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Valorization of Waste Medium-Density Fiberboard in Multifunctional Lightweight Cement Mortar: Effects of Cement-Slurry and Paraffin Pretreatments on Mechanical, Thermal, and Acoustic Performance

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Abstract

The growing generation of waste medium-density fiberboard (MDF) from construction, renovation, and furniture-related activities creates environmental concerns associated with disposal, landfilling, and inefficient material recovery. This study investigates the valorization of waste MDF as a functional lightweight aggregate in cement mortar and evaluates whether pretreatment can mitigate its high water absorption while retaining beneficial thermal and acoustic characteristics. Waste MDF was used in three conditions: untreated MDF, Portland cement slurry-treated MDF (MDFC), and paraffin wax-treated MDF (MDFP), at addition levels of 10–50% by cement weight. The untreated MDF exhibited a water absorption of 245%, which was substantially reduced to 60% and 15% after cement-slurry and paraffin pretreatments, respectively. Increasing MDF content generally reduced mortar flowability, density, compressive strength, and flexural strength, while enhancing thermal insulation and sound absorption. Among the investigated treatments, MDFC produced the highest density and mechanical performance because the cementitious coating improved particle grading, packing efficiency, and compatibility with the cement matrix. In contrast, MDFP provided the greatest reduction in MDF particle water absorption but exhibited comparatively lower mechanical performance because of weak interfacial bonding and particle agglomeration. Untreated MDF mortar achieved the lowest thermal conductivity, decreasing to approximately 1.76 W/m·K at the highest addition level, and exhibited the highest sound absorption coefficient and noise reduction coefficient. The results demonstrate that waste MDF can be valorized in non-structural cementitious materials, providing a potential pathway for reducing MDF disposal while producing lightweight, thermally insulating, and acoustically functional building materials.

Keywords: Waste medium-density fiberboard; Waste valorization; Cement mortar; Lightweight aggregate; Thermal insulation; Sound absorption; Circular construction

1. Introduction

The construction industry is a major contributor to solid waste generation and environmental burden worldwide. Recent global reports (United Nations Environment Programme and Global Alliance for Buildings and Construction 2025) indicated that construction, renovation, and demolition activities generate a large volume of construction and demolition waste more than one-third of all waste generated by others. However, most construction projects in many countries still lack a dedicated unit or a clearly responsible mechanism for managing waste materials. As a result, construction waste is often disposed of improperly causing environmental problems. To mitigate these problems, increasing attention has been given to the recycling and valorization of construction residues in cement-based materials. Previous studies have investigated the incorporation of waste concrete, lightweight brick debris, ceramic waste, and other discarded materials as partial replacements for conventional constituents in mortar and concrete (Grigorjev et al. 2024; Alkhteb and Dawood 2025; Meena et al. 2022). Although these approaches can reduce the construction waste, but practical use is often constrained by variable material quality, high cost in recycling procedures, and low economic return. In addition, processing and quality-control requirements and insufficient confidence in their reliability for primary structural applications (Silva et al. 2019; Neupane et al. 2025).

Medium-density fiberboard (MDF) is one of the waste materials generated by construction projects, furniture production, and interior fit-out works. MDF is an engineered wood-based composite panel manufactured from lignocellulosic or cellulosic wood fibers combined with synthetic adhesives and consolidated under heat and pressure. This manufacturing method produces a dense and homogeneous panel with good dimensional stability and surface quality (Maloney 1977; Pereira et al. 2004). In recent years, MDF has been widely used worldwide, with global production reported to exceed around 100 million m³ annually, mainly driven by construction and furniture industries (Food and Agriculture Organization (FAO) 2022; Mordor Intelligence 2023). The MDF is acceptable wooden products used worldwide in construction sector, from the beginning of the construction as formwork, later in the household products such as furniture, or decorating items. However, off-cuts and discarded MDF generated during construction and furniture fabrication are difficult to recycle and dispose of properly because of their composite nature and adhesive content. In current practice, MDF waste is commonly managed through energy recovery, high-pressure recycling processes, or conversion into new products. Nevertheless, these recycling efforts have not yet been achieved because the composite structure and adhesive content of MDF make its recovery and reprocessing technically difficult and economically limited (Zimmer and Bachmann 2023; Thirugnanam et al. 2022). In some cases, the MDF board waste has been reported to be landfilled or burned under incomplete combustion conditions, which creates adverse environmental impacts and contributes to pollution (Ali et al. 2024; Top 2015).

There is one particular issue that is often the weakest link in the mechanical properties of cement-based materials, as they are inherently brittle and possess low tensile strength, making them susceptible to microcrack formation due to shrinkage, thermal expansion, and external loading conditions, which can further propagate and affect long-term durability. This leads to a potentially attractive option, which is the incorporation of waste MDF into cement-based materials as a fiber-type reinforcement, as due to the fibrous nature of MDF, it can help mitigate microcrack formation. However, untreated MDF particles have intrinsic limitations, particularly high-water absorption, and relatively low strength, which can defeat the workability, mechanical performance, and long-term durability of cement composites (Vololonirina et al. 2025; Maier et al. 2025b; Turoboś and Przybysz 2025; Maier et al. 2024). In addition, the hydrophilic nature of fiber increases water demand during mixing, disrupts fiber dispersion and matrix homogeneity, and also reduces durability in cementitious materials (Kampragkou et al. 2024).

Despite the porous fibrous structure also offering beneficial functional properties, especially for applications requiring low density, improved thermal insulation, and enhanced sound absorption (Benmansour et al. 2014; Fornés et al. 2022; Rabbat et al. 2021). This is particularly relevant for non-load-bearing wall systems and interior partitions, where thermal and acoustic comfort are increasingly important. Conventional partition materials do not always provide adequate insulation performance, while specialized acoustic or insulating boards are often relatively costly. Therefore, if the compatibility of MDF with the cement matrix can be improved through suitable pretreatment, waste MDF could serve as a low-cost and sustainable functional additive for lightweight cement mortar products.

Although previous studies have investigated recycled lignocellulosic materials in cementitious composites, often focused on either untreated waste natural fiber or a single performance aspect (Vololonirina et al. 2025; Abdalla et al. 2023). A systematic evaluation of pretreated waste MDF in mortar, particularly with respect to its combined mechanical, thermal, and acoustic behavior, remains limited. Accordingly, this study investigates the use of waste medium-density fiberboard as a lightweight aggregate in cement mortar after pretreatment with Portland cement slurry and paraffin wax to improve performance and water absorption properties. The study aims to investigate the physical, mechanical, thermal, and acoustic properties of cement mortar containing pretreated waste MDF and non-treated MDF.

2. Materials and Methods

2.2 Raw Materials

- Cementitious material - Ordinary Portland cement type I.
- Fine aggregate - Natural river with particle size ranged from 0.074 to 4.75 mm and a fineness modulus of 2.77 in accordance to ASTM C33 (ASTM International 2024a).
- Medium-Density Fiberboard (MDF) - Waste MDF obtained from construction, built-in fitting, and furniture-related activities was used as a recycled fibrous material. The discarded MDF boards were crushed using a wood chipper to a maximum size of 4.75 mm, as shown in Fig. 1. After crushing, the material was analyzed for particle size distribution (Fig. 2). Although not used as a conventional aggregate, its physical properties, including fineness modulus and water absorption, were evaluated to understand its interaction with the cement matrix (Table 1).
- Paraffin wax - Paraffin wax with melting temperature of 48–68 °C , was used as the pretreatment material to improve the water tightness of the MDF particles. The properties of paraffin wax is showed as Table 2.
- Chemical Admixture: To prevent the loss of workability due to the high water absorption of MDF, a high-range water-reducing admixture type F (superplasticizer) with polycarboxylate base following ASTM C494 (ASTM International 2024b) was incorporated at 1% by cement weight in all mixtures.



Fig. 1 MDF crushing process

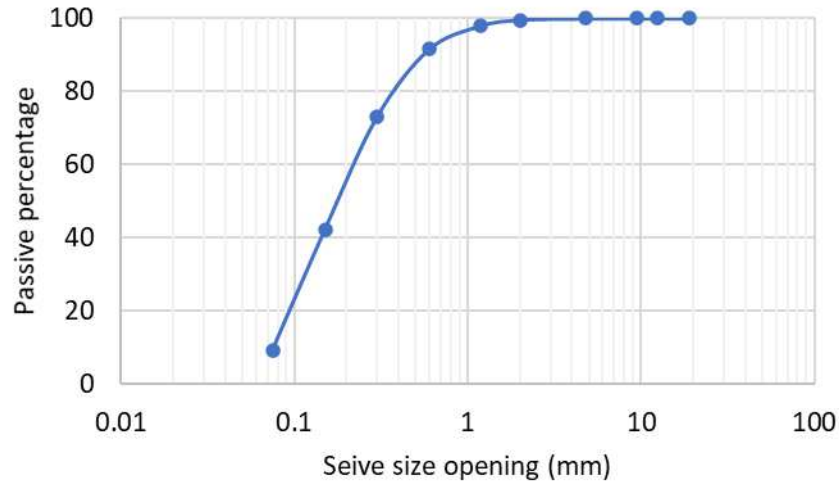


Fig. 2 Gradation of untreated MDF

Table 1. Properties of untreated MDF

Properties	Specification
Common name	Medium-density fiberboard (MDF)
Appearance	Brown to dark-brown fibrous board particles with a rough surface texture
Water absorption	245%
Dry density	420.50 kg/m ³
Saturated Surface Dry - SSD	1030.09 kg/m ³
Fineness modulus	0.96

Table 2. Paraffin wax

Properties	Specification
Common name	Paraffin wax (Cosmetic grade)
Appearance	Solid, white to pale yellow, waxy material
General chemical formula	C _n H _{2n+2}
Chemical class	Saturated hydrocarbon (Paraffinic hydrocarbon)
Melting point	48–68 °C
Specific gravity	0.88–0.92 g/cm ³
Source	By-product obtained from crude oil refining; produced from slack wax after oil removal (sweating purification)

2.3 MDF treatment

2.3.1 Untreated MDF

The waste MDF was crushed into small particles and used as the reference material in this study. Due to its lignocellulosic and porous structure, the untreated MDF has a rough and natural surface texture with high water absorption capacity. To minimize excessive water uptake during mixing, the crushed MDF particles were soaked in water overnight until reaching a saturated condition before being incorporated into the mortar (Fig. 3a).

