Effect of Wood Dust Particles on Physical and Mechanical Properties of Gypsum Particulate Composite

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Abstract

Gypsum is widely recognized in the construction industry for its favorable attributes, including fire resistance, thermal insulation, and workability. However, its broader application is often hindered by inherent drawbacks such as brittleness, low mechanical strength, and limited moisture resistance. In response to these challenges—and in alignment with global efforts toward sustainable material development, this research proposes the integration of wood dust, a biodegradable and abundantly available byproduct of wood processing, as a reinforcing filler. Composites were formulated with wood dust at varying weight fractions (0wt%, 15wt%, 30wt%, and 45wt%) and were fabricated through a standardized process of mechanical mixing, molding, and oven curing. Mechanical properties, specifically flexural and compressive strength, were evaluated in accordance with ASTM standards, alongside density assessments to determine the impact of filler content on material weight. The findings present compelling evidence that the addition of wood dust significantly reduces composite density, enhancing the lightweight nature of the material desirable feature in many construction applications. Notably, a filler content of 15wt% yielded the most favorable mechanical performance, with flexural strength increasing by 34.7% (from 3.34 MPa to 4.50 MPa) and compressive strength improving by 21.5% (from 6.68 MPa to 8.10 MPa). However, higher concentrations of wood dust (30wt% and 45wt%) led to a decline in mechanical performance, attributed to increased porosity and the disruption of mineral matrix continuity. These results underscore the importance of optimizing wood filler content to balance mechanical strength with material efficiency.

Keywords
Gypsum, Wood dust, Particulate composites, Bio-fillers and Weight fractions.

1. Introduction
Gypsum is considered white plaster. Now a days gypsum frequently replaces the traditional plaster materials in making pillars, home décor plasterboards etc. But gypsum is a brittle material. Products made with pure gypsum are brittle in nature. So, a lot of research has been done to modify gypsum made products by different types of fillers and fibers to increase the mechanical and physical properties. In this thesis work, wood dust bio filler is used to modify gypsum composites. As in the present world, environmental safety is a great issue so eco-friendly fillers are the main

consideration in this work. At the same time, the bio filler is ecofriendly and biodegradable and cost efficient. Wood dust filler will be added in four different proportions to make 4 different composites, and their physical and mechanical properties will be checked whether they exhibit good results compared to the traditional gypsum made products.

1.1 Objectives
In this research, different proportions of wood dust fillers are incorporated in gypsum composites, and the prepared composites are characterized for physical and mechanical properties.
The specific objectives of this research work are to-
- To fabricate the gypsum composites using a bio-fillers (Wood dust) by hand layup method.
- To investigate the physical properties of the prepared composites.
- To investigate the mechanical properties of the prepared composites.

2. Literature Review
Studies have been done on gypsum composites modified by different fillers for better mechanical strength and durability. K Regulska et al. investigated physical and mechanical properties of gypsum composites by adding organic straw filler in it. He mainly focused on the gypsum mixture composition, strength and thermal properties. The results were quite interesting. Fillers were added to the ratio of 2-6% compared to gypsum mass. When the compressive strength was 2MPa on average. It rarely reached 3MPa. When the water-gypsum ratio is 0.8, it showed higher strength. When around 30mm straw fillers were used, the bending strength became higher. Mineralization with calcium hydroxide was more favorable than mineralization with calcium chloride. The filler percentage must not be higher than 3% compared to gypsum mass (Petropavlovskaya et al., 2018). Victoria Petropavlovskaya et al. investigated physical and mechanical properties of the gypsum composites by adding basalt dust into it. The strength, density, water absorption after adding filler were checked here. Here basalt particle size was determined by laser diffraction. Water content varied from 0.36 g/cm3 to 0.375g/cm3. In this paper, it was noticed that the greatest bending strength is 7.96MPa and average density is 1697kg/m3. Compressive strength was also maximized by adding 10% basalt dust into it. Water must be kept around 0.365 more or less than this water content, different problems raised like, for excess presence of water, it didn't take part in any hydration process. For this reason, porosity was increased(Petropavlovskaya, Novichenkova, & Petropavlovskii, 2020). Victoria Petropavlovskaya et al. investigated whether glass granules are feasible for use in building material or not. The strength of the building is generally increased by adding glass particles. Also, this is an eco-friendly process. Water solid ratio must be kept in right amount which is from 0.6 to 0.62. The gypsum-reinforced composites with the addition of glass granules have an average strength of 11MPa at a density of 858 kg/m3 without adding chemical modifiers. Marketa Hostalkova et al. investigated whether gypsum composite with the addition of wood fiber is usable for building material or not. Wooden fiber is available and recyclable. It has lower thermal conductivity than straw fillers, so it works as a good insulator. Also, it is ecofriendly and economically advantageous. Dry ingredients were mixed in different proportions and mixed with 750mL water for 3 minutes and was placed in steel mold. Mold was removed after 24hrs and was in kept in rest for 7 days in 23.9°C. Among the samples, which had low proportion of wooden fiber, were totally damaged in center. But the samples which had high proportion of wooden fiber, had one crack in the center. Maximum flexural load was 2248N and minimum flexural load is 900N. Maximum compressive strength was 11.79MPa(Hošťálková et al., 2019). Large amount of wooden fiber reduced compressive and flexural strength. To improve compressive strength thinner stalk may be used and to improve flexural strength, longer stalk may be used (Fantilli et al., 2021).

Alessandro P. Fantili et al. explored the mechanical properties of the gypsum composite by adding bio fibers into it. Sheep wool fiber and hemp fiber were used throughout this research. Because of the high adhesion at the interface of the fiber and gypsum matrix, wool fiber showed better mechanical performance than hemp fiber. As well as this process is ecofriendly too. The fracture toughness is larger in wool fiber than hemp fiber. On the other hand, hemp fiber showed good crystallinity. But gypsum modifies the surface of wool fibers because it is covered completely by crystals (Ulubeyli et al., 2017). G.N Pervyshin et al. explored the modification of gypsum composite by adding manmade fillers, metallurgical dust and multi walled carbon nanotubes in it. By adding these fillers, the bending and compressive strength increased noticeably, which are 70.5% and 138% correspondingly. Metallurgical dust increases the pH value of the medium. By adding metallurgical dust, primary gypsum crystals formed amorphous soluble compounds based on calcium and aluminum hydro-silicates which bind the gypsum crystals in large block aggregates and protects them from water. By increasing the strength of contact, a dense structure of solid gypsum is formed. Thus, the mechanical and physical properties were enhanced (Pervyshin et al., 2017).

