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Mechanical Performance of Epoxy Composite Reinforced with Wood Dust and Crumb Rubber Waste

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Abstract. The incorporation of wood dust and crumb rubber waste as filler in polymer matrix composite still requires in-depth evaluation of mechanical properties because they have different characteristics. This study evaluates the tensile, flexural, and hardness properties of epoxy composites reinforced with various fractions of wood dust and crumb rubber (5, 10, and 15%). The results showed that the composite with 5% crumb rubber produced the highest tensile strength of 15.52 MPa (CR5), while the highest flexural strength was 30.46 MPa (CR10), and the highest hardness was 75.9 HRC (CR15), indicating superior performance for CR fillers. The observations of the fracture surface showed that increasing the fraction of wood dust contributed to lowering the mechanical performance due to the relatively large distribution of voids and agglomeration. This finding confirms the importance of filler type and fraction selection on composite performance. Future research is recommended to explore filler surface modification and hybrid combinations to improve dispersion and bonding between phases in composites.

Keywords: polymer composites, waste fillers, mechanical properties

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1. Introduction

The utilization of polymer matrix-based composite materials plays a crucial role in various industrial fields, including automotive, insulation materials, and building materials, because it presents advantages such as corrosion resistance, good mechanical properties, easy fabrication, and compatible properties with various types of fibers and fillers [1–4]. However, the use of conventional inorganic fillers that are expensive and not environmentally friendly is still a challenge in the development of composite materials. On the other hand, wastes such as wood dust and crumb rubber are increasingly abundant and have not been optimally utilized as fillers to support composite structures. Therefore, it is also desirable to develop a composite industry that considers not only the strength factor but also contributes positively to waste reduction and protects the water and soil ecosystems [5] [6].

A number of previous studies have evaluated and explored the utilization of wood dust as filler in polymer matrix composites [7] [8]. The contribution of wood dust is greatly influenced by its size, shape, and content [9]. In 2020, Fereda evaluated the variation of wood dust concentrations of 10, 20, 30, 40, and 50% in a polypropylene matrix composite. At 40% concentration, it produces maximum strengths including tensile strength, bending strength, impact strength, and compressive strength of 8.36 MPa, 46.1 MPa, 17.14 J/cm², and 35.56 MPa, but experiences a decrease in mechanical properties at 50% filler loading [10].

Meanwhile, crumb rubber from used tire waste shows a good ability to absorb energy. The addition of 5-15% crumb rubber in poly(butylene succinate) can increase impact strength by 6.81-11.51 kJ/m², but decrease tensile strength and Young's modulus by 32-23.94 MPa and 320-244.44 MPa [11]. On the other hand, the addition of 0.25 mm crumb rubber into polyurethane-based polymer mortar with 5% filler content resulted in maximum bending strength and compressive strength by 7.9% and 17.3% [12]. The contribution of crumb rubber to support the structure and performance of polymer matrix composite is strongly influenced by the bonding to the matrix and the concentration and distribution of filler [13] [14] [15].

Filler plays an important aspect in creating superior composite performance. The incorporation of wood dust and crumb rubber in polymer matrix composite exhibits different interaction behavior with various types of polymer. This is attributed to the different structures possessed within each material. Therefore, this research aims to compare the mechanical properties of epoxy composites reinforced with variations in wood dust and crumb rubber fractions of 5, 10, and 15%.

2. Methods

2.1. Materials

The matrix used in this research is epoxy resin type EPIKOTE 828, with a density of 1.18 g/cm³ and epoxy hardener (651) product from Hexion, USA, which was purchased from the IZE solution company in Kuala Lumpur, Malaysia. The natural filler used was wood dust (WD) obtained from local furniture industry waste in Indonesia. In addition, crumb rubber (CR) came from car tire waste, which was collected from the local automotive industry in Indonesia.

2.2. Sample Preparation

Wood dust and crumb rubber were cut using a cutting tool to obtain a chop size. Then, all materials were made into an average size of 1.5 mm using a crusher machine type Retsch ZM 200 grinder (Haan, Germany). After that, the filler was washed with distilled water and dried in a vacuum oven at 105°C for 24 hours [16]. Epoxy was poured into a 30 x 30 x 0.3 cm plastic molding containing filler according to the composition shown in Table 1. The mixing process uses the principle of mechanical stirring until the filler distribution reaches homogeneity and is allowed to dry at room temperature for 24 hours. The composite was cut using a cutting tool to obtain 5 test specimens and stored in a closed plastic box to avoid direct contact with humid air.

