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Development and Formulation of Abrasive Grinding Wheel Constituents Utilizing Coconut, Palm Kernel and Periwinkle Shells

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ABSTRACT

Nigeria imports grinding wheels to meet the rising demand for the wheels. The high cost of these imported non-biodegradable conventional abrasive grinding wheels and their pollution challenge to the users and their environment need to be looked into. Therefore this research work on the development and formulation of bio-degradable composite abrasive grinding wheels made from coconut shell (CNS), palm kernel shell (PKS) and periwinkle shell (PWS) with polyester resin (PSR) as a response to the challenge. Raw samples of CNS, PKS and PWS were collected respectively, sorted and pulverised using a hammer mill into different particle sizes of 250, 500 and 850 µm. These particles were blended at mixing ratios of 1:0, 0:1, 1:2and 2:1 of CNS, PKS and PWS; bonding with 23% weight of resin as a binder while 2% cobalt compound and methyl-ethyl ketone peroxide were used as a hardener to initiate polymerization and catalyse the reaction process respectively. The results obtained shown that 500 µm of palm kernel shell had the highest percentage of retaining with a low percentage finer of 49.43 and 50.57 respectively, followed by 200 µm, 250 µm and 850 µm with 20.27%, 18.94% and 11.36% respectively. For the periwinkle shell sample, 500 µm had the highest percentage retained of 48.45 and a low percentage finer of 51.55 followed by 250 µm, 200 µm and 850 µm with 22.71%, 17.53% and 11.32% respectively. Coconut shell sample, it is equally seen that 500 µm showed a better and stronger retained percentage of 54.05 and 45.95 percentage finer compared to that of 250 µm, 200 µm and 850 µm with 16.36%, 15.21% and 14.34% of the retained sample respectively. This implies that, for the production of abrasive grinding wheels from the blend of palm kernel shell, coconut shell and periwinkle shell, the range of 200 to 500 µm sieve size should be recommendable and preferred due to their large quantity retained, this is for semi coarse and smooth grinding. However, particle distribution depends on the intensity of the grinding samples, and the material surface finish required.

Keywords: Abrasive grinding wheel,agricultural waste, coconut shells, palm kernel shell, periwinkle shell

Introduction

Abrasives are known as grits which are known to have sharp cutting edges, hardness, brittleness, toughness, grain shape and grain size, the character of fracture, purity and uniformity of the grains, chemical stability and wear resistance. They are used in grinding wheels, sandstone, sandpapers, honing stones, polishes, cut-off wheels, ball mills, and other machining tools and products. They could be natural and synthetic substances ranging from relatively soft particles to the hardest known material like a diamond. Some naturally occurring abrasives are; clays, lime, aluminosilicate mineral, feldspar, calcined, chalk and silica, flint, kaolinite, diatomite and diamond (Odior & Oyewale, 2013).

Synthetic abrasives materials are produced and their qualities and compositions can be measured and predetermined. The main characteristic of synthetic abrasives is their purity which has an important performance in their efficiency (Sa'ad et al., 2021). Synthetic abrasive materials include silicon carbide, aluminium oxide, and Cubic Boron Nitride (CBN), while aluminium oxide and silicon carbide are the most common mineral in use today (Bhowmik & Naik, 2018). Abrasives can be synthesized from various types of materials (Durowaye et al., 2014). Bonded abrasives are a mixture of abrasive grains, fillers and bonding materials. Bonded abrasives can be used to cut off and grind on diverse hand-held machines such as angle grinders, petrol saws, and straight and vertical grinders. Grinding is an art and science of material cutting operation performed by the means of rotating abrasive wheels that act as cutting tools. It is the process of removing material by the abrasive action of a grinding wheel on a surface to give the desired finish and dimension (Phaneendra et al., 2015). Each abrasive grain is a cutting edge and as the grain passes over the workpiece, it cuts a small chip, leaving a smooth, accurate surface. As the abrasive grain turns out to be dull, it breaks away from the bonded material revealing new sharp grains (Odior et al; 2010). Research and developments related to the grinding wheel have been of great focus for both academic and industrial communities. This could be traced to the growing need for grinding wheels (GWs).

