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Abstract

Advances in power transmission using spur gear technology in some specific mechanical devices required lightweight to strength ratio of the gear material. This study evaluated the mechanical properties of a particulate palm kernel shell reinforced polyester composite (PPKSRPC) for spur gear application. The PPKSRPC sample was prepared and examined experimentally to determine its mechanical properties such as tensile strength, modulus of elasticity and shear modulus. The experimental result for 5% weight fraction of PPKSRPC gave a tensile strength, modulus of elasticity and shear modulus of 90.3 MPa, 2.35 GPa and 0.89 GPa, respectively. The value obtained was used to model the PPKSRPC spur gear under a torque of 140 N-m in ANSYS environment. The observed values of the responses (mechanical properties) of the PPKSRPC under loading conditions are lower compared to the conventional steel in spur gear application.

Keywords
Mechanical properties, Particulate palm kernel shell, Polyester, Spur gear

1. Introduction
The high strength to weight ratio and socio-economic benefits of natural fibre based composites make them suitable for many applications such as in polymer gears, vehicles interior and exterior components. More so, global quest for eco-friendly materials has sparked research interests into the development and use of natural composites. Some applications and advantageous properties of different natural composites have been reported in the literature (Sanjay, et al., 2017; Raju & Kumarappa, 2012; Rozman, et al., 2005; Razaka, et al., 2017; Kilanko, et al., 2018; Oreko, et al., 2018). A variety of agricultural residues ranging from soft banana peel to hard palm kernel shells (PKS) are being used to produce natural fibre based composites.

Palm fruit is widely cultivated in Nigeria (Poku, 2002). Palm Kernel Shell (PKS) is a by-product of palm fruit, and can be used as a natural reinforcement in the manufacture of polymer composites. Particulate PKS has surface elements and is crystalline. PKS has poor thermal conductivity and can serve as a thermal insulator (Ighodalo & Okoebor, 1996). It can be used for construction materials and water treatment granular filters (Okoriogwe, et al., 2014; Oti, et al., 2017; Alsalami, et al., 2018). It has successfully been used to develop friction materials such as brake pads for automobiles (Fono-Tamoa & Koyab, 2017; Ikpambese, et al., 2016; Elakhame, et al., 2014; Ibhadode & Dagwa, 2008). The characterisation of powder for use in polymer matrix composite has been reported (Dagwa, et al., 2012; Sanjay, et al., 2017). The size and percentage composition of PKS particles in the polymer composite and its effect on the mechanical and microstructural properties were also reported (Olumuyiwa, et al., 2012; Shehu, et. al., 2014). Currently, composite materials are used to produce gears for pumps, motors, actuators, and drive shafts of automobiles (Rajeshkumar & Manoharan, 2017; Anakhu et al., 2018). The design of gears is well discussed in the literature (Hewitt 1992; Maitra 1994; Khurmi and Gupta 2005). Although there are several gear types, (Mahendran, et al., 2014) opined that spur gears are usually the first choice of gears due to their design simplicity, ease of manufacture, excellent efficiency and wild range of applicability. Parey & Tandon, 2003 reported some dynamic models of spur gears and their defects, while finite element analysis of static stress in spur gears was given in (Rajak & Kumar, 2016; Singh, et al., 2017). Guptaa and Chatterjeeb applied finite element analysis to model the static stresses of spur gears of different plastic materials (Guptaa & Chatterjeeb, 2018). They reported that the stress values were below the permissible stresses regardless of the material types.

Polymer composites gears have been reported to become soften and suffer wear as surface temperature increases (Mao, 2007). However, their low cost, low noise advantages can still be annexed if they are well reinforced. For example, polymer reinforced with Polycarbonate/Acrylonitrile-Butadiene-Styrene (PC/ABS), though having low load carrying capacity, has been found to have sufficient resistance to fire, ultraviolet light and moisture (Yakut, et al., 2009). Just like PC/ABS, PKS has a high carbon content, thus when blended with the polymer, may serve as a suiTable material for the spur gear.

The aim of this study is to introduce a new area of application of PKS, particularly in the production of spur gears. Furthermore, advantage the use of such composites might have over the conventional spur gears made of cast steel was investigated. Particulate PKS reinforced Polyester Resin material was developed, its mechanical properties were investigated and used to model spur gears.

