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Original Research

Development of Environmentally Ecofriendly Composites Based on Polypropylene/Bahia Beige Waste: Effect of Reinforcement Content on Physical, Mechanical, Chemical, and Microstructural Properties

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Abstract

This article presents the development and characterization of environmentally friendly composites comprising polypropylene (PP) reinforced with Bahia Beige (BB) marble waste. The composites were prepared using different PP/BB weight ratios and analyzed for their chemical, physical, mechanical, microstructural, and thermal properties. X-ray fluorescence (XRF) analysis revealed the composition of BB, which exhibited a significant concentration of CaO, indicating the presence of calcite and other oxides. X-ray diffraction (XRD) analysis confirmed the presence of PP and identified calcite, dolomite, and quartz phases in the composites. Due to enhanced ceramic reinforcement, the composites displayed increased crystallinity with higher BB content. Fourier-transform infrared (FTIR) analysis demonstrated the interaction between PP and BB, with the bands corresponding to PP being replaced by bands related to BB as filler content increased. The density tests indicated a slight increase in composite density without deviating significantly from pure PP, which is advantageous for low-density applications. The hardness of the composites increased with filler content, while the impact resistance decreased notably. Scanning electron microscopy (SEM) images showed the good distribution of BB within the composites and the presence of ductile characteristics on the composite surface. The heat deflection temperature (HDT) results revealed that adding BB up to 40% by weight increased HDT, whereas a significant reduction occurred at a 50% BB content. These composites demonstrated favorable properties for engineering applications, offering a sustainable solution through utilizing natural waste resources and contributing to Brazilian sustainability efforts.

Keywords
Polypropylene; Bahia Beige; HDT; density; hardness; XRF; XRD; SEM; sustainability

1. Introduction

The growing concern for the environment and the need to reduce the environmental impact caused by the indiscriminate use of plastics have driven research and initiatives focused on sustainability and proper management of these materials. Additionally, using mineral waste from different industries has proven to be an important strategy in searching for more sustainable solutions [1-4].

Due to their versatile properties and low production cost, plastics have become widely used in various applications, from packaging to automotive components. However, improper disposal and the lack of effective recycling policies have resulted in a global environmental crisis, with the contamination of terrestrial and marine ecosystems by plastic waste [5, 6].

Parallel to the challenges related to plastics, the utilization of mineral waste also proves to be an important sustainability strategy. The extractive industry generates large quantities of waste, such as ashes, sludges, and tailings, which can pose significant environmental risks if not managed properly. However, these waste materials often have the potential to be reused in different applications, such as construction materials, additives in ceramic products, fertilizers, and even in the production of new composite materials [7-9].

Brazil is one of the leading global producers of dimensional stones, notably marble and granite, exported as blocks and slabs for surface coverings. Carbonate stones such as marble, limestone, and travertine account for 58% of dimensional stone production, while granites and other stones such as basalt, trachytes, and sandstones represent 38%. However, companies in the ornamental stone sector face economic challenges related to waste disposal. These wastes consist mainly of low-quality blocks that cannot be commercialized, blocks without suitable shapes for cutting, debris, crushed slabs/strips/tiles, and sludge from water treatment plants [10-12].

Among the various minerals used as ornamental stones, one material with great potential is Bahia Beige. Also known as Bege Ipê or Bege Bahia Clássico, Bahia Beige (Figure 1) is a natural stone widely recognized for its beauty, strength, and versatility. Originating from Bahia, Brazil, this sedimentary rock possesses unique characteristics that make it a popular choice for various architectural and decorative applications. With its soft tonality ranging from beige to cream and its elegant and homogeneous texture, Bege Bahia is extensively used in the architecture and design, adding sophistication and style to residential and commercial environments [13].

