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RESEARCH

Eco-Friendly (Water Melon Peels): Alternatives to Wood-based Particleboard Composites

The aim of this study was to investigate the suitability of using water melon peels as alternatives to wood-based particleboard composites. The water melon peels composite boards were produced by compressive moulding using recycled low density polyethylene (RLDPE) as a binder. The RLDPE was varies from 30 to 70wt% with interval of 10wt%. The microstructure, water absorption(WA), thickness swelling index(TS), modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding strength(IB), impact strength and wear properties of the boards were determined. The results showed that high modulus of rupture of 11.45N/mm^2, MOE of 1678N/mm^{2,} IB of 0.58N/mm^2, wear rate of 0.31g were obtained from particleboard produced at 60wt%RLDPE. The uniform distribution of the water melon particles and the RLDPE in the microstructure of the composites board is the major factor responsible for the improvement in the mechanical properties. The results showed that the MOE, MOR and IB meet the minimum requirements of the European standards, for general purpose like panelling, ceiling, partitioning. Hence, water melon particles can be used as a substitute to wood-based particleboard for general purpose applications also besides being environmental friendly of using watermelon and RLDPE in production of particleboard, this alternative to wood-based particleboard is very cost-effective.

Keywords: *Board composites, Water melon particles, Mechanical, Physical and Wear properties*

1. INTRODUCTION

The demand for wood composites from waste wood has been increasing as timber resources in natural forests decline. The use of renewable biomass as a raw material in composites production was one approach and the use of renewable biomass may result in several benefits such as environmental and socio-economic [1]. Today renewable biomass are mostly accepted as waste materials and are mostly ploughed into the soil or burnt in the field.

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Traditionally, particleboard has been made out of wood-based fibers bound together using a formaldehyde resin. The desired thickness is achieved by using a hot press that forms the board into sheets [2]. Particleboard has a homogenous structure and can be manufactured in different sizes, thickness, densities and grades for numerous uses, making it a desirable material with which to work [2].

One of the major challenges associated with wood-based particleboard is the use of Formaldehyde resin Formaldehyde is a volatile, colorless gas with a strong odor that is commonly used in industrial processes, particularly in manufacturing building materials. Pressed wood products, such as wood-based particleboard and medium density fiberboard, are made using adhesive resins containing urea-formaldehyde. Off-gassing levels are at their highest when the products are new, with emissions tapering off as they age. Exposure to formaldehyde in concentrations greater than 0.1 parts per million (ppm) can cause nasal and throat congestions, burning eyes, or headaches as well as increasing the risk of developing cancer [2].

According to the end uses of wood-wastes and their possible reuse products, particleboard has found typical applications as flooring, wall and ceiling panels, office dividers, bulletin boards, furniture, cabinets, counter tops, and desk tops [3, 4], and it seems that the manufacture of particleboard from biomass wastes is the most common way to reuse such waste materials [1, 6].

Wood composite industries demand more wood raw material everyday despite the fact that the forest resources are diminishing. The decline in wood material source has led researchers to study non-wood ligno-cellulosic biomass utilization in composite manufacturing including particleboard. Agricultural waste materials and annual plant fiber have become alternative raw materials for the production of particle or fiber composite materials. The most frequently referred alternative non-wood materials are flax, bagasse, hemp, reed, and cereal straws such as rice and wheat straw [1]. Today chemical pulp and panel products using wheat straw and other crop residues are being commercially manufactured in a number of countries including Nigeria [6]. There is still a growing need to find alternative sources of raw materials for composite manufacturing. Therefore, the aim of this study is to investigate the potential utilization of water melon peels using recycled low density polyethylene as binder in particleboard production as supplement, to alleviate the shortage of raw material in forest industry and also to avoid the toxic nature of Formaldehyde commonly used binder.

2. MATERIALS/ EQUIPMENT

The water melon peels used in this work was obtained from 'Sabon Gari' area of Zaria in Kaduna state Nigeria (see Figure 1).

Figure 1. Photograph of the water melon peels

Waste Pure water sachet (RLDPE)" used was collected literally from the streets of Zaria and around refuse dumps. Cut in to small pieces with the aid of blades and pair of scissors (see Figure 2).

