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RECYCLING WASTE POLYPROPYLENE TO PRODUCE NEW COMPOSITE MATERIALS WITH JUTE REINFORCEMENTS

ABSTRACT

Waste polypropylene (PP) polymer was collected, washed, dried and mechanically recycled into granules. Natural fibers are a sustainable and renewable resource, and in this work, *Corchorus olitorius* jute fiber was used as a reinforcing agent with waste PP. Jute fiber was collected from local market, cleaned, dried and cut into 1-2 mm in length for the production of waste PP-jute composites. The molecular structure of waste PP and virgin PP were characterized by the attenuated total reflection-fourier transform infrared (ATR-FTIR). The purpose of the current research was to examine the effectiveness of waste PP by comparing waste PP-jute composites and virgin PP-jute composites. The injection molding process was utilized to make jute fiber reinforced waste PP composites with various jute fiber loadings (5%, 10%, 15%, 20%, 25%, and 30% in weight).The same process was used to produce virgin PP composites reinforced with jute fiber. All composites undergo water absorption and tensile testing in order to assess the recycled PP. Injection molded virgin and waste PP's physico-mechanical, thermal, and tensile strengths are also examined. In comparison to waste PP, virgin PP has a 6% greater tensile strength and a 19% higher elongation at break. Results from waste PP-jute composites and virgin PP-jute composites did not significantly differ from one another. Products made from recycled PP can thus be both economically and environmentally viable.

Keywords: *Waste polypropylene; Mechanical recycling; Injection molded composites*

INTRODUCTION

Plastic production and waste are increasing globally. Plastic pollution causes major issues in the social and environmental sectors in the country and around the world. It is causing serious health and environmental hazards [1-2]. In Bangladesh, around 977,000 tons of plastic consumed in 2020, only 31 percent were recycled and the rest 69% were mismanaged and usually end up in the landfills, rivers and oceans [3]. So plastic recycling is crucial to overcome the plastic pollution in Bangladesh. Plastic recycling is a circular economy that may convert these plastic wastes into resources while minimizing plastic pollution to help achieve the Sustainable Development Goals (SDGs). On the other hand, jute is the cheapest long vegetable bast fiber in Bangladesh. Jute reinforced polypropylene (PP) composites are diversified jute product that has high potential for wider use and applications in the area of furniture's, plant boxes, packaging and tool box, automotive interior, particle board, ceiling, construction purposes, textiles/medical/ cosmetic, domestic appliances etc [4-6]. Generally, uses do not require strong mechanical resistance, resulting in lower purchasing and

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maintenance costs [6]. Residents in both rural and urban regions dump plastic garbage carelessly, which has a negative impact on ecosystem services and human well-being. Plastic particles are predicted to enter the oceans at a rate of more than 8 million metric tons per year globally [7]. Thermoplastics, which make up around 80% of all plastics used in consumer goods and are mostly utilized as packaging or textile fibers, can be recycled in an efficient manner to lessen the amount of waste thrown in landfills and the demand for new raw materials. [8]. Polypropylene, high and low density polyethylene (HDPE and LDPE), polyvinyl chloride, polystyrene, and others are some of the most important thermoplastics polymers [9-10]. It was discovered that recycled high-density polyethylene (HDPE) made from milk bottles and virgin HDPE had similar thermochemical properties, indicating that recycled HDPE might be employed in a variety of applications [9]. So, plastic recycling and re-use will not only help to clean up the environment, but will also allow the government to generate a lot of money by recycling and exporting plastics [7]. In fact, recycling contributes effectively in the reduction of production costs [10]. Companies like THRIVE make a variety of injection-molded composites from virgin and recycled polypropylene (rPP) and cellulose for use in automobiles, appliances, furniture, building materials, sports and leisure, as well as personal and household goods [11]. Waste Expanded Polypropylene (EPP) was used as a recycled matrix for kenaf fiber-reinforced Polypropylene composites, indicating that waste EPP might replace conventional PP matrix in natural fiber composites [12]. Natural fibers from many sources, including wood, grass, seed hairs, and plant stalks (bast and core fibers), are used to reinforce with polymer to make natural fiber reinforced polymer composites (NFRPCs). Injection molding, compression molding, extrusion, and other conventional polymer processing techniques are frequently used to process NFRPCs [13]. Natural fibers in polymeric matrices have the potential to cut the overall weight and cost by roughly 20% and 30%, respectively. Reduced vehicle weight results in fuel savings, which lowers greenhouse gas emissions [14]. Due to their great qualities, including renewability, biodegradability, recyclability, low density, low price, superior insulation and mechanical performance, natural fibers like jute, flax, coir, bamboo, etc., have the potential to be used in packaging. They also increase the composite structure's bio-based component [15]. In many industrial applications, polypropylene is one of the most widely used general-purpose thermoplastics [12, 14]. Comparing the cost of recycling plastics to using virgin materials, savings of 20–50% may be possible. Recycling thermoplastics also lessens the pollution that is produced when they are burned, reduces the amount of garbage that must be disposed of in landfills [14], and uses less petrochemicals in the manufacture of virgin PP [13-14].