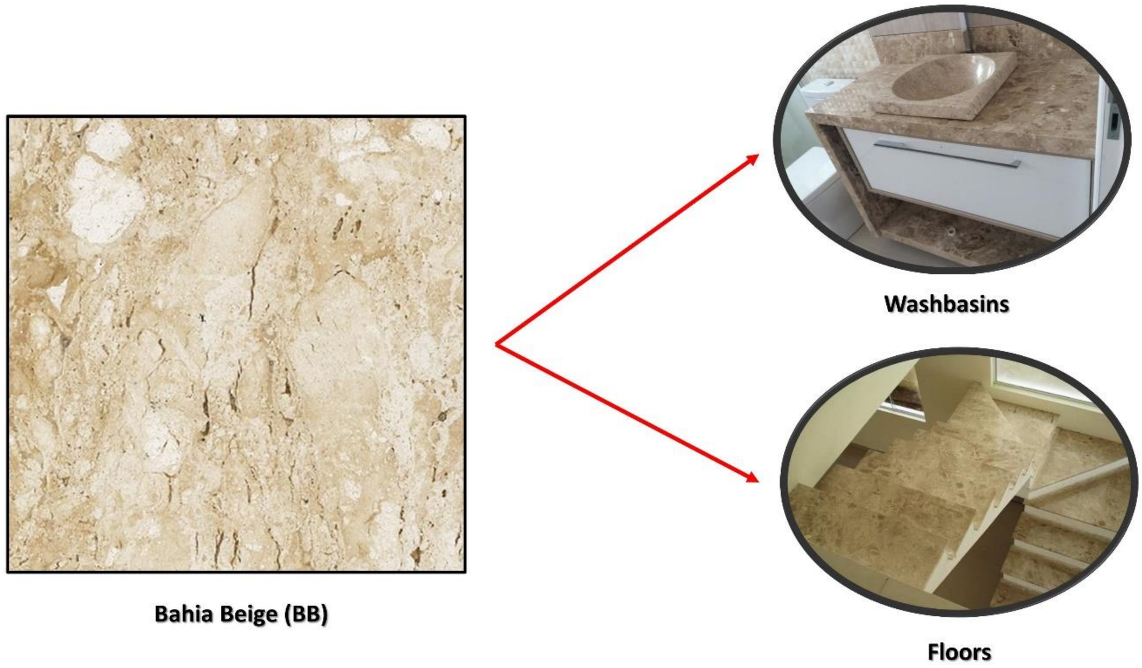

Figure 1 Marble Bahia Beige and its applications in architectural and decorative areas.

Utilizing these waste materials as substitutes in suitable applications can help mitigate their negative environmental and human health impacts. Furthermore, it can be economically and technically advantageous, leading to cost reduction and improvement in quality, respectively [8-10]. Many polymeric composites incorporate mineral fillers to reduce production costs and enhance the mechanical properties of these materials [14-16]. For example, Barros et al. [14] developed eco-friendly bricks using dimensional stone waste (limestone) and polyester resin, produced and compressed at room temperature, similar to the soil-cement brick production process. The compressive strength of the limestone/polyester brick (90/10) was 280% and 350% higher compared to the soil-cement brick and construction brick requirements, respectively. The average water absorption value for the soil-cement brick was approximately 16.3%, close to the limit specified by the standard (20%). In contrast, the eco-friendly limestone/polyester brick (90/10) had a water absorption value of only 4%. Flammability test results demonstrated that pure polyester resin tends to propagate flames. At the same time, no propagation occurred in the eco-friendly limestone/polyester brick (90/10) due to the higher fire resistance provided by the inorganic content. These environmentally friendly bricks exhibited high compressive strength, low water absorption, good thermal stability, and fire resistance when 90% of the weight comprised limestone waste. Chagas et al. [16] produced a hybrid composite for the automotive industry using recycled polypropylene, dimensional stone waste (Bahia Beige, BB), and coconut fiber (CF). The response surface methodology suggested that increasing the "coconut fiber content" is responsible for improving the mechanical properties of the composite.

Regarding the use of thermoplastic materials for composite matrices, polypropylene (PP) is one of the most widely used and versatile plastics due to its high crystallinity-to-weight ratio, which ensures good mechanical properties (high rigidity, good tensile strength). This makes it suitable for weight-sensitive applications. PP can be easily processed, is chemically inert to most diluted alkalis, acids, and solvents, is moisture resistant, and has a relatively high melting point, providing greater temperature resistance [17-20].

However, polypropylene has a high environmental impact, and many studies have focused on the recycling and reusing polypropylene-based materials. Another way to reduce the environmental impact of PP is by using natural fillers, especially when sourced from natural waste materials [21-23]. Many industries, including the automotive industry, have been developing lightweight materials for vehicle construction to minimize environmental impacts. Lightweight materials offer several advantages as they require less material during manufacturing, reducing costs and processing time. Additionally, they improve the energy efficiency of vehicles by reducing overall weight. For example, commonly used fillers in lightweight materials in the automotive industry include fiberglass, talc, and calcium carbonate [24-26].

As an example, the work of Sinha et al. [27], in which the authors investigated the effect of hybrid fillers, such as graphene nanoplatelets (GnPs) and titanium dioxide (TiO_2), on the mechanical properties of polypropylene (PP) composites. They used maleic anhydride-grafted polypropylene (MAPP) as a compatibilizing agent in polypropylene-based composites to improve the interfacial adhesion between the matrix and the fillers. Based on the obtained results, it was reported that adding hybrid fillers, GnPs and TiO_2, and MAPP as a compatibilizer, improved the modulus of elasticity and tensile strength. At the same time, the elongation at break and toughness decreased. Machado et al. [28] evaluated the effect of adding different amounts of bentonite and organoclay bentonite in post-consumer polypropylene matrices. The results indicated that adding up to 8% of bentonite or organoclay bentonite in the recycled polypropylene matrix increased the thermal stability of the composites.

Considering the premise adopted throughout this introduction, this article aims to develop polypropylene (PP) matrix composites reinforced with Bahia Beige (BB) waste for engineering applications. Developing composites using this mineral brings novelty to this research, as it is a material with great potential for reuse as a reinforcement in composites. This work used additions of BB ranging from 10 to 50 wt.%, and the physical, chemical, thermal, mechanical, and microstructural properties were analyzed.

2. Materials and Methods

2.1 Materials

Pellets of virgin PP (Braskem, Brazil) were used in the study. The PP pellets had a density of 0.905 g/cm³ and a melt flow index (MFI) of 3.5 g/10 min (measured at 230°C and a load of 2.16 kg). The pellets were sieved to achieve a granulometry of less than 10 mesh. The mineral samples used in the study were obtained from the Mineral Technology Center (CETEM, Rio de Janeiro, Brazil). These samples consisted of waste material from the cutting process of Bahia Beige marble. The density of the marble waste was determined to be 2.832 ± 0.0005 g/cm³ (from Ourolândia, Bahia), and its granulometry was less than 20 mm.

