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Research Article

Investigation of the mechanical behavior of recycled polypropylene-based composite materials filled with waste cotton and pine sawdust

İlyas KARTAL[1]*, Hilal SELİMOĞLU[2]

[1]Marmara University, Faculty of Technology, Metallurgical and Materials Engineering Dep., 34722, İstanbul-Turkey
* **Corresponding Author** : **Email:** ilyaskartal@marmara.edu.tr - **ORCID:** 0000-0001-9677-477X

[2]Marmara University, Institute of Pure and Applied Sciences, Polymer Science and Technology Dep., İstanbul-Turkey
Email: selimoglu.hillal@gmail.com - **ORCID:** 0000-0002-5344-7100

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Abstract:

Composite materials are produced synthetically with a matrix material and a filler or reinforcement to provide the desired properties. In composites, synthetic fillers are often preferred. Natural fibers and fillers, on the other hand, are now preferred over synthetic fillers. These materials can be found in polymer matrices as reinforcement and fillers. Composite materials made from natural materials are replacing traditional materials in the industry for many reasons, including easy processing, lightness, and low cost.
In this study, the usability of pine wood sawdust and cotton together in polymer matrix composites was investigated. Pine sawdust is a product that emerges as waste, especially in the furniture industry. On the other hand, cotton has a wide area of use in the textile industry and is also obtained as a waste product. Recycled Polypropylene is used as a matrix material due to its intense use in industry. Pine sawdust was prepared using a sieve in the size of 0-250 microns. Since the waste cotton is in different sizes, it was cut to be 1 cm to have certain sizes. Composite materials were produced by adding pine sawdust and textile waste to recycled Polypropylene at different ratios. Composite samples were prepared by injection molding method. The physical properties of the samples such as tensile, impact, hardness and water absorption properties were investigated. SEM images of the fracture surfaces were analyzed. As a result of the study, it was evaluated that pine sawdust and waste cotton would be used in polypropylene-based composite applications.

1. Introduction

Composite materials are developed to meet the needs of the industry by changing the type, morphology, or amount of their components and improving their properties. It is quite common to use reinforcement and/or filler materials to modify the properties of composite materials [1-3]. Composite materials offer flexibility to both the manufacturer and the consumer by providing the desired properties in different environmental conditions. Since the composites are designed according to needs, they are used in each sector of the industry [2].
The use of polymer-based composites is rather common among composite types. Polymer matrix composite materials are at least two-phase materials consisting of polymer, which is the continuous phase, and filler or fiber, which is the dispersed phase. The continuous phase is responsible for filling the volume and carrying the charges to the dispersed phase. The dispersed phase improves one or more properties of the composite. Polymer matrix composites are widely used as special engineering materials in aerospace, civil engineering structures, and automotive applications due to their remarkable mechanical properties [3].
In general terms, the concept of reinforcement in composites is used to describe all additives that provide the highest tensile strength. Fillers, on the other hand, improve other properties while reducing these properties. In thermoplastic materials, fillers increase the density and hardness, decrease the thermal expansion, increase the thermal conductivity, and thus improve the balance in the final part, while reducing the cost. The form of the particle, the average particle diameter, and the particle size distribution all influence how the added filler changes a property in the plastic. [4-7].
Thermoplastic materials with widespread use in the industry are Polyethylene (PE), Polypropylene (PP),

Polyvinylchloride (PVC), and polyethylene terephthalate (PET) polymers. Cost and physical properties explain the widespread use of these polymers. Engineering plastics have been replaced by most metals in industrial products due to their properties such as high strength, heat resistance, and impact strength [3,8-10].

Polypropylene, which is used extensively in thermoplastic-based composites, is one of the plastics with a high production volume and a wide range of uses such as refrigerators, washing machines, and air conditioners. It has a very good balance between its physical and mechanical properties. Polypropylene-based products are economical compared to other polymer materials and can be easily recycled. Because it does not react with most materials, it is extensively used in the packaging industry. Polypropylene is used in automobile engineering instead of traditional materials because it is lightweight, has a high impact strength, and is resistant to relatively high temperatures [11,12].

