Journal of Newviews in Engineering and Technology (JNET)
Vol 1, Issue 1, October 2019
Available online at http://www.rsujnet.org/index.php/publications/2019-edition

Model Development of Some Tribological Parameters for Coconut Shell-Reinforced Polyethylene Composites

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ABSTRACT:

The response of polyethylene-based coconut shell composites in a simulative test carried out on a pin-on-disc machine has been studied. Taguchi experimental plan with the objective of "smaller is better"and the technique of variance were used in the analysis to determine the effect of the applied load (L), sliding distance (S), and motor speed (V) on the coefficient of friction (μ) and wear rate(k) of the composites. The results obtained showed that the effect of L on the μ of the composites was 41.38%, while those of V and S were 9.28% and 4.60%, respectively. Also, the effect of V on k of the composites was 60.14% and those of S and L were 6.38% and 1.95%, respectively. Optimal values of 0.1519 and 2.64 $\times 10^{-4} mm^3 N^{-1} m^{-1}$ for μ and k, respectively, were obtained at 7N, 400Rev min^{-1}, and 30m. Further, the developed modelsfor μ and k were validated. Hence, it has been suggested that L and V are important parameters in the study of μ and k for polyethylene composite filled with coconut shell nano fillers.

Keywords: Friction, Simulation, Tribometer, Taguchi, Wear,

Cite This Article: Odi-Owei, S.,& Alibi, S. (2019).Model Development of Some Tribological Parameters for Coconut Shell-Reinforced Polyethylene Composites. *Journal of Newviews in Engineering and Technology (JNET)*, 1 (1) 1-7.

1. INTRODUCTION:

Polymers in the unreinforced form have limitations in engineering applications. In this state, the mechanical and tribological properties are poor. So, the quest for composites that have low density, produced from low-cost reinforcement has intensified research on polymers. It has been shown thatin the reinforced state, polymers have the potentials to replace steel in most engineering applications. Credence is given to the work of Schipper and Odi-Owei (1991), where the tribological behaviour of filled and unfilled polyoxymethylene was studied and Odi-Owei and Schipper (1992) in the design of a twin-transducer system for friction and wear study. Tribometers have gained prominence as laboratory equipment for the study of friction and wear by several other researchers, namely, Marjanovic *et al*. (2006), Aigbodion *et al* (2011), and Kalacska(2013). Also, Olumuyiwa *et al*. (2012), Sarki*et al*. (2011), and Keerthika *et al*. (2016) have revealed that the mechanical properties of polymers can be enhanced by adding fillers to a polymer matrix structure. Ihueze *et al*. (2016) showed that coconut-fibre reinforced polyethylene has improved mechanical properties. Ravikantha *et al*. (2017) performed dry sliding wear and abrasive trials test following Taguchi's experimental plan, on a pin-on-disc machine witha glass-epoxy filled coconut shell powder (CSP) composite. The results obtained showed that the inclusion of the CSP in epoxy resin improved the wear resistance of the composites. Also, Odi-owei and Alibi (2019) studied the tribological behaviour of polyethylene and polypropylene reinforced with coconut shell, and bagasse.They inferred that the performance of the coconut shell-reinforced matrix showed better promise based on friction and wear simulative test carried out on a pin-on-disc machine under parameters of applied load, motor speed, and sliding distance. These parameters have been used by Aigbodion *et al*. (2011) to investigate the effect of bagasse ash reinforcement on dry sliding wear behaviour of polymer matrix composites. Also, Odi-Owei and Onuba (2017) used a similar machine to investigate the tribological behaviour of carbon steels. However, the effect these parameters have on the friction and wear behaviour of tribo-pairand the optimum value for the normalized performance of friction and wearis seldom quantified.

