Research Article

Bayan Jabbar Fayzulla*

Effect of medium-density fiberboard sawdust content on the dynamic and mechanical properties of epoxy-based composite

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Abstract: The amount of waste produced by industrial processes continues to increase, necessitating its reuse. Medium-density fiberboard (MDF) sawdust is a waste product generated from woodworking. Since there is not an economical recycling method now, it is burned or disposed of. This study investigates the incorporation of MDF sawdust in epoxy-based composites. With micro-scale particle concentrations of 2, 5, 7, 10, 15, and 20 wt%, the specimens were made following ASTM standards. The results showed that the tensile strength and flexural strength increased by 11.16 and 6.90%, respectively, at a particle concentration of 5 wt% while absorbed energy increased by 11.05% at 2 wt% in comparison to the plain epoxy composite. The tensile modulus, flexural modulus, and hardness improved by 8.87, 13.33, and 26.78%, respectively, at 20 wt%. Moreover, density showed the greatest decrease at 20 wt% of MDF by 15.77%. The vibration test indicated that the damping ratio increased with MDF particles up to a 7 wt% by 3.91%, with a decrease at higher MDF content. The storage and loss modulus reached maximums of 5.56 and 9.14%, respectively, at 5 wt%; then, a decrease was observed at MDF contents exceeding 5 wt%.

Keywords: medium-density fiberboard, epoxy, mechanical properties, vibration

1 Introduction

Due to recent rapid industrial growth, massive amounts of solid waste – such as sawdust, ash, mud, or sludge – have been produced. These wastes now represent a threat to the environment and must be disposed of or used. Therefore, looking for innovative ways to recycle or utilize these wastes is crucial. A few of these waste products have been investigated for potential uses. The properties of some of these wastes, which are produced by diverse processes, make it clear that they have a high probability of being recycled and used to create a variety of products with additional benefits. Improved characteristics may result from the synergistic effects of filler particles incorporated into the polymer matrix [1–9].

The low density, acceptable cost, and ecological advantages of sawdust particles, among other industrial waste particles, have attracted scientists' interest [10–12]. In this context, Mostapha and Husseinsyah [13] studied the effect of coconut shell particle content on the mechanical, morphological, and water absorption properties of polyester composites. Results revealed that high particle content enhanced tensile strength, Young modulus, and water absorption, but decreased elongation at break. Chauhan *et al.* [14] evaluated how sawdust types, weight percentages, and particle sizes affected the material's tensile strength. Krishna *et al.* [15] investigated the effect of filler-to-resin ratio on epoxy composites reinforced with sawdust and fly ash. The findings demonstrated that adding more filler to a composite increases its durability and reduces its cost, but also decreases its mechanical and physical properties.

Predicting dynamic properties is essential for polymer composite structures. The dynamic properties of epoxy composites reinforced with nano- and macro-particles have been extensively studied [16–20], whereas the dynamic properties of sawdust particle-reinforced polymer composites have received less attention [21,22]. Medium-density fiberboard (MDF) is a product that contributes to waste creation. MDF is a type of wood sheet made of urea formaldehyde resin and wood fiber. It is produced under high pressure and temperature [23]. The use of MDF is expanding across a wide range of product fields, including kitchen cabinets, ready-to-assemble furniture, and furniture [24,25]. MDF sawdust, a waste product from woodworking, is abundant

*** Corresponding author: Bayan Jabbar Fayzulla,** Department of Automotive Technology Engineering, Erbil Technology College, Erbil Polytechnic University, Erbil, Iraq, e-mail: bayan_jabar@yahoo.com
ORCID: Bayan Jabbar Fayzulla 0000-0002-1146-5052

globally but lacks commercial recycling, leading to burning or disposal [26]. Some studies have explored the use of MDF sawdust in producing composite materials, which can effectively address environmental concerns and enhance the desirable properties of polymer composites. Chavooshi *et al.* [27] revealed that precise MDF dust and appropriate material-blending methods can enhance the mechanical and physical properties of sawdust/polypropylene composites. Hillig *et al.* [28] created wood plastic composites using polyethylene and wood sawdust materials like MDF residuals, loblolly pine, and eucalypt wood. Mechanical testing showed MDF sawdust improved impact and bending strength. Ayrilmis *et al.* [29] investigated the possibility of employing MDF sawdust and recycled manhole cover flour as inexpensive fillers in recycled polypropylene composites. Results showed an increase of bending strength and modulus, slightly declined tensile strength, and slightly increased water absorption. Gomes *et al.* [30] characterized a polymeric matrix composite with MDF residues from furniture production cut machines, demonstrating high tensile and flexural strength, modulus of elasticity, maximum deformation, and water absorption index. Kreutz *et al.* [31] studied virgin polystyrene composites reinforced with MDF residue Results showed composites with 4% MDF waste had the best characteristics, with higher thermal stability and homogeneity.

As is evident from the literature listed above, some studies were conducted on MDF sawdust-reinforced polymer composite. As far as the authors know, there has not yet been any work investigating the effect of adding MDF sawdust on the mechanical and dynamic properties of epoxy-based composites. In pursuit of this goal, an attempt has been undertaken to investigate the mechanical characteristics (tensile, flexural, impact, and hardness) of epoxy composite reinforced with micro-sized MDF particles. As well, it explores the vibration characteristics of epoxy composites filled with MDF microparticles as a creative endeavor, looking at damping ratio, natural frequency, storage modulus, and loss modulus. The specimens were created with 2, 5, 7, 10, 15, and 20 wt%. of MDF particles incorporated.

