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Research Article

Investigation of Mechanical Properties of Oak Sawdust Filled Polyester Composites

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Abstract:

Environmentalist studies in the composites industry mostly focus on the use of polymers and reinforcement materials (fibre or filler) from sustainable sources. The production of sustainable and recyclable products due to reasons such as the rapid decrease in natural resources in the world and environmental concerns is an issue that today's industry emphasizes. In recent years, many studies have been conducted on the use of natural materials obtained from agro-food industry wastes or by-products in the production of composites due to low environmental impact, recyclability and ease of processing. In this study, it is aimed to produce an environmentally friendly composite by using oak sawdust as filler material and polyester as matrix material. Composite materials were obtained by adding sawdust to polyester in different proportions in an open mould. First of all, sawdust was brought to certain dimensions using sieves. It was added to the polyester with the open casting method starting at 5% (5, 10, 15, 20) until it reached saturation. Mechanical properties of the samples such as tensile, impact and hardness were investigated. Thus, the ideal oak sawdust filler ratio added to polyester was determined as 5% by weight. At the end of the study, it was determined that tensile strength increased by 10%, Izod impact strength increased by 3%, and hardness increased by 3%. In addition, fracture surface image analysis of composite samples was also carried out.

1. Introduction

In recent years, the demand for environmentally friendly and sustainable material options has led to new searches in industrial applications. The environmental impacts of traditional materials and their availability from limited resources have increased the importance of naturally filled polymer-based composites. These materials are obtained by harmoniously combining natural fillers with thermosetting/thermoplastic resins and offer a sustainable alternative. The types of natural fillers used in composites are fillers obtained from natural sources that offer sustainable and environmentally friendly alternatives. Fibers and fillers obtained from natural sources such as wood sawdust and fiber, bamboo sawdust and fiber, hazelnut shell, wheat stalk, walnut shell, hemp, flax, jute, hemp, rice husk, palm kernel and cotton are widely used natural fillers in composites [1-2].

Natural filler-filled polymeric composites can be applied in various industrial fields and offer various advantages. In particular, the positive impact of these materials on the environment and low-cost production processes have made them an attractive option for a sustainable future. Filled composites are materials created by combining filler and matrix materials. The filler material is an important factor that determines the mechanical, thermal and electrical properties of the composite. The size and ratio of the filler material can significantly affect the performance of the composite material. Therefore, the size and ratio of the filler material in filler-based composites should be carefully evaluated [3].

The size of the filler material directly affects the physical and mechanical properties of the composite material. Large-sized filler particles can negatively affect the homogeneity and distribution of the composite. This may lead to low and variable mechanical properties as a result of the filler material being unevenly distributed within the matrix. Additionally, large filler particles can increase the density of the composite, resulting in a heavier material. On the other hand, small-sized filler particles can be mixed more homogeneously with the matrix material and provide better dispersion, increasing the mechanical properties of the composite. Since small-sized filler particles will have more contact surface with the matrix, it may lead to an increase in mechanical properties such as strength, hardness and toughness [4-5].

The proportion of filler material refers to the amount of filler and matrix in the composite. As the filler ratio increases, the effect of the filler material becomes more pronounced and affects the mechanical properties of the composite. Increasing the filler ratio can increase the mechanical properties of the composite, such as strength and hardness. However, excessively high filler rates can weaken the bonds between the matrix material and cause cracking. Additionally, the filler ratio also affects the density of the composite. Increasing the filler ratio can increase the density of the composite material and result in a heavier material. This can negatively affect the performance of the composite, especially when lightness is an important factor [6-7].

In particle-based composites, it is important to carefully select and optimize the size and ratio of the particles. Choosing the right size and ratio is a critical factor to achieve the desired mechanical properties and performance. Therefore, harmoniously combining the filler material and matrix material and determining the correct dimensions and proportions enables the successful design and use of filler-based composites [4-5].

Recent research on natural filler-filled polymer-based composites has included significant developments focusing on environmental sustainability, material performance and application areas. Such studies are an important step towards the development of more environmentally friendly materials and increasing their industrial use. Many studies have been conducted in the literature on this subject [8-10].

The use of wood sawdust as a natural filler is quite common in polymer-based composites. These composites are materials created by combining sawdust waste generated during industrial processes with a polymer matrix. Such composites play an important role in sustainability and waste management and offer several advantages over traditional polymers. Sawdust-filled polymer-based composites are a sustainable material option because they are produced by recycling waste sawdust. Sawdust generated during industrial processes are reused in composite material instead of harming the environment [11-13].