This study focuses on segregating waste PP from household garbage for recycling. The primary goals of this study are to recycle waste polypropylene into recyclates, develop injection-molded (IM) composites from waste PP and jute fibers, and assess how jute fiber loading affects the mechanical properties and dimensional stability of composites. Another goal is to carry out a comparison study between waste and virgin PP composites.

MATERIALS AND METHODS

Materials

A small number of families in Dhaka provided their used transparent PP boxes, single use cups, and glass items, which were gathered and segregated for recycling (Fig. 1). Virgin PP was collected from The Polyolefin Company, Pte., Ltd., Singapore. The melting point of these waste PP and virgin PP was determined to be 180^{o}C.

Jute fibers were obtained from a local market in Dhaka, Bangladesh. The jute fibers provided were of the Tossa variety (*Corchorus olitorius*). The center parts of the jute fibers were collected and chopped into lengths of roughly 1-2 mm (Fig. 2) for this study.



Fig. 1. Waste PP items



Fig. 2. Jute fiber

Cleaning and grinding of waste PP to make recyclates

PP waste was manually sorted according to melting point. It was cut, cleaned, and ground in a grinder to make recyclates.

Composite fabrication

Jute fibers were dried in an oven at 80 ^{o}C for 12 hours. PP polymers were dried in an oven at 105^{o}C for three hours. To make composites, jute fibers were thoroughly mixed with waste PP/ virgin PP. PP matrix and jute fibers were used in different weight fractions (Table 1). Jute-PP mixtures were extruded through a single screw extruder machine to make composites.

Table 1. *Relative proportions of jute and PP matrix by weight fraction (%)*

Reinforcing material (%)	Matrix polymer (%)	Composites structure
None	Waste PP: 100	100 wt % Waste PP
Jute: 5	Waste PP: 95	5:95 (wt %) Jute-Waste PP
Jute: 10	Waste PP: 90	10:90 (wt %) Jute Waste PP
Jute: 15	Waste PP: 85	15:85 (wt %) Jute-Waste PP
Jute: 20	Waste PP: 80	20:80 (wt %) Jute-Waste PP
Jute: 25	Waste PP: 75	25:75 (wt %) Jute-Waste PP
Jute: 30	Waste PP: 70	30:70 (wt %) Jute-Waste PP
None	Virgin PP: 100	100 wt % Virgin PP
Jute: 5	Virgin PP: 95	5:95 (wt %) Jute-Virgin PP
Jute: 10	Virgin PP: 90	10:90 (wt %) Jute-Virgin PP
Jute: 15	Virgin PP: 85	15:85 (wt %) Jute-Virgin PP
Jute: 20	Virgin PP: 80	20:80 (wt %) Jute-Virgin PP
Jute: 25	Virgin PP: 75	25:75 (wt %) Jute-Virgin PP
Jute: 30	Virgin PP: 70	30:70 (wt %) Jute-Virgin PP

