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Review Article

A Comparative Study of the Physio-Mechanical Properties of Iron Fillings and Mild Steel Chips in Reinforced Particleboard

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A B S T R A C T

This study compared the physio-mechanical characteristics of mild steel chips and iron fillings on sawdust-produced particleboard to regular particleboard made from sawdust alone, using identical production conditions. Particle board was made using 1.18mm sawdust, 3mm mild steel chips, and iron filler with diameters of 0.15mm, 0.425mm, 0.6mm, 1.18mm, and 2.0mm. 70g of sawdust, 40g of iron filings, and 40g of mild steel chips were used in the production process. 50 ml urea formaldehyde was used as a binder. The atomic absorption spectroscopy was determined for iron filings and mild steel chips. Particleboards were produced at a temperature of 160°C and a pressure of 20 tonnes for 15 minutes. The mechanical property tested indicates that particleboard containing iron filings has a lower MOR because the size of the iron filings in the particleboard reduces as the MOR increases. The particle size of iron filling with the value of 2.0 mm had the least MOR of 3.99 MPa/m² in iron filling samples. The MOR of mild steel chips was higher compared to all the samples analysed. The MOE of particleboard produced from iron filings increases as the particle sizes of iron filings increase. The samples containing iron filings alone showed the highest MOE of 244.89 MPa/m² for 2.0 mm particle board, while the ones containing mild steel chips had the highest MOE of 282.82 MPa/m² across all samples, suggesting their strength as reinforcement. The rate of water absorption and thickness of swell of particleboard produced from iron filings increases as the size of the iron filings increases.

Keywords: Modulus of rupture, Physio-mechanical properties, Urea formaldehyde, Sawdust, Mild steel chips, Iron filings

Introduction

Waste utilisation is a desirable substitute since it achieves resource conservation while lowering or even eliminating disposal costs and any pollution issues.[1-3] Energy and environmental issues must be incorporated with the utilisation plan in order to optimise the usage of available resources.[4] Preserving natural aggregate is crucial to ensuring that future

generations will have access to sufficient resources.[5-6] Reusing solid waste to partially replace aggregate reduces the need to harvest natural raw materials, which in turn saves landfill space.[7-9] Researchers and industries are looking for alternative raw materials for composite manufacture, like wood residues and agricultural waste, to replace traditional wood due to the depletion of natural resources and rising demand for wood and wood-based components.[7-13] The wood-based production industry now faces new challenges in optimising the use of available wood and other lignocellulosic raw materials, recycling and reusing wood and wood-based composites.[14-17]

There is a great need for alternative resources because of the expanding environmental concerns and new laws that encourage the cascading use of natural resources. [18-19] The scarcity of wood on the local market is a challenge for numerous companies and manufacturers of wood and wood-derived products, leading to intense competition among these industries. [20] The increasing production capacity that results in more supply in response to the rising demand will make this competition more and more severe. The price of timber could be influenced by a variety of arbitrary circumstances at any given time, which would raise the timber market's cost. [21] The raw material handling practices used by the wood-based panel industry are rather flexible because of regional variations in the availability of wood or the constantly fluctuating condition of wood raw materials. [10, 13, 17, 22-24] Furthermore, there has been a notable global growth in demand for wood, which was previously only utilised to manufacture wood-based panels, from other wood-based businesses and the energy industry.[25-28] The aforementioned constraints have compelled the wood-based industry to adopt alternative raw resources, such as reclaimed wood and other forest-based material, and to optimise technological manufacturing processes to ensure a stable level of quality. [29-31]

Particleboards are among the most important value-added panel products for the wood-based sector because of their wide range of applications. [32-33] Particleboard manufacturing can use lower-quality raw materials than the pulp and paper sector or building. [34-35] For the sake of the environment, proper waste management is crucial, especially with regard to wood and wood-based byproducts. [36-38] One potential solution to mitigate the anticipated decline in the technical qualities of the boards resulting from the incorporation of different lignocellulosic raw materials is to add more binder. [39-42] The type and concentration of resin employed are important factors in determining the right properties and intended uses of particleboard binding. [43-44]

