as jute, sisal or abaca, increased substantially between 2000 and 2004, both on a percentage basis and in absolute terms. In 2004 and 2005 flax prices have fallen, so the markets share of flax was increased. Injection molding has considerable future increases, partly due to their application in high-class interior parts [4, 5]. Around 55% of natural fibers are used in thermoset resins with remaining 45% in thermoplastics. A maximum of 2 000 tons of natural fiber composites are used outside the automotive industry in the EU [5]. Injection of flax or sisal fibers reinforced composites have been widely studied [3 – 6], but no references about banana fiber compounds injection molding have been found.

Banana is the first crop in Canary Islands, regarding to the production numbers, and the second one in cultivated area [7]. Residues of the crops (pseudostem and leaves) were used as fodder for cattle and goats, but have now become a waste material, with any or short use. Extraction and later use of this fiber in composites industry means a revaluation of this crop in the Archipelago. Nowadays around 9 562 ha of banana trees are cultivated in Canary Islands [8], with a potential in fiber production of about 25 000 tons per year. Banana fibers are placed in the superimposed leaves which form the pseudostem and provide resistance to the plant. These fibers run longitudinally along the leave [7].

2 Materials and testing methods

Banana fibers were extracted at Universidad de Las Palmas de Gran Canaria [8] and processed at Grupo Antolin Ingeniería, as part of research done within the Project entitled "Development of an automated process to extract fibers from the waste of banana food production for exploitation as a sustainable reinforcement in injection and rotomoulded products: BADANA", funded by the 7th Framework of the European Union (FP7 - 232287).

Banana fiber was characterized by different techniques. Fiber was treated to improve its characteristics and compounded to get the polypropylene (PP) composite to be used in injection molding for producing final parts. Obtained parts were tested to accurate they accomplish with standards and established requirements and rules.

2.1 Mechanical properties of banana fiber

Several single fibers were tested in an Instron 5564 test machine, at a rate of 1mm/min, in the Polymer Processing Research Centre (PPRC) facilities, at Queen's University of Belfast.

2.2 FTIR studies

FTIR studies of banana fiber were made at PPRC, in a Perkin Elmer Spectrum 100 FTIR Spectrometer with attenuated total reflectance (ATR) device. This equipment collects 60

spectra per second at a resolution of 16 cm^{-1}. These spectra were carried out with ATR, from 4000 to 500 cm^{-1}, obtaining the spectrum in terms of transmittance versus wavelength.

2.3 Thermal stability
Thermogravimetric analyses (TGA) were run to determine the thermal degradation of fiber. A Mettler Toledo TGA/DSC 1 analyzer was used at a heating rate of 5ºC/min in N_2 atmosphere.

2.4 Optical microscopy
Observations of samples were carried out in an Olympus BX51 optical microscope.

2.5 Chemical modification of fiber
Fiber was chemically treated to improve its thermal stability and to solve undesired components in the fiber, as lignin, pectin and waxes. Banana fiber was treated with a 6 % NaOH solution at room temperature for two hours. Treated fiber was also characterized.

2.6 Compounding
Compounding was prepared with a 10 % of treated banana fiber in PP grafted (10 %) with maleic anhydride (MA) as a compatibilizer (PP BH345MO with MFI of 45 g/10min and MA-g-PP Priex 20097, with 0.45 % grafted MA and MFI of 30 g/10min). Treated short banana fibers, 3 mm length, were mixed with PP using a Gale mini-mixer, a twin-screw batch mixer at 180 ºC, 75 rpm and 3 minutes mixing time.

2.7 Injection molding
Injection molding took place in an ENGEL bi-injection molding machine, with 800 tons. Compounding was dried at 80 ºC for two hours.

2.8 Final parts testing
Dimensional stability, odor and impact tests, among others, were carried out to find if produced parts fully fit with established requirements. Tests were performed according to standards established by rules and manufacturers.

3 Results

3.1 Mechanical properties of banana fiber
Up to 20 samples of banana fiber were tested, obtaining their stress – strain curves. Results show a tensile strength of 1032 ± 110 MPa and an elastic modulus of 36.9 ± 3.3 GPa.