Tolosa et al. investigated the physical and mechanical properties of gypsum composites by adding lime mud waste as a filler into it. 5%, 15%, and 25% of lime in proportion to gypsum was added for the tests of gypsum composites. This showed the result that flexural strength of gypsum after 21 days was 5.7MPa compared to 5.4MPa for G/LM5 (LM at 5%), the mean particle diameter was 6μm. After adding 25% of lime mud into gypsum, the results are: compressive strength of 9.6MPa (≥8.3MPa recommended), axial compressive strength of 8.5MPa (≥6.0MPa recommended) and flexural strength of 3.7MPa (≥2.0MPa recommended). Gomes looked over the mechanical performance, water resistance of gypsum composites by adding dispersible polymer as filler into it. Also, the influence on microstructural formation and on the bending performance was assessed. At the same time, it had been investigated too. 5% and 10% polymer in proportion to gypsum composite had been added as filler and water gypsum ratio must be kept 0.6. The addition of polymer and reduction of water gave more robust material. And mechanical performances were enhanced too (Gomes et al., 2019). V. Petropavlovskaya et al. focused on micro-fillers in combination with gypsum, to reduce the weight of gypsum composites. The focus of micro-fillers is on skin layer so that it can boost collagen and hydration. The main goal is to reduce weight of gypsum and enhance mechanical properties. By increasing the water content, the tensile strength decreases and density decreases too. Thus, the weight of gypsum reduced. Addition of water has the positive effect shown in this research. When the micro-filler percentage is 10%, it showed the best result as a filler in gypsum composite (Petropavlovskaya, Novichenkova, Petropavlovskii, et al., 2020). Selamat et al. explored the modification of gypsum composite by adding oil palm tank and rice husk into it. Both showed almost similar results. The rice husk gave more ash content than oil palm tank. As a result, it showed better performance in fire retardancy. On the other hand, lipid content in oil palm tank is higher than rice husk. Finally, the mechanical properties of the OPT/gypsum composite showed an excellent performance in comparison to the RH/gypsum composite (Selamat et al., 2019).

Wang et al. investigated the mechanical properties of gypsum composites by adding graphite as filler into it. The tests were performed by adding varying graphite content ranges from 0% to 25%. The addition of graphite increased the bulk density, and thermal conductivity of the samples to 19% and 97% respectively. But the use of plasticizers causes reduction in bulk density and thermal conductivity. The emissivity increases from 6.1% to 10.3% with graphite addition. Graphite gypsum plastic boards reduce thermal flux 6%-54% which means that it became a very good thermal radiant board (Wang et al., 2017). M Sophia et al. studied zeolite and bio-carbonate fillers (waste shell powders) as fillers to add with gypsum to enhance strength and stability. Natural zeolite combined with waste shells enhanced water hydration as it worked as an internal curing agent. It allowed large amounts of water absorption. Calcined zeolite worked as densifying agent and enhanced the water stability. It also reduced porosity (Sophia & Sakthieswaran, 2019). Guozhong et al. studied cotton stalk fiber and improved it by styrene acrylic emulsion which showed better mechanical properties. Addition of styrene emulsion made the matrix of the composite more flexible to strength and improved the water-resistant property (Li et al., 2003). Abou-bakr Cherki et al. focused on the improvement of thermal properties and lightness of gypsum plaster. The cork gypsum board used as false ceiling instead of plaster boards having improved thermal properties, making the building more efficient. In this paper, it's also shown that gypsum- cork board reduced thermal conductivity 3 times more than with cork in gypsum board (Cherki et al., 2014). M.Arikan et al. focused on adding different types of admixtures to improve compressive strength, consistency, setting time etc. This paper also covered the stepwise optimization approach to assess the composition of gypsum based composite material (Arikan & Sobolev, 2002). Natalia Chernysheva et al. mainly focused on thermal powerplant waste on the hydration process and focused on the gypsum cement binder composition. After 28 days of curing the binder, the physio-mechanical properties were improved (Chernysheva et al., 2020).

Ali Karaipekli et al. added phase change materials to the building materials to use them as low temperature thermal storage and can be used as solar heating, air conditioning purposes in building purposes. Three types of stable form composite materials were made by absorption of capric palmitic acid eutectic mixture, dodecanol and heptadecane. In this work, the FS-CPCMs were initially tested as plasters, which is comparable to large-scale building applications. Thermal performance experiments revealed that gypsum plasters with FS-CPCMs can improve thermal comfort while maintaining the indoor environment comfortable (Karaipekli & Sarı, 2016). Krzysztof Powala et al. investigated the building problems such as thermal insulation properties, mechanical properties etc. and modified gypsum composite with paraffin and polymer. Use of phase change materials is quite costly so polymer and paraffin can be great alternative to PCM. The best result showed by mixing 0.1% polymer content with gypsum. The experiments that use drying, hardening time, and paraffin absorption clearly showed it. While it is comparable in terms of volumetric heat capacity and differs little from the best result in the thermal diffusivity test, it deviated slightly from the best result in the thermal conductivity test (Powała et al., 2021). Q.L. Yu et al. focused on beta hemihydrate which is used as binder and lightweight aggregate. Thermal behavior and mechanical properties are observed at an elevated temperature. The

newly prepared composite showed better performance than traditional gypsum plasterboard (Yu et al., 2013). Zaki Ajji et al. prepared gypsum composites based on different doses of gamma radiation. They studied the mechanical properties and different doses of gamma radiation on the composites. As the irradiation dose is increased, the glass transition temperatures of the pure polymer and the composites both rise until they reach a plateau, with the pure polymer's glass transition temperature being lower than that of the composites. In distilled and alkaline medium, soaking experiments reveal that the weight of composites does not change, but after 1560hrs, there is a slight drop in acidic medium of about 3% (Ajji, 2005). In this work, the weight of gypsum composite will be reduced by adding wood dust filler and the prepared composites will be characterized for physical and mechanical properties.

3. Methodology
3.1 Gypsum Powder
In the current study, Gypsum, a soft sulphate mineral, was used as a building material after its modification. The raw material was composed of calcium sulphate dihydrate with a chemical formula of $CaSO_4.2H_2O$. It has been widely used as a fertilizer and has various other uses including plaster, blackboard, sidewalk chalk, and drywall. Gypsum is known for its moderate water solubility of approximately 2.0–2.5gm/L at 25°C. During the experiment, refined gypsum, which contained no water, was used, also known as $CaSO_4$. This type of gypsum consisted of 29.4% Calcium and 23.5% Sulfur (Figure 1). On the other hand, gypsum associated with water ($CaSO_4.2H_2O$) contained 23.3% Calcium and 18.5% Sulfur. It was found that the composition of gypsum could significantly impact its performance as a building material, and its properties could be enhanced through careful modification (Sophia & Sakthieswaran, 2019).

Figure 1. Gypsum powder

3.2 Wood Dust
In this work, a biodegradable and eco-friendly filler, namely wood dust was used. For the filler, a fresh piece of wood was taken from sawmill and dried before being placed into the machine. Wood dust was then prepared from this specimen, which was subsequently dried again in the sunshine to ensure its dryness. To obtain optimal performance in the tests, it was important to ensure that there was no presence of water in the wood dust. The wood dust was then further refined to improve the performance of the prepared composite. The use of such environmentally friendly fillers in this study aimed to reduce the environmental impact of the composite material. It was then further refined for better performance of the prepared composite (Figure 2).

