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Research Article

MANUFACTURING AND CHARACTERIZATION OF SUGAR BEET PULP PARTICLES FILLED POLYPROPYLENE MATRIX BIOCOMPOSITE

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Keywords

Biocomposite, Characterization, Mechanic and thermal properties, Polypropylene (PP), Sugar beet pulp waste.

Abstract

In this study, Polypropylene (PP) matrix biocomposites were developed with the aim of reducing sugar beet pulp (SP) waste and demonstrating the potential of agricultural waste materials in various applications. Sugar beet pulp extracted from a sugar production factory was subjected to a drying process and then mechanically ground. Following this process, the resultant powdered sugar beet pulp particles were subjected to a sieving process, yielding particles within the size range of 100–250 µm. These particles were then incorporated into the pure PP matrix at filling levels ranging from 5% to 20%. Subsequently, the mechanical (tensile, flexural, DMA), thermal (TGA, DSC), and chemical (FTIR) properties of these biocomposites were investigated. DMA results indicated a notable improvement in storage modulus with increased filler content, supporting the stiffening effect of sugar beet pulp particles. DSC analysis showed minimal change in melting temperature, but a slight decrease in crystallinity degree with higher filler ratios. FTIR spectra confirmed the presence of characteristic functional groups from lignocellulosic sugar beet pulp within the PP matrix, indicating successful incorporation. It was determined that the elastic modulus in the PP matrix biocomposites increased as the amount of sugar beet pulp particles increased. When the thermogravimetric analysis (TGA) data of PP and biocomposites were compared, an increase in the maximum degradation temperature (Tmax) was observed as the SP100 and SP250 ratio increased, while a decrease in the temperature at which degradation began (Ton) was observed. These biocomposites demonstrate promising potential for application in the automotive, packaging, and construction industries as sustainable materials.

ŞEKER PANCARI KÜSPESİ PARTİKÜLLERİ DOLGULU POLİPROPİLEN MATRİKS BİYOKOMPOZİTİN ÜRETİMİ VE KARAKTERİZASYONU

Anahtar Kelime

Biyokompozit, Karakterizasyon, Mekanik ve termal özellikler, Polipropilen (PP), Şeker pancarı posası atığı.

Öz

Bu çalışmada, şeker pancarı küspesi (SP) atıklarını azaltmak ve tarımsal atık malzemelerin çeşitli uygulamalardaki potansiyelini göstermek amacıyla polipropilen (PP) matrisli biyokompozitler geliştirilmiştir. Şeker üretim fabrikasından elde edilen şeker pancarı küspesi kurutma işlemine tabi tutulmuş ve ardından mekanik olarak öğütülmüştür. Bu işlemden sonra, elde edilen toz şeker pancarı posası parçacıkları elemeişlemine tabi tutuldu ve 100–250 µm boyut aralığında parçacıklar elde edildi. Bu parçacıklar daha sonra %5 ila %20 arasında değişen dolum seviyelerinde saf PP matrisine katıldı. Daha sonra, bu biyokompozitlerin mekanik (çekme, eğilme, DMA), termal (TGA, DSC) ve kimyasal (FTIR) özellikleri incelenmiştir. DMA sonuçları, dolgu içeriğinin artmasıyla depolama modülünde belirgin bir iyileşme olduğunu göstermiş ve şeker pancarı küspesi parçacıklarının sertleştirici etkisini desteklemiştir. DSC analizi, erime sıcaklığında minimum değişiklik, ancak daha yüksek dolgu oranlarında kristallik derecesinde hafif bir azalma olduğunu gösterdi. FTIR spektrumları, PP matrisinde lignoselülozik şeker pancarı posasından karakteristik fonksiyonel grupların varlığını doğruladı ve bu da başarılı bir birleştirme olduğunu gösterdi. PP matris biyokompozitlerdeki elastik modülün, şeker pancarı posası parçacıklarının miktarı arttıkça arttığı belirlendi. PP ve biyokompozitlerin termogravimetrik analiz (TGA) verileri karşılaştırıldığında, SP100 ve SP250 oranının artmasıyla maksimum bozunma sıcaklığında (Tmax) bir artış gözlemlenirken, bozunmanın başladığı sıcaklıkta (Ton) bir azalma gözlemlenmiştir. Bu biyokompozitler, otomotiv, ambalaj ve inşaat endüstrilerinde sürdürülebilir malzemeler olarak uygulama için umut verici bir potansiyel sergilemektedir.

Alıntı/Cite

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Highlights

- It is evident that a contribution was made to the economic value of sugar beet pulp.
- Thermal characterisation of the composites was performed.
- 25% decrease in tensile strength was observed.

Graphical Abstract

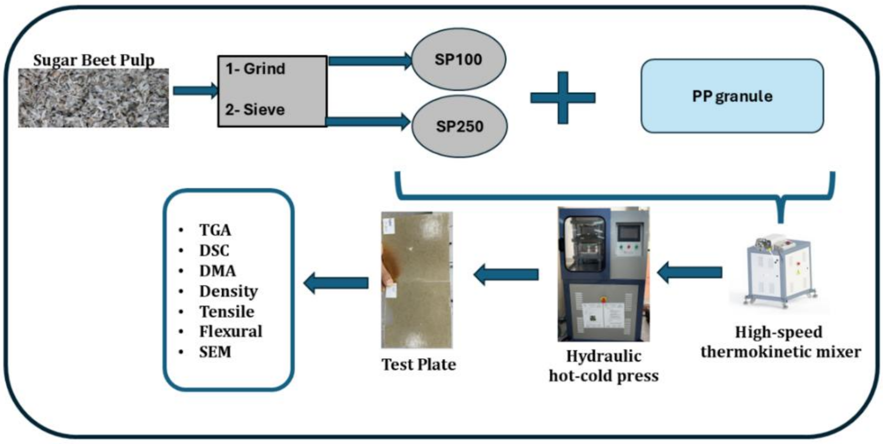

Figure. Flowchart of this study

Purpose and Scope

The present study constitutes an investigation into the production and characterisation of a new composite with a polypropylene matrix, utilising sugar beet pulp as a constituent. This particular type of agricultural waste is abundant.

