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Correlation Analysis of Biodegradable Additives, Temperature and Loading toward Tribology Behaviour of Musa Aluminata Balbisiana (MBS) Oil

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Identification of the effect of the tribological characteristics in lubricant application is a critical part of the experimental process. A correlation study is used to identify the effect of temperature, load and biodegradable additive on the coefficient of friction (COF) and specific wear (Ws) from the experimental data. Pearson correlation coefficient (r) and analysis of variance (ANOVA) are the statistical analysis used to identify the relationship between the parameters and the significant difference in response variable which are COF and Ws. Based on the result, there is a positive moderate linear relationship between temperature to both COF and Ws with a score of r between 0.354 to 0.676. In contrast, there is a negative linear relationship between load towards COF and Ws with a -0.285 to -0.460 score of r. There is approximately no correlation with the percentage of biodegradable additives respecting COF and Ws. The result also shows that there is no significant difference between COF and Ws using ANOVA testing with a p-value is more than 0.05. This work may facilitate improvements for other researchers to identify the variable in the experimental design process.

1. Introduction

In recent years, several studies have focused on the use of bio-based lubricants to replace conventional oil in the industry. A lot of researchers have reviewed the potential of green materials to replace synthetic materials in related industry. Koronis et al. (2013) mentioned that the usage of petroleum resources can reduce by using green composites. The disadvantages of crude oil in humans especially in health issues such as irritation of the throat, nose and lungs, dizziness, complications in breathing is one of the factors that bring the researchers to find the best materials that can perform as petroleum-based oils. In addition, recent studies prove the toxic effect of crude oil on humans, the environment and ecosystem as a whole (Almeda et al., 2013). Water-related natural event is one of the factors that contribute to environmental damage (Ricci et al., 2022). Specifically, Negri et al. (2018) report the comparative toxicity study between five individual oil dispersants formulations for coral life species. Numerous researchers had reported new bio-based lubricant oil to resolve this global issue. By using materials that are non-toxic, renewable, biodegradable, environmentally friendly and economical can give benefit to the manufacturer, user and environment. A number of studies have shown that the bio-based lubricant such as vegetable oil has their own strength that can perform good properties as conventional mineral based-lubricant (Albert et al., 2013). A lot of studies reviewed the excellent properties of plant oil in lubricant application (Mosiewicki and Aranguren, 2013).

A critical review of vegetable oil as a potential additive for the industry that can produce better physical and biodegradable properties is discussed by Masripan et al. (2020). In another study, Syahrullaii et al. (2011) found that palm oil is able to achieve lubricant performance as compared to paraffinic material oil. In addition, during the experimental design, this material can reduce the extrusion load. Jojoba oil is a vegetable oil that is commonly used in tribological applications to reduce friction and wear (Sadriwala et al., 2020). In different applications, soybean oil is used in tissue application in medical studies (Díez-pascual and Díez-vicente, 2014).

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It was found an optimum combination of mechanical, thermal, fluid transport and antibacterial properties. Banana skin is one of the natural plants used in a recent study. The epicarp of banana skin was discovered to perform better on a well-lubricated surface (Mabuchi et al., 2012). The lubricating effect is attributed to the follicular gel found in bananas. This gel can also increase the percentage of bio-oil extraction yields directly from banana peel waste. The follicular gel was tested at six degrees of freedom under a linoleum flat panel and was found to play the dominant role in the lubricant effect from banana skin (Mabuchi et al., 2012). Moreover, another study on fatty acids analysis found that MBS oil is composed of 46 % of saturated fatty acids and other two types of fatty acids (Hamid et al., 2017). A natural and synthetic chemical substance such as biodegradable additives is well known to react as a base oil that can improve various characteristics of lubricants parameters (Quinchia et al., 2014). In this study, the effect of biodegradable and environmentally friendly additive of ethyl cellulose (EC) and ethylene vinyl acetate (EVA) on the friction and wear properties of *Musa Aluminata Balbisiana* (MBS) Oil were investigated. In the early study, Quinchia et al. (2010) found that EVA can improve the viscosity of the materials compared to other vegetable oil in lubricant applications. Both EC and EVA are considered inert, nontoxic and safe materials (Quinchia et al., 2014). Recent research has shown that these additives can provide better performance within the temperature ranges tested and are thought to improve some of the shortcomings and withdrawal effects of vegetable oil (Delgado et al., 2017). A recent related study mentioned that the optimum EC was 0.5 % while the optimum EVA was 4 % using mean effect and signal-to-noise measurements (Hamid et al., 2022).