2 Materials and methods

The MDF sawdust was collected from the local woodworking shop in Kirkuk, Iraq. The MDF particles were sieved to create 75 µm-sized particles. The MDF powder was sieved to create a homogeneous mixture with the polymer and, eventually, better adhesion of the particle/matrix combination. Small additives provide uniform distribution in composites, while larger particles weaken interfacial adhesion. After that, they were dried at 120°C in an oven to remove any remaining moisture until the mass content was constant. The particle was then weighed, and the density was found to be 0.2654 g/cm^3. Sika Trading, Erbil, Iraq, provided the epoxy resin and hardener (Sikadur®-52 LP) type.

2.1 Specimen preparation and characterization

The specimens were created using six different MDF contents: 2, 5, 7, 10, 15, and 20 weight percentages of the total weight of the matrix (resin and hardener). The epoxy resin-to-hardener stoichiometric ratio was 2:1. To prepare the specimens, the MDF particle was mixed with epoxy resin for 15 min at 200 rpm using a mechanical stirrer. After that, hardener was added, and the mixture was stirred for an additional 6 min to achieve homogeneity. The particulate epoxy mixture was manufactured by pouring it into a metal mold. Finely finished composite specimens were obtained by removing the specimens from the mold after 1 day.

The specimens were post-cured for 1 week at room temperature before mechanical testing. According to ASTM D638 [32], ASTM D790 [33], and ISO 179-1 [34], respectively, specimens for tensile, flexural (vibration), impact, and hardness tests were prepared (Figure 1). For both flexural and vibration testing, the same specimens were examined. Following that, to find the density, specimens sized 10 mm × 50 mm were made. The dimensions and mass of specimens were measured to calculate their density following ASTM D792 [35].

2.1.1 Mechanical tests

The mechanical characteristics of plain epoxy and its composites were assessed using tensile and flexural tests, utilizing the extremely precise and adaptable Shimadzu universal testing equipment AG-X series (Kyoto, Japan). The precision and adaptability of a test apparatus were evaluated through: repeated observations, consistent results from well-known reference samples, regular calibration using traceable standards, and comparison with certified reference sources. The three-point bending method is used to measure flexural characteristics (Figure 2). Flexural tests were performed using a 16:1 span–to-thickness ratio.

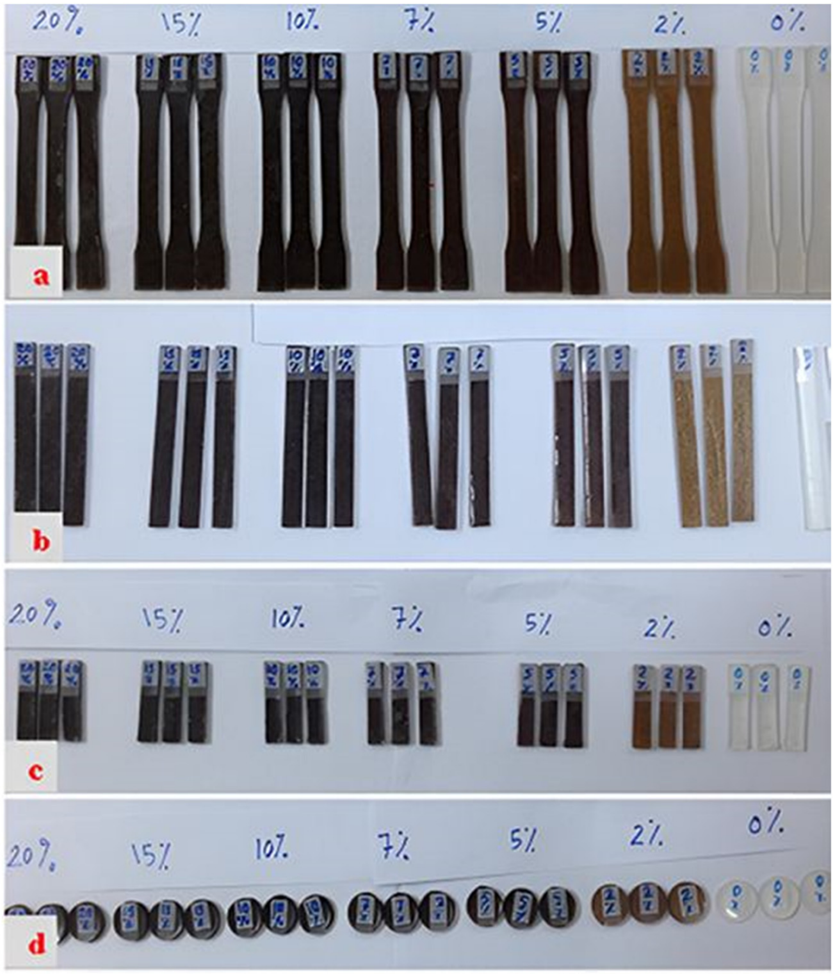


Figure 1: MDF/epoxy composite tests specimens of (a) tensile, (b) flexural, (c) impact, and (d) hardness.