Considering recent studies, cost-reducing and strength-increasing studies are widely carried out by adding additives to polymers. In this study, composite material will be obtained by using different ratios of fillers to polyester. Thus, by using wood sawdust, the cost of composite production will be reduced, the production of synthetic fillers will be reduced, the cost will be reduced, gas emissions will be reduced, and natural resources will be protected.

2. Material and Methods

Oak sawdust used as natural filler was obtained as waste from local companies producing furniture. Sawdust was used in the size range of 0-250 μm. Polyester resin was chosen because of its cheapest and most common use as a thermosetting resin in industry. Methyl ethyl ketone peroxide (Erco Boya Sanayi, Istanbul) was used as the reaction initiator. Cobalt naphthalate, used as an accelerator, was not used separately because it was contained in the resin. An open mold made of Teflon material was used to prepare the test samples.

2.1 Sample Preparation

The prepared composite samples are a combination of oak wood sawdust and polyester resin. Composite materials were obtained by adding wood sawdust to polyester in different proportions. First of all, sawdust was obtained in a certain size range (0-250 microns) using a sieve. Larger and coarser samples were not used. Composite samples were prepared separately at each ratio, starting from 5% (5, 10, 15, 20%) into polyester resin using the open casting method in a Teflon mold and continuing until saturation was reached.

2.2 Tests and Analysis

The tensile test was performed according to the ISO 527 standard on the Zwick brand Z010 universal type tensile tester, at a tensile speed of 5 mm per minute. For the impact test, the samples were tested without notches and were performed with a 5.4 J Izod hammer on the Zwick brand B5113.30 impact test machine. Hardness test measurements were made on a Zwick brand Shore D test device. For SEM analysis, the samples were coated with gold/palladium alloy and were carried out with the Polaron SC brand device at Marmara University Nanotechnology and Biomaterials Application and Research Centre Laboratory.

3. Results and Discussions

In this study, natural filler-filled thermoset-based composite was produced and its mechanical properties were examined. In the study, it was aimed to produce an environmentally friendly composite by using oak tree sawdust, which is abundant in our country, as a natural filler. General purpose unsaturated polyester resin, which is considered the locomotive resin of the composite industry, was used as the matrix material.

Tensile strength, E modulus and % elongation values of the samples are given in Table 1. The tensile strength properties of particle-filled polymer-based composites vary depending on the structure, size and ratio of the particle added to the polymer. It also depends on the charge transfer depending on the interface between the particle and the matrix (Figure 1).

Table 1. *Tensile strength properties of samples depending on the filler ratio.*

Filler Ratio, Weight %	Tensile Strength (MPa)	Elastic Modulus (MPa)	% Elongation
Neat Polyester	26,1	2040	1,25
5	27,7	2052	2,2
10	27,4	2084	2,0
15	25,3	2105	1,8
20	22,8	2108	1,8

When the amount of filler mixed into the polymer reaches a certain value, the mechanical properties of the polymer weaken and its hardness increases. Therefore, there is an upper limit to the filler to be used in polymers. In this study, the tensile strength of the samples was 5% and 10% higher by weight compared to pure polyester with the increase in the amount of filler. The highest tensile strength was determined in the sample filled with 5% sawdust. This is because the tensile strength values of the composites partially increased due to the reinforcing effect of sawdust. As expected, there was a decrease in the strength value after a certain rate (10% and above). This may be due to a decrease in the percentage of polyester resin that binds the composite tightly. Another possible reason could be that the weak interfacial bond between the polymer matrix and the filler content reduces the tensile strength of the composite. It has been stated in studies that as the amount of sawdust increases in the matrix, the tendency to agglomerate or the formation of insufficient hydrogen bonding between sawdust particles and polyester resin causes the tensile strength to decrease [14-16]. It was determined that at 20% filler ratio, the sample reached saturation in the amount of filler.

