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Effects of Sodium Hydroxide Treatment on the Wear Resistance of Palm Kernel Shell Particles Reinforced Polypropylene Composite for Piping Application

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Abstract

Natural fiber-reinforced composites stand as a better substitute for synthetic fiber-reinforced composites because of their numerous benefits, such as low cost, low density, and biodegradability. This study examined the effects of sodium hydroxide treatment on the wear resistance of palm kernel shell particle reinforced polypropylene (PKSP-PP) composite and determined the optimal composition of palm kernel shell particles (PKSP) and polypropylene (PP) for an optimum wear resistance of the composite. PKSP were subjected to NaOH treatment, washed, dried, crushed and sieved to a fine particle size of 53µm. Taguchi L18 Orthogonal array was employed in the design of experiments, considering PKSP, PP, wax, stabilizer, plasticizer and stearic acid as the materials, and the smaller-the-better signal-to-noise ratio was used in the analysis of the wear rate of PKSP-PP composites. The results showed that the optimal materials formulation that minimized the wear rate of PKSP-PP composite is $A_1B_2C_1D_2E_1F_2$ for the treated composite and $A_1B_1C_1D_1E_1F_1$ for the untreated composite. The treated PKSP-PP composite showed a better wear resistance than the untreated PKSP-PP. The findings of this study revealed that NaOH treatment improved the wear resistance of PKSP-PP; and the lower PKSP content, the better the wear resistance. This study concludes that alkali treated PKSP would be a useful material for reinforcement of PP for piping applications and in the other polymer composites applications where good wear resistance is highly needed as the quality characteristic of the products.

Keywords: Palm kernel shell particle, natural fiber reinforced composite, Taguchi robust design, Sodium hydroxide treatment, Wear resistance.

1. Introduction

Palm kernel shell (PKS) is an agricultural by-product rich in lignocellulose generated from extraction of palm oil fruit through a palm milling process with 33% charcoal, 45% pyroligneous liquor and 21% combustible gas (Ikumapayi, & Akinlabi, 2018; Anyaoha et al., 2018). The recent study by the United States Department of Agriculture (USDA) in 2018, showed that Indonesia leads the world palm oil production with 55% of world's total palm oil supply, Malaysia produced 28% of the world's total palm oil, Thailand, Colombia and Nigeria produced 4%, 2% and 1% respectively. The other countries have an accumulated production of 10% of the world's total supply (USDA, 2019). According to Tobi et al. (2019), the active palm milling process has continuously generated huge amount of waste such as palm kernel shell, palm empty fruit bunch (EFB), palm tree frond, palm mesocarp fiber, and palm trunk.

Palm kernel shells are mostly used as fuel with a resulting environmental pollution and adverse health and financial implications (Alfatah et al., 2022). The need to find a lasting solution to the identified problems and to convert the abundance waste into valuable and economic material for industrial production have attracted the attentions of scientists and researchers to this abundant waste material (Tobi et al, 2019; Cionita et al., 2022, Alfatah et al., 2022). Some of the benefits of this by-product to the manufacturing process include less abrasive, less damage to processing equipment over time, low cost, renewable, readily available, etc. (Pickering et al., 2016; Misnon, Zain et al., 2018; Baffour-Awuah et al., 2021; Ahmed et al., 2021).

Despite the enormous advantages of PKS to the manufacturing industries, poor interfacial adhesion, low melting point, and poor resistance towards moisture in their natural state reduce their relevance and usage as reinforcing material in composite industry. In order to improve on the relevance of PKS and its usage in polymer composites and other applications, surface modification or treatment is highly needed (Mattos et al., 2014; Agunsoye et al., 2014). Surface modification or chemical treatment improves the interfacial adhesion of natural fibers or fillers with polymer matrix (Pinto et al., 2020). This in turn enhances the mechanical properties of the polymer composites (Iwamoto et al., 2014; Borysiak et al., 2018; Ihueze et al., 2022).

Wear resistance of natural filler reinforced composite is the ability of a material to resist the gradual wearing away caused by abrasion and friction. It is one of the mechanical properties of interest, which needs to be ascertained before the materials are used in certain service environments (Oladele et al., 2015). Since the palm kernel shell particles (PKSP) reinforced polypropylene (PKSP-PP) composite being studied in this research would be subjected to wear challenges in the service environment, there is need to understand the wear behaviour of both the treated and the untreated PKSP-PP composites. Hence, this study is aimed at examining the effects of sodium hydroxide treatment on the wear resistance of PKSP-PP composites for piping applications.

This study is significant as converting palm kernel shells into useful material for industrial applications would be an eco-friendly solution to waste management of this agricultural by-product. This would also result to reduction in the cost of production of some polymer composites when the cheap and readily available waste replaces partly or completely the synthetic and costlier fillers used in plastic production. Though, research works had been done on the use of PKSP in polymer composites, but none was found, to the authors best of knowledge, on the use of PKSP as filler for production of pressure and conduit pipes. Also, to the authors best of knowledge, only very few research reports are available on PKSP reinforced PP composites. However, those studies did not consider the wear resistance of the mono PKSP-PP composites. Hence, the novelty of this work lies on the determination of the optimal formulation of PKSP and PP for development of an optimal PKSP-PP composite material for use in production of pressure and conduits pipes.

The objectives of this study are: (1) to produce both untreated (raw) and treated PKSP-PP composites, (2) to determine the wear rates of both untreated and treated PKSP-PP composite, (3) to determine the optimum formulation of PKSP and PP that will minimize the wear rate of both untreated and treated PKSP-PP composites, and (4) to examine the effect of treatment on the wear rate of the composites. Taguchi robust design technique, which utilizes orthogonal array and signal-to-noise ratio, would be employed in this study. The technique would be used in the design of experiments for optimal formulation of PKSP and PP, and in optimization of the wear rate of both treated and untreated PKSP-PP composites. This study when achieved, would help to reduce the cost of production of pressure and conduit pipes and in enhancement of industrial revenue.

