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Effect of Pumice Powder on Mechanical, Thermal, and Water Absorption Properties of Fiberboard Composites

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Abstract
Composites were produced using medium-density fiberboard (MDF) flour with pumice powder which was mixed at various ratios by the hand lay-up technique. Mechanical properties, such as tensile and three-point bending strengths, were determined by ASTM D3039 and ASTM D790 respectively. The best three-point bending and tensile strength properties were maximum values obtained from composites containing 20wt% pumice powder (pp) and 50wt% pumice powder (pp) respectively. It is observed that the water absorption rate into the composites decreases with an increase in the pumice powder-to-ratio. The composite filled with 50wt%pumice powder absorbed the least amount of water compared to the other composites. All composites were characterized by scanning electron microscopy (SEM), Fourier transforms infrared spectroscopy (FTIR), and differential scanning calorimetry analysis (DSC). SEM images revealed a near-homogeneous surface partly free of defects and holes. However, lateral profile images showed the presence of MDF flour particles agglomerated and a considerable number of bubbles and cavities that could interfere with the mechanical properties of the composites. The results of the mechanical, and thermal properties suggested that pumice powder epoxy composites with MDF flour can increase their tensile, three-point-bending strength, and glass transition temperature for the pure MDF flour composite.

Keywords
Mechanical properties, MDF, Pumice powder, Epoxy, Composites.

1. Introduction

Medium Density Fiberboard (MDF) is an engineered wood product made up of fine lignocellulosic fibers and a synthetic resin that is heated and pressed together to produce boards. One of the most important variables determining the mechanical qualities of MDF boards is the resin. As the cured resin bonds with the fiber matrix, the MDF board has structural integrity. The resin is responsible for 30% of the total cost of an MDF board. However, the total cost of the board can be greatly lowered by limiting resin consumption to a minimum, i.e. mixing as effectively as is feasible [1]. The market for wood-based panel composites, particularly MDF panels, has recently increased dramatically. With the advancement of technology, the MDF sector has demonstrated a noticeable growth tendency. Turkey has had the largest MDF capacity among European panel makers in recent years [2, 3]. Interior trim pieces, interior door skins, moldings, and more application areas can be found for MDF panels *[4]*. The relationship between fiberboard characteristics, adhesive application [5], and the adhesive filler [6] has been studied by a number of researchers [6].

Pumice is a natural volcanic glassy rock, mostly comprising SiO_2. Pumice is formed when magma cools rapidly and the gases inside depressurize. Pumice has a porous structure, which is generated by dissolved gases precipitating during the cooling process when the lava travels through the air. Pumice particles have high thermal stability, chemical resistance, polarity, and surface area, as a result of which pumice particles are becoming more popular in industrial applications. In polymer composites, polar groups with a large surface area of pumice particles provide a greater number of contact zones, resulting in improved mechanical qualities not shared by common fillers [7]. Most typical particle fillers cost more than pumice powder. In the literature, the use of pumice powder as a reinforcing ingredient in composites has received little attention. However, using pumice powder as a filler material in composite applications is becoming more popular day by day. The influence of pumice powder on the mechanical characteristics of polypropylene (PP) was examined by Sever et al. [8], who discovered that when 10 wt% of powder was loaded into PP, the maximum tensile and flexural strength values, 26.5 and 46.4 MPa, respectively, were attained. The mechanical and thermal properties of pumice powder-filled polyphenylene sulfide composites were studied by Sahin et al. [9]. Pumice powder-filled polyphenylene sulfide composites have mechanical and thermal characteristics. The use of pumice powder reinforcement increases the mechanical and thermal properties of composites. Dike [10], investigated the alteration of pumice minerals and their usage as a bio-composite material additive based on poly (lactic acid). The addition of pumice powder to the composite materials increased their tensile, impact, and water absorption properties.

In this study, the effect of varying weight percentages of pumice powder on mechanical, thermal, and water absorption properties of MDF flour/ epoxy composites was investigated.

