**International Journal of Materials Science and Applications**
2021; 10(1): 1-7
http://www.sciencepublishinggroup.com/j/ijmsa
doi: 10.11648/j.ijmsa.20211001.11
ISSN: 2327-2635 (Print); ISSN: 2327-2643 (Online)

# Effect of Production Variables on the Physico-Mechanical Properties of Fibre-Reinforced Plastic Composites Boards Produced from Waste Paper and Re-Cycled Polyethlene

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## To cite this article:

Aguda Lawrence, Kehinde Rebecca, Orire Luke, Olajide Benard, Akala Abisayo, Ajao Olawale. Effect of Production Variables on the Physico-Mechanical Properties of Fibre-Reinforced Plastic Composites Boards Produced from Waste Paper and Re-Cycled Polyethlene. *International Journal of Materials Science and Applications*. Vol. 10, No. 1, 2021, pp. 1-7. doi: 10.11648/j.ijmsa.20211001.11

**Received**: November 23, 2020; **Accepted**: December 8, 2020; **Published**: January 12, 2021

**Abstract:** The mechanical and physical properties of fibre reinforced composite boards (FRCB) made from waste paper and recycled polyethylene was investigated. The composite boards were produced at three levels of mixing ratio (50:50, 60:40 and 70:30) and three levels of board density (1000 $Kg/m^3$, 1100 $Kg/m^3$ and 1200 $Kg/m^3$). The fibre from the paper served as the reinforcement while the polyethylene served as the matrix or binder to form the composite board. The board produced was subjected to different standard tests to attain mechanical and physical properties such as modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA) and thickness swelling (TS). The mean values obtained for Thickness Swelling after 24 hours and 48 hours ranged from $0.02 \pm 0.04$ to $6.05 \pm 3.21$ and $3.06 \pm 1.27$ to $12.59 \pm 0.05$ respectively and that of water absorption after 24 hours and 48 hours ranged from $4.68 \pm 0.25$ to $15.78 \pm 6.15$ and $5.36 \pm 0.16$ to $18.37 \pm 6.03$ respectively. The mean value for MOR and MOE ranged from $16.36 \pm 9.71$ to $18.17 \pm 6.76$ and $3813.4 \pm 1938.76$ to $4842.8 \pm 1381.05$ respectively. These results shown that both the WA and TS decreased with the increase in the board density and mixing ratio. On the other hand, MOR and MOE of the board increased with the increase of board density and the mixing ratio. The results obtained from this study shown that natural fibre from waste paper and recycled polyethylene are compatible for use to produce composite material.

**Keywords:** Waste Paper, Matrix, Polyethylene, Composite Boards

## 1. Introduction

Composite technologies (plywood, particleboard, flake board and hardboard) have for decades been used to create value-added commodity for building and home furnishing products likes ceiling boards, floor and wall tiles [1]. More recently, new innovative bio-based composite products based on natural fibres, such as agricultural fibres or residues have also come into the market and now compete directly with traditional wood composites [17]. Other similar new hybrid products, such as wood or natural fibres plastic composites, have recently become popular for decking, roofing, fenestration, and millwork [11].

In the world today, plastic and paper waste is a major environmental concern. The high amount of waste generated, non-biodegradability and the fastest depletion of natural resources regarding its short life cycle, increased amount of material utilized in its production, and waste generated of plastic have become a great problem [15]. Lots of attempts have been made globally especially in developed countries to utilize these waste more importantly as an alternative to virgin material. Therefore utilizing plastic and paper wastes for the production of composite will help to reduce the pressure on the forest, reduce environmental pollution and hazards and also reduce emission of greenhouse gasses from burning these wastes which leads to global warming.

In recent time, there has been an increase in technological re-orientation towards utilization of waste in the creation of value added products. Examples of this is in the utilization of plastics reinforce with paper, agricultural residue or forest products waste in the production of plastic composites. This is an attempt to reduce waste by renewably using it in creating panel, construction or furniture products [13] as well as aiming towards environmentally safe usage of natural resources. The interest for collecting waste and recycling them for use has been increasing globally. The use of these recycled waste materials offers potential benefits both environmentally and socio-economically as they are cheap, abundantly available, resource oriented when handled appropriately and the environmental problems associated with inappropriate disposal are eliminated [2, 12].