2. Literature Review

Determination of alternative materials that can partly or completely replace non-renewable and depleting synthetic materials in industrial applications have been an endearing area of scientific and engineering research in recent years. Most of the alternative materials being sought after by researchers are natural plant fibers/fillers (Basumatary et al., 2014; Das et al., 2018; Khalid et al., 2021a, 2021b; Okafor et al., 2022; Ihueze et al., 2023a, 2023b, 2023c). These alternative materials are mostly agricultural wastes or by-products left behind after harvesting or processing.

Research on palm kernel shell as reinforcing filler in polymer composites has increased over the past decade (Oladele et al., 2015; Sahari and Maleque, 2016; Jaya et al., 2018; Alias et al. 2018; Sa'ad et al., 2021; Cionita et al., 2022). The growing interest is as a result of desirable features of PKS, such as availability, mechanical characteristics, biocompatibility, renewability, economic value and biodegradability (Alfatah et al., 2022).

Cionita et al. (2022) studied the influence of filler loading and alkaline treatment on the mechanical properties of palm kernel cake filler reinforced Epoxy composites. The palm kernel cake filler compositions used were 10, 20, 30 and 40% by weight. 5wt% and 10wt% NaOH concentrations were used in surface modification of the filler. The results showed that the highest tensile and flexural strengths were obtained at 30wt% of the filler. Also, 5% alkaline treatment gave better results than the 10wt% treated and the untreated fillers. The study did not consider the wear resistance of the composites.

Jaya et al. (2018) studied the effect of alkali treatment oil palm shell (OPS) on mechanical properties of OPS reinforced high density polyethylene (OPS-HDPE) composites. The results showed that the modulus of elasticity and the tensile strength of the fabricated composites were considerably improved in the treated OPS. However, the better performance of filler was identified in the treatment with 5% NaOH compared with 10% NaOH. The research however did not study the wear rate of the composites.

Sahari and Maleque (2016) studied the effect of the filler loading on the mechanical properties of palm kernel shell filler reinforced polyester composite. 10, 20 and 30vol% of palm kernel shell particles were used in the development of the composites. The results showed an increase in tensile strength and tensile modulus of the neat polyester due to addition of PKS. 30vol% PKS content gave the optimum tensile strength and tensile modulus of the composite. However, the wear rate of the composite was not studied.

Alias et al. (2018) studied the effect of PKS particulates on Polyvinyl alcohol (PVA). Tensile strength and elongation at break reduced with an increase in PKS particulate weight content. However, tensile modulus increased up to 30wt% PKS content. On the other hand, water absorption and water vapour transmission also increased as PKS loading increased. The biodegradability test indicated that PVA/PKS bio-composites degrade faster with PKS loading in terms of natural weathering and soil burial

Oladele et al. (2015) used palm kernel shell particles and palm fruit strands in polyester resin to develop both mono PKSP reinforced polyester composites and hybrid composites. The wear and thermal properties of the composites were studied. The composites were developed using open mould method with filler/fiber compositions by weight of 2, 4, 6, 8 and 10%. The results showed that the particulate reinforced composites gave the best outcomes with 2wt% and 10wt% producing the optimum wear resistance and thermal conductivity results respectively.

Biswal and Satapathy (2016) studied the sliding wear behaviour of epoxy composite reinforced with short Palmyra fibers (SPF). 5wt%, 10wt% and 15wt% SPF compositions were used in composites fabrication. The results showed that addition of SPF improved the wear resistance of the neat epoxy, and 15wt% SPF gave a better wear resistance than other compositions.

From the existing literature, some studies have been carried out on incorporation of PKS in thermoplastic polymer composites. However, most of the studies centred on tensile strength, modulus of elasticity, elongation and water absorption properties of PKS reinforced polymer composites. Only very little attention was paid to wear rate of PKS polymer composites and the effect of surface modification on the wear rate. Also, scanty literature is available on PKS reinforced polypropylene composites. Hence, this study aims at investigating the effect of sodium hydroxide treatment on the wear rate of PKSP-PP composite for piping applications.

3. Materials and methods

3.1 Materials

The following materials were used in this study: Palm kernel shell particles (PKSP) and polypropylene (PP). Palm kernel shells (PKSs) were obtained locally from Ichaka Oil Mill in Ofeahia Autonomous Community, Onuimo LGA Imo State. PKS is an agricultural by-product generated from extraction of palm oil fruit through a palm milling process. The polypropylene used as matrix in this study was obtained from Onitsha, Anambra State.

The reagents used were Sodium hydroxide (NaOH) and hydrochloric acid (HCl). NaOH was used in the mercerization of the collected, washed and dried PKSs. The essence was to remove unwanted soluble cellulose, hemicellulose, lignin, pectin, etc. from it (Ihueze et al., 2022). HCL acid was used to neutralize the NaOH used in the mercerization of the PKSs. NaOH and HCL acid were obtained from Onitsha, Anambra State. The following additives also obtained from Onitsha were used during composite formulations: paraffin wax, stabilizer, plasticizer and stearic acid.

3.2 Chemical Treatment of Palm Kernel Shell

The PKSs obtained were washed thoroughly with water and detergent to remove dirt, dried under the sun for 48hours, and made ready for chemical treatment. The PKSs were treated with 8% NaOH solution in water for 180 minutes and neutralized with 8% HCL acid solution in water. The treated PKSs were washed in distilled water until pH 7 was attained, and then dried under the sun for 48hours.