2. Material and methods

2.1. Materials

Medium-density fiberboard (MDF) flour was supplied by Camsan Ordu ıntegrated wood ındustry and Trade Inc. (Turkey). Firstly, a sieve analysis of MDF flour was made. The sieve stack was composed of 6 sieves, whose mesh sizes were 2000, 600, 300, 180, 150, and 75 µm from the top to the bottom, respectively. It was found to have an average particle size of 150 to 300 nm and average water content of 3.12%. The particle size distribution curve for MDF flour (%) is shown in Figure 1.

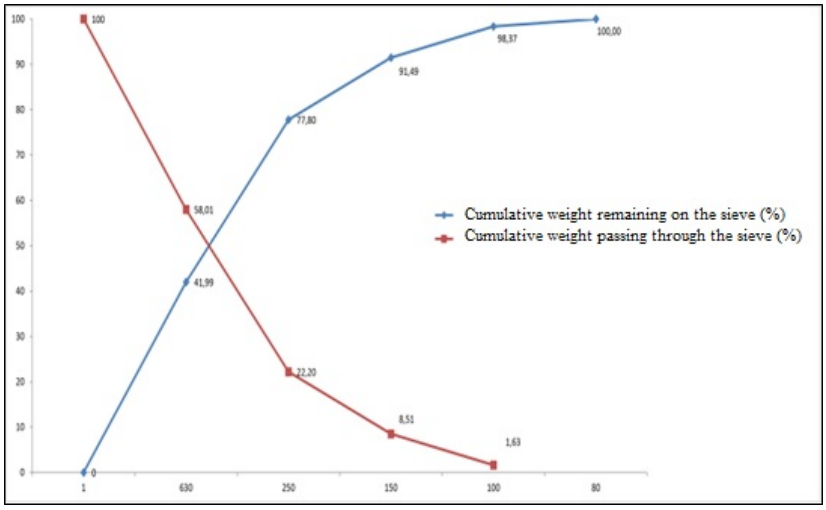

Fig. 1. Particle size distribution curve for MDF flour (%)

Purpox® epoxy resin EFLR-0190, provided by Polikor Inc. (Turkey), was used as matrix material, which is a solvent-free resin with a transparent coating. The density of this resin was 1.00 to 1.10 g/cm³, and the viscosity was 300-500 mPa.s.

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2.2. Fabrication of epoxy/ MDF flour composites

For fabricating the composites, a metal mold (a dimension of 250×25×3mm) was prepared, and coated with wax, which helped to easily remove the fabricated composite from the mold. All the samples were prepared by the hand lay-up technique. The weight % of the pumice powder filled was varied from 10 wt% to 50 wt% with an interval of 10% (i.e. 10%, 20%, 30%, 40%, and 50 wt %). The matrix was prepared by mixing epoxy resin with a hardener at a ratio of 100:50. Seven types of composites were fabricated and designated as pure pumice powder, pure MDF flour, 10wt%pp, 20wt%pp, 30wt%pp, 40wt%pp, and 50wt%pp type composites. The composites were left for curing at room temperature for 24-48 h.

2.3. Water absorption test

The sample plates manufactured, with dimensions of 50×50×10 mm, were used to prepare samples for each filler loading. The specimens were kept at a temperature of 20±2 °C for 24 hours. The weight of the specimens was then measured using an electronic balance (Sartorius GL 224i-1CEU, Germany) with an analytical balance capable of measuring 0.0001 g before they were drenched in water. Following that, samples were soaked in distilled water at room temperature for various periods of time. Before each measurement, water droplets on the surfaces of all the samples were wiped off with blotting paper after they had been taken from the water. The absorbed moisture content of each sample was estimated using Eq. (1).[13].

$$W\,(\text{water absorption}) = \left[\frac{Wt-Wo}{Wo}\right] \times 100 \quad (1)$$

Where W_t is the sample's weight after the immersion time and W_o is the sample's initial weight.