2.3.2 Cement treated MDF (MDFC)

For the Portland cement pretreatment, a cement slurry was prepared with a water-to-cement ratio of 0.67. The crushed MDF particles were soaked in the slurry and left overnight to allow a cementitious coating to form on the particle surfaces and partially penetrate into the porous structure. After treatment, the MDFC particles were removed and used for subsequent mortar mixtures (Fig. 3b).

2.3.3 Paraffin treated MDF (MDFP)

Paraffin wax was heated to about 70 °C until fully melted. The crushed MDF particles were then soaked in the molten paraffin in an oven for approximately 24 hours to form a thin hydrophobic coating on the particle surfaces. After cooling to room temperature, the paraffin-treated MDF (MDFP) particles were collected and used for subsequent mortar mixtures (Fig. 3c).

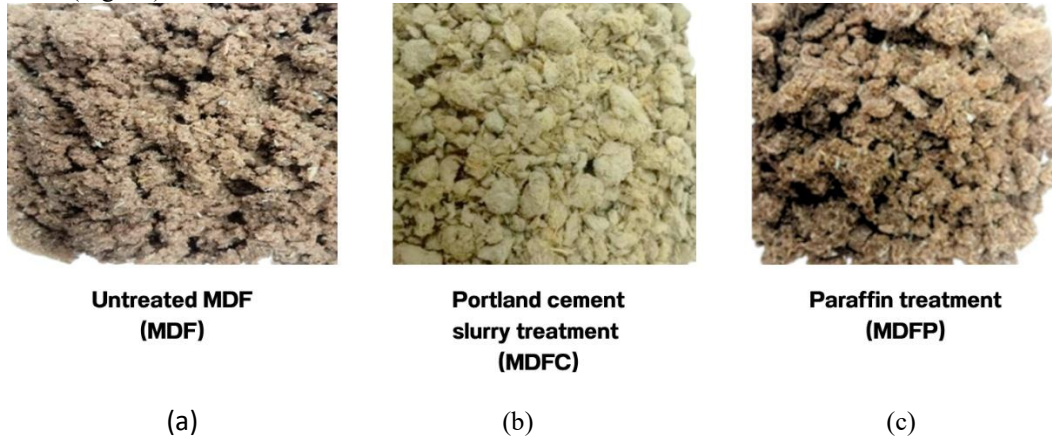


Fig. 3 Untreated and treated MDF

2.4 Mix proportions

The mortar mixtures were designed with a cement-to-sand weight ratio of 1:2. The water-to-cement ratio (w/c) was fixed at 0.40 for all mixtures. The dosage of water-reducing admixture was maintained at 1% by cement weight. A control mixture without MDF was prepared as a controlled reference mixture. All three types of MDF (MDF, MDFC, MDPF) were incorporated into the concrete mixture at the rate of 10, 20, 30, 40, and 50% by weight of cement. Table 3 shows the detailed mix proportions.

Table 3. Mix proportions (kg/m³)

Signature	MDF	MDFC	MDFP	Cement	Water	Fine aggregate
C	-	-	-			
10MDF	78	-	-			
20MDF	156	-	-			
30MDF	234	-	-			
40MDF	312	-	-			
50MDF	390	-	-			
10MDFC	-	78	-			
20MDFC	-	156	-			
30MDFC	-	234	-	780	312	1560
40MDFC	-	312	-			
50MDFC	-	390	-			
10MDFP	-	-	78			
20MDFP	-	-	156			
30MDFP	-	-	234			
40MDFP	-	-	312			
50MDFP	-	-	390			

2.5 Specimen preparation and curing

The mortar mixtures were then prepared according to the designated mix proportions. In each batch, fine aggregate was first placed in the mixing container, followed by the addition of cement. The dry materials were mixed for 1-2 minutes until uniformly distributed. Then, water and superplasticizer was added and the mixing process continued for approximately 1–2 minutes. Finally, the pretreated MDF particles were gradually introduced and mixed for approximately 2-3 minutes until a uniform mortar mixture was achieved.

The fresh mortar was cast into molds according to the required specimen geometry for each test. The compressive strength and flexural strength specimens were cast as a cylinder ($\phi 100 \times 200$ mm) in accordance with ASTM C39 (ASTM International 2026) and a prism ($100 \times 100 \times 350$ mm) in accordance with ASTM C78 (ASTM International 2022), respectively. For the thermal test, square panel specimens of $200 \times 200 \times 50$ mm were prepared, while specimens of $300 \times 300 \times 50$ mm were used for the acoustic test. After casting, the specimens were demolded and then cured by wrapping with plastic sheets to minimize moisture loss. All specimens were stored at room temperature and cured for 28 days before testing.

2.6 Experimental procedures and data analysis

2.6.1 Flow test

The fresh-state consistency of the mortar mixtures was evaluated by a flow table test. The flow value was determined following ASTM C1437 (ASTM International 2020). The fresh mortar was placed into the conical mold positioned at the center of the flow table. After the mold was filled and the top surface was leveled, the mold was lifted vertically, allowing the mortar to spread freely on the table surface. The table was then dropped 25 times within 15 s. After the dropping sequence, the spread diameter of the mortar was measured along four directions, and the average value was used to determine the flow as in Equation 1.

$$\text{Flow (\%)} = \frac{D_1 - D_0}{D_0} \times 100\% \quad (1)$$

Where D_0 is the diameter of the conical mold base. (100 mm), D_1 is the average diameter of the mortar spread after being dropped (mm).

2.6.2 Density and water absorption

The hardened density and water absorption of the mortar specimens were determined based on ASTM C642 (ASTM International 2021b). After curing, the specimens were dried to constant mass in an oven and then cooled to room temperature before weighing. The dry mass and specimen volume were used to calculate the bulk density of the mortar.

The water absorption of the mortar specimens was evaluated at 28 days of age. The specimens were first immersed in water for 24 h and then weighed in the saturated condition. After that, the mortar specimens were oven-dried at 110°C for 24 h and weighed again. The percentage of water absorption was then calculated using Equation 2.

$$\text{Water absorption (\%)} = \frac{W_w - W_d}{W_d} \times 100\% \quad (2)$$

Where W_w is the weight of saturated surface-dry mortar, W_d is the weight of the mortar after oven-drying.

2.6.3 Compressive strength

The compressive strength test was performed in accordance with ASTM C39 (ASTM International 2026). The specimens were tested at 28 days of age. Each specimen was placed at the center of the concrete compression machine, with its axis aligned with the centerline of the loading platen. During the test, the applied load was controlled at a constant rate of 0.25 ± 0.05 MPa/s until failure occurred. The maximum compressive load was recorded and calculated in compressive stress from the maximum load by the loading area of the specimen.

2.6.4 Flexural strength

The flexural strength test was performed in accordance with ASTM C78 (ASTM International 2022). The universal testing machine used for the flexural test was capable of applying the load continuously without interruption or sudden shock during loading. In this test, the applied load was controlled at a uniform rate corresponding to a stress increase of 0.9 to 1.2 MPa/min until the specimen failed. The flexural strength can be calculated as the modulus of rupture by using Equation 3.

$$R = \frac{PL}{bd^2} \quad (3)$$

Where R is the modulus of rupture (MPa), L is the span length (mm), b is the specimen width (mm), and d is the specimen depth (mm).

2.6.5 Thermal conductivity

The thermal conductivity of the specimens was evaluated using a laboratory-developed thermal test setup based on the principles of ASTM C518 (ASTM International 2021a). The specimen size used for thermal evaluation was $200 \times 200 \times 50$ mm. The same temperature-measurement system was intended for thermal-property testing, with sensors arranged to monitor both temperature and heat-flow behavior across the specimen thickness.

Fig. 4 shows the thermal conductivity testing apparatus that consists of (1) a temperature control unit for controlling the heat, (2) a power supply, (3) a data acquisition system with an amplifier for recording temperature and heat-flow signals during the test, (4) thermocouple can measurement range of -50 to 250 °C for monitoring both the surface and internal temperatures of the specimen, (5) heat flux sensors with a reported measuring range of 769 to 384,615 W/m installed at the specimen surfaces exposed to the heating side for monitoring the heat received by the test specimen, (6) a heating plate used as the thermal source, and (7) thermal insulation arranged to promote one-dimensional heat flow through the specimen thickness.

During testing, one side of the specimen was subjected to a higher temperature by the heating plate, while the temperature of the heating system was controlled using a microcontroller and relay switch. Once a temperature difference was established across the thickness of the mortar specimen, heat was transmitted through the specimen by conduction. The heat flux sensors continuously monitored the heat transferred through the specimen, while the thermocouples recorded the temperature at both sides of the surface and the middle of the specimen. The test was continued until the heat-flow response reached a steady-state condition, at which point the recorded data were used for thermal-conductivity calculation.

Thermal conductivity was measured at a temperature level of 42-45 °C and calculated using the following relationship (Equation 4):

$$K = \frac{(Q_2 - Q_1)L}{A(T_2 - T_1)} \quad (4)$$

Where K is the thermal conductivity (W/m.K), Q_1 is the heat flow before passing the specimen. Q_2 is the heat flow after passing the specimen. A is the heated specimen area (m^2). L is the distance between the heating plates (m). ($T_2 - T_1$) is the temperature difference across the specimen in a steady-state condition.

