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Full Length Research Paper

Potential of using recycled low-density polyethylene in wood composites board

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The aim of this study was to investigate the suitability of using recycled low density polyethylene (RLDPE) in wood board manufacturing. The composite board was produced by compressive moulding by increasing the percentage of LDPE from 30 to 50 wt% with interval of 10 wt% at a temperatures of 140 and 180°C, pressure of 30 to 40 Kg/cm^2 and pressing time 7 to 13 min. The microstructure and mechanical properties: Modulus of rupture (MOR), modulus of elasticity (MOE), tensile strength, impact strength properties of boards were determined. The results showed that high modulus of rupture of 20.31 N/mm^2 and MOE of 1363 N/mm^2 were obtained from board produced at 140°C, 60/40 wt% wood particles per LDPE content. The uniform distribution of particles and the recycled LDPE in the microstructure of composites board are the major factor responsible for the improvement in the mechanical properties. The results showed that the MOE and MOR meet the minimum requirements of the European standards, for general purpose. The boards produced had tensile strength that is within the requirement. Hence this LDPE can be used in board production for general purpose applications.

Keywords: Microstructure, polyethylene, physical and mechanical properties.

INTRODUCTION

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 (Hall et al., 1984; Han et al., 1998). 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 (Ives, 2001). 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 (Hofstrand et al., 1984; Kalaycioǧlu and Nemli, 1994).

Pressed wood products, such as wood-based particle-board and medium density fibreboard, 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 (Kalaycioǧlu and Nemli, 1994). It also escalates the number of "sick building syndrome" cases. Many wood-based building materials or furniture products that utilize formaldehyde resins may off-gas, contributing to reduced IAQ level.

Environmentally friendly alternatives to these wood-based materials include products that use polyethylene resins, which can help reduce or eliminate the formaldehyde that otherwise would be emitted into the air (Kuo et al., 1998; Rahim, 2009). However studies on wood particleboard composites based on recycled low-density polyethylene (LDPE) are very limited (Yamashita et al., 1999). With the current high interest in recycling, it was decided to make a wood/plastic composites using a post-consumer plastic (granulated low density poly-ethylene (LDPE). Hence, the aim of this present study was to explore the use of recycled LDPE for the production of wood particleboard composites. The effect of production parameter, that is, pressure, temperature and time on the microstructure and mechanical properties is also investigated.

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Table 1. Variables studied and the combination used in the manufacture of the composite board.

Board number	Temperature (°C)	Time (Minutes)	Pressure (Kg/cm^3)	Sawdust/LDPE
I	140	7	30	50/50
2	140	10	40	60/40
3	140	13	50	70/30
4	180	7	30	50/50
5	180	10	40	60/40
6	180	13	50	70/30

MATERIALS/ EQUIPMENT

The wood used in this work was obtained from Benin saw mill, Edo-State, Nigeria. The wood was hammer milled and reduced to small particles. The recycled low-density polyethylene sachet" used were collected literally from the streets of Awka and around refuse dumps. After cleaning, they were reduced to irregularly formed particles 1 to 3 mm in size in a specially designed plastic mill equipped with two rotating knives.

Equipment use in this research are, metal mould, hydraulic press, Avery Denison impact tester, Rockwell hardness machine, Instron machine, grinding and polishing machine and scanning electron microscope (SEM).

Characterization of wood

The wood was subjected to the following process before use:

1. The processing of the wood into wood particles: These involve collection, drying and grinding of the waste to form powder.
2. Sieve analysis of particles: The particle size analysis of wood particles was carried out in accordance with BS1377:1990 (EN 312-6, 1996, EPF, 2004). About 100 g of particles was placed unto a set of sieves arranged in descending order of fineness and shaken for 15 min which is the recommended time to achieve complete classification; the particle was retained in the BS. Sieve size 1000 µm was used in this study.

Variables for the composites board production

Table 1 shows the variables studied and the combination used in the manufacture of the composite board. The chosen parameter values (low-high) for temperature, time and pressure are in line with the production parameter of a conventional board (EPF, 2004).

Sample preparation

After drying in an oven at 105°C, the wood particles and the LDPE were 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 with a size of 350 by 350 mm. The boards were pressed as specific in Table 1 to a thickness of 4 mm and specific gravity of 075 to 0.81. At the end of press cycle, the board was removed from the press for cooling.

