Application of Coffee Production Waste to Obtain Composites with Biopolimeric Matrix of PBS and ECOVIO

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Numerous environmental problems have arisen due to excessive production and consumption of non-renewable polymers. Thus, some strategies have been developed to mitigate the impacts, including degradable biopolymers, PBS, and ECOVIO, whose properties are improved by adding vegetable fibers. This work aims to obtain composites whose biopolymeric matrix will be reinforced with coffee residues and to evaluate their mechanical properties. The methodology consisted of drying, extrusion, dehumidification, injection, and tensile testing. The added residue showed good interaction with the matrix, reduced the elongation and ductility of the composites, and increased their rigidity. Thus, it was concluded that the composite (PBS WC 70/30) increased 62.5% in the elastic modulus, showing that it is the best material among those studied.

Keywords: Biopolymers. Composites. Plant Fibers. PBS. ECOVIO.

Since the beginning of the last century, polymers have become indispensable in contemporary society due to their variety of applications, properties, versatility of use, and, mainly, low production cost [1,2]. On the other hand, large-scale production, excessive consumption, and incorrect disposal are the main factors responsible for the accumulation of these synthetic polymers in different environments, causing environmental problems, which have been the world's agenda for discussions and research in various fields branches of science [3-6].

As an alternative to mitigate the environmental impacts of plastic waste, some strategies have been employed, such as incineration, recycling, landfills, biodegradation, and using biodegradable polymers. The latter, in turn, has been gaining attention for being produced from renewable sources, in addition to its degradation proceeding from the action of microorganisms, producing CO_2, CH_4, cellular components, and other products.

Among the biopolymers, PBS has properties such as high flexibility, excellent thermal stability, biological and biodegradable base, eco-efficiency, and, mainly, because it is commercially available and exhibits a gas/humidity barrier like PLA (MITSUBISHI CHEMICAL CORPORATION).

ECOVIO, in turn, is a polymeric blend between PLA and PBAT and is responsible for giving the biopolymer moderate flexibility and impact resistance while still being commercially attractive, being widely used in flexible and resistant packaging, injected, and bags [7].

However, some properties of this class of polymers need to be improved. For this, additives are incorporated by combining two or more miscible and compatible materials to add color to the material, increase the mechanical or thermal resistance of the material, increase flexibility, decrease the influence of water on material properties, and so on [8]. Some additives widely used in packaging development are plasticizers and reinforcing agents that help in the materials' processability, mechanical strength, and water resistance [9,10].

The production of these blends together with materials of natural origin, with little added value and easy to obtain, such as coconut fibers, corn, sisal, rice husks, sunflower, and coffee residues, among others, are incorporated together with the polymeric matrix (continuous phase) promoting a sustainable alternative with a reduction in the cost

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of production and in the mass of polymer to be used in the manufacture of the product, in addition to reusing waste that is improperly disposed of in the environment [11,12].

Brazil, as a major coffee producer and exporter, occupies the second position in the world as the largest consumer of this drink and is one of the largest food industries in the world, being divided into two main sectors: separation of the husk and mucilage of coffee fruits and, the roasting and infusion stage of the beans.

However, the high demand for coffee has produced excessive by-products in all stages of coffee processing since only 10% of the fruit are products of interest. In comparison, the other 90% become waste with different chemical compositions, among them its high biodegradability [13].

This article aims to analyze the obtainment of composites through the sustainable use of coffee by-products as a reinforcing filler in commercial biopolymers and to evaluate their mechanical properties.

Materials and Methods

The methods used for the current study were drying, extrusion, dehumidification, injection of specimens, and tensile tests.

After drying the PBS, ECOVIO, and WC (post-stripping residue) in an oven at 90°C for about 48 hours, the materials were processed according to the formulations (Table 1) in an IMACOM twin screw correlational extruder, model DRC 30: 40 IF, with a thread diameter of 30 mm and an L/D ratio of 40. The material was extruded at 37/90 /137/138/137/148/145/142/137/140/144/143°C in the respective temperature zones, with a screw speed of 200 Rpm.