2. Materials and Method

2.1 Materials

The materials employed in this study include Palm Kernel Shells (PKS), unsaturated polyester resin; hardener or catalyst (methyl ethyl ketone peroxide); accelerator (cobalt naphthenate); release agent (A - Z grease); sodium hydroxide (NaOH); deionised water and the mould materials. The Particulate palm kernel shells act as the reinforcing materials and were obtained as waste materials from a palm kernel vendor at Effurun, Warri Delta state, Nigeria. Also, the polyester resin, catalyst (methyl-ethyl-ketone peroxide, MEKP), the accelerator (cobalt naphthenate) and other additives were purchased at Effurun market in Delta State, Nigeria.

2.1.1 The Mould

The mould was constructed to the required dimension of the tensile test specimen as shown in Figure 1, using PVC and silicon rubber.

Figure 1: The moulds (silicon rubber on PVC)

2.2 Method

The raw PKSs were cleaned to remove impurities (Figure 2a), crushed and ground into a fine powder known here as particulate palm kernel shell (PPKS) as shown in Figure 2b. The PPKS was treated by the mercerisation process, sundried and sieved (using a sieve of 850μm aperture).

Figure 2(a). Raw Palm Kernel Shells

Figure 2(b) Powdered PPKS

The average percentage weight composition of the particulate palm kernel shell reinforced Composites (PPKSRPC) with a weight fraction of 5% is shown in Table 1.

Table 1: Weight formulation of composites

S/N	**Material**	**% Weight composition**
1.	Polyester Resin + Hardener	94.98
2.	Accelerator	0.02
4.	Palm Kernel Shells Powder	5.00
	Total	100

2.3 Experimental Details

2.3.1 Tensile test

The tensile test experiment on PPKSRPC specimen with average gauge length 50mm and width 4mm, shown in Figure 3, was carried out using an electronic universal testing machine (Model: INSTRON 3369), at the Material Testing laboratories, Engineering Material Development Institute, EMDI, Akure, Nigeria.

Figure 3: Tensile test specimens.

2.3.2 Density Test

The PPKS based composite was sized accordingly, weighed and recorded as w (in grams), distilled water was poured into a measuring cylinder with initial volume recorded as V_1 (in cm^3). The weighed (dry) PPKSRPC was immersed into the measuring cylinder containing distilled water, and the final volume recorded as V_2 (in cm^3). The density of the PPKSRPC was calculated using the expression (Abdul Khalil, 2011):

$$\frac{w}{v_1 - v_2} \times \text{grams/cm}^3$$

Where: w = weight of the dried PPKS sample (g); v_1 and v_2 are the initial and final volume of water, respectively (cm^3)

2.4 Performance Modelling

Static structural analysis on PPKSRC for gear design was analysed and compared with the design on cast steel for spur gear application, developed by Mahendran et al., 2014. The geometric model of gear design was produced in solid works (Figures 4 and 5) and the model imported into ANSYS 15.0 and mesh was analysed (Figure 6). In the ANSYS environment, the connection types, material properties were inputted and the material selected (Table 2). Also, the mesh and static structural properties, boundary conditions were defined (Table 3).