2.4. Tensile strength test

Tensile strength was measured using a Universal Testing Machine (Instron 3369 UK) with a 50 kN load cell at room temperature at a rate of 2 mm/min in compliance with the ASTM D3039 standard [11]. The sample's length, width, and thickness measurements were 250×25×3 mm, respectively. Three samples were evaluated in each case, with three specimens yielding average tensile strength readings. A tensile grip was used to grasp the samples and then pull them until the specimen failed.

2.5. Three-point bending test

Flexural testing was carried out in accordance with ASTM D790 [12]. The crosshead moved at a rate of 2 mm/min. 160 mm was chosen as the span length. For each type, three samples were tested, and the average value was calculated. The tensile grip was used to grasp the samples and then pull them until the specimen failed.

2.6. Scanning electron microscopy (SEM) analysis

The topography of the broken surfaces of the MDF flour /epoxy composites after tensile testing was examined using field emission scanning electron microscopy (FESEM) with a Carl Zeiss Sigma 300 (Oberkochen, Germany) with an energy dispersive x-ray spectrometer (EDX), a 10 kV SE detector SEM instrument.

2.7. Fourier-transform ınfrared (FTIR) analysis

A Bruker Alpha spectrophotometer (Oberkochen, Germany) was used to perform Fourier-transform infrared spectroscopy of the samples within a wavelength range of 4000 cm^{-1} to 500 cm^{-1}. Throughout the experiment, a scanning rate of 60 scans per minute at a resolution of 4 cm^{-1} was maintained.

2.8. Differential scanning calorimetry (DSC) analysis

A Labsys Evo DSC machine (Geneva, Switzerland) was used to perform differential scanning calorimetry analysis on the composites; 10 mg composite samples were heated in an aluminum sample pan at a temperature range of 30 to 550 °C and heating rate of 10°C/min. The experiment was carried out in an argon atmosphere with a pumping rate of 20 mL/min of argon gas.

3. Results and discussion

3.1. Water absorption test

Changes in water absorption for filled and unfilled composites are shown in Figure 2. On the first day, all of the composites absorbed high amounts of water, but after that, they achieved an equilibrium, similar to what Chung et al [14] and Biplab and Maji [15] found. The proportion of water absorption decreased as the amount of pumice powder in the composite increased. Water accessibility to the composite was reduced due to the strong contact between pumice powder particles, MDF, and the epoxy matrix. Furthermore, the water absorption of epoxy composites is less than 1 %, as expected, due to the hydrophobic nature of the epoxy [16]. When compared to a 100 % MDF composite, pumice powder composites demonstrated less water absorption. The pumice powder integrated MDF composites absorbed lower amounts of water and had a stronger interface between the MDF/epoxy and pumice powder due to the much lower hydroxyl group availability of filled composites and the strong interfaces between the MDF/epoxy and pumice powder.