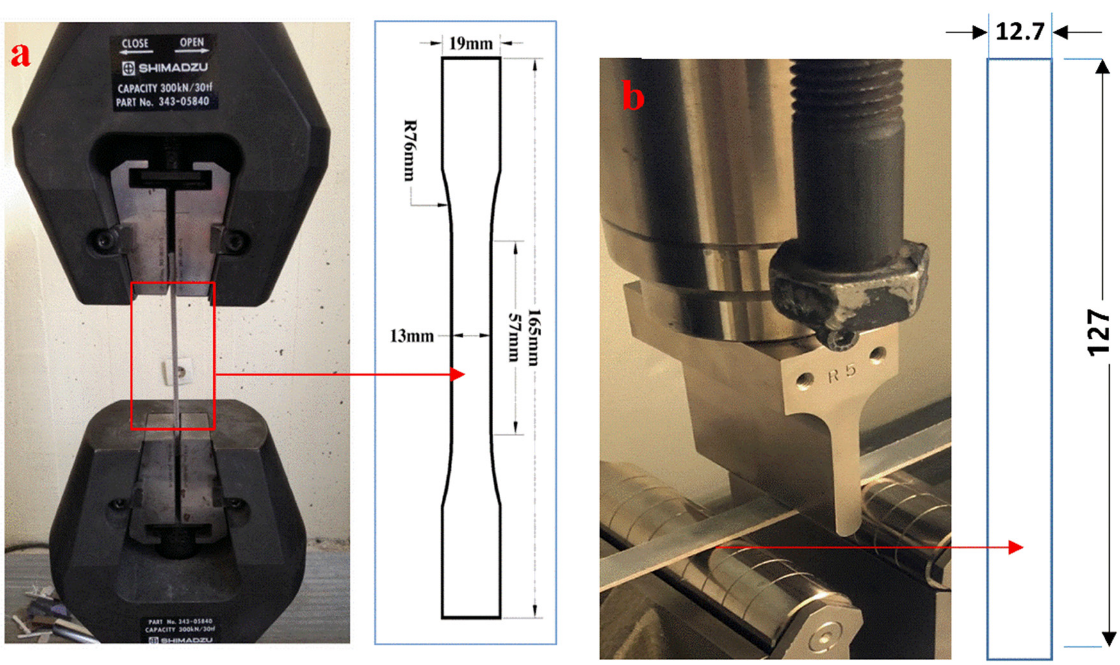


Figure 2: Test apparatus with a typical test specimen of (a) tensile and (b) flexural tests.

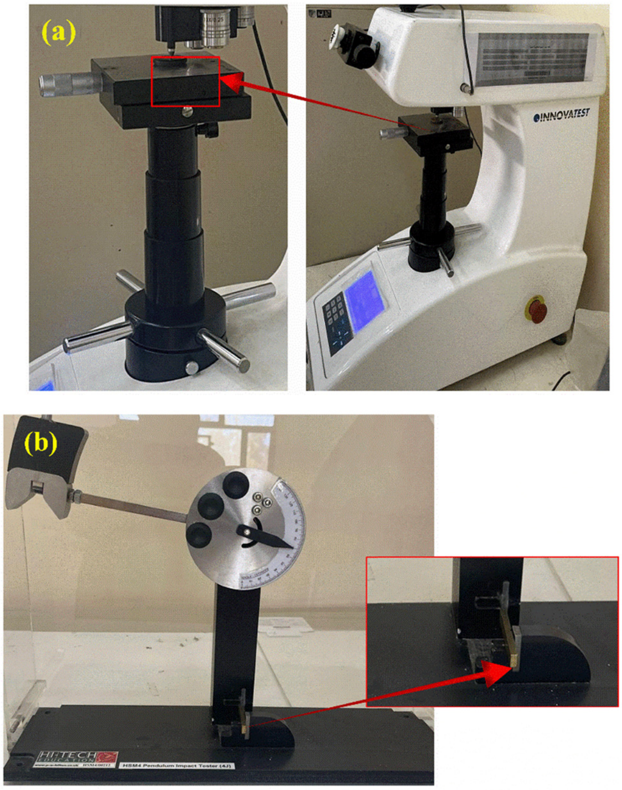


Figure 3: Tests setting up of (a) Vickers hardness and (b) Charpy impact test.

Flexural strength (σ_f) was calculated using Eq. (1), where P, L, b, and h represent the load at a point on the load-deflection curve (N), supporting span length (mm), specimen width (mm), and specimen thickness (mm), respectively [33]:

$$\sigma_f = (3PL/2bh^2). \tag{1}$$

The Charpy standard test was employed to evaluate the absorbed energy by the composite specimens. The HSM4 pendulum test device was used to conduct the test at room temperature, considering the specimen's position and the direction of the load impact on the specimens. Finally, the Vickers hardness test was conducted on every composite specimen. The test was carried out by pressing the surface of the indenter pin against the specimen, and the measured values were recorded digitally using the instrument's built-in display. The hardness of materials, including polymer composites filled with wood sawdust, is determined using the Shore and Vickers hardness tests. However, there are a number of advantages that the Vickers test has over the Shore test, including the test offers precision and accuracy by using a diamond indenter for hardness measurement; the method accommodates particle size and distribution variations, maintaining consistency and comparability in research; and has less sensitivity to filler morphology, ensuring uniform matrix hardness measurement. The Vickers hardness devise mechanism and the Charpy impact test apparatus are set up with the sample placed inside the frame as shown in Figure 3(a) and (b), respectively.