A ROMI injection machine, Primax model, with a capacity of 100 tons of closing force, universal screw with a diameter of 50 mm, and an L/D ratio of 20 was used to obtain the specimens (Table 2). Before injection, the material was dehumidified at 90°C in a PIOVAN model T501X dehumidifier for a minimum of 6 hours.

In order to evaluate the mechanical properties of the different composites, the specimens were subjected to a tensile test, carried out in a testing machine from the brand EMIC – Equipamentos e Sistemas de Ensaio Ltda, Model DL 2000, according to ISO 527 type 5, without the use of an extensometer. The load cell used was 8kN.

The properties of tension, modulus of elasticity, and deformation were evaluated at maximum force at a displacement speed of 50 mm/min.

The averages and their respective standard deviations were calculated using the data to obtain the stress *versus* strain graph using the Origin Pro 8.1 program. The moisture test was performed using a halogen moisture analyzer and an infrared touch screen REF m5-thermo BEL Engineering®.

Table 1. Composite formulations.

Polymers (%)		Coffee Waste	Reference Code
ECOVIO	100	0	ECOVIO
ECOVIO	80	20	ECOVIO WC 80/20
ECOVIO	70	30	ECOVIO WC 70/70
PBS	100	0	PBS
PBS	80	20	PBS WC 80/20
PBS	70	30	PBS WC 70/30

Table 2. Processing parameters of specimens processed in an injection.

Pressure (bar)	Speed (m/s)	Holding Pressure (bar)	Volume Dosage (cm^3)	Back Pressure (bar)	Dosing Speed (m/s)
950	95	700	62	10	450
Temperature Real (^oC)		**Heating**			
		Front	**Zone 3**	**Zone 2**	**Zone 1**
		180	150	150	148

Results and Discussion

To evaluate the mechanical properties of the composites and determine their tensile strength, the formulations were molded according to ASTM D638 (Figure 1) and subjected to a uniaxial tensile force gradually applied until failure. Table 3 shows the forces' mean values and respective standard deviations, tensile modulus, and elongation at break.

A stress-strain graph was obtained for each composite tested based on the above values. Figure 2 contains information about the mechanical behavior of the samples, including points of maximum stress and failure point.

From the tensile test, it was possible to observe that the composites obtained showed a lower tension compared to the starting materials (ECOVIO or PBS) due to the addition of residues that are responsible for reducing the elongation of the composites at the moment of rupture, taking into account considering that the formulated materials have intermediate characteristics between the matrix and the pure fiber due to the adopted principle of combined action. Cellulosic materials and those with a high fiber content have a higher modulus of elasticity than polymeric matrices, whose decrease in ductility shows an increase in the rigidity of the composites. According to Callister Jr. [14], the properties of composite materials are a function of the properties