If the board must have a high degree of water resistance, replace UF with a different resin, such as PF (phenol-formaldehyde) or PMDI (polymeric 4,4′-methylenediphenyl isocyanate). [45-46] This is standard practice when working with particles and will guarantee optimal bonding and strength parameters. The utilisation of substitute raw materials not only reduces the cost of producing panels but also contributes to the sustainable management of leftover forest biomass that isn't being put to better use. [10, 47-48]

The sawdust, wood chips, shavings, pulp, and other wastes from sawmill operations, together with bark, harvested and generated wastes, and unprocessed sawmill by-products, are some examples of replacement raw materials. [12, 36, 49] Wood leftovers and byproducts are being used increasingly extensively in industry to make wood-based panels, which is justified by the growing shortage of wood raw materials like roundwood and full-value wood. [22, 50-51] Particleboards can be made from one or more replacement raw resources, such as post-consumer wood, wood from fruit trees, and wood from urban greenery, crushed into lignocellulosic particles. [13, 52] One practical way to produce boards fit for furniture and interior uses is to recycle debris from building and demolition into residual medium-density fibreboard (MDF), particleboard, cardboard, and plywood. [53] Particle board is primarily composed of wood chips or fragments mixed with a suitable binder (such as synthetic resin) and heated to high pressure in a hot press to fuse together. [54-56] The entire interparticle bond between the particles is formed by the addition of binder, and other materials may have been added afterwards to improve specific features of the production of particleboard. [57] The pressing process gives particleboards additional characteristics. [58-60] The qualities of binding that are employed to fuse the materials together during particleboard processing also have an impact on the attributes, in addition to the composition and structure that can be obtained with these elements. [14, 61] Sawdust is

a crucial ingredient used in the production of particle board. [54, 62] The capacity of the sawdust size to allow bonding materials to distribute throughout the boards, enhancing the bonding quality, which in turn enhances the mechanical properties of the produced material. Equal mechanical qualities are maintained throughout the created board due to the size, which permits easy and equal spreading with additional material. [63] Traditional synthetic adhesives used in the production of wood-based panels include urea, formaldehyde, phenol, melamine, and others. [64-67] These adhesives are made from materials obtained from petroleum. [68] The addition of thermosetting resin treatment to wood (sawdust) and other particles improves the mechanical characteristics of particleboards. [69]

Materials and Method

Materials & Equipment

Sawdust of 1.18 mm diameter, urea formaldehyde resin, Iron filings of sizes 0.15 mm, 0.425 mm, 0.6 mm, 1.18 mm, and 2.0 mm, respectively, and A mild steel chip of 3mm thickness, a metal mould of dimension 12cm × 10cm × 3cm, a digital multi-thermometer of temperature range (-50 to 300ºC), Water used for testing water absorption and thickness of swelling, and urea formaldehyde. Schmidt hammer for testing the compressive strength of the particleboard, artist saw used for cutting the particleboard, the universal testing machine (500 tonnes) for testing the breaking load (KN) of the specimen, Vernier calliper used for obtaining the thickness of the particleboard, digital weighing balance and an electronic multi-thermometer. Figure 1, Figure 2 and Figure 3 represent samples of iron filings, samples of sawdust and the Schmidt hammer, respectively.

