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RESEARCH ARTICLE

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Characterization of physical and mechanical properties of recycled jute fabric reinforced polypropylene composites

Lamia Benhamadouche[1] | Mansour Rokbi[1] | Hocine Osmani[2] | Mohammad Jawaid[3] | Mohammad Asim[3] | Abu Bakar Mohd Supian[3] | Salih Mekideche[1] | Nafissa Moussaoui[1] | Hassan Fouad[4] | Ramzi Khiari[5]

[1]Department of Mechanical Engineering, M'sila University, M'sila, Algeria
[2]Laboratory of Non-Metallic Materials, Setif University, Setif, Algeria
[3]Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Serdang, Malaysia
[4]Applied Medical Science Department, Community College, King Saud University, Riyadh, Saudi Arabia
[5]CNRS, University of Grenoble Alpes, Grenoble, France

Correspondence
Mohammad Jawaid, Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Serdang, Selangor 43400, Malaysia.
Email: jawaid_md@yahoo.co.in

Funding information
King Saud University

Abstract
This research designed to contribute to reduce the environmental impacts through the preparation of composites with recyclable materials to be used in different applications. To this end, composites have been developed based on jute recovered from packaging bags and polypropylene (PP) reclaimed from scraps obtained from the manufacture of PP yarns. The developed composites were then characterized. First of all, the optimum mass fraction was determined in order to achieve good mechanical performance. Several mass fractions (30%, 40%, 45%, 50%, 60%, and 70%) were experimented to find that the best characteristics were those of the biocomposite with 40% reinforcement ($\sigma = 39.07$ MPa, $E = 4.60$ GPa). With this ratio, jute–PP biocomposites were further developed with different jute architectures (Satin, Serge 2 × 2, Taffeta). A structural study of the different jute fabric wastes was carried out to confirm whether they are suitable for use with a thermoplastic matrix (i.e., at a processing temperature of ≥200°C). Tensile and bending tests were carried out on these composites to find out the effect of the weave structure of the reinforcement.

KEYWORDS
composite, jute fabrics, polypropylene (PP), recycling, wastes

1 | INTRODUCTION

Composite materials are generally prepared from a mixture of two or more materials, which are held together by the matrix system called resin. For more than two decades, continuous research on composite materials has led to developing various mechanical properties and outstanding performance for a variety of utilizations.[1] Thus, fiber-reinforced composites have come to be recognized as notable materials for high-performance applications in automotive, aerospace, marine, construction, and motorsport areas.[2] Certainly, synthetic fibers are one of the recognized materials used in various high-performance gear utility because of its mechanical behavior, but the high demand for such materials has caused environmental and health issues associated with their production processes and nonbiodegradable wastes.[3]

Therefore, to fabricate environment-friendly composites for such applications, alternative composite materials based on natural fibers, such as linen, sisal, jute, kenaf, bamboo, and hemp,[4] are continuously investigated, with a special interest in various features and properties, such as low-cost processing, biodegradability, low density, low abrasion, good thermal properties, and so on.[1,3,5–7]

Lignocellulosic materials reinforced polymer composites have been demonstrated in various studies as a comparable material to synthetic fiber-reinforced composites in various aspects. However, natural fibers revealed some serious drawbacks of high moisture absorption, low adhesion, and low wettability, which steer into lower mechanical properties, compared to those of synthetic fiber materials. Thus, research efforts have been made to overcome the drawbacks of natural fiber composites and the issues have been solved by various techniques, such as hybridization reinforcement[8,9] and natural fiber treatment.[10,11]

Jute fiber is considered as the most common natural fiber for industrial and household applications. Generally, jute is produced in Bangladesh, India, Nepal, Thailand, and China, which account for more than 95% of the world production.[12] Previous studies have shown jute fiber composites as suitable for certain applications due to their mechanical properties.[13] Several authors have investigated different aspects related to jute fiber composites, including their mechanical behavior,[10,11,13–15] the effect of fiber modifications on mechanical properties,[10,11,16,17] dynamic mechanical behavior (DMA),[18] physical behavior,[15] anatomical structure, and manufacturing process.[19]

Jute is nowadays mainly used for the packaging industries. Woven canvas, fabrics, bags, and sacks are extensively used in transportation sector, storage of agricultural products, fertilizers, cement, and certain chemicals. Exponential growth and mass production of inexpensive synthetics as packaging materials affected the market for these traditional jute materials drastically.[20] As environment concern, limiting the usage of bioresources or managing disposable material has led to the recycling of materials at the end of their useful life. Well-known jute fiber bags are considered as waste at the end of their life; moreover, the residual jute fibers are not yet reused effectively.[21] Most developing countries are very rich in plant fibers and much of the agricultural waste is used as fuel.[22] In this research, recycled jute fiber was used as reinforced material and produced PP composites, the polymer composites were further studied for its mechanical behavior.

