# Production of Thermoplastic Composites reinforced with Posidonia Oceanica Fibers

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## ABSTRACT

**This study investigates the development and characterization of a new biocomposite and biodegradable material based on natural fibers. This new biocomposite is composed of commercially available biodegradable polylactic acid (PLA) as a matrix and Posidonia Oceanica (PO) fibers collected from the coasts of Tunisia as reinforcement. This new material is produced by heating and pressing the two components in a special device. The use of PO, or sea balls, will allow exploiting one of the marine residues abundant on Tunisian beaches, instead of exploited industrially, and to preserve the beaches from debris given the impact of tourist activity in the Tunisian economy. The PLA/PO coupling allowed obtaining a biocomposite with promising mechanical properties. The improvement in maximum stress and strain after the addition of PO is one of the highlights of the results of this work.**

***Keywords-biocomposites; Posidonia oceanica; natural fibers; characterization***

## I. INTRODUCTION

Natural fiber-reinforced biocomposites using biodegradable polymers as a matrix are currently experiencing a major boom in their applications and implementation techniques. They are attracting attention in applications that require both rigidity and lightness, such as transportation, marine, aerospace, sports and leisure, heavy industry, and civil engineering. The fabrication of these biocomposites requires the correct selection of fibers and matrix to obtain acceptable mechanical properties and sufficient adhesion between the fibers and the matrix. Several researchers have conducted research on cellulose-based fibers such as kenaf [1], flax [2], hemp [3], banana [4], or natural fibers such as fibers from date palm waste [5]. These fibers are used with thermoplastics or thermosets as a matrix. The most commonly used thermoplastics are polypropylene (PP) [6], polylactic acid (PLA) [7], polyethylene, and polyvinyl chloride (PVC). On the other hand, phenolic resins, epoxy resins, and polyester resins are the most commonly used thermosetting matrices [8]. This study represents a contribution to the development and characterization of new biocomposite and biodegradable materials based on Posidoni Oceanique (PO) fibers as reinforcement and PLA as matrix. PO is a coastal marine plant with elongated leaves and a stem with roots known as rhizomes. The rhizome ends in a bundle of elongated leaves [9, 10]. The plant has a leaf or bulb shape (Figure 1). Balls, also known as aegagropiles or sea balls, are formed from fibrous accumulations of leaves that have fallen around pieces of rhizomes by the movement of the sea and accumulate in large quantities on the coast every summer. The choice of sea ball fibers is justified for two reasons: They are abundant on beaches and they are biodegradable. Similarly, the choice of PLA is justified by two reasons. It is present in the market at a reasonable price and it is also biodegradable. This biocomposites material is produced by hot pressing. For this reason, we designed and manufactured a digitally controlled thermomechanical system consisting of a die and punch that can be mounted on a conventional tension compressor.

Fig. 1. Posidonia balls harvested from the Tunisia sea.

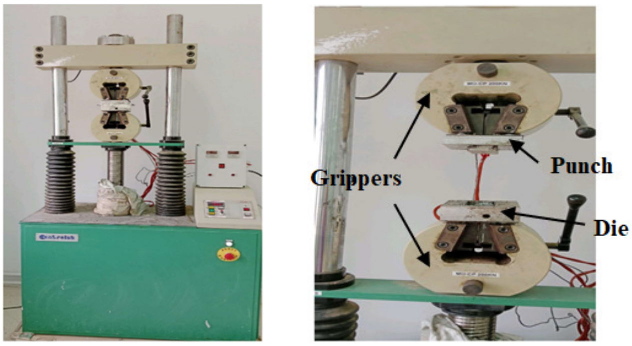
A biocomposite was created through a four-element, two-modality experimental design. These factors mainly depend on the manufacturing conditions of the biocomposite, such as the proportion of fibers used, the heating temperature of PLA, the retention time of the punch within the matrix during hot compaction, and the compressive force required between the die and the punch. A series of tensile tests were carried out on a standardized bio-composite [14] cut by a laser machine.

## II. MATERIALS AND METHODS

To develop the biocomposite with PLA matrix and PO reinforcement, we designed and manufactured a thermomechanical device that can develop it by thermal compression (Figure 2). This device basically consists of:

- Steel dice and punch.
- Two heating resistors, one in the die and another on the punch.
- Two thermocouples, one on the die and another on the punch.
- A digital controller to adjust the set temperature as needed.