Figure 2. The RLDPE Resin used

Equipment used in this research are-, Metal mould, hydraulic press, Avery Denison impact tester, Instron machine, grinding and polishing machine, Scanning electron microscope(SEM) and Pin on Disc wear machine.

2.1 METHOD

The particle size analysis of the water melon peels particles was carried out in accordance with BS1377:1990 [7]. About 100g of the particles was placed unto a set of sieves arranged in descending order of fineness and shaken for 15minutes which is the recommended time to achieved complete classification, the particle that was retained in the BS. 100µm was used in this study (see Figure 3).

Figure 3. Photograph of the water melon peels sieve particles

Metal Molds was used in the production of the board composite samples. Each mold had a cavity to accommodate the board composite samples. The dimensions and shapes of cavities were made according to the size and shape of the samples as per ASTM Standard D 638-90 for tensile testing and ASTM Standard D 790-97 for flexural testing [7]. After drying the water melon particles and RLDPE in oven at 105°C, the agro-waste particles and the RLDPE was then compounded in a two roll mill at a temperature of 130°C, into a homogenous mixture. Board production was carried out on an electrical heated hydraulic press. The mixtures were then placed in a rectangular mould. The boards were pressed by varying the RLDPE Resin from 30-70wt% with 10wt% interval. At the end of press cycle the board was removed from the press for cooling.

The scanning electron microscope (SEM) JEOL JSM-6480LV was used to identify the surface morphology of the board composite samples. The surfaces of the board composite specimens are examined directly by scanning electron microscope JEOL JSM-6480LV. The samples were washed, cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. The digitized images were recorded.

The basic method of determining the density of board composite samples was by measuring the mass and volume of the sample used. A clean sample is weighed accurately in air using a laboratory balance and then suspended in water. The weight of the sample when suspended in water was determined, the volume of the sample was determined from the effect of displacement by water (Archimedean principle). The density of the sample was then estimated from equation below [8]:

$$Density = \frac{Mass}{Volume}$$

Specimens with dimensions of 50 mm x 50 mm were prepared for evaluation of the thickness swelling. The thickness at the middle of the test specimen was measured with a micrometer. Then the test specimens were place into water in parallel for 30 mm and soaked for 24 h before further measurement of the thickness. The Thickness swelling rate (TS) was determined from the following formula [8]:

$$\mathrm{TS}_{24} = \frac{(t_{24} - t_0)}{t_0} \times 100$$

Where TS is the thickness swelling rate (%), t_0 and t_{24} are the thickness at the middle of the test specimen. The values of the WA as percentages were calculated [8]:

$$\mathrm{WA}(t) = \frac{\mathrm{W}(t) - Wo}{Wo} \times 100$$

where WA(t) is the water absorption (%) at time t, W_0 is the initial weight, and W(t) is the weight of the sample at a given immersion time t.

Bending specimens of 50 mm wide 275 mm long were cut from each full particleboard. A concentrated bending load was applied at the center with a span of 15 times the thickness of the specimen. The bending modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated from load deflection curves according to the following formula [8]:

$$\mathrm{MOR} = \frac{3P_b L}{2bh^2}$$

$$\mathrm{MOE} = \frac{P_{bp} L^3}{4bh^3 Y_p}$$

Where P_b is the maximum load (N), P_{bp} is the load at the proportional limit (N), Y_p is the deflection corresponding to P_{bp} (mm), b is the width of the specimen (mm), h is the thickness of the specimen (mm), and L is the span (mm).

The tensile strength perpendicular to the surface was determined using three conditioned specimens of 50 mm x 50mm from each particleboard. The rupture load (Ps) was determined and internal bond strength (IB) was calculated using the following formula [7].

$$\mathrm{IB} = \frac{P_s}{bl}$$

Where Ps is the rupture load, and l is the length of the specimen.

The impact test of the board composites sample was conducted using a fully instrumented Avery Denison test machine. A Charpy impact test was conducted on notched samples. Standard square impact test sample of measuring 75 x 10 x 10 mm with notch depth of 2 mm and a notch tip radius of 0. 02 mm at angle of 45° was used [7].

A pin-on-disc test apparatus was used to investigate the dry sliding wear characteristics of the composites as per ASTM G99- 95 standards [9]. The wear test was conducted using sliding speed of 1m/s, applied load of 10N and sliding distance of 1000m.