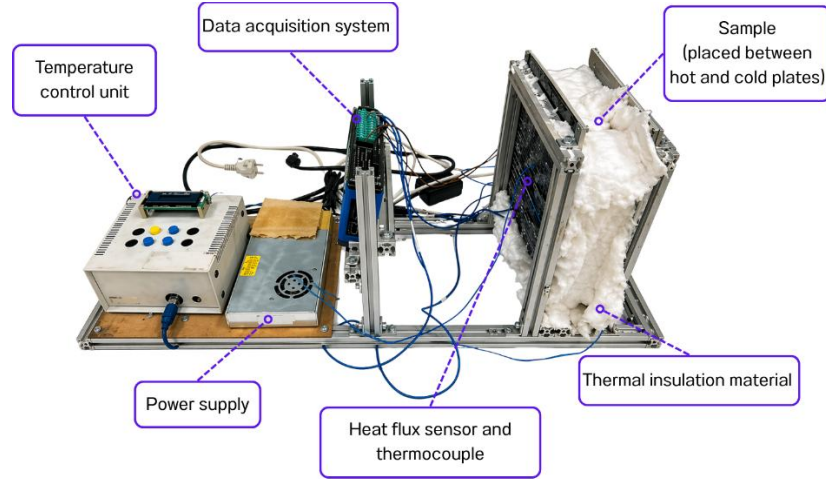


Fig. 4 Thermal conductivity test apparatus

2.6.6 Acoustic property

The acoustic performance of the mortar panels was evaluated using a laboratory-developed sound absorption test box based on the principles of ASTM C423 (ASTM International 2023) and the small-sized reverberation chamber approach described by del Rey et al. (2017), as shown in Fig. 5. The test focused on the determination of the sound absorption coefficient (SAC) and the noise reduction coefficient (NRC) of the mortar specimens.

The acoustic measurement system consisted of a laboratory-developed sound test chamber whose opposing walls were designed to be non-parallel in order to reduce sound reflection and standing-wave interference within the chamber. The test specimen size of 300×300 mm was installed at the central opening of the chamber. Acoustic measurements were carried out using an audio and acoustic analyzer equipped with a Class 1 microphone, capable of recording sound frequencies in the range of 5–20,000 Hz in accordance with IEC 61672 Class 1. The microphone was installed at 6 different positions to average the rate of sound decay.

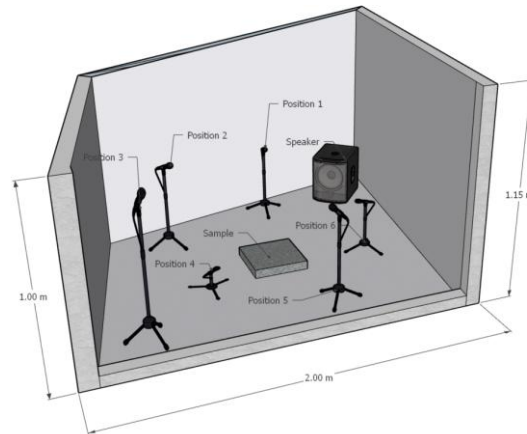




Fig. 5 Sound absorption test

During the test, the specimen was installed at the center of the chamber, and a sound source in the frequency range of 20–20,000 Hz was used to excite the system. The rate of sound decay (dB/s) was measured for the chamber with and without the specimen. The specimen sound absorption coefficient was determined using Equation 5.

$$\alpha = \frac{A_2 - A_1}{S} \quad (5)$$

Where α is the sound absorption coefficient, A_2 is the total sound absorption after the specimen was installed, A_1 is the total sound absorption before the specimen was installed, and S is the exposed area of the specimen (m^2).

The total sound absorption of the chamber was calculated from the chamber volume and the sound energy decay rate using Equation 6.

$$A = \frac{55.3Vd}{c} \quad (6)$$

Where A is the sound absorption of the chamber (m^2), V is the chamber volume (m^3), d is the decay rate of sound energy (dB/s), and c is the speed of sound in air (m/s). The speed of sound in air was calculated as a function of ambient temperature according to $c=331+0.6t$, where t is the air temperature. Equation 6 was used for both the empty chamber and the chamber containing the test specimen.

The noise reduction coefficient (NRC) was calculated as the average of the sound absorption coefficients measured at 250, 500, 1000, and 2000 Hz following Equation 7.

$$\text{NRC} = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \quad (7)$$

Where α_{250} , α_{500} , α_{1000} , and α_{2000} are the sound absorption coefficients at frequencies of 250, 500, 1000, and 2000 Hz, respectively.

3 Results and discussion

The untreated MDF used in this study exhibited extremely high water absorption, reaching approximately 245%, which makes direct incorporation into the mortar matrix impractical. Therefore, pretreatment was necessary before its use as a recycled aggregate in the mortar mixtures. This study defined two improvement methods: treatment of MDF with cement slurry (MDFC), and treatment of MDF with paraffin wax (MDFP). The results are discussed in terms of the physical, mechanical, thermal, and acoustic properties of mortar containing pretreated MDF. The influence of the

MDF pretreatment method and MDF content is examined by comparing with the untreated MDF mortar and the control mortar.

3.1 Physical properties of untreated and pretreated MDF mortar

The properties of pretreated MDF and particle-size gradation are shown in Table 4. and Fig. 6. After treatment, the MDFC exhibited larger agglomerated particles than the untreated MDF, with a fineness modulus of 5.38. The water absorption of MDFC was reduced to 60% that indicating a substantial improvement compared with the untreated MDF. Since Portland cement has a higher specific gravity than MDF, the absorption into the MDF particles caused MDFC to exhibit a slightly higher oven-dry unit weight. However, the water absorption was reduced, which resulted in the saturated surface-dry unit weight also decreasing accordingly. The paraffin-treated MDF (MDFP) showed the greatest reduction in water absorption among the two treatment methods. The molten paraffin formed a hydrophobic coating around the MDF particles, significantly decreasing the water absorption to 15%. However, the paraffin wax coating also caused the particles to agglomerate and form rough, irregular clusters, resulting in larger aggregate particles as gradation. The test results also showed the fineness modulus of MDFP equal to 6.47 and a higher dry unit weight than both untreated MDF and MDFC.

Table 4. Properties of pretreated MDF

Properties	MDFC	MDFP
Water absorption	60%	15%
Dry unit weight	468.71 kg/m ³	492.23 kg/m ³
Saturated Surface Dry - SSD	907.05 kg/m ³	627.18 kg/m ³
Fineness modulus	5.38	6.47

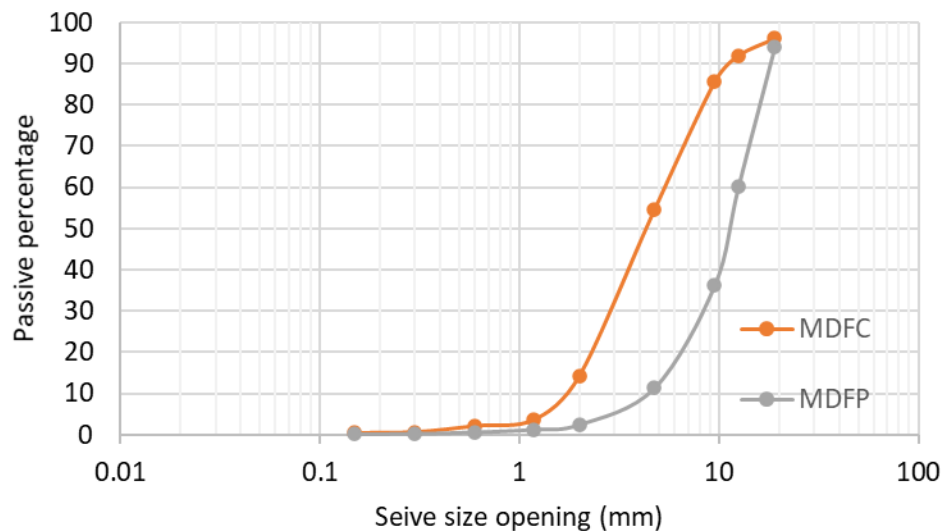
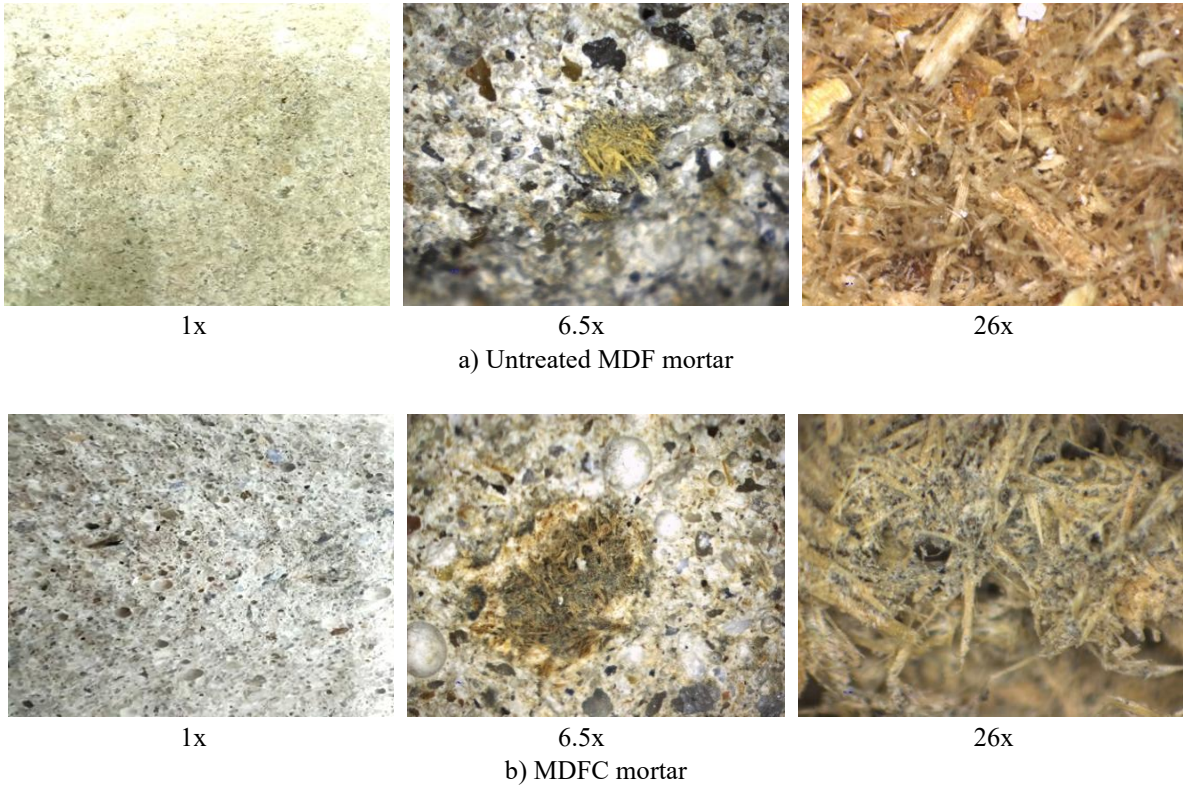


Fig. 6 Gradation of treated MDF

The visual appearance of the mortar containing untreated and pretreated MDF particles is shown in Fig. 7. The untreated MDF consisted of different types of fibers derived from the original wood pulp used in its manufacture, including a mixture of fibers in various lengths. These fibers appeared to be loosely bonded together in clusters. In general, plant cellulose-based materials exhibit relatively high porosity and water absorption because natural fibers provide a porous internal structure (Richely et al. 2022; Choi 2022; Han and Choi 2025). In untreated MDF mortar, the fibers appeared as distinct yellowish-brown wood fiber clusters embedded in the cementitious matrix. The preserved fibrous structure of untreated MDF and the interfacial voids around the fiber particles indicated a more porous and inhomogeneous internal structure, which is consistent with the lower density and high water absorption of the untreated MDF mortar.