Microstructural analysis

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 were examined directly by scanning electron microscope JEOL JSM-6480LV. The samples were washed, cleaned thoroughly, air-dried and coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. Samples were sputter -coated with gold to increase surface conductivity. The digitized images were recorded (ASTM E290, 1990).

Test procedure

All boards were cut to obtain 300 × 300 mm rectangles by trimming 20 mm thick strips along edges. Test samples were cut from the composite board for the mechanical test according to the recommended standard for each test (ASTM E290, 1990). Prior to the test, all the samples were conditioned at a temperature of 23±2°C and relative humidity of 65% according to ATM D618-08(ASTM E290, 1990). The density of the boards varied from 0.75 to 0.81 kg/cm^2.

Tensile test

The tensile properties of the composite board sample were measured on a Instron machine with a strain rate of $2 \times 10^{-3} S^{-1}$ as specified by the American Society for Testing and Materials (ASTM E290, 1990).

Static bending test

A static bending test (dry) was conducted according to American Society for Testing Materials Standard D1037 on six samples of each type size 150 × 50 × 4 mm, bending speed was 10 mm/min at 67% relative humidity at 23°C was used. The bending modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated from load deflection curves according to the following formula (ASTM E290, 1990):

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

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

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

Impact energy test

The impact test of the board composite sample was conducted in accordance with ASTM D256-93 (ASTM E290, 1990) using a fully instrumented Avery Denison test machine. Charpy impact tests were conducted on notched samples. Standard square impact test sample of measuring 75 × 10 × 10 mm with notch depth of 2 mm and a notch tip radius of 0. 02 mm at angle of 45°was used. Before the test sample was mounted on the machine, the pendulum was released to calibrate the machine. The test samples were then gripped horizontally in a vice and the force required to break the bar was released from the freely swinging pendulum. The value of the angle through which the pendulum has swung before the test sample was broken corresponded with the value of the energy absorbed in breaking the sample and this was read from the calibrated scale on the machine.

RESULTS AND DISCUSSION

Visual observation

Macrostructural studies of the particleboard revealed a uniform distribution of wood particles with the recycled LDPE. The distribution of particles is influenced by the compounding of the particle and the binder and good interfacial bonding. However during the blending of the wood/RLDPE it was observed that below 30% recycled LDPE, the compounding was very poor. The sawdust was not welted by the waste LDPE and therefore no good mixture. Hence the experiment was limited to 30 wt% recycled LDPE.

Surface morphology of the particleboard composites

The morphologies of the composite boards by SEM with EDS are shown in Figures 1 to 4. Morphological analysis using SEM clearly showed difference in morpho-logy of the composite boards produced by varying the production parameter respectively (Figures 1 to 4). The microstructure clearly shows that when the wood particles were added to recycle LDPE (resin), morphological change in the structure took place. The microstructure reveals that there were small disconti-nuities and a reasonably uniform distribution of wood particles and the recycled LDPE. The particles phase is shown as white phase, while the recycled LDPE phase is dark.

It can be seen that the wood particles are not detached from the resin surface as the weight fraction of wood particles increased in the resin; this is due to fairly interfacial bonding between the resin and the particles (Kuo et al., 1998; Rahim, 2009). This bonding was achieved due to the compounding of wood particles and the recycled LDPE in a two roll mill. However, due to hydrophobicity of the recycled LDPE and the hydrophilic nature of the wood particle, the fairly good bonding induced by blending alone did not improve the mechanical properties to a good level.

The EDS analysis show that there is no chemical interfacial reactions between the wood particles and the RLDPE, this is as a results of the temperature of processing that were not high enough to cause any chemical reactions. The major element revealed by the EDS are C and O, this element are the major functional group in the wood particles.

Mechanical properties of the particleboards

The values of modulus of elasticity (MOE), modulus of rupture (MOR), tensile strength and impact strength (IM) of the boards are shown in Table 2.