2 | MATERIALS AND METHODS

2.1 | Materials

The two main constituents used in our work for the development of biocomposites were polypropylene (PP), in the form of film, to serve as matrix and jute fabric for reinforcement. PP was supplied by "Textiles Divers Algeria" company in BEJAIA, it was intended for the manufacture of ropes, strings, and packaging bags. The jute fabric was recovered from packaging bags for food products, such as coffee, seeds, and other beans.

2.1.1 | Matrix

PP is one of the widely used thermoplastic polymers. Being used in many sectors, particularly in packaging, automotive industry, household appliances, sanitaryware, and textiles, its production represents more than a fifth of the plastics produced worldwide. In addition to these applications, PP is considered one of the most frequently used polyolefins as a matrix for natural fiber composites.[23–33] The PP has the highest modulus of elasticity among all polyolefins and relatively lower melting temperature (below 175°C), which is an advantage as matrix in hybrid composites.[34]

The PP film used in our work is the primary product in the manufacture of the yarn. The first step in the production of PP yarn is the production of a film from the PP grains using an extruder. The beginning of this PP film is always deformed, so it is always eliminated from the production of the yarn. Therefore, we used it as a recycled product.

2.1.2 | Reinforcement

Comparatively, jute fiber is a promising material and has gained much research interest due to its good mechanical characteristics, compared to those of, for example, sisal, coconut, and ramie.[35] Many studies have been dedicated to continuous jute fiber composites to examine various aspects, for example, mechanical,[10,11,14–17] dynamic mechanical properties,[18] the effect of fiber treatments on mechanical properties,[10,11,16,17] physical properties,[15] treatments, and microstructures.[19] From an ecological perspective, there is a trend in both control in utilization of limited resources and managing biowaste, and thus, the recycling of end-of-life materials is on the rise. It is known that jute bags at the end of their life will be considered as wastes, which are not yet effectively reused.[21] As part of this research, used jute bags were therefore recycled.

2.2 | Methods

2.2.1 | Structural analysis methods of jute fabric

1. Fourier transform infrared spectroscopy (FTIR)
   FTIR is an efficient method to determine the chemical and structural properties of the materials used. FTIR

analyses were performed in the Physico-Chemistry of High Polymers Laboratory (Setif University 1). Spectrum data were analyzed by using FTIR spectrometer (Spectrum Two PerkinElmer) between the wavenumbers of 4000 and 400 cm^{-1}.

2. Thermogravimetric analysis (TGA)
   TGA was used to study the thermal behavior at different temperature and decomposition rate of samples during the heat treatment as a function of temperature. In general, the manufacturing processes for polymer composites need temperature to set, and thermal behavior of polymer helps to prepare composites. The TGA was carried out using an SDT Q600 V20.9 Build 20 instrument at the Research for Emerging Materials Unit (Setif University), in the temperature ranging from 25 to 600°C under nitrogen N_2 flow, at a heating rate of 10°C/min. For ATG/DTG (thermo gravimetric analysis/derivative thermo gravimetric analysis) and FTIR analyses, jute was used in powder form.

2.2.2 | Preparation of jute–PP composites

This work was carried out in two steps. The first step aimed to prepare a jute/PP composite by varying the mass fraction of the reinforcement and characterize the composites obtained. The second step consisted in developing composites with different jute textures, using the optimum fraction of reinforcement offering the best mechanical characteristics, as found in the first stage. The manufacturing of the materials was realized in the Molding Laboratory of the Technological Hall (University of M'sila), using the hot compression molding process. To do so, we proceeded by following these steps:

a. The PP film and various jute bags are cut manually according to the dimensions of the mold (180 × 250 mm^2).
b. To ensure a planar orientation of the fibers, the jute fabrics are hot-pressed. The temperature is around 120°C, the pressure used is 12 bars for 10 min. These operations confer certain isotropy and make it possible to reduce the thickness of the folds and the thickness of the elaborated composite material.
c. Then, the reinforcement is steamed for 20 min at 100°C, to release hygroscopic moisture. The latter is harmful because the matrix used is hydrophobic.

To determine the optimal mass fraction, plates of the biocomposite were manufactured with different fractions according to the following equation[36]:

$$W_f = \frac{w_j}{w_m + w_j}, \tag{1}$$

$$W_m = \frac{w_j(1 - W_f)}{W_f}, \tag{2}$$

where W_f, w_j, and w_m are, respectively, the mass fraction of the fabric, the mass of the jute fabric, and the mass of the PP matrix. Six biocomposites were prepared with different mass fractions (Table 1), but identical fabric masses.

For the molding of composites, a heat press was used. It consisted of two plates whose temperatures were controlled by a regulator and could be adjusted. The cut plies of jute and PP were superposed to ensure good distribution of the reinforcement and the matrix. The layers were then placed in a mold, which was covered after the layers had been deposited. Once the mold was filled and covered, it was placed on the bottom plate of the press. The upper plate was then lowered slowly until it was closed and kept under the pressure of 40 bars at a temperature of 200°C, with a holding time of 10 min. Then, the mold was removed from the press and cooled. Thus, the composites were obtained (Figures 1 and 2).