3. RESULTS AND DISCUSSION

Macrostructural studies of the particleboard revealed a uniform distribution of agro-waste particles with the RLDPE binder. The distribution of particles is influenced by the compounding of the particle and the binder which resulted to good interfacial bonding (see Figure 3). However during the production of the boards, RLDPE resin binder at 10-20wt% addition did not give good bonding, as the RLDPE binder increased beyond 20wt% good bonding of the particles and the resin was obtained. This observation is in par with the earlier studying of *Atuanya et al* [2].

Figure 3. Photograph of the developed particleboard

The morphologies of the particleboard composites by SEM are shows in Figures 4-6. Morphological analysis using SEM clearly show difference in the morphology of the particleboard composites (see Figures 4-6). The microstructure clearly shows that when the agro-waste particle was added to the RLDPE resin morphological change in the structure take place.

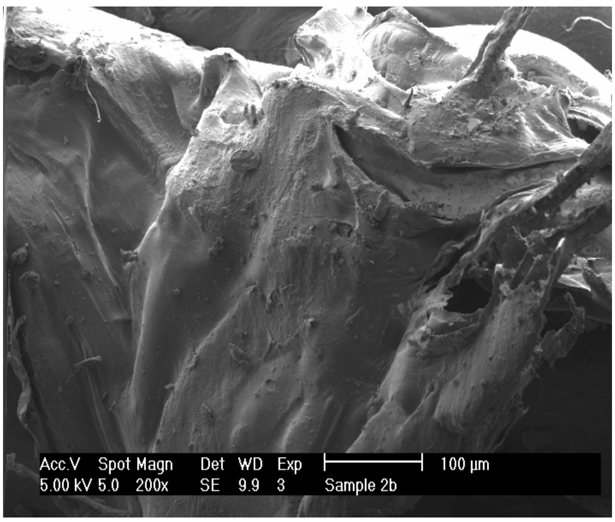

Figure 4. SEM microstructure of the water melon peels particleboard with 30wt% RLDPE Resin

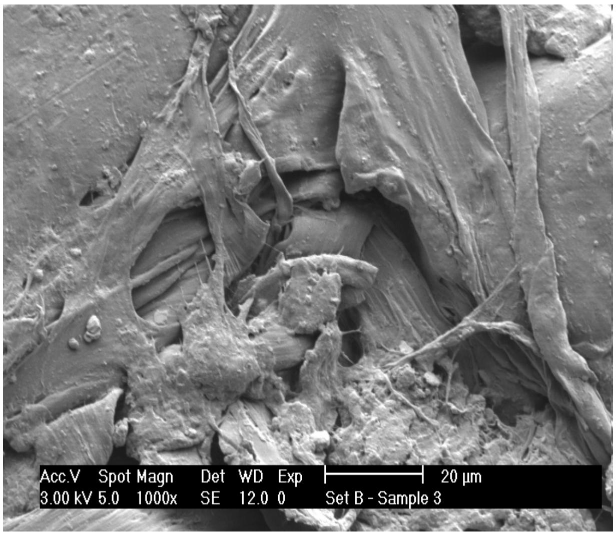

Figure 5. SEM microstructure of the water melon peels particleboard with 50wt% RLDPE Resin

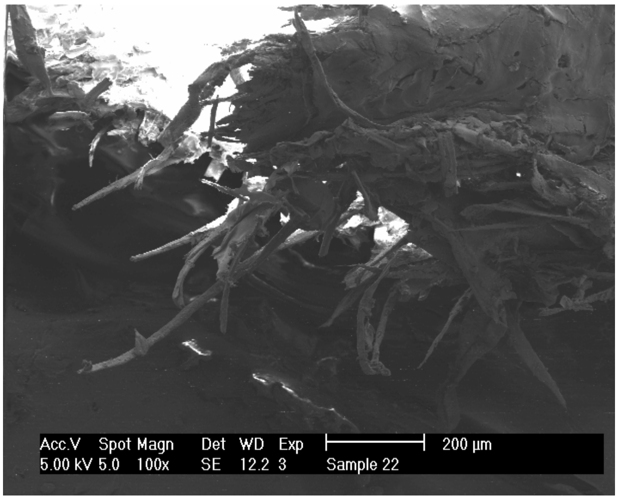

Figure 6. SEM microstructure of the water melon peels particleboard with 70wt% RLDPE Resin