The extrusion processing temperature was kept constant at 190°C, and the pressure was uniform. The jute-PP mixes were fed into the extruder in a continuous stream. The composites were delivered at a constant rate through a rod-shaped die. The composites were then sliced

into little pieces of 10-15 cm length using the Scissor. With a grinding mill, the small fragments were crushed into small granules (Grinder, Speed 2900 rpm, made by S.R International, Dhaka, Bangladesh). The granular materials were dried in an oven at 105^{o} C for 6 hours before being employed in injection moulding. The same procedure was followed for all waste PP composite compositions and virgin PP composite compositions.

Preparation of composites by injection molding

The dry granular products (Table 1) were molded using an injection-molding machine (Model-MH 45 T, Min Hui, China) in accordance with ASTM standard (tensile test bars). The pressure, temperature, and heating time of the samples were controlled at the same rate to prepare all composites. The injection-moulding machine in use is vertical (Fig. 3), and all of the tensile test specimens (Fig. 4) were produced using the molding method.



Fig. 3. Injection molding machine



Fig. 4. Injection molded (IM) composites

Attenuated Total Reflection-Fourier Transform Infrared (ATR-FTIR) analyses

ATR-FTIR spectroscopic analysis was used on a Perkin Elmer FTIR/NIR Model-Forntier Spectrophotometer to analyze and characterize waste and virgin PP.

Tensile properties analyses of the composites

Tensile characteristics of waste PP, virgin PP, and jute fiber reinforced composites were tested using a Universal Testing Machine (UTM), model 1410-Titan5, Load cell: 5000N, U.K. The experiment was carried out in accordance with ASTM D 638-10 at a cross head speed of 10 mm/min. The average values of tensile characteristics were calculated using five specimens.

Water absorption test of composites

Water absorption was determined for each sample. According per ASTM method D 570-99, the samples were dried in an oven at 105^{o}C for 2 hours before being immersed in boiling water for 2 hours. A soft towel was used to wipe excess water from the surface of the samples. The weights of the samples were then determined. The results were provided as the average of the tested specimens after three replicate specimens were tested. The % weight gain during immersion was calculated as follows:

$$\text{Increase in weight, \%} = \frac{(\text{wet wt - conditioned wt})}{(\text{conditioned wt})} \times 100$$

Thermal properties of virgin PP and waste PP

Simultaneous thermal analysis (STA) of virgin PP and waste PP was carried out using a STA device (model no. F3 Jupiter, NETZSCH, Germany). The nitrogen flow rate remained constant at 80 ml/min while the heating rate was 10°C/ min. The range of temperatures was 30–600°C.

RESULTS AND DISCUSSION

ATR-FTIR characterization of waste PP and virgin PP

The ATR-FTIR spectrum was produced to investigate the structure of waste PP and virgin PP, as illustrated in Fig. 5-6. ATR-FTIR spectroscopy was used to identify the crystalline and amorphous domains in the PP structure. The crystalline phase of PP causes absorptions at 1167, 997, 898, 842, and 808 cm-1, whereas the amorphous or irregular phase of PP causes absorptions at 974 cm-1. The peak assignments of the waste PP and virgin PP absorption bands, which are very comparable, are summarized in Table 2.

Table 2. *ATR-FTIR spectral data of waste PP and virgin PP*

Wave number (cm^{-1}) of waste PP	Wave number (cm^{-1}) of virgin PP	Possible Assignment
~ 2950—2838	~ 2950—2839	Doublet due to C—H vibration of —(CH_3) group
~ 1453	~ 1466	Methyl asymmetric deformation vibration
~ 1375	~ 1378	Methyl symmetric deformation vibration
~ 1167	~ 1167	C—C stretching, CH_3 wagging
~ 997	~ 998	C—C stretching, CH_2 rocking, CH_3 rocking Absorptions are due to the crystalline phase of PP
~ 972	~ 973	C—C stretching, CH_2 rocking, CH_3 rocking Absorption due to the amorphous or irregular phase of PP
~ 899	~ 899	C—C stretching, Coupled C—H deformation
~ 840	~ 841	C—C stretching, CH_2 rocking
~ 808	~ 805	C—C stretching, Coupled C—H deformation