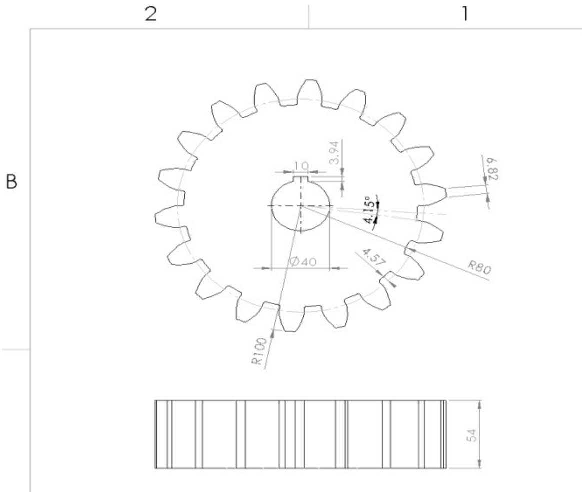

Figure 4: 2D drawing of spur gear

Figure 5: Solidworks Model

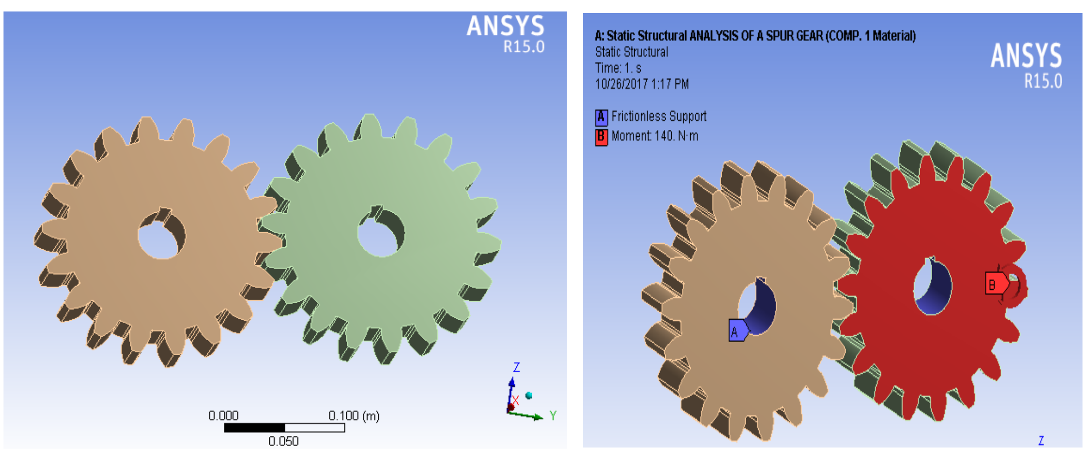

Figure 6: Model imported into ANSYS

Table 2: Connections

Model> Connections > Contacts	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies

Table 3: Mesh

Model> Mesh	
Physics Preference	Mechanical
Relevance	0
Patch Conforming Options	
Triangle Surface Mesher	Program Controlled
Statistics	
Nodes	307761
Elements	189022
Mesh Metric	None

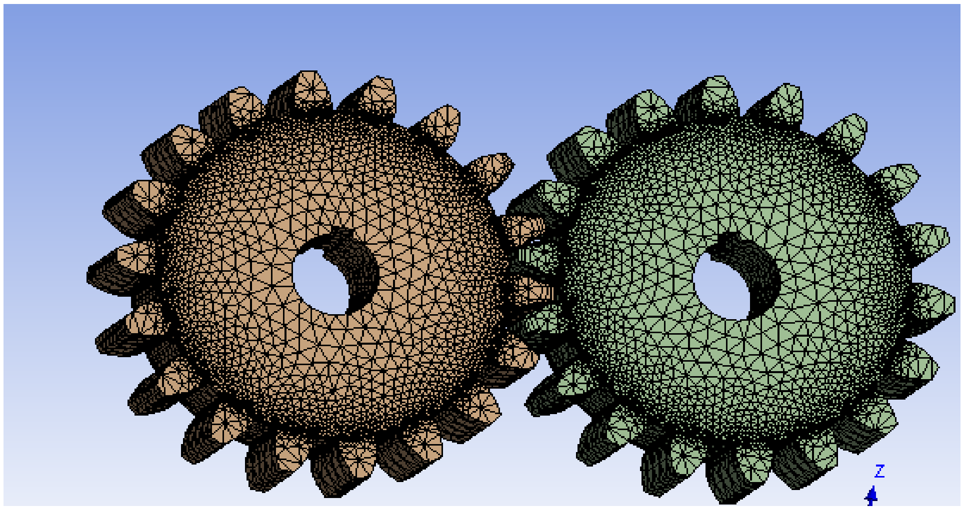

Figure 6. Analysis of Mesh in Ansys 15.0

3. Results and Discussion

3.1 Physical Properties of the Particulate Palm Kernel Shell

The following physical properties of the particulate palm kernel shell (PPKS) observed is shown in Table 4.

Table 4: Physical Properties of PPKS

Reinforcement Material	Diameter (µm)	Texture	Colour	Density
Palm Kernel Shells	850	Coarse	Dark Brown	0.846

3.2 Results for the Mechanical Properties of PPKSRPC

Table 5 is the average result of the tensile strength properties of PPKSRPC obtained. The stress-strain plot of the PPKSRPC is shown in Figure 7. At 90.3 MPa, failure of the PPKSRPC sample was observed.