Figure 1: Iron filings sample

Figure 2: Sawdust sample

Figure 3: Schmidt Hammer

Methods

Collection of raw materials

The raw materials used were sawdust, iron filings, mild steel chips and urea formaldehyde. The sawdust used for the investigation was obtained directly from a sawmill factory, after which it was dried in the open air to reduce the moisture content to about 6%.[70-71] The sawdust was sieved to obtain a particle size of 1.18 mm using a sieve of 1.18 mm in the Civil Engineering Department of Michael Okpara University of Agriculture. [72] The required quantity of sawdust weight was weighed in the weighing balance to obtain 800 g of sawdust, after which it was kept in a cool, dry place. The mild steel chips used for the study were obtained from the mechanical engineering workshop after machining the mild steel shaft of 25 mm diameter with a feed of 3 mm to avoid obtaining a rusted chip. The steel chips were weighed to obtain 100 g. The iron filings used were also obtained from the workshop using a chip gotten after machining a sample of 25 mm diameter. The iron filings were sieved to obtain particle sizes of 0.15 mm, 0.425 mm, 0.6 mm, 1.18 mm and 2.0 mm, respectively, using the corresponding sieve size. The iron filling was weighed to obtain 60 g for each particle size obtained. Figure 4 and

Figure 5 represent the weighted sawdust sample and the weighted iron filings sample.

Figure 4: Weighted Sawdust sample

Figure 5: Weighted Iron filings sample

Determination of the atomic absorption spectroscopy (AAS) of iron fillings and mild steel chips

The determination of the atomic absorption spectroscopy was carried out with the aim of determining the chemical elements constituent in the iron filings and mild steel chip. 10g of the prepared samples of iron filings and mild steel chips were measured, respectively. Each of the samples was put in two different beakers and mixed with about 50 ml of concentrated nitric acid (HNO_3) and perchloric acid. The mixture was put in the fume cupboard digester model ISOCIDE (Frontier Junior) for further digestion for about 24 hrs. The digested particles are further taken to the spectrophotometer, where they are atomised, and the chemical element composition is picked up by the cathode lamps. Figure 6 represents the atomic absorption spectroscopy setup.

Figure 6: Atomic absorption spectroscopy (AAS) setup

Urea formaldehyde

The urea formaldehyde resin that was used as the binding agent was prepared in the Department of Chemistry at Michael Okpara University of Agriculture. The raw materials used in this preparation were 100 g of urea, 200 g of formaldehyde, 80 g of sodium hydroxide, 100 ml of acetic acid and 100 ml of distilled water. The urea formaldehyde was prepared by adjusting the pH scale of 200 g formaldehyde (38%) to 7.5 with an aqueous solution of sodium hydroxide (NaOH) (10%), and 100 g urea was added. The mixture was stirred and heated with reflux for 1½ hours. Then about 30 ml of water was distilled off to obtain a resin of 60% solids and 2.5% free formaldehyde. Thus, the obtained liquid resin was treated with 0.3N acetic acid to a pH of 4.0 and cured under reflux for the purpose of proper dissolution of urea particles; this was done

for an additional 2 hours. A gelled product was found and was dried at about 45ºC for 1 hr to remove the moisture content, after which it was kept at room temperature.

Production of particleboard

Seven distinct containers were filled with precisely measured 70 g of the processed sawdust in preparation for the blending operation. A laboratory beaker was used to measure 50 ml of urea formaldehyde into seven distinct plastic containers. 40g of each of the iron filings with sizes 0.15mm, 0.425mm, 0.6mm, 1.18mm and 2.0mm, respectively, were measured and kept ready for blending. 40 g of the mild steel chips were also measured and kept ready for blending. Prior to the production process, 50 ml of urea formaldehyde and 70 g of sawdust were carefully combined to improve uniformity. The mixture was spread out on a metal mould measuring 12 cm by 10 cm by 3 cm. The mould was covered with aluminium foil to make removal easier and prevent the particleboard from burning, which was a crucial feature due to the foil's high heat resistance. Sawdust was placed between the metal mould and covered with folded aluminium foil. A mechanical stirrer was used to completely mix 70 g of the prepared sawdust and 50 ml of urea formaldehyde with each of the determined iron filler particle sizes. The 40g mild steel chip was also combined with 50ml of urea formaldehyde resin and used to reinforce one of the 70g sawdust.

For every sample, the mixing of the iron filler and 70 g of sawdust was repeated. Every generated sample was dispersed throughout the atmosphere for a further three hours of drying. Ultimately, the resulting particleboard was stored for testing. Figure 7 shows the produced samples of particleboard.

