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MECHANICAL AND PHYSICAL PROPERTIES OF SAWDUST-REINFORCED EPOXY RESIN COMPOSITES

锯末增强环氧树脂复合材料的机械和物理性能

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Abstract

Sawdust is one of the beneficial by-products of wood production, along with a number of others. In the construction of structures, sawdust, considered a waste material, is successfully used to create sawdust concrete. In the present study, a new analysis of the mechanical and physical properties of sawdust-reinforced epoxy resin composites (SRER) was presented. This mixing composite was fabricated using the compression molding techniques to produce three eco-friendly ratios between natural and synthetic materials: 75% of sawdust and 25% of epoxy (75S25E), 80% of sawdust and 20% of epoxy (80S20E), and 85% of sawdust and 15% of epoxy (85S15E). The images of the sawdust material were captured using Nikon SMZ 745T microscope, and their mechanical properties were analyzed using tensile, impact, and surface roughness tests. The collected data were analyzed using statistical analysis. Numerical computations and graphical demonstrations were carried out to observe the mechanical and physical properties of the SRER composite according to the three ratios. Their mechanical and physical properties will affect the different ratios of SRER composite. The outcomes demonstrated that due to the synergistic effect of reinforcements, the composite with 80% of sawdust had better mechanical properties than the other eco-friendly ratios composites. Furthermore, the mechanically tested samples were subjected to a surface roughness test to investigate the impact of the speed parameters of the CNC router machine spindle. The results show the significance of the CNC router machine spindle speed parameters for the eco-friendly ratios of SRER composite.

Keywords: Sawdust, Epoxy Resin, Mechanical Properties

摘要 锯末是木材生产的有益副产品之一，还有许多其他副产品。在建筑结构中，被认为是废料的锯末被成功地用于制造锯末混凝土。在本研究中，对锯末增强环氧树脂复合材料（SRER）的机械和物理性能进行了新的分析。这种混合复合材料是使用压缩成型技术制造的，在天然和合成材料之间产生三种环保比例：75%的锯末和 25%的环氧树脂（75 小号 25E）、80%的锯末和 20%的环氧树脂(80 小号 20E)，以及 85%的锯末和 15%的环氧树脂（85 小号 15E)。使用尼康 SMZ 745 吨显微镜拍摄锯末材料的图像，并使用拉伸、冲击和表面粗糙度测试分析其机械性能。使用统计分析对收集的数据进行分析。进行了数值计算和图形演示，以根据三个比率观察 SRER 复合材料的机械和物理性能。它们的力学和物理性能会影响 SRER 复合材料的不同配比。结果表明，由于增强材料的协同作用，含有 80%锯末的复合材料比其他环保比例复合材料具有更好的力学性能。此外，对机械测试样品进行表面粗糙度测试，以研究数控铣床主轴速度参数的影响。结果表明，数控刳刨机主轴转速参数对 SRER 复合材料的环保比具有重要意义。

关键词: 尘埃，环氧树脂，机械性能

I. INTRODUCTION

Nature materials have evolved to meet their needs as environmental awareness has grown, allowing researchers to produce materials with unique characteristics because they are easily obtainable, lightweight, dense, reusable, environmentally friendly, biodegradable, and have high specific strength [1]. Nature materials such as pineapple leaf [2], oil palm fiber [3], rice husk [4], bamboo [5], wood [6], plywood [7], jute [8], and sawdust [9]-[10] are renewable and biodegradable materials. They are largely available in nature worldwide and are most commonly used as reinforcing materials in the polymer composite industry.