The MDFC mortar exhibited a rougher and more porous surface than the untreated MDF mortar with visible voids distributed throughout the matrix. Consequently, the strength of the MDFC mortar remained no higher than that of the control mixture. Microscopic observation showed that the MDF particles were transformed into larger agglomerated clusters coated with cement paste, indicating improved compatibility with the cementitious matrix. This morphology is consistent with the relatively higher density and better mechanical performance of MDFC mortar. For MDFP, the mortar with MDFP showed larger brownish particle clusters and irregular agglomerated MDF particles with a dense paraffin-coated outer layer and local interfacial gaps. These characteristics explained that MDFP mortar exhibited reduced water absorption but also poorer packing efficiency.



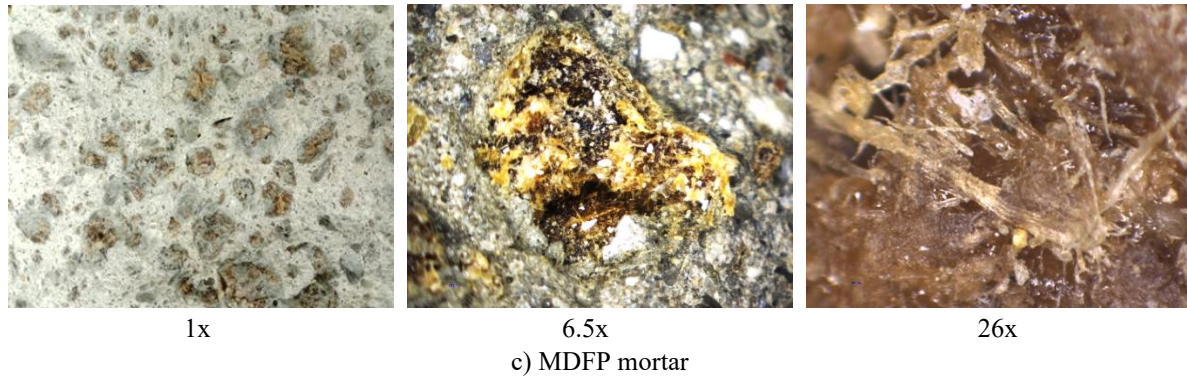


Fig. 7 Characteristics of mortar containing (a) untreated MDF, (b) cement-slurry-treated MDF (MDFC), and (c) paraffin-wax-treated MDF (MDFP) at different magnifications

3.2 Flowability

The flowability of the pretreated MDF mortar mixtures is presented in Fig. 8. Overall, the flow percentage decreased with the increase in MDF content, indicating that the incorporation of a higher volume of MDF adversely affected the workability of the fresh mortar mixtures. The flowability results showed that the incorporation of untreated MDF, MDFC, and MDFP reduced the flow of mortar compared with the control mixture. The decrease in flowability was mainly attributed to the high water absorption of the MDF particles, which reduced the amount of free water available in the mortar matrix and consequently lowered the consistency of the fresh mortar. Furthermore, the pretreatment process modified the surface characteristics and particle size of the MDF to form rough and irregular agglomerates. These pretreated MDF particles increased internal friction and restricted the movement of the fresh mortar during the flow test, resulting in a lower spread diameter. The flow results obtained in this study agree with the findings reported by García et al. (2024) and Maier et al. (2025a), who showed that increasing the content of natural fibers generally leads to a reduction in workability of mortar and concrete. This reduction is mainly attributed to the increase in internal friction and absorption of free water in the cementitious matrix.

Untreated MDF provided the highest flow at low content levels, especially at 10% and 20% MDF. This result can be explained by the relatively fine and fibrous texture of water-soaked MDF, which initially allowed better dispersion within the mortar matrix. However, the flow dropped sharply when MDF content increased, which indicated the fibrous particles tended to interlock and clump together, increasing internal friction and restricting the free movement of the fresh mortar. Although the flow of MDFC and MDFP mortar was lower than that of untreated MDF at low content levels, it became the highest among the treated MDF at 30-50%. These results agree that cement-slurry pretreatment and paraffin treatment caused the MDF particles to form more rounded and better-graded particles.

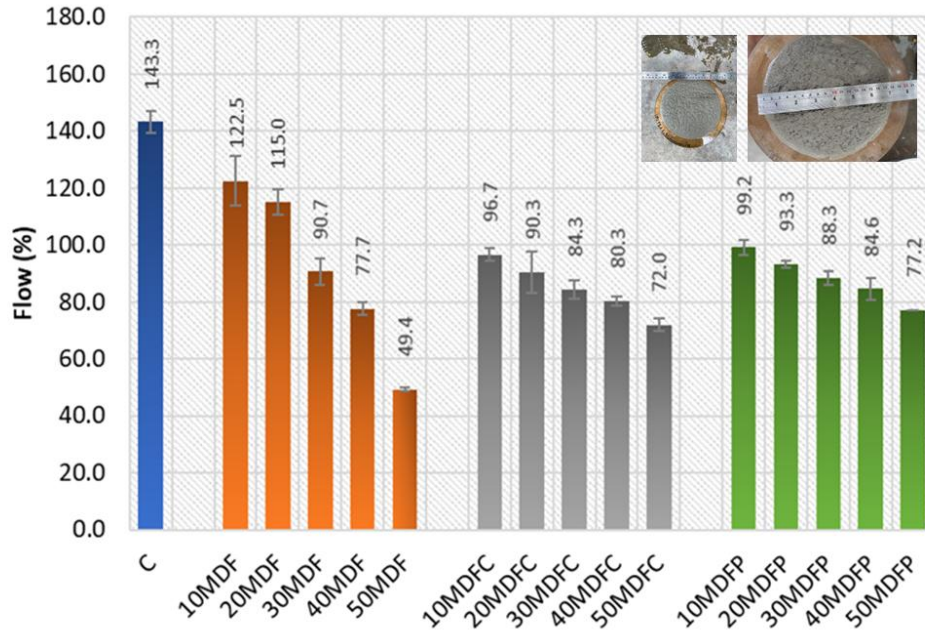


Fig. 8 Flow percentage

3.3 Density and water absorption

The density results in Fig. 9 show that all types of mortars containing MDF had lower density than the control mortar, and the density decreased as the MDF content increased. The control mixture exhibited a density of 2319 kg/m³, whereas the untreated MDF series decreased from 2096 to 1799 kg/m³, the MDFC series from 2216 to 1863 kg/m³, and the MDFP series from 2100 to 1773 kg/m³ as the addition level increased from 10% to 50%. This trend indicates the incorporation of MDF reduced mortar density because fiberboard particles have a lower unit weight than natural sand.

Comparisons with three specimen MDF types, the MDFC mortar generally exhibited the highest density, while untreated MDF and MDFP showed relatively similar values at the same addition levels. The comparatively high density of MDFC can be attributed to the Portland cement slurry pretreatment, which transformed the MDF particles into more granular and better-graded aggregate, leading to improved packing and reducing the negative effect of void formation in the mortar matrix.

For untreated MDF and MDFP, the densities were quite close to each other, even though the properties of the MDF particles were different. Based on the MDF characterization, the dry unit weight of MDFP (492.23 kg/m³) was higher than that of MDF (420.50 kg/m³). In principle, this higher particle unit weight should contribute to a denser mortar. However, the physical observations reported that the MDFP tended to form rough agglomerated clusters and exhibited poor particle packing, whereas untreated MDF had a finer fibrous texture and dispersed more uniformly, allowing better mixing and packing within the mortar matrix. These results are supported by Li et al. (2023) and de Oliveira Haddad et al. (2020), showing that particle size distribution, particle shape, and aggregate grading strongly influence packing density and void structure in mortars. Therefore, the beneficial effect of MDFP particles in higher unit weight was offset by the poor particle-size distribution and inefficient packing, which promoted void formation in the mortar matrix.

The water absorption results show the opposite trend to density in Fig. 10. In general, the water absorption increased as the MDF content increased, which indicates that the addition of larger amounts of MDF increased the permeability of hardened mortar. The control mixture showed the water absorption of 0.43% while the untreated MDF, MDFC, and MDFP mortars showed an increase to 7.17%, 5.17%, and 1.85% at 50% of addition, respectively. This behavior is consistent with the general response of cementitious composites containing wood particles or plant fiber, where the porous and hygroscopic nature of lignocellulosic (biomass) materials tends to increase water demand during mixing and create a more porous hardened matrix. Similar observations have been reported for wood chip, sawdust, and wood-waste-modified cement composites. (Dias et al. 2022; El Hamri et al. 2024)

Although paraffin treatment reduced the water absorption of the MDF particles to 15%, compared with 60% for MDFC and 245% for untreated MDF, the water absorption of MDFP mortar remained higher than that of the control mortar. This result indicates that mortar water absorption was governed not only by the intrinsic absorption of the MDF particles but also by packing density, particle dispersion, and void formation in the hardened matrix. Thus, the paraffin coating improved particle hydrophobicity, but particle agglomeration and inefficient packing still contributed to the water absorption of the MDFP mortar.