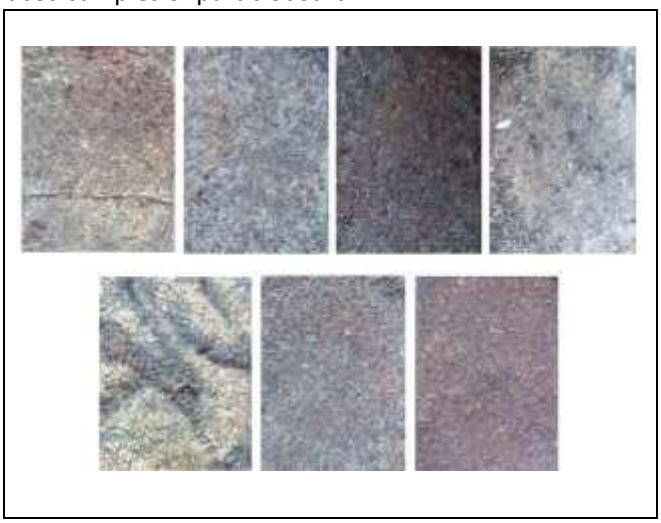

Figure 7: Produced particleboard

Produced particleboard testing methods

Compressive strength

The compressive strength of the particleboards produced above was determined using the Schmidt hammer. The manufactured boards were cut into a rectangular shape of dimensions 50 mm x 60 mm, and the thickness of each sample was measured and recorded. The prepared samples were fixed on a grip, and the Schmidt hammer was used to indent on the surface of the board, and the rebound number was noted and recorded; the corresponding compressive strength was read off from the rebound chart.

Tensile strength

The tensile strength of the particleboards produced above was determined using the universal testing machine (UTM). A sample with a 50 x 60 mm rectangular form was placed in the grip of a universal testing machine with a 500-tonne capacity, and it was then automatically loaded from the computer. The graph of load/extension was plotted on the computer interface, after which it was extracted for evaluation.

Modulus of rupture (MOR)

The modulus of rupture is a crucial mechanical property of particleboard that influences its ability to burst when a load is applied. This was derived using each sample's failure load value that was found as a consequence, applying the formula;

$$MOR = \frac{3PL}{2bd^2}$$

Where:

$P = Failure\ load\ (N)$

$b = Width\ of\ the\ board\ sample\ (mm)$

$L = The\ board\ span\ between\ the\ machine\ support$

$d = Thickness\ of\ the\ board\ sample\ (mm)$

Water absorption test

A top-loading digital weighing balance was used to weigh a sample of each particleboard that was manufactured. The samples were immersed in water for 24 hours before being weighed. The percentage that indicates the water absorption is the weight difference relative to the sample's initial weight. For every newly established board, this procedure was carried out.

$$Water\ absorption = \frac{W_2 - W_1}{W_1} \times \frac{100}{1}$$

Where;

$W_1 = Weight\ of\ sample\ before\ soaking$

$W_2 = Weight\ of\ sample\ after\ soaking$

Thickness swelling test

The veneer caliper was used to measure the thickness of each created board both before and after it was soaked in water for 24 hours. The thickness swell, which was calculated for each of the above-formed boards, is the ratio of the variations in thickness, to the sample's initial thickness represented as a percentage.

$$Thickness\ swell = \frac{T_2 - T_1}{T_1} \times \frac{100}{1}$$

Where;

$T_1 = Thickness\ of\ sample\ before\ soaking$

$T_2 = Thickness\ of\ sample\ after\ soaking$

Density test

The density of a particleboard is one of the important parameters to be determined, and the targeted value is between

0.6 and 0.8 g/cm³.. The density was determined by dividing the mass of the board sample before soaking by the volume of the sample. This complies with ANSI A208.1-1999, the American National Standard Institute's code. The aim is to produce standard board particles with densities ranging from 37 lb/ft³ to 50 lb/ft³, which is equivalent to 0.6 g/cm³ to 0.8 g/cm³.