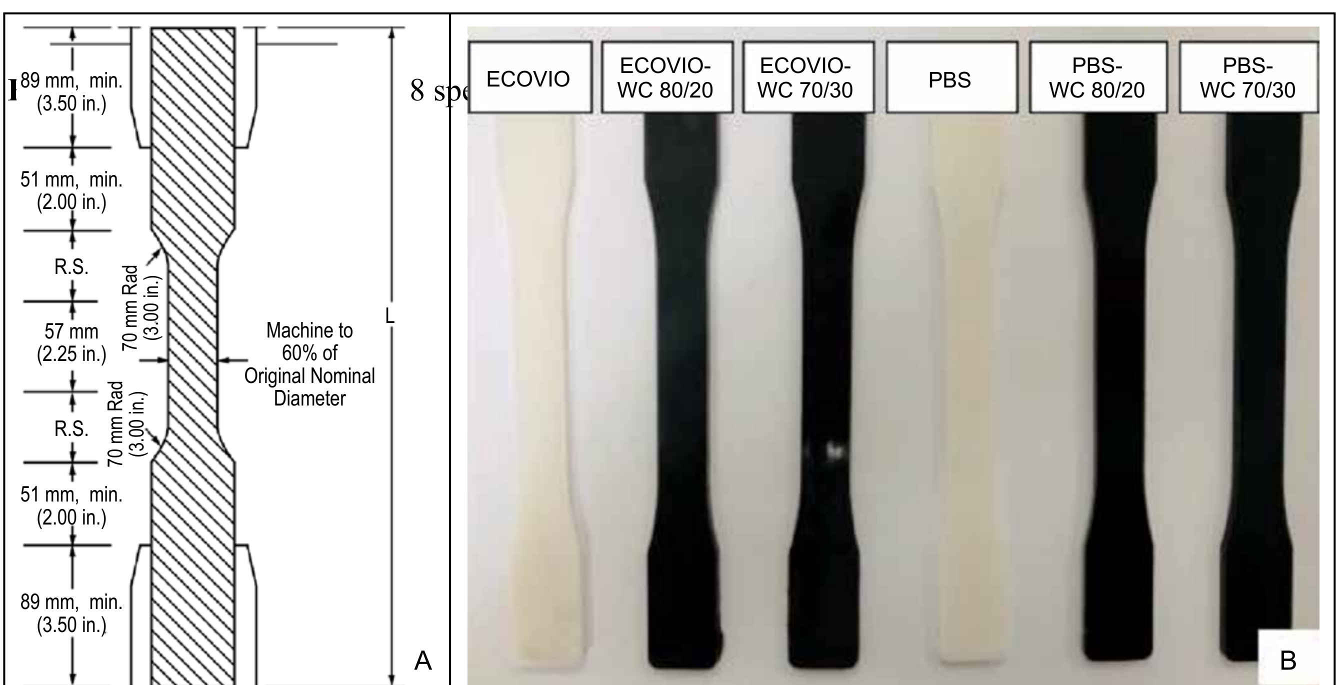
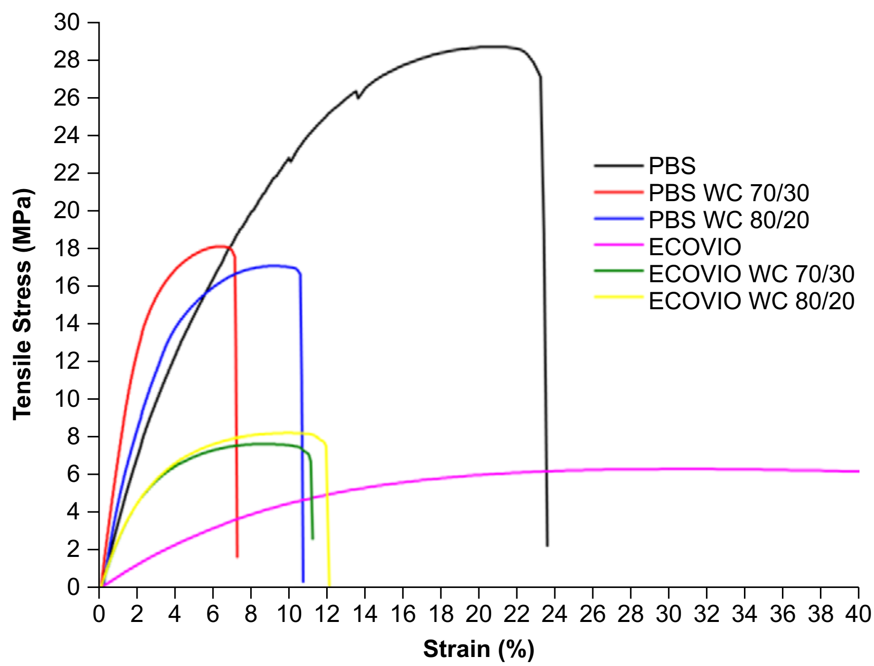


Table 3. Mechanical tests: Tensile strength, tensile modulus, and elongation break.