Palm kernel shell (PKS), coconut shell (CNS) and periwinkle shell (PWS) are agricultural residues obtained in the processing of palm oil, coconut oil and seafood respectively, and are available in large quantities in the tropical regions of the world. The development of abrasives from the huge amount of coconut and palm kernel shells available in Nigeria to manufacture tools and equipment is a suitable alternative to reduce cost, utilize and place economic values on these agricultural residues.

The production of non-degradable grinding wheels with materials like glass powder, steel abrasive, silicon carbide, diamond dust, Zirconia alumina, Boron carbide, Slags and other special grits of grinding wheels are imported on daily basis to meet the demand of the market. The cost of these non-biodegradable conventional abrasive grinding wheels is on the high side and it also poses a pollution challenge to its users and their environment. However, there are available degradable raw materials such as coconut, palm kernel and periwinkle shells that can be used for their products locally but are being considered residues and discarded unhealthily. Therefore, this study seeks to develop abrasive grinding wheels produced from coconut, palm kernel and periwinkle shells.This study aims to develop abrasive grinding wheels from a mix of coconut, palm kernel and periwinkles shells and determine the mechanical properties of the composite grinding wheels. First, we design and fabricate the mould for the production of abrasive grinding wheels and then the mixing and production of abrasive grinding wheel composite material.

The production of abrasive grinding wheels from the composite of degradable waste materials will meet the high demand, thereby reducing the high effect of environmental pollution and equally creating job opportunities which will improve the economic state of the nation.

Materials and Method

Overview of Materials Required

The raw materials that was used in this study are agricultural residues such as coconut (Cocos nucifera)shells, palm kernel (Elaeis guineensis)shells, periwinkle (Littorina littorea)shells, polyester resin bond, cobalt octoate (accelerator) and methyl ethyl ketone peroxide (hardener). The palm kernel shells was obtained from Ila Orangun town, Ila Orangun, Nigeria and they were obtained in the already cracked and oil-extracted form and the fibrous outer parts of the nut already removed. The coconut shells and the periwinkle shell was obtained from Oja-Oba, Ilorin, while the polyester resin, methyl-ethyl ketone peroxide (MEKP) and cobalt octoate was sourced from Lagos, Nigeria

The properties and application cases of the aforementioned agricultural wastes that were used in this study were highlighted in (Abnisa et al., 2013; Singh & Bhaskar, 2013; Tomas & Ganiron, 2013).

(a) (b) (c)

Figure 1: Agricultural residues used in the formulation of abrasive grinding wheel (a) Coconut shell (b)Palm kernel shell (c) Periwinkle shell

Polyester resin

Polyester resins, a sample of which is shown in Figure 2 are the most economical resin formula used in engineering applications, but with limited use in high-performance composites. They can be produced for a large variety of properties, from soft and ductile to hard and brittle. The principal advantages of polyesters are low cost, low viscosity and a relatively short curing period. However, polyesters have lower mechanical properties than other thermosets, poor weathering resistance and relatively high shrinkage. This volumetric shrinkage can be reduced by adding a thermoplastic component. Polyester resin offers the following advantages: adequate resistance to water and a variety of chemicals, adequate resistance to weathering and ageing, low cost, it polyesters can withstand a temperature up to 80°C, polyesters have good wetting to glass fibres and relatively low shrinkage at between 4-8% during curing. As a thermosetting agent, the polyester resin cures exothermically, and the use of an excessive initiator such as a catalyst can cause charring or ignition during the process. An excessive catalyst may also cause the product to fracture or form rubbery material.

Figure 2: Sample of the polyester resin

There are two principal types of resin used as a standard laminating system in the composite industry. Orthophthalic polyester resin is the standard economic resin used in many industries. Isophthalic polyester resin is now becoming the preferred material in industries such as marines where high water resistance is required. The other types of bonds are Vitrified (V) or Ceramic bonds, Resinoid or Organic (B) bonds, Rubber (R) bonds, Silicate (C) bonds, Shellac (E) bonds and Magnesite (O) bond, and Metal bonds. These binders are used for various kinds of grinding and cutting wheels for different applications.