Also, some simple but elegant friction and wear models by some early researchersare being phased out due to discrepancies on some of the assumptions. For instance, the 1966 Greenwood and Williamson theory concerning surface roughness and contact, which were widely accepted have been observed by Greenwood and Wu (2002) that the third assumption on asperity is quite wrong. The 1957 Archard idea "that roughness consists of protuberances on protuberances on protuberances" is accepted instead. The development in computer technology has encouraged more work on the deterministic models such as the work of Liu et al. (2000), and Bahrami *et al*. (2005), where the effect of roughness on the elastic contact of spherical bodies was studied. Contact pressure was identified as the parameter that has the greatest effect on the surface of the tribo-pairs. Adam and Nosonovsky (2000) divided contact model into a single-asperity model and a multi-asperity model. Robbe-Valloire *et al.* (2001) developed a normal contact model between two nominally flat and parallel rough surfaces on the micro-geometric scale.

The concern of the present research is to determine the effect of the following parameters; applied load (L), motor speed (V), and sliding speed (S), on the responses of coefficient of friction (μ) and wear rate (k), optimize the parameters, and develop a model for μ and k.

2. MATERIALS AND METHODS:

Three levels of the orthogonal design were selected, based on the parameters of interest L, V, and S. The response factors were μ and k. Further, an L9 Taguchi design (Table 1) was developed in Minitab 16 software. Anton Paar compact 600mm × 700mm, 500mm height pin-on-disc Tribometer was used for the simulative test (Figure 1).
A detailed description of the equipment is shown somewhere else in Odi-Owei and Onuba (2017). The pin was an AISI 420 stainless steel and the disc, polyethylene reinforced coconut shell composites (PE + CNS37). The pin was made to contact the disc. L, V, and S were selected based on the experimental plan (Table 1). The values of μ and k obtained were recorded for the nine(9) different experimental runs.

The obtained data were further subjected to analysis in the Minitab 16 software, where regression equations were developed alongside signal to noise (SN) ratio and variance. Further, the percentage contributions of L, S, and V on μ and k were obtained. The μ and k optimized values based on SN with the objective that "smaller is better" were obtained from Equation (1). This is an indication that optimal values of μ and k are obtained at the point where the value of SN ratio is smallest.

$$\frac{S}{N} = -10 \times \log \frac{1}{n} \sum Y_i^2 \quad (1)$$

where n is the number of observations, Y is the measured value of μ and k.

Table 1: Experimental plan

S/N	L(N)	V(rev min^{-1})	S(m)
1	2	400	10
2	2	180	22
3	2	120	30
4	5	400	22
5	5	180	30
6	5	120	10
7	7	400	30
8	7	180	10
9	7	120	22

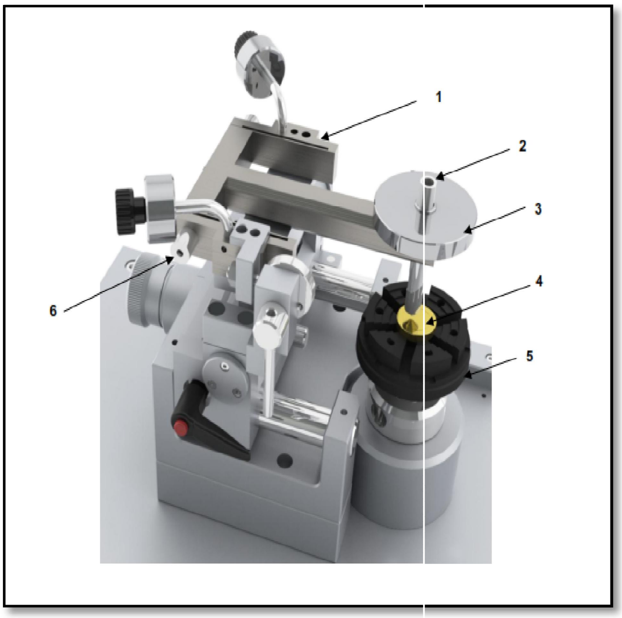

Figure 1 Pictorial view of the Tribometer

1. Elastic Blade; 2 Ball holder or pin holder; 3 Load; 4 Sample; 5 Mandrel or disc holder; 6 Tangential Force-Displacement Sensor.

