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RESEARCH

An Assessment on the Production of Abrasive Sandpaper from Locally Sourced Materials

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ABSTRACT

A comparative analysis of abrasive sandpaper made from two locally sourced and easily available materials, periwinkle and palm kernel shells was carried out to evaluate their viability as replacements for foreign imported abrasives sandpaper. Composites of crushed shells with polyester resin bond were developed separately for the periwinkle and palm kernel shell samples using mould compression, and the sandpaper prototype was produced using hand-spray method. A study on the physico-mechanical properties of the produced composite carried out was found that at 12 wt.% content of resin, periwinkle shell (PWS)/resin composites had higher physico-mechanical properties such as density with 77.74 % difference, hardness with 17.13 % difference and compressive strength with 182.42 % difference over the palm kernel shell-resin composites. Water absorption for palm kernel (PKS) shell/resin composite was a 186.59 % difference over the PWS/resin composite. Surface morphology using SEM revealed PWS/resin composite to have less distortional effects on the grains from compressive force of 15.7 N/mm2 applied compared to the palm kernel shell grains, and also shows PWS grains held together in close packing by the resin bond. The concentration used for sandpaper production was 87 wt.% of periwinkle shell grains to 12 wt.% of resin. The obtained physical and mechanical properties were compared to garnet sandpaper and found to be close to acceptable standards.

1. INTRODUCTION

Abrasive materials are very hard mineral materials used to shape, finish, or polish other materials. The abrasive materials are processed in a furnace after which they can further be pulverized and sifted into different grain sizes called grits [1,2]. The most important physical properties of abrasive materials are; hardness, brittleness, toughness, grain shape and grain size, character of fracture, purity and uniformity of the grains [3]. There are two common types of abrasive materials which are natural abrasive materials and synthetic abrasive materials. Coated abrasives are described in terms of shape, size, kind of abrasive, grit size, and type of base. Abrasives are small, hard particles having sharp edges and irregular shapes also known as grits [4]. Grits are characterized by sharp cutting points, hardness, chemical stability and wear resistance [5].

Efforts have been made in the past by different researchers to utilize locally sourced materials in the formulation and development, manufacture and construction of products such as building materials, design and manufacturing tools and equipment etc. Researches in Nigeria and all over the world today are focusing on ways of utilizing either industrial or agricultural wastes as a source of raw materials in industry. Utilization of these wastes will not only be economical, but may also result in foreign exchange earnings and environmental control [6].The need to channel this great potential of converting wastes into an industrial tool known as sandpaper is underscored by the importance of abrasive machining to the Nigeria's manufacturing sector.

Sandpaper is a type of paper whose surface has been fixed with an abrasive material and is used for sanding and smoothening in woodwork. They consist of a single layer of abrasive particles held to a flexible backing material by an adhesive bond [6]. Abrasives are small, hard substances used to grind, polish, abrade, scour, clean, or otherwise remove solid material [7]. Abrasive machining processes are widely applied to various industries such as mechanical manufacturing, woodwork industry, construction and refractory, due to its high technical adaptability unto various materials and surfaces [8].

Periwinkle shells incur environmental pollution particularly in the southern and riverine areas of Nigeria were this impact is felt most. Palm kernel shells are recovered as by-products in palm oil production. Large quantities of these shells are generated annually and only some fractions are used for applications such as palliatives for un-tarred roads and in producing activated carbon. The unused shells are dumped around the processing mill, constituting environmental and economic liability for the mill [9]. Periwinkles (Nodilittorina radiata) are small greenish blue marine snails with spiral conical shell and round aperture. The average winkle lives three years and grows to a shell height of 20 mm, but the largest recorded winkle grew to 52 mm. They are common in the riverine areas and coastal regions of Nigeria where they are used for food. The hard shells, which are regarded as wastes ordinarily posed environmental nuisance in terms of its unpleasant odour and unsightly appearance in open-dump sites located at strategic places [10].