The microstructure reveals that there are small discontinuities and a reasonably uniform distribution of water melon particles and the RLDPE resin. The water melon particles phase is shown as white phase, while the resin phase is dark [9]. The agro-waste particles are embedded within the amorphous matrix composed of randomly distributed in the matrix planar boundaries. The surface of the agro-waste particles is smooth indicating that the compatibility between particles and the resin was good. It can be seen that the agro-waste particles are not detached from the RLDPE surface as the weight fraction of agro-waste particles increased in the resin; this is due to good interfacial bonding between the resin and the particles [2, 8]. This good bonding was achieved from the compounding of the agro-waste particles and the resin.

The density, thickness swelling (TS) and water absorption (WA) of the particleboards are shown in Figures 7-9. The values obtained for the thickness swelling (TS) and water absorption (WA) of the particleboards were high (see Figures 7-8). This is due to not using water repellent agents in the particleboard manufacturing. But this results are better than that the resulted others authors obtained for wood based particleboard [6, 11-13].

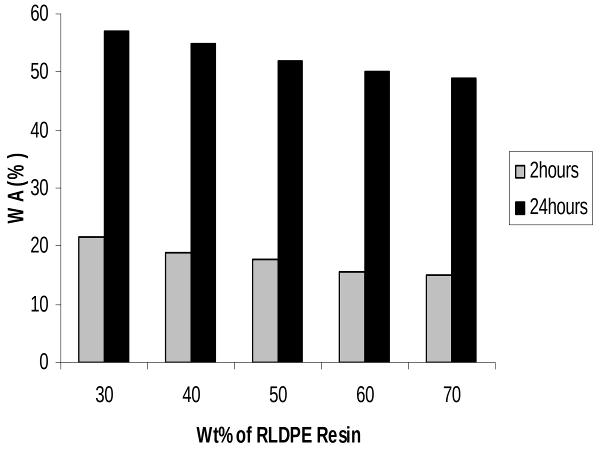

Figure 7. Variation of Water absorption with RLDPE addition

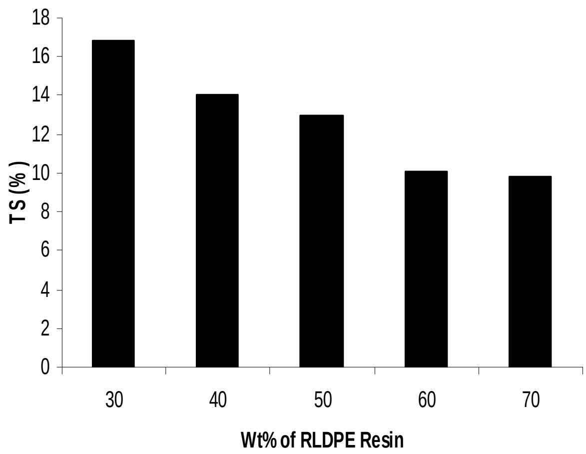

Figure 8. Variation of Thickness swelling with RLDPE addition

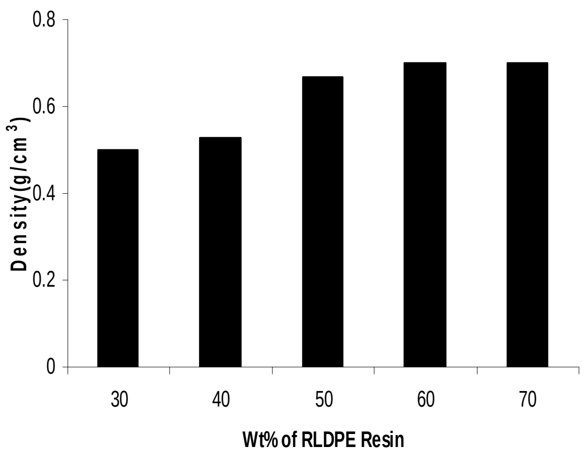

Figure 9. Variation of Density with RLDPE addition

The water melon particles affected the WA and TS properties negatively. Similar results were found by Ntalos and Grigoriou [11]. Decreasing the resin increased the WA and TS of particleboards. This may be due to high solubility values of the particles. In addition, wall thickness of particles was found to be within the ranges of that of common wood species [9].