Table 1. Composition epoxy matrix composite reinforced wood dust and crumb rubber

Sample	Epoxy (%)	Wood Dust (%)	Crumb Rubber (%)
WD5	95	5	0
WD10	90	10	0
WD15	85	15	0
CR5	95	0	5
CR10	90	0	10
CR15	85	0	15

2.3. Testing of Specimen

Five test specimens were prepared for each composition and subjected to mechanical testing. Tensile and bending tests were conducted using a Universal Testing Machine (INSTRON 3367, USA) of 30 kN capacity with a crosshead speed of 2 mm/min. This test aims to obtain tensile strength, tensile modulus, and tensile displacement at break based on ASTM D638 [17], as well as flexural strength, flexural modulus, and flexural displacement at break based on ASTM D790 [18]. In addition, the specimens were subjected to hardness testing using a ZwickRoell Rockwell Hardness Tester (Germany). The fracture surfaces from the tensile test results were used for observation of the fracture behavior of the specimens using MEIJI TECHNO, Japan, with a magnification of 2.0 times.

3. Results and Discussion

3.1. Mechanical Properties

Table 2 shows the epoxy matrix composite reinforced with wood dust and crumb rubber, which shows significant variation in mechanical properties depending on the type and percentage of filler used. The composite with CR5% showed the highest tensile strength of 15.52 MPa and the highest tensile modulus value of 1,099.91 MPa. In the flexural testing results, the CR10 composite showed the highest flexural strength and displacement of 30.46 MPa and 4.05 mm, respectively. Meanwhile, the composite with WD15 experienced the most dramatic decrease in both tensile strength (5.26 MPa) and flexural strength (19.24 MPa). This indicates that the addition of crumb rubber shows better mechanical performance than wood dust.

This phenomenon can be explained in terms of the physical characteristics and interactions between the constituent materials in the composite. The findings in this study prove that at low concentrations (5-10%), crumb rubber tends to spread evenly and create strong interlocking in the epoxy matrix, thus acting as a reinforcing material as well as an energy absorber, which makes the composite more resistant to tensile and flexural loads [19]. In addition, CR10 showed higher deformation ability, reflected by the increased tensile displacement at break and flexural displacement at break values, indicating a ductile material. However, at CR15, although the deformation values are still high, there is a decrease in strength and modulus, which is likely due to the formation of voids due to the behavior of fillers that are difficult to move to occupy empty areas as well as the difference in curing systems between fillers and epoxy. This creates stress concentrations and starting points for crack propagation [20] [21] [22].

On the other hand, in wood dust-based composites, increasing WD content contributes to a decrease in the strength and modulus of the material. This is caused by poor interface adhesion between the wood dust particle and the epoxy matrix. In addition, the appearance of micro-holes and agglomeration during the fabrication process in the composite structure hinders the transfer of stress from the matrix to the filler [23]. In WD15, the significant decrease in strength indicates that too much filler presence can disrupt the phase continuity of the matrix, which ultimately decreases the material's ability to withstand loads before reaching failure [24]. This confirms that the selection of filler type and composition greatly affects the mechanical properties of the composite. Crumb rubber provides advantages in terms of tensile strength and flexural strength, especially at 5-10% composition. More than that, wood dust is less effective as a reinforcement if used in too high an amount. Therefore, composites for applications that require balanced strength and flexibility, a 10% crumb rubber concentration is the most optimal choice in this study.

Table 2. Mechanical properties of epoxy matrix composite reinforced with wood dust and crumb rubber filler

Sample	Tensile Strength (MPa)	Tensile Modulus (MPa)	Tensile Displacement at Break (mm)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Flexural Displacement at Break (mm)
WD5	11.7	830.68	1.23	27.01	1,545.60	2.57
WD10	10.39	777.16	1.22	29.77	2,047.72	2.53
WD15	5.26	481.47	1.22	19.24	619.93	2
CR5	15.52	1,099.91	1.33	28.51	1,247.30	2.65
CR10	13.18	811.72	1.48	30.46	1,289.61	3.41
CR15	13.06	696.58	2.04	23.54	777.28	4.05

Figure 2 reveals the results of the Rockwell C (HRC) hardness test, where the hardness value of the epoxy composite (WD10) increases as the reinforcement fraction of both wood dust and crumb rubber increases. In the wood dust-based composite, the hardness value increased from 43.68 HRC (WD5) to 54.44 HRC (WD10) and reached 65.8 HRC at WD15. A similar trend was also shown in the crumb rubber-based composite, with an increase from 53.14 HRC (CR5) to 62.78 HRC (CR10), and the highest value was obtained in CR15 with a hardness of 75.9 HRC. This clearly shows that the addition of filler in the epoxy matrix contributes a positive influence on the hardness of the material.

