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CIRCULARITY OF PLASTICS AS A POTENTIAL SOLUTION TO REDUCE MICROPLASTICS: RECYCLED PP/COCONUT FIBER OR SUGARCANE BAGASSE COMPOSITES

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ABSTRACT

It is imperative to improve understanding of plastic losses throughout the plastics value chain and to develop appropriate strategies to mitigate the environmental impacts of plastics. To encourage the circularity of plastics, in this work composites based on virgin and recycled polypropylene and two types of natural fiber (coconut and sugarcane bagasse) with or without content of 10% by weight were prepared in a mono-screw extruder. Pelletized samples obtained by extrusion were stamped from plates obtained by compression in a bench press and these materials were characterized through measurement of density, hardness and melt flow index (MFI). The density results indicated good fiber-matrixadhesion for all types of fiber and matrix used. A slight decrease in the hardness of formulations in relation to the matrix was associated with uneven distribution of fibers in the matrix. The MFI results were sufficient for these materials to be submitted to traditional polymer processing methods.

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INTRODUCTION

Microplastics are particles smaller than five millimeters in length derived from the degradation of plastic objects present in the environment. Primary MPs are purposefully produced and enter the environment as particles/powder (less than 0.5 mm), used for example as abrasives in cosmetic products or scrubbers to blast-clean surfaces. In contrast, secondary MPs originate from the fragmentation of larger plastic litter. The most common process of generating secondary MPs is weathering, which typically occurs when plastic is exposed to solar UV radiation that catalyzes the oxidative degradation of polymers (Ragusa *et al.*, 2021; Torres-Agulo *et al.*, 2021). The link betweennthe idea of a circular economy and micro (nano) plastic contamination is seldom explicit, even though the vast majority of MPs (and NPs) found in the environment are secondary breakdown products, meaning particles that come from fragmentation of larger plastic pieces,such as household products. This implies that reducing plastic pollution in general will also reduce micro (nano) plastic contamination (Syberg *et al.*, 2015). According to a 2017 IUCN report, microplastics are responsible for 30% of the Great Pacific Garbage Patch, thus being a major source of marine pollution. Indeed, in many developed countries these materials are a greater marine plastics pollution source than the visible larger pieces of litter

In the study by Ragusa *et al.* (2021), six human placentas, collected from consenting women with physiological pregnancies, were analyzed by Raman microspectroscopy to evaluate the presence of microplastics. All told, 12 microplastic fragments (ranging from 5 to 10 μm in size), with spheric or irregular shape were found in four placentas (five in the fetal side, four in the maternal side and three in the chorioamniotic membranes).All microplastic particles were characterized in terms of morphology and chemical composition. All of them were pigmented; three were identified as composed of stained polypropylene (a thermoplastic polymer), while for the other nine it was possible to identify only the pigments, which were all used for manmade coatings, paints, adhesives, plasters, polymers, cosmetics and personal care products. Possible consequences on pregnancy outcomes and the fetus are the transgenerational effects of plasticizer on metabolism and reproduction. Demand for single-use-plastics (SUP) has increased due to the high contagion level of COVID-19. As a result, many governments have delayed SUP bans and have encouraged people to use them to avoid cross-contamination despite the negative effects of these plastics, including those infacemasks (polypropylene, polyethylene), in marine ecosystems. Thus, the fraction of MPs coming from masks is expected to increase in ensuing years (Torres-Agullo *et al.*, 2021). Transition to a circular plastic economy is viewed as the cornerstone to assure a more sustainable future for plastic consumption (European Commission,

for as long as possible and reducing the pressure on the environment from resource consumption (Syberget *al*., 2022). Natural fiber-reinforced polymer composites have attracted strong scientific interest due to their wide availability, biodegradability, renewability, environmental friendliness, low cost and density, good thermal and acoustic properties, low energy consumption and high energy recovery, and non-abrasive nature, among other benefits (Ray *et al*., 2020). In order to encourage the circularity of plastics, in this work, composites based on virgin and recycled polypropylene and two types of natural fiber (coconut and sugarcane bagasse) withor without content of 10% by weight were prepared in a mono-screw extruder. The pelletized samples obtained by extrusion were stamped from plates obtained by compression in a bench press. The materials were characterized through measurement of density, hardness and melt flow index (MFI).

EXPERIMENTAL PROCEDURES

Raw Materials: The virgin polypropylene (PP) used in this work was acquired from Braskem S/A (density of 0.905 g.cm^{-3} and melt flow index of 3.5 g/10 min at 230°C/2.16 Kg), while black recycled polypropylene (rPP) was donated by PolialbinoTermplásticos (São Paulo, SP, Brazil). The coconut fiber was acquired from Empresa Coquim (São Paulo, SP, Brazil). The sugarcane bagasse (SC) wasprovidedby HC Sucroquímica (Rio de Janeiro, RJ, Brazil). Initially, the bagasse was shredded in a blender with distilled water, in the proportion of 3:1. The bagasse was dried at 105 ºC, in an oven for 24 hours and then shredded again in the blender for 10 minutes, in order to separate the fibers.Coconut fibers (*Cocus Nucifera*) were supplied in ground form. To reduce the costs of the process, no coupling agent was used.