2.1.2 Vibration tests

Dynamic properties were determined using the experimental setup as illustrated in Figure 4. Using the fixed-free boundary condition, the test specimens were fixed in the frame. Test specimens had the accelerometer attached to their surface near the fixed edge. The sample was stimulated by employing the impact hammer at three different excitation positions. The data acquisition system was connected *via* appropriate signal transmission cables.

Frequency response curves from the output signal were plotted on a computer using LABVIEW software. The predefined frequency range of 0–500 Hz was used to obtain frequency responses. Three different specimens and points were tested to evaluate vibration characteristics; the

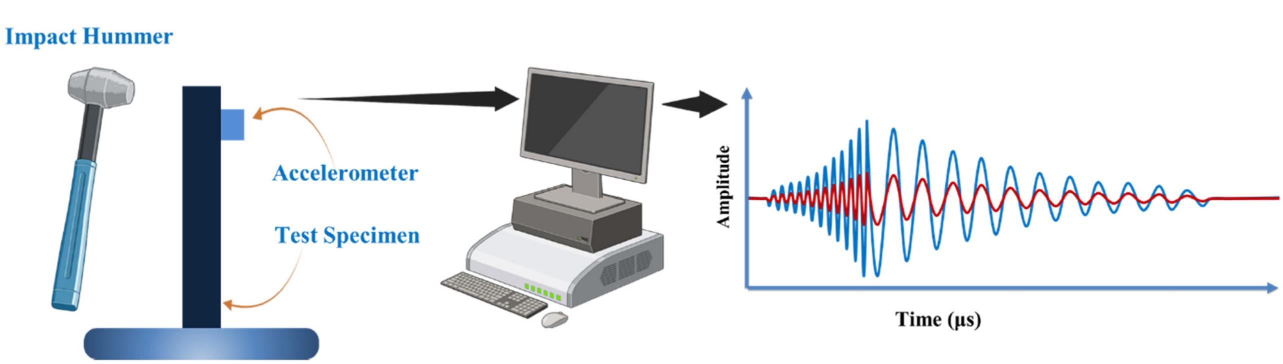


Figure 4: Setting up of vibration test.

Table 1: The overall properties of the MDF/epoxy composites

Specimens	MDF content (%)	Density (g/cm^3)	Tensile strength (MPa)	Tensile Modulus (MPa)	Flexural strength (MPa)	Flexural modulus (MPa)	Absorbed energy (J)	Vickers Hardness (HV)
M0	0	1.071 (±0.013)	24.2 (±0.6)	3,661 ± 20	63.7 (±0.3)	2,385 (±09)	0.371 (±0.011)	21.28 (±0.12)
M2	2	1.032 (±0.014)	26.4 (±0.4)	3,784 ± 16	67.3 (±0.3)	2,399 (±12)	0.412 (±0.01)	24.36 (±0.11)
M5	5	1.009 (±0.011)	26.9 (±0.2)	3,797 ± 12	68.1 (±0.5)	2,412 (±17)	0.401 (±0.014)	26.12 (±0.16)
M7	7	0.983 (±0.017)	23.4 (±0.4)	3,873 ± 19	58.4 (±0.6)	2,457 (±11)	0.366 (±0.015)	26.49 (±0.13)
M10	10	0.977 (±0.009)	22.6 (±0.5)	3,910 ± 17	54.9 (±0.2)	2,491 (±13)	0.329 (±0.014)	26.86 (±0.13)
M15	15	0.909 (±0.011)	22.3 (±0.3)	3,955 ± 17	54.3 (±0.4)	2,544 (±15)	0.313 (±0.016)	26.89 (±0.16)
M20	20	0.902 (±0.015)	20.6 (±0.4)	3,986 ± 11	50.2 (±0.6)	2,703 (±17)	0.211 (±0.01)	26.98 (±0.18)

average results of these tests were reported. Using Eq. (2), the first mode of natural frequency values was identified to evaluate damping ratios [36]:

$$\xi = \frac{\omega_2 - \omega_1}{2\omega_n}, \tag{2}$$

where ξ is the damping ratio, ω_n is the natural frequency of the first mode, and ω_2–ω_1 is the bandwidth. The storage modulus E' and loss modulus E'' of the beam were then estimated using Eqs. (3) and (4):

$$\omega_n = \frac{1.875^2}{2\pi L^2}\sqrt{\frac{E'I}{\rho A}}, \tag{3}$$

$$E''(\omega) = 2E'(\omega)\xi(\omega). \tag{4}$$

The length, density, moment of inertia, and area of the specified cross-section of the beam are represented by L, ρ, I, and A.

3 Results and discussions

The tensile, flexural, impact, and hardness tests were performed on a minimum of three specimens, and the average value of the outcomes was identified. In the case of the hardness test, each specimen was assessed for three indentations, and the mean of the three values was calculated. The density and mechanical performances of the MDF/epoxy in terms of tensile, flexural, absorbed energy, and Vickers hardness are disclosed in Table 1.