Figure 2. Wooden Filler

3.3 Frame Making
Distilled water is a type of purified water that has gone through a process of distillation to remove any impurities and minerals that may be present in regular tap water. The process of collecting distilled water is done by using a distillation apparatus, which is comprised of a boiling chamber and a condensing chamber. The water is first placed

in the boiling chamber and heated to the point of boiling. As the water boils, steam is created which rises and passes through a cooling system that causes the steam to condense back into liquid form. The liquid that is collected in the condensing chamber is then considered to be distilled water. The collection process of distilled water can be done in several ways, depending on the distillation apparatus being used. One common method is through the use of a separate collection flask that is attached to the condenser, which collects the distilled water as it drips down. Another method is by using a built-in collection system, which allows the distilled water to be collected directly from the distillation apparatus. The collected distilled water is then stored in a clean and dry container until ready to use. The collection of distilled water is crucial in many industries, including pharmaceuticals, laboratory research, and also in this study.

3.4 Mold Frame
A glass frame was prepared in local market to make the samples. The dimension of the frame was 200mm×200mm and thickness was 12mm. It was connected by glue so that after making of one sample it can be removed and new sample can be made in the same mold (Figure 3- Figure 16).

Figure 3. Mold Frame

3.5 Fabrication of Composite
In the process of preparing the composite, 600g of raw gypsum powder was first measured using a weight machine. For first sample 0% wood dust is required. Wood dust fillers used in the rest of the samples in this experiment, wood, was measured in a mug using the same weight machine. Measured wood dust fillers weight for the 2nd, 3rd, and 4th
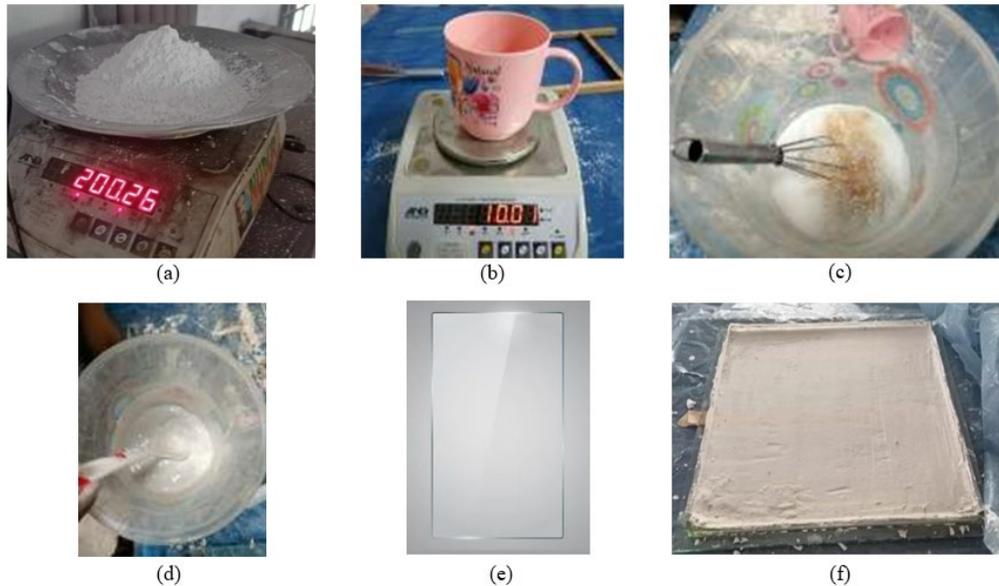

Figure 4. (a) Gypsum powder, (b) Wooden filler measurement, (c) Dry mixture of gypsum and wood, (d) Water addition to dry the mixture, (e) Glass, (f) Final dry sample

samples are 90g, 180g and 270g respectively. The dry mixture of the gypsum and wood was then properly blended to form a uniform mixture. Next, 360g of pure water was measured and added evenly to the dry mixture.

Figure 5. Final samples made with filler

Continuous stirring of the mixture was carried out using a spoon to achieve the desired consistency, which was then ready to be poured into the mold. The mold was filled with the mixture, and it was then placed in a vacuum chamber to remove any air bubbles, and finally, it was left to dry in the oven at 80°C for 24hrs. After 24hrs, by removing the screws, the sample was demolded. In this same procedure, the molds for 0% wood, 15% wood dust, 30% wood dust, and 45% wood dust were made (Table 1).

Table 1. Mixture Component

Composite	Gypsum Content		Wooden Filler Content		Water Content
	by wt%	by weight	by wt%	by weight	by weight
0wt%	100%	600g	0%	0g	360g
15wt%	85%	510g	15%	90g	360g
30wt%	70%	420g	30%	180g	360g
45wt%	55%	330g	45%	270g	360g

3.6 Test Specimen Preparation

A setup was prepared to cut the sample specimens precisely. A setup which is consisting with motor, cutter, power transmission belt, metal frame was made to cut all the samples equally and precisely. A wooden block was set from
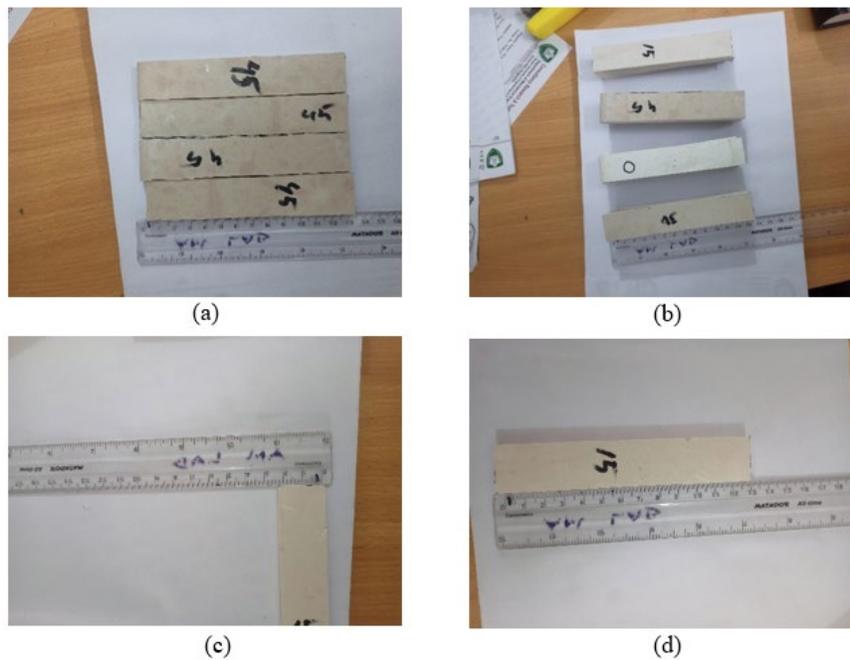