There is an increase in modulus of elasticity with increasing pressing pressure, pressing time and decreasing the amount of LDPE addition for boards produced at 140°C, while for the boards produced at 180°C the reverse was the case. This is expected since the addition of LDPE to the wood particles increases the stiffness of the composite boards (Table 2). The fairly uniformity of microstructure of the composite boards has efficiently hindered the chain movement during deformation. This mechanism will increase the stiffness of the board composites as well as modulus of elasticity (Ives, 2001).

The MOR ranged from 16.25 to 20.31 N/mm^2 (Table 2), which meet the MOR requirements of 11.5 N/mm^2 for general purpose boards by EN 312-2 (EN 312-6, 1996). All the boards are within the minimum recommended standard for general purpose. However boards produced at 140°C at 60/40 wood particles/LDPE have higher MOR of 20.31 N/mm^2 and MOE of 1363 N/mm^2.

The range of data in tensile strength was from 12.58 to 19.35 N/mm^2 (Table 2). The tensile strength meets the requirements for general purpose board (Hall et al., 1984l; Han et al., 1998). The boards produced at 180°C have the tensile strength with increase in the pressing time and compression pressure. The increases in the tensile strength may be due to the fairly good interfacial bonding, which is the same as described in previous studies (Hall et al., 1984; Han et al., 1998). The pressing pressure and time has a positive effect on the tensile property, because it strengthens the interfacial bonding between the wood particles and the LDPE, which resulted in good stress propagation and improved the tensile strength.

All the boards met the mechanical strength require-ments for general purpose applications specified by European standard. In fact, the strengths of boards produced at 180°C met the requirements for load-bearing board for use in dry condition (EN 312-6, 1996).

The result of the impact strength shows that the impact strength of the composite board almost in the same ranges. High strain rates or impact loads may be expected in many engineering applications of composite materials. The suitability of a composite