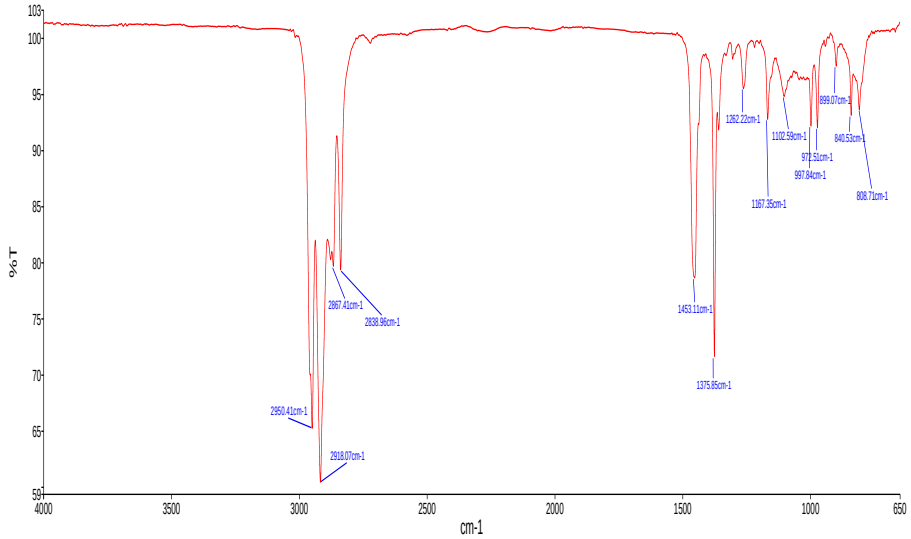


Fig. 5. ATR-FTIR of waste PP

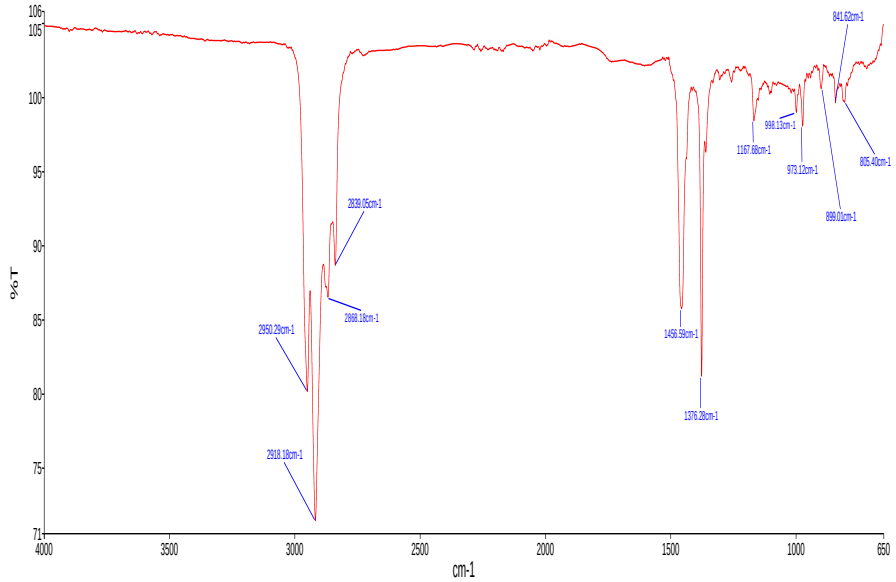


Fig. 6. ATR-FTIR of virgin PP

Physico-mechanical characterization of waste PP composites and virgin PP composites