Design/methodology/approach

The methodology of the study comprised the following series of processes: firstly, the transformation of agricultural waste into a suitable state for the production method; secondly, the production of composites in a laboratory-scale thermo-kinetic mixer; and finally, the characterisation of the composites.

Findings

It was established that the thermal stability of the composites increased, with no significant change being observed in Tm values. Furthermore, mechanical values of SP 100 filled composites were found to be superior to those of SP250.

Originality

This study aims to develop environmentally friendly biocomposite materials by incorporating sugar beet pulp (SP), an underutilized agricultural by-product, into a polypropylene (PP) matrix. The primary goal is to valorize agricultural waste and explore its potential to serve as a low-cost, sustainable reinforcement material in thermoplastic-based composites. Unlike conventional fillers or widely studied natural fibers, sugar beet pulp offers a distinct composition rich in cellulose, hemicellulose, and pectin, which can influence interfacial bonding and material performance. The novelty of this work lies in the use of SP particles with a controlled size range (100–250 μm) as a filler in PP, and the comprehensive characterization of resulting composites through thermal (TGA, DSC), chemical (FTIR), and mechanical (tensile, flexural, DMA) analyses. This holistic approach provides new insights into structure–property relationships in biocomposites, demonstrating the feasibility of SP-based composites for automotive, construction, and packaging applications.

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1. Introduction

Researchers working on the development of polymer composites are aware of new environmental regulations, predictions that oil and its derivative resources will be depleted in 50–60 years, and agreements to reduce greenhouse gas emissions that cause gases such as CO_2 to be released into the atmosphere. Recent open-access studies also highlight the potential of incorporating agricultural waste like wheat straw and rice husk into PP composites, achieving improved thermal resistance and eco-efficiency without compromising structural integrity (Yussuf et al., 2022; Zhang et al., 2023). Additional research confirms that using sugarcane bagasse, corn stover, and bamboo fibers enhances tensile strength, thermal stability, and moisture resistance in PP matrices (Patel et al., 2021; Ramos et al., 2022; Liu and Wang, 2023). Moreover, studies on lignin-enriched PP composites report up to 15% increase in storage modulus and significant reductions in carbon footprint (Garcia-Rodriguez et al., 2020; Chen et al., 2024). The development of new materials that can replace existing conventional non-renewable reinforcing materials, such as glass fibre, has been necessitated by the demands of the industrial sector, particularly in the domains of automotive, construction, and packaging (Estrada and Lee, 2013; Oliver-Ortega et al., 2019; Şen et al., 2024; Tuna and Akkoyun Kurtlu, 2024). Fibers obtained from plants such as cotton, hemp, sisal, pineapple, ramie, bamboo, banana, etc., as well as from plants such as wood and flax seeds, are alternative renewable materials used today (Goutianos et al., 2006; Vigneshwaran et al., 2020). It is anticipated that the production of materials derived from renewable raw materials will rise from 5% in 2004 to 12% in 2010, 18% in 2020, and 25% in 2030. Projections indicate that in the future, renewable resources will be utilised in two-thirds of the global composite industry, representing an estimated value of 1.5 trillion US dollars (Gurunathan et al., 2015) .By-products from agricultural activities such as leaves, shells, and plant residues refer to all organic materials. Especially in developing countries, large amounts of agricultural waste are produced each year as by-products of agricultural (and wood) harvesting and processing activities (Dungani et al., 2017; Singh et al., 2024).

The estimated amount of agricultural waste for lignocellulosic biomass in the world has been determined to be approximately 1.5 million tons. Only a small amount of the biomass waste that emerges after this huge production is used for different applications in large-scale industries and various businesses. Agricultural wastes are often used as filling materials to reduce costs. Approximately 10% of agricultural biomass waste is currently converted to raw biomaterials, thereby obtaining products that exhibit higher performance specifications (Dungani et al., 2017; Pattanaik et al., 2019; Singh et al., 2024). Sugar beet consists of about 75% water, 18% sugar and about 5% cell wall. Turkey, due to climatic conditions, the only sugar beet, sugar production is among the countries engaged. sugar beets are produced in 55 countries in the world with 6.2% share of Turkey and Russia, France, Germany, after the US and ranks the 5th (Tosun, 2017). Beets of suitable quality are separated from the materials such as soil, grass, stone with the help of holders and cleaned. It is cut mechanically with the help of specially designed blades and directed to the scalding boat. Sugar is obtained by temperature changes, carbonation and the last process, boiling sherbet. After this process, beet leaves, beet pulp and waste sorbet are obtained as waste material. Leaves and pulp are mostly used as animal feed. The pulp represents 22-28% dry matter that cannot be dissolved in sugar beet roots during sugar extraction (Altunbay et al., 2016).Sugar beet pulp (SP) is a by-product of sugar extraction. The composition of the material under consideration is as follows: cellulose (20-25%), hemicellulose (25-35%), pectin (22-32%), protein (10-15%) and insoluble lignin (1-3%), with the percentage quantities given on a dry basis (Martínez et al., 2018).

In this study, sugar beet pulps, particles and polypropylene (PP) were utilised in the production of biocomposites, with sugar beet pulps particles incorporated into pure PP in the range of 5% to 20%. A comprehensive series of evaluations was conducted to assess the mechanical and thermal properties of these biocomposites. This encompassed rigorous testing procedures, including tensile tests, flexural tests, dynamic mechanical analysis (DMA), thermogravimetric analyses (TGA), and differential scanning calorimetry analyses (DSC).

2. Experimental Details

2.1. Materials

Sugar beet pulp, obtained from Konya Şeker Factory, was subjected to a drying process that involved exposing it to the sun for a period of approximately 20 days. Subsequently, the material was ground using a laboratory-scale mechanical grinder. Following the grinding process, different particle sizes were obtained by sieving the material below 100µm and between 100-250µm. Copolymer polypropylene (PP LG M1500) was utilised as the matrix material.