$$Density = \frac{mass}{volume}$$

Where;

$$Volume\ of\ sample\ (cm^3) = length \times width \times thickness$$

$$Mass\ (g) = mass\ of\ sample\ before\ soaking\ in\ water$$

Results and Discussion

Results

Table 1: Chemical compositions of Iron filings and Mild steel Chips (%)

Elements	Iron fillings	Mild steel chip
Ca	2.001	6.802
CaO	3.80	9.516
Mg	0.973	1.763
MgO	1.613	2.923
LOi	1.48	6.34
K	1.25	1.425
K_2O	1.506	1.717
Na	5.525	5.425
NaO	7.45	7.313
Fe	11.08	12.07
Fe_2O_3	15.73	17.14
Zn	11.21	15.54
Zn_2O	13.95	22.46
MC	0.96	2.34
Pb	4.71	4.58
Mn	6.08	6.02

Table 2: The dimensions of the tested sample

Mat	Particle size of iron fillings (m)×10^{-3}	Length of the sample (m)	Width of the sample (m)	Thickness of the sample (m)	Cross-sectional area (m)
Sd	0 [Control]	0.06	0.05	0.0095	4.75×10^{-4}
	0.15	0.06	0.05	0.0095	4.75×10^{-4}

	0.425	0.06	0.05	0.0095	4.75×10^{-4}
IF	0.6	0.06	0.05	0.00951	4.75×10^{-4}
	1.18	0.06	0.05	0.00952	4.75×10^{-4}
	2.0	0.06	0.05	0.009523	4.75×10^{-4}
MSc	3.0	0.06	0.05	0.009525	4.75×10^{-4}

Table 3: The modulus of Rupture results for the tested samples

Mat	Particle size of iron fillings (m)×10^{-3}	Length of the sample [L] (m)	Width of the sample [b] (m)	Depth [d] (m)	Breaking load [P] (KN)	Modulus of rupture (MPa/m^2)
Sd	0 [control]	0.06	0.05	0.0095	0.16	3.19
	0.15	0.06	0.05	0.0095	0.28	5.58
IF	0.425	0.06	0.05	0.0095	0.25	4.98
	0.6	0.06	0.05	0.00951	0.23	4.58
	1.18	0.06	0.05	0.00952	0.22	4.38
MSc	2.0	0.06	0.05	0.009523	0.20	3.99
	3.0	0.06	0.05	0.009525	0.35	6.98

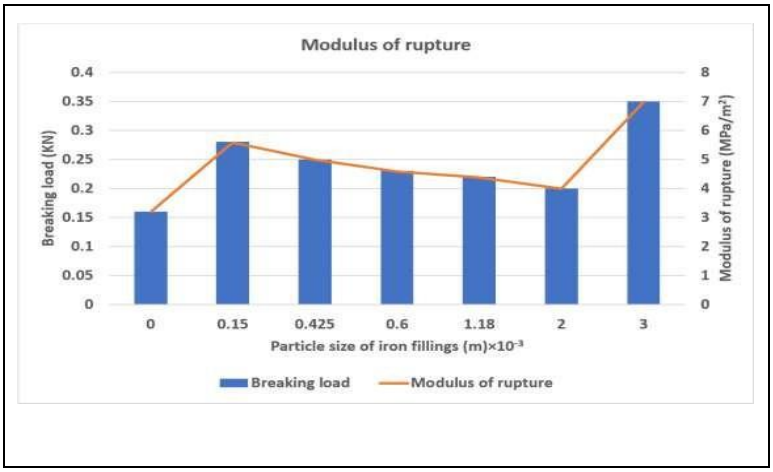

Figure 8: Modulus of rupture according to applied load

Table 4: The density of the tested sample

Mat	Particle size of iron	Weight	Length	Width	Thickness	Volume	Density
	fillings (m)×10^{-3}	(g)	(cm)	(cm)	(cm)	(cm^3)	(g/cm^3)
Sd	0 [Control]	20.53	6	5	0.95	28.5	0.72
	0.15	22.21	6	5	0.95	28.5	0.77
	0.425	21.571	6	5	0.95	28.5	0.75
IF	0.6	23.38	6	5	0.951	28.53	0.81
	1.18	24.219	6	5	0.952	28.56	0.84
	2.0	24.20	6	5	0.952	28.56	0.84
MSc	3.0	24.40	6	5	0.952	28.56	0.74

