Journal of Materials Science Research and Reviews

2(3): 429-438, 2019; Article no.JMSRR.51651

Selected Physical and Mechanical Properties of Medium Density Fibreboard Composite Produced from Waste Paper and Sawdust

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Authors' contributions

This work was carried out in collaboration among all authors. Author JKA designed the study, Author KOO performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KOO and EAA managed the analyses of the study. Author FGA managed the literature searches. All authors read and approved the final manuscript.

Article Information

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Complete Peer review History: http://www.sdiarticle4.com/review-history/51651

Original Research Article

Received 17 July 2019
Accepted 19 September 2019
Published 25 September 2019

ABSTRACT

Waste paper and sawdust poses huge problems as degrading urban environment, producing offensive odor during rain and pollute the air with smoke when burnt indiscriminately, thus contributing to environmental degradation and global warming. In addition, if not timely disposed, becomes breeding places for worms and insects. There is therefore need for its proper utilization. This study aims to determining selected physical and mechanical properties of medium density fibreboard produced from waste paper and sawdust. Heterogeneous wood sawdust from logs and waste papers were purchased, hence board formation was done with respect to density and blending proportion after which it was prepared for testing. The mean water absorption and thickness swelling were 87.83±8.51% and 28.61±5.28% for the 850kg/m^3 density board, while 84.09±8.21 and 28.03±4.05 were obtained for the 1000kg/m^3 density board. Meanwhile, 1.32±0.14 and 15.95±5.05 N/mm^2 were obtained for Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) for 850kg/m^3 density board while 1.35±0.14 and 19.04±5.05 N/mm^2 for 1000kg/m^3 respectively. Density of boards formed was not found to significantly affect the selected physical and mechanical properties whereas blending proportion does. However, board density of 1000kg/m^3 with blending proportion of 0/100 was most dimensionally stable.

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Keywords: Board; sawdust; adhesive; waste paper; composite.

1. INTRODUCTION

Medium Density Fibreboard (MDF) is an engineered wood product made by breaking down hardwood or softwood residuals into wood fiber, often in a deliberator, combining it with wax and a resin binder, and forming panels by applying high temperature and pressure [1]. MDF is generally denser than plywood. It is made up of separated fibers, but can be used for so many purposes and application similar in application to plywood. It is stronger and much denser than particle board. The name medium density fiberboard is derived based on the distinction in densities of fiberboard. large scale production of MDF began in the 1980s, in both North America and Europe [2].

Sawdust or wood dust is a by-product of cutting, grinding, sanding, drilling or otherwise pulverizing wood or any other material with a saw or other tool; it is composed of fine particles of wood. It can also be a by-product of certain animals, birds and insects which live in wood, such as wood pecker and carpenter ant. Sawdust is one of the major component of the waste cottage generated by sawmills in Nigeria. [3]

Meanwhile, paper is a material made up of cellulose pulp derived mainly from wood or rags of certain grasses. Paper wastes are paper that are thrown away or discarded because it has been used or it's no longer needed. However, [4] projected an increase in world population by the end of twenty first century, meaning that demand for wood and its product may rise accordingly. As a result, more pressure is mounted on forest estates thereby leading to the over exploitation of the available forest in both natural and plantation forest. The over-exploitation of Nigeria's hardwood species from the natural and plantation forests necessitates the need to focus on alternative source of raw materials, at least for use in panel products manufacturing which could substitute for use of sawn wood (lumber) and plywood for some specific end uses notably for production of different grades of furniture. Such potential panel products include particleboard and fiberboard.

Also, [5] stated that sawdust waste generated by saw mills is about 3.89 million cubic meters per year, and that the waste generation increases with industrial growth. This sawdust waste, if not properly managed will be burnt and in turn contributes to global warming which thus against the current campaign on global warming which marked burning of wood waste, agricultural waste and paper waste as the contributor to climate change.