The density profile of a board is dependent on the particle configuration, moisture distribution in the mat, hot press temperature and rate of closing, resin reactivity and the compressive strength of the particles [9]. The boards density increased with increasing the weight fraction of the RLDPE resin (see Figure 9). Increasing of board density from 0.50 to 0.70 g/ cm3 decreased the TS and WA for 2 h immersion. This is due to low porosity and difficult diffusion on the high board density. The swelling that occurs is the sum of two components, namely, swelling by hygroscopic particles and the release of compression stresses imparted to the board during the pressing of mat in the hot press [5]. The release of compression stresses, known as spring-back, is not recovered when the board is in a dry state.

The values of modulus of elasticity (MOE), modulus of Rupture (MOR), internal bond strength (IB) strength and impact strength (IM) of the boards are shown in Figures 10-12.

Tensile modulus and internal bonding strength measurements are among the most important indicators of strength in a material and are most widely specified property. Tensile modulus, an indication of the relative stiffness of a material [11-14]. Tensile test is a measurement of the property of a material to withstand forces that tend to pull it apart and to determine to what extent the material stretches before breaking.

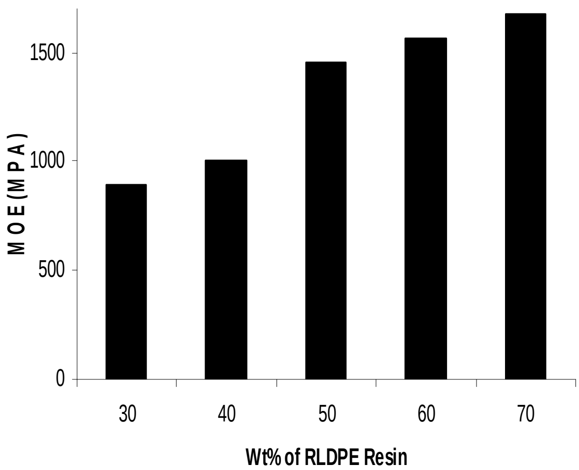

Figure 10. Variation of Modulus of Elasticity with RLDPE addition

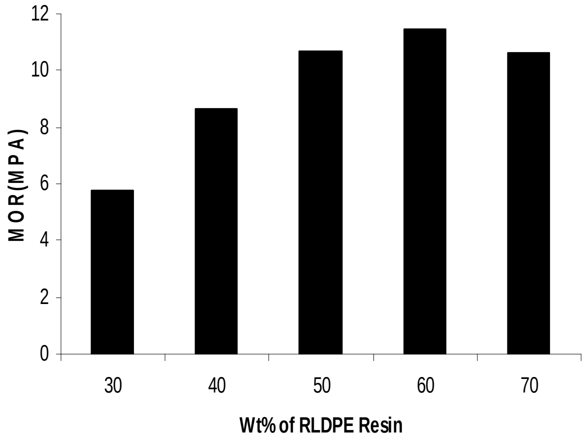

Figure 11. Variation of Modulus of Rupture with RLDPE addition

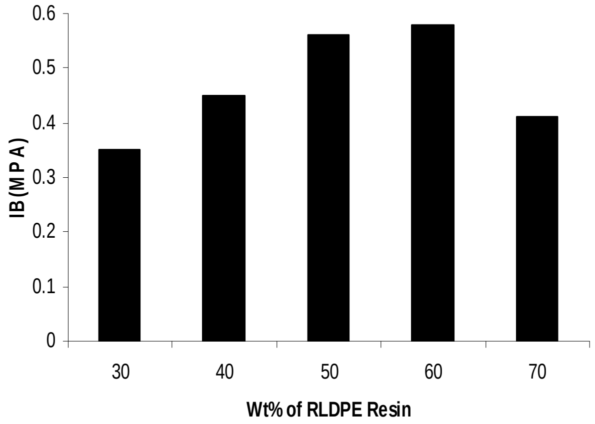

Figure 12. Variation of Internal bonding strength with RLDPE addition

The improvement in internal bonding strength and tensile modulus was notice with the developed particleboard. These indicates that used of water melon particle and RLDPE in production of the particleboard improves the load bearing capacity of the board. Similar observations have been reported by [2, 8, 10, 11] for other particleboard. In addition, the developed particleboard deforms less until maximum load, which gives a higher tensile modulus. The increase in Young's modulus with increasing RLDPE is expected since the addition of RLDPE to water melon particles increases the stiffness of the particleboard. The presence of polar group in the RLDPE may contribute to electrostatic adsorption between RLDPE and water melon particles. This phenomenon is driven by different charges acting on RLDPE or water melon particles surfaces; this mechanism will strengthen the RLDPE/water melon particles interface. It will hold them together and increase their resistance to deformation [9], this helps in increment of the board modulus. The fairly uniform of water melon particles distribution has efficiently hinders the chains movement during deformation. This mechanism will increase the stiffness of the board as well as tensile modulus.