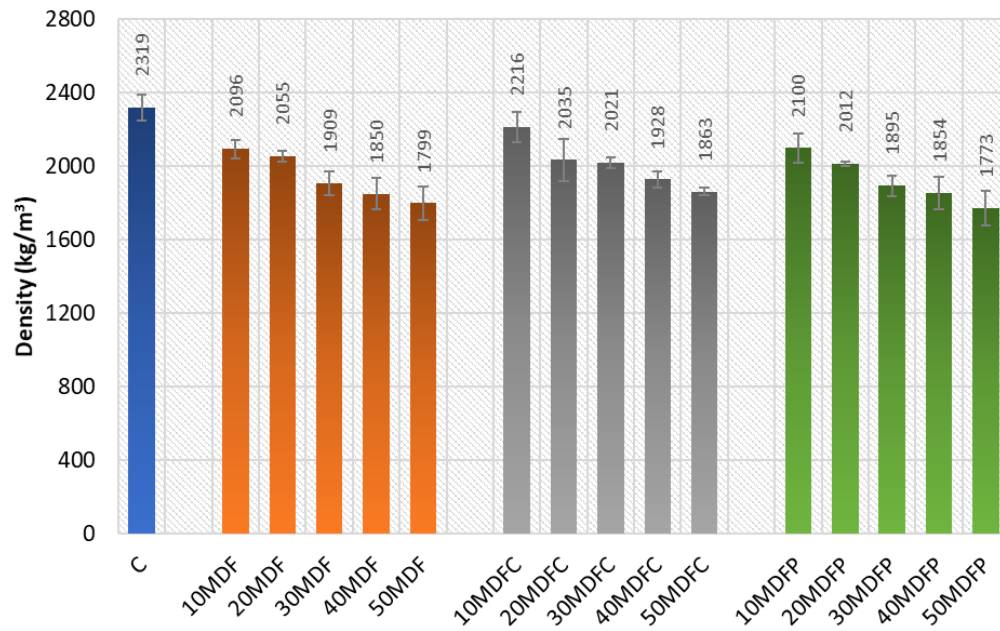


Fig. 9 Density

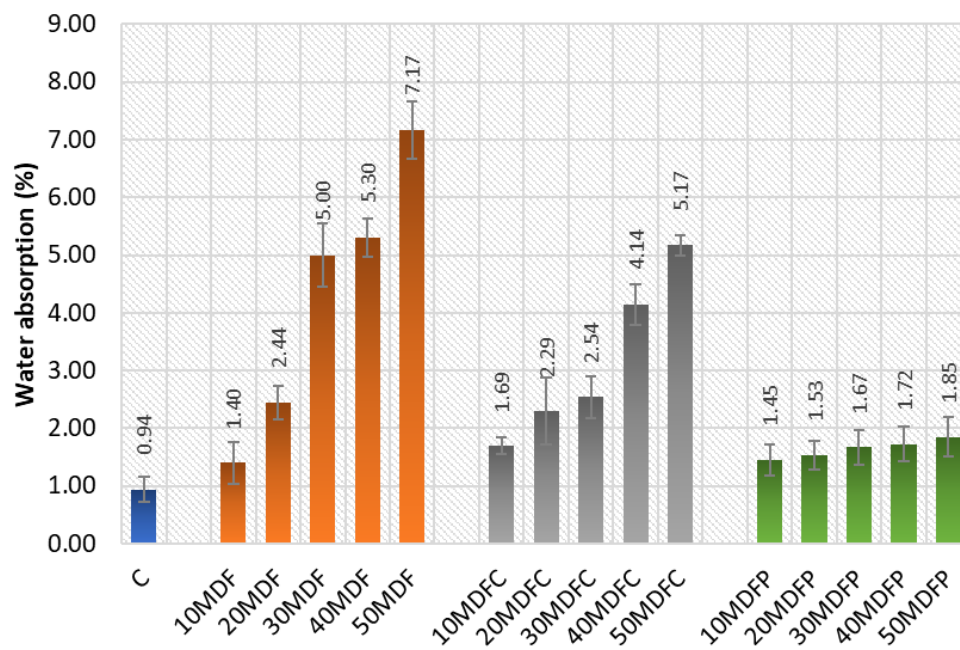


Fig. 10 Water absorption

3.4 Compressive and Flexural Strength

The compressive and flexural strength results show in Figs. 11 and 12 that the compressive strength and flexural strength of all types of MDF mortar are lower than that of control mortar, and both strengths decrease with increased MDF content. According to experimental results, the MDFC exhibited the highest compressive and flexural strength, followed by untreated MDF and MDFP. This result indicated that the cement-slurry pretreatment improved the strength properties of MDF particles into harder and more rounded granules due to the hardened cement coating. In addition, the MDFC particles were reported to have a great particle size distribution, which improved packing and enhanced compatibility with the mortar matrix. Similar behavior has been reported with Maier et al. (2025a) and Liu et al. (2022), who showed that the compressive and flexural strength of wood-cement composites can be improved after modifying the surface roughness of wood particles, which enhances interfacial properties and mechanical performance.

In contrast, the MDFP mortar exhibited the lowest compressive and flexural strength. Although paraffin treatment significantly reduced the water absorption of MDF, the wax-coated particles led to a smooth and glossy surface, which weakened the bond between MDFP and the surrounding mortar matrix. Moreover, the paraffin coating promoted poor particle-size distribution and the formation of rough aggregates, which likely increased internal voids and reduced matrix continuity (Al-Mohamadawi et al. 2016). In addition, the paraffin wax treatment promoted MDF particles into larger irregular aggregates, which acted as weak points under compression and flexural loading. As a result, crack initiation and propagation would be expected to occur more easily in MDFP mortars. The weak interfacial bonding and poor particle dispersion are highly detrimental to strength performance in wood-containing cement composites (Ince et al. 2021; Frybort et al. 2008). A similar concept has been discussed in studies on paraffin-coated lignocellulosic aggregates, in which coating improved water absorption, but the mechanical properties response depended strongly on particle morphology and matrix bonding (Al-Mohamadawi et al. 2016). Therefore, the paraffin pretreatment was beneficial in terms of water resistance, but cannot convert into an improvement in strength.

The untreated MDF showed compressive and flexural strength higher than MDFP but lower than MDFC. This behavior can be explained by the relatively fine texture of MDF, which allowed better dispersion and a more homogeneous mixture than MDFP. However, the MDF remained porous and more water sensitive than MDFC, its contribution to strength was still limited. The highly porous and hydrophilic nature of MDF, which can disturb the local water during hydration, increases internal porosity and weakens the hardened matrix. In mortars reinforced with waste wood fibers, the increase in wood content led to lower density and overall strength because of poor compatibility and increased voids in the cementitious system (Maier et al. 2025a; Kunchariyakun et al. 2022; Lin et al. 2025).

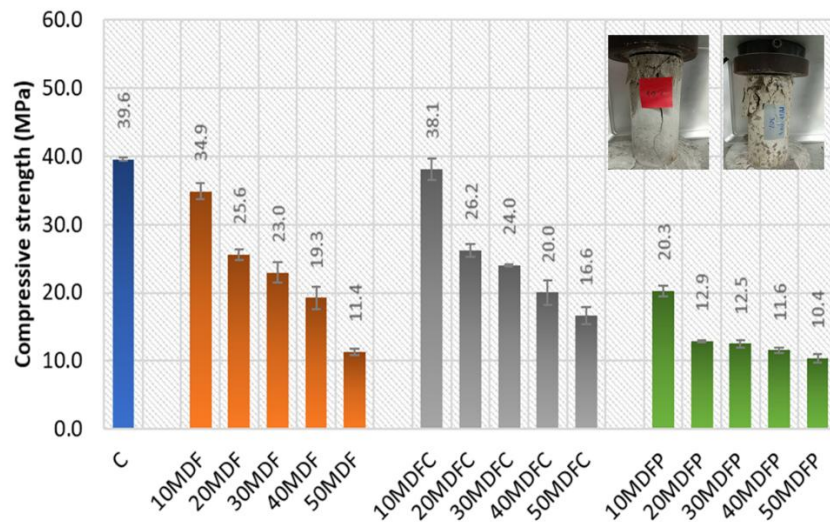


Fig. 11 Compressive strength

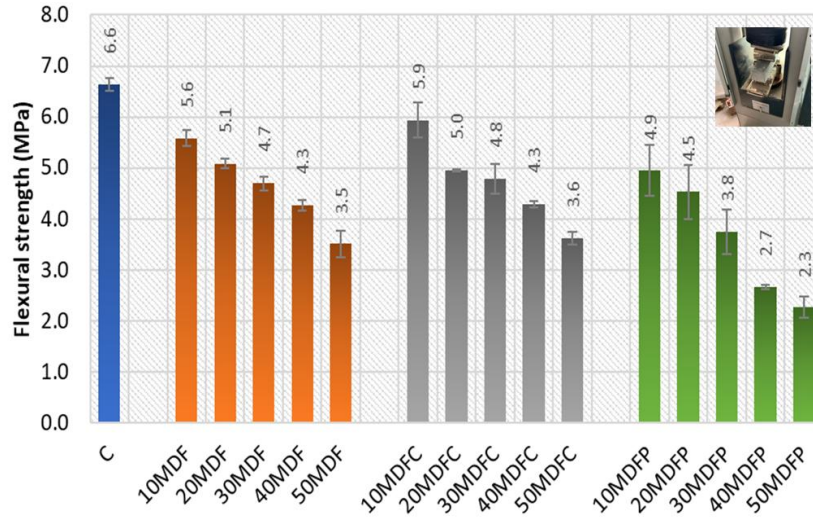


Fig. 12 Flexural strength

3.5 Thermal properties of Pretreated MDF mortar

The thermal conductivity of MDF mortar was presented in Fig. 13. The results showed that mortars containing untreated and pretreated MDF exhibited lower thermal conductivity than the control mix. The control specimen showed a thermal conductivity of 2.33 W/m·K, whereas the values of the untreated MDF mortars ranged from 2.07 to 1.76 W/m·K, 2.12 to 1.95 W/m·K for the MDFC series, and 2.10 to 1.85 W/m·K for the MDFP series. In general, thermal conductivity decreased with increasing MDF content, indicating that MDF improved the thermal insulation performance of the mortar.