Data from Table 1 and Figure 5 demonstrate that density decreased as MDF dust concentrations increased. Because MDF sawdust has a lower density (0.2654 g/cm^3) than epoxy matrix, the overall density of the MDF/epoxy composite specimens decreased, as is generally predicted. When comparing the density to plain epoxy, the greatest reduction was 15.77% at 20 wt% of MDF content.

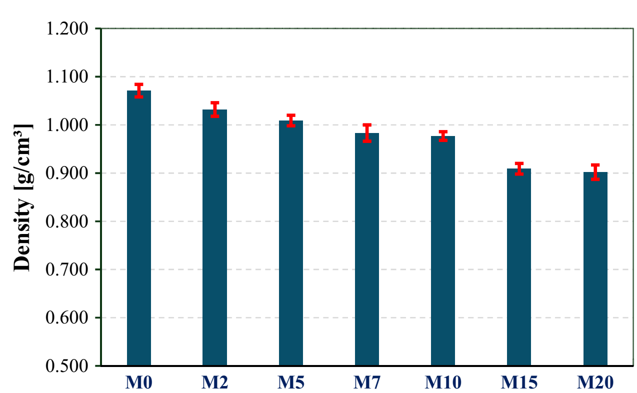


Figure 5: The density of the MDF/epoxy composites.

While there was a decrease in tensile strength when MDF sawdust was added to composites filled at 7, 10, and 20 wt% MDF, at 2 and 5 wt% MDF, there was an increase in tensile strength by 9.09 and 11.16%, respectively. When compared to plain epoxy composite (Figure 6a). This may be explained by the dispersed nature of MDF sawdust throughout the polymer matrix, caused by its tendency to agglomerate at high particle concentrations. In line with expectations, tensile modulus values increased as the amount of MDF particles increased. Compared to a plain epoxy specimen, the highest value with a loading of 20 wt% was 3,986 MPa, an increment of 8.87% (Figure 6a). Similar findings have also been documented in earlier research [29,30]. The main reason for this trend is that when filler content increases, the composite's elongation at break decreases. The failed tensile test specimens for various particle concentrations are illustrated in Figure 6b. The fact that every specimen exhibits a flat fracture surface devoid of necking indicates the brittle nature of fractured specimens while being tested.

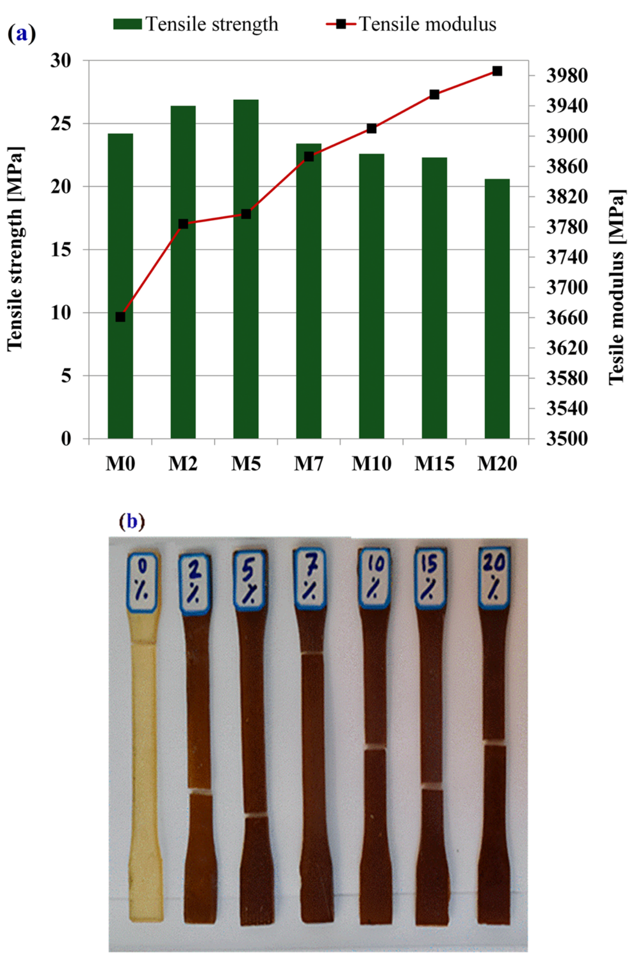


Figure 6: (a) Tensile strength and modulus of the MDF/epoxy composites, (b) some of the tested specimens.

Scanning electron microscopy (SEM) images were obtained over the broken surfaces of composites to further investigate the failure characteristics (Figure 7), where images were taken at 30 kV with a 100 magnification factor. The SEM images show that the MDF sawdust had a perfect dispersion at 2 and 5 wt% (Figure 7a and b), which improved its characteristics; however, as more particles were added, there was particle aggregation, which reduced the overall properties of the MDF/epoxy composites. The aggregated particle size grew at 7 wt% (Figure 7c) and reached the highest level of particle aggregation at 20 wt% (Figure 7d). As the MDF content increases beyond 5 wt%, particle agglomeration becomes more pronounced (Figure 7c and d). These clusters act as stress concentration points, which negatively impact the mechanical properties of the composite by weakening interfacial bonding. This is further evidenced by the reduction in absorbed impact energy and flexural strength at higher filler contents (Figures 8 and 9a). Similar trends have been reported in previous studies on polymer composites reinforced with particulate fillers, where excessive filler content leads to a deterioration in mechanical performance due to poor stress distribution.