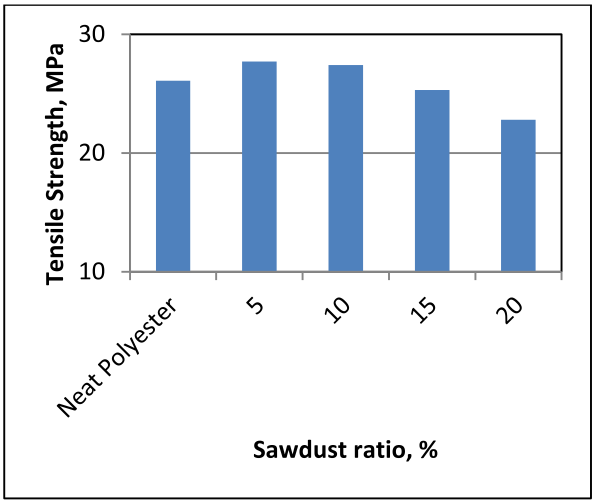


Figure 1. *Tensile strength properties of samples depending on the filler ratio*

While the addition of filler in composites may increase the tensile strength up to the ideal ratio and then cause it to decrease, on the contrary, the modulus value may increase as the amount of filler increases. If the tensile strength increases and then decreases as the amount of filler increases, it may mean that the filler material is incompatible with the polymer matrix or that weak zones are formed that weaken when the filler content exceeds a certain threshold. At this point, the interaction between the filler and the matrix is important to ensure correct distribution and a homogeneous structure. On the other hand, as the amount of filler increases, the modulus value increases, indicating that the hardness and rigidity of the composite increases. This may indicate that the filler interacts more effectively with the matrix, providing a positive effect on the mechanical properties of the filler [17]. The highest E modulus (figure 2) value of the composite samples was reached with 15% sawdust filler (2095 MPa). With the addition of sawdust, the modulus value increased by approximately 10%. The modulus value of all samples is higher than pure polyester.

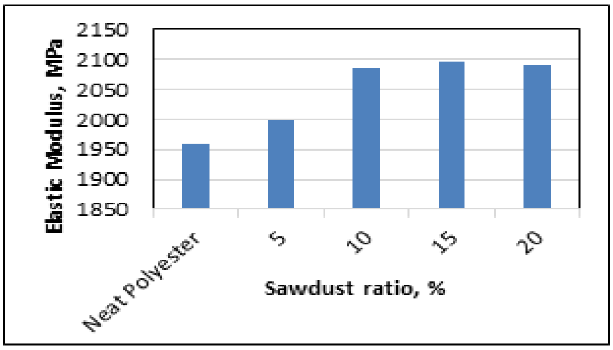


Figure 2. *Elastic modulus properties of samples depending on filler ratio*

The addition and quantification of natural filler requires careful balancing in the process of optimizing the properties of the composite. Experimental studies, microstructural analysis and modeling methods can be used to find this balance. Determining the ideal filler amount and distribution ensures that the composite has mechanical properties that best suit the specific application requirements. The impact properties of the composite are also important for different applications. In this study, notchless impact test was applied to the samples. While the impact strength of pure polyester was 1.4 kJ/m^2, it partially increased with the addition of 5% sawdust, and this value decreased at later ratios. The lowest impact strength was determined in the sample filled with 20% sawdust (1.2 kJ/m^2).

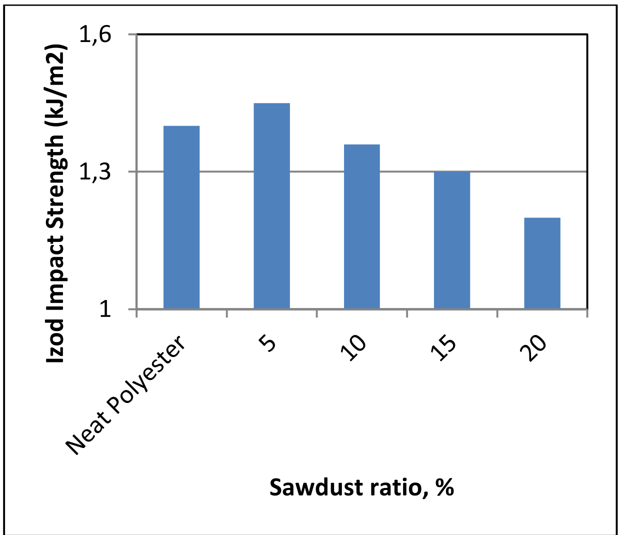


Figure 3. *Izod impact strength properties of samples depending on the filler ratio*

The increase in the modulus value as the amount of filler increases indicates that the hardness and rigidity of the composite increases. This may indicate that the filler interacts more effectively with the matrix, providing a positive effect on the mechanical properties of the filler (figure 3). As the amount of sawdust in the samples increased, the hardness partially increased [5,6]. While the lowest hardness value was found in pure polyester (66 Shore D), the highest hardness value was determined in the sample filled with 15% sawdust (68 Shore D) (figüre 4). Figure 5 shows the SEM images of the fractured surfaces of the samples. As can be seen from the SEM image of pure polyester in Figure 5a, there is a brittle fracture on its surface. The other SEM image, is the broken surface image of the sample containing 10% sawdust. It is obvious that the sawdust adheres well to the polyester resin. It can be seen that there are many different sizes and shapes of sawdust in the sample. As can be seen from the images, there are shavings of 10 microns in size as well as 150