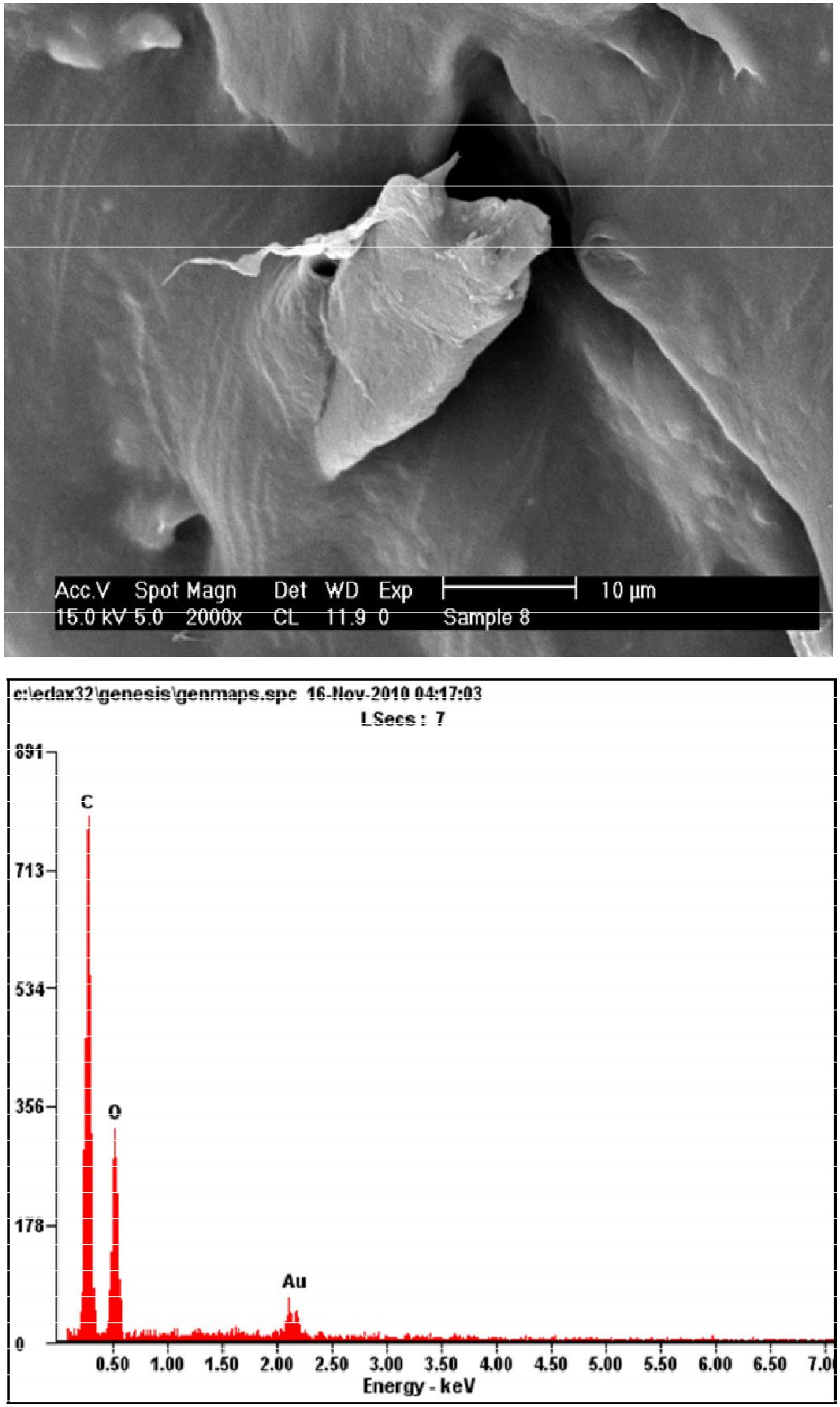


Figure 1. SEM/EDS microstructure of Board at 140°C (50/50).