A comparison between the MDF-filled specimens and plain epoxy specimens concerning flexural strength and flexural modulus variations is shown in Figure 8. Because the compatibility between the matrix and filler was reduced when there were more MDF particles present, it seems reasonable to observe that the flexural strength increased to 5 wt% in the MDF-filled samples before trending downward. In comparison to a plain epoxy specimen, the maximum value at 5 wt% loading was 68.1 MPa, representing a 6.90% increase. The addition of more wood sawdust also led to a decrease in flexural strength, as reported by Mohd Idrus and Othman [37] when considering filler content. Because stiff particles had a considerably higher stiffness than the polymer matrix, adding MDF to the polymer matrix improved the flexural modulus; Gomes *et al.* [30] also found similar results. A 20 wt% percent MDF filler content resulted in the greatest improvement in the flexural modulus, indicating a 13.33% increase. The observed improvement in mechanical properties at 5 wt% MDF is attributed to the balanced distribution of particles within the epoxy matrix, which enhances load transfer efficiency. At this concentration, the interfacial adhesion between MDF particles and epoxy is optimized, leading to an increase in both tensile and flexural strength (Figures 6 and 8). However, beyond this level, the presence of particle clusters reduces stress transfer efficiency,

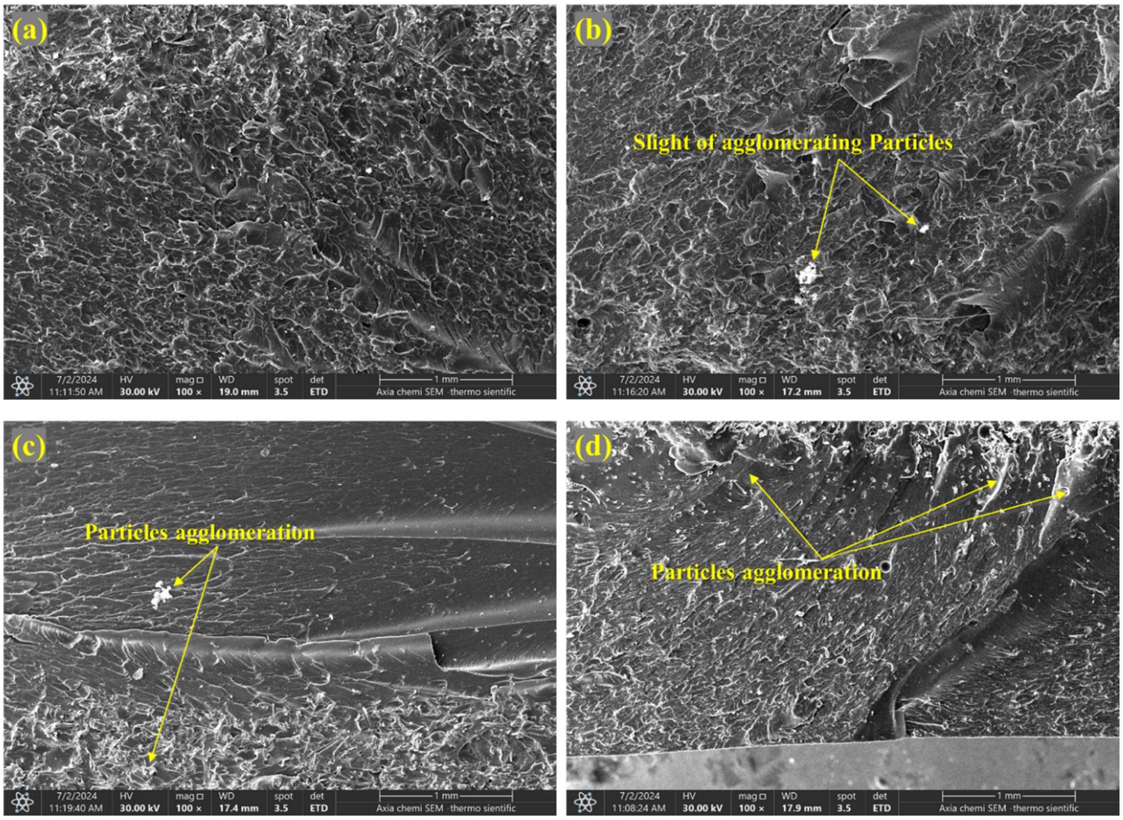


Figure 7: The SEM images of MDF/epoxy composites with (a) 2, (b) 5, (c) 7, and (d) 20 wt% MDF.

contributing to premature failure and mechanical degradation. Therefore, 5 wt% MDF appears to be the optimal filler content for balancing reinforcement effects while minimizing the negative impact of agglomeration.