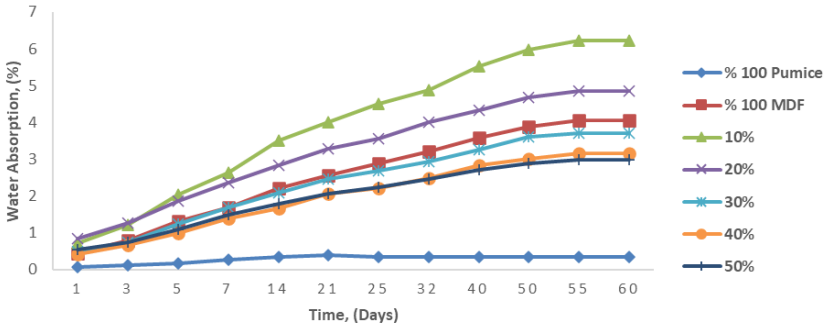


Fig. 2. Water absorption kinetics

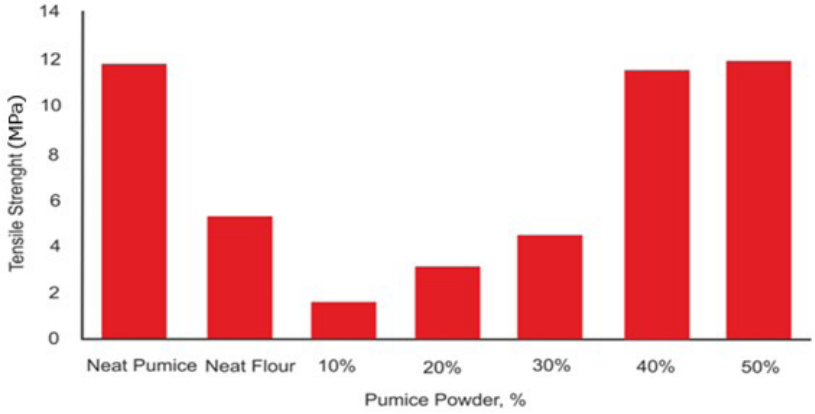


Fig. 3. Tensile strength of the composites

3.2. Tensile strength test

Figure 3 illustrates the tensile strength of the composites made entirely of pumice powder, made entirely of MDF flour, and loaded with various percentages of pumice powder. The tensile strength value of the samples steadily rises up to 50 wt% of the pumice powder added, as shown in the figure. However, at 50 wt% the pumice filled composites' maximal tensile strength was achieved. This emphasizes the fact that the filler in the mix has a more uniform dispersion and is up to 50 % filled. In other words, this filler provides a wide interfacial area of contact, resulting in better interfacial adhesion. The pumice powder was not well integrated with MDF in the 10, 20, and 30 wt% composites, which can result in a weak connection. When epoxy resin was mixed with pumice powder, it had a low fluidity. The clustering of pumice powder on the MDF surfaces causes increased surface tension, resulting in poor adhesion between the MDF surfaces. A similar finding was also observed in [7, 8].

3.3. Three-Point Bending test

The clean MDF composite had a three-point-bending strength of about 5 MPa. Furthermore, as the amount of pumice powder was added to the composites, the flexural strength improved marginally (Figure 4). The average surface area in contact with the epoxy matrix rose as the amount of pumice powder used increased, resulting in more bonding points and higher connection. The addition of 20 wt% pumice powder to the composite enhanced the composite's three-point bending strength. The three-point bending strength of the 20 wt% pumice composite was measured at around 16 MPa. The excellent dispersion of pumice in the epoxy matrix could be the main reason for the increase in three-point bending strength. Furthermore, because pumice