This work was inspired by identifying another usage of the periwinkle shells which is considered to be an agricultural waste material. The outer shell is hard and rough to touch. On the local scale, periwinkle shell grinded to powder form is used as scouring powder by rural dwellers to scrub bottom of aluminium cooking pots. On closer inspection of the bottom of these pots, it is observed that there are shiny scratch patterns which are the result of the scrubbing over a period of time. As a way of converting agro-wastes into a useful tool for finishing processes of selected materials, this work aims to reduce environmental pollution, enhance and improve on the application of abrasive periwinkle and also increase the value and revenue to local manufacturers.

Many researchers have worked on abrasive tools. Wai and Lilly [11] worked on manufacturing of emery cloth/sand paper from local sourced materials. They used silicon sand (quartz) as their abrasive grits and processed it by sieving into fine grit 180μm and coarse grit 50 μm. The bonds used were epoxy resins. They obtained samples of produced sand paper by adopting the hand spray method of producing sand paper, and recommended the manufacturing process for small scale industries based on a successful pilot work.

Odior and Oyawale [12] studied the formulation and manufacture of silicon carbide abrasives using locally sourced raw materials in Nigeria. The Taguchi method was used to conduct a systematic search for an optimal formulation of silicon carbide abrasives on five local raw material substitutes identified through a pilot study which were quartz, coal, sodium carbonate, saw dust and sodium chloride.

Palm kernel and periwinkle shells have both been used as reinforcements to develop polymer matrix composites for load bearing and wear applications. Koya and Fono [9] developed asbestos-free automotive brake pad using palm kernel shell as frictional filler material.

Yawas et al. [13] worked on the development of asbestos-free automotive brake pad using periwinkle shell particles as frictional filler material. Both researchers concluded that palm kernel and periwinkle shell were suitable for use as friction material in automotive brake-pads.

Hence the objective of the present research is to produce sand paper by the hand spray method [11] using processed periwinkle and palm kernel shell grains as grits and polyester resin as binder, to characterize the bond mixture for each of them and to determine their effectiveness in abrading operations.

Therefore, the specific objectives of this research are as follows:

- To process the periwinkle and palm kernel shells separately by crushing and sieving into particle sizes of 420µm which is P40 sandpaper grit size (according to Federation of European Producers of Abrasive standard).
- To determine binding properties of polyester resin on the periwinkle and palm kernel shell grains by varying the weight percent of resin from 4 – 12 weight % with fixed percentage of catalyst and accelerator (0.5 weight % each).
- To determine the physical and mechanical tests of periwinkle grains/polyester resin, palm kernel shell grains/polyester resin composites such as density, water adsorption, compressive strength, hardness and wear.
- To use composition with best properties in producing sand paper samples using hand spraying method [9] into P40 (medium grade) sandpaper.
- To compare properties of produced sandpaper with Garnet sandpaper.

2. MATERIAL AND EXPERIMENTAL PROCEDURE

Materials/equipment

The periwinkle was obtained from fishermen in Akwa Ibom State, Southern Nigeria. Palm kernel shells were purchased in palm farms in Akwa Ibom State of Nigeria. Other materials used were polyester resin, methyl ethyl ketone peroxide (MEKP) and cobalt nephthanate. The equipment used were: ball milling machine, ASTM E11 sieves size 420 µm, digital weighing machine, hydraulic press, mechanical mixer, Shore A durometer, universal testing machine, Scanning Electron Microscope and Pin-on-disc machine.

Method of production

The palm kernel shells (PKS) and periwinkle shells (PWS) after purchase were washed in detergent water to remove traces of dirt and oil on them. Then they were sun dried for 3 days followed by oven drying at 100 °C for 3 hours until moisture content was reduced to the barest minimum. They were then charged into a ball milling machine, milled and then sieved using sieve size 420 µm (ASTM E11) to categorize the PKS and PWS grains into FEPA abrasive grits of P40 standard.

The digital weighing balance was used to weigh out 114 g, 111.6 g, 109.2 g, 106.8 g and 104.4 g grams of PKS and PWS grains which corresponds to 95 wt.%, 93 wt.%, 91 wt.%, 89 wt.% and 87 wt.%. After weighing, they were poured into separate clean plastic containers. A measure of polyester resin in mass of 4.8 g, 7.2 g, 9.6 g, 12.0 g and 14.4 g which corresponds to 4 wt.%, 6 wt.%, 8 wt.%, 10 wt.% and 12 wt.% was weighed and added to the weighed out PKS and PWS grains respectively in their plastic containers, followed by 0.6 g of cobalt naphthalene accelerator and 0.6 g of methyl ethyl ketone peroxide hardener, each making the balance of 100 wt.% in material composition, into all containers. The mixture was blended one after the other in a mechanical mixer for 5 minutes into a thick paste. Table 1 shows the adopted formulation of the composites.