3.3 Preparation of Palm Kernel Shell Particles Reinforced Polypropylene (PKSP-PP) Composite

The dried PKSs were passed through a hammer mill, crushing them into particles. PKS particles were sieved according to ASTM E-11 No. 270 Standards. A sieve size of 53μm was used to sieve the crushed PKSP in order to obtain a fine particle size needed for optimum results. Lower shell particulate sizes had been found to show good interaction, bonding and best mechanical properties (Agunsoye et al., 2014; Ikumapayi and Akinlabi, 2018).

The PKSP-PP composite was prepared following the relationships between the mass and the volume of fiber and resin.

$$M_c = M_f + M_R \quad (1)$$

$$V_f = \frac{M_f}{\rho_f} \quad (2)$$

$$V_R = \frac{M_R}{\rho_R} \quad (3)$$

$$V_c = V_f + V_R \quad (4)$$

$$V_{fr} = \frac{M_f}{V_c} = \frac{V_f}{V_f + V_R} \quad (5)$$

$$V_R = \frac{V_f}{V_{fr}}\left(1 - V_{fr}\right) \quad (6)$$

Where: M_c = Mass of the composite (g), M_f = Mass of PKSP, M_R = Mass of resin (g), V_c = Volume of the composite (cm^3), V_R = Volume of resin (cm^3), V_{fr} = Volume fraction of PKSP, V_f = PKSP (cm^3) as determined from Archimedes principle, ρ_f = Density of PKSP (g/cm^3), ρ_R = Density of resin $(0.946\ g/cm^3)$.

Composite samples were prepared with PKSP of 53μm size at different volume fractions of 10%, 20% and 30% with polypropylene as the matrix. The additives were added in part per hundred resin (polypropylene) as shown in Table 1. The volume fractions selected for this study were arrived at after exhaustive brainstorming and review of related literature (Sahari and Maleque, 2016; Abdul-Khalil, 2019). Sahari and Maleque (2016) advocated for 10, 20 and 30 vol% of PKS in filler reinforced polymer composites as the good PKS compositions. However, their study did not investigate the wear rate of the composite formed, and the resin used was not PP. This study adopted the volume fractions used in Sahari and Maleque (2016).

3.4 Taguchi Robust Design of Experiment

Taguchi robust design is a technique which utilizes orthogonal array (OA) and signal-to-noise ratio (SNR) in determination of optimal process parameters that will optimize the quality characteristics of the product or process. In this study, six materials – PKSP, PP, paraffin wax, stabilizer, plasticizer and stearic acid at various levels (quantities) were used in the development of the composites as shown in Table 1. The material parameters used and their levels were arrived at after brainstorming and review of related literature on composite design and Taguchi robust design. Three levels of each of the materials were chosen because three or more levels allow a nonlinear effect of the parameters on the quality characteristics to be revealed (Hamzaçebi, 2020; Ihueze at al., 2023d). Based on the number of factors and the factor levels, L18(3^6) orthogonal array (Table 2) was selected and used in the design of experiments for optimization of the quality characteristics of PKS-PP composite. In L18 (3^6) OA, the 18 rows represent 18 experiments to be conducted with six parameters at three levels of the parameters. The L18 OA used allowed all the possible combination of material parameters to be examined.

The experimental results were analyzed using SNR. For proper analysis of the data and arriving at the optimal results, the appropriate SNR must be chosen. The SNR to be used depends on the objective function or performance characteristics to be optimized (Ihueze et al., 2023a). Smaller-the-better, larger-the-better and nominal-the-best are most common Taguchi SNR. In this study, the abrasion wear rate of the PKS-PP composite is the quality characteristics being optimized in this study, and it is expected to be as small as possible. Hence, Taguchi's smaller-the-better SNR as shown in Eq. (7) was used in the analysis. In robust design, the factor levels that maximized the SNR are the optimal. The higher value of SNR is always desirable because greater SNR will result in smaller product variance around the target value. The design of the experiments and the analysis of results were done using Minitab 16 statistical software.

$$SNR = -10\ log\left(\frac{1}{n}\sum {y_i}^2\right) \tag{7}$$

Table 1: Raw Materials for Palm Kernel Shell particles PP Composite when Resin and PKS are (70, 85, 100)%, (10, 20, 30)% respectively for PKS particulate size $53\mu m$

S/N	Raw Material	(%) 1	2	3
A	Wax (paraffin)	0.5	1	-
B	Resin (PP)	70	85	100
C	Stabilizer(Ca-Zn)	1	1.5	2
D	Plasticizer	2	2.5	3
E	Palm Kernel	10	20	30
F	Stearic Acid	0.1	0.2	0.3

Table 2: L18(3^6) Orthogonal Array Experimental Design

S/N	Material (%)					
	A	B	C	D	E	F
1	0.5	70	1	2	10	0.1
2	0.5	85	1	2.5	20	0.2
3	0.5	100	1	3	30	0.3
4	0.5	70	1.5	2	20	0.2
5	0.5	85	1.5	2.5	30	0.3
6	0.5	100	1.5	3	10	0.1
7	0.5	70	2	2.5	30	0.1
8	0.5	85	2	3	10	0.2
9	0.5	100	2	2	20	0.3
10	1	70	1	3	20	0.3
11	1	85	1	2	30	0.1
12	1	100	1	2.5	10	0.2
13	1	70	1.5	2.5	10	0.3
14	1	85	1.5	3	20	0.1
15	1	100	1.5	2	30	0.2
16	1	70	2	3	30	0.2
17	1	85	2	2	10	0.3
18	1	100	2	2.5	20	0.1

3.5 Wear Resistance Test

The composites produced using L18 orthogonal array were subjected to abrasion wear test using Din Abrasion Tester (Model FE 05000). The test samples were prepared and tested in accordance with ASTM D1650 and ISO 4649 standards. The standards were meant for determining resistance of rubber and thermoplastics to abrasive force using a rotating cylindrical drum under a 10N constant load and through abrasion distance of 40m. The equipment was used to measure the capability of the composite to resist abrasion when in contact with abrasive surface. During the test, a 16mm diameter of each sample was cut and inserted into the sample holder. The test specimen was rotated while moving laterally across the cylinder. The motion assured uniform contact of the test specimen to the abrasive material. The experiments were conducted at a constant sliding speed of $0.32\, m/s$. The wear rate was estimated by measuring the weight loss of the specimen after each test. The weight loss and the specific wear rates of the composites were computed using the following equations (Basumatary et al., 2014);

$$WR = \frac{\Delta W}{\rho \times S_d \times F} \quad (8)$$

$$\Delta W = \left(w_i - w_f\right) \quad (9)$$

Where: ΔW = weight loss in g, w_i = Initial weight in g, w_f = final weight in g, F = applied load in N, WR = specific wear rate in cm^3/Nm, ρ = density of composite in g/cm^3, S_d = sliding distance in m.