Figure 6. Prepared setup to cut the sample

Figure 7. (a) – (d) Sample after cutting in the setup prepared for flexural Test

the cutter at a distance of 25mm. When the switch was on then motor was rotating and the belts attached to it transmitted the power from motor to the cutter pulley. As a result, the cutter started rotating and when the sample was passed between the cutter and wooden block, samples were cut at 25mm width. The approximate dimension of these samples is: 25mm×130mm×7.5 mm. These sample were sent to the UTM (Universal Testing Machine) machine for flexural test.
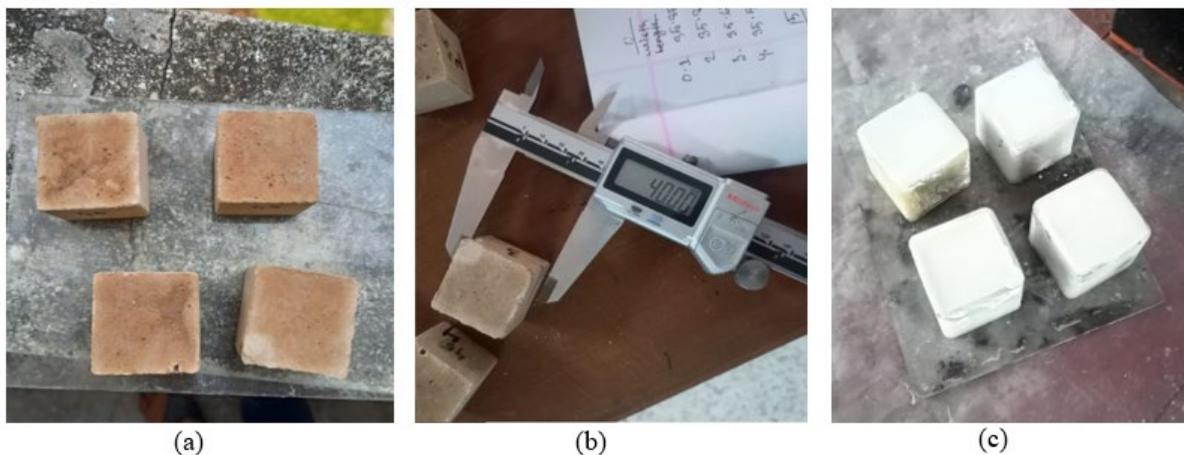

Figure 8. (a) – (c) Samples after cutting in the setup prepared for compression test

The approximate dimension of these samples is: 40mm×40mm×40mm. These samples were cut to perform compression test in UTM (Universal Tensile Machine).

4. Testing Mechanical Properties
4.1 Flexural Test
All kinds of composites were subjected to a flexural test. Figure 9(b) depicts the geometry. The test was carried out using a Universal Testing Machine in accordance with ASTM-D790 (Ganesh Gupta K et al., 2021). The maximum stress encountered inside the substance at the point of yield is indicated by the flexural strength.

$$\sigma = \frac{3FL}{2bd^2} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (1)$$

$$\epsilon = \frac{6Dd}{L^2} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (2)$$

Here,

σ = Stress in outer fibers of midpoint (N/m2)
ϵ = Strain in the outer surfaces
F = Load at the midpoint of the specimen (N)
L = Specimen length (m)
b = Specimen width (m)
d = Specimen thickness (m)
D = Maximum deflection of the center of the specimen (m)

According to ASTM-D7264 the length of the Flexural test specimen should be,

$$L = d \times 32 + (d \times 32) \times 20\% \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (3)$$

(a)   (b)

Figure 9. (a) Geometry of the specimen for flexural test, (b) Flexural test in UTM

4.2 Compressive Test

The compressive strength of a material is the maximum amount of compressive stress it can withstand before breaking. This characteristic is essential in assessing the suitability of a material for mechanical or structural purposes. To determine compressive strength, the material is subjected to a compressive load using a hydraulic press or a universal testing machine on a cylindrical or cubic specimen. The point at which the specimen fails or deforms is recorded as
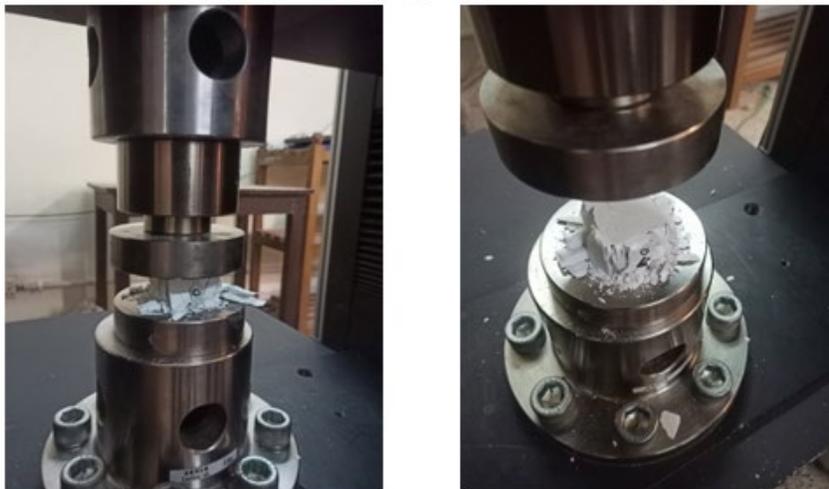

Figure 10. Samples after compressive test

the maximum load, which indicates the compressive strength. The compressive strength is typically measured in pounds per square inch (psi) or megapascals (MPa).

The results of a compressive test can be utilized to compare the strength of different proportions materials and to choose the most suitable one for a specific application. However, compressive strength is only one of several factors to be considered when selecting a material for a particular purpose. Other important characteristics that need to be taken into account include the material's tensile strength, hardness, ductility, and fatigue resistance.

$$\sigma_c = \frac{F}{A} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Here, $\sigma_c =$ Compressive Stress
The prepared gypsum composites will be placed in the Universal Testing Machine and compression tests will be done according to the ASTM C365 standard. The crosshead velocity is 5 mm/min.

5. Experimental Data and Calculation
5.1 Experimental Data for Flexural Test

$$Density = \frac{Mass}{Volume} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (5)$$

$$Max.Sp.Flexural\ Stress = \frac{Max.\ Flexural\ Stress}{Density} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (6)$$

Table 2. Raw data from flexural test

Sample Name	Thickness (mm)	Width (mm)	Length (mm)	Mass (g)
Gypsum (Base)	6.60	25.26	130	27.03
15wt% Wood	7.10	24.21	130	25.91
30wt% Wood	9.20	23.88	130	32.04
45wt% Wood	8.08	25.57	130	29.49

Table 3. Calculated data from flexural test

Sample Name	Density (kg/m³)	Max. Flexural Stress (MPa)	Max. Specific Flexural Strength
Gypsum (Base)	1247.14	3.34	2.88
15wt% Wood	1159.28	4.50	4.01
30wt% Wood	1122.03	4.34	3.48
45wt% Wood	1097.97	3.18	2.90

5.2 Experimental Data for Flexural Test

$$\sigma_c = \frac{F}{A} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (7)$$

Here,
Compressive Stress = σ_c
F = Force
A = Cross sectional area.