Table 1. Batch Formulation of PKS and PWS composite samples.

Materials	Weight percent of varied composition				
PKS and PWS grains	95 %	93 %	91 %	89 %	87 %
Polyester Resin	4 %	6 %	8 %	10 %	12 %
Cobalt naphthalene accelerator	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Methyl Ethyl Ketone Peroxide Catalyst	0.5 %	0.5 %	0.5 %	0.5 %	0.5 %
Total composition	100 %	100 %	100 %	100 %	100 %

Fig. 1. PKS/resin composite samples.

Fig. 2. PWS/resin composite samples.

The PKS and PWS/resin composite samples shown in Figs. 1 and 2 were produced using compression moulding technique in a hydraulic press. Compression was done at fixed pressure of 15.7 N/mm^2 under room temperature.

2.3 Method of Characterization

The Shores hardness of composite samples was read directly from the dial of Shore A Durometer ASTM D 2240 ISO 7619 equipment. The compressive strength test was carried out using a Norwood universal testing machine with a nominal testing force of 100 kN. The samples of diameter 20.5 mm was subjected to compressive force, loaded continuously until failure occurred. The load at which failure occurred was then recorded.

The coefficient of friction of composite samples was measured using a pin on disc machine (ASTM G99 -95) by sliding it over a cast iron surface at a load of 40 kg and sliding speed of 2.4 m/s and time of 20 minutes. Tests were conducted at room temperature, and then samples were preheated to 50 °C and 150 °C prior to testing. The initial weight of the samples was measured using a single pan electronic weighing machine with an accuracy of 0.0001 g. During the test, the pin was pressed against the counterpart rotating against a cast iron disc (hardness 65 HRC) of counter surface roughness of 0.3 μm by applying the load. A friction detecting arm connected to a strain gauge held and loaded the pin samples vertically into the rotating hardened cast iron disc. The coefficient of friction was calculated by:

$$\mu = \frac{F_y}{P} \tag{1}$$

where μ is the coefficient of friction, F_y is the frictional force read directly from the friction detecting arm strain gauge and P is the normal reaction. The schematic of the setup is shown in Fig. 3.

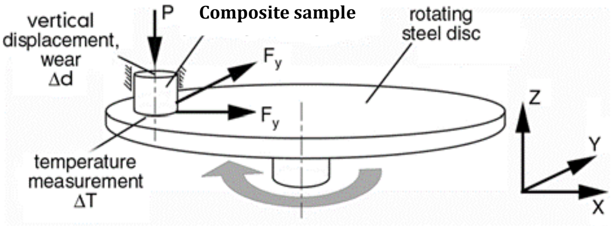


Fig. 3. Pin-on-disc setup for steady-state friction measurements [14].

Density measurements were carried out on the PKS and PWS resin composite using Archimedes' principle. The buoyant force on a submerged object is equal to the weight of the fluid displaced. This principle is useful for determining the volume and therefore the density of an irregularly shaped object by measuring its mass in air and its effective mass when submerged in water (density = 1 g/cc). This effective mass under water was its actual mass minus the mass of the fluid displaced. The difference between the real and effective mass therefore gives the mass of water displaced and allows the calculation of the volume of the irregularly shaped object. The mass divided by the volume thus determined gives a measure of the average density of the sample [15].

The water absorption was determined by weighing the sample (w_1) and placing in a closed container containing water. The sample was then weighed after 24 h as (w_2). The percentage weight gained was calculated and recorded for each sample using the following formula [15,16]:

$$(\%)\ weight\ gained = \frac{Wi - Wo}{Wo}\ x\ 100\ \% \qquad (2)$$

The developed PKS and PWS resin composites of varying composition were viewed using Phenom ProX scanning electron microscope with a magnification of 2000x. The samples for investigation were made conductive to the passage of electrons by gold spraying the sample for 5 seconds using a spouting machine. Thereafter the sample was transferred unto the sample holder and set at a depth of 2.5 mm by turning the knob clockwise 5 times (each revolution is 0.5 mm). The setup was then loaded into the column which is connected to the monitor in a closed loop for which control and feedback are actualized. A finely focused electron beam with voltage energy of 15 KV was scanned across the surface of the sample and generates secondary electrons, backscattered electrons, and X-rays. The magnification is computed by the ratio of the image width of the output medium divided by the field width of the scanned area.