The weight loss was measured at a sliding distance of 40m.

4. Results and Discussion

4.1 Wear Rate of Treated Palm kernel Shell Particles Reinforced Polypropylene Composite

Table 3 shows the experimental results of the specific wear rate of the treated PKSP-PP composites for different PKSP contents obtained using L18 orthogonal array design of experiment. From Table 3, the signal-to-noise ratio and the mean of the means of the wear rate were computed with the aid of Minitab 16.0. The wear rate of the PKSP-PP composite should be as small as possible. Hence, smaller-the-better signal to noise ratio was utilized in the optimization of the wear rate of the treated PKSP-PP composite.

Table 3: Results of L18 Orthogonal Array Experiments for the Wear Rate of Treated PKSP-PP Composite

S/N	Material (%)						Specific Wear rate (cm^3/Nm)
	A	B	C	D	E	F	
1	0.5	70	1	2	10	0.1	0.00024
2	0.5	85	1	2.5	20	0.2	0.00024
3	0.5	100	1	3	30	0.3	0.00025
4	0.5	70	1.5	2	20	0.2	0.00048
5	0.5	85	1.5	2.5	30	0.3	0.00049
6	0.5	100	1.5	3	10	0.1	0.00049
7	0.5	70	2	2.5	30	0.1	0.00049
8	0.5	85	2	3	10	0.2	0.00049
9	0.5	100	2	2	20	0.3	0.00049
10	1	70	1	3	20	0.3	0.00073
11	1	85	1	2	30	0.1	0.00024
12	1	100	1	2.5	10	0.2	0.00024
13	1	70	1.5	2.5	10	0.3	0.00025
14	1	85	1.5	3	20	0.1	0.00049
15	1	100	1.5	2	30	0.2	0.00049
16	1	70	2	3	30	0.2	0.00049
17	1	85	2	2	10	0.3	0.00049

18	1	100	2	2.5	20	0.1	0.00049

The responses evaluated and their rankings for the wear rate of the treated PKSP-PP composite based on the smaller-the-better quality characteristics are shown in Table 4 for the signal to noise ratio and the mean of means values. Table 4 shows the extent to which each material contributed to the variability on the abrasion wear rate of the composite. From the table, material C has the highest influence on the wear rate of PKSP-PP composite as it is ranked 1st, materials D, E, F and B ranked 2nd, 3rd, 4th and 5th respectively. Material A has the least influence on the wear rate of the treated PKSP-PP composite.

Table 4: Response Table for the Signal to Noise Ratio and the Mean of Means for Smaller-the-better of the Treated PKSP-PP Composite.

Response	Signal to Noise Ratio (dB)					
Level	Material					
	A	B	C	D	E	F
1	68.24	67.66	70.73	68.29	69.24	68.26
2	67.84	68.26	67.20	69.24	66.68	68.29
3		68.20	66.20	66.59	68.20	67.57
Delta	0.40	0.61	4.53	2.64	2.53	0.73
Rank	6	5	1	2	3	4
Response	Means (cm^3/Nm)					
Level	A	B	C	D	E	F
1	0.0004067	0.0004467	0.0003233	0.0003667	0.0003667	0.0004067
2	0.0004344	0.0004067	0.0004483	0.0004867	0.0004867	0.0004050
3		0.0004083	0.0004900	0.0004083	0.0004083	0.0004500
Delta	0.0000278	0.0000400	0.0001667	0.0001200	0.0001200	0.0000450
Rank	6	5	1	2	3	4

Fig. 1 shows the main effect plots of the smaller-the-better signal to noise ratio of the wear rate of treated PKSP-PP composite. Because the diversity of quality characteristics is inversely proportional to the SNR, the experimental condition with the highest SNR is deemed the best (Hamzaçebi, 2020; Ihueze et al., 2023a). The factor levels that maximized the SNR are the optimal because greater SNR will result in smaller product variance around the target value. In this study, the highest SNR for material A is at the level 1 (0.5%), the highest SNR for material B is at level 2 (85%), the highest SNR for material C is at level 1 (1%), the highest SNR for material D is at level 2 (2.5%), the highest SNR for material E is at level 1 (10%) and the highest SNR for material F is at level 2 (0.2%). From the figure, the optimum material parameters that minimized the wear rate of the composite was selected as $A_1B_2C_1D_2E_1F_2$. Table 5 shows the summary of the optimum material formulation for the minimum wear rate of the treated PKSP-PP composite. As can be seen in Table 5, the optimum materials contents for optimum wear rate are: wax = 0.5, resin (PP) = 85, stabilizer = 1, plasticizer = 2.5, palm kernel shell = 10 and stearic acid = 0.2vol%.

From the foregoing, it shows that 10% volume fraction of PKS was the optimum filler content needed in PKS-PP composite in order to minimize the wear rate of the composite. This implies that lower PKS filler content is needed in production of filler reinforced thermoplastic composites in which the wear resistance is highly needed as quality characteristic of the products. The implication is, the lower the PKS filler content, the lower the wear rate of the composite. Thus, the better the wear resistance of the composite.