Statistical analysis is an important data analysis that should be done from an experimental work for making a good conclusion. A good statistical analysis can reduce out-service time and exposure to the operators (Ancione et al., 2022). There are multiple methodologies and approaches used such as Taguchi method (Oliaei et al., 2016) and response surface methodology (Wongkaew et al., 2016) to identify the optimum parameters. Yet, there is no correlation analysis on the interconnection between the tribological parameters such as COF, Ws temperature, load and percentage of the additive. Furthermore, by identify the correlation of the parameters in experimental design is an important task for design engineers in the manufacturing process. The design engineer should identify significant parameters that contribute to the response variable in experimental procedures that can reduce the cost of the raw materials and sample testing. In fact, Noryani et al. (2018a) proved that statistical analysis by using regression analysis that includes correlation measurements can minimize the time during the material selection application. The above literature review inspires the incorporation of statistical analysis and secondary data from previous experimental work on COF and Ws of tribological behavior. In this study, correlation analysis is used in detail to identify the interconnection between the biodegradable additives, temperature and loading toward COF and Ws. This study contributed extra information towards the relationship and contribution of each parameter for tribological characteristics. Further statistical analysis such as regression analysis is one interesting analysis in future studies.

2. Methodology

The experimental data from the previous study is used to identify the relationship between the tribological behaviour and the parameter involved such as percentage of the biodegradable additive (P), temperature (T) and applied load (L) (Hamid et al., 2020). The interdependency of the parameters is described by the coefficient of correlation. The significant parameter toward the response variable is explained by the analysis of variance. The effect of each parameter also discuss by calculating the Pearson correlation coefficient (r).

2.1 Materials

In this study, *Musa Aluminata Balbisiana* (MBS) oil from banana peel waste is used with biodegradable additives such as EC and EVA are prepare based on tribological procedure that explained detail by Hamid et al. (2020). There are three stages to prepare the MBS oil as shown in Figure 1. The tribological responses are recorded used windocom 2008 software and the statistical analysis is perform using IBM SPSS Statistics (Version 25).

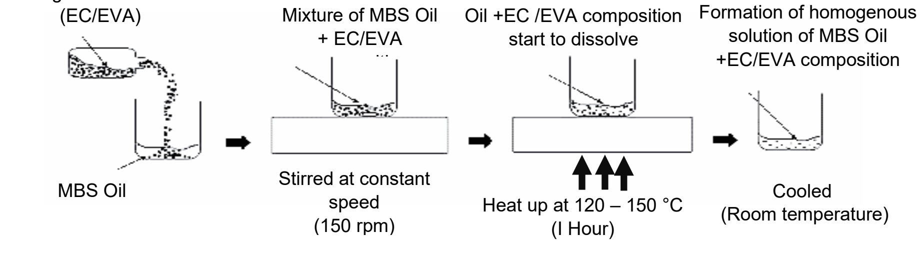

Figure 1: The preparation of MBS oil with biodegradable additives

2.2 2.2 Tribological variables

In this study, coefficient of friction (COF) and specific wear rate (Ws) are the respond variables measured using Eq(1) - Eq(3).

$$Vloss = \frac{\pi d^2}{64R} \quad (1)$$

$$COF = \frac{F}{W} \quad (2)$$

$$Ws = \frac{Vloss}{W \times L} \quad (3)$$

where, F = frictional force and W = applied load; both units are in N; Ws = specific wear rate (mm^3/Nm); L = sliding distance (m); Vloss= wear volume losses of the pins; *d*= wear scar diameter in unit of meter; R= radius of the pin (fixed value at 0.00149 m).