Composite processing: Coconut fibers (CF) and sugarcane bagasse(SC) were previously dried in an oven with forced air circulation at 100 °C until constant weight (approximately 24 hours), and stored in a desiccator for another 24 hours before processing. The materials were mixed manually. The matrix/fiber formulations were composed of proportion of 100/0 and 90/10 (by weight percentage) according to Table 1. Each formulation was fed into a mono-screw extruder (AX Plásticos) with three temperature zones (160, 170 and 200ºC) from the head to the die, respectively, operating at32 rpm. For characterization, the pellets from each extruded composite were pressed at 190 ºC and 3 tons for 300 seconds and cooled in a cold press for 60 seconds. Figure 1 shows the extruded composites.

Table 1. Formulations of extruded composites

Sample	Weight percentage (%)	Matrix (g)	Fiber (g)
rPP	100	100	0
rPP/CF	90/10	90	10
rPP/SC	90/10	90	10
PP	100	100	0
PP/FC	90/10	90	10
PP/SC	90/10	90	10

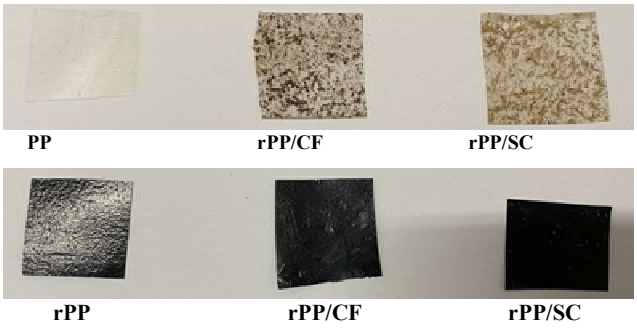

Figure 1. Extruded and pressed composites

CHARACTERIZATION

Density: The density was determined according to the ASTM D792-2013 standard, with a densimeter (Gehaka model DSL 910) using three specimens of each prepared composite.

Hardness: Hardness tests were performed according to ASTM D2240–05 (2010). We used a Shore D Durometer (Type GS 702) to obtain the Shore D hardness values of the materials, using three specimens of each prepared composite.

Melt flow index (MFI): To determine the melt flow index (MFI), a CEAS Quick Index instrument was used according to the ASTM D1238-2013 standard, at a temperature of 190 ºC and load of 2.16Kg, using five specimens from each sample, weighed on an analytical scale (Mars AY220).

RESULTS AND DISCUSSION

Table 2 and Figure 2 show the results of density analysis, namely 0.826, 0.837 and 0.801 g.cm^{-3} for PP, PP/CF and PP/SC, respectively, indicating good fiber-matrix adhesion. All composites showed density close to that of virgin PP. For recycled matrix, the density results were 0.557, 0.767 and 0.834 g.cm^{-3} for rPP, rPP/CF and rPP/SC, respectively, showing that sugarcane bagasse was better incorporated inthe recycled matrix than coconut fiber. Density variations can come from differences in particle packing and particle wall roughness (Ou *et al*., 2014; Bastos *et al*., 2018; Bakshi *et al*., 2020; Chagas *et al*., 2022).

Table 2. Density results of formulations

Formulations	Sample 1	Sample 2	Sample 3	Density (g.cm^{-3})
rPP	0.633	0.604	0.434	0.557±0.107
rPP/CF	0.832	0.751	0.717	0.767±0.059
rPP/SC	0.889	0.802	0.812	0.834±0.047
PP	0.831	0.829	0.817	0.826±0.007
PP/CF	0.855	0.709	0.948	0.837±0.120
PP/SC	0.816	0.805	0.781	0.801±0.018

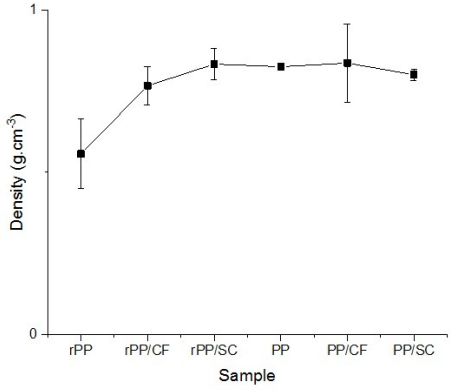

Figure 2. Density results of formulations: rPP; rPP/CF (90/10); rPP/SC (90/10); PP; PP/CF (90/10); PP/SC (90/10)