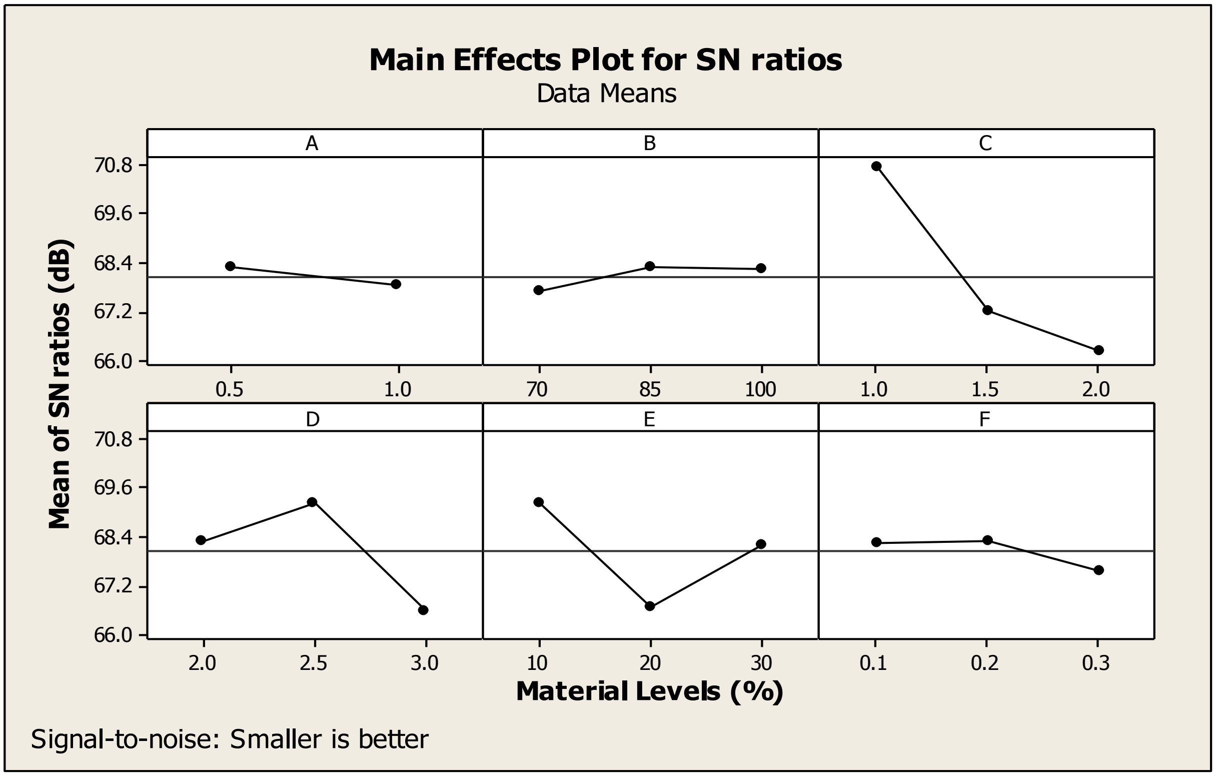

Fig. 1: Smaller-the-better Signal to Noise Ratio of the Wear Rate of the Treated PKSP-PP Composite

Table 5: Optimum Material Formulation for the Reduction of Wear Rate for treated PKSP-PP composite.

Material		Optimum Level	Optimum Value (%)
Wax (paraffin)	A	1	0.5
Resin (PP)	B	2	85
Stabilizer (Ca-Zn)	C	1	1
Plasticizer	D	2	2.5
Palm Kernel	E	1	10
Stearic Acid	F	2	0.2

The expected responses were predicted with the optimum material formulation levels from the main effects plots (Fig. 1), and the values from the response table for the signal to noise ratio and for the means (Table 4) using Eq. (10) (Ihueze et al., 2023a; 2023d). The predicted responses (mean and signal to noise ratio) are shown in Table 6.

$$EV = AVR + (A_{opt} - AVR) + (B_{opt} - AVR) + (C_{opt} - AVR) + (D_{opt} - AVR) + (E_{opt} - AVR) + (F_{opt} - AVR) \quad (10)$$

Where: EV is the expected value, AVR is the Average response, A_{opt} is the mean value of the response at optimum setting of material A, B_{opt} is the mean value of the response at optimum setting of material B, C_{opt} is the mean value of the response at optimum setting of material C, D_{opt} is the mean value of the response at optimum setting of material D, E_{opt} is the mean value of the response at optimum setting of material E, F_{opt} is the mean value of the response at optimum setting of material F.

Table 6: Predicted Responses for treated PKSP-PP Composite

Material	Level	Value (%)	Predicted Value	
			Mean (cm^3/Nm)	SN Ratio (dB)
A	1	0.1	0.00017222	73.7941
B	2	85		
C	1	1		
D	2	2.5		
E	1	10		
F	2	0.2		

3.2 Wear Rate of Untreated Palm kernel Shell Particles Reinforced Polypropylene Composite

Table 7 shows the experimental results of the wear rate of the untreated palm kernel shell particles reinforced polypropylene composites for different PKS contents obtained using L18 orthogonal array design of experiment.