In the experiment, the untreated MDF mortar specimens were measured for thermal conductivity at high temperature, which led to the water evaporation in MDF. A more porous internal structure of mortar interrupts heat-flow paths and increases the volume of entrapped air, which reduces heat transfer through the composite. Thus, the untreated MDF showed the lowest thermal conductivity, which can be explained by the high porosity associated with untreated MDF. These results agree with previous studies showing that the incorporation of bio-based or wood-derived particles into cementitious materials tends to lower thermal conductivity because of the reduction of density lead increased pore volume of the composites (Awoyera et al. 2022; Taoukil et al. 2013; Penazzato et al. 2025).

The MDFC mixtures exhibited the highest thermal conductivity among the treated MDF and untreated MDF mortars overall addition levels. The cement slurry-coated particles create a harder MDF and reduce the porosity. Also, the MDFC forms well gradation, producing a denser mortar, which likely provided a more continuous solid path for heat conduction. Similar findings have been discussed in the literature on porous materials composites, where improvements in compatibility and densification of the matrix can enhance mechanical performance but may simultaneously limit the reduction in thermal conductivity (Al-Mohamadawi et al. 2016; Sukontasukkul et al. 2019).

For the MDFP mortar, the thermal conductivity results indicated that the paraffin treatment improved thermal insulation more effectively than MDFC, but less than untreated MDF. This behavior can be attributed to the combined effects of the paraffin coating on the surface and the internal pore structure of the MDF particle, leading to a reduction in thermal properties. On the other hand, the wax treatment appeared to promote the formation of denser, rougher agglomerated aggregates. As a result, the poor grading of MDFP adversely affected the packing efficiency of the mortar matrix, leading to the formation of additional internal voids. This increase in porosity reduced the continuity of the heat-transfer path and consequently lowered the thermal conductivity.

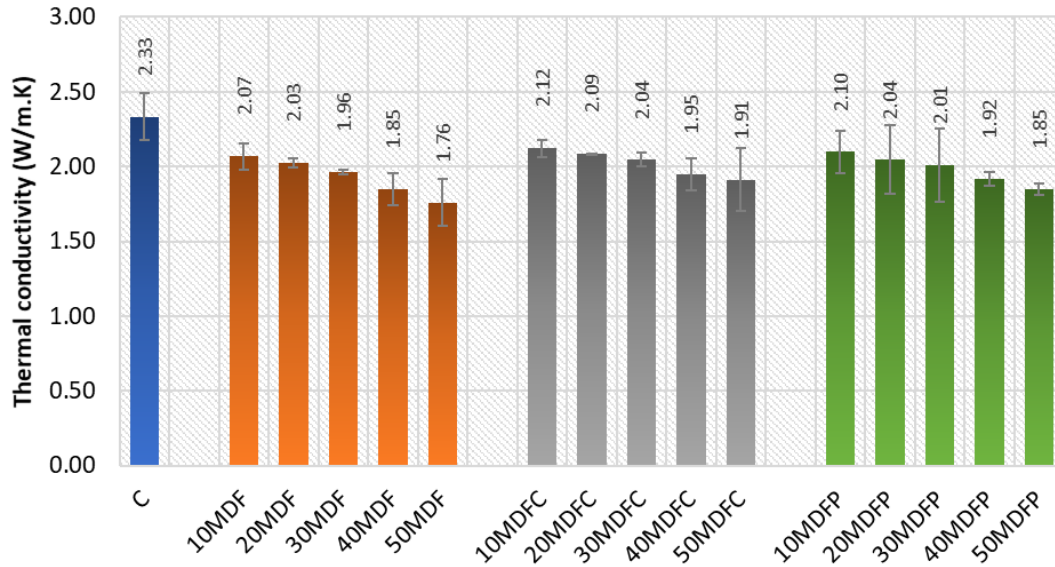


Fig. 13 Thermal conductivity

The important observation is that the thermal conductivity of all three MDF mortar series decreased progressively as the MDF content increased from 10% to 50%. From these results, the relationship between thermal conductivity and density was plotted in Fig. 14. A strong relationship between these two parameters showed that thermal conductivity increased with increasing density. When the density decreases, the material generally contains a higher volume of pores and entrapped air, leading to lower thermal conductivity than solid cementitious phases. The increase in porosity interrupts the heat-transfer path through the mortar and reduces the overall thermal conductivity (Khushefati and Akbarnezhad 2022; Daza-Badilla et al. 2024; Gavela et al. 2025). Therefore, the addition of a part of the mortar constituents with MDF increased the lightweight and insulating character of the material.

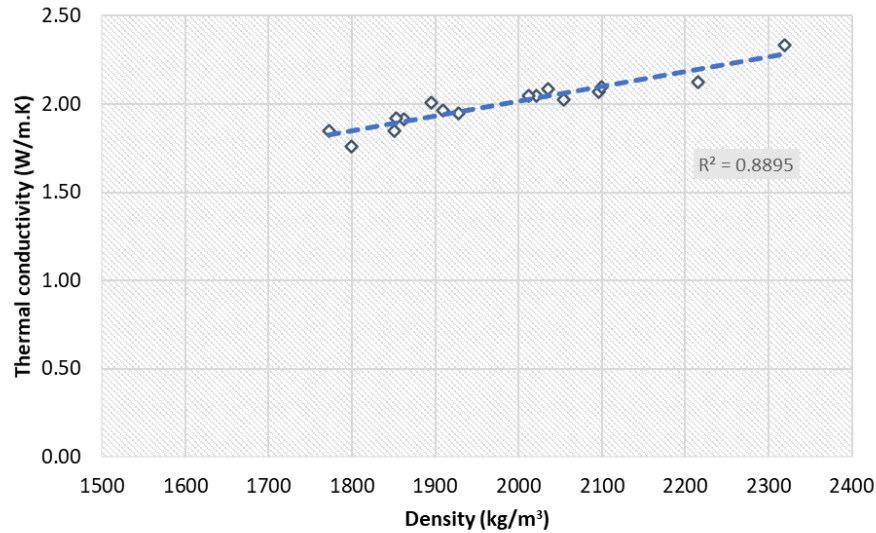


Fig. 14 Relationship between thermal conductivity and density

The regression results obtained in this study by Equation 8 confirm that the reduction in thermal conductivity of MDF mortar was related to a reduction in density. The incorporation of MDF reduced density and increased thermal insulation. In other words, the lighter mortar provided the better heat flow resistance.

$$K = 0.0008\rho + 0.3419 \quad (8)$$

Where K is the thermal conductivity of MDF mortar, ρ is the density.

3.6 Acoustic properties of Pretreated MDF mortar

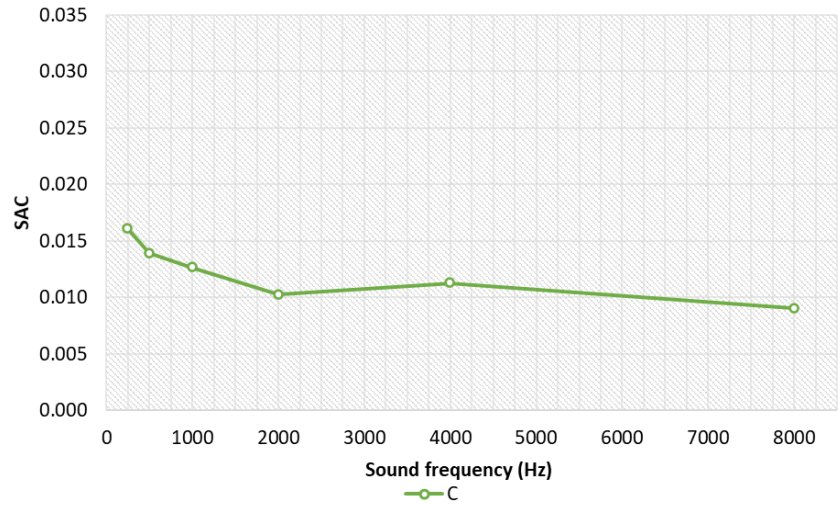
3.6.1 Sound absorption coefficient (SAC)

The SAC results of the control, untreated, and pretreated MDF mortars are shown in Fig. 15. The control mortar exhibited very low sound absorption over the tested frequency range, with SAC values of approximately 0.009-0.016.

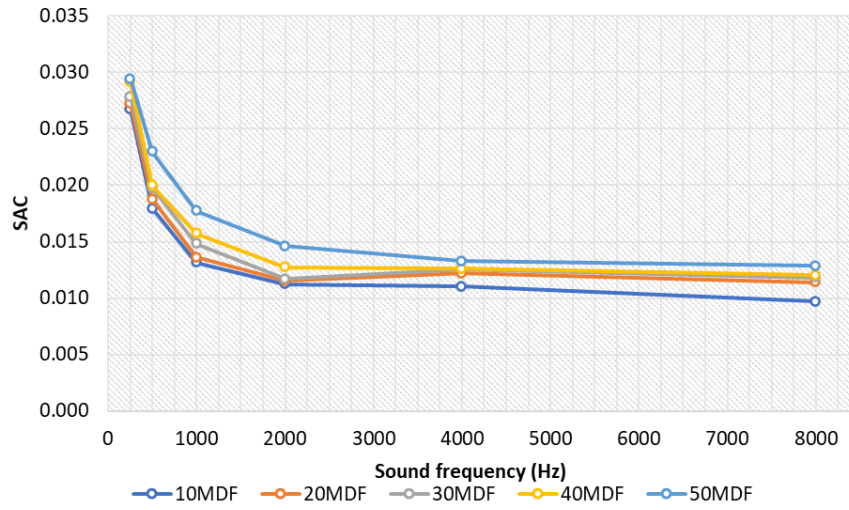
For the incorporation with MDF, all types of MDF mortars showed higher SAC than the control mixture at the same frequency. The SAC was highest at 250 Hz, then decreased with increasing frequency up to 1000-2000 Hz, and showed a stable trend around 4000 Hz. The results indicated the sound absorption behavior of MDF mortar was strongly influenced by frequency, and MDF effectively improved sound absorption occurring in the low-frequency range. The behavior of acoustic response for untreated and treated MDF mortars was governed by the internal pore structure and the ability of the material to dissipate incident sound energy through frictional and viscous losses within interconnected pores (Rodrigues et al. 2022; Moges et al. 2022).