Both wood waste and paper waste are concomitant aspects of living which cannot be eradicated but can only be managed. Notwithstanding, they pose problems such as degrading the urban environment, producing offensive odor during rain and pollute the air with smoke when they are burnt indiscriminately, leading to environmental degradation and global warming, and if not timely disposed, they become breeding places for worms and insects [6]

Over time the term MDF has become a generic name for any dry process fiberboard. Its density is typically between 500 and 1000 kg/m^3. MDF is typically made up of 82% fiber, 9% urea-formaldehyde resin glue, 8% water and 1% paraffin wax [7]. There are a number of reasons why medium density fiberboard may be used instead of plywood or chip wood: it is dense, flat, and stiff, has no knots and easily machined. Because it is made up of fine particles it does not have an easily recognizable surface grain, thus it can be cut, drilled, machined and field without damaging the surface. MDF may be dowelled together and traditionally wood work joints may even be cut. This study therefore aims at determining selected physical and mechanical properties of medium density fiberboard produced from waste paper and sawdust.

2. MATERIALS AND METHODS

2.1 Preparation of Samples

2.1.1 Sawdust preparation

Heterogeneous wood sawdust from logs within the same ecological zone was collected from sawmill section of Forest Products Development and Utilization (FPD&U), Forestry Research Institute of Nigeria [FRIN], Oyo State, Ibadan, Nigeria. The heterogeneous sawdust particles was spread out in the open air for three weeks in order to allow for gradual degradation of stackers and sugar present in them that could impede setting of the binder. After which it was weighed out. Pretreatment of the sawdust was carried out at about 80°C for a soaking period of one hour in order to facilitate removal of water-soluble sugar and other extractive present in the raw materials which may possibly retard or completely inhibit the setting and curing of the adhesive. The hot water was drained off while the saw dust was washed with cold water and air dried to enhance thorough draining of water. The sawdust was later sieved using a 2mm standard sieve to attain a homogenous material. They were then bagged and stored in a polythene bag in readiness for use.

2.1.2 Waste paper preparation

Waste paper was purchased in bulk from a waste paper collection center, located in Ogunpa Ibadan, Oyo State, Nigeria. The waste paper was then shredded into smaller sizes manually using knife and later soaked inside a tank filled with water for 7 days in order to soften the paper. The softened paper was then squeezed and sieved out of the water and manually re-shredded/torn apart into more smaller sizes and was later air dried for two days before taking down to the milling center for grinding into particles. The grinded paper particles were air-dried for a period of one week and sieved through a 4mm-wire sieve. The sieved particle was also stored for further use.

2.1.3 Adhesive preparation

A resin synthetic adhesive (FEVICOL) was used as the binder and mixed with 150ml of tap water measured out using a measuring cylinder and the adhesive was made constant for all the blending proportion for both nominal densities (850 and 1000 kg/m^3). 40% of the total composites of FEVICOL was added to the total mass for each nominal density (850 kg/m^3 and 1000 kg/m^3) and blending proportion; sawdust/paper (0/100, 25/75, 50/50, 75/25, 100/0%) in grams of the total mass for each blending proportion.

2.1.4 Mould preparation

A wooden mould of 350×350×5 mm was prepared. The mould was thoroughly cleaned. Polythene nylon was spread on the mould in other to ensure easy removal of the boards that will be produced.

2.1.5 Board formation

Two nominal densities were used (850 kg/m^3& 1000 kg/m^3). The blending of sawdust and waste paper was done based on weight in gram of each of the blending proportion with respect to the total mass in gram and replicated three times. The adhesive concentration was constant for all the boards that were produced. The blending was done in a bowl and poured inside the wooden mould of 35cm x 35cm x 0.5cm and proper formation was ensured.

After the formation of the boards, it was kept under hydraulic press for cold pressing and was left under the hydraulic press for 72h under a pressure of 1.23 Nm^{-2}. This was done in-order to remove excess water that is still present in the boards and to ensure even compaction of the board. After demolding, the boards were wrapped with black polythene nylon and taken to the conditioning room for 28days. The boards were unwrapped and allowed to air dry for some days before being taken down to the trimming machine where the boards were trimmed in order to avoid edge effect according to [8].

Three replicates of 50×50×5 mm [9] of each test samples were taken with respect to blending proportion and density of the board for carrying out thickness swelling, water absorption, while 195×50×5 mm was used for modulus of rapture (MOR), modulus of elasticity (MOE). Thus, a total of 60 samples were used for the experiment. 30 samples each for physical and mechanical tests.