Table 5: Tensile Strength Properties Results

Material/ Composition	Average Load at break (N)	Average Extension at break (mm)	Average Tensile stress at break (MPa)	Average Tensile strain at break (mm/mm)	Average Modulus (MPa)
PPKSRC	1083.53	2.92	90.30	0.058	2354.25

Tensile Ultimate Strength (MPa)	Young's Modulus (GPa)	Poisson's Ratio	Bulk Modulus (GPa)	Shear Modulus (GPa)	Density (kg/m^3)
90.29	2.3543	0.33	2.3081	0.89	846

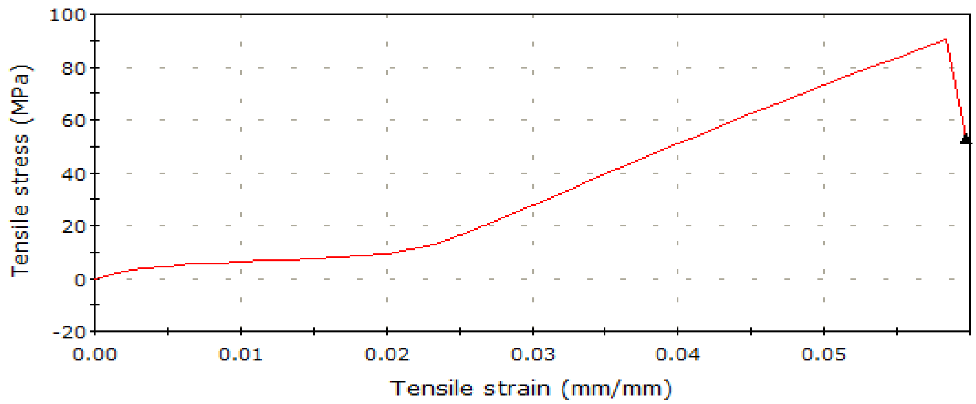

Figure 7. Stress-Strain Plot of PPKSRC

The tensile strength obtained from the PPKSRPC was 90.3MPa. This value is lower than the tensile strength of Cast steel of 540 MPa used for the design of spur gear by Mahendran et al., 2014. However, the tensile strength of PPKSRPC obtained can be used for the designed and development of spur gear where its application requires maximum loading condition less than 90.3 MPa.

3.3 Modelling of PPKSRPC Spur Gear

With a torque of 140N-m, the PPKSRPC spur gear was modelled, the von-mises stress distribution and elastic strain are shown in Figure 8. It can be observe that the values of stresses and strain are minimal and well distributed around the modeled spur gear. However, stresses are higher around the keyway due to stress concentration effect. Figure 9 shows the total deformation of the shear stress of the modelled spur gear. Deformations are higher around the teeth areas of the modeled spur gear. As such, proper clearance should be given when designing spur gears made of PKS polyester resin composites. The maximum von-mises stress and shear stresses for both the developed material model and that of steel are shown in Figure 10. The von-misses stresses and maximum shear stress of the developed material compare favourably with those of steel material. The maximum Von-misses stress of the modeled spur gear (5.00 MPa) is however lower than the value of yield stress (90.0 MPa) obtained during the uniaxial test of the PKS composite. Therefore, spur gears developed with the PKS composite are not likely to fail under the design conditions.