One of the key considerations in assessing the recyclability of polymer composites is their mechanical performance. The mechanical performance of recycled polymer composites is also significantly influenced by the type of fiber, polymer, and reprocessing technique used [13]. In this work, different percentages of jute fibers (5 wt.% - 30 wt.%) reinforced waste PP composites and virgin PP composites were made by injection molding machine under optimal conditions. Size of the grinded and sieved jute fibers was 1-2 mm (approx.). The addition of the short jute fiber greatly increases the stiffness of the recycled polypropylene when compared to the sample without the fiber [14]. The tensile properties and melting point of injection molded waste PP and virgin PP are presented in Table 3. It is found from Table 3 that virgin PP has a 6% higher tensile strength and a 19% higher elongation at break than waste PP. The polymer doesn't change during recycling; instead, the loss in molecular weight due to chain scissions and contamination of the parent polymer (matrix) with other polymers is what results in the reduction in mechanical properties [16].

Table 3. *Tensile properties and melting point of injection molded waste PP and virgin PP*

Materials	Tensile strength (MPa)	Elongation at break (%)	Melting point
IM waste PP	28.79	9.05	180-190°C
IM virgin PP	30.52	10.77	180-190°C

Tensile strengths and elongation at break for injection molded jute-waste PP composites and jute-virgin PP composites are shown in Fig. 7 and 8 respectively. The tensile properties of jute-waste PP composites are also slightly lower than those of jute-virgin PP composites, as shown in Fig. 7-8. The interfacial interaction between the fibers and the matrix, the fiber arrangements, and the tensile strength of the reinforcing fibers are all important factors that affect the tensile performance of fiber reinforced composites [15]. A variety of recycled PP/virgin PP ratios were taken into consideration while developing composites for automotive parts, but it was found that as the recycled PP content rose, the composite's mechanical properties decreased [17]. It was demonstrated that recycled PP represents a useful material for the production of eco-composites based on the results for the mechanical flexural properties of PP/kenaf fiber and PP/rice hulls composites, in which PP was employed as a matrix [18]. It is found from Fig. 8 that as the jute fiber loading increased, all composites' elongation at break decreased. Wood flour (WF) added to PP matrix increases hardness and stiff characteristics while significantly reducing elongation at break, and the decreasing trend persisted with progressive WF loading [19]. After multiple processing or at least up to six times, most of the fundamental properties of the PP are still retained [19-20]. Recycling can be used to create new products that have the same or different properties as the source PP composites, which help reduce plastic waste, protect the environment, and create new business opportunities [20]. Recycled PP has the potential to play a significant role in reducing waste accumulation by producing composite materials with good mechanical properties for use in the construction and other industries [20-21].Tensile properties of jute-waste PP composites (Fig. 7-8) show that it is also a useful material for eco-composites production.

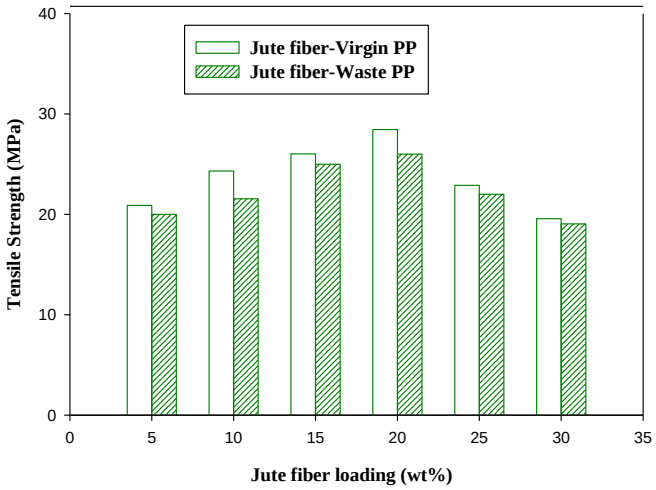


Fig. 7. Tensile strength (MPa) vs jute fiber (wt%) loading curves for composites of virgin PP and waste PP