Second step: Preparation of composites with different jute fabric architectures

After the characterization of the composite elaborated by varying the mass fraction of the reinforcement, three types of composites with different architectures of recycled jute fabric were prepared (Table 2). The mass fraction used in this part is the optimal fraction determined in the first part. The biocomposites were manufactured according to the same steps already mentioned earlier. The composites were denoted as Bio-Com A, Bio-Com B, and Bio-Com C, according to the different weaves.

2.2.3 | Mechanical characterization

The mechanical behaviors of the composites were evaluated by using Zwick–Roell traction/compression machine type Z100 at room temperature at the Non-Metallic Materials Laboratory (LMNM-Institute of Optics and Precision Mechanics, Setif University).

TABLE 1 Fiber fraction of biocomposite material

Sample	Designation	W_f (%)
01	Bio-Com 30	30
02	Bio-Com 40	40
03	Bio-Com 45	45
04	Bio-Com 50	50
05	Bio-Com 60	60
06	Bio-Com 70	70

FIGURE 1 Constituents used in the development of biocomposites: (A) polypropylene film and (B) jute bags

FIGURE 2 Plates from the composite jute–polypropylene

Tensile test

Tensile test was carried out according to ASTM D638-03[37] using a crosshead speed of 1 mm/min. The tensile strength was calculated on the average of five results of samples.

Flexural test

Flexural test was done according to ASTM D 790-03[38] with crosshead speed of 3 mm/min. Average values of five samples were used to calculate the flexural properties.

Preparation of test specimens

From the prepared composite panels, specimens were cut to the required size and shape according to ASTM standards, using a CNC process on a numerically controlled machine (Figure 3).

The dumbbell shape and dimensions of the specimens are shown in Figure 3 and flexural sample (Figure 4). The CNC technique has the following advantages:

- provides identical specimens,
- a gain of time,
- absence of residual stresses.

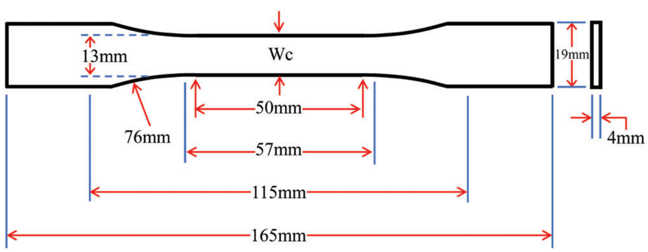
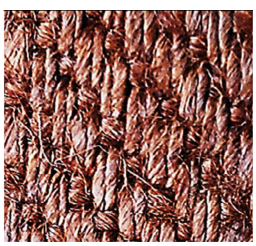


FIGURE 3 Tensile test specimen ASTM D638-03

TABLE 2 Different jute fabrics used

Denotation	Fabric A	Fabric B	Fabric C
Fabric	 Satin	 Serge 2 × 2	 Taffetas
Number of weave threads per 10 cm	34	26	37
Number of warp threads per 10 cm	74	54	37
Surface mass (g/m^2)	550	500	350