Fillers are commonly used in composites. Environmental awareness, ecological concerns, and new regulations have caused organic fillers to replace inorganic fillers in polymer composites [13]. Renewability, low cost, non-toxicity, low density, and low abrasiveness during processing are the main reasons for the development of natural fillers in polymer composites [14].

The use of natural fibers or fillers in composites is also common, and some natural fibers used are cotton, banana, coconut, jute, kenaf, flax, bamboo, sisal, nutshell, rice, and wheat straw [15-18]. Polyolefin group polymers are often used in the production of composites with natural fibers. This requires the processing temperature to be below 200ºC. The degradation of the fibers was observed above this temperature [19-21]. In recent years, many studies have been conducted on the use of natural fillers and fibers [22-30]. The use of recycled plastic in such composites is also common. Thus, it offers a solution for some of the disposal problems in the waste of petroleum-based plastics [31-33].

In this study, waste cotton and pine wood sawdust were used as fillers. Millions of tons of waste are produced annually in the world, both in textile production and furniture production. The vast majority of these wastes go to waste collection areas. Although the textile industry has made efforts to reduce the amount of waste in recent years, only a small part of textile waste is recycled today. In 2050, the textile industry is expected to account for 26% of the world's carbon budget [34]. Synthetic fibers do not decompose in nature and are therefore harmful to living organisms. Moreover, the production and consumption of textiles have doubled in recent years, and the presence of potential waste and groundwater pollution is also being considered [34-35]. These problems have become a necessity to introduce regulations to reduce waste and environmental impact in the textile industry [36-38]. For this reason, every step towards reducing the increasing textile industry waste is significant. It is imperative to improve the efficient use of all kinds of waste to create a sustainable ecosystem. A large percentage of textile waste consists of cotton and its blends with other synthetic fibers. [37]

In this study, the co-usability of pine wood sawdust and waste cotton in polymer matrix composites was investigated. Recycled Polypropylene material, which is used extensively in the industry, was used as the matrix material. It is expected that the use of the two wastes together will create synergy in the mechanical properties of recycled Polypropylene.

2. Materials and Method

2.1 Materials

Recycled Polypropylene was preferred as a composite matrix material due to its intense use in the industry and was obtained from local companies. Textile waste cotton and pine wood sawdust were used in the furniture sector as filler material. Filler materials were also obtained from local companies as waste. Since the waste cotton is in different sizes, it was cut to be 1 cm as seen in Figure 1 to have certain dimensions. Pine sawdust was prepared by using a 250-micron sieve.

Figure 1. *Image of waste cotton*

2.2 Sample preparation

Pots are produced from recycled Polypropylene used in this study. Pots were also produced from the prepared mixture. The mixture contents are given in Table 1. Waste cotton and pine sawdust were added to Recycled Polypropylene in different weight ratios as seen in the table.

Table 1. *Contents of samples (by weight, %)*

Samples	Pine Sawdust	Waste Cotton	Recycled Polypropylene
rPP	0	0	100
5PS15C	5	15	80
10PS10C	10	10	80
15PS5C	15	5	80
20PS	20	0	80
20C	0	20	80

Abbreviations: rPP, recycled polypropylene; PS, pine sawdust; C, cotton

It is preferred to use a maximum of 20% filler addition to recycled Polypropylene by weight. Composite samples were homogenized using Haisi brand twin screw extrusion line. Tederic DT-200 branded injection machine was used to produce the samples.