Methyl ethyl ketone peroxide

Methyl ethyl ketone peroxide (MEKP), a sample of which is shown in Figure 3 is organic peroxide, a colourless liquid with a strong irritant to skin and tissue. Used as an initiator for room temperature cure of unsaturated polyester resins. MEKP is a colourless, oily liquid whereas acetone peroxide is a white powder at STP; MEKP is slightly less sensitive to shock and temperature, high explosive and more stable in storage. Table 1shows the chemical and physical properties of Methyl Ethyl Ketone Peroxide.

Figure 3: Sample of methylethylketoneperoxide

Table 1: Chemical and Physical Properties of Methyl Ethyl Ketone Peroxide (Johnson, 2017)

Chemical name	**Methyl ethyl ketone peroxide**
Compound formula	$C_8H_{16}O_4$
Molecular weight	210.22 g/mol
Appearance	Colourless liquid
Density	1.170 kg/m^3
Boiling point	80 ^oC

Cobalt Octoate

Cobalt octoate (Cobalt 2-ethylhexoate) is one of the most active major driers and is used alongside with auxiliary drier to stimulate an even surface through drying. Care needs to be applied when measuring Cobalt to prevent an excess of it which could cause fast drying that would result in surface wrinkling. Cobalt octoate speed up the catalytic action of Methyl ethyl ketone peroxide (MEKP) to polymerize unsaturated polyester resin. Cobalt octoate is used as an accelerator in the polymerization of unsaturated polyester resins. It is better compared to cobalt naphthenate as it has a pale colour, low toxicity and low odour. The sample of Cobalt octoate is shown in Figure 4.

Figure 4: Sample of the cobalt octoate

Table 2: shows the chemical and physical properties of Cobalt octoate (European Chemicals Agency (ECHA), 2019)

Chemical name	**Cobalt octoate (Cobalt 2-ethylhexoate)**
Compound formula	$C_{16}H_{10}CoO_4$
Molecular weight	345.34 g/mol
Appearance	Purple Liquid
Density	1.01 kg/m^3
Exact mass	345.147603 g/mol
Monoisotopic mass	345.147603 g/mol

Grinding Wheel

A grinding wheel often called a grinding disc is a wheel composed of an abrasive compound used for various grinding, abrasive cutting and abrasive machining operations. The wheels are generally made from a composite material consisting of coarse-particle aggregate pressed and bonded together by a cementing matrix (bond in grinding wheel) to form a solid, circular shape. Various profiles and cross sections are available depending on the intended usage of the wheel. They may also be formed from a solid steel or aluminium disc with particles bonded to the surface. Surface finish, which is also known as surface texture or surface topography, is the nature of a surface as defined by the three characteristics such as lay, surface roughness and waviness (Obot et al., 2015). It comprises small, local deviations of a surface from the perfectly flat ideal plane materials such as metal sheets and woods. Surface texture is one of the main factors that control aesthetics in engineering. The grinding process is constantly adapting to new requirements in the industry, with a particular focus on the production of high-quality surface finish while increasing process efficiency (Godino et al., 2018).

The various type of grinding wheels are; straight, cylinder or wheel ring, tapered, straight cup, dish cup, saucer and diamond grinding wheel. Some are shown in Figure 5.

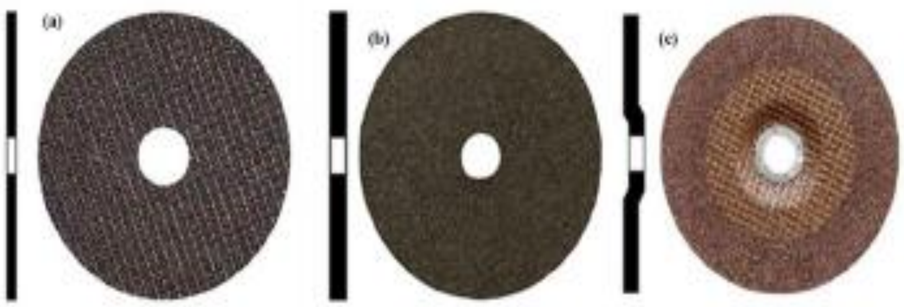


Figure 5: (a) Flat reinforced cutting-off wheel (b) flat reinforce grinding wheel (c) depressed centre-reinforced grinding wheel