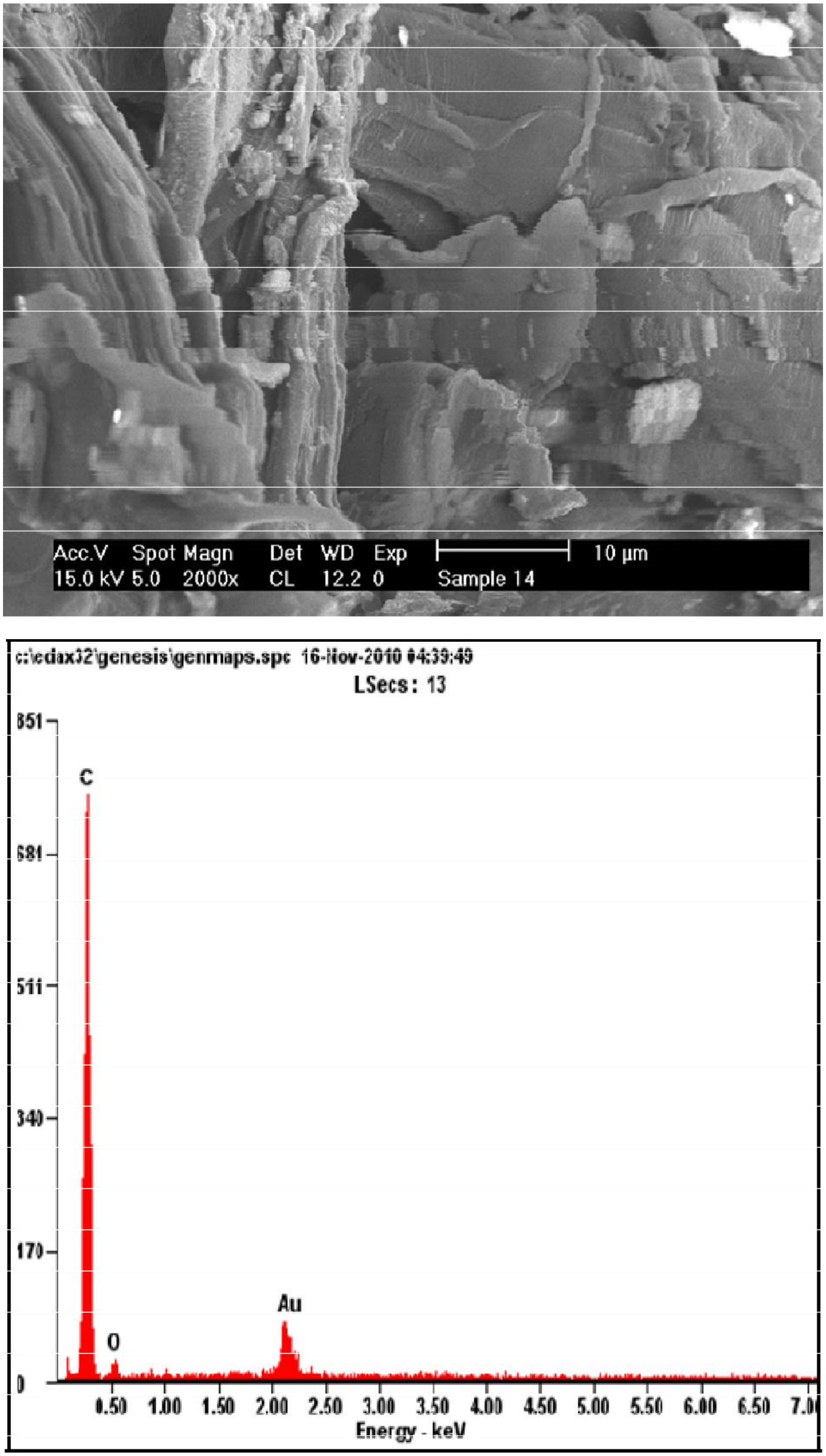


Figure 2. SEM/EDS microstructure of board at 180°C (50/50).