Fibre reinforced-plastic composite can be made from virgin materials as well as recycled ones, in Nigeria, plastic waste is enormous and its disposal has always been a challenge. In using recycled plastic for FRPCs, the advantages are that; the raw materials are readily available; it controls the plastic waste hazard and also save some virgin and natural products. The use of plastic in the world and Nigeria specifically is increasing daily due to the fact that plastic is cheap, light, flexible, easy to shape and recyclable [19]. These properties and others makes plastic find their way into the production of many product, from engineering, construction, domestic, electronics and many more products [16].

The interest in using plastic as binder in composite board is attributed to its properties displayed and recently, organic fillers from wood, paper and agricultural plants have gained tremendous attention from plastic industry. The introduction of organic fillers in plastic industries was attributed to the improved strength properties, high dimensional stability, environmental friendly and resistance to insect and fungal attack [2]. The advantages of using organic fillers (wood residues) in thermoplastics can be attributed to its low densities, low cost and non-abrasive in nature [9].

# 2. Materials and Methods

### *2.1. Location of the Study Area*

This study was carried out at the Forestry Research Institute of Nigeria, Ibadan and in the Department of Forestry and Wood Technology, Federal University of Technology Akure, Ondo State, Nigeria.

### *2.2. Methods of Production*

Collection and Preparation of Waste Paper and density polyethylene.

The waste paper that was used for the project was gotten from provision stores and dumping site at Aleshinloye Market, Jericho, Ibadan, Oyo state, Nigeria. The waste paper (cartons) was shredded and soaked in water for 7 days for easy defibration and to extract the chemicals. The soaked paper was air-dried as well as oven dried for three weeks before it was taken to the mill to be grinded into fine particles. The grinded paper was sieved using 2mm sieve mesh to get fine particles. Also, the low density polyethylene was obtained at the Department of Forest Production and Utilization Unit (FPD&U) at Forest Research Institute of Nigeria, Jericho. The used-polyethylene was washed and air dried and latter cut into smaller particles and then shredded with the use of milling machine.

### *2.3. Board Formation*

The waste paper and Plastic was weighed at different mixing ratio of 1:1, 2:1 and 3:1 at densities of 1000 kg/m$^3$, 1100 kg/m$^3$, 1200 kg/m$^3$. Based on the mixing ratio, the plastic and waste paper was put into the Mixer cylinder machine then latter introduced into mold. The compressor was used to press the material in the mold at a regulated temperature for board formation, the board was then be allowed to cool before de-molding.

### *2.4. Board Testing*

#### *2.4.1. Physical Properties Test*

The test samples dimension for physical properties was 50 mm x 50 mm x 10 mm

***(i) Water Absorption***

The water absorption and thickness swelling were carried out according to American Standard Method (ASTM…….). The water absorption and thickness swelling is determined using the equation 1 and equation 2

$$WA = \frac{W_2 - W_1}{W_2} \times 100 \quad (1)$$

Where:

WA = water absorption (%), $W_2$ = final weight after immersion (g), $W_1$ = initial weight before immersion (g).

***(ii) Thickness Swelling***

The thickness of the specimens was measured with electronic veneer caliper before soaking and after soaking for 24 hours and 48 hours respectively. The thickness swelling was express as the percentage of increase in thickness of the board over the initial thickness.

$$TS = \frac{T_2 - T_1}{T_2} \times 100 \quad (2)$$

Where: TS = Thickness swelling (%), $T_2$ = Final thickness after immersion in water (mm)

$T_1$= Initial thickness before immersion in water (mm)

#### *2.4.2. Mechanical Test Properties*

The mechanical properties determined are Modulus of Elasticity (MOE) and Modulus of Rupture (MOR), following the ASTM 1987 American Society of Testing Material. (d1037-78) standard methods of evaluating the properties of wood based fibre and particle panel materials.