Fiber	Tensile strength (MPa)	Elastic modulus (GPa)	Reference
Banana	1032	36.9	--
Flax	802	33	3
Banana ties	963	38	7
Palm	377	3	9
Bamboo	503	36	9
Cotton	400	12	10
Sisal	575	15	11

Table 1. Mechanical parameters for different vegetable fibers

Tests carried out with banana ties give similar values: elastic modulus obtained was 38 GPa, while the tensile strength was 963 MPa [7]. As can be observed in table number 1, the obtained values are comparable, even better, to those obtained by other authors for different natural vegetable fibers.

3.2 FTIR analysis

Figure 1 shows the IR spectra obtained for virgin and treated banana fiber. Spectrum for virgin fiber shows typical absorption bands of lignocellulosic fibers: cellulose, hemicellulose and lignin [12]. These compounds are mainly formed by alkenes and aromatic structures, but also by compounds containing groups with oxygen, such as alcohols, ketones or esters.

At 3326 cm^{-1} it is observed a broad peak, corresponding to vibration of bonds O – H in these strings. The peak at 2971 cm^{-1} is the characteristic absorption band at 2917 cm^{-1}, due to the vibration of C – H bonds in CH and CH_2 groups in cellulose and hemicellulose. At about 1700 cm^{-1} another peak is observed and it is mainly attributed to ketones or carbonyl groups (C=O) in lignin, waxes and pectins. The band at 1430 cm^{-1} indicates the presence of metoxi radical ($O\text{-}CH_3$), associated with hemicellulose in fiber. There are several peaks with weak intensity between 1369 and 1100 cm^{-1}, mainly related to aromatics and C-O in lignin and hemicellulose [12]. The more intense band appears at 1060 cm^{-1} and it is linked to C – OH groups (secondary alcohols), quite frequent in sidechains of cellulose, hemicellulose and lignin.

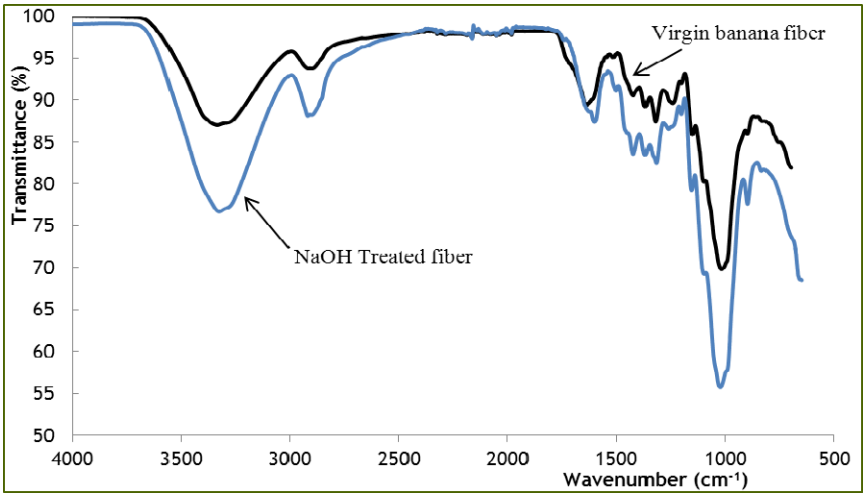

Figure 1. FTIR – ATR spectra for untreated banana fiber (in black) and for NaOH treated fiber (in blue)

Spectrum obtained for banana fiber are very similar to those obtained for other authors [3, 9, 12, 13] for different vegetal fibers, which allows concluding that all these fibers have a very similar chemical composition. If the spectrum for banana fiber is compared with the obtained ones for cellulose, hemicellulose and lignin [12], it can be observed that an important similitude with the cellulose curve exists. It has been found [9] that the composition of banana fiber is 60-65 % cellulose, 6 – 8 % hemicellulose, 5 – 10% lignin and 1 – 2 % ashes, demonstrating that an important part of banana fiber is formed by cellulose.

Spectrum of NaOH treated fiber shows the reduction of the content in lignin in the fiber, because of the reduction of the peak at 1700 cm^{-1} (C = O groups in lignin, pectin and waxes). Furthermore, a short peak appears at 1500 cm^{-1} for treated fiber, being attributed to the formation of carboxylate groups. The introduction of this group in the fiber could lead to decrease its hydrophilic character, because of the substitution of COOH groups by COONa.