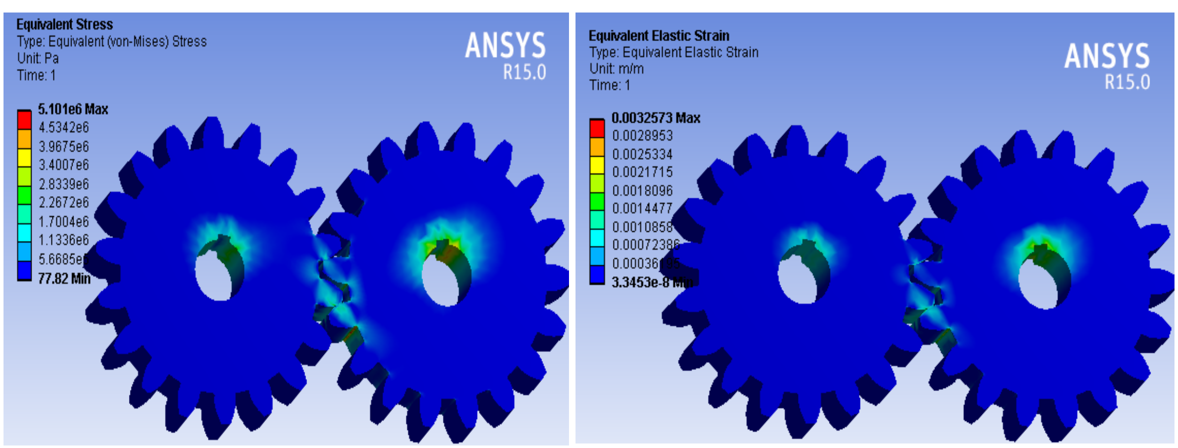

Figure 8. Von-Mises Stress Distribution and Elastic Strain of PPKSRPC Spur Gear

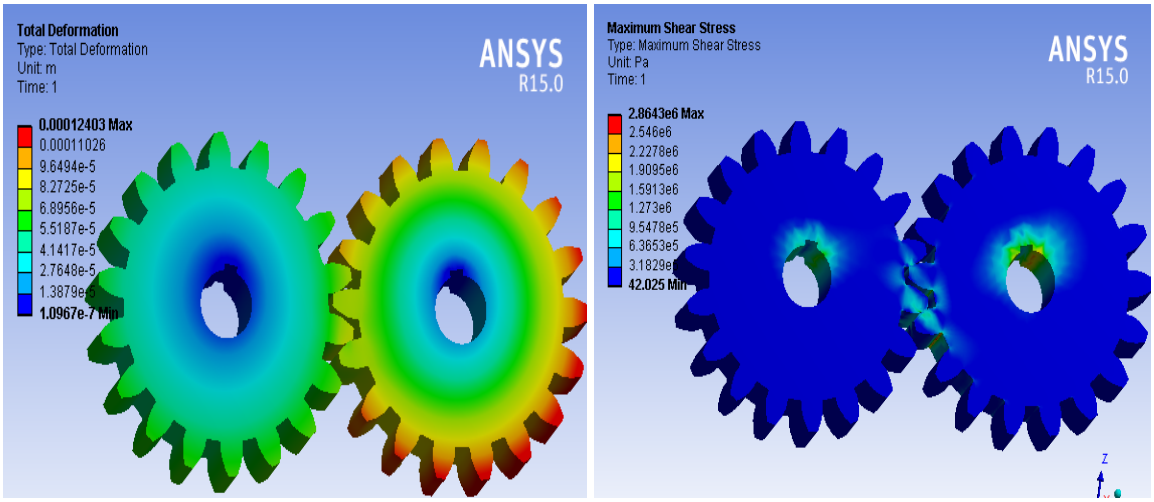

Figure 9. Total Deformation Maximum Shear Stress of PPKSRPC Spur Gear

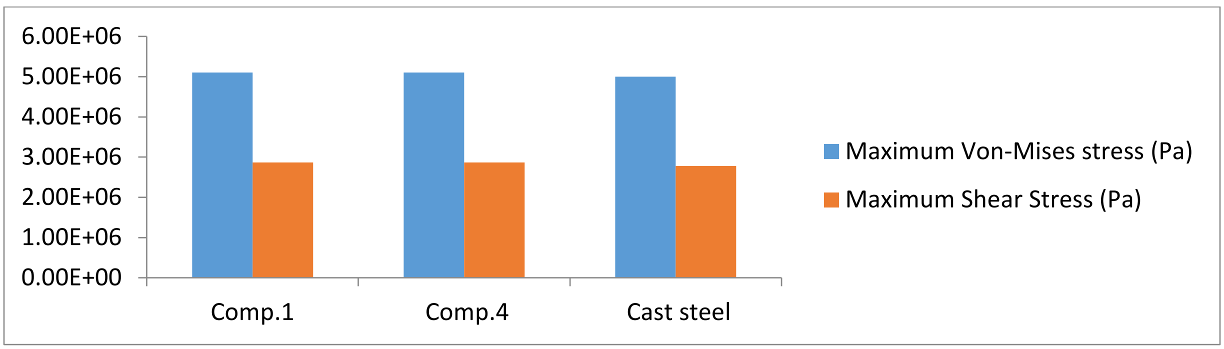

Figure 10. Stresses in PPKSRC spur gear.

Conclusion

In this work, particulate palm kernel shells reinforced polymer composite PPKSRPC was experimentally and analytically studied. The developed composites were investigated by determining their physical and mechanical properties. Their static structural performance in spur gears was analysed and modelled. The results obtained for a 5% weight fraction for PPKSRPC indicated that it could perform well in gear application where loading condition and torque requirement is less than 90.3 MPa and 140 N-m.

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