3. RESULTS AND DISCUSSION

PWS/resin composite is denser than the PKS/resin for all weight percent compositions tested as indicated in Fig. 4. It is also seen that its density increases with increasing resin content. This implies an interaction between PWS grains and resin binder. The reverse however is the case for PKS/resin composite with its density decreasing with increasing resin content.

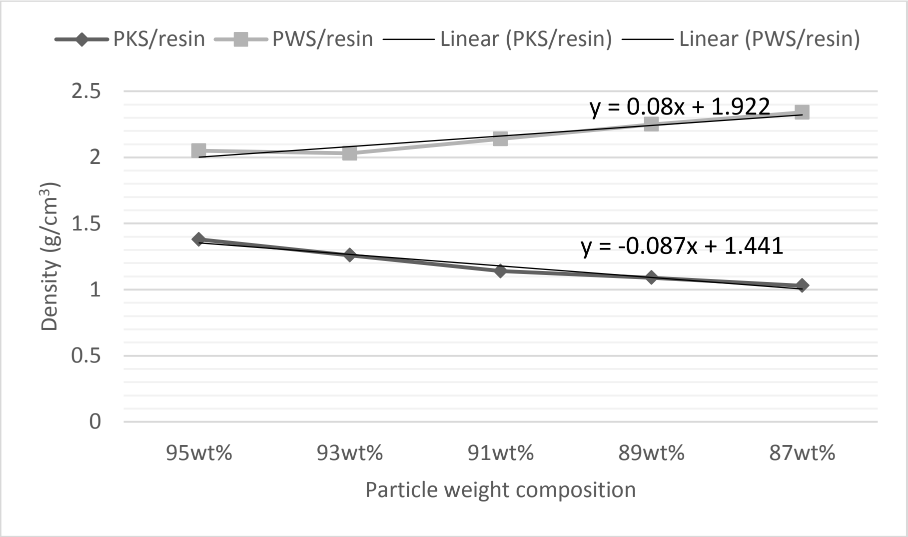


Fig. 4. Density of PKS& PWS/resin composite with particle weight percent variation.

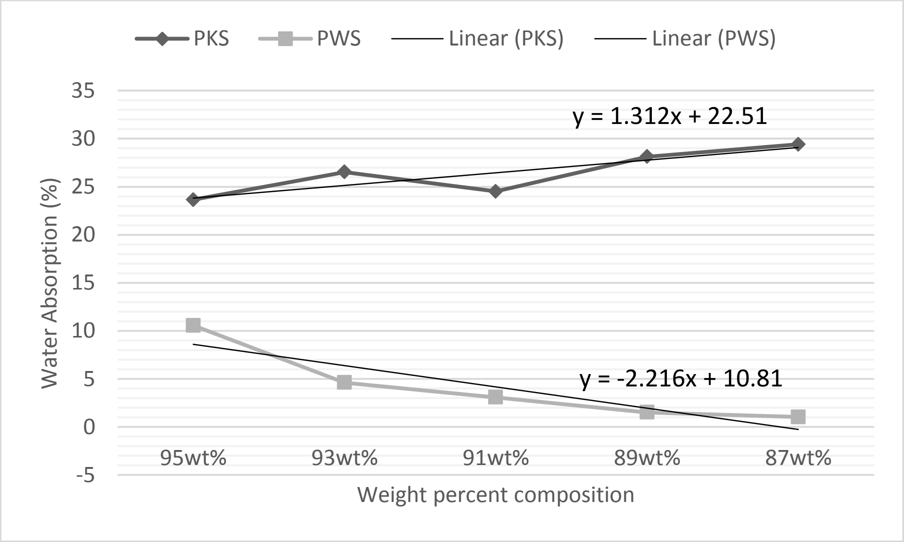


Fig. 5. Water Absorption of PKS& PWS/resin composite with particle weight percent variation.