3.3 Thermal stability

TGA analysis (figure 2) shows that thermal degradation of banana tree fibers in N_2 atmosphere is about 221 ºC, as that is the temperature were weight loss start (after the moisture in the fiber is removed). This temperature is marked in figure 2 as left limit temperature. Results obtained by other authors show a degradation temperature of 205 ºC for jute, 250 ºC for hemp and 220 ºC for okra [13].

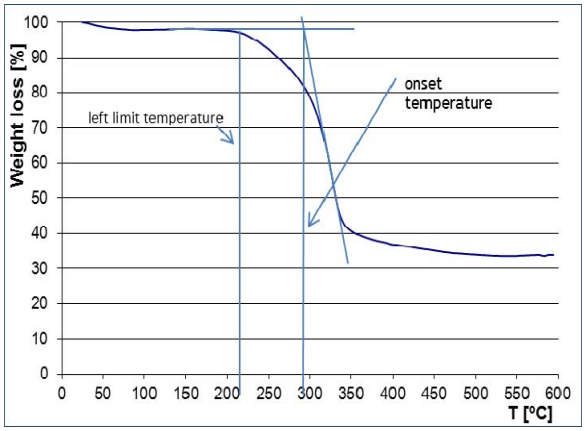

Figure 2. Thermogravimetric curve for banana fiber in nitrogen atmosphere

Weight loss until 105º C is due to moisture evaporation (around 2 %). After this point there is no weight loose until the temperature of 220 ºC; above this temperature the fiber is degrading. In the first stage, from 220 to 278 ºC, the depolymerisation of hemicellulose and pectin is taking place; in the second one, from 278 to 359 ºC, cellulose degradation is happening. At the end of the test it is observed a residue of 33 %, formed by carbonaceous residues or undegraded compounds.

NaOH treated fiber increases its degradation temperatures, reaching 264 ºC for left limit temperature. Onset temperature also increases from 295 ºC to 320 ºC. This improvement in thermal stability of fiber, due to chemical treatment, allows processing it with lower problems of burning during compounding and molding. Residue at the end of the test seems to be higher (up to 40 %) for treated fiber, probably due to the presence of inorganic compounds because of the chemical treatment.

3.4 Optical microscopy

Banana fibers were observed at different magnifications, under normal and polarized light. Banana fiber has an average diameter about 100 μm (figure 3). Different structures can be observed in the picture, as the light refracts in different ways. These differences in light refraction might be due to single microfibrils existing in the fiber, bonded together by pectin and other non-cellulosic components. Diameters of microfibrils measeure 11 to 17 μm. In order to deep in the knowledge of banana fiber geometry SEM studies are needed; these studies are being made in the near future.

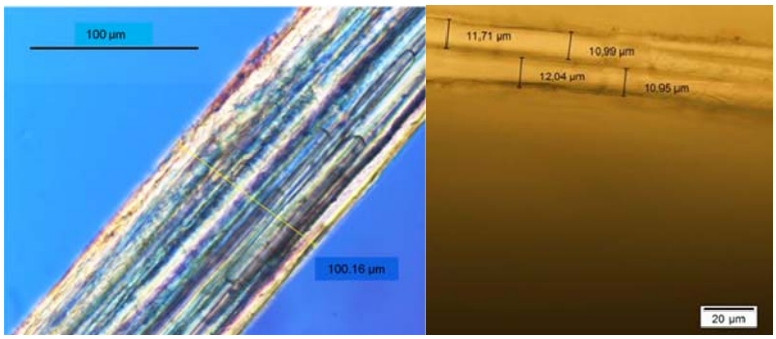

Figure 3. Polarised virgin banana fiber (x500); diameter measurements for fiber (left) and microfibrils (right)

3.5 Injection molding and validation of parts

Parts obtained have a nice appearance, with clearly visible fiber, as shown in next picture (figure 4).