Table 5: The compressive strength of sizes of iron filings and Mild Steel Chip

Particle size of iron fillings (m)×10^{-3}	Compressive strength N/mm^2
0 [Control]	10.00
0.15	10.200

0.425	11.00
0.6	15.00
1.18	16.00
2.0	18.200
3.0 [Mild steel]	20.00

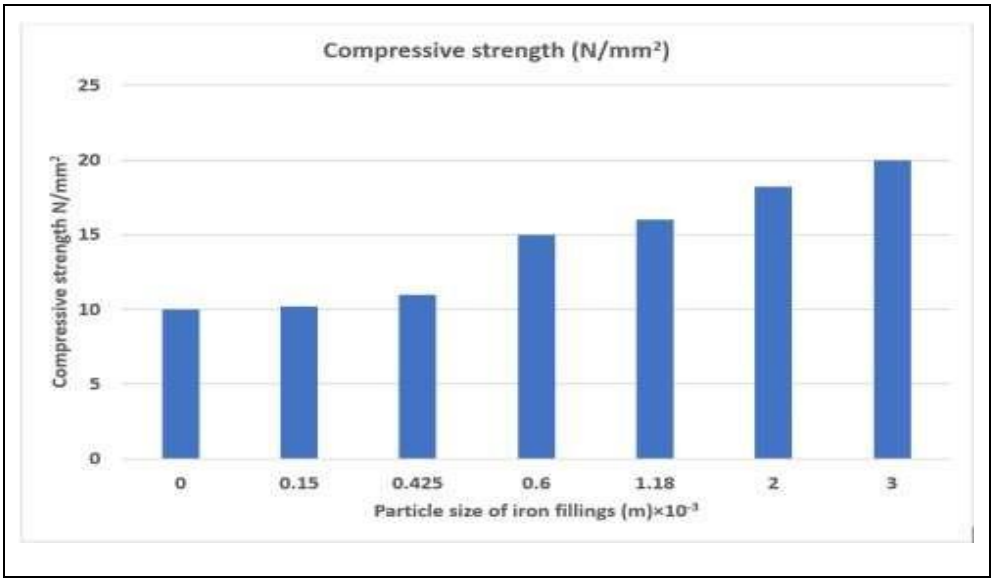

Fig 9: Compressive strength according to particle size

Table 6: Water absorption of the iron filings and Mild steel Chips particleboards

Mat	Particle size of iron fillings (m)×10^{-3}	Weight before soaking in water (g)	Weight after soaking in water (g)	Water absorption %
Sd	0 [control]	20.53	32.13	56.5
	0.15	22.21	33.10	49
	0.425	21.57	32.2	49.2
IF	0.6	23.38	34.92	49.4
	1.18	24.21	37.12	53.3
	2.0	24.20	37.45	54.75
MSc	3.0 [Mild steel chip]	21.40	33.25	55.57

Table 7: Thickness of swell of iron filings and mild steel chip particle boards

Mat	Particle size of iron fillings (m)×10^{-3}	Thickness before soaking in water (mm)	Thickness after soaking in water (mm)	% thickness of swell
Sd	0 [Control]	9.500	13.525	42.36
	0.15	9.500	10.600	11.57
	0.425	9.500	10.80	13.68
IF	0.6	9.510	11.00	15.66
	1.18	9.520	10.5	10.29
	2.0	9.523	12.10	27.06
MSc	3.0	9.525	13.50	41.7