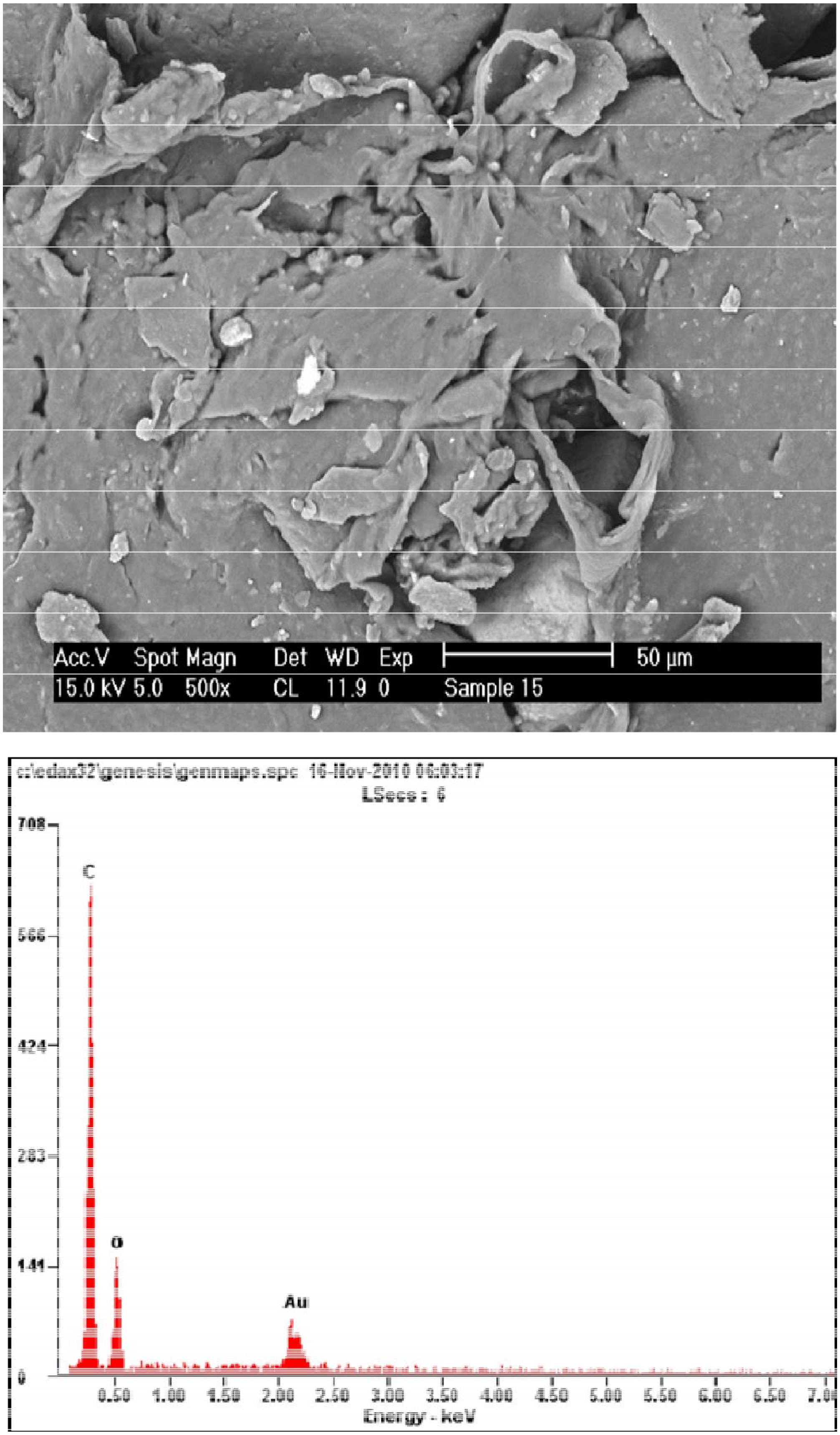
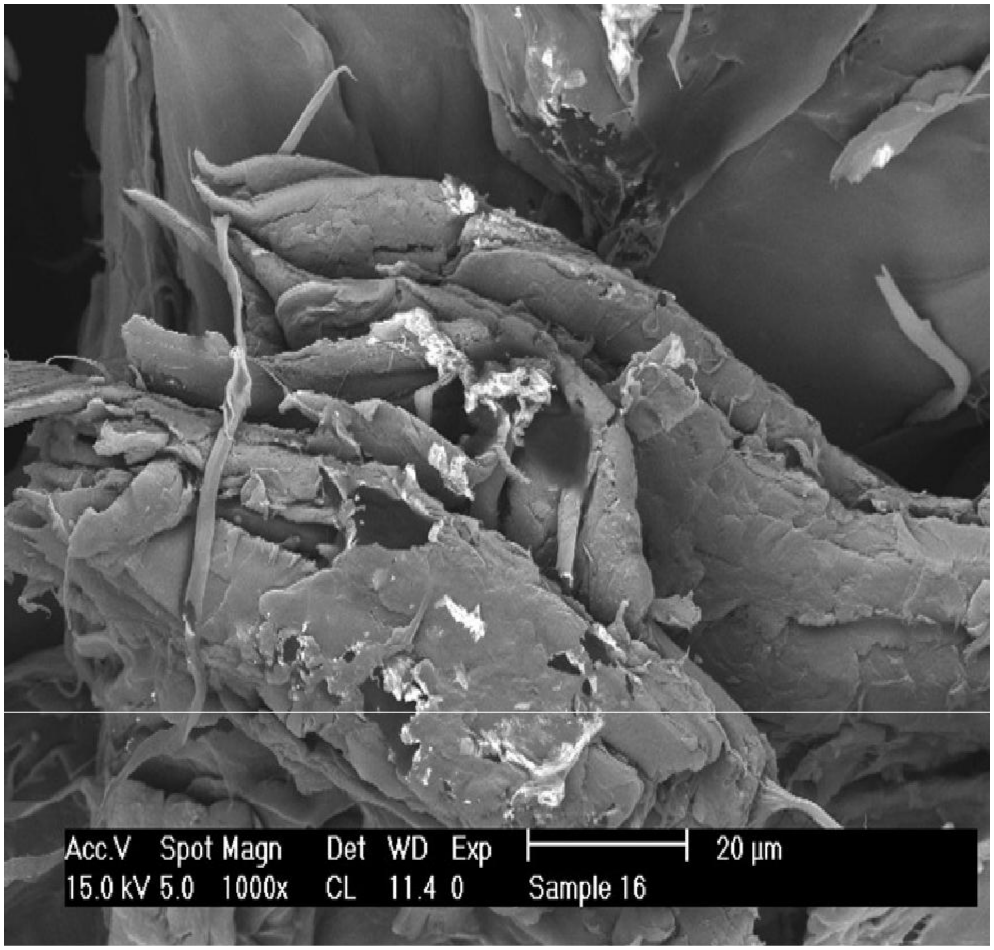


Figure 3. SEM/EDS microstructure of board at 140°C (70/30).