Table 4. Raw Data from compressive test

Sample Name	Width (mm)	Length (mm)	Thickness (mm)	Mass (g)
Gypsum (Base)	35.74	36.16	35.69	54.95
15wt% Wood	36.17	35.54	35.92	53.09
30wt% Wood	35.95	36.30	36.08	52.72
45wt% Wood	35.78	36.58	35.78	50.20

Table 5. Calculated data from compressive test

Sample Name	Density (kg/m^3)	Max. Compressive Stress (MPa)	Max. Specific Compressive Stress
Gypsum (Base)	1191.26	6.68	5.81
15wt% Wood	1149.73	8.12	6.82
30wt% Wood	1119.70	6.80	6.07
45wt% Wood	1071.93	5.35	4.99

6. Result and Discussion

In this experiment, a bio filler was used to make gypsum composites in different composition. Filler is: wood dust. They were mixed in three percentages 15wt%, 30wt% & 45wt%. Four compositions (with base gypsum) showed different types of mechanical strengths and properties. Flexural test and Compression test had been carried out to find mechanical properties (Table 2- Table 9).

6.1 Flexural Test for Gypsum Base Composite

In a frame, dimension of 200mm×200mm had been used to make raw sample of gypsum. 600g gypsum powder and 360g water had been used to prepare this sample. The solid block of gypsum then tested in the UTM (Universal Testing Machine) and the bending test had been performed. The data had been taken until the sample was broken. After collecting all data from the program, load Vs displacement graph had been plotted in Microsoft excel.
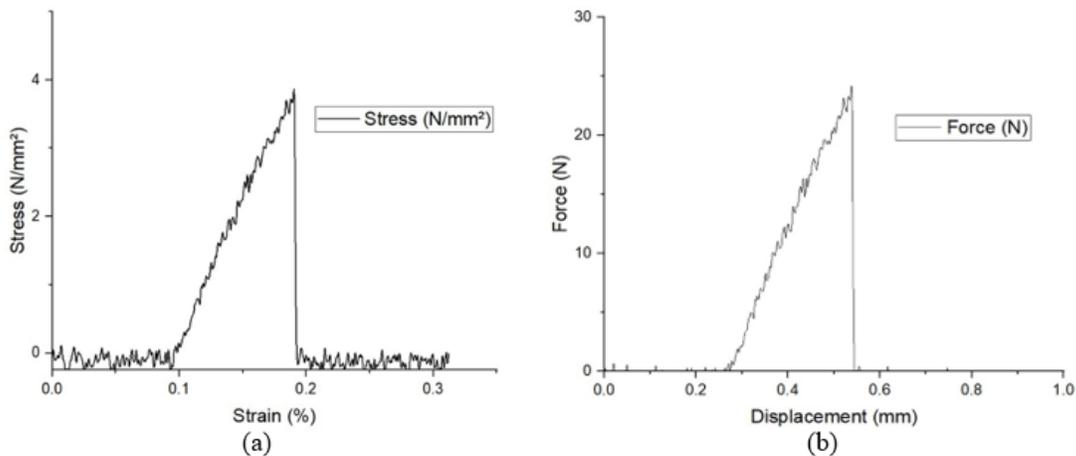

Figure 11. (a) Stress vs Strain graph for solid gypsum block, (b) Load vs Displacement graph of solid gypsum block

In the graph 11(b), it is seen that with the curve first developed and the load had been increased until it reaches the maximum stress termed Ultimate Flexural Strength, at which point the block of solid gypsum had been broken. The bending test actually shows the ultimate point that a material can withstand with the load. When the load had been exceeded the maximum load, the gypsum block had been broken. This showed the sudden decrease in load in the graph. And the material had been displaced a little bit without any load on it. The maximum flexural stress of the solid gypsum block is 3.34MPa.

Table 6. Results of the flexural test of gypsum composite

Sample Name	Density (kg/m³)	Max. Flexural Stress (MPa)	Max. Specific Flexural stress
Gypsum	1247.14	3.34	2.88

6.2 Flexural Test for Gypsum Composite with Wood Dust Mixture

Wood dust had been mixed with gypsum in three proportions to form four composites having different types of material properties. These three composites showed different results than the traditional gypsum block. Also, these three composites showed different properties varied from each other. Their breakdown points are also different. Taking all data from the experiment, the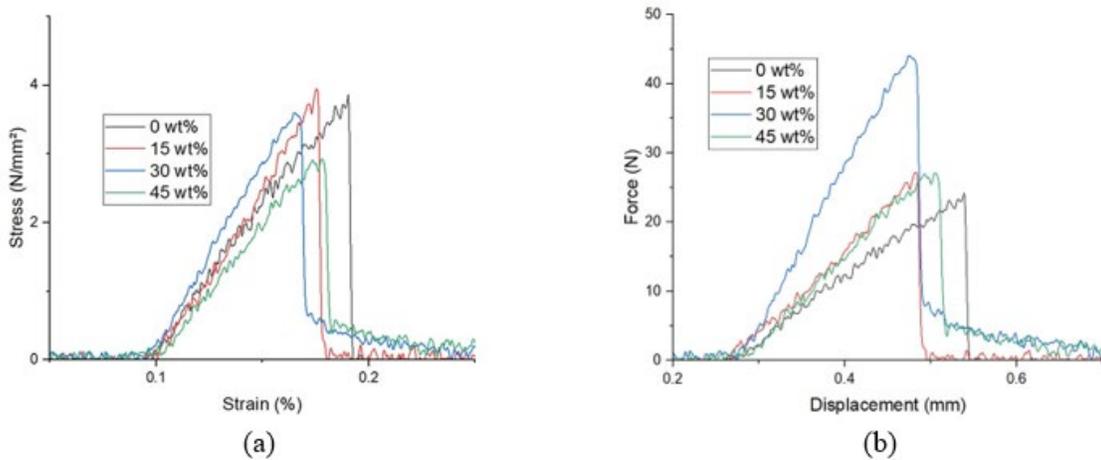 both graphs had been plotted in Microsoft excel which is shown. Figure 12. (a) Stress Vs Strain Graph of gypsum with wood for flexural test, (b) Load Vs Displacement graph of gypsum composite with wood

It is seen that the composite consisting of 15wt% of wood particles have the highest load bearing capacity. But its stroke length is small. Other composites containing 30wt%, 45wt% of wood particles have the similar kind of load bearing capacity which is less than the gypsum composite containing 15wt% of wood (W15). But composite W15 has the smaller stroke. That means it had been undergoes less deformation before rupture than the three other composites.

