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# Biocomposites from *Musa textilis* and polypropylene: Evaluation of flexural properties and impact strength

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Abaca (*Musa textilis*)-reinforced polypropylene composites have been prepared and their flexural mechanical properties studied. Due to their characteristic properties, *M. textilis* has a great economic importance and its fibers are used for specialty papers. Due to its high price and despite possessing very distinctive mechanical properties, to date abaca fibers had not been tested in fiber-reinforced composites. Analysis of materials prepared showed that, in spite of reduced interface adhesion, flexural properties of the PP composites increased linearly with fiber content up to 50 wt.%. Addition of a maleated polypropylene coupling agent still enhanced the stress transfer from the matrix to the reinforcement fiber. As a result, composites with improved flexural properties were obtained. The mechanical properties of matrix and reinforcing fiber were evaluated and used for modelling both the flexural strength and modulus of its composites. In addition, the impact strength of materials was evaluated. Comparison with mechanical properties of composites reinforced with fiberglass points out the potentiality of abaca-reinforced polypropylene composites as suitable substitutes in applications with low impact strength demands.



## 1. Introduction

The potential substitution of fiberglass by natural fibers on composite materials has been intensely debated during the last decades [1–4]. Their physical and mechanical properties, in combination with their ecological characteristics, propelled natural fiber-reinforced composites into many industrial sectors [5]. Since the 90's, when Daimler-Benz presented the first car components made of natural fiber-reinforced composites, incorporation of biomaterials in the automotive industry is expanding [6–8]. Recently, in the quest for a 100% vegetal car, Toyota presented the 1/X compact hybrid vehicle, a concept car partially produced from bio-plastics derived from kenaf and ramie plants. Whilst allowing the utilization of standard manufacturing processes, these price-competitive materials provided enhanced heat and noise insulation and an important weight reduction, contributing to diminish petrol consumption. Nevertheless, substitution of fiberglass for natural plants in thermoplastics used in structural parts remains one of the most successful approaches.

In order to develop more efficient ecological-friendly composite materials, in recent years, the number of publications discussing the utilization of natural fibers as reinforcement has progressively increased [9–12]. However, these natural-based composites must fulfill heavy automotive constraints (side/frontal crash, ageing, fatigue strength...). In spite of the efforts devoted, mechanical properties of composites reinforced with natural fibers are still far from those containing fiberglass. For this reason, despite their increasing usage in the automotive sector, construction remains as the main industrial application of natural fiber-reinforced materials. Lower mechanical demands have propelled these composites in decking, siding, cladding, furniture ... [13].

Poor mechanical strength of natural fiber-reinforced composites has commonly been attributed to a deficient cohesion between the hydrophilic reinforcement and the hydrophobic matrix. To overcome this situation, many compatibilization strategies have been applied, but so far, none has entirely succeeded to generate the optimal properties predicted by the models. Most works published center their attention on the tensile properties of the composites [14,15]. Even though for some applications the flexural response remains more relevant, references to flexural properties can be found more scarcely [16–18]. For this reason, in this paper we focused our attention to the mechanical response of abaca-reinforced composites to flexural and impact tests.

Due to their porosity, mechanical properties and resistance, abaca fibers (*Musa textilis*, also known as Manilla hemp) are used to produce specialty papers for tea bags or banknotes. Sometimes referred too as abaca, fibers from *Musa sapientum* (commonly

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known as banana plant) possess poorer mechanical properties and in consequence are destined to less demanding applications [19,20]. Recently some works have studied the mechanical properties of polypropylene reinforced with abaca. However in several of these works *M. sapientum* fibers were used instead, whilst in others the true nature of the fiber was not reported [21–25]. Although some research groups have reinforced biopolymers with abaca [26] to our knowledge this is first study specifically centering its attention on flexural properties of *M. textilis*-reinforced-polypropylene.

In order to facilitate its comparison, the mechanical properties of analogously prepared fiberglass-reinforced polypropylene materials have been evaluated. In addition, some of the most commonly accepted micromechanical models have been applied in order to evaluate the efficiency of the reinforcing fibers.

## 2. Materials and methods

### 2.1. Materials

Polypropylene was provided by Repsol YPF under the trade name ISPLEN PP 090 G2 M, nominally with a melt flow index of 30 g/10 min (at 230 °C, 2.16 kg) and density of 0.905 g/cm$^3$, according to the manufacturer's data. The maleic anhydride-grafted polypropylene (MAPP) coupling agent used in this work was Epolene G 3015 (Eastman Chemical) (acid number 15; density 0.913 g/cm$^3$; Mw = 47,000; Mn = 24,800). Abaca strands (*M. textilis*) were supplied by CELESA. Sized E-fibreglass Vetrotex® (Sant-Gobain Vetrotex) was used to compare with the properties of the composites by the abaca strands.