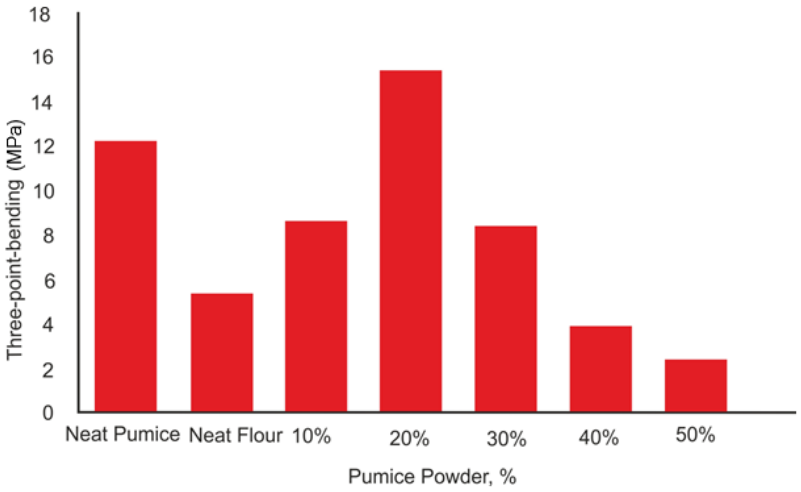


Fig. 4. Three-point- bending strength properties of the composites

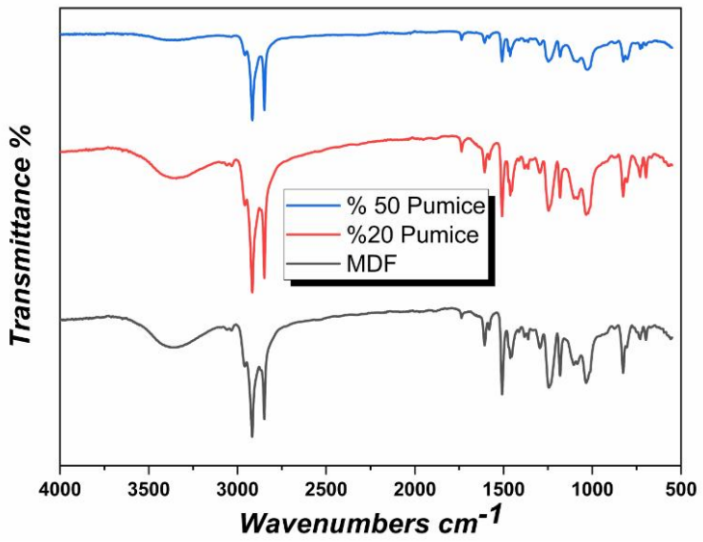


Fig. 5. FTIR spectra of composites

powder has a significant amount of SiO_2, this behavior is attributable to an increase in the likelihood of adhesion with MDF and epoxy polymer [17, 18]. However, when the amount of pumice powder in the composites increased from 30 to 50 wt%, the three-point bending strength of the composites diminished. At larger filler loadings, the weak interface interaction between the filler and the matrix becomes more prominent, resulting in a decrease in three-point bending strength [8, 19].

3.4. FTIR analysis

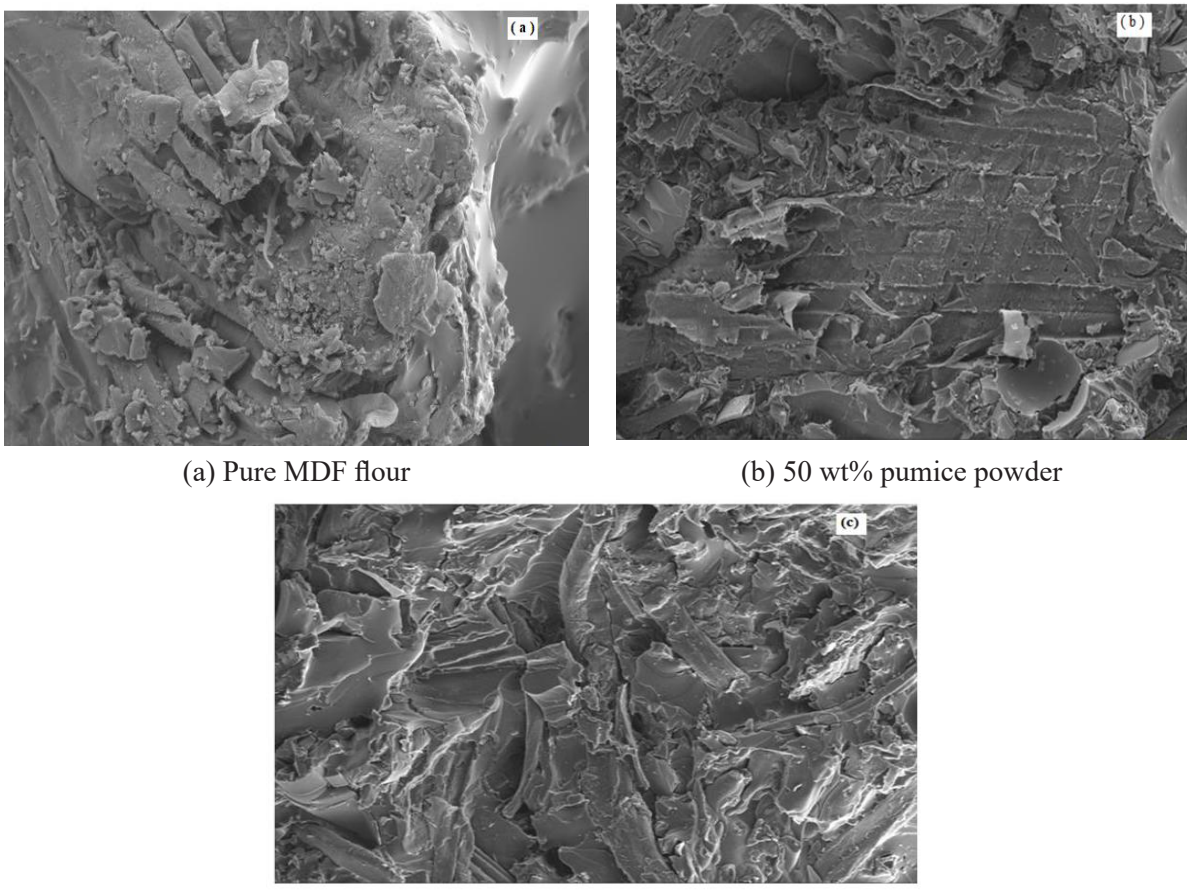
Figure 5 shows the FTIR spectroscopy data of all chemical groups of MDF flour composites and those filled with pumice powder. Different peaks were recorded at 3325, 2900-2800, 1745, 1615, 1500, 1235, 1020-1150, and 800-750 cm^{-1}. The bands at 3325 cm^{-1} and 2900 cm^{-1} refer to the stretching of the cellulose present in the composites. Afterwards, the filled composites significantly see a decrease in the band, which could be detected in the spectra transmittance at 1500 cm^{-1}. This was followed by peaks at wave numbers 3100 cm^{-1}, 1700 cm^{-1}, 1250 cm^{-1}, 1650 cm^{-1}, and 1350 cm^{-1}, thereby effecting a significant reduction. It clearly shows the less percentage of MDF flour content, which is unbeneficial, because low contents of MDF flour will affect the mechanical properties of the composite [7, 20, 21].