3. RESULTS AND DISCUSSION:

Experimental values of μ and $k$and the SN ratio values obtained for μ and k, utilizing Equation 1, are presented in Figures 2 and 3. Optimized values for L, V, and S are at the point where μ and k have the smallest value of SN ratio. These were obtained at a load of 7N, motor speed of 400 rev/min and sliding distance of 30m (see Table 1). Figures 2 and 3 present the optimization results of μ and k. Shown in Figure 2, the optimal value for μ is 0.1519, corresponding to the smallest value 16.3688 of SN ratio. In Figure 3, the optimal value of k is $2.640 \times 10^{-4} mm^3N^{-1}m^{-1}$, corresponding to the smallest value 71.5570 of SN ratio.

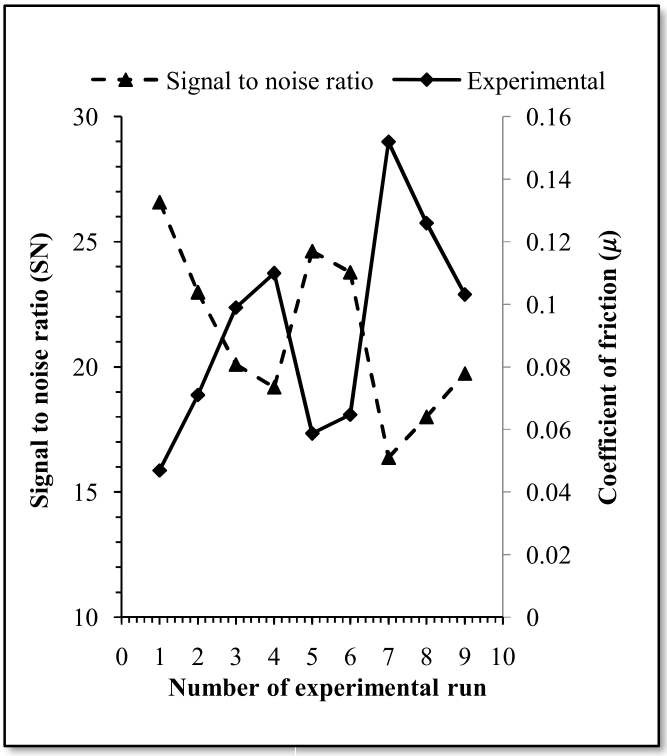

Figure 2 Experimental and computational coefficient of friction

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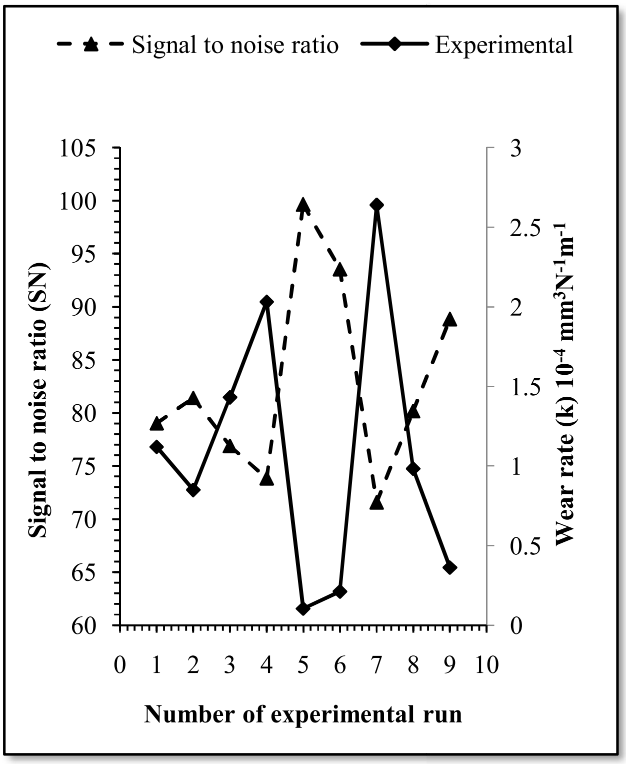