***(i) Modulus of Rupture (MOR)***

Modulus of rupture is the maximum load carrying capacity of a wooden member. The modulus of rupture (MOR) of the PPC was determined using the Universal Testing Machine, Modulus of Rupture was calculated using the formula below:

$$MOR = \frac{Pl}{bd^2} \quad (3)$$

Where; MOR = Modulus of rupture (N/mm$^2$), P = failed load at a given point (N), L = board span between center of supports (mm), b = width of the board sample (mm), d = thickness of the board sample (mm).

***(ii) Modulus of Elasticity (MOE)***

Modulus of Elasticity (MOE) which is the measure of the stiffness properties of the board was determined from the bending test carried out on the specimen. The Modulus of Elasticity of the board was calculated using the formula below:

$$MOE = \frac{Pl}{db\Delta} \quad (4)$$

Where: MOE = modulus of elasticity (N/mm$^2$), P = load (N), L = the span of load of board samples between the machine supports (mm), b = width of the board sample (mm), d = thickness of the board sample (mm), ΔS = slope from the graph.

# 3. Experimental Design

The statistical model used for this research work was 3x3 factorial experimental in completely randomized Design CRD with 3 levels of board density and 3 levels of mixing ratio resulting to 9 experimental specimens of the total board produced. The data collected was analyzed using the Statistical Package for Social Science (SPSS) and Microsoft Excel spreadsheet, analysis of variance (ANOVA) was also performed to determine the significant effect of the factors of production and Duncan Multiple Range Test was used to determine the level of significance between the levels of each of the factors at 5% probability level.

# 4. Results and Discussion

## *4.1. Physical Properties*

The mean value obtained for water absorption and thickness swelling after immersion in water for 24 hours and 48 hours are presented in Table 1. The mean values of water absorption ranges from 15.78 ± 6.15% to 4.68 ± 0.25 and 18.37 ± 6.03% to 5.36 ± 0.16% respectively as represented in Figure 1. The thickness swelling after 24 hours and 48 hours water immersion ranges from 6.05 ± 3.21% to 0.02 ± 0.04% and 12.59 ± 0.05% to 3.06 ± 1.27% as presented in the Table 1 and represented in figure 2.