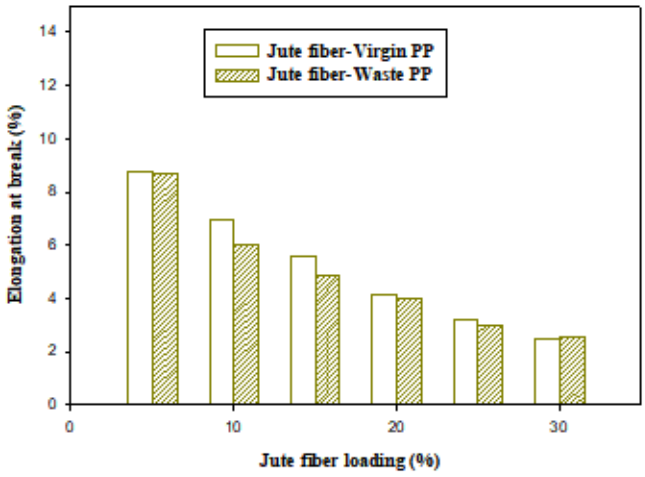


Fig. 8. Elongation at break (%) vs jute fiber loading (%) curves for composites of virgin PP and waste PP

Water absorption of waste PP composites and virgin PP composites

Water absorption is an important characteristic that will also determine how long the finished items will last [15]. Fig. 9 shows the properties of composites formed of virgin and waste PP with regard to water absorption. After two hours of immersion in hot water, the water absorption rates for the waste PP and virgin PP composites were assessed. It is evident from Fig. 9 that the water uptake rates for the jute-waste PP and jute-virgin PP composites increased progressively as per jute content. A hydrophilic hydroxyl group is present in lignin, cellulose, and hemicellulose, which are the main components of jute fibers [22]. Jute fibers' hydrophilic nature, which tends to hold water in the spaces between them, as well as their low density due to the air holes present in the composite structure, may also contribute to this behavior. The tendency to hold water increased along with the amount of fiber [15].

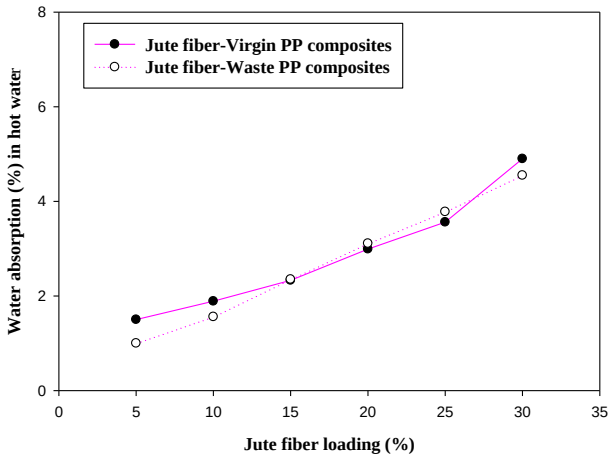


Fig. 9. Hot water absorption (%) vs jute fiber loading (%) curves for composites of virgin PP and waste PP

Thermal properties of virgin PP and waste PP

Figures 10 and 11 demonstrate the findings of STA's thermal analyses of virgin and waste PP, respectively. Figure 10 shows the results of the thermogravimetric analysis (TGA) of virgin and waste PP. It is discovered that below 324.1^{o}C, there is no degradation. Additionally, it is discovered that the residual mass at 478 ^{o}C is 41.91%. Similar findings were made, with the predominant PP degradation occurring at 448 ^{o}C [23]. On the other hand, the degradation of waste PP began at 114.7 ^{o}C, and at 466.4 ^{o}C, 18.40% of the mass is still present. This observation makes it obvious that virgin PP is more thermally stable than waste PP.

