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SYNTHESIS AND EXPERIMENTAL INVESTIGATION OF TRIBOLOGICAL PERFORMANCE OF A BLENDED (PALM AND MAHUA) BIO-LUBRICANT USING THE TAGUCHI DESIGN OF EXPERIMENT (DOE)

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ABSTRACT

The increasing prices of commercial lubricants and global attention towards a green environment have become the key issues to re-think about alternatives to commercially available lubricants. With these prospects in mind, vegetable oils can be utilized as an option to commercially available lubricants, due to their biodegradable and nontoxic nature. Moreover, they possess certain advantages like lower volatility and high flash/ fire points, higher viscosity index, excellent lubricity and cost savings. These properties of bio-lubricants are more often considered as important in the preparation of various bio-fuels. So far bio-lubricants have been employed in the preparation and testing of bio-fuels for various automotive applications. The primary aim of this study is to infer a novel application of bio-lubricants in the subject area of machining. During machining, machinability and performance are most frequently determined by the friction and wear characteristics of the tool and workpiece materials. In this work, first friction and wear characteristics of bio-lubricants (blended vegetable oils in various proportions) formulated from Palm and Mahua oils have been investigated using a Pin-on-Disk wear testing machine. A bio-lubricant (composed of blended vegetable oils) is synthesized by using two base oils and blending them in different possible proportions. The tribological properties have been studied over an AISI 1040 Steel disc specimen with aluminium pins under various bio-lubricant environments using the Taguchi Design of Experiment (DOE). During the study, it was observed that the abrasive and adhesive wear were the main wear mechanisms that occurred in the tests. The results have shown that total wear of the test specimens under all machining conditions for 90% Mahua and 10% Palm blended oil combination is found to be at a minimum.

Keywords: Blended bio-lubricant; Friction; Tribological performance; Wear

1. INTRODUCTION

In any mechanical system, the greater the number of moving parts, the greater the chance of an excess amount of heat being generated between the surfaces, resulting in friction and wear of the two parts. To obviate this condition, lubricants are generally applied. Even though the application of commercially available lubricants in diverse areas of manufacturing is favored, it has been discovered that the use of these lubricants leads to environmental pollution and high manufacturing costs. To avoid these adverse conditions, nowadays vegetable oils or bio-lubricants are being used. From the literature review, it was observed that the friction and wear

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characteristics of Jatropha oil-based bio-lubricants (blended vegetable oils) could be formulated by blending the base oil (SAE 40) with 10%, 20%, 30%, 40% and 50% of the Jatropha oil (Shahabuddin et al., 2013). It was found that the addition of 10% Jatropha oil in the base lubricant is the optimum for automotive application, as it showed the best overall performance in terms of wear, coefficient of friction, viscosity, and rise in temperature factors. Syahrullail et al. (2013b) tested the performance of vegetable oils as a lubricant, using a four ball tribometer under extreme pressure conditions. It was concluded that vegetable oil shows potential for development as an industrial lubricant by adding proper additives. Syahrullail et al. (2013a) investigated the performance of refined, bleached and deodorized (RBD) palm olein by using a Pin-on-Disk wear testing machine. It was found that the RBD palm olein showed better anti-friction and anti-wear performance when compared to hydraulic mineral oil. Ting and Chen (2011) carried out viscosity and working efficiency analysis of soybean oil-based bio-lubricants. Habibullah et al. (2014) investigated the effect of jatropha oil doped with lube oil on the tribological characteristics of an IP 239 standard, using a four ball tribotester. The overall results of this experiment reveal that the addition of 5% Jatropha oil with a base lubricant shows better performance and anti-wear characteristics.

Hu et al. (2005) studied the lubricity enhancing properties of biodiesel. Unrefined biodiesel and refined biodiesel derived from vegetable oils were made and then were added to a base diesel. The wear scar diameter values were measured by the High Frequency Reciprocating Rig method. It was found that unrefined biodiesel showed higher lubricity properties than refined biodiesel. A tribological investigation, in terms of the coefficient of friction and wear resistance of refined, bleached and deodorized palm olein, was conducted using a Pin-on-Disk tribotester by Syahrullail et al. (2014). It was concluded that the coefficient of friction for specimens lubricated with RBD palm olein showed the lowest value compared to hydraulic oil and paraffinic mineral oil at both low speed (0.25 m/s) and high speed (1.0 m/s). The tribological behavior of pyrolysis bio-oil with a synthesized nano-Lanthanum oxide (La_2O_3) additive was evaluated by Xu et al. (2015), using a point contact four ball tribometer under different frictional conditions. The results show that nano-La_2O_3 impregnated bio-oil had better tribological properties than the control groups.