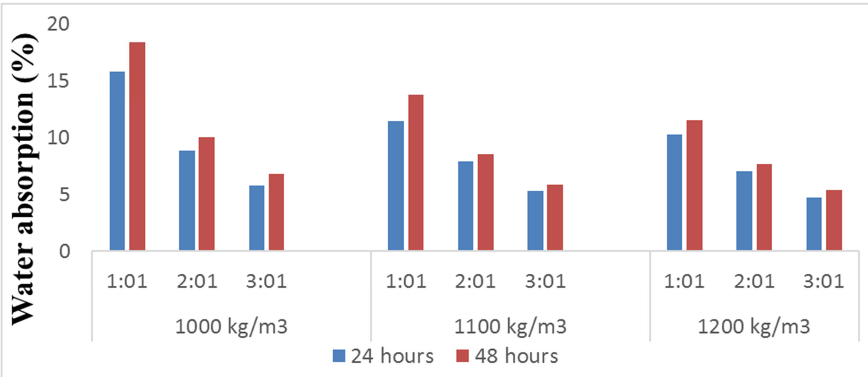


***Figure 1.*** *Effect of density and mixing ratio on water absorption of the paper plastic board.*

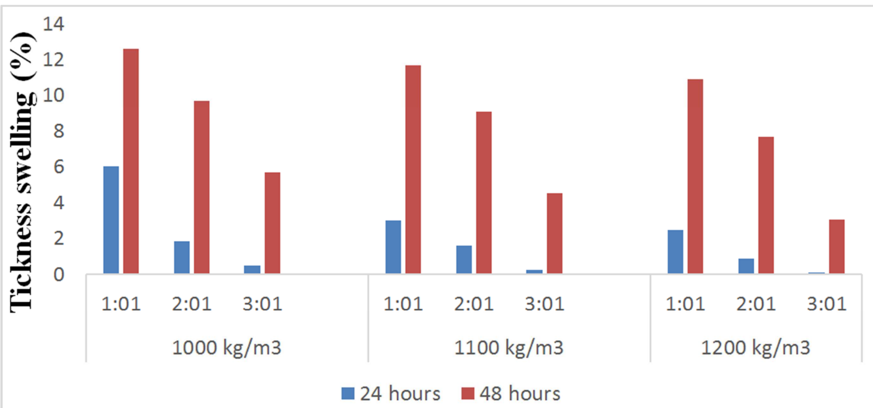


***Figure 2.*** *Effect of density and mixing ratio on Thickness swelling of the paper plastic board.*

***Table 1.*** *Mean values for Thickness swelling (TS) and Water absorption (WA) of plastic composite.*

| Mixing ratio | Density (Kg/m$^3$ | WA (%) 24h | WA (%) 48h | TS (%) 24h | TS (%) 48h |
|---|---|---|---|---|---|
| | 1000 | 15.78 ± 6.15 | 18.37 ± 6.03 | 6.05 ± 3.21 | 12.59 ± 0.05 |
| 1:1 | 1100 | 11.41 ± 0.14 | 13.78 ± 0.45 | 2.99 ± 0.26 | 11.67 ± 0.03 |
| | 1200 | 10.20 ± 0.39 | 11.50 ± 1.19 | 2.48 ± 0.08 | 10.89 ± 0.29 |
| | 1000 | 8.79 ± 0.32 | 9.99 ± 0.28 | 1.82 ± 0.19 | 9.71 ± 0.72 |
| 2:1 | 1100 | 7.87 ± 0.09 | 8.48 ± 0.07 | 1.58 ± 0.14 | 9.05 ± 0.07 |
| | 1200 | 7.06 ± 0.61 | 7.67 ± 0.47 | 0.88 ± 0.38 | 7.66 ± 1.29 |
| | 1000 | 5.81 ± 0.24 | 6.81 ± 0.32 | 0.47 ± 0.11 | 5.70 ± 0.47 |
| 3:1 | 1100 | 5.30 ± 0.14 | 5.84 ± 0.35 | 0.23 ± 0.10 | 4.55 ± 0.31 |
| | 1200 | 4.68 ± 0.25 | 5.36 ± 0.16 | 0.02 ± 0.04 | 3.06 ± 1.27 |

It was observed that as the Mixing ratio and board density increases, the TS and WA decreases. This is in agreement with the work on strength and dimensional Properties of plastic composite boards produced from *Terminalia superba* [5]. The work on short term performance of cement bonded hard wood flake boards [8]. The work on the dimensional stability and strength properties of inorganic bonded particle Boards made from *Eupatorium odorata* particles [9]. The work on effect of blending method on the mechanical properties of wood plastic composites [10]. Also the work on effect of weathering on strength and physical properties of Wood plastic composites produced from *Gmelina arborea* [14]. The findings of these authors also showed that both the mixing ratio and board density affect the water absorption and thickness swelling of the board produced. This result shows that the rate of water absorption of the board increased from 24 hours of soaking through 48 hours, the TS at 24 hours and 48 hours; WA at 24hours and 48 hours of the board produced decreases with increase in the board density and mixing ratio as illustrated in the figures 1 and 2. This result agreed with the findings from Comparative Studies on physic-Mechanical Properties of Wood Plastic Composites produced from three indigenous wood species [3]. Production of plastic bonded panel from waste materials [6]. Also from Strength Sorption properties of Plastic Bonded Board Produced from Coffee Chaff [18]. The paper plastic composite material with 50% of plastic and 50% (1:1) of paper has the highest mean values for percentage water absorption and thickness swelling, while the composite material with 75% plastic and 25% paper (3:1) has the lowest mean for WA and TS. This is due to reduction in pore spaces and good internal bond formation as the matrix or binder which is plastic increases. Because it is the cellulosic fibre from paper that absorb water thereby increasing water absorption property of the paper.