2.2 Physical Properties Test

2.2.1 Water absorption

The test samples were weighed and the readings were recorded, after which they were immersed completely in water for 24 hours. The samples were there after were removed from the water and reweighed. Thus, water absorption (% W.A) was calculated as shown below: [10]

Water absorption percentage (% W.A)

$$=\frac{W2-W1}{W1}X100 \tag{1}$$

where:

W_2 = Final weight after soaking;
W_1 = Initial weight before soaking

2.2.2 Thickness Swelling

The initial thickness of the boards' test samples were recorded using veneer caliper and the samples were thereafter soaked in distilled water for 24 hours after which they were removed from the water and their thickness was taken and recorded. The thickness swelling was expressed as the percentage of the increase in thickness of the board of the original thickness and it was calculated using the formula: [10]

Percentage Thickness Swelling (% T.S)

$$=\frac{T2 - T1}{T1} X\ 100 \qquad (2)$$

where:

T_2 = Final thickness after soaking
T_1 = Initial thickness before soaking

2.3 Mechanical Strength Properties

2.3.1 Flexural test

This test was carried out with a universal testing machine (Instron) at Obafemi Awolowo University Ile-Ife, Nigeria. The test specimen were mounted one by one on the machine and the load was applied at the center with the aid of an electro mechanical motor till the point where failure occurs. The recording of the ultimate failure load (P) was estimated.

Modulus of Rupture (MOR) was calculated by eq. 3 while Modulus of Elasticity (MOE) was calculated by eq. 4 using the values obtained from the load deflection graph during the test.

$$\text{MOR (N/mm}^2\text{)} = \frac{3Pl}{2bd^2} \qquad (3)$$

where:

P = maximum load (N)
l = span of the board (mm)
b = width of the board (mm)
d = depth of the board (mm)

$$\text{MOE (N/mm}^2\text{)} = \frac{Pl^3}{4bd^3\Delta} \qquad (4)$$

where:

P = load at proportional limit (N)
l = the span of the board sampled between the machine support (mm)
b = width of the test sample (mm)
Δ =deflection at beam center at proportional limit
d = thickness of the test sample (mm)

2.4 Experimental Design

The experiment was designed to be 2×5 factorial in a Completely Randomized Design (CRD). Each of the boards were replicated three times making thirty boards altogether:

Factor A= Two (2) Board density 850kg/m^3 and 1000kg/m^3
Factor B= Five (5) blending proportion of sawdust/paper (0/100; 25/75; 50/50; 75/25 100/0) %

2.5 Data Analysis

All data obtained were subjected to Statistical Analysis using Analysis of Variance (ANOVA) to estimate the relative importance of various sources of variation for flexural strength, density, water absorption and thickness swelling. The follow up test was done using Duncan Multiple Ranged Test (DMRT) were necessary.

2.6 Statistical Model

The statistical model that was used is Completely Randomized Designed, it is given as:

$$Yij = \mu + Ai + Bj + ABij + Eijk \qquad (5)$$

where:

Y_{ij} = General observation
μ = General mean
A_i = Effect of Density
B_j = Effect of blending proportion
AB_{ij} = Interaction effect between Density and Blending proportion
E_{ijk} = Error term

3. RESULTS AND DISSCUSSION

3.1 RESULTS

The mean values of water absorption and thickness swelling of boards produced were shown in Table 1. It showed values obtained for boards of density of 850kg/m^3 and 1000 kg/m^3. Blending proportion of 100/0% (sawdust/paper) had the lowest water absorption (63.88%) at board density of 850kg/m^3 while highest water absorption (112.57%) was recorded at 1000 kg/m^3 for blending proportion of 0/100% (sawdust/paper). Meanwhile, the mean values obtained for thickness swelling (TS) of the boards produced for density 850 and 1000 kg/m^3 ranged from 15.58 to 47.46 and 16.74 to 40.71% respectively. The result showed that 850kg/m^3 density board with blending proportion (0/100%) had the lowest thickness swelling value (15.58%) while 50/50% blending proportion of the same board density had the highest thickness swelling (47.46%).

Table 2 shows the mean values obtained for selected mechanical properties of the boards. For MOR, least value (0.95N/mm^2) was obtained at 100/0% BP for board density of 850kg/m^3. MOR for blending proportion of 25/75% at 1000kg/m^3 board density had the highest mean value.

Meanwhile, highest value for MOE (37.03N/mm^2) was recorded at 100/0 % BP of 1000kg/m^3 board density while the least value (6.38N/mm^2) was found at 0/100 % BP of 850 kg/m^3. It can be observed that blending proportion of 100/0% had the highest MOE values of 35.32 and 37.03N/mm^2 for both 850 and 1000 kg/m^3 boards.