2.2. Manufacturing of composite materials

A series of PP matrix composites containing 5, 10, 15, and 20% SP were produced by utilising a laboratory-type high-speed thermokinetic mixer. A mixture consisting of 70 g of SP and PP was processed in the mixer at 2000 rpm, thereby yielding SP-filled PP composites. The composite plates were then manufactured using a hydraulic press at 170°C, applying pressures ranging between 40-120 bar for 210 seconds. Following this, the plates were cooled to 20°C at 120 bar pressure for a duration of 120 seconds within the cold press.

2.3. Tests and Analyses

2.3.1. Particle Size Analysis

The average size of sieved sugar beet pulp particles (100 µm and 100–250 µm) was determined using the dry dispersion method with a Laser Diffraction Particle Size Analyzer (Malvern Mastersizer 3000). This method aligns with established protocols for characterizing agricultural waste-derived fillers (Zhang et al., 2023).

2.3.2. Thermogravimetric (TGA) Analysis

Thermal stability was evaluated using a TA Instruments SDT Q600 under N_2 gas flow (30–600 °C, 10 °C/min). Similar methodologies have been employed in studies assessing lignocellulosic filler composites, where TGA revealed filler-induced shifts in degradation temperatures (Patel et al., 2021; Liu and Wang, 2023).

2.3.3. Differential Scanning Calorimetry (DSC) Analysis

Differential scanning calorimetry (DSC) analysis was carried out utilising a DSC Q2000 instrument (TA Instrument). The samples were subjected to a thermal history removal process, involving heating to 200°C at a rate of 10°C/min and maintenance at this temperature for a duration of 3 minutes. Thereafter, a cooling phase was initiated, with the samples being cooled to 20°C for 1 minute. Finally, the samples were reheated to 200 °C at a heating rate of 10 °C/min. DSC is widely adopted for studying crystallinity changes in natural fiber-reinforced polypropylene, as noted in recent works (Yussuf et al., 2022; Chen et al., 2024).

2.3.4. Dynamic mechanical (DMA) analysis

The present study employed a Dynamic Mechanical Analyzer (Q800 model, TA Instruments Inc.) to conduct a dynamic mechanical analysis (DMA) of PP (polypropylene) and SP-filled composites. A single cantilever was utilised in the analysis of all specimens, with the multi-frequency-strain mode selected for the analysis. The temperature of the specimens was varied between 40 and 140 °C in an air atmosphere. DMA is critical for evaluating storage/loss moduli in biocomposites, as demonstrated in studies on agro-waste-filled polymers (Garcia-Rodriguez et al., 2020).

2.3.5. Density

The densities of PP and its composites were calculated with a Shimadzu-Aux321 apparatus according to the Archimedes principle. Density measurements are standard for assessing filler dispersion and composite porosity, as highlighted in research on rice husk-PP composites (Zhang et al., 2023).

2.3.6. Fourier Transform Infrared Spectroscopy

A Nicolet 50 spectrophotometer was used to obtain FTIR spectra. A total of 16 scans were executed to record FTIR spectra ranging from 4.000 to 600 cm^{-1}. FTIR is routinely used to confirm filler-matrix interactions in biocomposites, such as in sugarcane bagasse-PP systems (Patel et al., 2021).

2.3.7. Mechanical Tests

An universal tensile testing machine (Shimadzu AG-IC with a 5 kN load cell) was utilised in determining the tensile and flexural properties of the biocomposite samples under investigation. Tensile and three-point bending tests were conducted in accordance with the standards stipulated in ASTM D638 and ASTM D790. Crosshead speed was set at 50 mm/min for the tensile test and 1 mm/min for the three-point bending test. Comparable methods are employed in studies on natural fiber composites, where interfacial adhesion critically impacts strength (Ramos et al., 2022).

2.3.8.Scanning electron microscopy (SEM)

An investigation was conducted to examine the fractographic characteristics of the composites under scrutiny. Utilising a scanning electron microscope (SEM) (Carl Zeiss 300VP, Germany) operating at 2.5 kV, the fractured surfaces of the composites were subjected to comprehensive observation. In order to minimise the occurrence of sample arcing during the SEM observation process, a thin layer of gold was methodically applied onto the fractured surfaces of the composites through the utilisation of the QUORUM Q150 RES sputter coater. This procedure was executed prior to the SEM investigation, thereby ensuring the reliability and reproducibility of the experimental results. SEM is essential for visualizing filler-matrix compatibility, as seen in lignin-enforced PP composites (Chen et al., 2024).

3.Results And Discussion

3.1. Particle Size Distribution Analysis

As demonstrated in Figure 1, the distribution of particles in SP100 and SP100-250 powders exhibits a Gauss distribution. This finding indicates that the particle volume distribution follows a Gaussian curve, a type of statistical distribution characterised by its symmetrical shape around the mean value. The mean diameter of SP powders with a D50 below 100 µm was found to be 54.6 µm, while the median D10 and D90 were determined to be 15.5 µm and 136 µm, respectively. The average size (D50) of the 100-250 µm range was found to be 261 µm, with D10 and D90 being recorded as 156 µm and 476 µm, respectively.

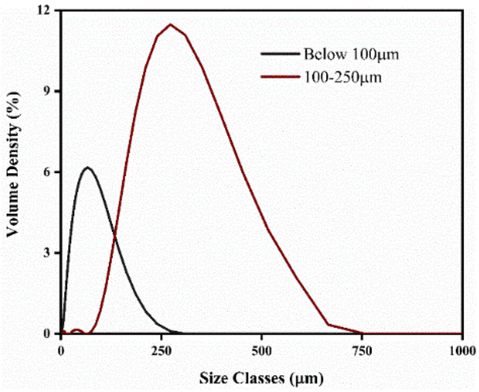

Figure 1.Particle size distribution of SP powders.