Table 7: Results of L18 Orthogonal Array Experiments for the Wear Rate of Untreated PKSP-PP Composite

S/N	Material (%)						Specific wear rate (cm^3/Nm)
	A	B	C	D	E	F	
1	0.5	70	1	2	10	0.1	0.00024
2	0.5	85	1	2.5	20	0.2	0.00049
3	0.5	100	1	3	30	0.3	0.00048
4	0.5	70	1.5	2	20	0.2	0.00049
5	0.5	85	1.5	2.5	30	0.3	0.00073
6	0.5	100	1.5	3	10	0.1	0.00073
7	0.5	70	2	2.5	30	0.1	0.00049
8	0.5	85	2	3	10	0.2	0.00049
9	0.5	100	2	2	20	0.3	0.00049
10	1	70	1	3	20	0.3	0.00073
11	1	85	1	2	30	0.1	0.00049
12	1	100	1	2.5	10	0.2	0.00049
13	1	70	1.5	2.5	10	0.3	0.00049
14	1	85	1.5	3	20	0.1	0.00049
15	1	100	1.5	2	30	0.2	0.00049
16	1	70	2	3	30	0.2	0.00049
17	1	85	2	2	10	0.3	0.00049
18	1	100	2	2.5	20	0.1	0.00049

The responses evaluated and their rankings for the wear rate of the untreated PKSP-PP composite based on the smaller-the-better quality characteristics are shown in Table 8 for the signal to noise ratio and the mean values. Table 8 shows the extent to which each material contributed to the variability in the wear rate of PKSP-PP composite. From the table, material D has the highest influence on the wear rate of PKSP-PP composite as it is ranked 1st; materials C, F, E and B are ranked 2nd, 3rd, 4th and 5th respectively. Material A has the least influence on the wear rate of the untreated PKSP-PP composite.

Table 8: Response Table for the Signal-to-Noise Ratio and the Means for the Smaller-the-better of the Untreated PKSP-PP Composite

Response	Signal to Noise Ratio (dB)					
Level	Material					
	A	B	C	D	E	F
1	66.12	66.62	66.65	67.22	66.63	66.62
2	65.83	65.64	65.05	65.63	65.64	66.22
3		65.65	66.22	65.06	65.65	65.07
Delta	0.29	0.98	1.60	2.16	0.99	1.55

Rank	6	5	2	1	4	3
Response			Means (cm^3/Nm)			
Level	A	B	C	D	E	F
1	0.0005153	0.0004893	0.0004880	0.0004482	0.0004891	0.0004893
2	0.0005160	0.0005292	0.0005701	0.0005295	0.0005293	0.0004885
3		0.0005283	0.0004888	0.0005691	0.0005286	0.0005690
Delta	0.0000007	0.0000399	0.0000821	0.0001209	0.0000402	0.0000805
Rank	6	5	2	1	4	3

Fig. 2 shows the main effect plots of the smaller-the-better signal to noise ratio of the wear rate of the untreated PKSP-PP composite. To minimize variability, the level of each parameter that produced the greatest SNR was selected as the optimum value for that parameter. The output variability is reduced when the SNR is maximized. From the figure, the optimum material parameters that minimized the wear rate of the composite was selected as $A_1B_1C_1D_1E_1F_1$. Table 9 shows the summary of the optimum material formulation for the minimum wear rate of the treated PKSP-PP composite. As can be seen in Table 9, the optimum materials contents for optimum wear rate are: wax = 0.5, resin (PP) = 70, stabilizer = 1, plasticizer = 2, palm kernel shell = 10 and stearic acid = 0.1vol%.

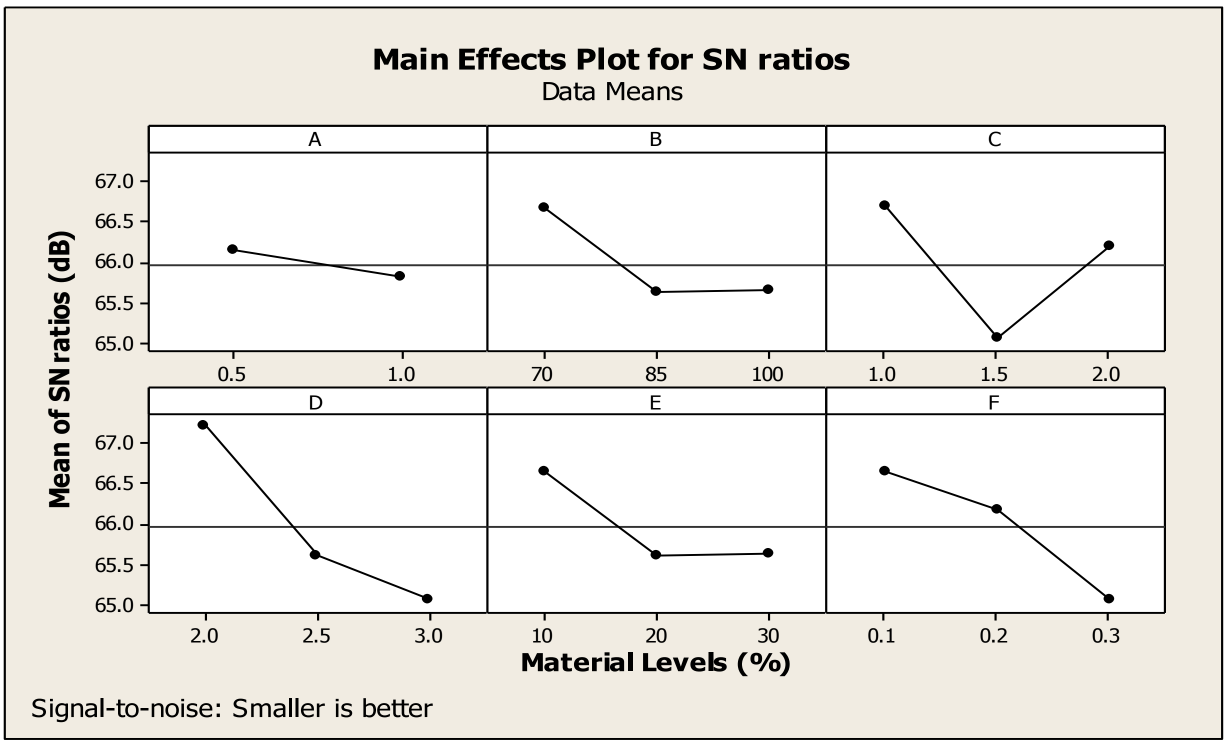

Fig. 2: Smaller-the-better Signal to Noise Ratio of the Wear Rate of the Untreated PKSP- PP Composite