Table 2. *Injection conditions in composite production*

Process	Injection Conditions
Temperature (°C)	190-220
Pressure (bar)	100-110
Mold waiting time (s)	12

2.3 Tests and Analysis

For the tensile test of the composites, the sample was cut from the pots. The tensile test was performed on the Zwick brand Z010 universal type tensile tester at a tensile speed of 5 mm per minute. The hardness test was performed with a Zwick Shore D device, waiting for 10 seconds. The impact test was carried out on the Zwick B5113.30 brand test device with a 5.4 J hammer. For SEM analysis, samples were prepared from the fractured surfaces of the impact strength samples. For SEM analysis, the samples were coated with a 10 Å thick gold/palladium alloy. SEM test was performed with Polaron SC branded device. The samples were kept in water for 50 days to determine the water uptake ratio.

3. Results and Discussions

The strength value in filled polymer matrix composites varies depending on the active load transition between the matrix structure and the filler. Factors such as the filler ratio and size, and the bonding strength of the matrix layer between the filler also affect the strength.

The tensile strength and % strain values of the samples are given in table 3. The tensile strength of the recycled Polypropylene sample without filler was determined as 21.30 MPa. According to the tensile test, it was observed that the highest tensile strength was in the sample coded 10PS10C (Figure 2). A slight increase in tensile strength was obtained compared to pure recycled Polypropylene. The tensile strength of the samples with a pine sawdust ratio of 20% was the lowest. The tensile strength of the samples decreased as expected after the sawdust ratio of 10%. Since cotton is based on cellulose, it has slightly reduced the tensile strength of pure recycled polypropylene.

The weak interfacial bond between the polymer matrix and the filler content reduces the tensile strength of the composite. It has been stated in different studies that the tendency to agglomerate with the increase of the filler amount or the insufficient hydrogen bond between the sawdust particles and the matrix causes a decrease in the tensile strength [39,40].

Table 3. *Tensile strength properties depending on the filler ratios in the samples*

Samples	Tensile Strength (MPa)	Max Strain (%)
rPP	21,30	7,40
5PS15C	20,71	6,26
10PS10C	21,40	5,30
15PS5C	18,15	4,54
20PS	17,11	4,18
20C	19,20	4,13

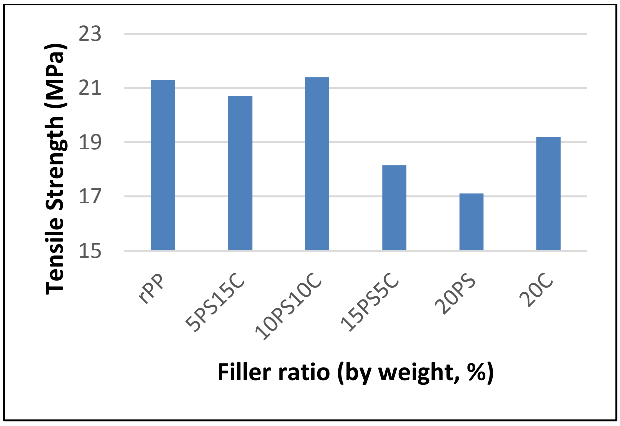

Figure 2. *Tensile strength properties of composites materials*

The values of Izod impact strength according to filler ratios is given in Figure 3. As a result of the impact test, it was observed that the impact strength of pure recycled Polypropylene was 23.15 kJ/m^2. As expected, the impact strength of recycled Polypropylene was the highest. The highest value in filler-added composite samples was measured as 19 kJ/m^2 with the sample coded 10PS10C. The lowest impact strength was observed in the 20PS sample with a value of 8.85 kJ/m^2. The negative effects of natural fillers and fibers added to the polymer matrix on the impact strength of the composites are also seen in other studies in the literature [41].