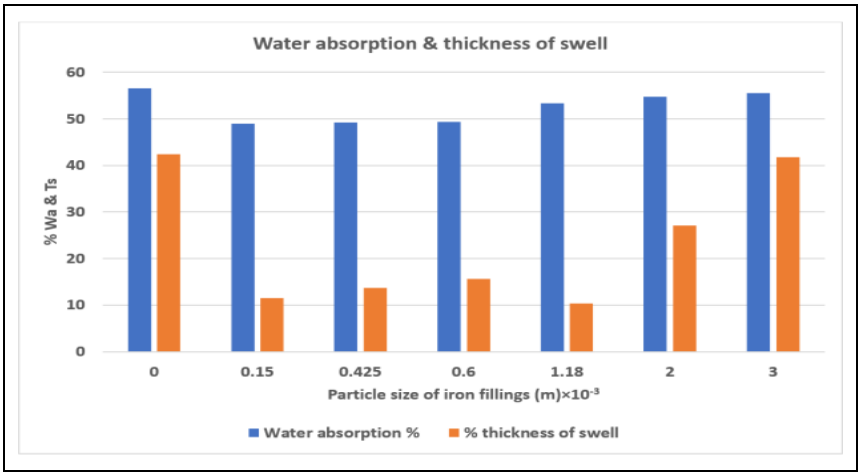

Figure 10: Water absorption & thickness of swell according to particle size

Table 8: Modulus of Elasticity of the tested samples

Mat	Particle size of iron fillings (m)×10^{-3}	Tensile strength (MPa)	Strain (e)	MOE (MPa/m^2)	% Elongation
Sd	0 [Control]	2	0.0266	75.18	2.66
IF	0.15	4	0.045	88.88	4.5
	0.425	7	0.05	140	5
	0.6	16	0.076	210.52	7.6
	1.18	20	0.0866	230.95	8.6
	2.0	24	0.098	244.89	9.8
MSc	3.0	28	0.099	282.82	9.9

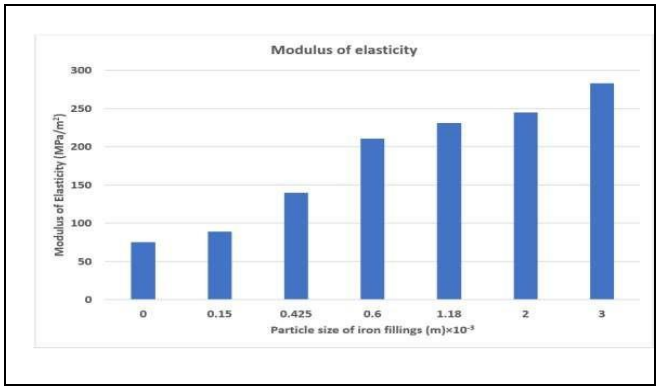

Figure 11: Modulus of elasticity according to particle size

Discussion

Table 1 shows the result of the atomic absorption spectroscopy obtained for iron filings and mild steel chips. It can be observed that the iron filings contain 11.08% Fe, 11.21% Zn, 6.08% Mn, 1.25% K, 4.71% Pb, 5.525% Na, 2.01% Ca, 0.973% Mg and their corresponding oxides. While the mild steel chips contain 6.812% Ca, 1.763% Mg, 1.425% K, 5.425% Na, 12.07% Fe, 15.54% Zn, 4.58% Pb, 6.02% Mn and their corresponding oxides. Table 2 shows that the thickness of samples containing mild steel chips and iron filings with sizes of 0.6 mm, 1.18 mm, and 2.0 mm increased to 9.51 mm, 9.52 mm, 9.523 mm, and 9.525 mm. However, because of the huge filler particle size and the hydraulic press's strong compressive strength, the results were the same for the control and samples with 0.15 mm and 0.425 mm iron filings. Table 3 shows the modulus of rupture of the samples, and it was observed that the MOR of the sample with mild steel chips was the highest, with 6.98 MPa/m² MOR, as shown in Figure 8. The least is the control sample with 3.19 MPa/m², whereas in samples with iron filings the MOR decreases with respect to the increase in particle sizes, having values of 5.58 MPa/m², 4.98 MPa/m², 4.58 MPa/m², 4.38 MPa/m² and 3.99 MPa/m² for iron filing particle sizes of 0.15 mm, 0.425 mm, 0.6 mm, 1.18 mm and 2.0 mm, respectively (Figure 4-5).