3.2. TGA analysis

Thermogravimetric analysis is used to determine mass gain or loss as a function of temperature. Figure 2 shows the thermal degradation behaviors of composites with different mixture ratios and particle sizes. Table 1 presents TGA data from pure PP and SP/PP composite samples. The initial decomposition temperature (Ton), the maximum decomposition temperature (Tmax), and the mass loss of pure PP and SP composites are all reported in this analysis. The initial decomposition temperature has been identified in these experiments as the temperature that equals 5% of total weight loss. PP shows a one-step degradation process, as can be seen in Figure 2. As shown in Table 1, the mass loss of PP is 99.06%. After SP was filled into PP, the amount of non-volatile carbonaceous material increased (Hansen et al., 2019; Ngaowthong et al., 2019). Considering the SP filler size in polypropylene, no significant differences were observed. For PP and PP-SP composites, Tmax is between 460 and 465 ºC. Except for PP-5SP100, the T5 values of other composites decreased. It can be seen that the T5 values of PP-20SP100 and PP-20SP250 decreased by 137.3 and 132.86 °C, respectively. Lignocellulosic materials thermally degrade between 150°C and 500°C. The temperature at which a degradation of the substances under consideration becomes observable is defined as the degradation temperature. The degradation temperature ranges of hemicellulose, cellulose and lignin are thus 150–350°C, 275–350°C, and 250–500°C, respectively (Patel et al., 2023; Vigneshwaran et al., 2020). The initial decrease in Ton can be attributed to the early thermal degradation of hemicelluloses and pectin present in sugar beet pulp, which are known to break down at relatively low temperatures, initiating earlier mass loss in the composite material (Essabir et al., 2018; Patel et al., 2021). This effect becomes more pronounced with increasing SP content, as evidenced by the progressive decrease in Ton values from 418.32°C for pure PP to 275.65°C and 281.05°C for PP-20SP100 and PP-20SP250, respectively. Additionally, the incorporation of sugar beet pulp disrupts the homogeneity of the PP matrix, creating heterogeneous regions that facilitate heat transfer and reduce the energy barrier for thermal degradation initiation. Conversely, the slight increase in Tmax values (from 460.33°C for PP to approximately 464°C for most composites) suggests that once decomposition is fully initiated, the SP filler provides some thermal stabilization, possibly through the formation of carbonaceous residues that slow down the final stages of degradation and contribute to the increased residual mass observed in the composites.

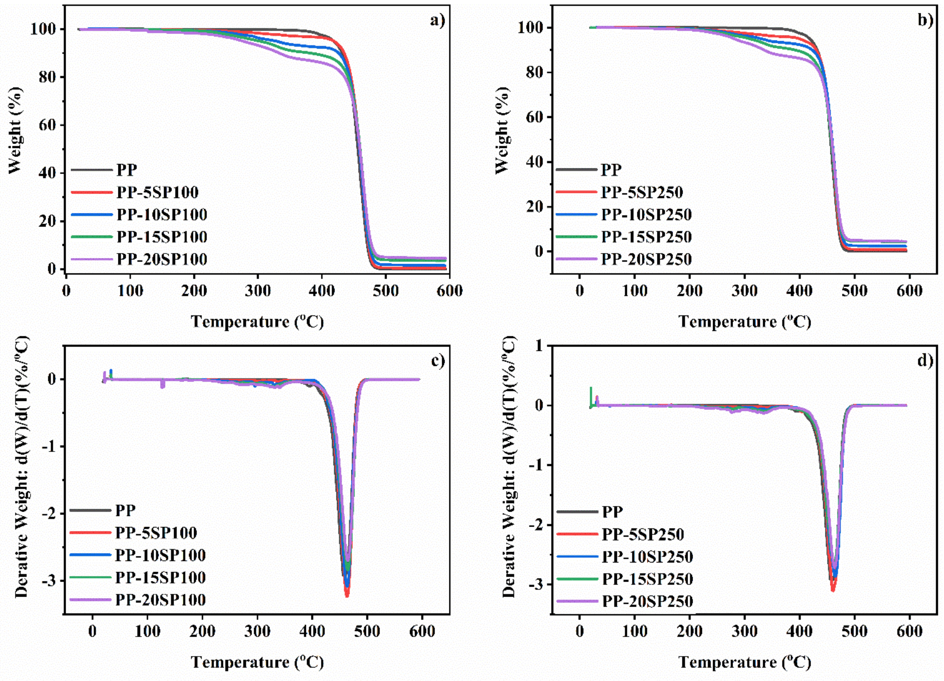

Figure 2. TGA curves of PP, PP-SP100 and PP-SP250 composites.

Table 1.TGA data for the PP and SP-PP composite.

Sample Code	T_{on} (°C)	T_{max} (°C)	Mass Loss (600 °C) (%)
PP	418.32	460.33	99.06
PP-5SP100	418.69	463.34	99.50
PP-10SP100	329.13	463.51	98.29
PP-15SP100	302.72	464.68	96.35
PP-20SP100	275.65	464.43	95.22
PP-5SP250	400.11	460.98	99.04
PP-10SP250	330.21	464.98	97.45
PP-15SP250	309.1	463.20	95.47
PP-20SP250	281.05	463.32	95.26

3.3. DSC analysis

Figure 3 exhibits the DSC curves of PP and PP-SP composites. Table 2 presents the melting temperature (T_m), crystallization temperature (T_c), crystallization enthalpy (H_c), and melting enthalpy (H_m) determined through DSC analysis. Equation (1) was used to calculate the degree of crystallinity (Xc) of PP composites.

$$X_{C(\%)} = \frac{\Delta H_m / \%_{PP}}{\Delta H_m^0} x100 \qquad (1)$$

where H_m has been taken to correspond to the melting enthalpy of 100% crystalline PP (209 J/g), and%PP is the PP weight percentage in the composite (Selvakumar and Manoharan, 2014; Yao et al., 2014).