For PP and PP composites (PP/CF and PP/SC), a slight decrease in hardness (Table 3 andFigure3) in relation to the virgin matrix was observed. According to the literature (Borsoi *et al*., 2014; Bastos *et al*., 2018; Lima *et al*., 2021; Coelho *et al*., 2021; Chagas *et al*., 2022) this occurs due to the possible non-uniform distribution of the components in the matrix. For the recycled matrix and composites (rPP, rPP/CF and rPP/SC), the hardness showed lower values. The fact that the material is recycled explains these lower values in relation to virgin PP, since the post-consumption disposal and

Table 3. Hardness results of formulations

Formulations	Sample 1	Sample 2	Sample 3	Hardness (Shore D)
rPP	62.00	55.00	54.00	57.00±4.36
rPP/CF	53.00	53.00	52.00	52.67±0.58
rPr/SC	52.00	52.00	50.00	51.33±1.15
PP	68.00	65.00	68.00	67.00±1.73
PP/CF	58.00	58.00	57.00	57.67±0.58
PP/SC	59.00	59.00	58.00	58.67±0.58

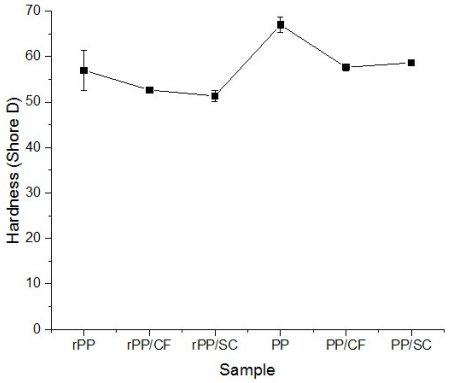

Figure 3. Hardness results of formulations: rPP; rPP/CF (90/10); rPP/SC (90/10); PP; PP/CF (90/10); PP/SC (90/10)

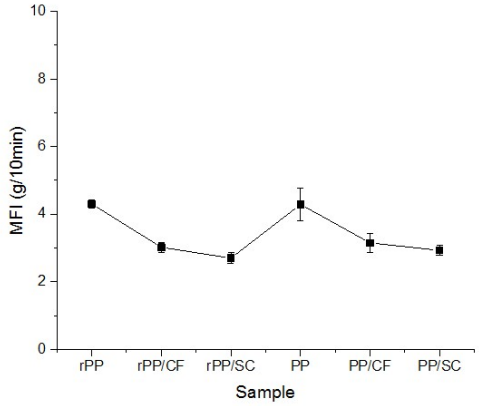

Figure 4: MFI results of formulations: rPP; rPP/CF (90/10); rPP/SC (90/10); PP; PP/CF (90/10); PP/SC (90/10)

Table 4. Melt flow index (MFI) results of formulations

Formulations	S1	S2	S3	S4	S5	MFI (g/ min)	MFI (g/10 min)
rPP	0.442	0.436	0.435	0.418	0.419	0.430	4.30±0.11
rPP/CF	0.296	0.288	0.290	0.314	0.321	0.302	3,02±0.15
rPP/SC	0.260	0.285	0.277	0.248	0.279	0.270	2,70±0.15
PP	0.484	0.408	0.479	0.391	0.384	0.429	4.29±0.48
PP/CF	0.325	0.357	0.288	0.287	0.316	0.315	3.15±0.29
PP/SC	0.311	0.299	0.297	0.281	0.277	0.293	2.93±0.14

*S – sample

In addition, some additives might have been used to improve the reprocessing of the rPP (Martins *et al*., 2019; Gerardo *et al*., 2020). The MFI results are shown in Table 4 and Figure 4.The MFI values were 4.30, 3.02, 2.70, 4.29, 3.15 and 2.93 g/10 min forrPP, rPP/CF, rPP/SC, PP, PP/CF and PP/SC, respectively. There was a slight decrease in the flow rate in the samples after the insertion of the fiber. The presence of fibers in the melted material and their partial misalignment significantly affect the viscoelastic dynamics of the melt, hampering molecular chain mobility and therefore flow. For the extrusion process, the lowest permissible MFI values are about 0.1–0.3 g/10 min, and for compression molding it can be lower than 0.1 g/10 min. All extruded formulations maintained sufficient fluidity, and the MFI values were high enough to process these materials with the traditional polymer processing methods (Bastos *et al*., 2018; Kajaksa*et al*., 2018; Soccalingame *et al*., 2015; Pereira *et al*., 2015; Coelho *et al*., 2021).

CONCLUSIONS

In this work, composites from recycled and virgin PP, coconut fiber and sugarcane bagasse were obtained by extrusion and characterized by analysis of density, hardness and melt flow index. The density results indicated good fiber-matrix adhesion. Density variations were attributed to the difference in particle packing and particle wall roughness. The slight decrease in the hardness of formulations in relation to the matrix is associated with uneven distribution of fibers in the matrix. For the extruded formulations, the MFI results were sufficient for these materials to be submitted to traditional polymer processing methods. These results are promising, since extruded composites were obtained without the use of a coupling agent, indicating the possibility of reducing not only the costs of final products, by fiber waste incorporation, but also microplastics pollution, encouraging the circularity of plastics.

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