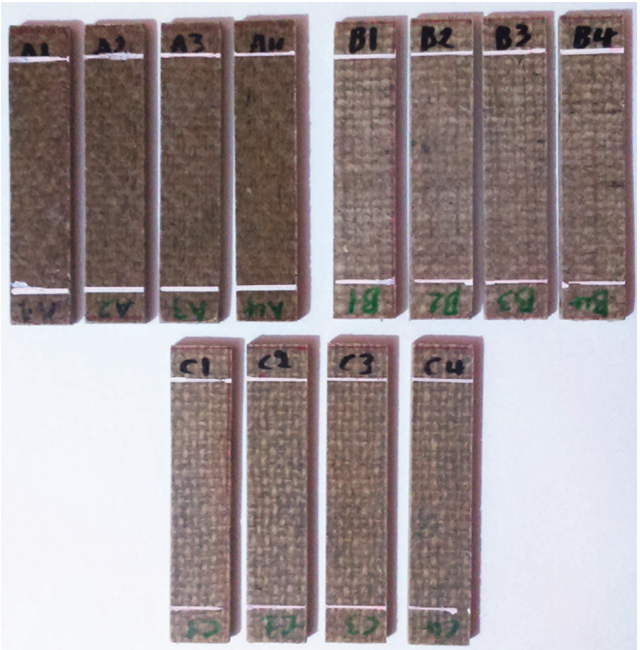


FIGURE 4 Flexural test specimens

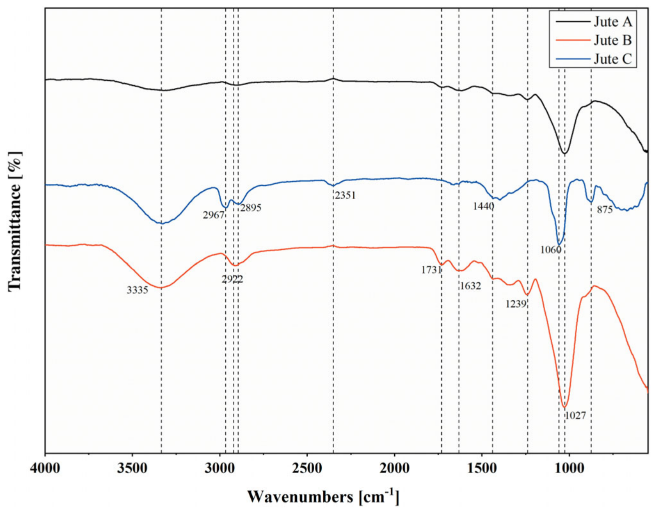


FIGURE 5 Fourier transform infrared (FTIR) spectroscopy of jute fabrics

3 | RESULTS AND DISCUSSION

3.1 | FTIR spectroscopy

In our study, the purpose of analyzing the jute fabric with FTIR has been to ensure by comparing with the spectrum of raw cellulosic fiber that there are no excess contaminants in the recycled fibers and that these fibers have not lost their main components. Figure 5 shows the automatic terminal recognition (ATR)–FTIR spectra of the Jute A, Jute B, and Jute C fabrics. These spectra are focused in the spectral range from 4000 and 400 cm^{-1}. The peak at 875 cm^{-1} showed β-glucosidic linkage and attributed to the O—C—O stretching during the C—H deformation of cellulose, this peak is strongly present in Jute C compared to the other two types of jute. In principle, the 700–900 cm^{-1} region represents the cellulose of natural fibers.[39,40]

The sharp peak at 1027 cm^{-1} was associated with the C—O group of hydroxyl and ether groups present in the cellulose.[41] Another sharp peak at 1060 cm^{-1} represented the alcohol group (C—OH) present in cellulose particles.[42,43] The peak at 1239 cm^{-1} in the spectra of Jute A and Jute B is assigned to the C—O stretching of the acetyl group of lignin.[44,45] The absorbance at 1440 cm^{-1} is associated with the CH_2 symmetric bending present in lignin. The intense peak indicated at 1731 cm^{-1} attributed to the C═O group of the acetyl groups present in hemicelluloses.[46]

The high peak revealed at 1632 cm^{-1} corresponds to the moisture content (H—O—H group) of the natural fiber.[47,48] or to the carbonyl groups (C═O) present in lignin and hemicelluloses.[49,50] The visible peak at 2350 cm^{-1} presented wax and it related to the C═C group,[51] this peak appears only for Jute C, being absent in the spectra of the two others. The peaks at 2967, 2922, and 2895 cm^{-1} indicate the presence of the aldehyde group, C—H stretching and bending showed the presence of CH and CH_2 in cellulose and hemicelluloses.[41,52] The final peak at 3335 cm^{-1} is due to the presence of O—H stretching of the hydrogen bonding network, which corresponds to the presence of α-cellulose in the fiber.[5,53–55] Generally, the band between 3100 and 3600 cm^{-1}, attributed to the O—H group (stretching of the hydroxyl bond), strongly increased in intensity, due to the increase in the proportion of cellulose in the fibers. Comparing our results with those found in the literature, the conclusion is that the jute used in this work is not exceedingly contaminated, since, basically, the spectra reveal the presence of the same or almost the same components as in raw fibers.

3.2 | Thermogravimetric analysis

TGA allows observing the variation of the mass of a sample as a function of temperature. The main goal of this analysis is to better understand the thermal behavior of the jute fiber to predict its failure (degradation) during the manufacture of our biocomposites with a thermoplastic matrix. The curve in Figure 6 represents the superposition of the three types of jute used in this study. This curve allows identifying more clearly the thermal stability of Satin, Twill 2 × 2, and Taffeta