In Fig. 5, there is a marked difference in water absorption between PWS and PKS composites. The nature of their absorption also differs as a result of the respective interaction between the resin binder and the grains of PWS and PKS. PWS composite has very low absorption which diminishes with increasing resin content implying a positive interaction and closer compactness among the grains in the resin binder. PKS composite has proneness to water absorption due to negative interaction with the grains and the resin binder. This results in inter-particle spaces in the composite (porosity).

Figures 6 and 7 show the SEM/EDS micrograph of PWS and PKS composite (PWS, PKS/resin composite with 87 wt.% particle chosen by virtue of superior physic-mechanical properties). From Fig. 6 it is clear that there is closer packing of PWS grains held in the resin binder. The composite is composed of 59.8 % calcium. Also carbon, antimony and silicon are present.

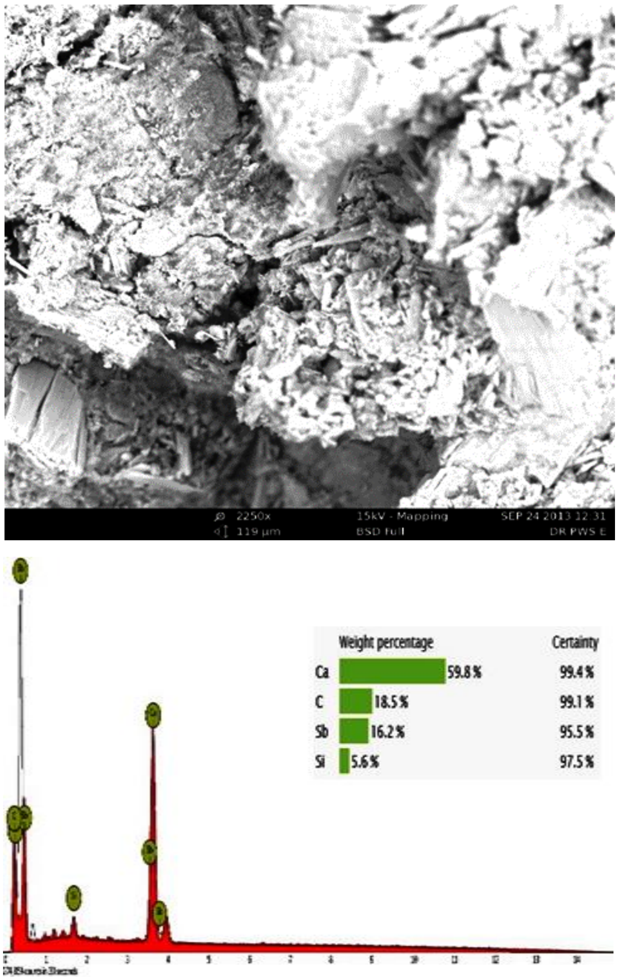


Fig. 6. SEM/EDS microstructure (2000x) of PWS/resin composite with 87 wt.% particle.

The PKS composite microstructure from Fig. 7 show grains flattened out in the matrix by compression force from the composite development stage. Pore spaces are visible in the microstructure. This is validated by high presence of oxygen in the composite at 76.5 %.