Grain Size

Some of the important physical properties of abrasive materials are hardness, brittleness, toughness, grain size and grain shape, purity and uniformity of the grains (grit). The grinding wheel is made from large numbers of abrasive grain particles. The grain size or grit number, shown in Table 3 implies the size of the abrasive grains used in making a wheel or the size of the cutting teeth. The size of grain grits is determined by sorting the material through the process of passing through sieves with the number of meshes per linear inch. The grain size determines stock removal rate and generates surface finish, coarser grits remove stock more rapidly, but do not leave a good finish. Conversely, finer grits give a better finish, but slower stock removal rates. The selection of grain size is determined by the nature of the grinding operation, material to be ground, material removal rate and surface finish required.

Table 3: Particle grits sizes and applications

S/N	**Size**	**Type**	**Applications**
1	10, 12, 14, 16, 20, 24	Coarse	Rapid material removal
2	30, 36, 46, 54, 60	Medium	Stock removal and surface finish
3	80, 100, 120, 150, 180	Fine	Less stock removal high surface finish
4	220, 240, 280, 320	Very fine	Very high surface finish grinding hard material

Equipment

The equipment that was used during this research study is a 3,730 W hammer mill, a set of mechanical sieves (Figure 6), Citizen Electronic weighing balance (Model MP5000 with 0.001 g resolution), Universal Testing Machines (Testometric M500-100AT), Universal Testing Machine (Testometric FS5080) capacity 50 KN and electric handheld grinder. The laboratory tools to be used include a manual stirrer, bowls and scrapper.

Figure 6: Standard sieve test apparatus

Methods

The step-by-step experimental work of this research study was conducted in the following stages which are: material preparation, mixing ratio, material selection for the mould, design and fabrication of mould, formulation and production of coconut and palm kernel shell abrasive grinding wheels and the Physico-mechanical characterization of the produced wheels.

Material Preparation

A quantity of 5 kg of palm kernel shell (PKS), 5 kg of coconut shells (CNS) and 5kg of periwinkle shell (PWS) samples was obtained and sorted to remove dirt and other unwanted materials such as palm fibres, uncrushed palm fruits, stones and other plant residues. The sorted sample will then be sun-dried for four days for initial moisture contents removal, followed by oven drying at 100 for 2 hours to remove the unbounded moisture completely. The samples was pulverized separately using a 3,730 W hammer mill. The mass of each sample was measured using an electronic weighing balance. The pulverized samples will then be sieved using three sieve sizes of 250, 500, and 850 (ASTM E11) to categorize the (CNS/PKS/PWS) grains into FEPA abrasive grits of P60, P40 and P25 respectively (FEPA Abrasives, 2013).Electronic weighing balance (Model SF-400) was used to weigh out 75/0/25, 0/75/50, 25/50/75, 37.5/37.5/37.5, and 50/25/25g of CNS/PKS/PWS abrasive particles. This is shown in Table 4. After weighing on the digital balance, they were poured into separate plastic containers and then 25 g of polyester resin will also be measured in five separate containers to be mixed with each of the blends. Two 2 g of cobalt octoate and methyl ethyl ketone peroxide which will correspond to 2% of the entire mass of the mixture was poured into each of the plastic containers and kept constant throughout the sample composition.

Table 4: Mass composition of 250, 500 and 850 µm CNS/PKS/PWS/resin bond/Cobalt/MEEK

CNS (g)	PKS (g)	PWS (g)	Resin (g)	Cobalt/MEEK	Total Mass (g)
75.0	0.00	0.00	23.0	2.00	100
0.00	75.0	0.00	23.0	2.00	100
0.00	0.00	75.0	23.0	2.00	100
40.0	20.0	15.0	23.0	2.00	100
20.0	40.0	10.0	23.0	2.00	100
30.0	30.0	15.0	23.0	2.00	100

Mixing Ratio

Particles of coconut, palm kernel periwinkle shell abrasives were blended separately as controlled samples and then different ratios of CNS, PKS and PWS will also be blended to enhance and attain uniformity of the mixtures as shown in Table 5. The polyester resin binder, hardener and accelerator quantity were kept constant throughout the entire mixing ratio of the particles which were in line with what was practised by Odior & Oyawale (2013) and Kagawa (1975).