***Table 2.*** *Result of analysis of variance conducted for Water absorption and thickness swelling.*

| Source of variation | df | Sum of squares | Mean square | Fcal | sig |
|---|---|---|---|---|---|
| WA 24h Mixing Ratio | 2 | 318.362 | 159.181 | 37.04 | 0.00* |
| Board Density | 2 | 49.782 | 24.891 | 5.792 | 0.00* |
| Mixing ratio*Board Density | 4 | 27.689 | 6.922 | 1.611 | 0.20ns |
| Error | 27 | 116.028 | 4.297 | | |
| Total | 35 | 511.86 | | | |
| WA 48h Mixing Ratio | 2 | 457.804 | 228.902 | 53.488 | 0.00* |
| Board Density | 2 | 78.353 | 39.176 | 9.154 | 0.00* |
| Mixing ratio*Board Density | 4 | 35.301 | 8.825 | 2.062 | 0.11ns |
| Error | 27 | 115.546 | 4.279 | | |
| Total | 35 | 687.003 | | | |
| TS 24h Mixing Ratio | 2 | 80.625 | 40.313 | 34.096 | 0.00* |
| Board Density | 2 | 17.442 | 8.721 | 7.376 | 0.00* |
| Mixing ratio*Board Density | 4 | 14.769 | 3.692 | 3.123 | 0.03* |
| Error | 27 | 31.923 | 1.182 | | |
| Total | 35 | 144.76 | | | |
| WA 48h Mixing Ratio | 2 | 322.128 | 161.064 | 347.121 | 0.00* |
| Board Density | 2 | 27.521 | 13.761 | 29.657 | 0.00* |
| Mixing ratio*Board Density | 4 | 1.155 | 0.289 | 0.622 | 0.65ns |
| Error | 27 | 12.528 | 0.464 | | |
| Total | 35 | 363.331 | | | |

*significant at ($P < 0.05$) probability level; ns= not significant at ($P> 0.05$) probability level. WA= Water Absorption; TS= Thickness swelling

The result of analysis of variance (ANOVA) conducted for thickness swelling and water absorption at 0.05 level of probability in Table 2 shows that the board density and mixing ratio have significant effect ($p<0.05$) on TS at 24hours and 48 hours and for WA at 24 hours and 48 hours of the composite produced at 5% probability level. The result of the Duncan's Multiple Range Test at 5% level of probability presented in Table 3 shows that significant difference exist in TS at 24 hours and 48hours for mixing ratio 1:1, 2:1 and 3:1, similarly for WA at 24 hours and 48 hours. Also, no significant difference exist between board density levels of 1100 kg/m$^3$ and 1200kg/m$^3$ TS at 24 hours and 48 hours; also for WA at 24 hours and 48 hours.

***Table 3.*** *Result of Duncan Multiple Range Test for Water Absorption and Thickness Swelling.*

| Production variables | Levels | WA (%) 24h |
|---|---|---|
| | 1000 ($Kg/m^3$) | $10.13^a$ |
| WA 24h Density | 1100($Kg/m^3$) | $8.19^b$ |
| | 1200($Kg/m^3$) | $7.31^b$ |
| | 1:1 | $12.46^a$ |
| Mixing ratio | 2:1 | $7.91^b$ |
| | 3:1 | $5.26^c$ |
| | 1000 ($Kg/m^3$) | 11.72a |
| WA 48h Density | 1100($Kg/m^3$) | 9.36b |
| | 1200($Kg/m^3$) | 8.17b |
| | 1:1 | 14.54a |
| Mixing ratio | 2:1 | 8.71b |
| | 3:1 | 6.00c |
| | 1000 ($Kg/m^3$) | 2.78a |
| TS 24h Density | 1100($Kg/m^3$) | 1.60b |
| | 1200($Kg/m^3$) | 1.13b |
| | 1:1 | 3.84a |
| Mixing ratio | 2:1 | 1.43b |
| | 3:1 | 0.24c |
| | 1000 ($Kg/m^3$) | 9.34a |
| TS 48h Density | 1100($Kg/m^3$) | 8.42b |
| | 1200($Kg/m^3$) | 7.20c |
| | 1:1 | 11.71a |
| Mixing ratio | 2:1 | 8.81b |
| | 3:1 | 4.44c |