2.2 Composites Processing

The materials were dried in a forced-air oven at 100°C until a constant weight was achieved, typically taking approximately 24 h. Subsequently, they were stored in a desiccator for 24 hours before further processing. Manual mixing was employed to combine the materials, and the PP/stone dust composites were prepared with PP/BB ratios of 100/0, 90/10, 80/20, 70/30, 60/40, and 50/50 wt.% as shown in Table 1. Each formulation was subjected to hot compression molding at 190°C and 6 tons of pressure for 300 seconds. The thickness of the samples was controlled using two steel bars with a thickness of 1.36 mm. Following hot pressing, the composite was cooled to room temperature under a pressure of 6 tons for 240 s.

Table 1 Formulations of materials.

Sample (wt.%)	Mass of PP (g)	Mass of BB (g)
PP	5.0	-
PP/BB (90/10)	4.5	0.5
PP/BB (80/20)	4.0	1.0
PP/BB (70/30)	3.5	1.5
PP/BB (60/40)	3.0	2.0
PP/BB (50/50)	2.5	2.5

2.3 Characterization

2.3.1 X-Ray Fluorescence (XRF)

The mineralogical composition of BB was assessed using X-ray fluorescence (XRF) analysis with a Malvern Panalytical Axios Max WDXRF spectrometer operating at 4 kW. Simultaneously, the calcination loss was measured using a Leco TGA-701 thermogravimetric analyzer. The analysis involved two heating ramps: the first ramp ranged from 25 to 107°C at a rate of 10°C/min, while the second ramp spanned from 107 to 1000°C at a rate of 40°C/min. The test concluded after three consecutive weight measurements, each yielding identical results.

2.3.2 X-Ray Diffraction (XRD)

The XRD patterns of the formulations were acquired using a Bruker AXS D4 diffractometer (Ettlinger, Germany) equipped with Cuka radiation (λ = 1.5406 Å). The instrument operated at 35 kV and 40 mA. The spectra were recorded within the diffraction angle range of 4-80°, with a step size of 0.02° and a counting time of 1 second per step. The crystallinity degree, X_c (%), was determined using Equation (1).

$$X_c(\%) = \frac{A_c}{A_c + A_a}.100\% \quad (1)$$

where A_c the total area of the crystalline peaks and A_a the amorphous halo were measured [29, 30].

2.3.3 Fourier Transform Infrared Spectroscopy (FTIR)

The Fourier-transform infrared spectra were obtained using a Nicolet 6700 FTIR spectrometer (Thermo Scientific). Before scanning, the samples were mounted on an attenuated total reflectance (ATR) accessory equipped with a ZnSe crystal. The spectra were acquired by accumulating 128 scans.

2.3.4 Density Measurements

Density analyses were conducted following the guidelines of ASTM D792 [31]. A Gehaka DSL910 densimeter (located in São Paulo state, Brazil) was employed at ambient temperature. Five samples for accurate density determination represented each group.

2.3.5 Shore D Hardness

The Shore D hardness tests were conducted by ASTM D2240-05 [32], utilizing a GS-702 durometer. The arithmetic mean of five measurements was calculated for each sample.

2.3.6 Izod Impact Test

The Izod impact strength test was performed on the processed specimens, including PP and composites, following the ASTM D-256 standard [33]. A universal pendulum impact tester was utilized for this purpose. The samples were securely positioned vertically and subjected to a 5.5 J force at the center, delivered by the pendulum strike.

2.3.7 Scanning Electron Microscopy (SEM)

The SEM analysis was conducted using a Hitachi TM3030 Plus tabletop microscope operating at 15 kV to observe specimens coated with gold. Additionally, cryogenically fractured transverse sections of the samples were evaluated, and the images were captured at a magnification of 200×.

2.3.8 Heat Deflection Test (HDT)

Each test was conducted following the ASTM D-648 standard [34]. The heat deflection temperature (HDT) was measured using a Ceast HV3 6911.000 tester. To ensure accuracy, at least three repetitions of the HDT test were performed for each material composition, and the average results were obtained. The test parameters included an imposed stress of 1.82 MPa, a temperature ramp rate of 2°C/min, and a maximum deflection of 0.2 mm.

3. Results and Discussion

3.1 XRF Results

Table 2 presents the results of the chemical characterization of sample BB through X-ray fluorescence analysis. The results reveal the predominant composition of Bahia Beige marble, with 50% calcium, while 47% of the loss is attributed to calcination, corresponding to the present carbonates. This material occurs naturally as calcium carbonate, specifically calcite [14-16].

Table 2 XRF results of Bahia beige.

Oxide	BB (wt.%)
MgO	6.05
Al_2O_3	0.48
SiO_2	4.50
CaO	45.70
Fe_2O_3	0.16
Loss on Ignition	43.15

In addition to the high concentration of CaO resulting from calcite, Bahia Beige marble exhibits lower proportions of other oxides such as SiO_2 (4.50%), MgO (6.05%), Al_2O_3 (0.48%), and Fe_2O_3 (0.16%). The presence of these oxides in Bahia Beige can be attributed to various geological factors and formation processes, commonly found in rocks and minerals. SiO_2 is indicated as a common component in igneous and sedimentary rocks, and its presence in smaller fractions in Bahia Beige suggests the presence of other minerals beyond calcite, possibly as inclusions or impurities. On the other hand, Al_2O_3 and Fe_2O_3 in low concentrations can be explained as inclusions of minerals rich in aluminum and iron, such as clays or iron minerals [35]. These inclusions contribute to the tonal variation and unique appearance of Bahia Beige. Furthermore, the presence of MgO in Bahia Beige results from geological processes related to the transformation of pre-existing rocks during marble formation. This combination of oxides in Bahia Beige contributes to its distinct characteristics and properties, influencing its visual appearance and aesthetic qualities [36].