Notwithstanding Table 3 shows analysis of variance of the physical and mechanical properties tested at 5% level of probability. It shows that board density is not significantly different with respect to the physical and mechanical properties tested. Whereas, blending proportion shows a significant difference with respect to the physical and mechanical properties tested. Meanwhile, interaction between board density and blending proportion was significant different for thickness swelling only. Thus, Table 4 shows the post-hoc analysis done for blending proportion for the physical and mechanical properties.

Additionally, Figs. 1 to 4 show the trend of the water absorption, thickness swelling, MOR, and MOE of the board with varying blending proportions respectively. BP of 0/100% (sawdust/paper) had the highest water absorption rate, while 50/50 BP was highest for thickness swelling, 25/75 BP was highest for MOR, and 100/0 BP was highest for MOE.

Table 1. The mean values of the board's physical properties

Board density (kg/m^3)	Blending proportion (%)	Water absorption (%)	Thickness swelling (%)
	0/100	110.78±4.72	15.58±2.50
	25/75	90.72±17.49	30.17±9.89
850	50/50	99.90±19.71	47.46±12.46
	75/25	73.87±10.80	23.67±4.08
	100/0	63.88±4.84	26.16±4.08
Mean		87.83±8.51	28.61±5.28
	0/100	112.57±4.94	16.74±2.49
	25/75	93.36±15.68	32.15±10.14
1000	50/50	76.19±26.60	23.31±2.34
	75/25	76.46±9.99	40.71±14.10
	100/0	65.85±5.88	27.22±4.14
Mean		84.09±8.21	28.03±4.05

Where BP = Blending proportion (sawdust/paper)

Table 2. Mean values of the board's mechanical properties

Board density (kg/m)	Blending proportion (%)	MOR (N/mm^2)	MOE (N/mm^2)
	0/100	1.15±0.23	6.38±2.00
	25/75	1.77±0.17	11.47±2.40
850	50/50	1.36±0.14	15.49±3.40
	75/25	1.39±0.18	11.08±5.02
	100/0	0.95±0.45	35.32±8.31
Mean		1.32±0.14	15.95±5.05
	0/100	1.12±0.23	7.54±1.89
	25/75	1.89±0.12	12.50±2.58
1000	50/50	1.24±0.29	16.77±1.63
	75/25	1.21±0.33	21.34±0.28
	100/0	1.30±0.44	37.03±8.32
Mean		1.35±0.14	19.04±5.05

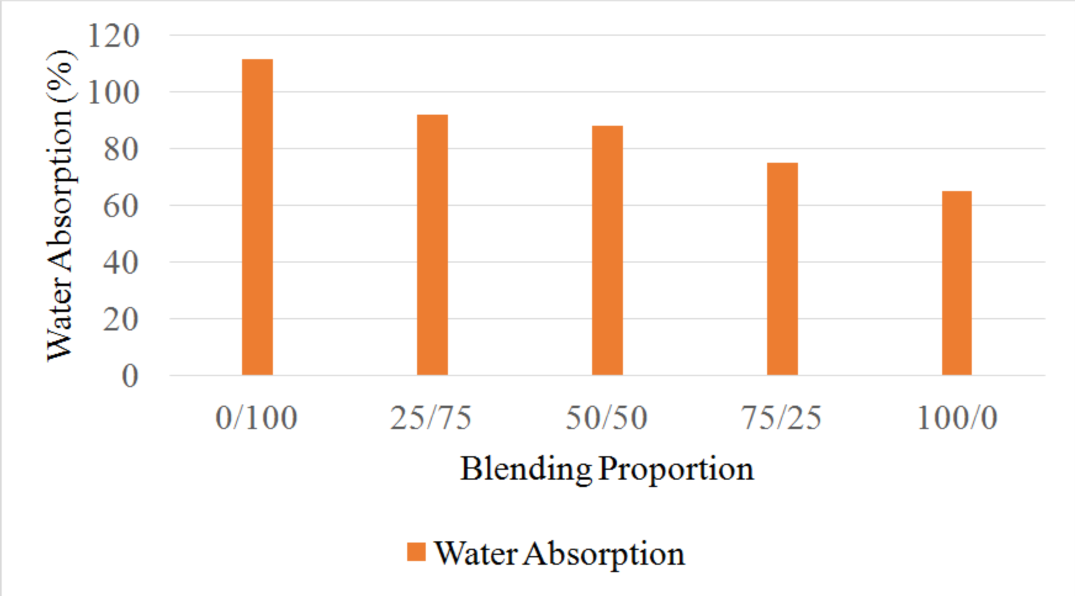

Fig. 1. Water absorption of the board with respect to blending proportions

Table 3. Analysis of Variance showing P-values for properties tested on the board