There are three parameters involved in this study, which are the percentage of biodegradable additives (EC/ EVA) (P), temperature °C (T), and applied load N (L). Each parameter has three different levels in this study; 0.5 %, 2.5 % and 4 % for the biodegradable additive, 27 °C, 40 °C and 100 °C for temperature and 60 N, 80 N and 100 N for the load applied. Meanwhile, control variables in this study such as sliding speed (RPM), sliding distances (m) and sliding times (min) are constant set as 50, 314 and 50.

2.3 Single effect of parameter on tribological behavior

The effect of each parameter toward respond variable is identifying by using Pearson correlation coefficient using Eq(4). There are two type of relationship between the respond variables and parameter; positive and negative linear relationship. Positive linear relationship occurs when respond variable increase as parameter increase while negative linear relationship occurs when respond variable decrease as parameter increase. This interconnection between the variable can describe the important of each parameter toward respond variable. Noryani et al. (2018b) study the interdependency of mechanical properties of composite by using Pearson correlation coefficient.

$$r = \frac{SS_{xy}}{\sqrt{SS_{xx}SS_{yy}}} \quad (4)$$

where SS_{xx} is sum of square of the regressor, SS_{xy} is sum of square of the interaction of regressor and respond variable and SS_{yy} is sum of square total.

2.4 Multiple effects of parameter on tribological behavior

More than one parameter can explain the respond variable. Multiple effect of the parameters is discussed in this study. The variations of respond variable are identifying by calculating the coefficient of determination (R^2) of the data set using Eq(5).

$$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_{RES}}{SS_T} \quad (5)$$

where SS_R is sum of square of regression, SS_T is a measure variability of respond variable without considering the effect of the parameters and SS_{RES} is sum of square residual which is the error between the estimation and the exact value of respond variable.

2.5 Analysis of variance on tribological behavior

The significant of statistical model is identify by using analysis of variance (ANOVA). Statistical F-test is used in ANOVA. The ratio of mean square regression and the residual is measured for each COF and Ws. A lot of study on materials used ANOVA to identify the significant mechanical (Jumaidin et al., 2017), physical (Tsai et al., 2017) and morphological (Emre et al., 2017) properties of a composites in different applications.

3. Result and discussions

In this section, the measurement of COF and Ws are recorded. Both measurements are the response variables in this study. Comprehensive discussion about the relationship between the response variable and parameter is explained to identify the effect of biodegradable additive, temperature and applied load toward COF and Ws.

The effect of each parameter is described by the coefficient of correlation (r) and the variation of COF and Ws are explained by coefficient of determination (R^2).

3.1 Respond variable score of COF and Ws

The values of COF and Ws by the experimental procedures from multiple levels of parameter is recorded in Table 1. Ethyl cellulose (EC) and ethylene vinyl acetate (EVA) are the additive used in the experiment. The value of COF for EC is between 0.0568 and 0.1911 and COF for EVA is between 0.0693 and 0.3078. The range of Ws for EC are small compared to Ws for EVA which the minimum and the maximum are 0.43739, 3.02968 and 0.30311, 4.03957. A wide range in data collection can contribute to the large distribution. Small range is better for estimation in statistical modelling.

Table 1: The respond of COF and Ws of EC and EVA

EC		EVA		P	T	L
COF	*Ws*	*COF*	*Ws*			
0.1911	2.42215	0.077	0.51847	0.5	27	60
0.0568	0.43739	0.093	0.88808	0.5	40	80
0.1316	2.20364	0.1184	1.68573	0.5	100	100
0.1144	0.39648	0.1071	1.75709	2.5	27	60
0.1182	1.08692	0.1448	1.69173	2.5	40	80
0.1077	2.17339	0.3078	4.03957	2.5	100	100
0.1004	0.49291	0.0884	0.70902	4.0	27	60
0.1842	1.89927	0.1101	2.09223	4.0	40	80
0.1086	3.02968	0.0693	0.30311	4.0	100	100