Table 9: Optimum Material Formulation for the Reduction of Wear Rate of Untreated PKSP-PP Composite

Material		Optimum Level	Optimum Value (%)
Wax (paraffin)	A	1	0.5
Resin (PP)	B	1	70
Stabilizer (Ca-Zn)	C	1	1
Plasticizer	D	1	2
Palm Kernel	E	1	10
Stearic Acid	F	1	0.1

The expected responses for the untreated composite were predicted with the optimum material formulation levels from the main effects plots (Fig. 2), and the values from the response Table 8 for the signal to noise ratio and the response for mean of means using Eq. (10). The predicted responses are shown in Table 10.

Table 10: The Predicted Responses of the Wear Rate of the Untreated PKSP-PP Composite

Material	Level	Value (%)	Predicted Value	
			Mean (cm^3/Nm)	**SN Ratio (dB)**
A	1	0.5	0.0003367	70.1368
B	1	70		
C	1	1		
D	1	2		
E	1	10		
F	1	0.1		

4.3 Effects of Treatment on the Wear Rates of Palm kernel shell particles Polypropylene (PKSP-PP) Composites

Surface modification of natural reinforcement materials have been found to improve the interfacial interactions between the matrix and the filler, and in turn enhances the mechanical properties of the resulting composites (Pinto et al., 2020). Fig. 3 compares the wear rates of the treated and the untreated PKSP-PP composites as obtained from Tables 3 and 7 respectively. The red line with circular marker shows the wear rates of the treated PKSP-PP composites over the eighteen experimental runs. The blue line with triangular marker shows the wear rates of the untreated PKSP-PP composites over the eighteen experimental runs. From the figure, the wear rate of the treated PKSP-PP is lower than that of the untreated PKSP-PP. This shows that the treated PKSP-PP has a better wear resistant than the untreated PKSP-PP. This is in agreement with the submission of Husna et al. (2019), that found that surface modification of oil palm shell (OPS) for reinforcement of recycled HDPE composites successful enhanced the adhesion and interaction of OPS-rHDPE which led to better mechanical properties compared to the untreated composites.

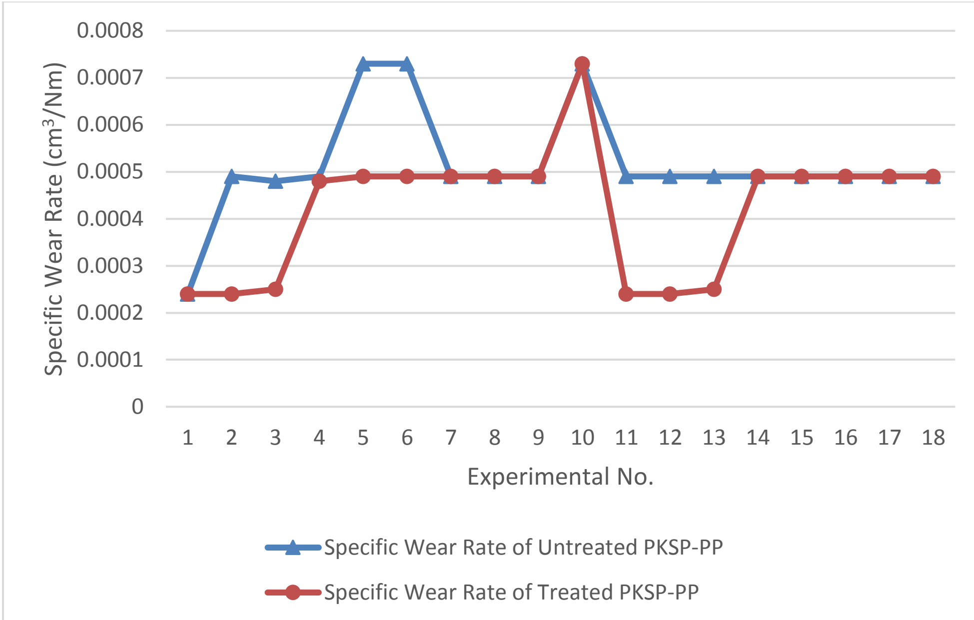

Fig. 3: Comparison of the Wear rates the Treated and the Untreated PKSP-PP Composites

Fig. 4 shows the comparison of the predictions of abrasion wear rate made by Eq. (10) for the treated and the untreated PKSP-PP at PKSP volume fraction of 10% as can be seen in Tables 6 and 10 respectively. For the treated, the specific wear rate predicted is 0.000172cm^3/Nm while the specific wear rate predicted for the untreated is 0.000337cm^3/Nm. From the predictions, an improvement of over 49% can be achieved in the wear resistance of PKSP-PP as result of surface modification of PKSP using NaOH.