### *4.2. Mechanical Properties*

The result obtained for Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) are represented in table 4. The mean values obtained for modulus of elasticity and modulus of rupture ranges from 1242.2 ± 1224.58 $N/mm^2$) to 6242.8 ± 971.76 $N/mm^2$ and 11.54 ± 7.25 $N/mm^2$ to 24.95 ± 7.63 $N/mm^2$ The MOR of board density 1200$kg/m^3$ has the highest mean value with the mixing ratio of 3:1 while the lowest mean value recorded was for 1000$kg/m^3$ with mixing ratio 1:1. the same is applicable for MOE. It was observed that as the board density and mixing ratio increases, the modulus of rupture and modulus of elasticity increases as shown in figures 3 and 4.

***Table 4.*** *Mean values for Modulus of elasticity and Modulus of rupture of plastic/ paper Composite.*

| Mixing ratio | Density ($Kg/m^3$) | MOE ($N/mm^2$) | MOR ($N/mm^2$) |
|---|---|---|---|
| | 1000 | 1242.2 ± 1224.58 | 11.54 ± 7.25 |
| 1:1 | 1100 | 3654.2 ± 935.48 | 14.54 ± 4.47 |
| | 1200 | 4842.8 ± 1381.05 | 18.17 ± 6.76 |
| | 1000 | 3302.2 ± 1364.64 | 12.14 ± 5.73 |
| 2:1 | 1100 | 3406.9 ± 734.36 | 16.59 ± 5.22 |
| | 1200 | 4110.2± 651.84 | 15.29 ± 2.82 |
| | 1000 | 3813.4 ± 1938.76 | 18.07 ± 2.51 |
| 3:1 | 1100 | 4721.9 ± 189.09 | 16.36 ± 9.71 |
| | 1200 | 6242.8 ± 971.76 | 24.95 ± 7.63 |

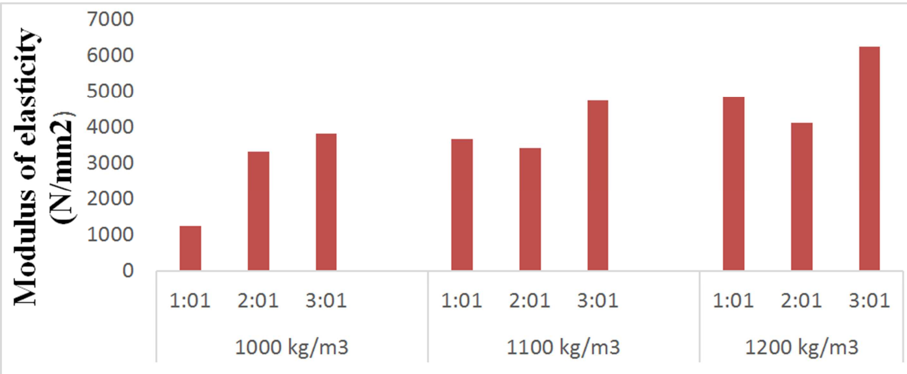


***Figure 3.*** *Effect of density and mixing ratio on Modulus of Elasticity of the paper plastic board.*

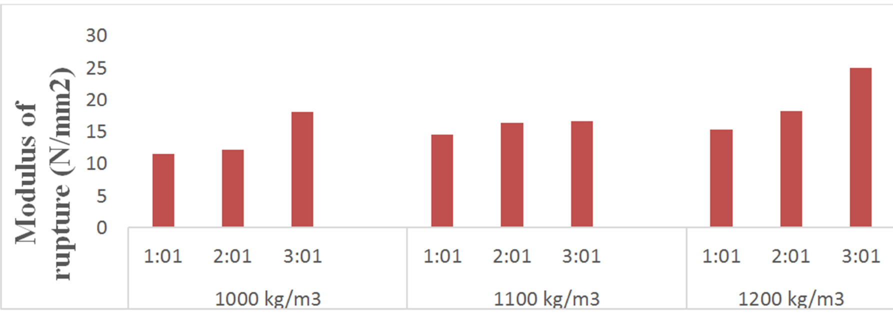


***Figure 4.*** *Effect of density and mixing ratio on Modulus of Rupture of the paper plastic board.*

According to [7], the higher the board density and mixing ratio, the stronger and dimensionally stable the board produced. This may be attributed to the increase in binder content, which is accountable for increase in hardness of the board as it showed highest resistance to bending force. This is also in agreement with finding on comparative study on properties of wood plastic composites produced from coffee chaff and *Ceiba pentandra* sawdust [4]. This result is in agreement with the work on production of plastic bonded panel from waste materials [6]. Also on short term performance of cement bonded hard wood flake boards [8].