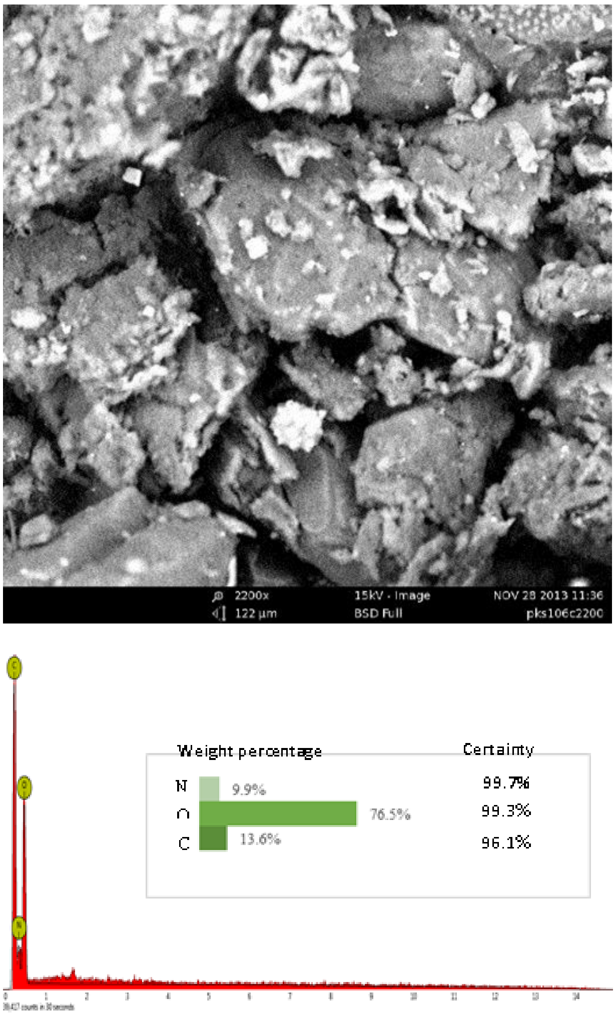


Fig. 7. SEM/EDS microstructure of PKS/resin composite with 87 wt.% particle.

Due to the densification of PWS and greater interaction with resin, the PWS/resin composite predictably show comparably higher mechanical properties. The hardness test results in Fig. 8 indicate PWS composite having higher shore hardness value than the PKS composites at all tested weight percent compositions. It is seen also that this hardness is increased with increasing polyester resin. The greatest hardness value is obtained from 87 wt.% PWS with value of 93.5 shores which exceeds the PKS of same weight composition which is 78.75 shores.

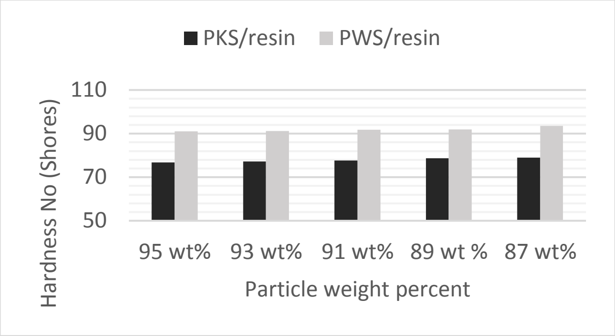


Fig. 8. Shore hardness number of PKS & PWS/resin composite with particle weight percent variation.

Compressive strength tests has PWS composites again exceeding the values of PKS composite samples as seen in Fig. 9. There is a sharp increase in the compressive strength of the PWS composite with increasing resin content having PWS 87 wt.% with highest value of 114.21 N/mm². The effect of low density and high porosity on the compressive strength of PKS composite is clear from Fig. 9. The strength of bonding between particles and resin readily yields under loading compared with PWS resin bond. The highest value for PKS 87 wt.% is 5.25 N/mm².

Coefficient of friction increased by 80 % with increase in polyester resin from 4 – 12 wt.% as seen in Fig. 10. The improvement in coefficient of friction accompanying the presence of increasing polyester resin binder in the periwinkle shell composite follows the increase in average hardness values and compressive strength of the PWS resin composite.