Table 7. Results of the gypsum composite with wood

Sample Name	Density (kg/m³)	Max. Flexural Stress (MPa)	Max. Specific Flexural Stress
0wt%	1247.14	3.34	2.88
15wt%	1159.28	4.50	4.01
30wt%	1122.03	4.34	3.48
45wt%	1097.97	3.18	2.90

Figure 12. (a) Stress Vs Strain Graph of gypsum with wood for flexural test, (b) Load Vs Displacement graph of gypsum composite with wood

6.3 Comparison of Pure Gypsum and Filler Added Composite

From the above discussion it is clear that the flexural stresses of the composites are almost same as the pure gypsum block. But from the observation during experiment, it had been observed that pure gypsum block has properties that are similar to the brittle materials. When it had been exceeded the maximum load, it broke down suddenly. The cracking and breaking of material are almost at a shortest distance which are similar as brittle materials. But when the of composites had been cracked at the same flexural stress but it broke after a while. That means the cracking fillers

had been added to the pure gypsum, it reduced the brittleness of the material. The block and breaking time are at a considerable distance which increases the ductility of the material.

The flexural-strength plot shows a clear composition-dependent trend: strength rises from 3.34MPa for neat gypsum (0wt%) to a maximum of 4.50MPa at 15wt% wood dust, then declines to 4.34MPa at 30wt% and 3.18MPa at 45wt%. Thus, the best bending capacity occurs at an intermediate loading (≈15wt%), representing a +34.7% gain over the baseline; 30wt% still outperforms neat gypsum (+29.9%), while 45wt% falls slightly below the baseline (−4.8%). The modest error bars indicate reasonably tight scatter, suggesting the observed ordering (15 % > 30 % > 0 % ≳ 45 %) is robust. Mechanistically, small additions of wood dust promote crack-path tortuosity and limited particle pull-out/bridging, which elevates peak load; as the filler fraction increases further, rising porosity and disrupted mineral continuity counteract these benefits, producing the downturn at high content.
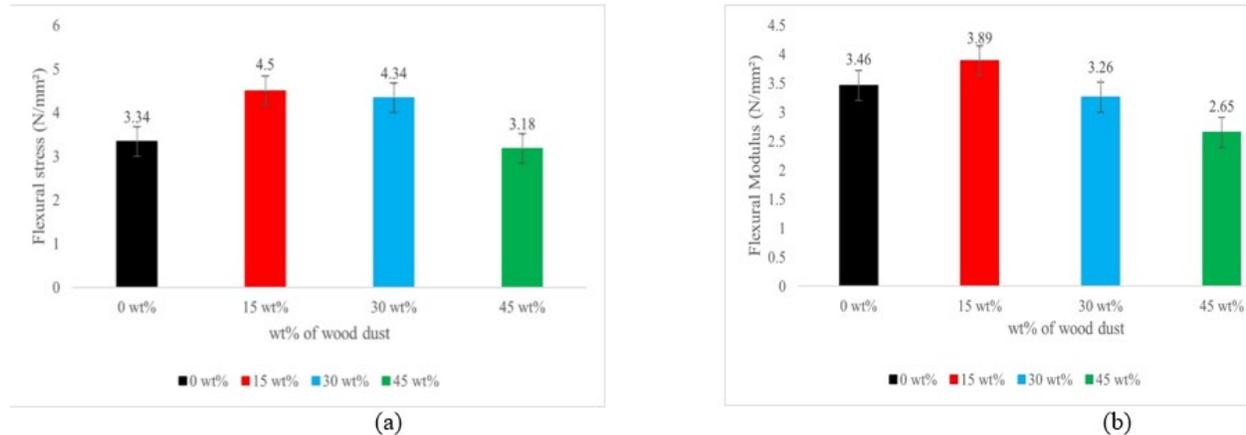

Figure 13. (a) Comparison of composites and solid gypsum, (b) Comparison of composites and solid gypsum

The "bending modulus" plot exhibits a similar but softer peak: stiffness increases from 3.46MPa to 3.89MPa at 15wt% (≈+12.4%), then drops to 3.26MPa at 30wt% and 2.65MPa at 45wt% (≈−23.4% vs baseline). This behavior is consistent with the microstructure: at low–moderate loadings, improved microcrack control can slightly stiffen the initial response, whereas at higher loadings the much lower intrinsic stiffness of wood and the increased void content make the composite more compliant. For reporting clarity, specify in the caption that the modulus was obtained from the initial linear slope of the load–deflection curve using standard three-point-bending geometry. Taken together, the figures imply that ~15wt% wood dust offers the best balance for bending—maximizing strength and maintaining the highest stiffness before both metrics deteriorate at 30–45wt% due to porosity growth and loss of mineral continuity.

6.4 Compressive Test for Gypsum Base Composite

In a frame, dimension of 200mm×200mm is used to make raw sample of gypsum. 600g gypsum powder and 360g water has been used to prepare this sample. The solid block of gypsum then tested in the UTM (Universal Testing Machine) and the compression test has been performed. The data has been taken until the sample is broken. After collecting all data from the program, load Vs displacement graph has been plotted in Microsoft excel. The compression curve shows three regions of material. Elastic region, plastic region and ultimate strength or failure region. At the elastic region, the graph has increased rapidly, and displacement is proportional to the force. When the load has been removed, the material regained its shape. After the elastic region, the curve has been decreased a little because of energy release. But when the material has reached the ultimate strength, the graph again increased rapidly as it moves towards to the rupture point and material has been broken. A solid gypsum powder-based block can't take much load after compression, and it shows the properties of brittle material.
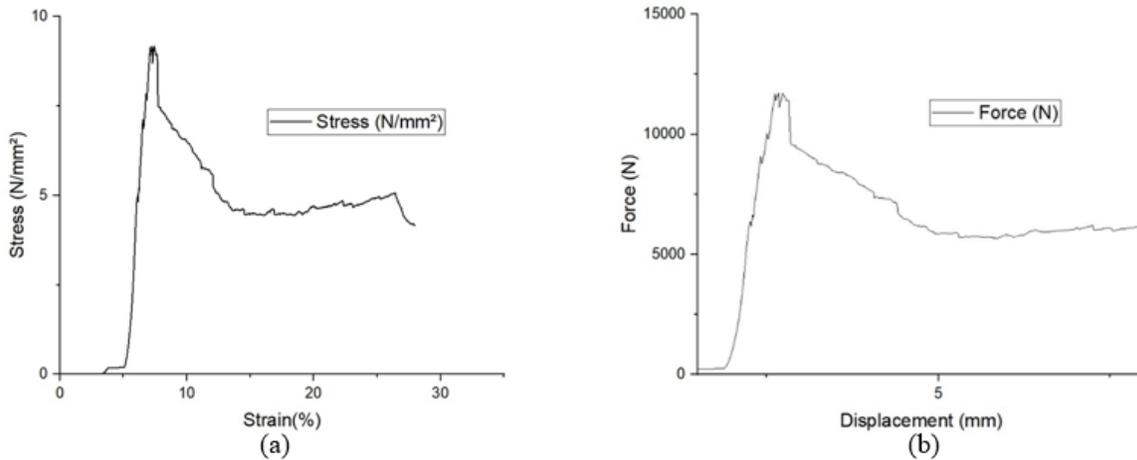
Figure 14. (a) Stress Vs Strain Graph of gypsum for compressive test, (b) Load Vs Displacement graph of gypsum