The MOR ranged from 5.78 to 11.6N/mm2 (Figure 11). The MOR requirements of 11.5 N/mm2 for general purpose boards by EN 312-2[12]. Particleboards made from 30wt% RLDPE resin had MOR lower than the requirement for general purpose. In addition, although increasing of RLDPE Resin addition increasing the MOR upto 60wt %, beyond this level no further increased in MOR was obtain.

The range of data in IB was from 0.35 to 0.58 N/mm2 (see Figure 12). The IB requirements of 0.24 N/ mm2 for general purpose boards, 0.35 N/mm2 for interior fitments, load-bearing boards and 0.50 N/mm2 for heavy duty load bearing boards by [10-13] respectively.

The internal bond strength is comparable with values reported by Razali and Kuo [16] and Chew et al. [4]. The water melon peels board surpassed the mechanical strength requirements for general purpose applications specified by European standard. All of the particleboards produced from are within the recommended standard i.e for general purpose, interior fitments, load-bearing boards and heavy-duty load bearing boards.
The results of the impact strength shows that the impact strength of the board composites slightly increased with increases in RLDPE resin addition (see Figure 13).

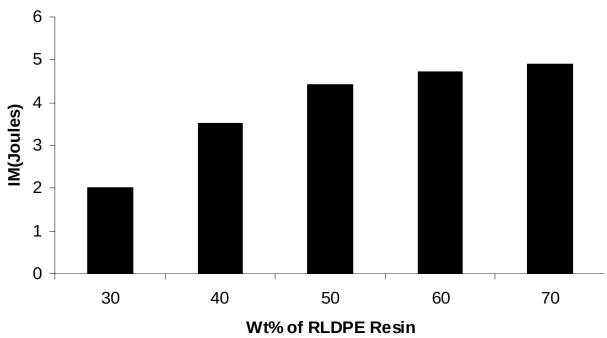

Figure 13. Variation of Impact strength with RLDPE addition

High strain rates or impact loads may be expected in many engineering applications of particleboard composite materials. The suitability of a particleboard composite for such applications should therefore be determined not only by usual design parameters, but by its impact or energy absorbing. The steep increased in the impact strength board composites could be attributed to the presence of particles well bonding by the RLDPE resin this factor leads to increase in impact energy.

The results obtained for the wear rate of the developed particleboard show in Figure 14, from the results there is appreciable reduction in the wear rate of the particleboard with the addition of the RLDPE up to 60wt% for example: wear rate obtained are 0.56g at 30wt% and then to 0.31g at 60wt% RLDPE. The decrease in wear rate of the composites be attributed to higher load bearing capacity of hard particleboard and better interfacial bond between the particle and the matrix reducing the possibility of particle pull out which may result in higher wear (see Figure 14) [9]. The increased in wear rate beyond 60wt% RLDPE may be attributed to low values of internal bonding strength obtained (see Figure 12). The wear mechanism reported was adhesion and delamination. This observation is on par with the one observed by Aigbodion et al [9]. It is well known that wear process involve fracture, tribochemical effects and plastic flow. Transitions between regions dominated by each of these commonly give rise to changes in wear rate with load.