This phenomenon of increased hardness is due to the rigid nature of wood dust that supports the structure of the composite. These particles create a denser structure and inhibit plastic deformation when the composite receives a load [25]. On the other hand, although crumb rubber is more elastic than wood dust, the presence of crumb rubber creates a strong interlocking with epoxy, although there are some voids formed. This leads to the ability of the composite to keep its structure more stable, increase the surface resistance to penetration by external loads, and reduce the failure rate [26]. This phenomenon was seen in the CR15 composite, which produced the highest hardness value.

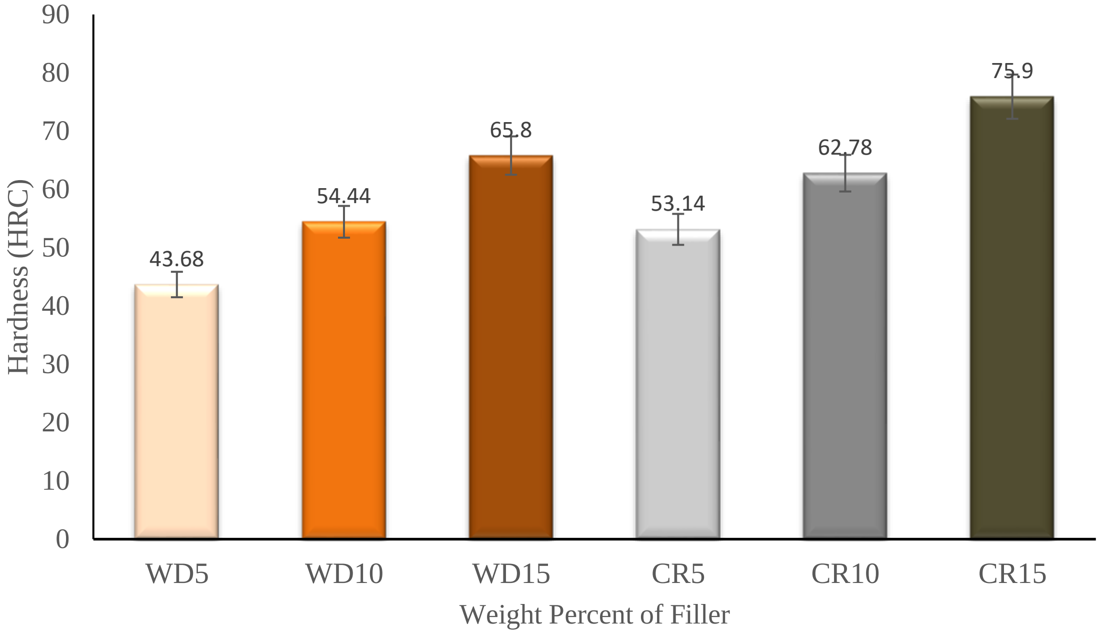

Figure 2. Hardness properties of epoxy matrix composite reinforced with wood dust and crumb rubber filler

3.2. Morphology Fracture

Figure 3 displays the fracture surface of the epoxy matrix composite reinforced with wood dust and crumb rubber. In the WD5 sample, there are voids scattered in the composite, which indicates that the filler mixing is not fully homogeneous. This creates stress concentrations that are the beginning of cracks. The WD10 and WD15 composites show larger voids and agglomeration phenomena that reduce the quality of the bond between the filler and the epoxy matrix, so that the load is not evenly distributed towards the filler [27]. As a result, the tensile strength decreased to 10.39 MPa and 5.26 MPa. This finding proves that the presence of wood dust with a high concentration makes it difficult for the filler to disperse well in the epoxy matrix and causes internal defects that trigger premature failure during tensile testing [28].

On the other hand, sample CR5 shows a fracture surface with a more even distribution of filler and bridge cracking, indicating a strong interface between filler and matrix [29]. This phenomenon indicates an energy absorption mechanism during fracture, resulting in a higher tensile strength of 15.52 MPa. However, voids were found in the CR10 composite, although the distribution was not too damaging. The tensile strength slightly decreased to 13.18 MPa but was relatively high compared to CR15 and WD (5-15%). This clearly shows that the negative effect of voids has not fully dominated, probably due to the positive contribution of the strong adhesive between wood dust and crumb rubber. In CR15 composites, the difficulty of filler movement in the matrix creates larger voids, making it difficult for the filler to create a strong bond with the matrix and resulting in brittle areas in the composite structure [30].