### 2.2. Composite preparation

Abaca-reinforced composite materials were obtained by means of an intensive melt mixer Brabender® plastograph working at 180 °C for 10 min. The composites were prepared with 20, 30, 40 and 50 wt.% of reinforcement. When needed, the coupling agent (MAPP) was directly added into the extruder in a 4%, 6% or 8% fiber weight. The composite blends were homogenized and granulated in a blade mill before being injected using a Meteor 40 (Mateu&-Sole) injection machine. Injection was carried out in a steel mould according to ASTM D3641 standard. Before testing, specimens were conditioned (3 days at 23 °C, 50% humidity) according to the ASTM D618 standard. Flexural and impact tests were conducted following standard protocols (ASTM D790 and D256 respectively). At least five specimens were tested for each mechanical property. Further description can be found in a previous paper [27].

## 3. Results and discussion

### 3.1. Characterization of the reinforcing fibers

The measurement of flexural properties of single fibers is yet to be resolved and no reports have described the relationship between flexural modulus and Young's modulus. Under optimal stress transfer, also under flexural strain, the reinforcing fibers perform at their Young's modulus full potential. For this reason, Shibata et al. (2008) proposed the utilization intrinsic tensile properties for modeling the flexural properties.

Typical stress–strain curves for abaca strands were linear, although with slight fluctuations assigned to breakage of individual fibers. Nevertheless, the slope was consistent enough throughout the test for the determination of Young's modulus. Before mechanical testing abaca strands were analyzed with a digital electronic micrometer to determine their diameter. Furthermore, abaca strands were analyzed by SEM microscopy and optical image analysis, and their average diameter was found to be 91 μm, much larger than for fiberglass (13.1 μm). The average Young's Modulus of the abaca strands was 34.4 GPa, in agreement with other reports [23]. Due to the presence of defects within the fiber, tensile strength of abaca strands depended on their length according to the equation: $\sigma_t = 606.5–15.2\,L$. Thus, ultimate tensile strength can be considered to be around 600 MPa. Further details on the mechanical characterization can be found in a previous paper [27]. In comparison, glass fibers had superior tensile strength (2850 ± 400 MPa) and Young's modulus (76 ± 12 GPa).

### 3.2. Effect of fiber content on flexural properties

PP-based composites were reinforced with different proportions of abaca strands (20–50 wt.%/wt.%) following the procedure described above. The flexural properties of materials are summarized in Table 1.

As described for other natural fiber-reinforced materials [28], the flexural modulus of the composites increased proportionally to abaca content, reaching values up to five times higher than those of plain PP samples. These values are in agreement with the expected increase in stiffness and are corroborated by the diminished capacity to sustain plastic deformation.

The effect of abaca content on strength is lower than that observed on modulus, but still almost doubled the properties of the non-reinforced matrix. As demonstrated on a previous paper [27], those enhancements are achieved in spite of a poor fiber–matrix adhesion. With reinforcing-fiber content up to 30 wt.%, mechanical properties evolved following trends commonly observed in other natural fiber-reinforced composites [29,30]. Thus, as the reinforcement volume fraction increased so did both ultimate flexural strength and flexural modulus of the corresponding composites. However, unlike other natural-fiber composites, evolution of flexural strength kept the linear trend at reinforcement ratios of 40–50%. This behavior results rather exceptional since usually, ultimate tensile strength stabilizes at 30–35% reinforcement [31]. Furthermore, it also differs from behavior of the same material when subjected to tensile stresses [27].

The reason for this particular behavior remains unclear. Mechanical interlocking in the highly irregular fiber surface topography could be responsible for the strength increase. However, surface roughness is common to all natural fibers. Furthermore, the polarity of the abaca strands does not differ either from that of other fibers used to reinforce polypropylene. Thus, the reason might be related to diffusion of polypropylene inside the large lumen of abaca strands during the first stages of extrusion and/or the partial separation of individual fibers from the main strand, leading to increased mechanical interlocking.

### 3.3. Effect of MAPP coupling agent on flexural properties

For most applications, and in order to be competitive from an industrial point of view, the enhancements on mechanical

**Table 1**
Flexural properties of polypropylene composites reinforced with abaca strands.

| Fiber content | Flexural modulus (GPa) | Flexural strength (MPa) | Strain at break (%) |
|---|---|---|---|
| 0 | 1.1 ± 0.1 | 40.2 ± 1.0 | 9.6 ± 0.2 |
| 20 | 2.8 ± 0.1 | 56.5 ± 1.0 | 5.5 ± 1.0 |
| 30 | 3.6 ± 0.1 | 64.4 ± 1.1 | 3.8 ± 0.3 |
| 40 | 5.1 ± 0.2 | 72.7 ± 1.4 | 3.1 ± 0.2 |
| 50 | 5.6 ± 0.2 | 78.9 ± 1.4 | 2.7 ± 0.2 |