Figure 3 Experimental and computational wear rate

Table 2 Coefficient of friction

Source	L(N)	V (rev min^{-1})	S (m)
DF	1	1	1
Seq SS	0.00396	0.00044	0.00089
Adj SS	0.00396	0.00044	0.00089
Adj MS	0.00396	0.00044	0.00089
F	4.64820	0.51671	1.04164
P	0.08361	0.50443	0.35426
PC%	41.38205	4.60021	9.27871

Table 3:Wearrate (*k*) $mm^3N^{-1}m^{-1}$

Source	L(N)	V (rev min^{-1})	S (m)
DF	1	1	1
Seq SS	0.11946	3.68225	0.3908
Adj SS	0.11946	3.68225	0.3908
Adj MS	0.11946	3.68225	0.3908
F	0.30945	9.53875	1.0124
P	0.60199	0.027206	0.3605
PC%	1.95111	60.1412456	6.3828

3.1 Coefficient of Friction and Wear Rate:

Analysis of variance was carried out to determine the percentage contribution of the selected parameters on friction and wear behaviour of the composites. Tables 2 and 3 show the results of the percentage of contribution (PC %) of L, V, and S each for μ, and k. In Table 2, L has the greatest effect on μ followed by S and V. The order of their magnitudes is 41.3820%, 9.2787% and 4.6001%. In Table 3, V has the greatest effect on$k$followed by S and L. The order of magnitudes is 60.1412%, 6.3828% and 1.9511%.

3.2 Coefficient of Friction and Wear Models:

The model developed showed the relationship between the responses (μ, and k) and the parameters (L, V, and S). The regression equation for μ, have a positive intercept and also show the parameters and their effect on μ in this order L, S and V. Also the regression equation for k has negative intercept and the order of effect of the parameter on k is V, S, and L. The validity of the model was tested and the validated results based on μ, and k are presented in Figures 4 and 5.

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$$\mu = 6.16682 \times 10^{-3} + 1.0214 \times 10^{-2} \mathrm{L}\,(\mathrm{N}) + 5.81339 \times 10^{-5} \mathrm{V}\,(\mathrm{rev\,min}^{-1}) + 1.20753 \times 10^{-3}\,\mathrm{S}\,(\mathrm{m}) \quad (2)$$

$$k = -8.1581310^{-5} + 2.694910^{-6}\,\mathrm{L}\,(\mathrm{N}) + 4.8729410^{-7} \mathrm{V}\,(\mathrm{rev\,min}^{-1}) + 3.0707210^{-6}\,\mathrm{S}\,(\mathrm{m}) \quad (3)$$