Generally, the SAC tended to increase with increasing the MDF, MDFC, and MDFP content in mortar, which can be attributed to the greater amount of porosity introduced into the mortar matrix. This increasing tendency indicates that the addition of MDF generally improved the sound absorption performance of the mortar. This behavior occurred due to dense cementitious material, which is usually highly reflective and exhibits very low sound absorption, whereas the introduction of fibrous or porous materials can enhance the dissipation of incident sound energy (Amran et al. 2021). Similar improvements in acoustic absorption have been reported in cementitious materials incorporating porous natural fibers, the lignocellulosic fiber phase and pore structure increase viscous and frictional losses during sound wave propagation, thereby enhancing sound energy dissipation and improving acoustic performance (Amran et al. 2021; Kueh et al. 2023; Palomar et al. 2022; Petrella et al. 2022).

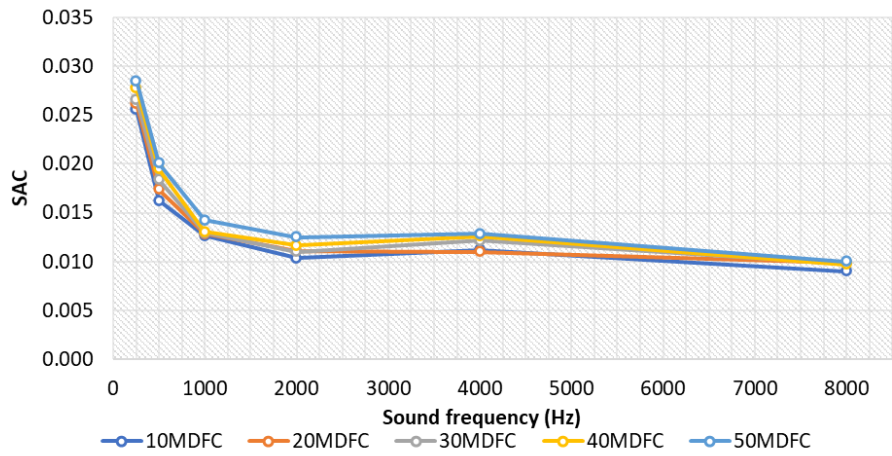
Compared with all types of MDF mortar, the untreated MDF mortar presented the highest SAC overall frequencies and MDF content, followed by MDFP and MDFC, respectively. These results related to the porosity of specimens, where the untreated MDF preserved a more porous structure by fiber, which promoted greater dissipation of sound energy within the mortar matrix. In contrast, the Portland cement-slurry pretreatment in MDFC coated the particle's surface and partially reduced the effectiveness of the pore structure for sound absorption. Similar to MDFP, the paraffin wax altered the surface condition and partially affected pore connectivity in MDF, leading to reduced acoustic performance but still allowed better acoustic absorption than MDFC.



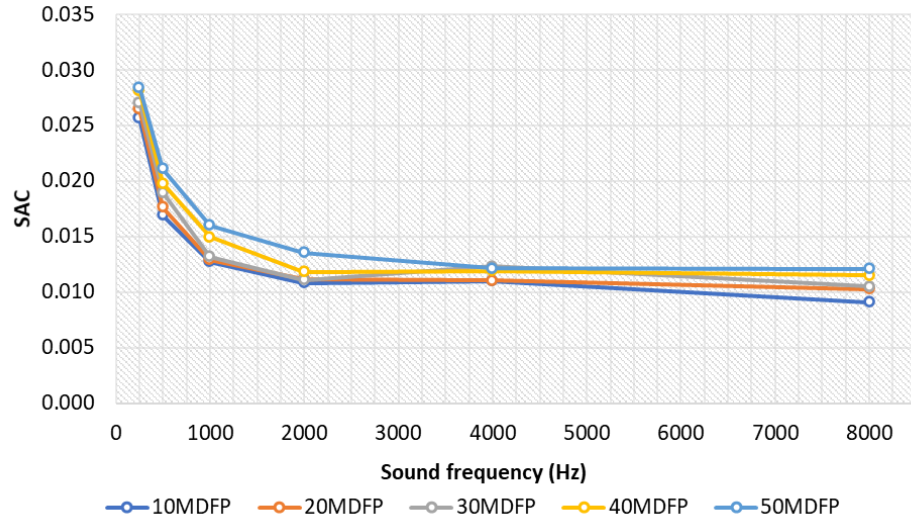
a) Control mortar



b) Untreated MDF mortar



c) MDFC mortar



d) MDFP mortar

Fig. 15 Sound absorption coefficient (SAC)

3.6.2 Noise reduction coefficient (NRC)

The noise reduction coefficient (NRC) is a scalar rating number used to measure the average sound absorption performance of a material. Therefore, the NRC of untreated and pretreated MDF mortar can be calculated from the average of the SAC values at 250, 500, 1000, and 2000 Hz as shown in Fig. 16. All-MDF mortar specimens exhibited higher NRC than the control mixture, indicating the incorporation of MDF improved the acoustic performance of mortar within the frequency range used for NRC evaluation. In general, the NRC tendency is consistent with the SAC results, which increase with increasing MDF content from 10% to 50%. The mortars containing untreated MDF performed the highest NRC, followed by MDFP, whereas the MDEC mixtures tended to the lowest NRC.

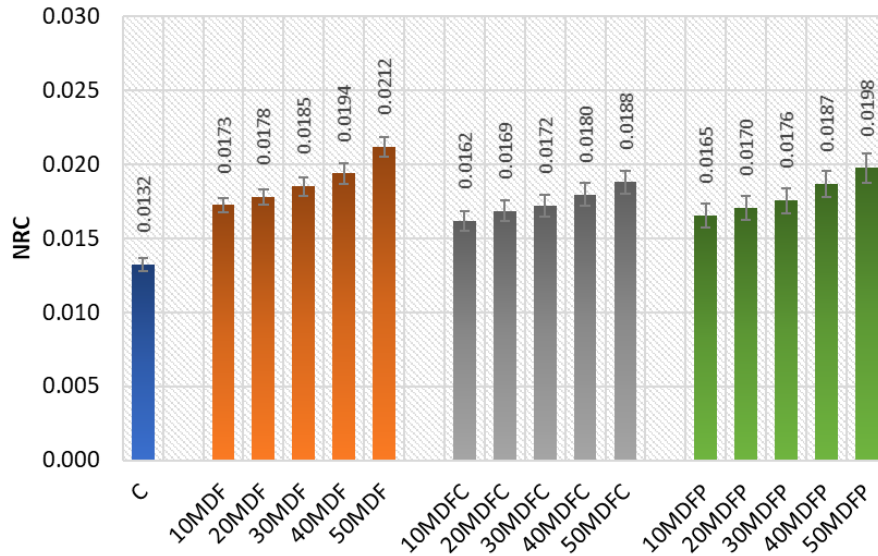


Fig. 16 Noise reduction coefficient (NRC)

These acoustic results support that the improvement in acoustic absorption in MDF mortar is closely associated with increasing internal porosity and reducing density. The average sound absorption represented by NRC tends to increase as the material becomes lighter and more porous. Equation 9 and Fig. 17 show the relationship between the noise reduction coefficient (NRC) and the density of the untreated and pretreated MDF mortars. This

regression analysis confirms that the acoustic performance of the MDF mortars was related to specimen physical structure. Lower-density mortars generally exhibited higher NRC because of the porous internal network, whereas denser mortars provided fewer sound energy absorption.

$$\alpha_{\text{MDF}} = -1.0 \times 10^{-5} \rho + 0.0391 \quad (9)$$

where α_{MDF} is the noise reduction coefficient of MDF mortar, ρ is the density.

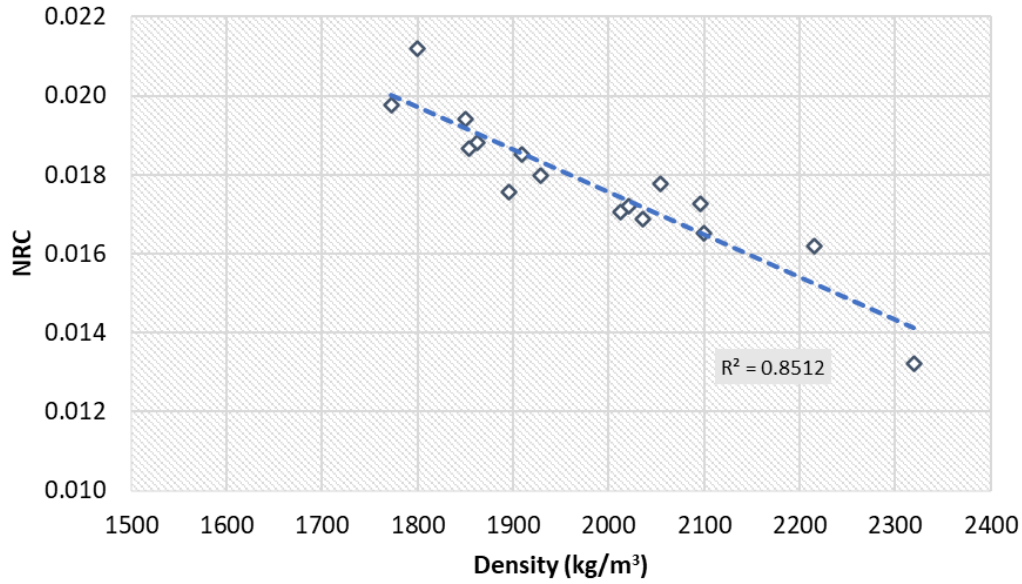


Fig. 17 Relationship between NRC and density

The acoustic properties results in this study also agree with studies on fiber-reinforced and bio-based cementitious materials, which have been reported to achieve higher sound absorption when the internal structure becomes more porous and less dense by a pore system that remains sufficiently open and interconnected (Chen et al. 2020; Wijesinghe et al. 2024). The mortar generally contains a higher volume of pores and entrapped air when the density decreases, which promotes greater dissipation of incident sound energy through viscous friction, multiple reflections, and tortuous wave path through the pore network. (Rodrigues et al. 2022; Yoon et al. 2020; Cao et al. 2018).