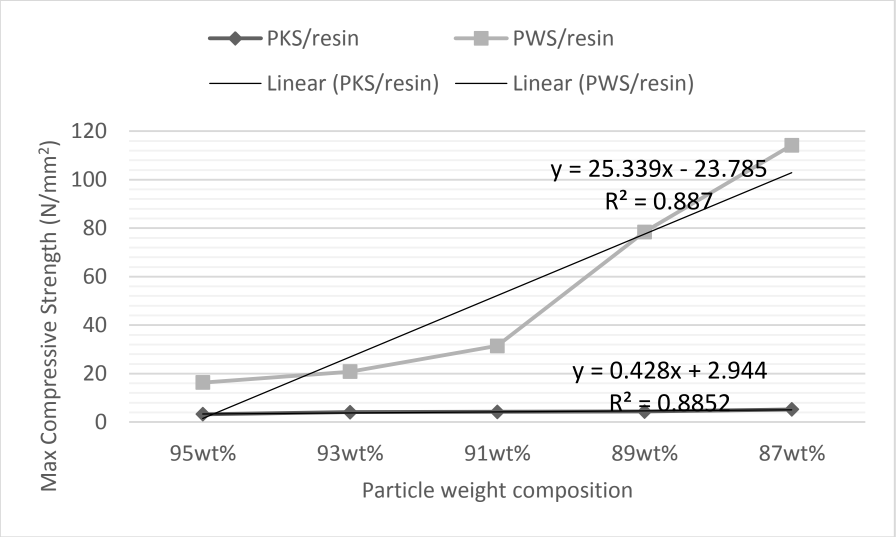


Fig. 9. Max compressive strength of PKS& PWS/resin composite with particle weight percent variation.

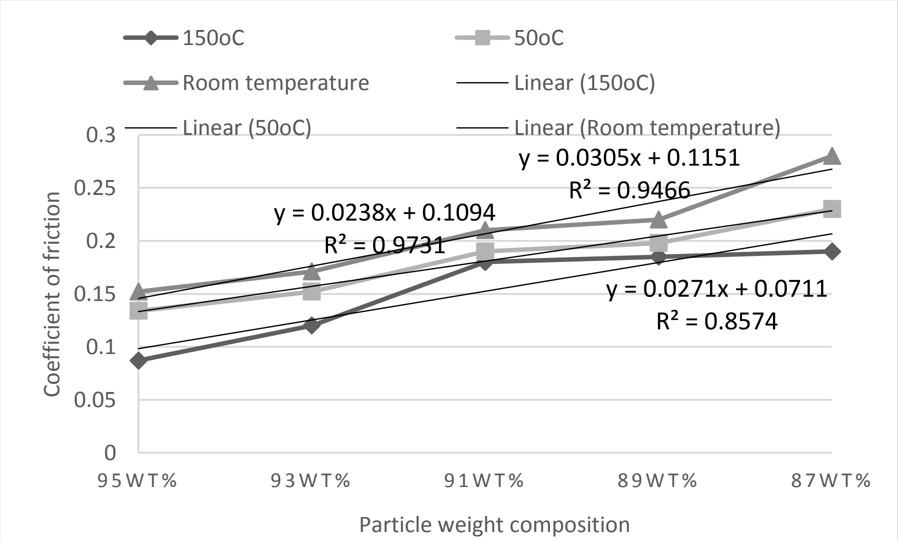
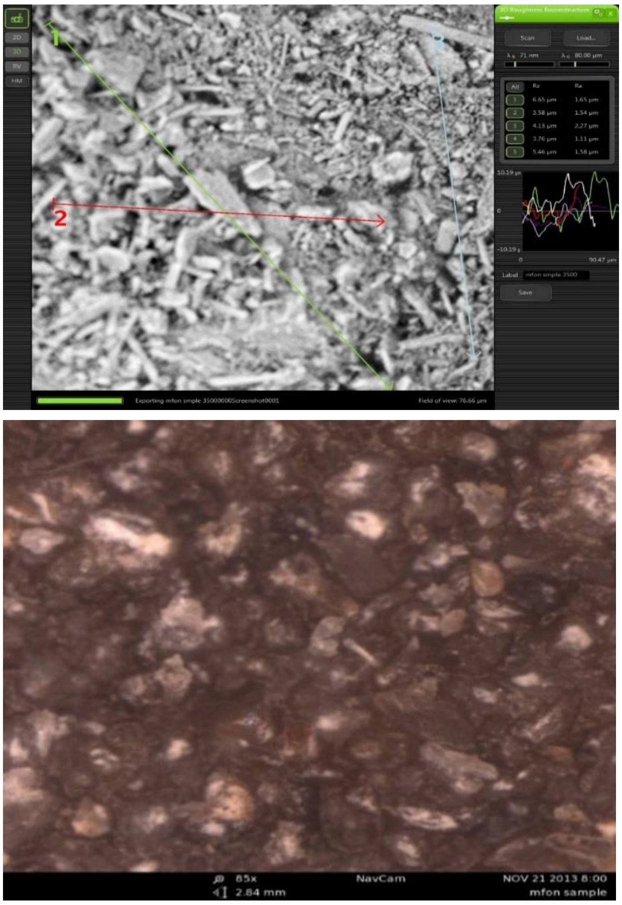


Fig. 10. Coefficient of friction of PWS/resin composite with particle weight variation.