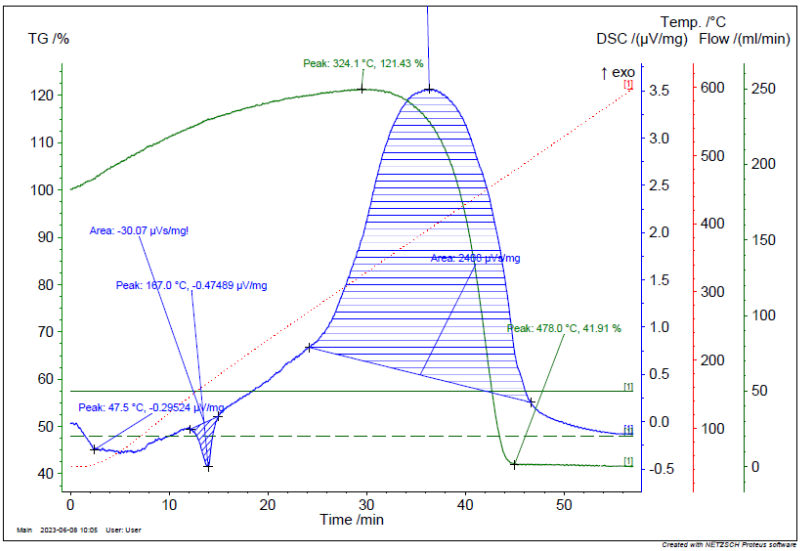


Fig. 10. STA of virgin PP

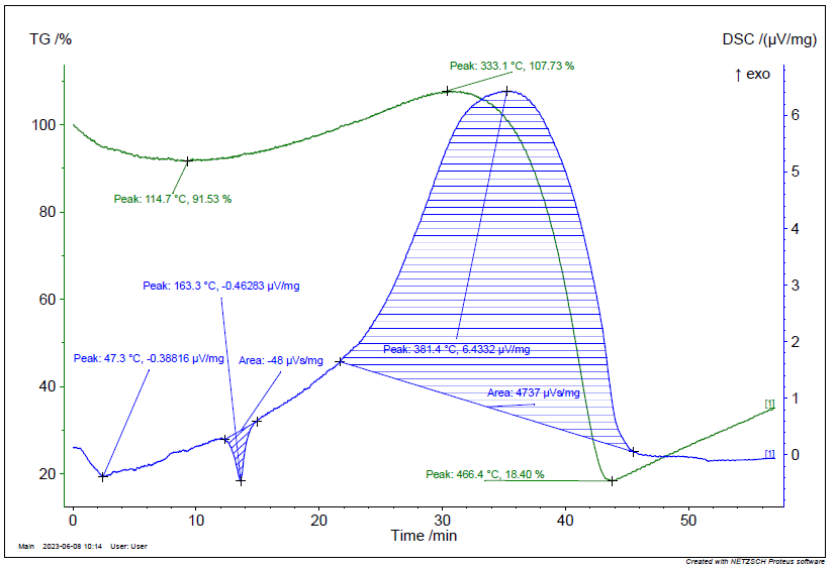


Fig. 11. STA of waste PP

Fig. 10-11 also shows differential scanning calorimetry (DSC) results for virgin and waste PP. The two primary characteristics of virgin and waste PP, the glass transition temperature (Tg) and melting point (Tm), are discovered using DSC research. Figure 10

demonstrates that for virgin PP, the first and second physical changes occur at temperatures of 47.5 ^{o}C and 167 ^{o}C, respectively, at differential peaks. On the other hand, it is found from Fig. 11 that for waste PP, the first and second physical changes occur at temperatures of 47.3 ^{o}C and 163.3 ^{o}C, respectively, at differential peaks. As a result, virgin PP may have glass transition and melting points of 47.5 ^{o}C and 167 ^{o}C, respectively, while waste polypropylene may have values of 47.3 ^{o}C and 163.3 ^{o}C, which are nearly equivalent.

CONCLUSIONS

ATR-FTIR study of waste PP and virgin PP revealed that the chemical structures of waste PP and virgin PP are almost same, and waste PP did not degrade. The results of physico-mechanical, DSC, tensile and water absorption examinations of injection molded waste PP and virgin PP are nearly identical. Both waste and virgin PP composites also exhibit almost similar tensile and water absorption results. So, the re-melting and re-molding of waste PP into various new industrial products can be a valuable replacement of virgin PP and will convert PP wastes into resources.

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