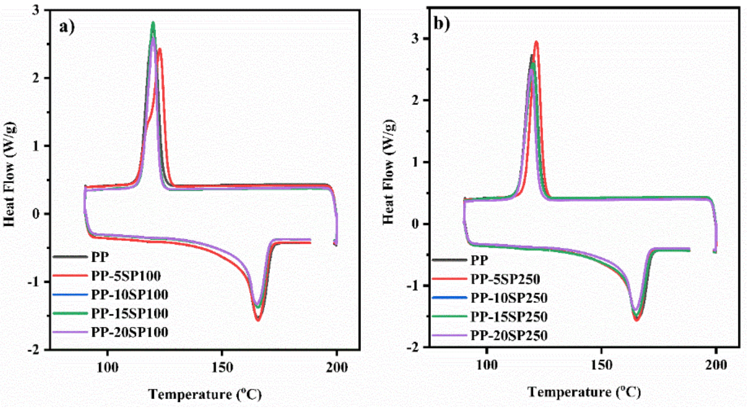

Figure 3. DSC curves of PP, PP-SP100 and PP-SP250 composites.

Table 2.DSC data for the PP and SP-PP composite.

Sample Code	ΔH_m j/g	T_m °C	ΔH_c j/g	T_c °C	X_c %
PP	83.00	165.62	86.96	123.98	39.71
PP-5SP100	80.18	165.68	85.73	122.81	40.38
PP-10SP100	70.02	165.58	74.75	119.91	37.22
PP-15SP100	66.78	165.42	71.52	119.66	37.59
PP-20SP100	64.59	165.23	69.04	120.00	38.63
PP-5SP250	79.26	165.31	82.67	121.53	39.91
PP-10SP250	78.43	165.12	79.28	120.12	41.69
PP-15SP250	68.85	165.24	71.20	118.92	38.75
PP-20SP250	64.41	164.91	68.78	119.31	38.52

The melting temperature (T_m) of PP did not change with the addition of SP. This indicates that the crystal size of PP is not affected considerably (Kaya et al., 2018; Sever et al., 2019). The crystallization temperature (T_c) reduced with the incorporation of SP. In general, adding SP to PP decreased its X_c by 1-2%. This is possible because lignocellulosic particles that absorb water molecules and come into direct contact with the polymer matrix create microstructural changes that lower the crystallinity of the polymer(Colom et al., 2000). On the other hand, when 5%SP100 and 10wt% SP250 were added into PP, the degree of crystallinity of the the composites slightly increased compared with that of PP. PP-10SP250 composite exhibited the highest crystallinity in all composites. Table 2 shows that ΔH_c and ΔH_m decreased significantly as a result of adding 20 wt% SP to PP. The change in melting enthalpy can be considered an indicator of the change in degree of crystallinity (Sever and Yılmaz, 2020).

3.4. Dynamic mechanical (DMA) analysis

The viscoelastic properties of PP and PP-SP composites were examined using dynamic mechanical analysis (DMA). Figure 4 presents the temperature-dependent variation of storage modulus, loss modulus and tan delta (tan δ) for PP and SP-PP composites. It can be observed that the storage modulus values of SP-PP composites exceed those of PP at all temperatures. This increase can be attributed to the mechanical constraints imposed by the SP filler within the polymer matrix(Salazar-Cruz et al., 2022; Sever et al., 2013; Sever and Aycan, 2019). This suggests that the stiffness of the composites increased as the SP particles were loaded (Sever et al., 2013). The highest filler addition led to the highest storage modulus. Table 3 summarizes the storage modulus values as well. Table 3 points out that the storage modulus values of PP-SP composites decrease with increasing temperature. The polymer chain mobility increases as the temperature rises (BAŞTÜRK, 2021). This causes polymers to soften and relax (Sever et al., 2013).

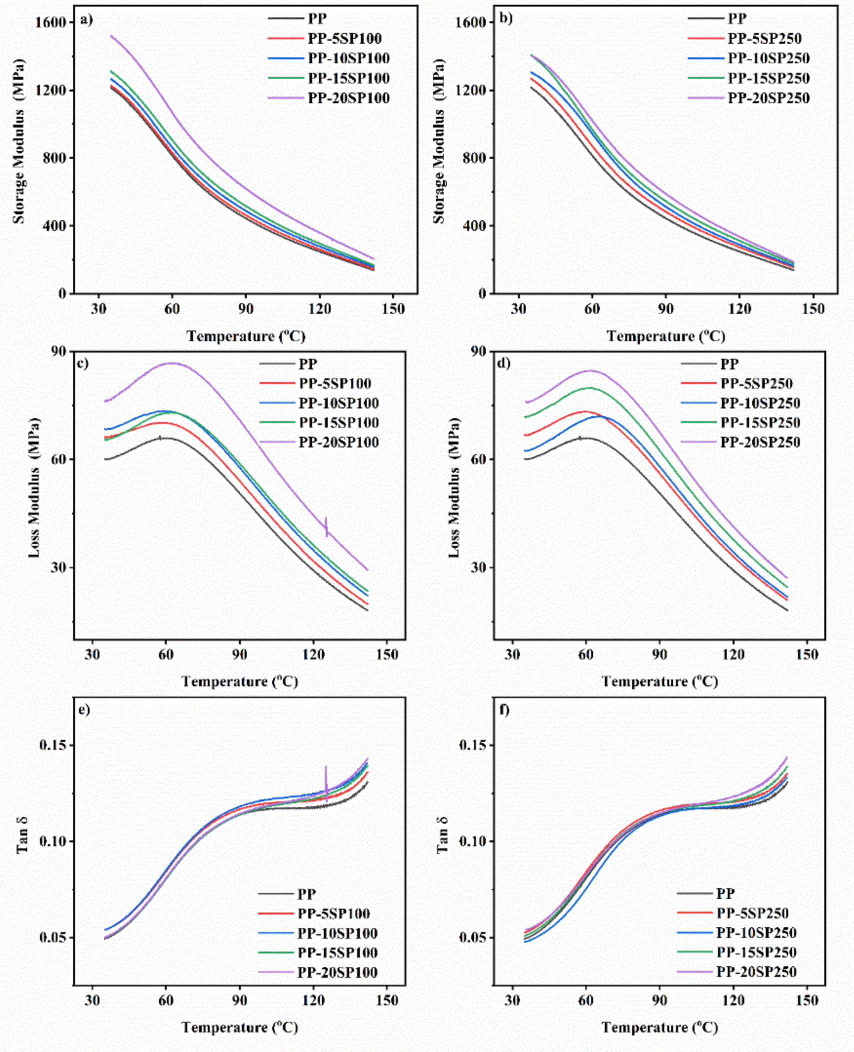

Figure 4. Variations of storage modulus (a-b), loss modulus (c-d) tan δ (e-f) of PP, PP-SP100 and PP-SP250 composites