The die holding the layer of the biocomposite (PLA/PO) is fixed by the lower jaw of the traction machine, and the punch is fixed by the upper jaw (Figure 2). Figure 3 shows the die, punch, bottom, and top PLA layers, and the PO layer. The two holes represent the location of the heating resistor and the thermocouple connected to the temperature controller. The die punch assembly attaches to the HM-S 200KN 04M4210 series tensile testing machine (Figure 2).



(a) (b)

Fig. 2. Experimental set-up for the elaboration of the new material: (a) PLA/PO compression phase, (b) die/punch after the disassembly of the PLA/PO plate.

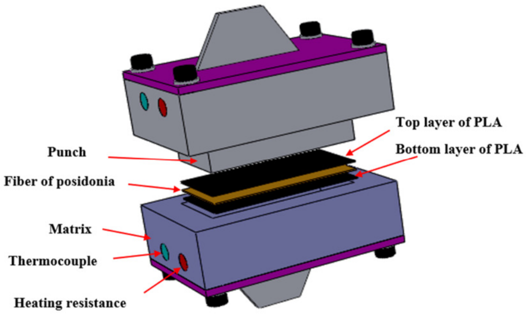


Fig. 3. 3D compound of the die and punch of the new experimental device.

Our novel biocomposite characterization process is divided into three major steps:

### 1) *Step 1*

- Preparation of the PO fibers (washing and fiber disentangling) according to the dimensions of the desired biocomposite panel (Figure 4).
- PLA preparation: PLA was manually cat into 0.5-1 cm pieces.
- Panels from the new biocomposite were obtained by hot pressing.

### 2) *Step 2*

- Laser cutting of PLA/PO biocomposite samples was conducted according to the ISO 527-2 standard (Figure 5).
- A series of tensile tests were performed.

### 3) *Step 3*

The results are analyzed (determination of the mechanical properties of biocomposites).

## III. EXPERIMENTS

To develop the new PLA/PO material, we used the experimental setup described in Figures 2 and 3. Four design parameters were taken into account for the development of the new material: the heating temperature *T* (°C), the percentage of reinforcement (% of PO), the pressure holding time *t* (min) of the bio-composite and the pressure force $F$ ($10^3$ daN). These parameters are at two levels (min and max) as shown in Table I. Eight specimens of the bio-composite were made according to Table II and Figure 6.

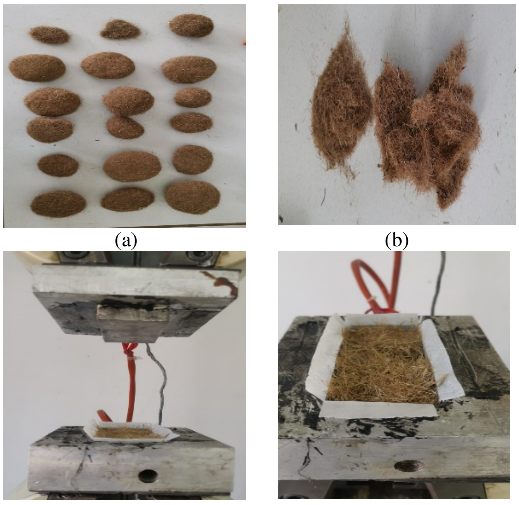

(a) (b)
(c) (d)

Fig. 4. Preparation of PO reinforcement: (a) PO before treatment, (b) fiber detanglement, (c) and (d) preparation of the PO layer in the matrix.

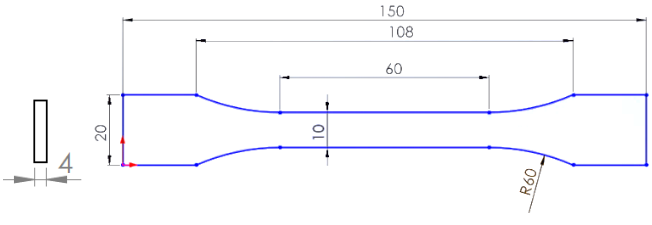


Fig. 5. Tensile test specimens in accordance with ISO 527-2.

TABLE I. DESIGN PARAMETERS CONSIDERED FOR THE DEVELOPMENT OF THE NEW BIO-COMPOSITE

| Independent variable | Factor levels | |
|---|---|---|
| PLA heating temperature (°C) | 160 | 170 |
| % of fiber in bio-composite (% PO/PLA) | 5 | 10 |
| Punch holding time in the die (min) | 10 | 20 |
| Pressure force between die and punch ($10^3$ daN) | 10 | 14 |

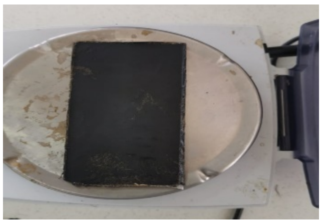


Fig. 6. Example of a PLA/PO plate.