Table 5: Blend ratio of different particle sizes of coconut, palm kernel and Periwinkle shells

Sieve sizes (µm)	Blend ratio (Coconut shells: Palm kernel shells: Periwinkle shell) (%)				
250	1:0	0:1	1:1	1:2	2:1
500	1:0	0:1	1:1	1:2	2:1
850	1:0	0:1	1:1	1:2	2:1

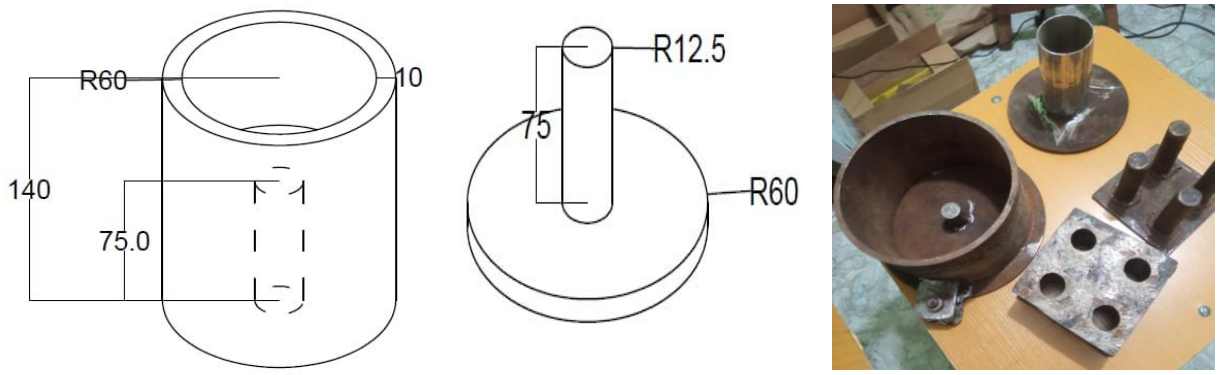
Material selection for the mould

The material to be used for the mould is mild steel. Mild steel was used because of its ease of machinability, availability, cost-effectiveness and good corrosion resistance. It can withstand high pressure under compression, mild steel is harder and displays higher strength than pure iron, and good malleability as a result of the reduced carbon content of mild steel makes it easier to shape, drill, step turn, weld and cut than other more brittle varieties of steel.

Design and fabrication of the mould

The moulddesign was designed using AutoCAD software 2018 and then fabricated as shown in Figure 7.

The dimensions of the proposed grinding wheel/disc fabricated are; outer diameter (D) = 120 mm, hole diameter (d) = 22 mm and thickness (t) = 6 mm
The dimensions of the mould are outer height =140 mm, internal height =75 mm, wall thickness = 10 mm
piston outer diameter =115 mm and piston hole diameter = 25 mm



(a) (b)