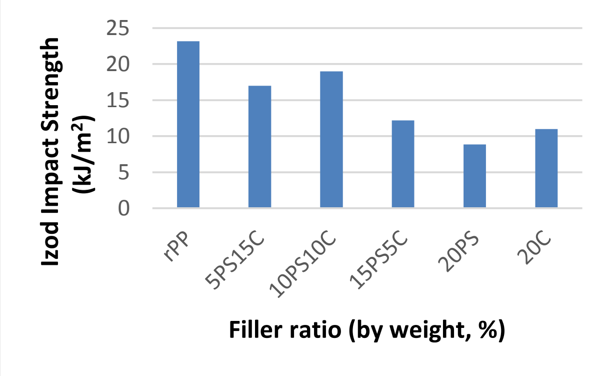

Figure 3. *Izod impact strength properties composite samples*

In Figure 4, the variation of the hardness values according to the filler ratios is given. The hardness of pure recycled Polypropylene was determined as 60 Shore D. The highest value was measured as 66 Shore D with the sample coded 10PS10C and showed an increase of around 10%. A decrease in the hardness value was observed in the subsequent filler ratios. With these results, it was determined that the hardness values of the natural filled composites added to the polymer matrix were compatible with the studies in the literature. [26,41].

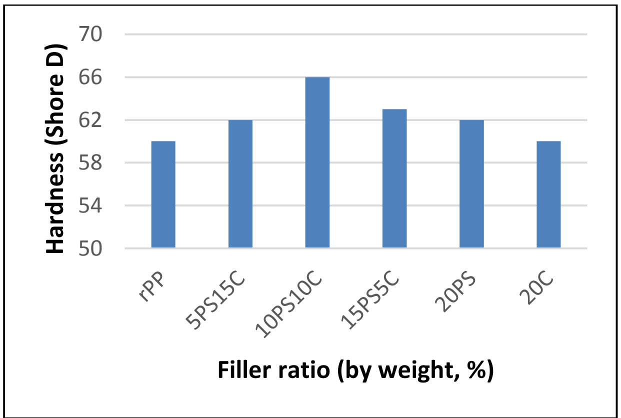

Figure 4. *Hardness properties of composites materials*

In Figure 5, the 50-day water absorption test results of the samples are given. At the end of 50 days, the highest water uptake was observed in the 20PS-coded sample. It is clearly seen that the water absorption rate increases as the sawdust content increases. An increase in water uptake was observed in all of the composite samples within 50 days. At the end of this period, the change in weight gains is around 1.6% and it has been determined that the curve tends to become flat.

In the literature, it is known that polypropylene has hydrophobic properties, while cellulose-based materials are hydrophilic. The increase in water absorption in composites with cellulose-based materials is clearly seen in the graph. Although the waste cotton filler is cellulose-based, it absorbs relatively less water than sawdust due to the dyed layer on its surface. The data obtained as a result of this study are following the literature [41].

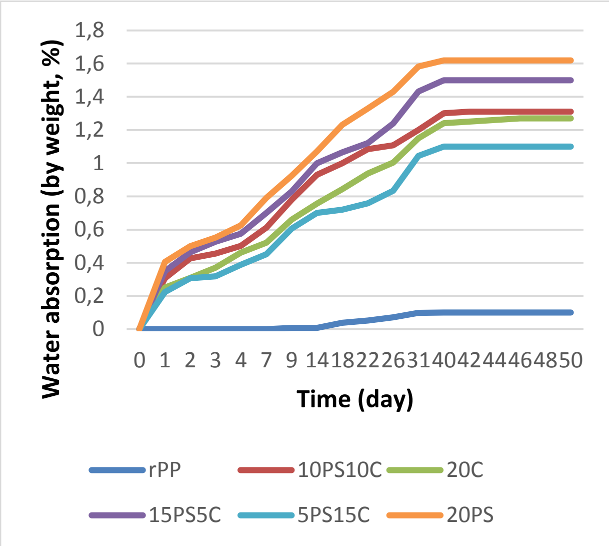

Figure 5. *Water absorption properties of composites samples*

SEM images of the fracture surfaces of the samples are given in Figure 6. Pure recycled PP showed high elongation as seen in SEM images (6a). This elongation value is also confirmed in the tensile test data. The sawdust in the 20% pine sawdust-filled sample is shown in Figure 6b. The length of the sawdust is over 150 microns, as predicted from the picture. According to the image, it can be said that there is not a very good adhesion between PP and sawdust. This situation can also be understood from the tensile and impact tests. The cotton fiber in polypropylene structure is seen in 6c and The fibrils were found to be around 10 microns in diameter. In 6d, sawdust and cotton are seen in the same image.