## IV. RESULTS AND DISCUSSION

In order to characterize the new PLA/ PO bio-composite, a series of tensile tests were carried out on specimens in accordance with ISO 527 [14] (Figure 5) from the 8 levels obtained by hot pressing using the thermomechanical system parameters shown in Table II. Each level was laser-cut into 3 specimens.

TABLE II. EXPERIMENTAL PARAMETERS

| Specimen N° | $T$ (°C) | PO (%) | $t$ (min) | $F$ ($10^3$ daN) |
|---|---|---|---|---|
| 1 | 160 | 5 | 20 | 10 |
| 2 | 160 | 5 | 20 | 14 |
| 3 | 170 | 5 | 20 | 10 |
| 4 | 170 | 5 | 20 | 14 |
| 5 | 160 | 10 | 10 | 10 |
| 6 | 160 | 10 | 10 | 14 |
| 7 | 170 | 10 | 10 | 10 |
| 8 | 170 | 10 | 10 | 14 |

These tests resulted in at least one fracture for each tested specimen. The stress-strain curves are plotted in Figures 7 and 8, showing the behavior of the bio-composite containing 5% (PLA/PO-5) and 10% (PLA/PO-10) fibers, respectively. The tensile behavior of all specimens is similar and can be broken down into three main phases:

The first phase corresponds to a linear increase in the stress applied with the strain in the strain zone [0.05% - 0.25%] in accordance with ISO 527-4 [15]. This phase is the elastic zone of the stress-strain curve, where the modulus of elasticity can be determined from Hook's law by [1]:

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \tag{1}$$

where $E$, $\Delta\sigma$, and $\Delta\varepsilon$ are respectively the modulus of elasticity (GPa), the difference in the applied tensile stress between two strain points, and the difference between the two strain points.

In the second phase, the beginning of this part is inclined, becoming almost linear up to the maximum stress value, except for a few peaks in this linear zone due to fiber breaks.

The third and final phase, in which stress is completely released, is the phase of total rupture of PLA and fibers in the bio-composite.

Table III and Figure 9 summarize the tensile test results for two types of the developed bio-composite, PLA/PO -5, PLA/PO-10, and PLA alone. They represent the mean values and standard deviations of the mechanical properties ($\rho$, $\sigma_{Max}$, $\varepsilon$, and $E$) of the two tensile-stressed bio-composites compared to those of PLA alone.

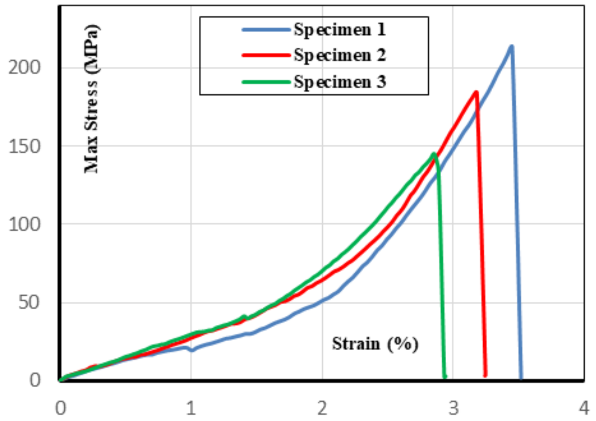


Fig. 7. Tensile curves for samples of 5% PO (level 2).

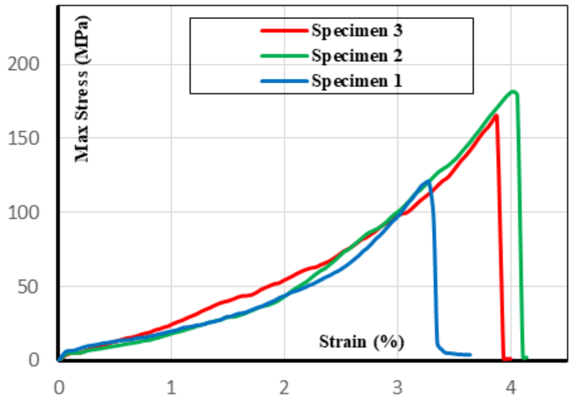


Fig. 8. Tensile curves for samples of 10% PO (level 6).