Figure 7: The mould (a) drawing (b) fabricated

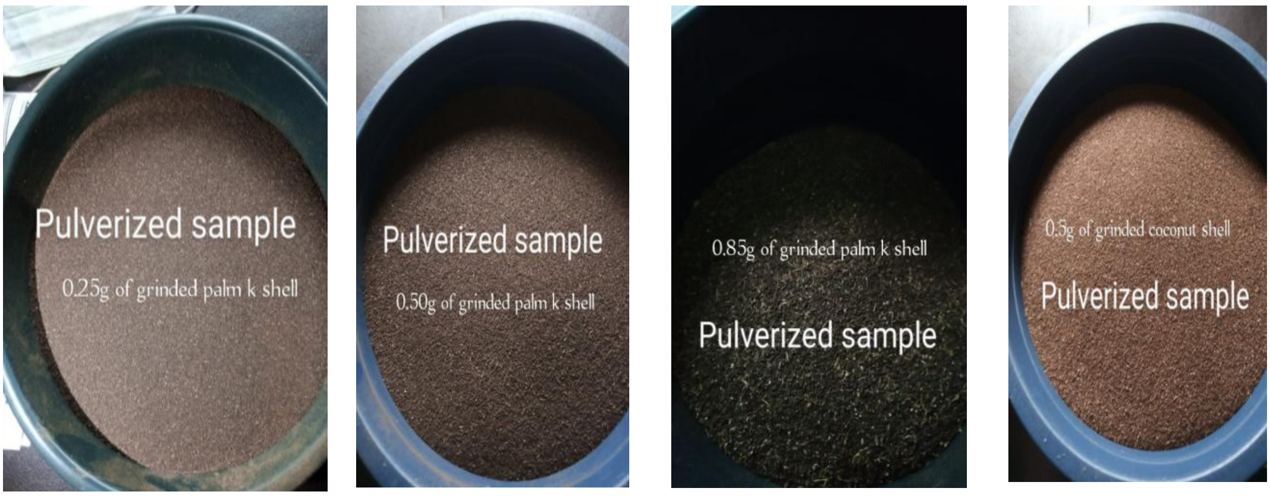
Formulation and production of coconut and palm kernel shell abrasive grinding wheel

The methods by Kagawa (1975), Odior & Oyawale (2013) and Shehu et al. (2014) were adopted in this research study. The measured coconut and palm kernel shell abrasives were firstly blended manually before a mixture of the polyester resin, cobalt octoate accelerator and methyl ethyl ketone peroxide hardener was added and stirred thoroughly using a manual stirrer to ensure homogeneity of the mixture. The homogenous mixture is then poured into the prepared mould and compressed with a force of 180 kN using a manual compression machine, by placing the mould in between the compressive plates of the machine before releasing the piston which exerted force on the blend to produce the abrasive wheel. The same process was repeated to produce other abrasive samples. The samples will then be cured in an oven at a temperature of 80 ^{o}C for ten hours (Kagawa, 1975).

Results and Discussion

Physical and Mechanical Property

Some samples of the pulverized constituent for the abrasive grinding wheel are shown in Figure 8. The subsequent sieve analysis is shown in Tables 6-8 and Figures 8-9.



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 8: Samples of the pulverized abrasive grinder constituent (a) 0.25g of grinded palm kernel shell (b)0.50g of grinded palm kernel shell (c)0.85g of grinded palm kernel shell (d)0.50g of grinded coconut shell (e)0.85g of grinded coconut shell (f)0.25g of grinded periwinkle shell (g)0.50g of grinded periwinkle shell (h)0.85g of periwinkle coconut shell

Table 6: Sieve analysis table for palm kernel

Sieve size (µm)	Weight of sieve(g)	Mass of particles retained (g)	Percentage retained (%)	Percentage finer (%)
200	281	107	20.27	79.73
250	306	100	18.94	81.06
500	345	261	49.43	50.57
850	471	60	11.36	88.64
		Total= 528		

Percentage retained =mass retained/∑M x 100%

Where ∑M is the total mass retained on each sieve (g)

1. % retained of 0.20 mm → 107/528 x 100 = 20.27%
2. % retained of 0.25 mm → 100/528 x 100 = 18.94%
3. % retained of 0.50 mm → 261/528 x 100 = 49.43%
4. % retained of 0.85 mm → 60/528 x 100 = 11.36%

Percentage finer is 100 – percentage retained

0.20mm → 100 – 20.27 = 79.73%

0.25mm → 100 – 18.94 = 81.06%

0.50mm → 100 – 49.43 = 50.57%

0.85mm → 100 – 11.36 = 88.64%

Table 7: Sieve analysis for periwinkle

Sieve size (µm)	Weight of sieve(g)	Mass of particles retained(g)	Percentage retained (%)	Percentage finer (%)
200	281	254	17.53	82.47
250	306	329	22.71	77.29
500	345	702	48.45	51.55
850	471	164	11.32	88.68
		Total = 1449		

Table 8: Coconut sieve analysis

Sieve size (µm)	Weight of sieve(g)	Mass of particles retained(g)	Percentage retained (%)	Percentage finer (%)
200	281	87	14.34	85.66
250	306	99	16.36	83.64
500	345	327	54.05	45.95
850	471	92	15.21	84.79