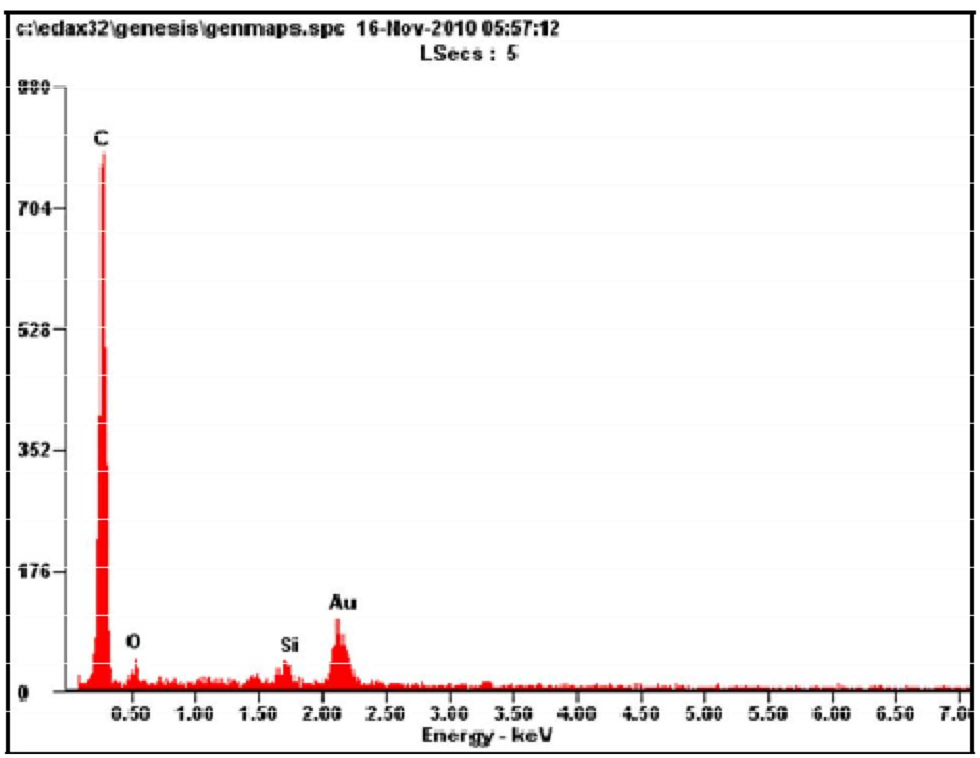


Figure 4. SEM/EDS microstructure of board at 180°C (70/30).

Table 2. The results of the mechanical test.

Board number	Tensile strength (MPA)	MOR (MOR)	MOE (MPA)	Impact energy (Joules)
1	12.81	18.32	1035	4.0
2	12.45	20.31	1363	2.5
3	12.58	19.34	1515	3.5
4	13.82	17.60	1210	2.0
5	16.25	16.25	1057	2.0
6	19.35	19.35	1617	2.0

boar d for such applications should therefore be determined not only by usual design parameters, but by its impact or energy absorbing. The improvement in the impact strength of the composite boards could be attributed to the presence of particles well bond by the resin, this factor leads to increase in impact energy (Yamashita et al., 1999).

Conclusions

This present research is centred on the development and characterization of the microstructure and mechanical properties of composite board manufactured using wood particles and recycled LDPE with variable production parameter. From the aforementioned results and discussion, the following conclusions are made:

1. This work shows that successful fabrication of the wood particles/ recycled LDPE composite boards by simple compressive moulding technique is attainable.
2. The tensile properties obtained are in line with the results obtained from the analysis of impact strength.
3. The higher modulus of elasticity was obtained from board produced at 180°C, 50/50 wood particles/LDPE.
4. The higher modulus of rupture of 20.31 N/mm^2 and MOE of 1363 N/mm^2 was obtained from board produced at 140°C, 60/40 wt% wood particles/RLDPE boards.
5. The uniform distribution of the particles and the recycled LDPE in the microstructure of the composite boards is the major factor responsible for the improvement in the mechanical properties.
6. The developed board composites can be used in density boards for general purpose requirements like panelling, ceiling, partitioning etc. Since the properties of board composites used in this area compared favourably due to properties of the developed boards

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