Table 3. Storage modulus values of PP-SP composites at different temperature

Sample Code	Storage Modulus (MPa)				
	35 °C	60 °C	90 °C	120 °C	140 °C
PP	1216.7	812.2	443.2	247.7	149.4
PP-5SP100	1228.4	828.5	461.4	261.0	157.8
PP-10SP100	1266.7	860.7	487.4	278.4	169.7
PP-15SP100	1312.9	900.8	514.1	295.1	179.9
PP-20SP100	1520.8	1065.6	618.0	358.8	220.2
PP-5SP250	1269.5	867.6	481.2	272.9	166.1
PP-10SP250	1306.1	939.4	510.4	287.5	175.0
PP-15SP250	1409.5	964.8	542.8	310.7	189.1
PP-20SP250	1401.0	1021.1	588.6	335.5	202.6

As illustrated in Figures 4(e) and 4(f), the tan δ spectra of the PP and SP-PP composites are presented. Tan δ is a mechanical dampening factor that can be described as the rate of the E' and E" moduli. The α relaxation is associated with the mobility of chain segments in the crystalline phases, which is probably due to the reorientation of defect areas in the crystals. (Kaya et al., 2018; Sever et al., 2013). For PP and SP-PP composites, relaxation occurs about 80 °C (Hansen et al., 2019).

3.5. Density

Density is one of the most important features of the particle-filled composites. The density values of SP-filled PP composites are presented in Figure 5. The incorporation of SP particles into the PP matrix caused a progressive increase in the density of the composites compared to neat PP. The density values of PP-5SP100, PP-10SP100, PP-15SP100, and PP-20SP100 increased by approximately 0.3%, 3.0%, 4.0%, and 5.6%, respectively. Similarly, the density values of PP-5SP250, PP-10SP250, PP-15SP250, and PP-20SP250 composites were also found to be higher than that of pure PP. Specifically, the density of the PP-20SP250 composite increased from 0.906 g/cm^3 to 0.955 g/cm^3.

This concentration-dependent increase in density can offer specific functional advantages in certain applications. Higher density in polymer composites has been associated with improvements in mechanical stability, particularly in terms of compressive strength and stiffness, as the closer packing of particles and reduced void content enhance load transfer efficiency within the matrix (Abdelwahab et al., 2015; Kuan et al., 2021). Additionally, denser composites may provide enhanced vibrational energy dissipation, which can be beneficial in automotive and structural applications where vibration control is desired (Tang and Yan, 2020). In thermal applications, increased density correlates with greater thermal mass, enabling better resistance to rapid temperature fluctuations and improving thermal stability under cyclic heating conditions (Rajak et al., 2019). Therefore, while lightweight design is often preferred in polymer composites, such incremental increases in density due to SP loading can translate into improved structural and functional performance in applications where these properties are prioritized over weight considerations.

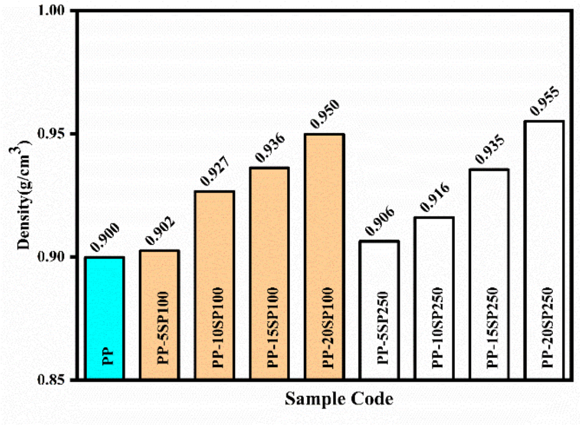

Figure 5. Density values of PP-SP composites

3.6. FTIR Analysis

As illustrated in Figure 6, the FTIR spectra of the PP-SP100 and PP-SP250 composites reveal a broad band at approximately 3280 cm^{-1}, which is attributed to the O–H stretching vibrations of the hydrogen-bonded hydroxyl (OH) group. In addition, the peaks observed at 2909 cm^{-1} are attributed to the aliphatic saturated C–H stretching vibration in lignin polysaccharides, which comprises cellulose and hemicelluloses.(Ruangudomsakul et al., 2015; Sidi-Yacoub et al., 2019). In addition, the peaks between 1600 and 1800 cm^{-1} are characteristically associated with different pectin types, and the absorption bands at 1730-1745 and 1630-1650 cm^{-1} are indicative of free and esterified carboxyl groups, respectively. (Sidi-Yacoub et al., 2019). Figure 6 (a-b) depicts that the CH and CH_2 bonds of PP are stretched between 2950 and 2838 cm^{-1}, and the asymmetric and symmetric deformations of CH and CH_3 are observed at 1455 and 1375 cm^{-1}, respectively. There were no significant differences in the SP100-filled PP and SP250 filled PP composites.