It was noted that the sample with mild steel chips had the highest compressive strength of 20 MPa/mm², while that of samples with iron filings increased gradually as the particle size increased, as shown in Figure 9. For the water absorption, particleboard without iron filings (control) maintained the highest water absorption rate of 56.5%, as seen in Table 6, while particleboard with 0.15 mm, 0.425 mm, 0.6 mm, 1.18 mm, and 2.0 mm iron filings has water absorptions of 49%, 49.2%, 49.4%, 53.3%, 54.75%, and 55.37%, respectively. Based on the findings, we can infer that the rate of water absorption owing to porosity increases with the size of iron-filled particles. Conversely, mild steel chip particleboard likewise has a high water absorption rate of 55.37%. Figure 10 illustrates the samples' swell thickness. As compared to the samples with iron filing sizes of 0.15 mm, 0.425 mm, 0.6 mm, 1.18 mm, and 2.0 mm, respectively, the control sample exhibited a high value of thickness of swell (42.36%). The samples also demonstrated a progressive increase in swell. Additionally, it is observed that the iron filing sample exhibited a sudden decrease in thickness followed by an increase; this is due to the iron filing and sawdust particles having similar particle sizes. However, compared to mild steel chips, particleboard containing iron filings has a better swell thickness (Table 7).

Lastly, according to Figure 11, the sample containing mild steel chips from Table 8 has the highest modulus of elasticity, measuring 282.82 MPa/m², while the sample containing iron filings shows a gradual increase, going from 88.88 MPa/m² to 140 MPa/m², 210.52 MPa/m², 230.95 MPa/m², and 244.89 MPa/m² at the sizes of 0.15 mm, 0.425 mm, 0.6 mm, 1.18 mm, and 2.0 mm, respectively. However, the control has the lowest modulus of elasticity of 75.18 MPa/m².

Conclusion

This paper examines the comparative study of the physio-mechanical properties of iron filling and mild steel chips in reinforced particleboard. The following conclusions were drawn based on the results obtained from this research work.

- The mechanical property tested indicates that particleboard containing iron filings has a lower modulus of rupture (MOR) because the size of the iron filings in the particleboard reduces as the MOR increases. The particle size of iron filling with the value of 2.0 mm had the least MOR of 3.99 MPa/m² in samples of iron filling alone. The MOR of mild steel chips was higher compared to all the samples analysed.
- Modulus of elasticity (MOE) of particleboard produced from iron filings increases as the particle sizes of iron filings increase. Particle 2.0mm has the highest MOE of 244.89 MPa/m² in samples of iron filings only, while samples of mild steel chips were seen to have the highest value of 282.82 MPa/m² of MOE compared to all the samples, indicating its strength as reinforcement.
- The rate of water absorption and thickness of swell of particleboard produced from iron filings increases as the size of the iron filings increases. The water absorption rate was high with mild steel chips due to porosity as a result of weak inter-particular bonds between the chips and the sawdust particles.
- The significance of this research is to obtain particle board with good strength, a smooth surface and better resistance to swelling. It is advised to utilise a homogenous material that is highly slender (long, thin particles) and

free of dust, splinters, and oversized particles.

Disclaimer (Artificial intelligence)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of manuscripts.

Abbreviations

AAS	*Atomic absorption spectroscopy*
MOR	*Modulus of rupture*
IF	*Iron filings*
MSc	*Mild steel chips*
MOE	*Modulus of Elasticity*
Sd	*Sawdust*

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