3.2 XRD Results

Figure 2 illustrates the XRD patterns of the PP and PP/BB composite samples.

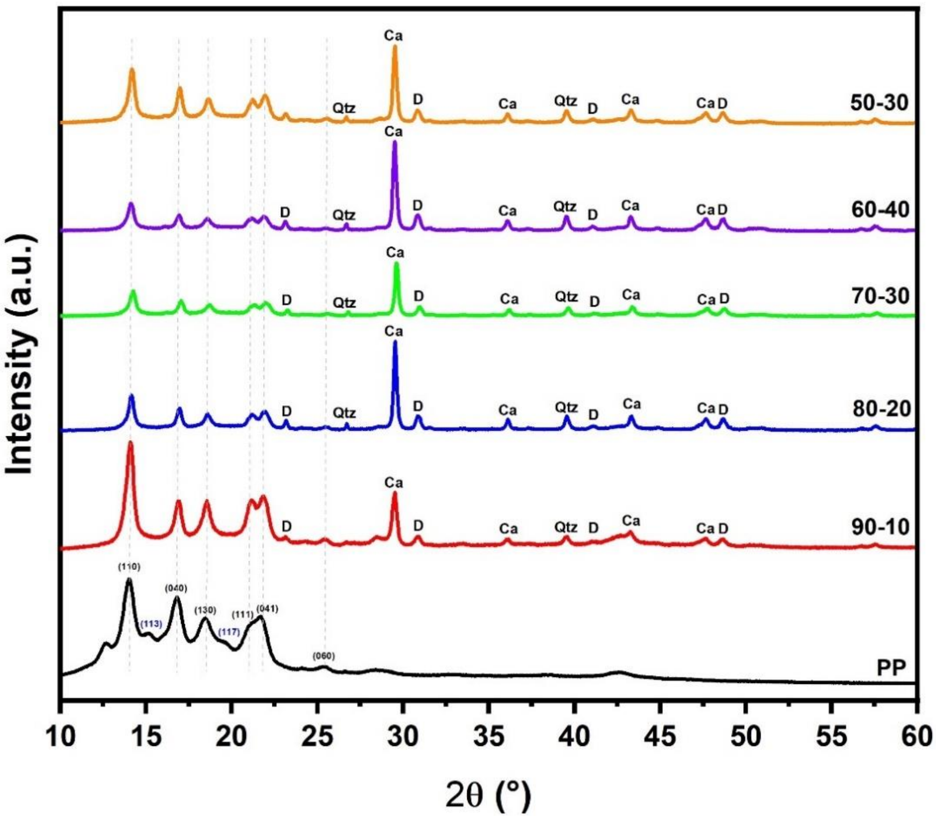

Figure 2 Diffractograms of PP and PP/BB composites. The black lines represent the crystallographic planes related to the formation of α-polypropylene, while the blue lines correspond to the γ-polypropylene phase. The abbreviations represent the following phases: Ca-Calcite; D-Dolomite; Qtz-Quartz.

In the diffractograms, peaks corresponding to the phases of the polypropylene matrix can be observed, as well as peaks related to the phases present in the BB in the composites. In the diffractogram of PP (100/0), six distinct peaks are identified at 2θ angles of 14.01°, 16.79°, 18.46°, 21.08°, 21.69°, and 25.37°, corresponding to the (110), (040), (130), (111), (041), and (060) planes, respectively, of the alpha phase of polypropylene. Two additional peaks are also observed at 15.07° and 19.49°, which correspond to the (113) and (117) planes of the gamma phase of polypropylene [37]. The calculation of crystallinity resulted in an X_c value of 19.8% for the PP.

Incorporating BB as a reinforcement in the composites caused changes in the diffractograms. The peaks corresponding to the gamma phase of polypropylene disappeared, and the peak related to the (060) plane of the alpha phase of polypropylene. The addition of ceramic reinforcements resulted in peaks corresponding to the phases present in Bahia Beige, where three distinct phases were identified: calcite, dolomite, and quartz. The calcite peaks were registered at 29.51°, 36.09°, 43.26°, and 48.63°, while the dolomite peaks were observed with lower intensity at 23.11°, 30.85°, 41.09°, and 48.67°, and the quartz phase peaks were identified at 26.71° and 39.55°. These results are consistent with the XRF data, where the calcite peaks are much more intense than those of dolomite and quartz, indicating a higher concentration of CaO in the composition of Bahia Beige marble.

The addition of different amounts of BB increased the crystallinity of the composites, resulting in an increased X_c value of approximately 47.9% (90/10), 58.9% (80/20), 61.4% (70/30), 65.1%

(60/40), and 55.9% (50/50) for different composite compositions. However, as the filler content exceeds 40%, the X_c value of the composites gradually decreases. This decline can be attributed to the restricted mobility of the polypropylene chains [14, 38-41].