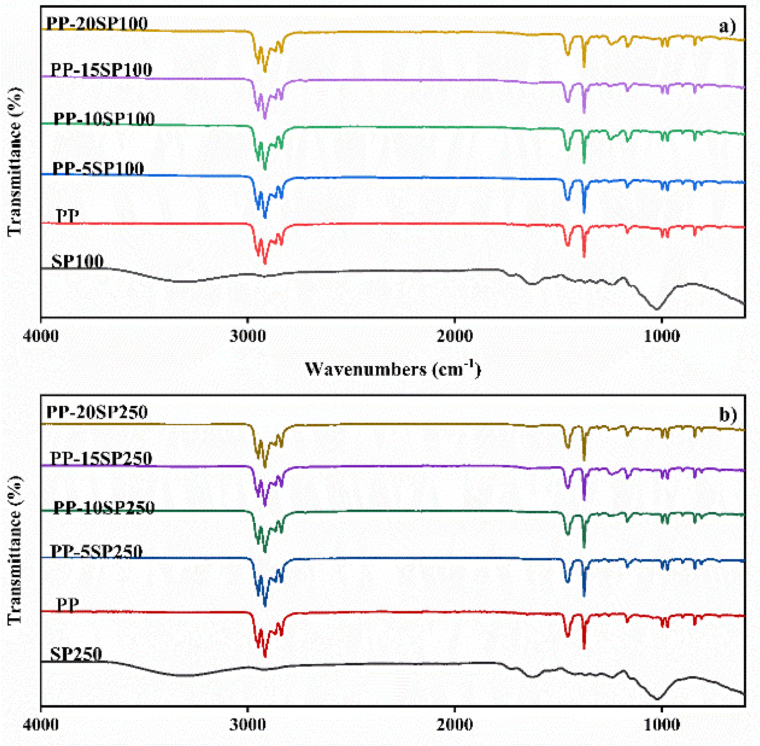

Figure 6. FTIR /ATR analysis of PP-SP100 (a) and PP-SP250 (b) composites

3.7. Mechanical Test

As demonstrated in Figure 7(a-b), the tensile properties of PP and PP-SP composites, including tensile strength and Young's modulus, are influenced by the filler weight ratio.The tensile and flexural properties of PP and PP-SP composites are outlined in Table 4. As demonstrated in Figure 7(a-b), the tensile strength and Young's modulus values of unfilled PP were obtained as 23.85 and 979.44 MPa, respectively.Subsequent to the incorporation of SP100 and SP250 fillers into PP, resulting in a decrease of tensile strength values for PP-SP composites relative to PP.This phenomenon is primarily attributed to interface incompatibility between the hydrophobic nature of PP and the hydrophilic properties of SP, which is evident in the reduced adhesion between the fillers and the polymer matrix. This decline is attributable to inadequate wetting of SP250 with the matrix, in conjunction with suboptimal adhesion between the filler and the matrix (E. Onishi, 2015; Shumigin et al., 2011) . Additionally, SP fillers with an irregular shape are not conducive to the transfer of stress to the polymer matrix of the composite (Kilinc et al., 2016).

As the weight ratio of both SP100 and SP250 increased, the Young's modulus of the composites increased, and the ductility and tensile strength of the composites decreased. The maximum reductions in tensile strength were obtained at approximately 21% for PP-20SP100 samples and 26% for PP-20SP250 samples. When the fracture surfaces of the samples were observed by SEM analysis after the tensile tests, it was seen that there was no adhesion at the interface between SP fillers and PP in SP-SP250 composites, and it creates larger voids on the fracture surface. The highest Young's modulus was obtained by loading 20 wt% SP100 filler into PP; this represents a 24% increase compared to PP. This increase is attributed to the rigidity of SP particles (Essabir et al., 2018). Since the lignocellulosic material is more rigid than the polymer, SP composites are stiffer than pure PP (Öztürk et al., 2015). It can be stated that the filler size does not make a significant difference in the Young's modulus of the composites.

As demonstrated in Figure 7(c-d), there is a clear variation in flexural strengths and modulus of PP and PP-SP composites. It is evident that the flexural strength values of composites are lower than those of PP, with a decrease observed from 38.00 MPa to 27.29 and 25.68 for 20 wt% SP100 and SP250 fillers, respectively. The reasons for this phenomenon can be attributed to the aforementioned factors.It is noteworthy that the flexural modulus value of PP decreases with the incorporation of 5 wt% SP filler, while the flexural modulus of PP-SP composites increases with the increase in filler.The highest flexural modulus value was obtained as 1179.24 MPa for PP-20SP250.

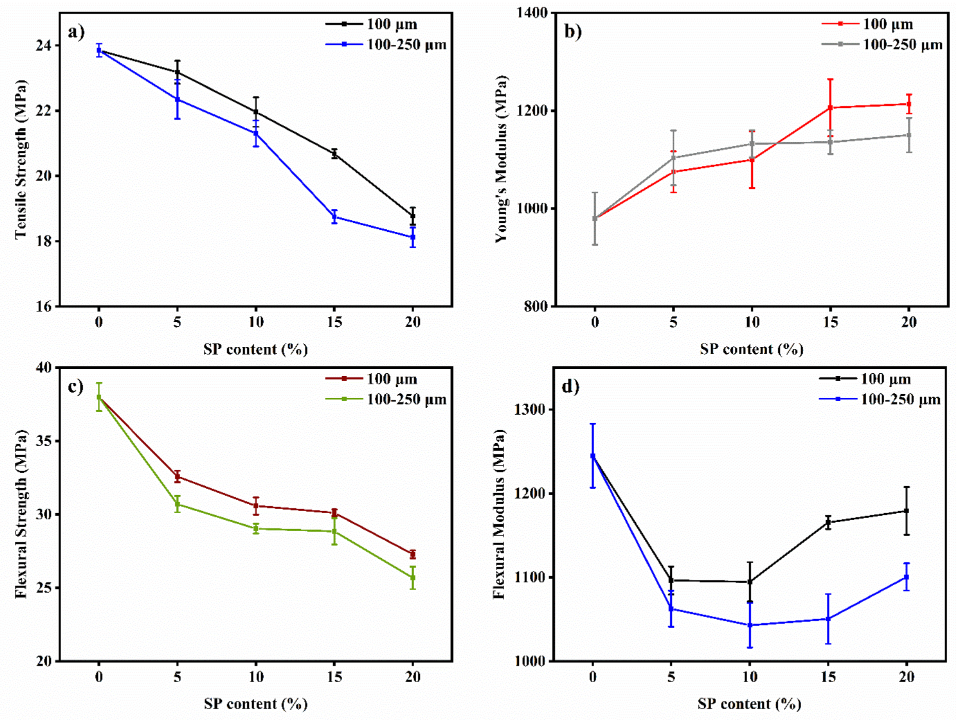

Figure 7. Tensile Strength (a), Elastic modulus (b), Flexural Strength (c) and Flexural modulus (d) of PP, SP100 and SP250 composites.