Table 8. Results of the gypsum under compression loading

Sample Name	Density (kg/m³)	Max. Flexural Stress (MPa)	Max. Specific Flexural stress
Gypsum	1191.26	6.68	5.81

6.5 Compressive Test for Gypsum Composite with Wood Dust Mixture
Wood dust has been mixed with gypsum in three proportions to form three composites having different types of material properties. These three composites have been showed different results than the traditional gypsum block. Also, these three composites have showed different properties varied from each other. Their breakdown points are also different.

The stress–strain plot in Figure 15(a) (area-normalized), shows the material response more cleanly: an elastic regime at small strains, then a peak stress and progressive softening. Representative curves illustrate that wood-filled mixes exhibit less catastrophic post-peak decline than neat gypsum—especially around 15–30wt%, where crack deflection and local compliance allow the specimen to carry residual stress over a broader strain range. The 45wt% curve, by contrast, peaks lowest and softens earliest, consistent with excessive porosity and disrupted mineral ligaments. Note that a single representative curve can rank differently from the mean in the bar chart; that is normal scatter. The bar chart—based on replicate averaging—is the correct basis for reporting the composition that maximizes compressive strength (15wt%), while the curves are best for explaining how the material carries and then sheds load.

The force–displacement plot (raw machine output) should be read qualitatively. Because it is force (not normalized by area), ranking can be skewed by small specimen-to-specimen geometry differences; for quantitative comparison you should rely on the stress results. Even so, the curves reveal important features shared by all compositions: a roughly linear elastic rise, a distinct peak followed by post-peak softening with serrations (step-wise cracking), and a long tail as the crushed core compacts. Neat gypsum shows a high, sharp peak and then a steeper post-peak drop—typical of brittle crushing. With wood dust, the peak generally occurs at a slightly lower displacement, but the post-peak slope is gentler, indicating more gradual load decay and greater energy absorption (microcrack deflection, frictional sliding, and particle knock-down).
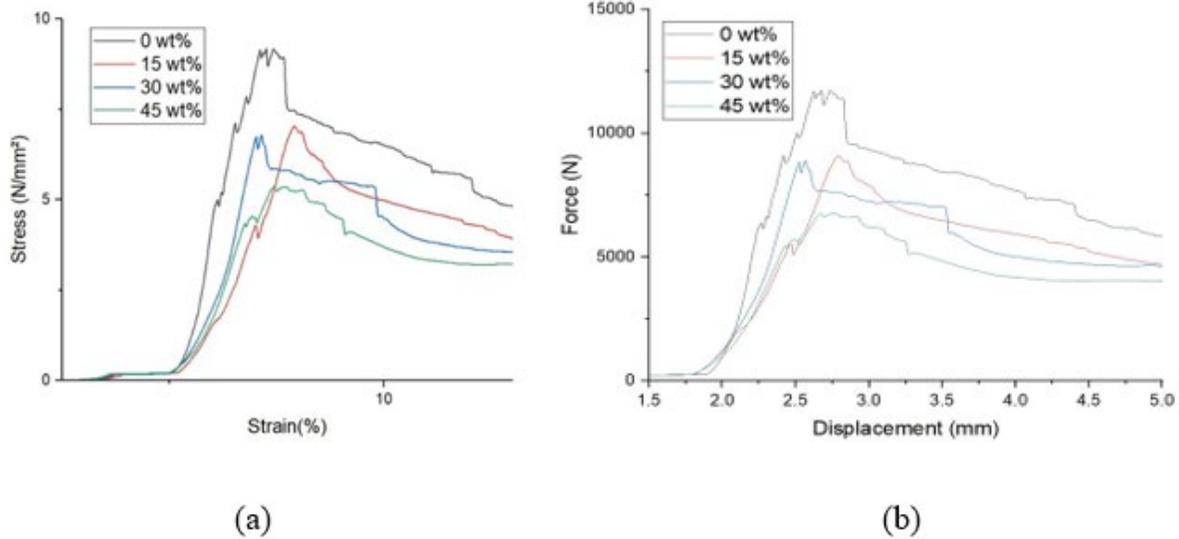
Figure 15. (a) Stress vs Strain Graph of gypsum composite with wood for compressive test, (b) Load Vs Displacement graph of gypsum composite with wood under compressive loading Load vs Displacement graph of gypsum

In design terms in Figure 15(b), the data imply that if compression capacity governs, ~15wt% wood dust offers the best trade-off—raising strength while also delivering a more forgiving, less brittle post-peak response. At higher loadings (≥30wt%), stiffness and continuity losses outpace any crack-toughening benefit, so both peak strength and usable post-peak capacity deteriorate. As the solid gypsum block, the compression curve of gypsum composites has also three different regions. Here the 0% of wood filler shows the maximum load carrying capacity. Then the 15% mixture with gypsum has been taken huge load and 30% and 45% wood with gypsum has been showed almost same properties. With increase of the load, the displacement has been occurred rapidly and after the elastic region has been reached, due to energy release the load has been decreased. Again, the displacement has been occurred rapidly when the material moves towards to the rupture point.

Table 9. Results of the different wt% of wood-gypsum composite under compression loading

Sample Name	Density (kg/m³)	Max. Compressive Stress (MPa)	Max. Specific Compressive Stress
0wt%	1191.26	6.68	5.81
15wt%	1149.73	8.12	6.82
30wt%	1119.70	6.80	6.07
45wt%	1071.93	5.35	4.99