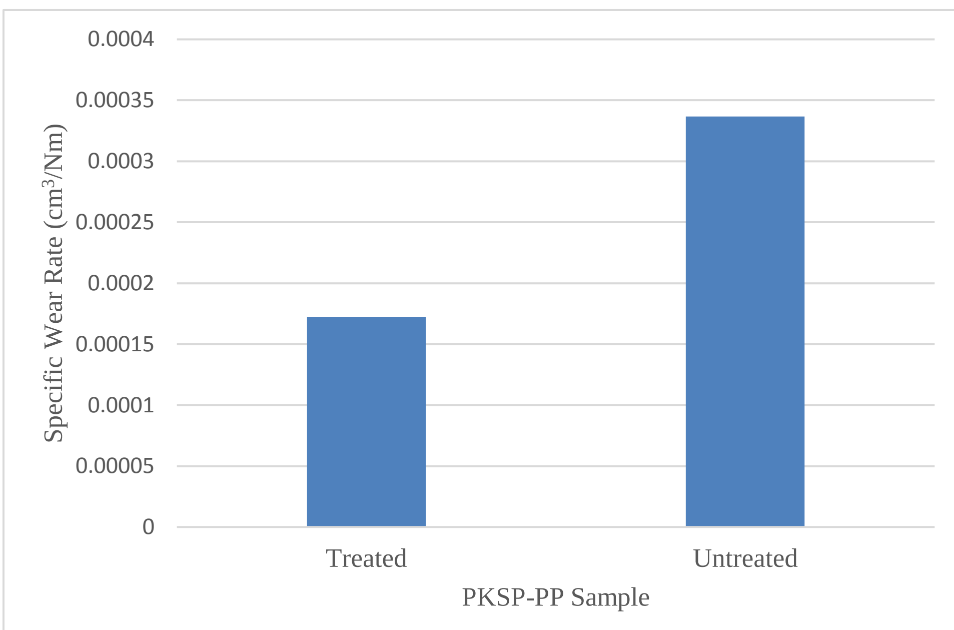

Fig. 4: Comparison of the Wear Rates Predictions for the Treated and Untreated PKSP-PP

Also, on the effect of the filler content on the PKSP-PP composite, the optimum PKSP content of for the minimum wear rate occurred at the 10vol% for both the treated and untreated PKSP, which implies that the lower the filler content, the better the wear resistance of the PKSP-PP composites. This is in agreement with the findings of Oladele et al. (2015) and Sa'ad et al. (2021). Both found that the lower the natural filler content, the better the wear rate of filler reinforced polymer composites.

Table 11 compares the specific wear rates of natural fibers/fillers reinforced polymer composites and that of PKSP-PP. From the Table, it shows that PKSP-PP has good specific wear rate compared to other natural particulate polymer composites. The wear rate of PKSP-PP is very close to that of oil palm empty fruit bunch reinforced epoxy composite (Zuhair et al., 2020), woven glass reinforced unsaturated polyester composite (Younis et al., 2018) and basalt reinforced epoxy composite (Talib et al., 2021). This shows that the developed PKSP-PP composite can be a useful material for applications where wear resistance is very necessary.

Table 11: Comparison of the Wear Rates of PKSP-PP and Other Composites

Filler/Fiber	Matrix	Specific Wear rate (cm^3/Nm)	Source
Oil palm empty fruit bunch	Epoxy	0.00058	Zuhair et al. (2020)
Woven glass	Unsaturated polyester	0.00075	Younis et al. (2018)
Hemp	Polystyrene	0.00000827	Zafar and Siddiqui (2021)
Luffa cylindrical	Polyester	0.000036761	Patel and Dhanola (2016)
Biobased hybrid (banana stem and coconut shell)	Unsaturated polyester	0.000000139	Okafor et al. (2023)
Kenaf	Epoxy	0.0000025	Shuhimi et al. (2016)
Short betel nut fiber	Epoxy	0.00002412	Choudhary et al. (2021)
Basalt	Epoxy	0.000003	Talib et al. (2021)
PKSP	Polypropylene	0.000172	Present Study

5. Conclusion

This study examined the effect of sodium hydroxide treatment on the wear resistance of palm kernel shell particles reinforced polypropylene composite for piping applications. Taguchi robust design of experiment was employed in determining the optimum composition of PKSP and PP for both treated and untreated fillers and in the optimization of the wear rate of the PKSP-PP composites. L18 Orthogonal array was used in the design of experiment, and smaller-the-better SNR was used in the analysis of the experimental results. The material parameters used in composite formulation were wax (A), polypropylene (B), stabilizer (C), plasticizer (D), palm kernel shell particle (E) and stearic acid (F) at three parameter levels. The PKSP volume fractions of 10%, 20% and 30% were used in the development of PKSP-PP composites in this study. This study showed that chemical treatment of PKSP using NaOH affects the wear rate of PKSP composites. The following were arrived at in this study:

a. The optimum materials formulations that minimized the wear rates of the untreated and the treated PKSP-PP composites are $A_1B_1C_1D_1E_1F_1$ and $A_1B_2C_1D_2E_1F_2$ respectively.
b. The optimum PKSP content for optimum wear rate of the composite is 10vol% for both the treated and the untreated composites.
c. The predicted wear rates for both untreated and treated PKSP-PP at optimum materials formulations are $0.000337cm^3/Nm$ and $0.000172cm^3/Nm$ respectively
d. The abrasive wear rate was lesser for the treated samples when compared to the untreated samples. Hence, treatments of PKSP with NaOH lowers the wear rate of PKSP-PP composite.
e. NaOH treatment improved the abrasion resistance of PKSP-PP, and lower PKSP content gave a better wear resistance.
f. Based on the predictions made, an improvement of over 49% in the wear resistance of PKSPP-PP could be achieved as a result of NaOH treatment of PKSP.

This study is significant as it demonstrated the application of Taguchi robust design in determination of the optimum formulation of PKSP and PP that enhanced the wear resistance of PKSP-PP composite meant for pressure and conduit piping applications. This study contributes to the body of knowledge on the use of agricultural by-product (waste) for natural filler reinforced polymer composites. It determined the wear rates of raw and alkali treated PKSP-PP composites developed from locally sourced agricultural waste. This study revealed that PKSP-PP composite is a valuable composite for reinforced polymer composite applications as can be seen in its good wear resistance property. The developed composite can be considered for application in production of pressure and conduit pipes. In this study, only abrasion wear rate was studied, and volume fractions of PKSP between 10% and

30% were applied. The future study will consider other mechanical and electrical insulation properties of the composite, and the PKSP volume fractions below and above the used range will be considered.

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