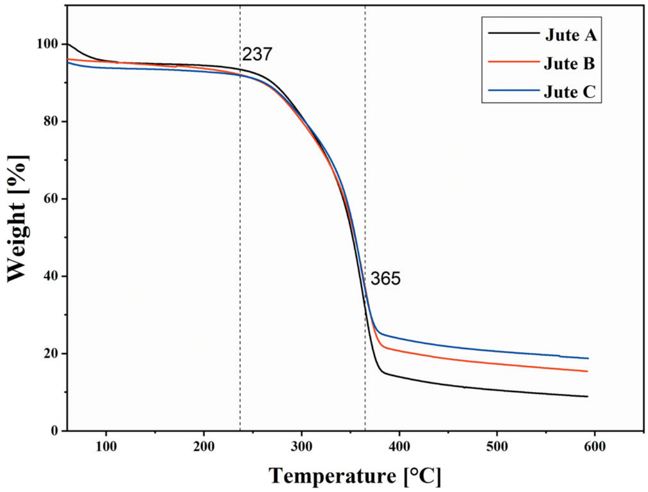


FIGURE 6 Thermogravimetric analysis of jute fabrics

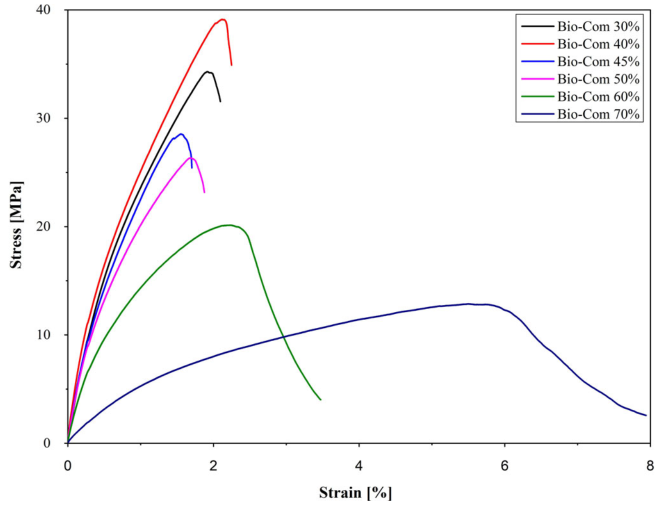


FIGURE 7 Stress evolution as a function of deformation for different mass fractions of the reinforcement

fabrics. TGA was carried out between room temperature and 600°C, with a heating rate of $10°C min^{-1}$ in Nitrogen N_2 atmosphere.

The first decomposition step of the fiber components is due to the wax (above 120°C) and pectin (above 180°C), followed by the degradation of cellulose and hemicelluloses,[56] and then by that of lignin.[57] According to the literature, the first mass loss, observed in the range of 50–100°C in the figure, is due to the evaporation of hygroscopic water. The second mass loss occurring around 237°C is mainly due to pectin degradation, and the third—around 365°C is due to decomposition of lignin and other cellulosic substance.[58] Beyond that temperature, the jute is thermally degraded.

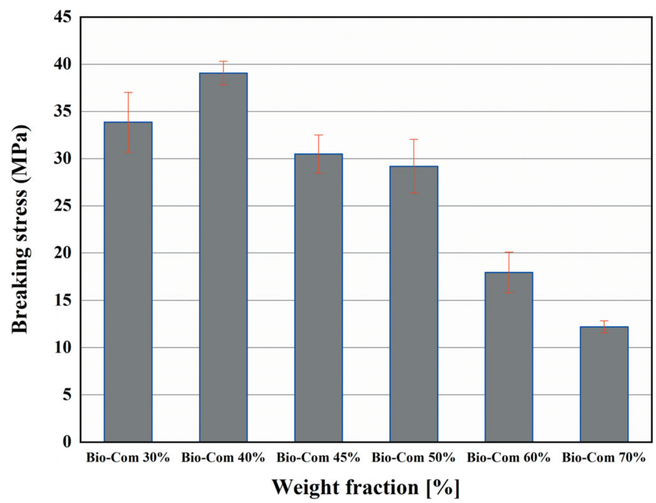


FIGURE 8 Evolution of the breaking stresses of biocomposites in the function of the mass fraction

3.3 | Mechanical performance of composite: Identification of optimum jute fiber content

In the following, the results of mechanical tests, obtained from tensile and flexural testing of biocomposites, are illustrated and discussed. This part aims to determine the best fiber loading to use for reaching optimal performance. For this purpose, biocomposites with different mass fractions (30%, 40%, 45%, 50%, 60%, and 70%) were prepared. The results of the static tests performed according to ASTM D638-03 of the different materials tested are shown in Figure 7. Figure 7 represents the typical stress as a function of deformation of biocomposite PP/jute specimens loaded in static tensile stress with different mass fractions, as already mentioned earlier. It should be noted that the biocomposite with the mass fraction 40% (Bio-Com 40%) presents good performance ($\sigma = 39.07$ MPa), followed by the Bio-Com 30% material ($\sigma = 33.85$ MPa). Meanwhile, the rest of the biocomposite materials: Bio-Com 45%, Bio-Com 50%, Bio-Com 60%, and Bio-Com 70%, show a behavior inversely proportional to the mass fractions of jute fibers, that is, as the mass fraction increases, the breaking stress of the material decreases.

This behavior is expected because the fiber ratio increases considerably, unfavorably affecting the PP fiber/matrix adhesion. It should also be noted that the behavior of the biocomposites varies significantly. In the case of the materials with a lower mass fraction of jute, that is, Bio-Com 30%, Bio-Com 40%, Bio-Com 45%, and Bio-Com 50%, the behavior is semi-controlled, while a purely controlled behavior is noted for Bio-Com 60% and Bio-Com 70%. This is explained by the poor impregnation of the jute fiber with the PP matrix. Also, the histogram in Figure 8 provides more details on the selection of the best