3.5. Scanning electron microscopy (SEM) analysis

Figure 6 illustrates FESEM images of tension fractured samples (a-c). Figure 6 (a) shows some of the voids in the composites. The image also shows the brittle deformation that pure MDF undergoes during tensile strain (Figure 6 (b,c)). Morphological alterations created in the surface of the MDF-matrix network due to the addition of a varying amount of pumice powder content can be confirmed using these fractured micrographs. As the weight percent of pumice powder increased, the surface became less rough, as seen in Figure 6 (b–c). This is due to the strong connections between MDF and pumice powder, which cause MDF to stick together and drag the matrix to a joining point. When it comes to crack and void development between epoxy matrix surfaces and MDF, MDF contact areas result in poor interaction, and non-homogeneous wide range particle size distribution has an uneven effect on mechanical properties [22]. Hydrophilic natural fibers and hydrophobic polymer matrices have poor adhesive interactions [23, 24]. As a result, adding pumice powder to the composite resulted in a considerable change in mechanical characteristics, which was confirmed by SEM pictures.

3.6. Differential scanning calorimetry (DSC) analysis

Differential scanning calorimetry was used to explore how varying wt% of pumice powder affects the thermal transition of composites blended with pumice powder (Figure 7). Two endothermic strong peaks were seen in the DSC curves of the MDF, 20 and 50 wt% samples, respectively, at 50 to 100 °Cand 350 to 400 °C. The glass transition temperature (T_g) of the three specimens is specified by the early peak, which ranges from 53 to 55 °C. T_g values of 53.9, 54.9, and 53.2 °C were found for pure MDF and 20 and 50 wt% pumice powder, respectively. The polar nature of the porous pumice powder imparts an increase in the free volume, which lowers the T_g value. The thermal



(a) Pure MDF flour (b) 50 wt% pumice powder

(c) 20wt% pumice powder

Fig. 6. SEM images of MDF-epoxy resin composites with various contents of pumice powder (a) pure MDF, (b) 50 wt% pumice powder, (c) 20 wt % pumice powder