Table 4. Tensile and flexural test results of PP and its composites with SP 100 and SP250.

Sample Code	Tensile Strength (MPa)	Elastic Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (Mpa)
PP	23.85 ± 0.20	979.44 ± 53.40	38.00 ± 0.96	1244.98 ± 38.00
PP-5SP100	23.18 ± 0.35	1075.16 ± 42.14	32.58 ± 0.39	1096.38 ± 16.73
PP-5SP250	22.35 ± 0.60	1103.73 ± 56.15	30.70± 0.56	1062.74 ± 21.51
PP-10SP100	21.96 ± 0.45	1099.78 ± 57.70	30.58 ± 0.59	1094.78 ± 23.40
PP-10SP250	21.30 ± 0.40	1132.28 ± 28.11	29.03 ± 0.34	1043.00 ± 26.46
PP-15SP100	20.68 ± 0.14	1206.23 ± 58.40	30.11 ± 0.23	1165.43 ± 7.79
PP-15SP250	18.75 ± 0.20	1135.86 ± 24.26	28.85 ± 0.90	1050.47 ± 29.62
PP-20SP100	18.77 ± 0.26	1213.66 ± 19.46	27.29 ± 0.27	1179.24 ± 28.48
PP-20SP250	18.12 ± 0.30	1150.16 ± 35.13	25.68 ± 0.77	1100.55 ± 16.21

3.8. SEM Observation

SEM images of PP and its composites are shown in Figure 8. SP particles are clearly visible where they exhibit irregular shape and size. SP particles in the PP matrix are randomly distributed, and the particle sizes of SP vary from macrosize to microsize. As filler material is added, voids form in the matrix (Kaya et al., 2018) . Many voids were observed throughout the matrix for PP15SP and PP20SP composites. This indicates that the interfacial adhesion between the SP filler and the PP matrix is poor. Stress cannot be transferred efficiently from the matrix to the fillers. It is seen that the mechanical test results are compatible with the SEM images of the composites.

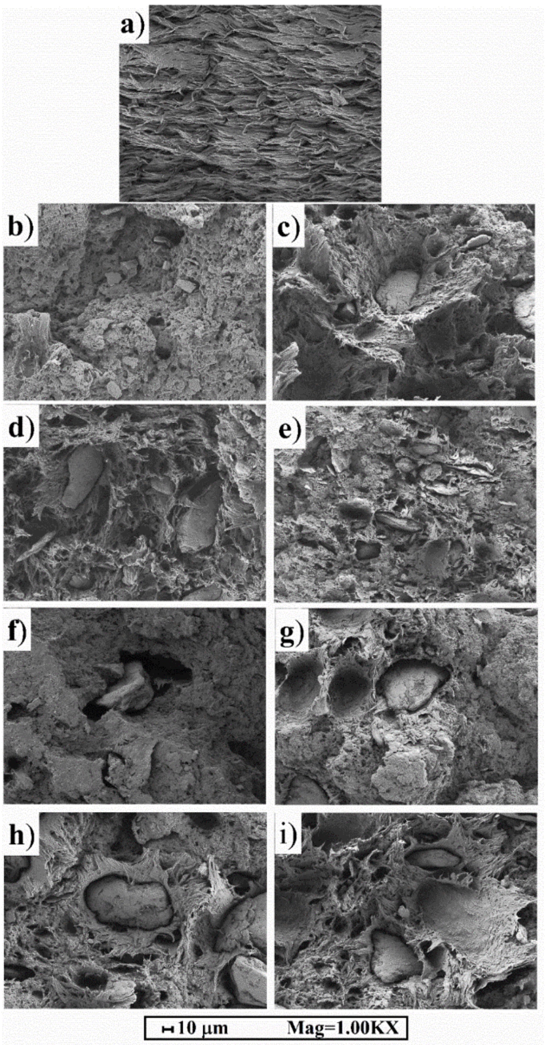

Figure 8. SEM images of the composites. a) PP, b) PP5SP100, c) PP10SP100 d) PP15SP100, e) PP20SP100 f) PP5SP250, g) PP10SP250 h) PP15SP250, i) PP20SP250.

4. Conclusion

Sugar beet pulp particles and polypropylene (PP) were used to produce biocomposites in this study. Sugar beet pulp particles in the range of 5%-20% were added to pure PP. Tmax values of the composites are often greater than PP values. Tmax for PP and PP-SP composites is between 460 and 465 ºC. When compared to PP, SP-filled PP composites had increased thermal stability, as seen by a shift in Tmax to a higher temperature. While the melting temperature (Tm) of PP did not change when SP was added, , the crystallization temperature (T_c) reduced with the incorporation of SP. Storage modulus values of SP-PP composites are higher than PP at all temperatures with SP fillers in the polymer matrix. The highest filler addition resulted in the highest storage modulus. As the weight ratio of SP100 and SP250 increased, the composites' Young's modulus increased while their ductility and tensile strength decreased. Tensile strength was reduced by approximately 21% for PP-20SP100 samples and 26% for PP-20SP250 samples. When the fracture surfaces of the samples were examined using SEM following the tensile testing, it was found that there was no adhesion at the interface between the SP fillers and the PP in the SP-SP250 composites, resulting in greater voids on the fracture surface. The highest Young's modulus was obtained by adding 20 wt% SP100 filler into PP; this represents a 24% increase higher than PP.

Conflict of Interest

No conflict of interest was declared by the authors.

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