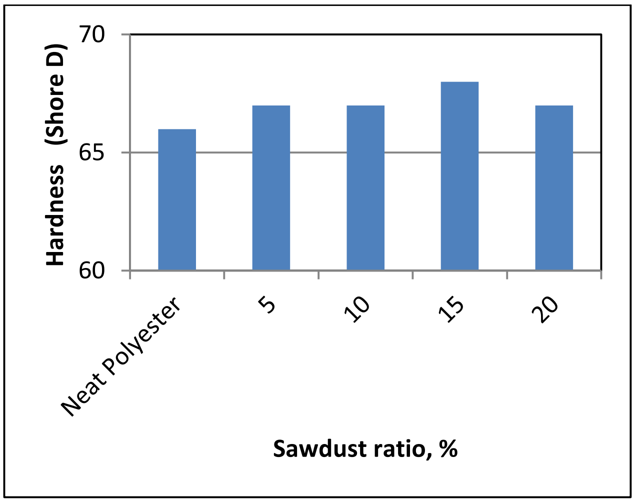


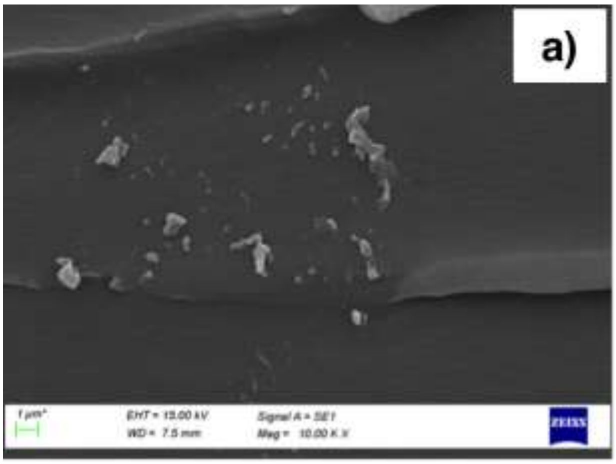
Figure 4. *Shore D hardness properties of samples depending on filler ratio*

microns in size. Additionally, as the weight ratio of sawdust particles in the resin increased, agglomeration was observed in the samples. This is thought to cause the formation of bubbles and pores that can interfere with the mechanical properties of the composites.

Polyester filled with 10% sawdust by weight can be considered to have a good interface. As the amount of sawdust increases by weight, there may not be enough polyester resin left to completely cover all cellulosic surfaces. Thus, it can be understood why composites containing 5% sawdust by weight show better mechanical properties than composites containing 20% sawdust by weight. Similar observations in this study have been reported in other studies [15-18].

4. Conclusions

The main reason for using fillers is to reduce the amount of polymer used and reduce the cost of the



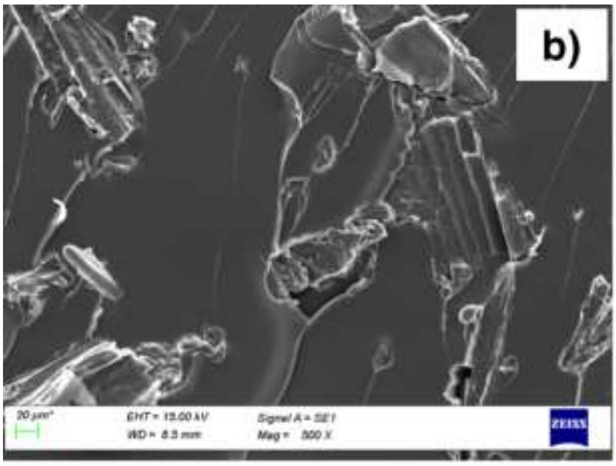


Figure 5. *SEM images from the broken surfaces of the samples (a) neat polyester (b) composite with 10% sawdust filler*

material. Therefore, the price of the filler must be significantly lower than the polymer it replaces. In addition to reducing the price of the polymeric product, fillers can positively affect some of the polymer's hardness, mechanics, durability, heat resistance, appearance, chemical resistance, physical and mechanical properties. When the amount of filler mixed into the polymer reaches a certain value, the mechanical properties of the polymer weaken and its hardness increases. Therefore, there is an upper limit to the filler to be used in polymers.

In this study, oak wood sawdust was used as a filler in polyester. As expected, mechanical properties were improved to a certain extent. The highest values of the composite samples were achieved in tensile strength with 5% filler, in elasticity modulus with 15% filler, in Izod impact test with 10% filler (figüre 3), and in hardness test with 15% filler. In this study, it was concluded that oak wood sawdust can be used as filler for its intended purpose, regardless of the mechanical properties used.

At the end of the study, it was determined that oak wood sawdust filler would reduce the amount of polyester resin usage, which would reduce the cost and contribute positively to the mechanical properties. It is also clear that using natural fillers instead of synthetic fillers will contribute to the solution of environmental problems.

Author Statements:

- The authors declare that they have equal right on this paper.
- 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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