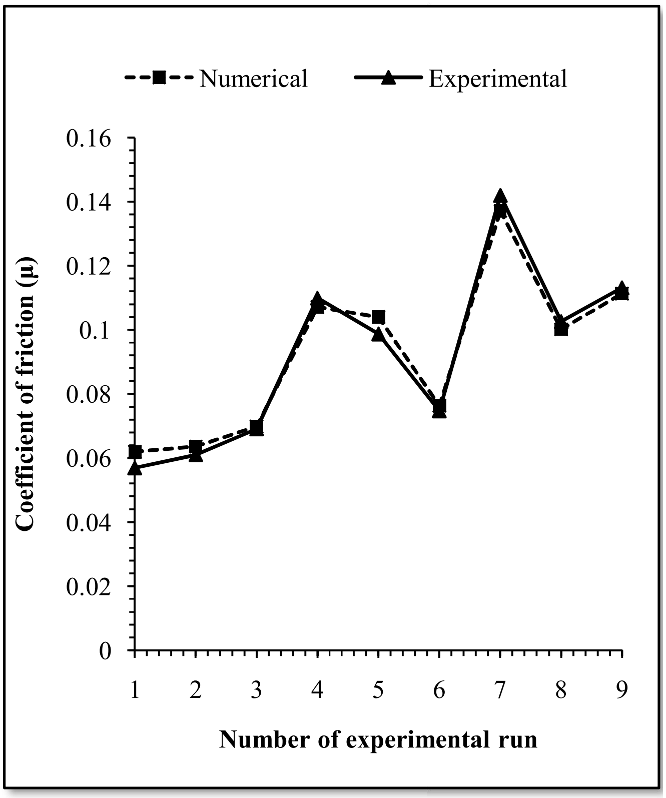

Figure 4 Experimental and analytical coefficient friction

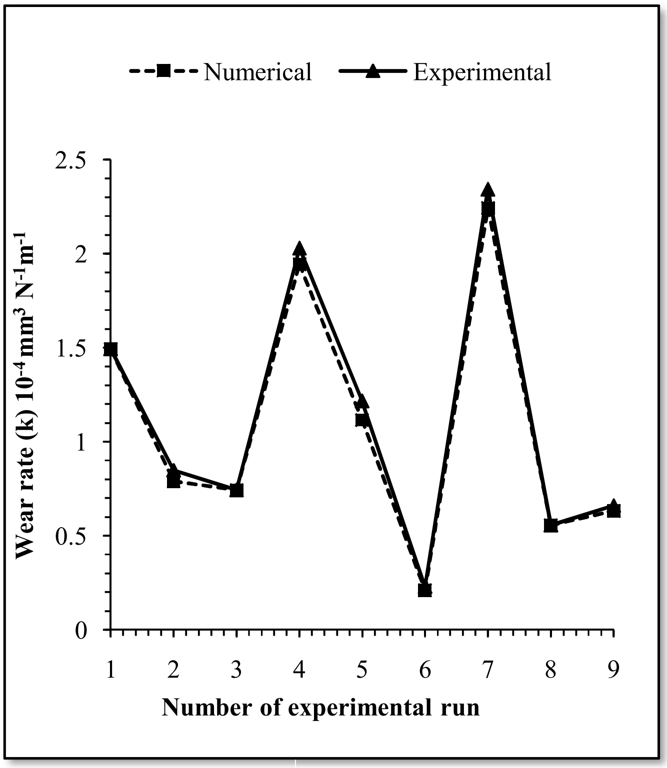

Figure 5 Experimental and analytical wear rate

4. CONCLUSION:

Many types of research on friction and wear of polymers are centred on the coefficient of friction, wear rate, transfer of the polymer and the percentage composition of fillers in the polymer. However, the area of applicability of the resultant composites is also subject to the load-bearing capacity, nature of the sliding and numbers of times the sliding is made. All these are put together to give a better understanding of the composites material.

(i) Based on the selected parameters (L, S and V) for this study and the effect these parameters have on the responses (μ and k), the conclusions drawn from the analysis are as follows:

(a) In the dry sliding of PE+CNS37.2 the parameter that has the greatest effect on the coefficient of friction was L, followed by V, and S. The parameter that has the highest effect on the wear rate was V, followed by S and L. Also the optimal values for μ, and k in the simulative test was obtained at the combined effect of L, V, and S with 7N, 400Rev min^{-1} and 30m respectively.

(b) The optimal value of μ and k with high influence on the dry sliding test based on the signal to noise ratio "smaller is better" objective, are 0.1519, and 2.64 $\times 10^{-4} mm^3 N^{-1} m^{-1}$, respectively.

(ii) From the analysis of variance, the order of magnitude load has the greatest effect on the coefficient of friction while velocity has the greatest effect on the wear rate of the composite.

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NOMENCLATURE:

CSP	Coconut shell powder
μ	Coefficient of friction
k	Wear rate ($mm^3N^{-1}m^{-1}$)
L	Load (N)
V	Motor speed ($revmin^{-1}$)
S	Sliding distance (m)
PE	Polyethylene
CNS	Coconut shell
SN	Signal to noise ratio
PC	Percentage contribution