Composition	Tensile Strenght (MPa)	Tensile Modulus (MPa)	Elongation at Break (%)
ECOVIO - WC 80/20	9.9 ± 0.42	381.7 ± 10.11	9.7 ± 0.95
ECOVIO - WC 70/30	9.4 ± 0.52	403.6 ± 12.69	9.29 ± 1.38
ECOVIO	13.0 ± 1.08	89.95 ± 17.50	679.67 ± 18.01
PBS - WC 80/20	21.4 ± 0.52	769.8 ± 76.62	11.00 ± 1.15
PBS - WC 70/30	21.5 ± 0.58	1214.8 ± 36.7	5.51 ± 0.43
PBS	35.0 ± 0.64	455.22 ± 51.55	22.71 ± 0.95

Figure 2. Composite stress-strain graph.



of the constituent phases, their relative quantity, and the geometry of the dispersed phase, such as shape, size, distribution, and orientation of the added particles. Thus, the added fiber load entered the polymeric matrix, promoting good interaction and performance, increasing its rigidity, and evidencing a lower ductility of the composites. As for the tensile modulus, it was found that the addition of fibers to the matrices provided the composites with an increase in this value, so PBS + 30% WC was the material that acquired more excellent resistance to reversible deformation, that is, a capacity for less elastic deformation in the face of an applied force. Natural fibers present hydrophilic behavior due to hydroxyl groups in their structure, thus absorbing water from the atmosphere. According to Dackal and colleagues [15], this hydrophilic behavior of the fibers can be a problem since the absorption of water can reduce the mechanical properties. Thus, the humidity test was performed for the waste under study (WC), and an average value equal to 11,34% was found, considered, according to 16-19, above the maximum allowed, corresponding to 9%.

This difference may be associated with a prolonged exposure time of the fiber and high porosity, which facilitates water entry into its structure.

We observed that all composites presented air spaces/bubbles inside their test specimens (Figure 3) which may have contributed to its fracture, masking the accurate result regarding the material's resistance. Among the formulations, the composites with PBS presented a lower incidence of bubbles and a smaller diameter. This intervention may have come from the presence of moisture in the fiber, volatility of compounds present in the composite, or failure during the injection process to produce specimens.

Conclusion

We concluded through the tensile tests the results were promising, so that the addition of residues in the composites from the coffee industry presented a good interaction with the biopolymer matrix (ECOVIO and PBS), causing a reduction in the elongation of composites due to their high fiber content. This effect is responsible for causing a reduction in the ductility of the materials and, consequently, an increase in their rigidity. Among the formulations studied, the one containing PBS + 30% WC was the one that showed the most significant resistance deformation in the face of an applied tension force, whose calculated increase was approximately 37.5%. In this way, these composites can be used as an alternative to minimize the costs of biodegradable polymers and to be a destination for the waste in question. Other characterizations will be carried out later to elucidate the properties of these materials.

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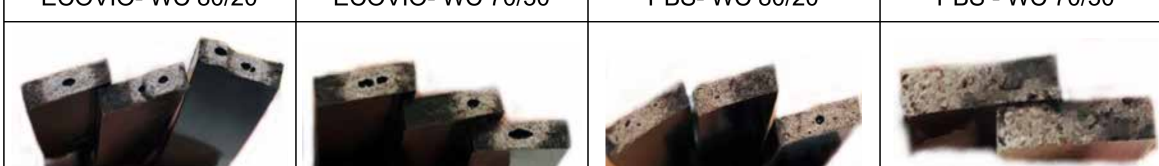
Figure 3. Specimens of composites after tensile test.

ECOVIO- WC 80/20	ECOVIO- WC 70/30	PBS- WC 80/20	PBS - WC 70/30



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