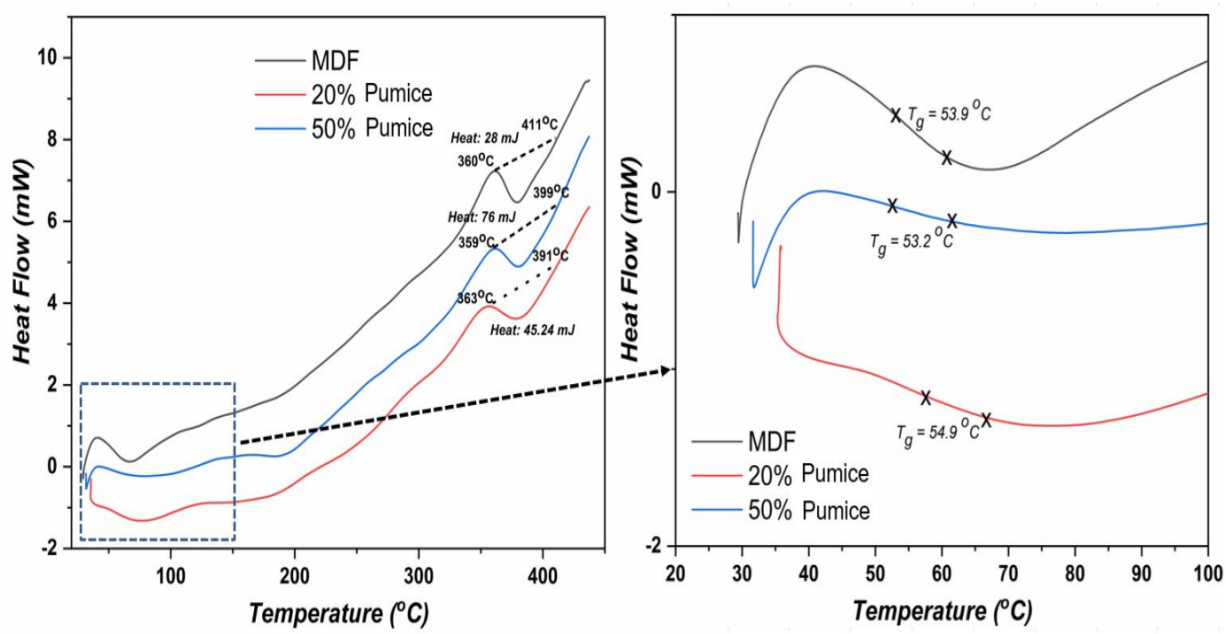


Fig. 7. Heating curves of DSC for MDF flour composite and 20 wt%, and 50 wt% pumice powder composites

depolymerization of the hemicelluloses and cellulose was detected at a temperature between 350 °C and 400 °C, resulting in the second endothermic peak. The 20 wt% pumice composite, on the other hand, had an exothermic peak at 363 °C. Due to its strong adhesion between the matrix and MDF, the inclusion of 20 wt% pumice enhances the degradation temperature (T_d). Cui et al. [25] and Sahin et al. [9] both made a similar observation.

4. Conclusion

Experimentally, the properties of tensile, three-point bending, and water absorption behaviors of MDF powder/epoxy composite samples with different filler loadings of 10 to 50 wt% were examined. As a result of the findings acquired, it can be concluded that:

– The tensile strength of composite materials with 50 wt% filler was determined to be around 12 MPa. The mechanical properties of the composite were higher than for the pure MDF composite, and the tensile and three-point bending values increased with the addition of pumice powder. The three-point bending strength of composite materials containing 20 wt% filler was determined to be approximately 16 MPa.
– The glass transition temperature Tg values rise as the amount of pumice powder is increased, according to DSC test findings.
– The MDF flour/epoxy composite had substantially more water absorption than the filled composites. Pumice particles can be employed as an effective filler material to increase thermal stability, decrease water absorption, and improve mechanical properties.

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