The combination of nature with synthetic materials was found to be a good alternative reinforcing material due to increased strength [11]. In recent years, many researchers have studied the mechanical and physical characteristics of the combination between sawdust and synthetic material. However, sawdust is available in various types, and sawdust accumulations can cause various health problems. The health of the lungs is severely harmed by sawdust. However, efficient sawdust utilization can help overcome some environmental issues [12]. The effect of nature materials powders on the mechanical and physical properties of glass fiber or epoxy composite was analyzed in [9]. Rice husk ash, carrot powder, and sawdust were used as natural materials and function as filler. Chauhan et al. [10] studied and evaluated the mechanical properties of sawdust reinforced epoxy composite. They investigate the impact of mechanical, thermal, and water absorption properties of sawdust-based composites. The mechanical properties of two kinds of granular biomass, sawdust and woodchips were determined at five levels of moisture content and under three levels of normal pressure [13]. The moisture contents and testing pressures were adopted to reflect the operation conditions on handling equipment in practice. The effect of particle size on the static and dynamic compression properties of sawdust-high density polyethylene composites was analyzed under various strain rates [14]. New properties of sawdust concrete were observed and studied, inspecting its thermal behavior, exploring its mechanical and physical properties, and discovering the premier mixture proportions for saving energy (heat transfer) [15]. Then they evaluated the sawdust concrete at elevated temperatures. The use of corncob and sawdust as a composite material in ceiling board production was investigated, and the best blending proportion that gives the finest board was determined [16]. The findings covered comprehensive experimental laboratory investigations on the ceiling boards produced from the mixture of corncob and sawdust as a replacement for other conventional materials. The experimental statistical study [17] revealed that temperature, compaction time, and proportion of the mixture between rice husks and pine sawdust influenced the mechanical properties of the briquettes. The statistically significant parameters that affect the mechanical properties of the jute-fiber and waste teak sawdust composite were identified to develop regression models for the mechanical properties using the response surface methodology [18]. Then they can predict the mechanical properties such as tensile strength, impact strength, flexural strength, and hardness of the composite.

This study is aimed to analyze the mechanical and physical properties of sawdust-reinforced epoxy resin composites (SRER). Three eco-friendly materials ratios were fabricated and cut in the specimen using three different spindle speed parameters of the CNC router machine to analyze the surface roughness. At the same time, the mechanical properties of SRER composite were investigated based on the tensile and impact tests. Finally, the experimental results were interpreted and presented via statistical analyses. The novelty of this study is in the systematic approach to give people from both the academic and industrial worlds a viewpoint on selecting appropriate processing parameters for the manufacturing of composite materials. In addition, the production and characterization of the materials are aided by research into sawdust-reinforced epoxy composites.

II. Materials and Methods

A. Materials and Composite Fabrication

In this study, sawdust and epoxy resin were used for mixed composite fabrication. These materials were purchased from a local company. The mechanical properties of epoxy resin are shown in Table 1. The microscope Nikon SMZ 745T was used to determine the size of the sawdust, the result of the data measurements is shown in Table 2.

Table 1.
Mechanical properties of epoxy resin

Density (g/cm^3)	Modulus of elasticity (GPa)	Poisson' ratio
1.2	2.7	0.4

Table 2.
Sawdust data measurements for the average of the samples

	Average
Mean	1.6158
Min.	0.9182
Max.	2.4080
Sum.	16.1587
Std. Dev.	0.4723
Variance	0.2372

Fabrication composites of SRER were prepared by using the hand mixing technique. First, the mixing materials were produced to a round shape for the compressing process. Then the compressed specimen is left for approximately 24 hours for the dry and hardening process. Three eco-friendly ratios of SRER composite were prepared: 75% of sawdust and 25% of epoxy (75S25E), 80% of sawdust and 20% of epoxy (80S20E), and 85% of sawdust and 15% of epoxy (85S15E). Next, the SRER composites were cut using a CNC router machine to obtain the dimensions of the specimen for mechanical testing as per standard. Three different spindle speeds parameter was used during the cutting process, which are 400 rpm, 600 rpm, and 800 rpm.

B. Mechanical and Physical Testing

The specimens of three eco-friendly ratios of SRER composite were prepared for the tensile test per the ASTM 3039 (250 mm x 25 mm x 7 mm) standard size. This test was performed using the universal testing machine. The elongation of the specimen during the test was recorded. The test was repeated three times for each specimen's eco-friendly ratios SRER composite, and the results were analyzed using a one-way analysis of variance (ANOVA).