4. Conclusions

In this study, the effect of waste cotton and pine sawdust fillers on recycling polypropylene was investigated;

- The highest tensile value was seen in the 10PS10C coded sample among the composites. The tensile values of the following samples decreased compared to pure rPP.

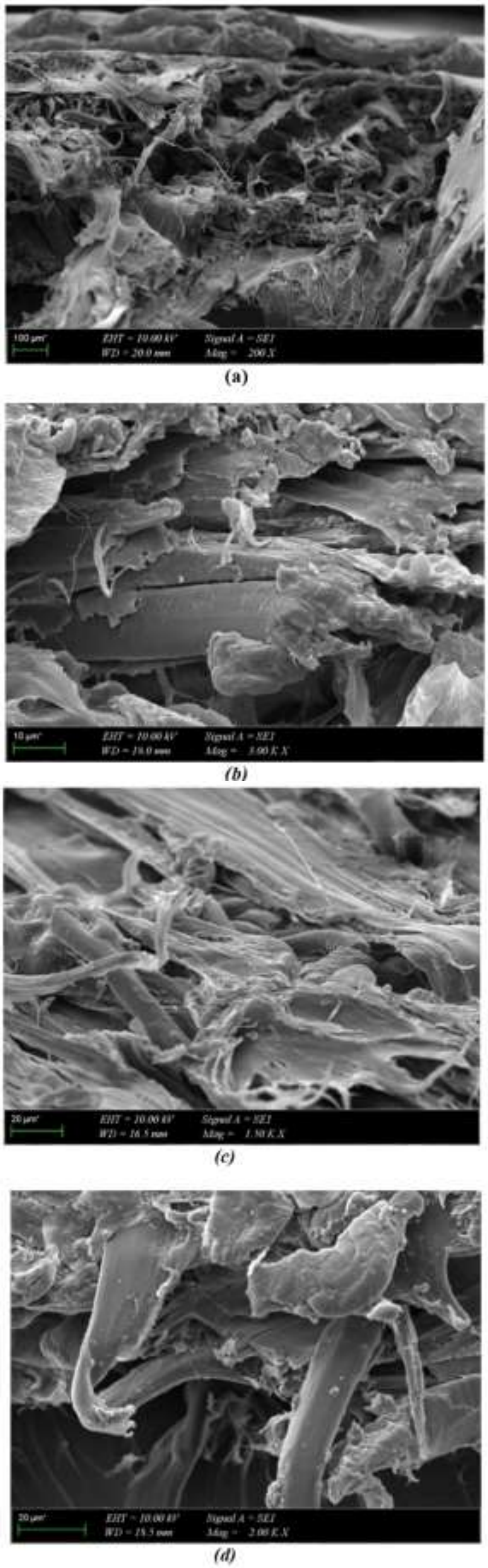

Figure 6. *SEM images of samples a)rPP b)20PS c)20C d)15PS5C*

- When we look at the water uptake data, it is seen that the composite samples absorb more water than pure rPP.
- Impact strength decreased in general composite samples compared to rPP, but this decrease was less in the 10PS10C-coded sample.
- It was determined that each composite sample had a partial increase in hardness values.
- The samples were prepared homogeneously as confirmed by SEM images. However, in certain samples, a strong bond between the matrix and the filler was not formed.

As a result of the study, it was evaluated that cotton and pine sawdust can be used together as filler in Polypropylene matrix composite materials, and the ideal ratio is 10% pine sawdust and 10% waste cotton (sample with code 10PS10C).

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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