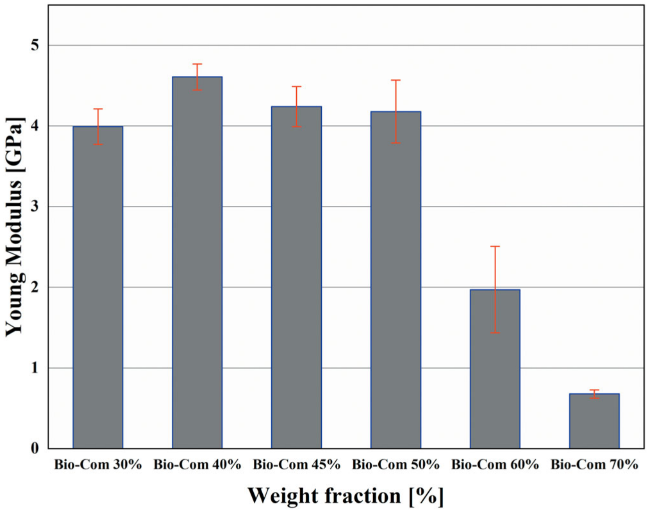


FIGURE 9 Evolution of Young's modulus of biocomposites in the function of the mass fraction

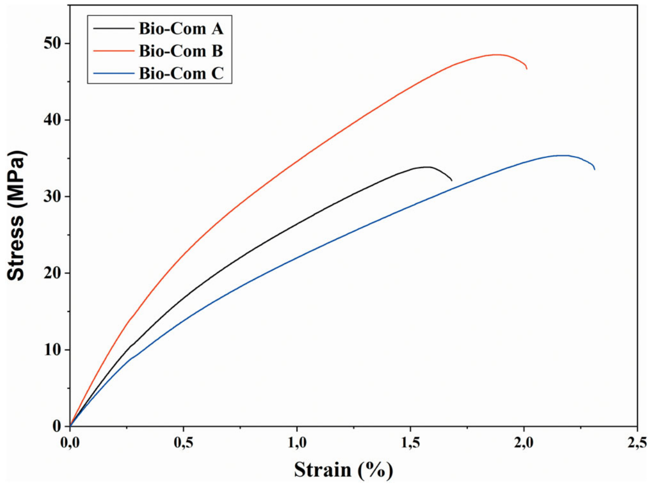


FIGURE 10 Stress–strain curve of the different biocomposites

fiber content. On this histogram, the stress value is maximum for Bio-Com 40% ($\sigma = 39.07$ MPa), while this stress is significantly higher than that recorded for the other grades (30%, 45%, 50%, 60%, and 70%).

Another comparative parameter that can also be considered is Young's modulus. The histogram in Figure 9 shows the stiffness modulus values for the different biocomposites developed in the study. The material Bio-Com 40% shows the highest stiffness ($E = 4.60 \pm 0.16$ GPa), followed by Bio-Com 45% and Bio-Com 50%, with modulus values of $E = 4.23 \pm 0.24$ GPa and $E = 4.17 \pm 0.38$ GPa, respectively. However, it should be observed that the material Bio-Com 30% showed a lower modulus value than the above-mentioned biocomposites. In conclusion, the Bio-Com 40% material has recorded good performance in terms of both strength and stiffness. Therefore, the 40% mass fraction of fiber has been selected for further studying the effect of the type of fabric weave on the behavior of such biocomposites.

3.4 | Mechanical properties: Tensile

Mechanical properties of jute-reinforced PP composites depend on the strength of the matrix and reinforcement and their adhesion properties. This section aims to determine the mechanical performance of composites with different woven fabrics used as reinforcement (Fabric A, Fabric B, and Fabric C). The tensile properties of a composite material provide better information of interfacial bonding of fiber—matrix; however, the modulus shows more about the reinforcement and matrix strength individually.[59]

The results of the static tests, performed according to ASTM D638-03, of the different materials tested are shown in Figure 10. This figure reveals the typical stress evolution as a function of the strain of the biocomposite PP/Jute specimens loaded in static tension, with different woven fabrics as reinforcement. All three types of biomaterials exhibit a semi-controlled behavior. The biocomposite material obtained from Fabric B and PP (Bio-Com B) reveals the desired good performance. The last two materials (Bio-Com A and Bio-Com C) have almost the same load level, but the displacements at break are different. This difference is a reflection of the architectural structure of the two fabrics.

3.5 | Mechanical properties: Breaking stress

The histogram in Figure 11 presents the stress values of the different biocomposite materials obtained. It can be seen from the figure that, of the three biocomposites, the 2×2 twill fabric composite had the highest tensile strength ($\sigma = 44.43 \pm 4.23$ MPa), 23% higher than that of the other two fabrics, which recorded the following values: Bio-Com C ($\sigma = 34.27 \pm 2.87$ MPa) and Bio-Com A ($\sigma = 33.73 \pm 0.1$ MPa). This difference can be explained by the structural morphology of the 2×2 twill fabric (Bio-Com B). Therefore, the 2×2 Twill structure is recommended when tensile strength is the main concern.