3.3 FTIR Results

Figure 3 presents the FTIR-ATR spectrum of PP, BB, and their composites.

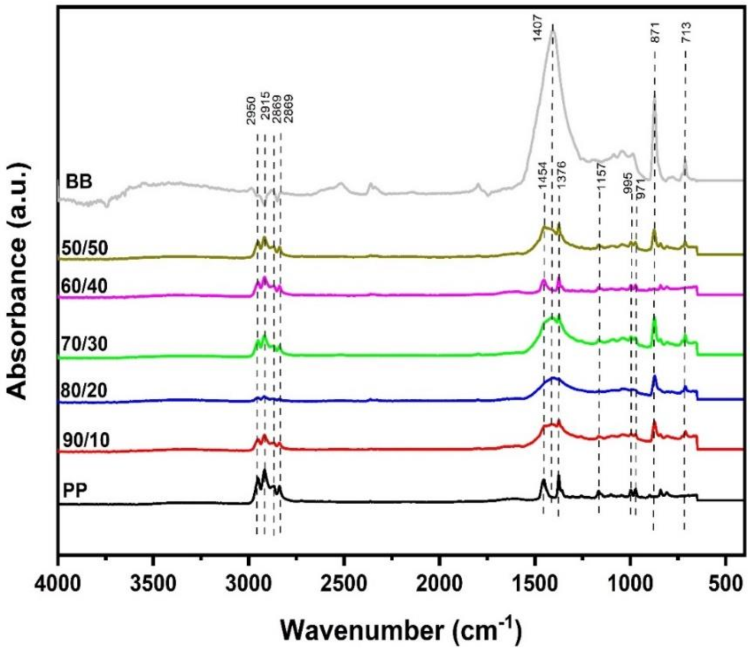

Figure 3 FTIR-ATR results of PP/BB formulations.

The PP spectrum exhibited peaks at approximately 2950 and 2836 cm^{-1}, corresponding to CH_2 and CH_3 vibrations. The symmetric bending vibration of CH_3 was observed around 1454 and 1376 cm^{-1}. Additionally, the stretching vibrations of CH_3 were detected at approximately 1157 and 971 cm^{-1}, with medium-intensity peaks observed at around 871 cm^{-1} (C-H). The infrared bands of BB displayed results consistent with the characteristic bands of limestone, namely 2950-2869 cm^{-1} (C-H stretching) and 1490-1376/871-713 cm^{-1} (carbonate ion stretching). The composites exhibited a physical interface as no changes were observed in the infrared peaks [14, 16, 41, 42].

3.4 Density, Hardness and Impact Resistance

The results of the physical and mechanical properties of PP/BB composites, including density, hardness, and impact resistance, are presented in Table 3 and Figure 4.

Table 3 Results of density, hardness and impact resistance.

Sample	Density (g.cm^{-3})	Hardness (Shore D)	Impact Izod (KJ.m^{-2})
100/0	0.892 ± 0.016	63.00 ± 0.00	21.83 ± 0.00
90/10	0.875 ± 0.013	67.33 ± 0.58	11.62 ± 0.00
80/20	1.039 ± 0.020	68.67 ± 1.53	6.68 ± 0.00

70/30	1.062 ± 0.031	70.00 ± 0.00	8.27 ± 0.00
60/40	1.209 ± 0.011	65.00 ± 0.00	6.63 ± 0.00
50/50	1.185 ± 0.015	67.00 ± 0.00	4.18 ± 0.00