The specimens of three eco-friendly ratios of SRER composite were prepared for the impact test per the ASTM E23 (55 mm x 10 mm x 10 mm) standard size. This test was performed using the universal testing machine. The energy in joule for specimens during the test was recorded. The test was repeated three times for each specimen eco-friendly ratios of SRER composite, and the results were analyzed using one-way ANOVA.

The specimens of three eco-friendly ratios of SRER composite were prepared for the surface roughness test. This test used a microcomputer-based viewing device to analyze scattered light patterns from the surface to obtain the parameter of ruggedness. In addition, reading was taken twice for each specimen, and three specimens were chosen for each specimen's eco-friendly ratios SRER composite and CNC router machine spindle speed parameters. Therefore, six results were obtained from the surface roughness test for each specimen's eco-friendly ratios SRER composite.

III. Results and Discussion

A. Tensile Test Results

To investigate the mechanical properties, a tensile test was performed to get the tensile strength and elongation of the three eco-friendly ratios of SRER composite, which are 75S25E, 80S20E, and 85S15E of the materials. Then, one-way ANOVA was applied to analyze the tensile strength and elongation of the materials, as shown in Tables 3 and 4.

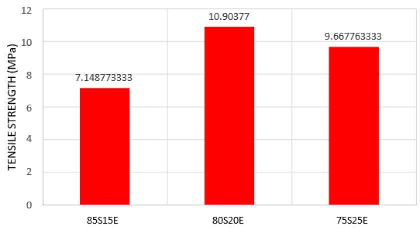
Table 3.
ANOVA of tensile strength for three eco-friendly ratios of SRER composite

Source of Variation	SS	df	MS	F	P-value
Between Groups	21.97302	2	10.98651	4.76861	0.05758
Within Groups	13.82353	6	2.303921		
Total	35.79655	8			

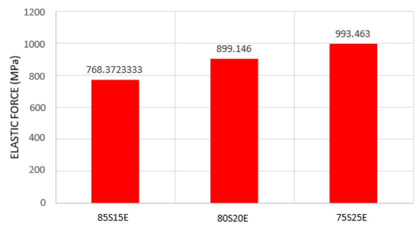
Table 4.
ANOVA of elongation for three eco-friendly ratios of SRER composite

Source of Variation	SS	df	MS	F	P-value
Between Groups	76663.26	2	38331.63	0.95191	0.43746
Within Groups	241608.6	6	40268.09		
Total	318271.8	8			

The results presented that the tensile strength and elongation of SRER composite for all three eco-friendly ratios were insignificant since the P-value is higher than the significant cut-off level $\alpha = 0.05$. The variation of tensile strength and elongation for various eco-friendly ratios of SRER composite is shown in Figures 1(a) and 1(b), respectively. The results showed that the value of tensile strength for 80S20E is greater than the other composites (Figure 1(a)). Comparatively, 85S15E had the lowest value of tensile strength (Figure 1(a)). However, the eco-friendly ratios of SRER composite for 75S25E and 85S15E have the highest and lowest value of elongation, respectively, as presented in Figure 1(b). This observation suggested that the tensile strength of the eco-friendly ratios of SRER composite becomes stronger as the percentage of sawdust is around 80%.



(a) Tensile strength



(b) Elongation

Figure 1. Tensile strength and elongation for three eco-friendly ratios of SRER composite

B. Impact Test Results

The variation of energy absorbed by three eco-friendly ratios of SRER composite is shown in Figure 2.

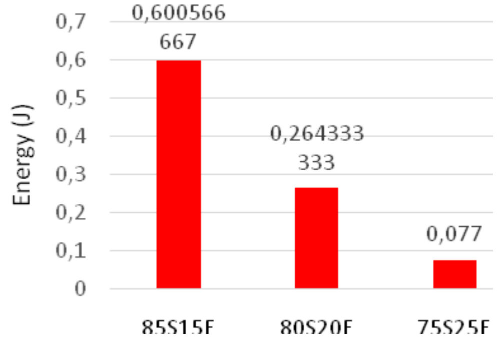


Figure 2. Energy absorbed during impact by three eco-friendly ratios of SRER composite