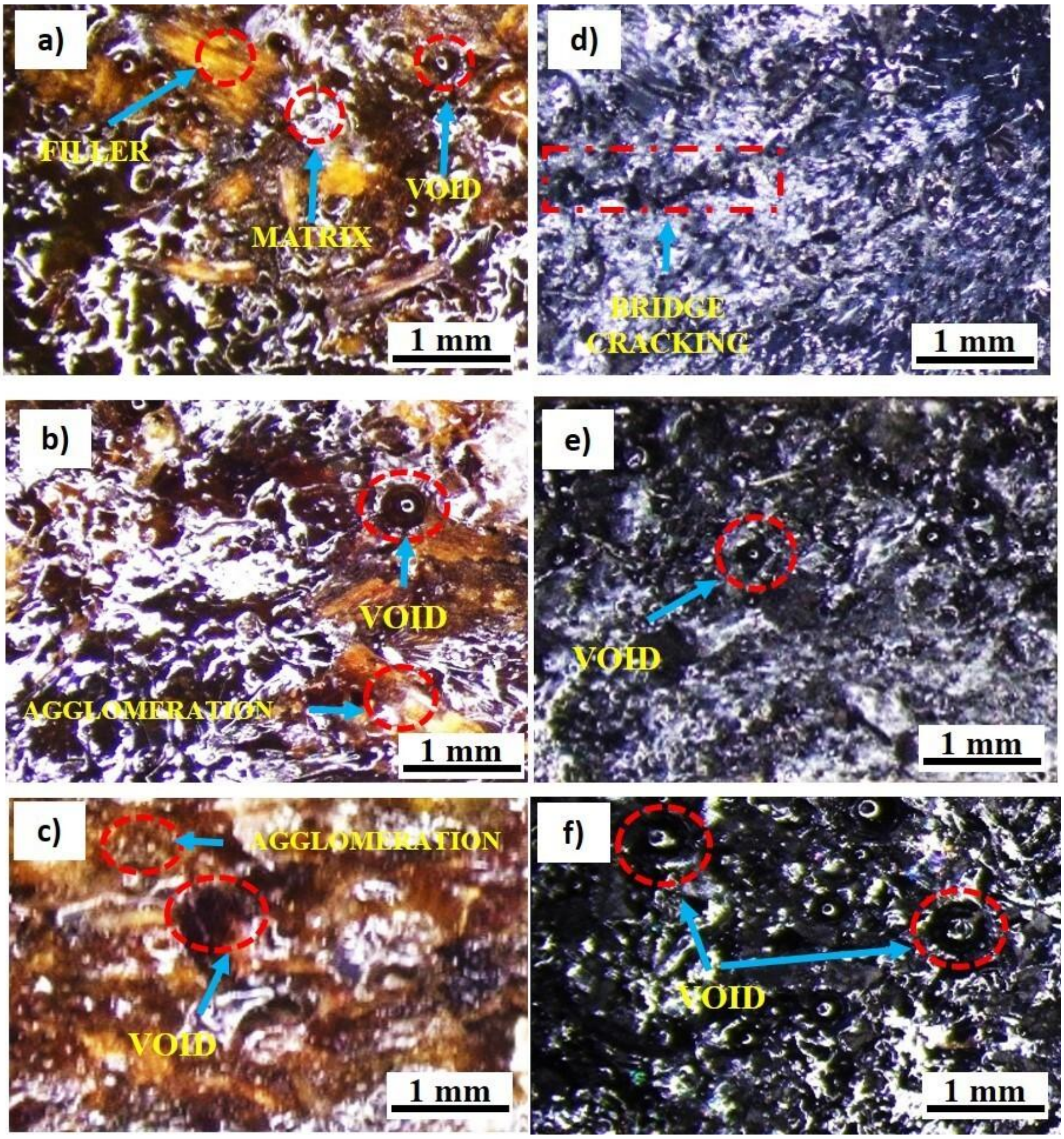

Figure 3. Fracture surface of epoxy matrix composite reinforced with a) WD5, b) WD10, c) WD15, d) CR5, e) CR10, and f) CR15

4. Conclusion

This study aims to compare the mechanical properties of epoxy matrix composite reinforced with variations in the concentration of wood dust and crumb rubber by 5-15% as filler. The test results show that the CR5 composite has the highest tensile strength performance, reaching 15.52 MPa, while the flexural strength is 30.46 MPa (CR10), and the hardness is 75.9 HRC (CR15). On the other hand, the WD15 composite produced the lowest mechanical performance, with a tensile strength of 5.26 MPa and flexural strength of 19.24 MPa, while the lowest hardness was produced at 43.68 HRC by the WD5 composite. The microstructure observation results, this phenomenon is in line with the fracture surface observation results, where crumb rubber shows better filler distribution and less void distribution. This looks different with the addition of wood dust in the matrix, forming voids and agglomeration, which weakens the composite structure. These findings make it clear that the choice of filler type and concentration is crucial in determining the strength and hardness of the composite. The main contribution of this study is to provide an in-depth understanding that crumb rubber, especially at low fractions, is more effective in improving the mechanical properties of epoxy matrix composites than wood dust. For future research, composite development can focus on filler surface modification and hybrid composite evaluation to improve the bond between reinforcement and matrix and reduce the formation of internal defects.

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