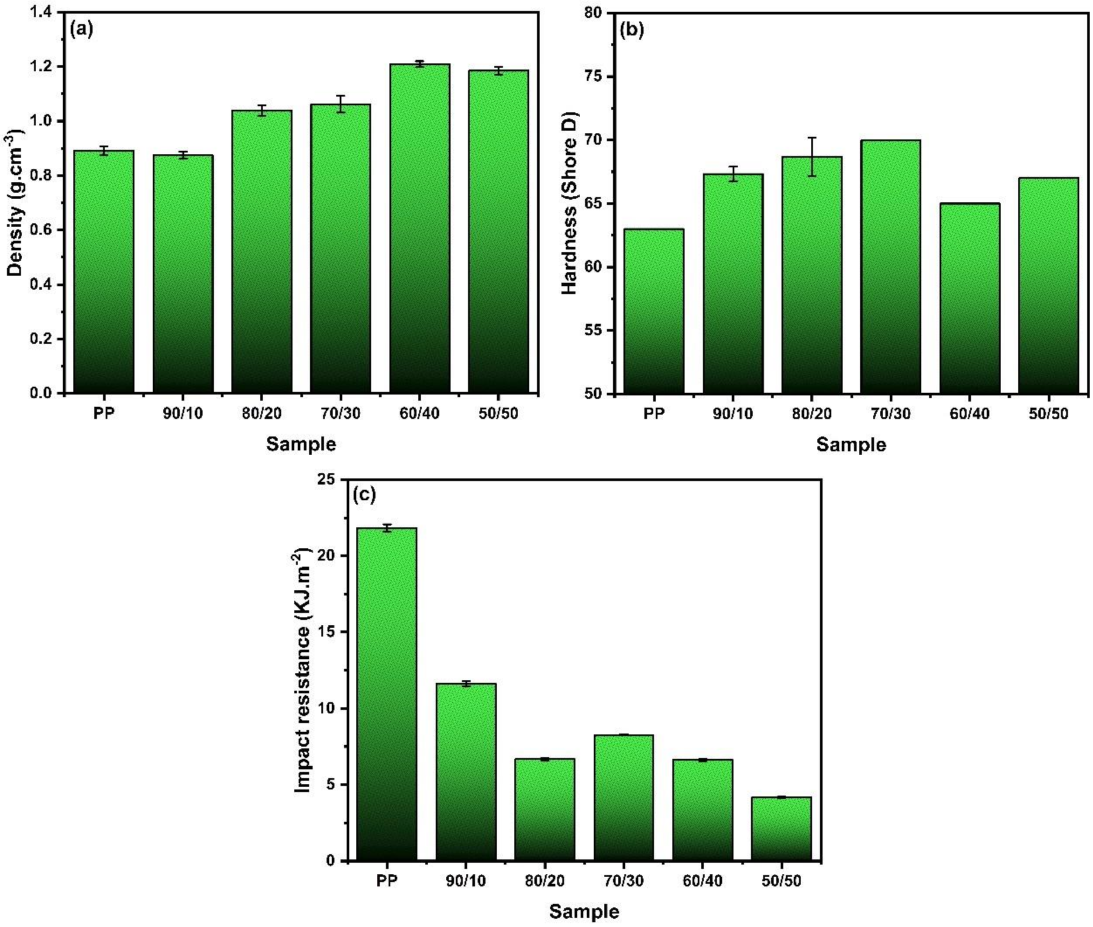

Figure 4 Physical and mechanical results of PP/BB composites: (a) Density; (b) Hardness; (c) Impact resistance.

The density results presented in Table 3 and Figure 4a ranged from 0.875 to 1.209 g/cm³, corresponding to different levels of particulate material ranging from 10% to 50%. It was found that the increase in density is directly proportional to the content of Bahia Beige added to the composite. These results are consistent with previous studies in the literature. For example, Chagas et al. [16] developed recycled polypropylene (rPP) composites with additions of Bahia Beige and coconut fibers, obtaining density values between 0.829 and 1.096 g/cm³. Bakshi et al. [42] produced PP matrix composites with additions of marble and gypsum residues, obtaining density values similar to those in this study. The variations in density can be attributed to differences in particle compaction and particle wall roughness.

The Shore D hardness results, presented in Table 3 and Figure 4b, indicate an increase in the property of the composites compared to PP. This increase in hardness can be attributed to the relatively high hardness of the mineral reinforcement. When adding fractions of 10%, 20%, and 30% by weight of Bahia Beige, an increase in the hardness of the composite was observed. However, the 40% and 50% fractions also showed an increase in hardness, although to a lesser extent than the lower reinforcement additions. This occurred due to the high content of Bahia Beige in the composite, which hindered homogenization, resulting in an uneven distribution of the reinforcement agents in the matrix. Other studies have also investigated the properties of thermoplastic composites reinforced with ceramic particles. For example, Cardoso et al. [43] developed high-density polyethylene (HDPE) composites reinforced with alumina (Al_2O_3) and silicon carbide (SiC) particles, focusing on ballistic applications for low calibers. By adding fractions of 40%, 50%, and 60% by weight of reinforcement, the authors observed an increase in the hardness of the composite, which initially was 46 in the pure polymer, reaching 72 with the highest reinforcement addition.

Analyzing the impact resistance results in Table 3 and Figure 4c, it can be observed that the addition of reinforcement in the PP matrix composites resulted in a considerable reduction in impact resistance. The impact strength of the PP/BB composites decreased with the addition of Bahia Beige, due to the lower ductility associated with mineral filler. Pure PP (100/0) exhibited an impact strength of 21.83 kJ/m², while additions ranging from 10% to 50% by weight reduced the impact strength to 11.62 kJ/m² in the (90/10) composite and 4.18 kJ/m² in the (50/50) composite. When adding particulate reinforcements, it is common to observe a decrease in mechanical strength properties to some extent, depending on the content of the particulate filler. The magnitude of this decrease will depend on the aspect ratio of the particles and, consequently, the particle size.

3.5 Microstructural Analysis (SEM)

The SEM images of Bahia Beige powders are shown below in Figure 5.