Source of variance	DF	Water absorption	Thickness swelling	MOR	MOE
Density	1	0.57^{ns}	0.84^{ns}	0.81^{ns}	0.07^{ns}
BP	4	0.01*	0.01*	0.01*	0.01*
Density * BP	4	0.42^{ns}	0.01*	0.87^{ns}	0.33^{ns}
Error	20				
Total	29				

*ns = not significant * = significant at 5% level of probability P ≤ 0.05*
BP=Blending proportion; MOE = Modulus of elasticity; MOR= Modulus of rupture

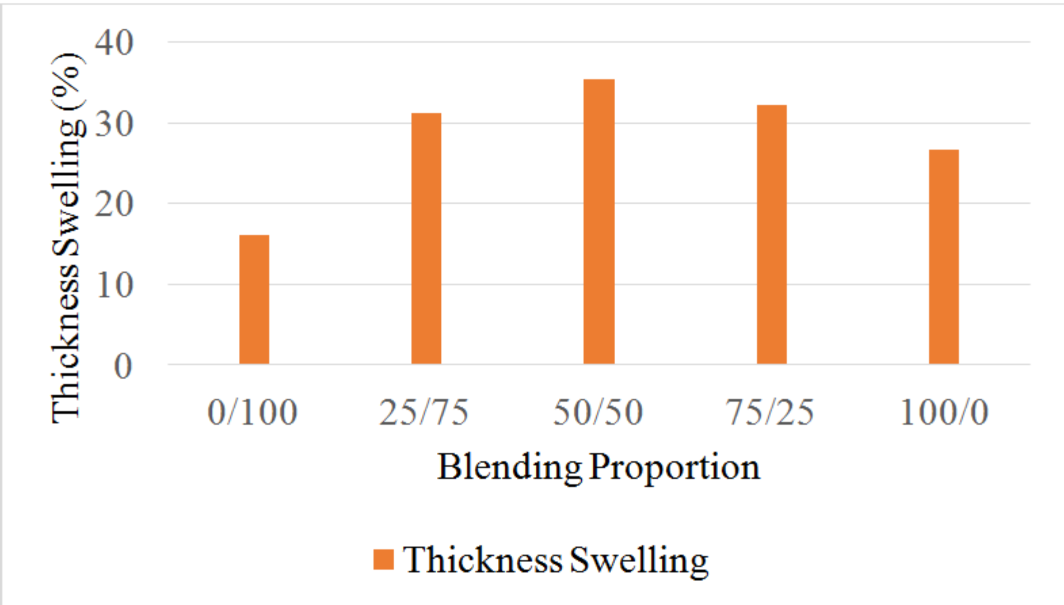

Fig. 2. Thickness swelling of the board with respect to blending proportions

Table 4. Post-hoc analysis of blending proportion

BP (sawdust/paper)	Water absorption	Thickness swelling	MOR	MOE
0/100	111.68[d]	16.16[a]	1.13[a]	6.96[a]
25/75	92.04[c]	31.16[b]	1.83[b]	12.00[b]
50/50	86.04[c]	35.39[b]	1.30[a]	16.13[b]
75/25	75.17[b]	32.19[b]	1.30[a]	16.21[b]
100/0	64.87[a]	26.69[ab]	1.30[a]	36.18[c]

Means in the same column having the same alphabetical superscripts are not significantly different (P ≤ 0.05)