According to Charpy impact testing, absorbed energy first increased at a filler content of 2 wt% MDF by 11.05% and then declined as the filler amount increased (Figure 9a). Higher MDF content causes an increase in crack propagation, which results in a decrease in absorbed energy of up to 2 wt% of MDF particles. As a result, the composites become less ductile and stiffer as the amount of MDF dust increases, which lowers the amount of energy absorbed [29,38]. Finally, Vickers hardness testing on the MDF/epoxy composites showed that the highest hardness of all was found at 20 wt% MDF particles, that is 26.78% more than plain epoxy composite (Figure 9b). The higher hardness of the MDF particles in comparison to the plain epoxy is what causes the increase in hardness. Murugapoopathi *et al.* [39] also noted that using virgin high-density polyethylene and low-density polyethylene with teak wood sawdust improved the hardness. The agglomeration of particles might result in clusters that may not be evenly dispersed throughout the epoxy matrix. The hardness may therefore be higher in regions with a concentration of the harder MDF particles and lower in regions with fewer or no agglomerated particles of MDF. To eliminate this problem, hardness testing was done on at least three specimens, and each specimen was evaluated for three indentations (points).

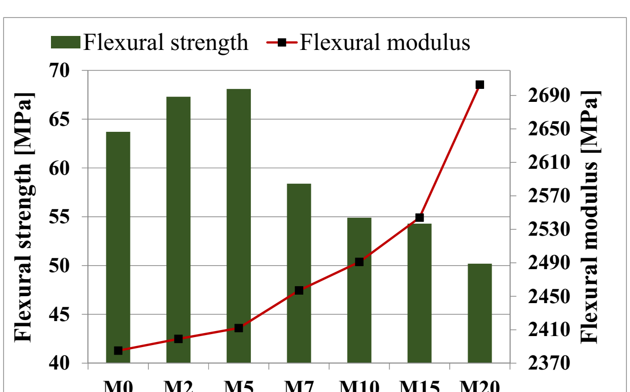
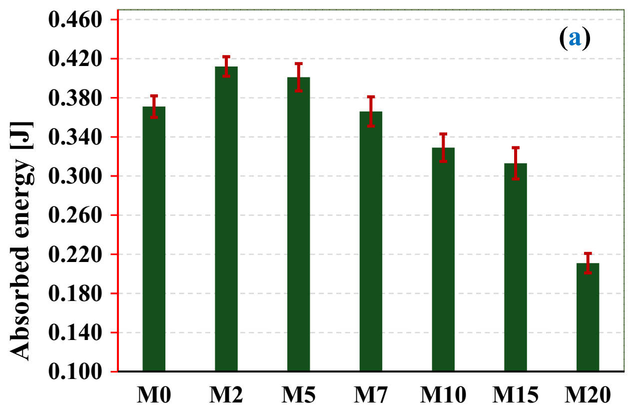


Figure 8: Flexural strength and flexural modulus of the MDF/epoxy composites.

The dynamic test findings, which show how the inclusion of MDF affects the natural frequency, damping ratio, storage modulus, and loss modulus of epoxy composites,



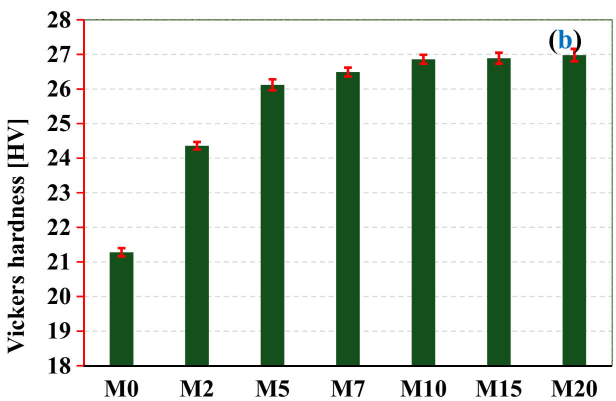


Figure 9: (a) Absorbed energy, (b) Vickers hardness values of the MDF/epoxy composites.

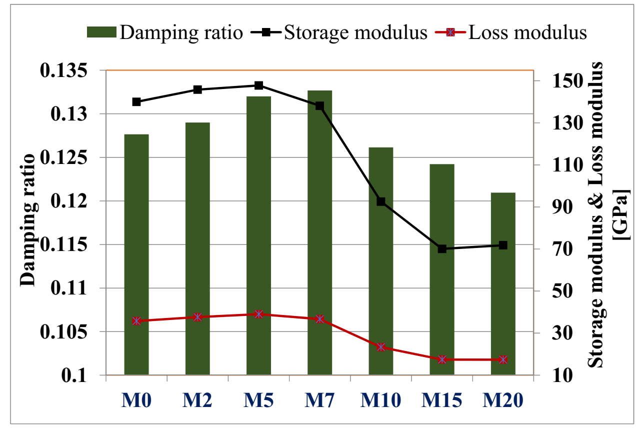


Figure 10: Dynamic properties of the MDF/epoxy composites.