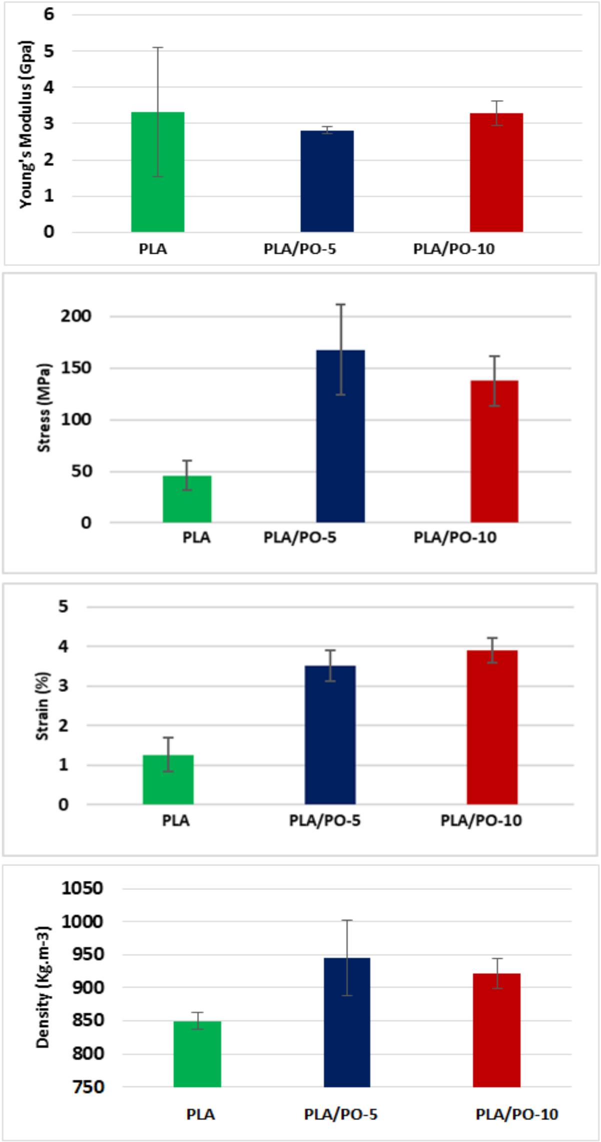


Fig. 9. Variation in mechanical properties of bio-composite as a function of PO fiber content.

There was a significant improvement in the maximum stress, strain, and density of PLA/PO-5 and PLA/PO-10 biocomposites in comparison with PLA alone, at the cost of degradation in the Young's modulus of PLA/PO-5. Indeed, the increases in $\sigma_{Max}$ and $\varepsilon$ for PLA/PO-5 are 264.94% and 177.78%, respectively, while for PLA/PO-10 the increases are 199.44% and 209.52%, respectively. The degradation of Young's modulus for PLA/PO-5 bio-composite is 15.06%, while it is not significant for PLA/PO-10. We also note that an increase in the fiber content of 5% allowed an improvement of the Young modulus of 14.28% at the cost of 17.94% degradation of the maximum stress.

TABLE III. AVERAGE PROPERTIES OF BIO-COMPOSITES PLA/PO

| Material | $\rho$ (Kg/m$^3$) | $\sigma_{Max}$ (MPa) | $\varepsilon$ (%) | $E$ (GPa) |
|---|---|---|---|---|
| PLA | 850±12 | 46±14 | 1.26±0.43 | 3.32±1.77 |
| PLA-PO-5 | 945±57 | 167.87±43.46 | 3.50±0.39 | 2.82±0.1 |
| PLA-PO-10 | 922±23 | 137.74±24.32 | 3.9±0.30 | 3.29±0.34 |

## V. CONCLUSION

The main objective of this work was the development and characterization of a new biocomposite composed of commercial PLA as matrix and PO fibers as reinforcement. Posidonia balls are in abundance in Tunisia beaches and are considered an annoyance for seaside tourism. In the first step, we designed and manufactured a digitally controlled thermomechanical device for the development of the new biocomposite by hot compression.

As a second step, and to characterize our new biocomposite, a series of tensile tests on standardized specimens from 8 PLA/PO specimens was carried out. These specimens were manufactured taking into account four experimental parameters: the heating temperature, the percentage of reinforcement, the time of holding the biocomposite under pressure t, and the pressure stress.

The results showed a clear increase in the maximum stress and strain of PLA/PO-10 and PLA/PO-5 compared to plain PLA, at the cost of degradation of the Young modulus of PLA/PO-5. In addition, an increase in fiber content of 5% allowed an improvement of the Young modulus of 14.28% at the cost of the degradation of the maximum stress of 17.94%. The study of the impact of humidity and its effect on the mechanical characteristics of the biocomposite, the study of the formability of this new material, and the improvement of its biodegradability could be new areas for improvement in this work.

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