3.2 The effect of parameter toward responds variables

Pearson correlation coefficient (r) of biodegradable additives (P), temperature °C (T), and applied load N (L) for both COF and Ws is shown in Table 2. Load applied in this experiment have a negative linear correlation with COF and Ws. It represents a weak to moderate negative linear relationship toward respond variables as shown in Table 2. The value is between -0.285 and -0.460. In contrast, temperature have a moderate positive linear relationship to COF and Ws which is the value is between 0.354 and 0.676. There is too weak positive linear correlation between COF and Ws with percentage of biodegradable additive (P) where the values are between 0.012 and 0.054. The relationship between friction and wear of cylinder liner and piston ring pair also reported by using correlation coefficients (Kapsiz et al., 2011). The parameters involved in their study was sliding velocity, load and oil types. The effect of these parameters toward weight lost and coefficient of friction are reported.

Table 2: The correlation between response and regressors

Interconnection	P	T	L
COF-EC	0.032	0.464	-0.460
Ws-EC	0.030	0.676	-0.397
COF-EVA	0.012	0.445	-0.285
Ws-EVA	0.054	0.354	-0.326

3.3 Analysis of variance (ANOVA) of *COF* and *Ws*

Table 3 show the analysis of variance for using F-distribution. There is no significant difference of the variation for both COF and Ws where all the p-value are more than 0.05. The result was consistent with the value of R^2 and adjusted R^2 in Table 3. All values represent small variations of COF and Ws is explained by the P, T and L. For example, there is 38.4 % variation of COF-EVA is explained by P, T and L. In contrast, by using Taguchi method on previous study of jojoba oil found that the are significant difference between load used towards friction and wear behaviour (Sadriwala et al., 2020). Another result reported using scanning electron microscopy (SEM) show different images on the surface of the materials (Hamid et al., 2020). This study mentioned to further analysis needed to identify the influenced factors for better understanding the tribological regimes. Different types of analysis and equipment effect the results and concussion of the study. Comparative study of the tools in experimental work also can increase the trustworthy of the researcher to choose the data analysis to in related study.

Table 3: The analysis of variance of COF and Ws

Response variables	Sum of squares		df	Mean square	*F*-test	p-value	R^2/ $AdjR^2$
COF-EC	Regression	0.003	3	0.01	0.525	0.684	0.217
	Residual	0.011	5	0.02			
	Total	0.014	8				
COF-EVA	Regression	4.786	3	1.595	2.660	0.160	0.384
	Residual	2.999	5	0.600			
	Total	7.784	8				
Ws-EC	Regression	0.012	3	0.004	0.645	0.619	0.154
	Residual	0.030	5	0.006			
	Total	0.042	8				
Ws-EVA	Regression	2.420	3	0.807	0.510	0.693	0.225
	Residual	7.910	5	1.582			
	Total	10.330	8				

4. Conclusions

The effect of biodegradable additive, temperature and loading on tribological behaviour such as coefficient of friction and specific wear rate of Musa Aluminata Balbisiana oil were successfully presented in this study using correlation analysis and analysis of variance. Various level of biodegradable additive, temperature and loading used in the previous experimental work. There are nine response combination from different parameter with two types of biodegradable additive which are ethyl cellulose and ethylene vinyl acetate. The effect of the parameters is identified by statistical analysis such as correlation coefficient, determination of coefficient and analysis of variance. Percentage of biodegradable additive have a week positive linear relationship toward both coefficient of friction and specific wear rate. Moderate positive linear relationship is the effect of the temperature for the tribological behaviours. In contrast, load applied have is a negative linear relationship toward coefficient of friction and specific wear rate in this study. Further analysis found that there is no significant difference coefficient of friction and specific wear rate in all levels of parameters. The statistical model should be constructed to estimate the COF and Ws for future analysis. Together these results provide an important insight into tribological behaviour for the experimental work in other application and different materials.

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