are shown in Table 2. Natural frequencies at 0, 2, 5, 7, 10, 15, and 20 wt% of MDF content were 17.8, 19.2, 19.4, 19.3, 17.9, 16.6, and 16.4 Hz, respectively. It is evident that the highest increase of 8.98% was attained at 5 weight in comparison to plain epoxy composite. Such an increase in natural frequency results from the stiffness that was increased by the MDF reinforcement in the matrix. The natural frequency decreased when there were more MDF aggregates present because they reduced stiffness. Damping is a material attribute that depends entirely on the viscoelastic characteristics and microstructure of the material. However, the damping property increased with the addition of MDF particles up to a 7 wt% MDF content (Figure 10), at which point the highest damping ratio of 3.91% was achieved, and then the pattern declined. The decrease in the slipping effect between the particle and matrix may explain the reduction in damping ratio with the use of more MDF, indicating a low capacity for energy absorption for a composite system. The damping ratio of MDF sawdust-reinforced epoxy composites can be influenced by various factors, affecting its composition and structure. As MDF sawdust content increases, interfacial friction between MDF particles and matrix increases, enhancing energy dissipation. At low MDF content, the matrix dominates, but at an optimal level around 7 wt%, high interfacial area and sawdust properties contribute optimally to damping. The sawdust's energy dissipation decreases due to alterations in MDF particle agglomeration and epoxy resin exfoliation, which can negatively impact the composites' viscoelastic and mechanical properties. Additionally, to have a better understanding of the dynamic properties of the particulate composite storage and loss modulus were assessed. Figure 10 illustrates the comparison of storage

Table 2: The vibration properties of the MDF/epoxy composites

Specimens	MDF content (%)	Density (g/cm^3)	Natural frequency (Hz)	Damping ratio	Storage modulus (GPa)	Loss modulus (GPa)
M0	0	1.071 (±0.013)	17.8 (±0.7)	0.1276 (±0.009)	139.99 (±1.8)	35.74 (±0.95)
M2	2	1.032 (±0.014)	19.2 (±0.2)	0.1290 (±0.004)	145.80 (±1.3)	37.62 (±0.76)
M5	5	1.009 (±0.011)	19.4 (±0.7)	0.1320 (±0.010)	147.78 (±2.1)	39.01 (±1.06)
M7	7	0.983 (±0.017)	19.3 (±0.8)	0.1326 (±0.009)	138.11 (±1.6)	36.65 (±0.21)
M10	10	0.977 (±0.009)	17.9 (±0.3)	0.1261 (±0.007)	92.53 (±1.4)	23.35 (±0.56)
M15	15	0.909 (±0.011)	16.6 (±0.2)	0.1242 (±0.003)	70.07 (±2.7)	17.41 (±0.41)
M20	20	0.902 (±0.015)	16.4 (±0.6)	0.1209 (±0.0046)	71.80 (±1.5)	17.37 (±0.26)

and loss modulus values of the test samples according to MDF content. It is evident that at a 5 wt% MDF content, the storage and loss modulus reached their maximums of 5.56 and 9.14%, respectively. Therefore, compared to other composites, the specimens with a 5 wt% MDF content have the highest elastic modulus and the largest dissipation energy. A decrease in the storage and loss modulus was observed at MDF contents greater than 5 wt%; this can be ascribed to the agglomeration effect, which reduces the interfacial bonding of MDF-epoxy interfaces. The fact that MDF is composed of several materials, such as wood fiber and urea-formaldehyde resin, may have contributed to the particle's aggregation. Other researchers also observed that particle aggregation reduced the storage and loss modulus [19,40]. Improved damping performance significantly impacts practical applications, such as noise reduction in vibration-induced sound, stress reduction in structural components, and enhanced user comfort and safety in furniture and flooring. It also influences energy-harvesting systems' efficiency and stability.

Based on the findings, 5 wt% MDF was identified as the most effective filler content, providing a balance between mechanical strength, impact resistance, and damping performance. Beyond this concentration, particle agglomeration increases, leading to stress concentration and a decline in composite performance. Future studies could explore surface treatment techniques or alternative processing methods to mitigate agglomeration and enhance the effectiveness of higher MDF loadings. The optimal wood sawdust to epoxy resin ratio is crucial for composite behavior. Using incremental wt% ratios helps establish conclusions. Future research should focus on long-term durability, moisture resistance, and potential applications in automotive and construction fields, addressing unanswered questions.

4 Conclusions

This study examines the effects of adding MDF sawdust on the mechanical and dynamic properties of epoxy-based composites, minimizes environmental problems, and enhances economic effectiveness. The specimens for the tensile, flexural, impact, and hardness tests were created and evaluated using a metal mold with 75 µm-sized particles with concentrations of 2, 5, 7, 10, 15, and 20 wt% under ASTM standards. The findings demonstrated that, in comparison to the plain epoxy composite, the absorbed energy increased by 11.05% at a 2 wt%, while the tensile and flexural strengths increased by 11.16 and 6.90%, respectively, at a particle concentration of 5 wt%. Furthermore, density reduced as particle loading increased; hence, the largest reduction of 15.77% was observed at 20 wt% of MDF content. It is noteworthy that at 20 wt% particle loading, the improvement in tensile modulus, flexural modulus, and hardness was 8.87, 13.33, and 26.78%, respectively. The vibration test showed that the damping ratio improved with MDF particles up to 7 wt%, reaching 3.91%, and then decreased as the MDF content increased. After reaching their maximums of 5.56 and 9.14%, respectively, at 5 wt%, the storage and loss modulus showed a decline with MDF amounts higher than 5 wt%. These findings suggest that 5–7 wt% MDF provides an optimal balance between mechanical and dynamic enhancement and material density reduction. The results demonstrate that MDF sawdust can serve as a sustainable and cost-effective reinforcement in composite materials, particularly for lightweight structural applications in automotive, construction, and furniture industries.

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