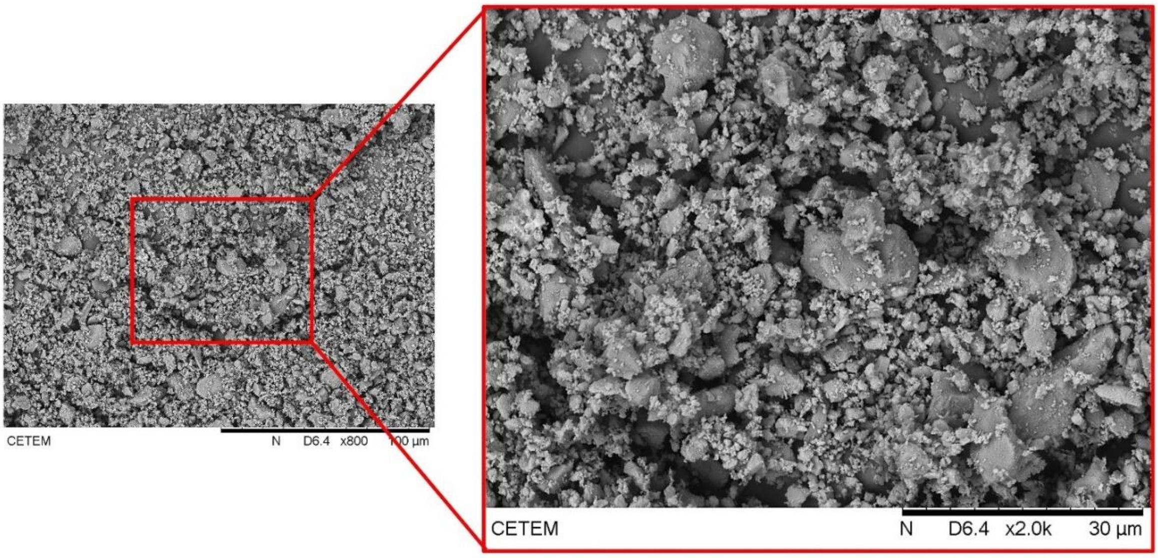

Figure 5 SEM images of Bahia Beige powders at a magnification of 800×, followed by further magnification to an image at 1200×.

The SEM images in Figure 5 illustrate the morphology of Bahia Beige grains, revealing an uneven distribution with the presence of coarse grains, indicative of incomplete grain comminution. The particle size during comminution can be influenced by the processing time. Another factor that may have contributed to the appearance of these larger grains is the absence of a sieving step in the powder preparation. Next, in Figure 6, the images of PP and PP/BB composites are illustrated.

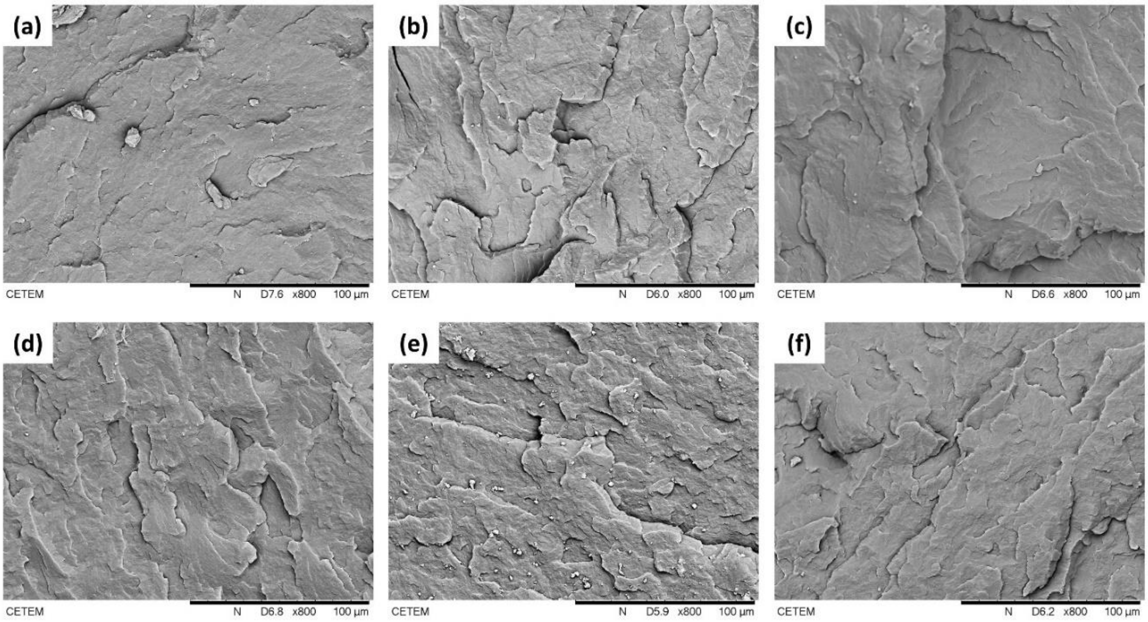

Figure 6 SEM images of the surface of PP and PP/BB composites with a magnification of 800×: (a) PP; (b) 90/10; (c) 80/20; (d) 70/30; (e) 60/40; (f) 50/50.

The SEM images presented in Figure 6 revealed the microstructure of the pure polymer and the composites. Figure 6a shows the surface of the pure polypropylene, displaying visible marks of ductile fracture on the fractured surface. Even with the addition of particulate reinforcement in different fractions, including high fractions (50 wt.%), a ductile fracture surface is still observed. This indicates that the mixing and interfacial adhesion between the matrix and reinforcement phases were well accomplished, resulting in well-homogenized surfaces. In the 60/40 composite (Figure 6d), agglomerates are present on the surface due to the excess reinforcement in the composite. The PP/BB composites containing 10 to 40 wt.% of BB were considered more suitable substitutes for virgin PP, effectively reducing environmental impact while maintaining favorable properties [16].

3.6 HDT Results

Figure 7 illustrates the results of the HDT (Heat Deflection Temperature) characterization of PP and PP/BB composites.