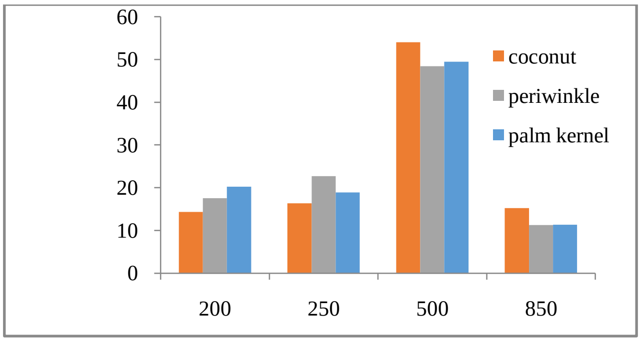


Figure 8: Percentage retain on the vertical axis while particle size is for the horizontal axis

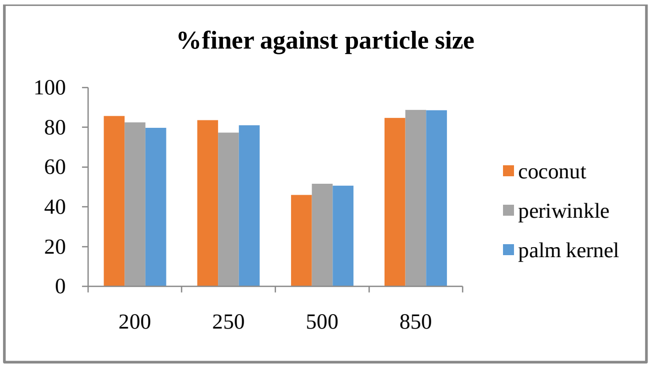


Figure 9: Percentage of overall quantities against particle sizes

Discussion of Sieve analysis

From Tables 6-8 and Figure 8-9, it is seen that 500 µm of palm kernel shell had the highest percentage of retaining with a low percentage finer of 49.43 and 50.57 respectively, followed by 200 µm, 250 µm and 850 µm with 20.27%, 18.94% and 11.36% respectively. For the periwinkle shell sample, 500 µm had the highest percentage retained of 48.45 and a low percentage finer of 51.55 followed by 250 µm, 200 µm and 850 µm with 22.71%, 17.53% and 11.32% respectively. Coconut shell sample, it is equally seen that 500 µm showed a better and stronger retained percentage of 54.05 and 45.95 percentage finer compared to that of 250 µm, 200 µm and 850 µm with 16.36%, 15.21% and 14.34% of the retained sample respectively. This implies that, for the production of abrasive grinding wheels from the blend of palm kernel shell, coconut shell and periwinkle shell, the range of 200 to 500 µm sieve size should be recommendable and preferred due to their large quantity retained, this is for semi coarse and smooth grinding. However, particle distribution depends on the intensity of the grinding samples, and the material surface finish required..

Conclusion

In answer to the challenge, the study described the creation and formulation of biodegradable composite abrasive grinding wheels constructed from coconut shell, palm kernel shell, and periwinkle shell with polyester resin. Raw samples of CNS, PKS, and PWS were each collected, sorted, and ground into varied particle sizes of 250, 500, and 850 µm using a hammer mill. These particles were blended at mixing ratios of 1:0, 0:1, 1:2and 2:1 of CNS, PKS and PWS; bonding with 23% weight of resin as a binder while 2% cobalt compound and methyl-ethyl ketone peroxide will be used as a hardener to initiate polymerization and catalyse the reaction process respectively. The output was sieved to obtain various grit sizes. This implies that the range of 200 to 500 µm sieve size should be recommended and preferred due to their large quantity retained, this is for semi-coarse and smooth grinding. This is for the production of abrasive grinding wheels from the blend of palm kernel shell, coconut shell, and periwinkle shell. However, the intensity of the grinding samples and the desired material surface polish determine how the particles are distributed. In the future, we will fabricate the abrasive grinding wheel using the fabricated mould and the formulated constituents.

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