***Table 5.*** *Result of analysis of variance conducted for Modulus of Rupture and Modulus of Elasticity.*

| | Source of variation | df | Sum of squares | Mean square | Fcal | sig |
|---|---|---|---|---|---|---|
| | Mixing Ratio | 2 | 18770000 | 9384301.38 | 7.129 | 0.00* |
| | Board Density | 2 | 25070000 | 12540000 | 9.524 | 0.00* |
| MOE | Mixing ratio*Board Density | 4 | 15450000 | 3862385.91 | 2.934 | 0.04* |
| | Error | 27 | 35540000 | 1316364.49 | | |
| | Total | 35 | 94830000 | | | |
| | Mixing Ratio | 2 | 416.94 | 208.47 | 6.35 | 0.01* |
| | Board Density | 2 | 375.96 | 187.98 | 5.73 | 0.01* |
| MOR | Mixing ratio*Board Density | 4 | 203.85 | 50.96 | 1.55 | 0.22ns |
| | Error | 27 | 885.79 | 32.81 | | |
| | Total | 35 | 1882.54 | | | |

*significant at ($P < 0.05$) probability level; ns= not significant at ($P > 0.05$) probability level. WA= Water Absorption; TS= Thickness swelling

The result of the ANOVA as presented in table 5 shows that BD and MR had significant effects on the MOE and MOR of the composites produced at 5% probability level. There is no significance difference between the interaction of the BD and MR. The DMRT result in Table 6 also shows that for MOE at board density level, there is significant difference between board densities 1000kg/m$^3$ and 1100 kg/m$^3$, 1000 kg/m$^3$ and 1200 kg/m$^3$, but there is no significant difference between board density 1100 kg/m$^3$ and 1200 kg/m$^3$. But for mixing ratio, there is no significant difference between 1:1 and 1:2 but there is significant different between 3:1 and 1:1, and 3:1 and 2:1 (Table 5). The result of DMRT for MOR at the density level in Table 6 shows that there is significant difference between board density 1000 kg/m$^3$ and 1100 kg/m$^3$, 1100 kg/m$^3$ and 1200 kg/m$^3$. Also at the mixing ratio levels, the DMRT shows that there is no significant difference between 1:1 and 2:1.

***Table 6.*** *Result of Duncan Multiple Range Test for Water Absorption and Thickness Swelling.*

| Production variables | Levels | WA (%) |
|---|---|---|
| | 1000 (Kg/m$^3$) | 5065.3a |
| MOE Density | 1100(Kg/m$^3$) | 3088.8b |
| | 1200(Kg/m$^3$) | 3624.8b |
| | 1:1 | 3246.4b |
| Mixing ratio | 2:1 | 3606.4b |
| | 3:1 | 4926.0a |
| | 1000 (Kg/m$^3$) | 11.58b |
| MOR Density | 1100(Kg/m$^3$) | 14.95ab |
| | 1200(Kg/m$^3$) | 19.47a |
| | 1:1 | 11.54b |
| Mixing ratio | 2:1 | 14.68b |
| | 3:1 | 19.79a |

## 5. Conclusion

This result of this study shows the suitability of waste paper and polyethylene for the production of fibre Reinforced plastic Composite. The dimensional stability of the board is enhanced with increased in the level of mixing ratio and board density. Higher proportion in the plastic caused increase in mechanical properties (MOE and MOR) and decrease in dimensional movement of the board. From the production and investigation of the properties of the board, it was observed that: the TS and WA decreased with increased in plastic/ paper mixing ratio as well as the board density, and the MOE and MOR increased with increased plastic/ paper mixing ratio and board density.

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