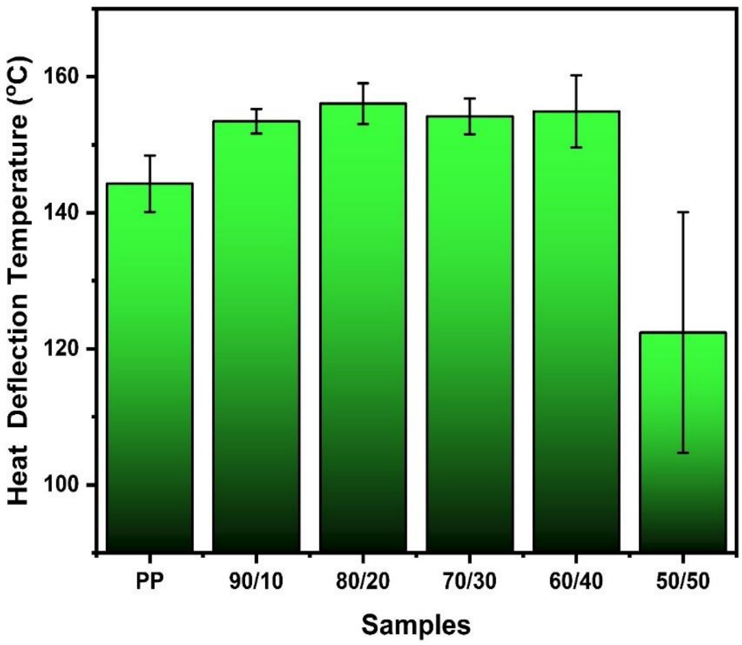

Figure 7 Heat deflection temperature of PP/BB composites.

Observing the graph in Figure 7, it can be inferred that the heat deflection temperature (HDT) increased with the addition of BB in the composites. The HDT value for pure PP was 144.3°C, while for the (90/10) composite, it was 153.5°C. The (80/20) composite exhibited an HDT of 156.0°C. The (70/30) and (60/40) composites showed a slight reduction compared to the (80/20) composite, with temperatures of 154.2°C and 154.9°C, respectively. Lastly, the (50/50) composite exhibited a considerable reduction in temperature compared to all other composites, with a value of 122.4°C. The composites with BB additions up to 40 wt.% showed higher HDT values compared to pure PP, with increases of approximately 6.4% (90/10), 8.1% (80/20), 6.9% (70/30), and 7.3% (60/40), respectively. However, when the BB proportion was increased to 50% (50/50), the HDT decreased by 15.2% compared to pure PP. This reduction is attributed to the distribution and increase in the volumetric fraction of BB, leading to the formation of agglomerates within the matrix, as supported by the Izod impact test [44, 45].

4. Conclusions

In this article, environmentally friendly polypropylene composites reinforced with Bahia Beige marble waste were developed, and their chemical, physical, mechanical, microstructural, and thermal properties were analyzed. Based on the results obtained, the following conclusions can be highlighted:

XRF analysis revealed the composition of Bahia Beige, showing a significant concentration of CaO, indicating the presence of calcite in the mineral and other oxides that compose the material. XRD analysis identified the phases of PP and revealed the presence of calcite, dolomite, and quartz in the composites, resulting from the addition of Bahia Beige in the formulation. Furthermore, the composites exhibited increased crystallinity due to the increased ceramic reinforcement content.

FTIR analyses demonstrated the interactions in the composites. They revealed that the bands corresponding to PP in the region between 1500 and 100 cm^{-1} were replaced by bands related to Bahia Beige as the filler content increased in the composites.

Density tests showed an increase in the density of the composites due to the higher density of Bahia Beige compared to polypropylene. However, the density variation was insignificant, remaining close to pure PP, which is favorable for applications involving low-density materials.

The hardness of the composites increased in all analyzed compositions. On the other hand, the impact resistance values of the composites decreased considerably with the increase in filler content. SEM images revealed the surface of the composites, where the ductile characteristic was observed, along with a good distribution of Bahia Beige in the composites.

Finally, the HDT results showed that, for additions of up to 40% by weight, the reinforcement increased the heat deflection temperature. However, in the 50% by weight fraction of Bahia Beige, a significant reduction in temperature occurred.

In summary, the developed materials possess good properties and are potential candidates for engineering applications, contributing to the reuse of natural waste and promoting Brazilian sustainability.

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Author Contributions

Conceptualization, Daniele Cruz Bastos and Roberto Carlos da Conceição Ribeiro; Methodology, Daniele bastos, Roberto Carlos da Conceição Ribeiro and Rayara Silva dos Santos; Formal analysis, Rayara Silva dos Santos, Pedro Henrique Poubel Mendonça da Silveira, Beatriz Cruz Bastos and Marceli do Nascimento da Conceição; Investigation, Rayara Silva dos Santos, Pedro Henrique Poubel Mendonça da Silveira, Beatriz Cruz Bastos and Marceli do Nascimento da Conceição; Resources, Daniele Cruz Bastos and Roberto Carlos da Conceição Ribeiro ; Data curation, Rayara Silva dos Santos; Writing — original draft, Rayara Silva dos Santos, Daniele Cruz Bastos and Pedro Henrique Poubel Mendonça da Silveira; Writing — review & editing, Pedro Henrique Poubel Mendonça da Silveira; Visualization, Daniele Cruz Bastos; Supervision, Daniele Cruz Bastos and Roberto Carlos da Conceição Ribeiro; Project administration, Daniele Cruz Bastos and Roberto Carlos da Conceição Ribeiro.

Competing Interests

The authors have declared that no competing interests exist.

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