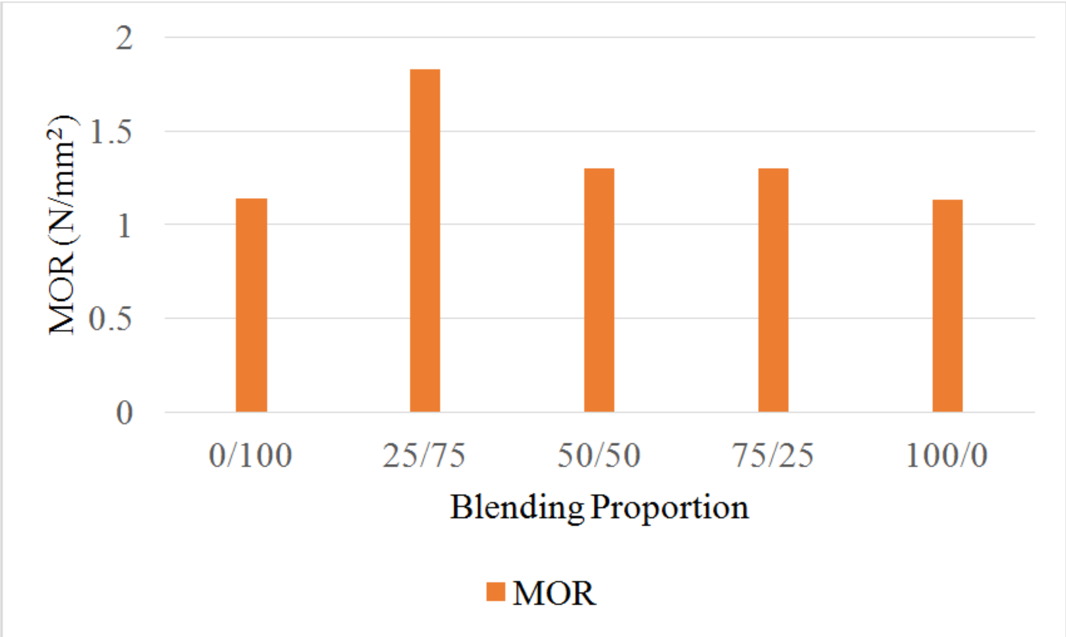

Fig. 3. MOR of the board with respect to blending proportions

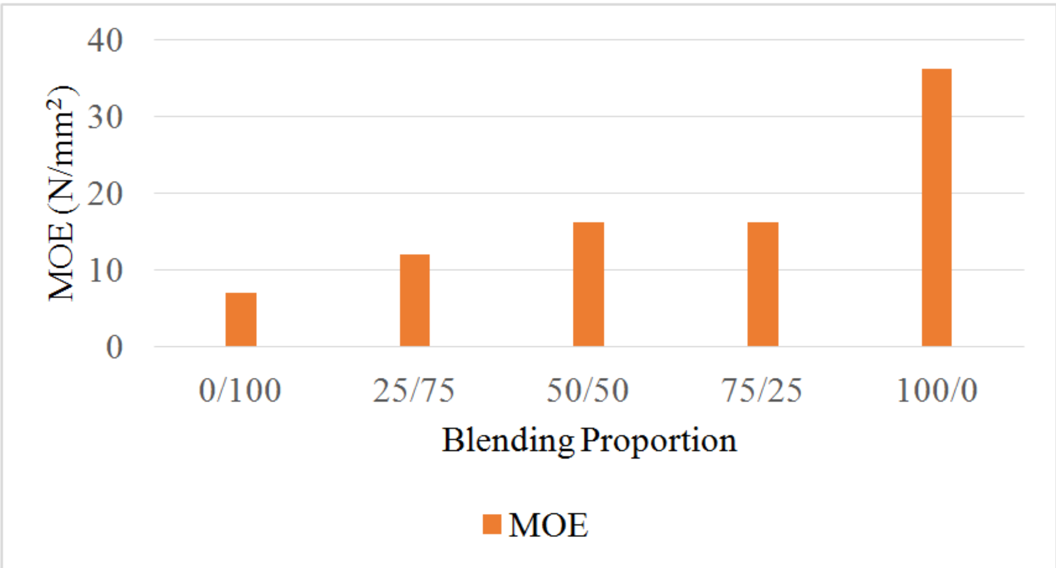

Fig. 4. Board MOE with respect to blending proportions

4. DISCUSSION

4.1 Percentage Water Absorption (% WA)

This test gave insight into the rate at which the boards absorb water, and since values above 0% were recorded then the boards can be dimensional unstable during service. Hence, a high rate of water absorption can be a disadvantage to a board when in service, as it will tends to destabilize its dimension. Therefore, 1000kg/m^3 density board is expected to be more dimensionally stable than 850kg/m^3 board owing to its lower mean value of water absorption. However, analysis of variance done suggested no significant difference between values of WA with respect to board density since P-value was greater than 0.05.