3.6 | Mechanical properties: Young's modulus

The tensile modulus of 2×2 twill biocomposites (Bio-Com B) also exhibited a higher value ($E = 5.36$

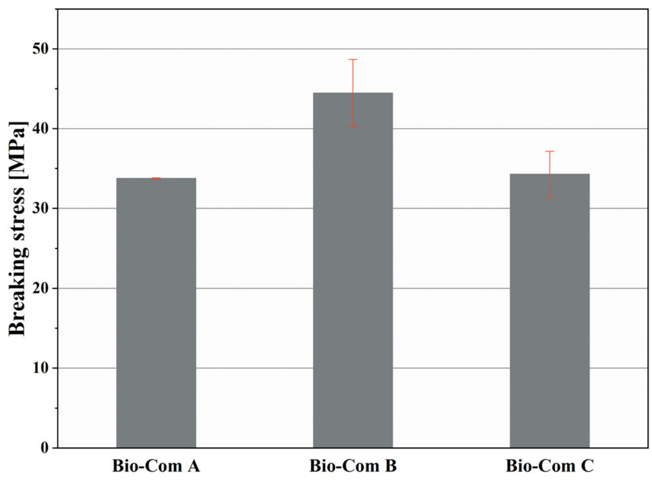


FIGURE 11 Evolution of the breaking stresses of biocomposites

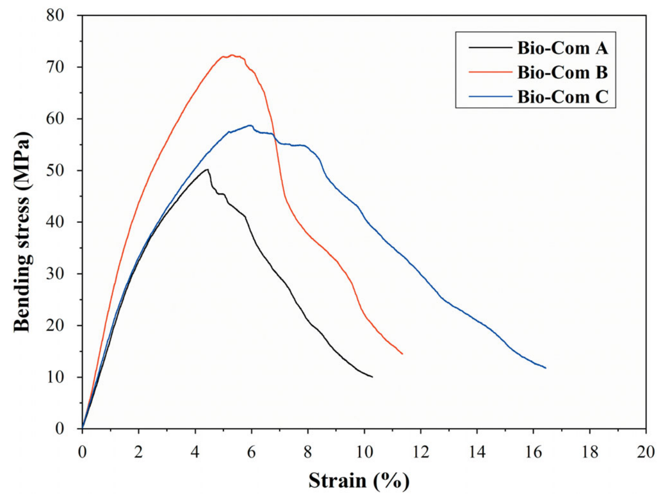


FIGURE 13 Stress evolution as a function of deformation

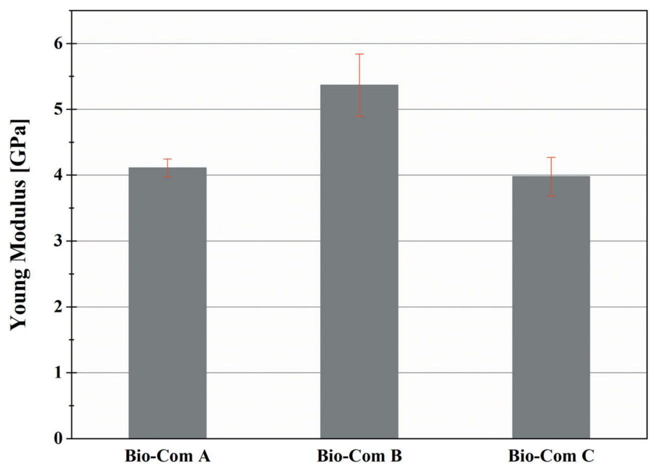


FIGURE 12 Evolution of the Young's modulus of biocomposites

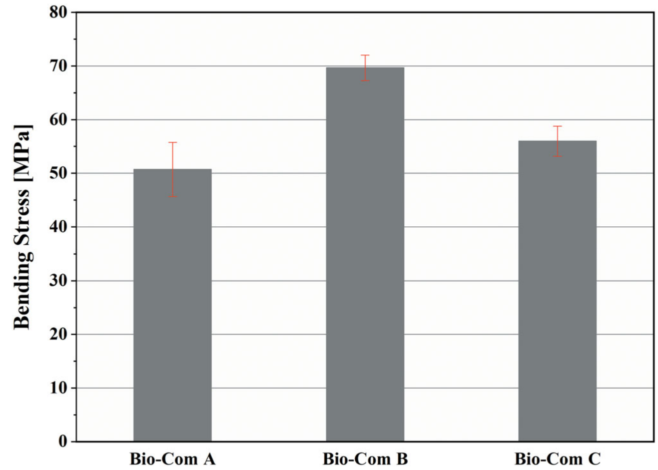


FIGURE 14 Evolution of the stress of biocomposites

± 0.47 GPa) than those of the other two biocomposites. The twill structure shows better stiffness compared to the other two materials. The histogram in Figure 12 shows the values of Young's modulus recorded for the different biocomposite materials, as obtained from the tests on different weaves. The Serge 2 × 2 fabric structure allowed a difference of about 23% in the modulus level, compared to Bio-Com A ($E = 4.11 \pm 0.13$ GPa) and of 26% compared to Bio-Com C ($E = 3.97 \pm 0.29$ GPa). It should be noted that the weaving structure of the Bio-Com B material explains the recording of such a high modulus of rigidity. This could be also attributed to the better dispersion of the 2 × 2 twill fabrics in the PP matrix.[59]