4. Potential applications

The experimental results indicate that both untreated and pretreated MDF mortars should be positioned primarily as non-structural or multifunctional cementitious materials rather than as load-bearing structures. Due to the increasing MDF content reduced workability and strength of mortar, but a trade-off with lightweight, an increase in thermal resistance, and sound absorption. Fig. 18 presents a comparative performance map of the three mortar mixtures containing 50MDF, 50MDFC, and 50MDFP by performance ratio compared to the control mortar.

MDFC showed the best performance in mechanical properties, particularly in compressive strength and flexural strength, which is consistent with the improved particle grading and stronger interfacial compatibility produced by the cement-slurry pretreatment. In contrast, untreated MDF exhibited the highest performance in thermal insulation and

sound absorption, as the results from the porosity of the MDF fiber. The MDFP mixture showed the greatest in lightweight effect and workability, but mechanical performance was the lowest.

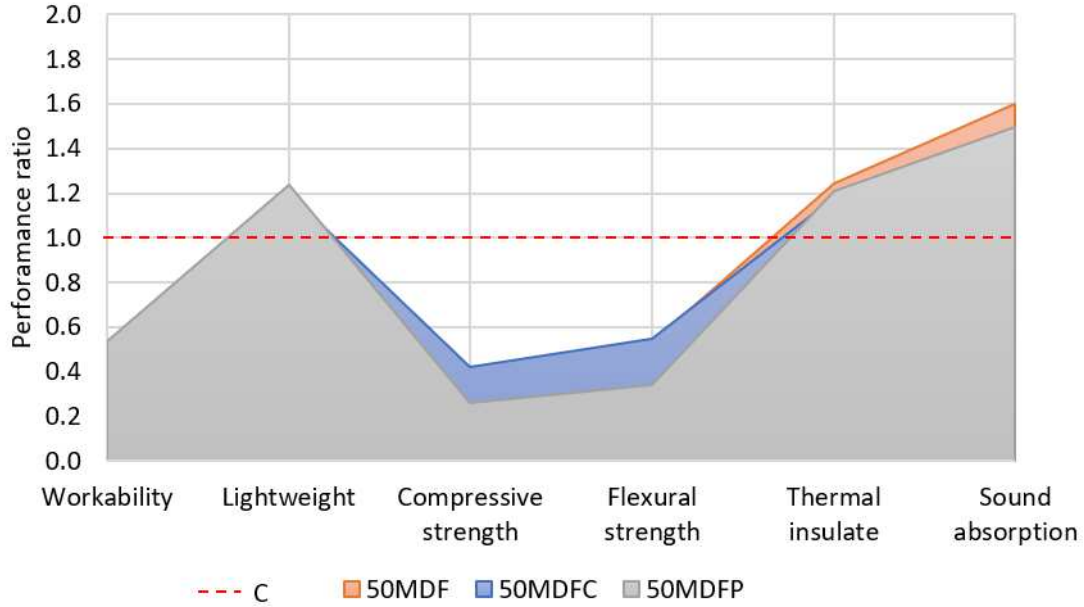


Fig. 18 Performance of mortar mixtures containing 50% untreated and pretreated MDF

The comparison in Table 5 confirms that the incorporation of MDF consistently reduces the workability and mechanical strength of mortar or concrete, while improving lightweight and thermal-insulation performance. However, the degree of trade-off depends strongly on the type of fiber, replacement or addition level, and pretreatment method.

Overall, the comparison indicates that the incorporation of mortars with recycled natural fiber is suited for non-structural and semi-functional building applications rather than for primary load-bearing elements. Those modified cementitious composites can be positioned as promising sustainable materials for lightweight architectural components or traditional baked clay brick with combined mechanical, thermal, and acoustic functions, bridging the gap between conventional mortar and highly insulating but mechanically weak bio-based cementitious composites.

Table 5. Comparison of the cementitious composites properties incorporating recycled natural fiber in the current and previous studies.

Research	Fiber type	Fiber content	Fiber-pretreated method	Cementitious composites properties				
				Unit weight Kg/m ³	Workability (%)	Compressive strength (MPa)	Flexural strength (MPa)	Thermal conductivity (W/m.K)
Current study	Medium-density fiber board	10-50% by cement weight	-	2,096 to 1,799	85.48 to 34.47	34.9 to 11.4	5.6 to 3.5	2.07 to 1.76
			Portland cement slurry coating	2,216 to 1,863	67.48 to 50.24	38.1 to 16.6	5.9 to 3.6	2.12 to 1.91
			Paraffin wax coating	2,100 to 1,773	69.22 to 53.87	20.3 to 10.4	4.9 to 2.3	2.10 to 1.85
Dias et al. (2022)	Wood chips	5-25 % by vol.	-	2,250 to 2,050	-	55.3 to 34.8	5.7 to 5.3	1.45 to 1.10

Research	Fiber type	Fiber content	Fiber-pretreated method	Cementitious composites properties				
				Unit weight Kg/m ³	Workability (%)	Compressive strength (MPa)	Flexural strength (MPa)	Thermal conductivity (W/m.K)
	Sawdust	5-25 % by vol.	-	2,260 to 2,190	-	63.7 to 57.9	5.4	1.80 to 1.60
Lin et al. (2025)	Waste wood fibers	0.6-1.2 % by weight of binder	NaOH treatment	-	76.92 to 18.17	67.3 to 50.0	8.0 to 6.3	-
Özkan et al. (2024)	Sawdust	25-100% by vol. (replaced silica sand)	-	1,580 to 1,034	92.14 to 35.71	3.56 to 1.77	1.5 to 0.9	0.33 to 0.28
Ma et al. (2025)	Recycled Wood Fibers	10-30% by vol.	Nano-silica modification	1,550 to 1,250	-	45.1 to 16.0	11.9 to 5.1	0.27 to 0.21
			Silane coupling agent modification	1,580 to 1,330	-	47.0 to 19.9	13.1 to 6.3	0.29 to 0.26
Gavela et al. (2025)	Wood shavings	30-70% (replacement aggregates)	-	2,104 to 1,714	-	45.0 to 27.0	10.1 to 9.4	1.90 to 1.10
	Wood sawdust		-	2,033 to 1,996	-	50.0 to 48.0	11.2 to 10.0	1.63 to 1.36
Petrella et al. (2022)	Wheat straw	6.4-12.2% by weight of cement	-	1,215 to 900	-	6.2 to 1.6	2.5 to 1.3	0.27 to 0.17
Kunchariyakun et al. (2022)	Wood fiber waste	1–5% by cement weight	Hot water	2,100 to 1,690	-	10.5 to 4.0	6.1 to 3.8	-
Özen et al. (2024)	Jute fibers	0.25 and 0.5 % by vol.	graphene oxide coating	-	96.15 to 76.92	63.0 to 59.0	7.1 to 5.0	-
Zhao et al. (2024)	Bamboo fiber	0.5-2% by vol.	-	-	76.00 to 58.00	105.0 to 80.0	13.5 to 9.0	-
Tuğluca et al. (2023)	Waste wood fiber	2.00% of total volume (replaced sand)	sodium hydroxide solution	-	-	46.3 to 43.5	-	-

5. Conclusion

This study investigated the use of untreated and pretreated waste medium-density fiberboard (MDF) as an aggregate in cement mortar. Due to the MDF exhibiting very high water absorption, reaching up to 245%, pretreatment was necessary before incorporation into the mortar mixtures. Two pretreatment methods were applied: Portland cement slurry coating and paraffin wax coating. The treated MDF was incorporated into cement mortar at a rate of 10–50% by weight of cement. The physical, mechanical, thermal, and acoustic properties of the mortar were evaluated. Based on the experimental results, the following conclusions can be drawn:

- The incorporation of untreated and pretreated MDF reduced the workability of mortar as the MDF content increased. Untreated MDF provided the lowest flowability at high addition levels, whereas pretreated MDF showed higher flowability.
- The density decreased progressively with increasing MDF content. MDfC aggregate exhibited the highest density due to improved particle grading and packing efficiency.
- The water absorption of mortar increased with increasing MDF content. Among the MDF-containing mortars, MDfP exhibited the lowest water absorption because the paraffin coating effectively reduced the hydrophilic behavior of the MDF particles.
- The mechanical properties of all MDF mortars were lower than those of the control mortar, and both compressive and flexural strengths decreased as the MDF content increased. MDfC mortar showed the

highest compressive and flexural strengths because the cement coating enhanced interfacial compatibility, improved particle shape and grading, and promoted more effective stress transfer within the mortar matrix.

- All types of MDF mortar showed lower thermal conductivity than the control mortar, and thermal conductivity decreased with increasing MDF content, which indicates improved thermal-insulation performance. Untreated MDF mortar showed the lowest thermal conductivity by association with porosity and entrapped air, which interrupted the heat-transfer path through the mortar.
- The MDF mortars improved acoustic performance with increasing MDF content. Untreated MDF provided the highest SAC and NRC values, with the porous fibrous nature of untreated MDF creating an internal structure for sound-energy dissipation.

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Statements and Declarations

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Authors' Contributions

Buchit Maho: Conceptualization, methodology, investigation, data curation, formal analysis, visualization, and writing – original draft. Phattharachai Pongsopha: Investigation, validation, and writing – review and editing. Darrakorn Intarabut: Validation. Piti Sukontasukkul: Methodology, supervision, project administration, and writing – review and editing. All authors reviewed and approved the final manuscript.

Ethical Approval

This is not applicable.

Consent to Participate

This is not applicable.

Consent to Publish

This is not applicable.

Competing Interests

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.

Data Availability Statement

The data generated and analyzed during the current study are included in this article. Further inquiries can be directed to the corresponding author.

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