It can be seen that the energy absorbed by 85S15E is higher than the other eco-friendly ratios of SRER composite. This observation shows that the highest energy will be absorbed during the impact test for the highest percentage of natural materials. The one-way ANOVA was applied to analyze the impact testing for three eco-friendly ratios of SRER composite, and the result is shown in Table 5. The results indicated that the energy applied for all three eco-friendly ratios of SRER composite was significant since the P-value is smaller than the significant cut-off level $\alpha = 0.05$. This observation indicated that all the energy absorbed during the impact test for three eco-friendly ratios of SRER composite have different averages on the power impact.

Table 5.
ANOVA of impact testing for three eco-friendly ratios of SRER composite

Source of Variation	SS	df	MS	F	P-value
Between Groups	0.422269	2	0.21113	21.24236	0.00189
Within Groups	0.059636	6	0.00993		
Total	0.481905	8			

C. Surface Roughness Test Results

Three different spindle speed parameters for the CNC router machine were applied (i.e., 400 rpm, 600 rpm, and 800 rpm). The relationship between surface roughness of eco-friendly ratios of SRER composite (75S25E, 80S20E, and 85S15E) and three different spindle speed parameters were analyzed using one-way ANOVA as shown in Tables 6, 7, and 8, respectively. The results indicated that the CNC router machine spindle speed parameters for eco-friendly ratios of SRER composite were significant since the P-value is smaller than the significant cut-off level ($\alpha = 0.05$). This observation indicated that the surface roughness of eco-friendly ratios of SRER composite (75S25E, 80S20E, and 85S15E) has different averages when using different CNC router machine spindle speed parameters, and this condition is applied to 400 rpm, 600 rpm, and 800 rpm spindle speed parameters.

Table 6.
ANOVA for surface roughness of three eco-friendly ratios of SRER composite using 400 rpm spindle speed

Source of Variation	SS	df	MS	F	P-value
Between Groups	434.1398	2	217.0699	293.5477	9.4E-13
Within Groups	11.09206	15	0.739471		
Total	445.2318	17			

Table 7.
ANOVA for surface roughness of three eco-friendly ratios of SRER composite using 600 rpm spindle speed

Source of Variation	SS	df	MS	F	P-value
Between Groups	48.59415	2	24.29708	13.79667	0.000399
Within Groups	26.41624	15	1.761083		
Total	75.01039	17			

Table 8.
ANOVA for surface roughness of three eco-friendly ratios of SRER composite using 800 rpm spindle speed

Source of Variation	SS	df	MS	F	P-value
Between Groups	148.1219	2	74.06096	58.47183	8.3E-08
Within Groups	18.99914	15	1.266609		
Total	167.121	17			

IV. CONCLUSION

This study investigated the mechanical and physical properties of eco-friendly ratios of SRER composite such as 75S25E, 80S20E, and 85S15E. At the same time, the effects of CNC router machine spindle speed parameters on eco-friendly ratios of SRER composite were presented. The main findings of the present study pointed out that eco-friendly ratios of SRER composite become stronger as the percentage of sawdust is around 80% of the total percentage of SRER composite due to the synergistic effect of reinforcements. Besides that, based on ANOVA results, CNC router machine spindle speed parameters for the eco-friendly ratios of SRER composite were significant.

Since natural fibers are rapidly being employed in the polymer industry to create bio composites for various applications, including textiles and other industries, this study is crucial. The polymer sector is particularly interested in natural materials due to their renewability, affordability, and low abrasiveness. Additionally, manufacturers are adopting the technology to satisfy consumer demand because of the rise in high-performance applications and the environmental impact of conventional materials. Therefore, it is crucial to research the ideal ratios for producing stronger materials.

Some recommendations could help further study the composition of the sawdust composite and different ratios. Based on this study, 80% of sawdust material was used to give the highest tensile strength results. Then the different eco-friendly ratios with approaches to 80% of sawdust material can be chosen to get the exact percentage that gives the stronger materials. Besides that, it is recommended to continue with another cutting method such as water jet and laser cut machine.

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