6.6 Comparison of Pure Gypsum and Filler Added Composite

It is seen that, gypsum with 15% filler shows the best result here. Maximum load can be carried by this composite. Wood filler can also carry good amount of load before breaking. This addition of fillers has made the traditional gypsum a ductile material. Traditional gypsum and gypsum composite with wood dust shown almost similar kind of properties but 15% wood withstand with load longer than 0% wood or pure gypsum. The gypsum made materials shows sudden break generally. The compressive-strength bar chart shows a non-monotonic response with a clear intermediate optimum. The mean strength increases from 6.68MPa at 0wt% to 8.12MPa at 15wt% (≈+21.5%), then drops to 6.80MPa at 30wt% (≈+1.8% vs. baseline) and further to 5.35MPa at 45wt% (≈−19.9%). The error bars are modest, so the improvement at 15wt% and the degradation at 45wt% are not only practical but also likely statistically meaningful when tested with one-way ANOVA. Mechanistically, low–moderate wood loading preserves continuous gypsum load paths while adding crack blunting and local compliance; beyond that, increasing porosity and loss of mineral continuity dominate, depressing the peak load in compression.
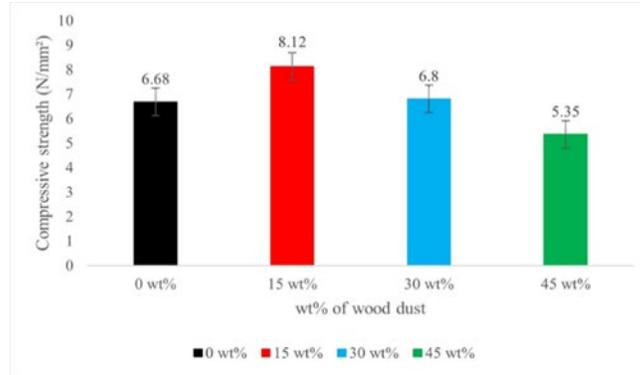
Figure 16. Comparison of composites and solid gypsum in compression test

7. Conclusion

This study evaluated gypsum composites reinforced with wood dust at 0, 15, 30, and 45wt% to determine the compositions that maximize strength and weight-normalized performance for practical building applications. A single-filler design was adopted to remove confounding from multi-filler surveys. Specimens were prepared by dry mixing, fixed W/G slurry casting, vacuum deaeration, and controlled oven curing. The program measured bulk density, three-point-bend strength (flexural), and cube compressive strength, and reported specific properties where density data were available.

- Density decreased monotonically with wood content in the flexural family, from 1247kg/m³ (0%) to ~1098kg/m³ (45%), confirming wood dust as an effective lightweighting agent under the adopted process.
- Under flexure, strength rose from 3.34MPa (0wt%) to a maximum of 4.50MPa at 15wt% (+34.7%), remained above baseline at 30wt% (4.34MPa; +29.9%), and dropped below baseline at 45wt% (3.18MPa). The corresponding specific flexural strength also peaked at 15wt%, demonstrating that the best bending efficiency occurs at an intermediate filler level.
- In compression, the same pattern held: strength increased from 6.68MPa (0wt%) to 8.12MPa at 15wt% (+21.5%), then declined to 6.80MPa (30wt%) and 5.35MPa (45wt%). Thus, the optimum for compressive capacity also lies at ~15wt%.
- Collectively, these results show that moderate wood-dust additions (~15wt%) deliver the most favorable balance between lightweighting and mechanical capacity. Higher loadings (≥30wt%) progressively erode performance due to porosity growth and loss of continuous mineral load paths, while 45wt% is not recommended for strength-critical service.

Within the scope of single-filler, room-temperature mechanical testing, the study provides a reproducible baseline (materials, processing, and calculations) and clear design guidance:

- For bending-limited components, specify ≈15wt% wood dust.
- For compression-limited elements, ≈15wt% again maximizes capacity with reduced mass.
- 30wt% may be used where additional density reduction is desired and some loss of margin is acceptable; 45wt% should be avoided for load-bearing roles.

The principal limitations are incomplete replication for formal inference in every sub-set and the absence of thermal/moisture durability measurements. These do not alter the central outcome—that an intermediate wood-dust fraction is optimal—but they delimit the conditions under which the recommendations presently apply.

In summary, wood dust is a viable, low-cost modifier for gypsum; when used at ~15wt%, it improves both flexural and compressive performance while lowering density, thereby enhancing the material's lightweight efficiency for interior building applications.

8. Future Recommendations

Future work should focus on improving the understanding and performance of gypsum–wood dust composites. This includes testing advanced mechanical properties like impact resistance and fatigue, as well as evaluating durability under moisture, temperature changes, and long-term use. Thermal insulation and fire resistance should be assessed to confirm suitability for building applications. Microstructural analysis using SEM and related tools like XCT and FTIR/EDS can help to improve filler–matrix bonding. Further optimization of wood dust particle size, surface

treatment, and mixing processes could enhance strength and reduce porosity. Producing and testing full-size panels according to construction standards will validate real-world performance. Finally, a life cycle and cost analysis, along with health and safety checks, will support sustainable use. A practical design guide should be developed to help apply these materials effectively in the construction industry.

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Joy Ganguly was a student (or academic) in the Department of Mechanical Engineering at KUET, Bangladesh. During his time at KUET, he has developed a keen interest in mechanical design, fluid mechanics, and thermal systems. Alongside his academic coursework, Joy has been exploring how mechanical engineering principles can be leveraged for sustainable energy applications and industrial solutions. He is also interested in collaborative research and enjoys participating in team-based projects that combine theoretical learning with hands-on system modeling and experimentation. Joy aims to contribute to the development of efficient mechanical systems relevant to Bangladesh's industrial context.

Md. Shahin Alam is affiliated with the Department of Mechanical Engineering at KUET, Khulna, Bangladesh. His focus during his studies includes mechanical design, materials science, and the foundational principles of machine dynamics and thermodynamics. Shahin is interested in exploring how mechanical engineering can intersect contemporary needs. for instance, sustainable manufacturing or lightweight material design. He is also curious about future developments in mechanical engineering in Bangladesh, and hopes to contribute either through academic research or by working in industry to help build efficient, low-cost mechanical systems for production, infrastructure, or energy applications.

Md. Radwanul Kabir studies in the Department of Mechanical Engineering at KUET, Khulna, Bangladesh. He has a strong interest in fluid dynamics, heat transfer, and computational modeling — areas that align with modern mechanical engineering challenges. Radwanul is particularly drawn to research involving flow behavior, energy systems, and thermal management. Beyond his academic studies, Radwanul hopes to work on projects that integrate mechanical engineering with sustainable technologies, such as renewable energy or efficient heating/cooling systems for industrial and environmental applications.

Dibakar Das has been working as an R&D engineer at the air conditioner manufacturing factory of Walton Hi-Tech Industries PLC since November 2021. Previously, he worked at Renata PLC as a maintenance engineer for pharmaceutical machinery and HVAC utility systems from August 2018 to October 2021. He graduated in Mechanical Engineering from the Bangladesh University of Engineering and Technology (BUET) in 2017. His research interests include heat transfer, computational fluid dynamics, materials engineering, and additive manufacturing.

Nazmus Sakib was a student (or academic) in the Department of Mechanical Engineering at Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh. He has built strong fundamentals in core mechanical engineering, and shows interest in areas such as design, thermodynamics, manufacturing, and possibly robotics/automation while reflecting the broad scope typical in his department. Beyond coursework, Nazmus is motivated to apply engineering knowledge to real-world problems, particularly in sustainable and practical mechanical systems. His future ambitions include engaging in research projects or industry work that could contribute towards Bangladesh's infrastructure and manufacturing sectors.