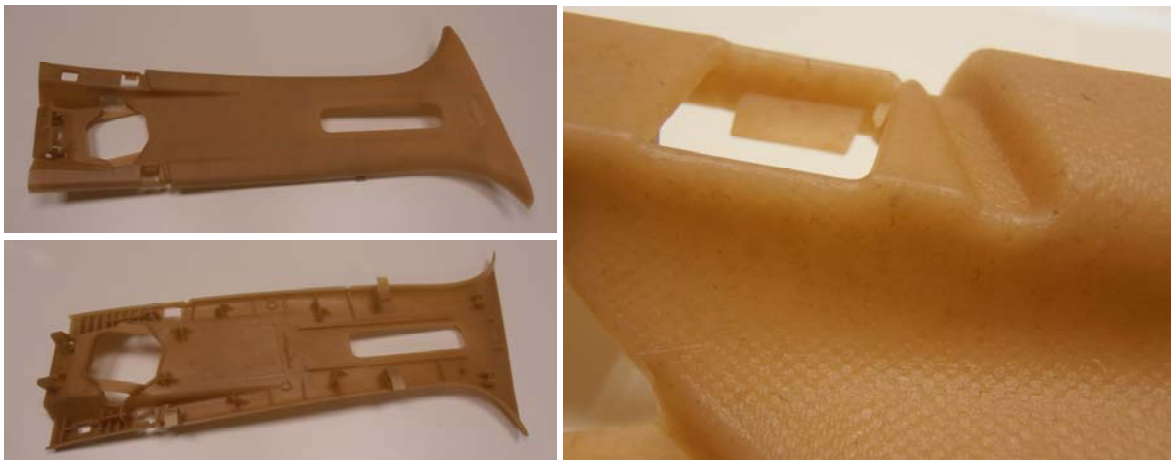

Figure 4. Pictures on final parts produced

There are a quite important number of tests to be done to any non – conventional part to be used in a car, so that over thirty tests were carried out. This paper just shows some of these tests, because of lack of space. By this formulation, a 6 % of weight reduction was achieved in this part, but with 0.25 % more shrinkage than serial part. This shrinkage could be reduced by optimizing injection parameters.

Window B-pillars made from banana compound have stiffness enough to pass standard tests. It is measured by applying 5 dN for 5 seconds in the part, and measuring both deformations during applied force and residual deformation, which was found to be null.

Resistance to scoring by abrasion was another of featured tests. It consists in rubbing the surface of a flat specimen with an abrasive paper; its aim is to find the resistance to scoring of plastic parts used for interior trims. This test was also passed by banana injected part.

Thermal resistance test is done by putting the part in a climatic chamber at 90 ºC for 22 hours. After that, it has been found that the banana part does not have any gap, deformation or aspect color changes, so it pass the test. A similar test measures the resistance to humidity, putting

the sample in different cycles, at different temperatures and relative humidity degrees for different times. This climatic cycle is also passed.

Fogging is an important test, because of it has to be ensured that the amount of volatile compounds settled are not very high. Part is placed in a controlled bath at 90 ºC for three hours, and volatile products are measured. This test is also passed. This test is in the same line of volatile organic compounds emitted from materials inside the vehicle, also passed.

Resistance to crash is featured by testing the part in three different impact points at room temperature (23 ºC) and at – 30 º C. It is observed that at room temperature the banana injected part does not pass the test, as it has a small breakage, while at – 30 ºC it does not break and just show a slight white mark. This problem could be solved by changing PP used to an impact modified grade of PP or by adding impact modifiers to the formulation.

There were also performed odor tests to banana compound and parts. These materials were placed in a chamber at 40 ºC for 24 hours with water, for one test, and at 80 ºC for two hours, for another trial. After that, trained persons valuated the odor on the samples (compound and part), giving a number from 1 to 6, depending on the odor intensity (1 means odorless and 6 is intolerable). Banana compound passed with mark 3 for both tests, which is noticeable but not irritating; odor problems were neither detected for final part.

4 Conclusions

Banana fiber appears as another option in the vegetable fibers market, with the advantage of being extracted from wastes of banana food production, so that no food displacing exists and there is no need of new crops.

The parts produced by injection molding present a good aspect.

Chemical modification of banana fiber by NaOH solution achieves higher stability of fiber, as degradation temperatures increased. Furthermore, both compound and parts produced with this fiber pass odor tests.

Window B-pillars produced with banana fiber composite pass most part of featured tests; those presenting a poor behavior can be easily improved by a slight change in the formulation.

The industrial trial with this compound has been successful. No problems have been detected during the injection process. Final part produced accomplish with most part of performed tests.

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