3.7 | Mechanical properties: Bending properties

This part of the study aims to determine the performance of the biocomposites reinforced with different weaves (Fabric A, Fabric B, Fabric C) under bending stress. The results of the static tests, carried out according to ASTM 970, of the different materials tested are shown in Figure 13. This figure illustrates the typical stress versus strain evolution of jute/PP biocomposite specimens under three-point bending stress. The flexural properties of the biocomposites with different fabric structures are shown in Figure 14. The highest bending strength value was observed for the 2 × 2 twill fabric composites (Bio-Com B), which was $\sigma = 69.64$ MPa, much higher than those of

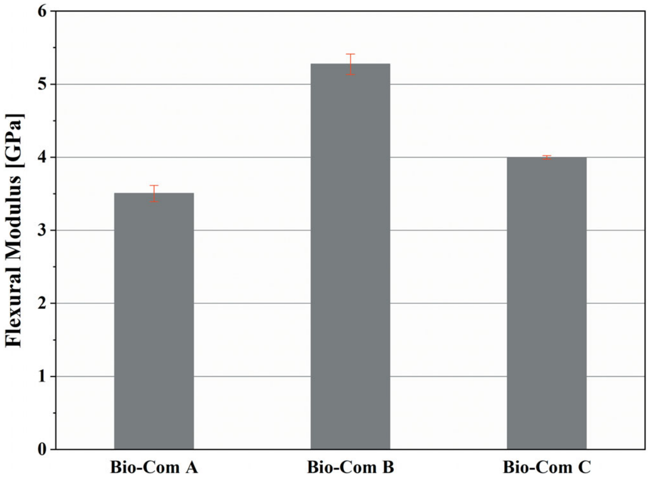


FIGURE 15 Evolution of the flexural modulus of biocomposites

the other bio-composites (Bio-Com C and Bio-Com A), which had almost similar bending stress at break values ($\sigma = 55.96$ MPa and $\sigma = 50.7$ MPa, respectively). This means that the latter two biocomposites have almost the same mechanical behavior in bending. In general, the flexural strength is much higher than the tensile strength, which is due to the failure behavior of the outermost matrix layer.[59]

3.8 | Mechanical properties: Flexural stress

The histogram in Figure 14 shows that the flexural breaking stress of a biocomposite is influenced by the weaving nature of the reinforcement. As can be seen in Figure 14, the stress of the Bio-Com B material reached a maximum value, which is of the order of $\sigma = 69.64 \pm 2.38$ MPa, compared to those of the other two materials Bio-Com A and Bio-Com C, which were significantly lower ($\sigma = 50.7 \pm 5.05$ MPa and $\sigma = 55.96 \pm 2.82$ MPa, respectively).

3.9 | Comparison of biocomposites reinforced with different weaves: Flexural modulus

The histogram in Figure 15 shows that the biocomposites reinforced by different weave morphologies (Fabric A, Fabric B, and Fabric C) have quite different flexural modulus values.

As can be seen in the figure, the flexural modulus of the Bio-Com B biocomposite (2×2 Twill Fabric) has a value of the order of $E = 5.27 \pm 0.14$ GPa, while the other two biomaterials, Bio-Com C and Bio-Com A, had a rather low flexural modulus compared to the first material, that is, $E = 3.99 \pm 0.02$ GPa and $E = 3.50 \pm 0.11$, respectively. As already discussed in the case of tensile strength, the flexural modulus performance of the Bio-Com B composite stems from the 2×2 Twill weave, which ensures a good distribution of the reinforcement in the PP matrix.

4 | CONCLUSION

Although in the past jute bags were used exclusively for the transport of coffee beans, cocoa, and other foodstuffs, today such bags have reached a completely new dimension. Considered to be the best solution for preserving the environment, jute bags are being increasingly used by private individuals and professionals for gardening and construction works, as well as for many other uses. Our contribution consists in recovering these bags after use and reusing them as reinforcement of a thermoplastic matrix, which, in this study, is another residue resulting from the manufacturing process of PP yarns.

Our work has been carried out in two stages. The first stage was aimed to determine the optimum fiber reinforcement ratio to achieve the best mechanical characteristics. This step revealed that 40% by mass is an adequate fiber loading to reach good mechanical properties ($\sigma = 39.07$ MPa, $E = 4.60$ GPa). Using this percentage, in the second step, jute–PP biocomposites with different jute fabric architectures (Satin, Serge 2×2, Taffeta) were developed. The characterization of the biocomposites in tension and flexion revealed that the Bio-Com B material (serge 2/2) recorded good performance in terms of both tensile strength ($\sigma = 44.43 \pm 4.23$ MPa) and flexural strength ($\sigma = 69.64 \pm 2.38$ MPa). Also, the material exhibited good tensile stiffness ($E = 5.36 \pm 0.47$ GPa) and flexural stiffness ($E = 5.27 \pm 0.14$ GPa). As regards elongation at break, the difference between the strain of the three materials in tension and bending is not noticeable.

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ORCID

Mohammad Jawaid https://orcid.org/0000-0001-5348-5740

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