On the other hand, there existed a downward trend in water absorption values for blending proportions. It can be inferred from the DMRT that the BP containing only paper had the highest and significantly different water absorption while the least water absorption rate was found at BP containing only sawdust. This therefore implies that board formed with sawdust only had the best dimensional stability as it was significantly different from others. It also suggests that using waste paper only for board production is not suitable for a better water absorption. Meanwhile, sawdust and paper are expected to have performed relatively the same because they are both lignocellulose materials. However, disparity have occurred because the waste paper may have contained secondary fibers.

Also, the significant percentage increase of water absorption in sawdust with respect to decrease in the percentage of water absorption in paper may be due to poor water retention ability of saw dust due to the presence of pore spaces, while high water retention ability of paper is due to the presence of fused fibre, and as such supports [11]

Values of water absorption found in this study was similar to [12] who recorded a value of 100 - 148.5% for board produced from sawdust and plastic waste, but was higher than fiberboard made form giant bamboo (14.9-28%) [13]. This could therefore mean that board produced from other materials may be more dimensionally stable than ones made from sawdust only. Nevertheless, there was a need to test for thickness swelling of board produced, so as to ascertain the possible extent of the influence of water absorption on dimensional stability of the boards.

4.2 Percentage Thickness Swelling (% TS)

[14,15] asserted that wood composite material will absorb variable amount of moisture that can cause dimensional changes. Also, [13] recorded higher TS with respect to higher WA. Therefore, water absorption is expected to result in dimensional changes such as its thickness swelling. The thickness swelling recorded in this study thus increases with respect to the WA of the board density. However, TS of the boards are not significantly different from each other. This implies that the dimensional changes in the boards produced are not as a result of difference in the board density. However, significant interaction of density and blending proportion suggests that board density of 1000kg/m^3 with BP of 0/100 was most dimensional stable. Meanwhile, lowest value of TS for BP of 0/100 was significant difference from other BP as evident in the post hoc analysis done. As such, this study found that BP can affect dimensional stability of composite boards

Although, higher water absorption may be expected to mean higher thickness swelling, but BP of 0/100 which had the highest WA was found to have the lowest TS. Notwithstanding, [14] stated that variation in thickness swelling of composite materials can also be attributed to factors such as; the method of production, adhesive use, and wood species.

Since the adhesive used in this study is not water resistance, higher water absorption rate and variation in dimensional stability exhibited by the boards produced may have occurred because of the adhesive used, thus contributing to the intersperse variation in percentage thickness swelling.

4.3 Flexural Strength

Modulus of Elasticity is the ability of a material to regain its original shape and size after being stressed [16]. [17] stated that the ability of wood member to bend freely and regain normal shape is called flexibility, and the ability to resist bending is called stiffness. The Modulus of Elasticity (MOE) which is the measure between stress and strain within the limit of proportionality provides a convenient measure of stiffness or flexibility of a timber.

The findings of this work thus suggest that MOR and MOE of composite board increases with higher density. Although there was no significant difference in these values, this observation is still in line with the findings of [14,18] with an acknowledgement that decrease in the density also leads to decrease in flexural strength properties while an increase in density the increases the flexural strength. In addition, [19] and Fernandez [20] stated that, at constant moisture content, the higher the density of the board, the greater its strength. On the other hand, BP can also affect flexural strength as BP of 25/75 had better and significantly different MOR from other BP, while BP of sawdust alone (1000/0) had the best and significantly different MOE.

MOR and MOE are both flexural test, as such BP which performed better at MOR should performed better for MOE too. However, the reverse is the case as BP of 25/75 performed better for MOR and 100/0 for MOE. This trend is unexpected and contradictory. Nevertheless, [14] and [18] opined that most of the physical and mechanical properties of composite and panel boards depend mainly on the interaction between wood and the adhesive material. Therefore, poor interaction between the sawdust/paper and adhesive may have been the cause of this trend.

5. CONCLUSIONS

A durable Medium Density Fiberboard was successfully produced from sawdust and waste paper using FEVICOL as the binder. Thus, can help to reducing environmental degradation and pollution caused during the indiscriminate disposal and burning of waste paper and sawdust, and eventually create a clean environment. Density of boards formed was not found to significantly affect the selected physical (water absorption and thickness swelling) and mechanical properties (MOR and MOE) whereas blending proportion does. However, board density of 1000 kg/m^3 with BP of 0/100 was most dimensional stable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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