Also improved are the interfacial bonding and positioning of the grains by the polymer resin which is instrumental to the composite further resisting pull-out effect during wear and sanding applications. This correlates previous research that polymer resin binder acts as stress buffer for the PWS grains under uniaxial compressive stresses, maintaining grain alignment with minimal distortion effect [17]. The resultant effect of increased polyester resin bond generates increased friction of PWS with less grain pull-out effect from wear under loading against the surface of the rotating disc in the experiment. Previous researches have established a correlation between coefficient of friction and surface roughness [18]. Therefore, a higher surface roughness, which is a characteristic of sandpaper surfaces, is obtained from higher content of the resin binder upon periwinkle shell grains.



All	Rz	Ra
1	6.65 µm	1.65 µm
2	3.58 µm	1.54 µm
3	4.13 µm	2.27 µm
4	3.76 µm	1.11 µm
5	5.46 µm	1.58 µm

Fig. 11. SEM microstructure of 87 wt.% PWS sandpaper with roughness index profilometry.

It can be observed from the result that PWS samples with 87 wt.% PWS gave the best properties as a result of good interfacial bonding and close grains packing of the PWS grains in the resin binder as seen in its microstructure in Fig. 6 and from the physical and mechanical tests. Subsequently a prototype of sandpaper was produced using this material and composition.

Figure 11 show the surface micrograph and profilometer of produced P40 sandpaper. The computed values of roughness parameter R_a = 1.63 μm and R_z = 4.716 μm.

Table 2 below gives the test values of PWS and PKS composites and their computed percentage differences.

Table 2. Computed Percentage Differences for the Various Physico-Mechanical Tests.

Tests	Density (g/cm3)		Water Absorption (%)		Max Compressive Strength (N/mm2)		Hardness (Shores)	
	PWS	PKS	PWS	PKS	PWS	PKS	PWS	PKS
	2.34	1.03	1.02	29.41	114.21	5.25	93.50	78.75
% Diff	77.74 %		186.59 %		182.42 %		17.13 %	

Conditions: Sieve size at 420 microns, resin content at 12 wt.%.

Table 3. Summary of result findings compared with Garnet sandpaper [19,20].

Parameters	**Standard Garnet sandpaper**	**87 wt.% PWS sandpaper**
Grit No, Mean diameter	P40, 420μm	P40, 420 μm
Specific gravity (g/cm^3)	3.9 – 4.1	2.34
Hardness (Vickers)	1200	860*
Coefficient of friction (μ) at P40	0.35	0.28
Surface roughness Ra	0.8- 1.2	1.63

*hardness conversion from Engineers Reference Handbook [21].

CONCLUSION

From the results and discussion in this work the following conclusions can be made:

1. Periwinkle shell (PWS)/resin composites have higher physico-mechanical properties such as density with 77.74 % difference, hardness with 17.13 % difference and compressive strength with 182.42 % difference over the palm kernel shell-resin composites. Water absorption for palm kernel (PKS) shell/resin composite was a 186.59 % difference over the periwinkle shell (PKS)/resin composite.

2. Surface morphology on the produced composite reveal the microstructure of PWS/resin composite to have closer packing PWS grains held by polyester resin and to exhibit less distortional effect from applied compression forces. The microstructure of the PKS/resin composite is shown to have pore spaces with the grains exhibiting effects from compression forces.
3. Periwinkle shell (PWS)/resin composites show an 80 % improvement in the coefficient of friction value with increase in polyester resin from 4 – 12 wt.%. This is as a result of the increasing average hardness and compressive strength with increase in polyester resin. This in turn is due to the close packing of PWS grains and interfacial bonding between periwinkle particles and polyester resin.
4. Periwinkle shell (PWS) grains sandpaper are close to properties of garnet sandpaper and therefore show promising applications as abrasive grits with further improvement.
5. Palm kernel shell (PKS) grains at high concentrations held in a polymer resin matrix are not suitable for abrading operations due to the porous nature of the composite.

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