The developed particleboard exhibited the higher wear resistance under the sliding distances. This behaviour can be attributed to the presence of watermelon particles on the counter surface, which act as a transfer layer and effective barriers to prevent large-scale fragmentation of RLDPE. This is also evident from the small size of the wear debris observed. The wear resistance of the particleboard is improved by preventing direct contacts that induce subsurface deformation. The addition of hard watermelon particles improves the resistance to seizure. The water melon particulate allows considerable thermal softening effects without having adverse effects on the wear behaviour [9]. The watermelon particles also cause higher hardness and less coefficient of thermal expansion within the RLDPE resin. The presence of the ceramic particles provides a higher thermal stability, increased abrasion and sliding wear resistance at high and delays the transition from mild to severe wear [9].

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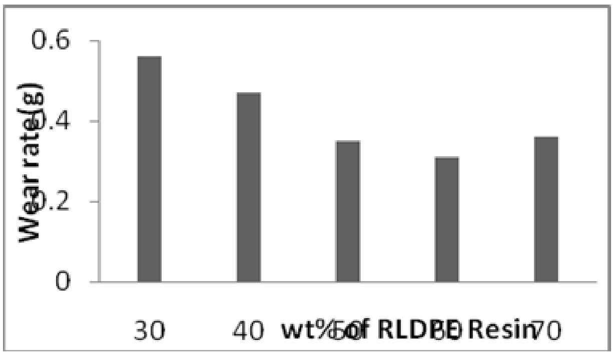

Figure 14. Variation of Wear rate with RLDPE addition

The particleboard produced with 60wt%RLDPE and watermelon particles were compared with that of Flax-board made with flax fibers and urea resin glue (Urea Formaldehyde) and that of Medium Density Fiber-board (MDF) made of wood composite materials(see Table 1), which was tested under similar conditions. The results are in close agreement. This study showed that watermelon particles can work well with RLDPE when used in the production of the particleboard. Also, different components of RLDPE had significant influence on mechanical properties of particleboard. In generally the boards produced with the watermelon particles at 50-60% RLDPE resin addition conform to the BIS specifications of density particleboards for general purpose requirements like panelling, ceiling, partitioning e.tc (interior decoration). Besides being environmental friendly of using watermelon and RLDPE in production of particleboard, this alternative to wood-based particleboard is very cost-effective.

Table 1. Summary of the result findings compared with existing ones

Properties	MDF (www.finsa.es) [17]	MDF (www.spanogroup.be) [18]	flax-board (www.linex-pg.nl) [19]	Present study watermelon particle at 60wt%RLDPE
Board density (g/cm2)	0.85	0.60-0.65	0.35-0.8	0.75
Internal boding strength (N/mm2)	0.90	0.40-0.45	0.1	0.65
Modulus of elasticity (N/mm2)	NA	1400-1700	750	1650
Modulus of Rupture (N/mm2)	NA	NA	NA	12.0
Bending strength (N/mm2)	38	14.0-20.0	45	
Thickness swelling (%)	15	11-20	NA	10.05
Wear rate (g)	NA	NA	NA	0.31

Note: Flax-board is a particle-board composite of flax fibers and urea resin glue (Urea Formaldehyde).
Medium Density Fiber-board (MDF) is a wood composite material made by wood fibers. NA: Not available

4. CONCLUSION

This present research is centred on the development and characterization of the microstructure and properties of particleboard composites using water melon peels and RLDPE as binder as alternative to wood and Urea Formaldehyde particleboard. From the above results and discussion the following conclusions are made:

- This work shows that successful fabrication of water melon peels and RLDPE resin particleboard composites by simple compressive moulding technique.
- The density increased as the percentage of resin increases in the particles.
- The percentage of thickness swelling and water absorption increased in decreasing the weight fraction of the RLDPE resin.
- The tensile properties obtained are in agreement with the results obtained from the analysis of impact strength.
- The uniform distribution of the particles and the resin in the microstructure of the board composites is the major factor responsible for the improvement in the mechanical properties.
- The wear rate decreased as the weight percentage of RLDPE increased upto 60wt%.
- The developed particleboard composites can be use in density particleboards for general purpose requirements like panelling, ceiling, partitioning e.tc. Since the properties of particleboard composites used in this area compared favorably with the properties of the developed board composites at 50-60wt% RLDPE resin.
- It is recommended that besides being environmental friendly of using watermelon and RLDPE in production of particleboard, this alternative to wood-based particleboard is very cost-effective.

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