Fazal et al. (2013) investigated the friction and wear characteristics of palm biodiesel at different concentration levels by using four-ball wear machine. Results showed that wear and friction decreased with the increase of biodiesel concentration. Shashikant and Raheman (2005) developed a technique to produce biodiesel from Mahua oil having high free fatty acids (19% FFA). Ramos et al. (2009) studied the influence of the raw material composition on biodiesel quality, using a trans-esterification reaction. Mao et al. (2014) experimented to understand the role of nanofluid in grinding, using a Pin-on-Disc apparatus. During the study, Al_2O_3 was mixed with various base fluids like de-ionized water and canola oil. Results have proven that the nanoparticles have decreased the friction coefficient and the worn weight. Jain and Suhane (2012) investigated the tribological properties of non-edible bio-lubricant oils. Results have indicated that the tribological performance is good with a blend of 20% mixing ratio of castor and Mahua oils. Fazal et al. (2013) found that the wear characteristics are less with the increase of bio-diesel concentration, while in testing the steel specimens. Bongfa et al. (2015) compared the lubricant properties of castor and commercially available oils. During the study, it was found that castor oil blended with additives had significantly lost its energy, while being tested in IC engines. Jianwei et al. (2010) studied the tribological performance of two vegetable oils and identified that the additives present in rape seed oil acts as a protective lubricating film. Jayadas and Nair (2005) found that the anti-wear properties of coconut oil were good compared to high oleic vegetable oils.

Based on a literature review, it was found that vegetable oil can be used as an alternative to the commercially available lubricants. Tribological characteristics of the materials would be better when two vegetable oils are mixed in proper proportions to form a new bio-lubricant. Bio-diesels prepared from these blended bio-lubricants can perform effectively, compared to the commercially available bio-diesels. In this study blended bio-lubricants are prepared by mixing palm and Mahua vegetable oils in proper proportions. Later on in order to study the tribological performance of these blended bio-lubricants, Taguchi DOE was framed and tested on a wear tester.

2. DESIGN OF EXPERIMENTS USING TAGUCHI METHOD

2.1. Parameters and their Levels Considered for the Wear Test of AISI 1040 Steel

Experiments planned for the wear test of AISI 1040 steel specimen are designed using Taguchi DOE methodology (Figure 1). With all possible combinations of input parameters and their levels at L_{16} ($4^{(3-1)} = 4^2 = 16$), a Taguchi orthogonal array was designed as shown in Tables 1 and 2. In all the experiments the time is kept as constant (3 mins).

Table 1 Parameters and their levels for wear test of AISI 1040 Steel

S.No	Input parameters/Factors	Levels			
		1	2	3	4
1	Load (N)	19.61	39.22	58.83	78.45
2	Sliding speed (rpm)	200	400	600	800
3	Track Diameter (mm)	20	40	60	80

3. EXPERIMENTATION ON PIN-ON-DISC WEAR TESTING MACHINE

A Pin-on-Disc tribometer, as shown in Figure 2, consists of a stationary "pin" under an applied load in contact with a rotating disc. For the present study a DUCOM tribotester with an inbuilt software WINDUCOM was used to trace wear of the steel specimen under various combinations of input parameters. The technical specification of the DUCOM tribotester is given in Table 3.

3.1. Experimental Setup and Procedure Involved

The Pin-on-Disc wear testing machine represents a substantial advance in terms of simplicity and convenience of operation, ease of specimen clamping and accuracy of measurements, both of wear and frictional force. The equipment is made compatible for using water during testing by having the parts which come in contact with other parts made of EN-31 material. It is designed to apply loads up to 100N and for speeds ranging from 100 to 1000 rpm, provision is made to conduct tests under dry and lubricated conditions. This apparatus facilitates study of friction and wear characteristics in sliding contact under different test conditions, sliding occurs between the stationary pin and a rotating disc. The normal load, rotational speed and wear track diameter can be varied to suit test conditions. Tangential frictional force and wear are monitored with electronic sensors and recorded on a PC. These parameters are available as functions of load and speed. The elements of the tribometer, as shown in Figure 2, are a "pin" sliding on the flat face of a disc rotating in a vertical plane, with provisions for controlling load, speed and oil temperature, and for measuring friction and time. It consists of a 1:1 lever, one end of which is attached to the pin and the other end is attached to external loads. Whatever may be the load applied on the one end of the lever will be applied on the disc by the pin. It also consists of a linear variable differential transducer (LVDT) which will give the amount of wear on the pin and disc during the test.

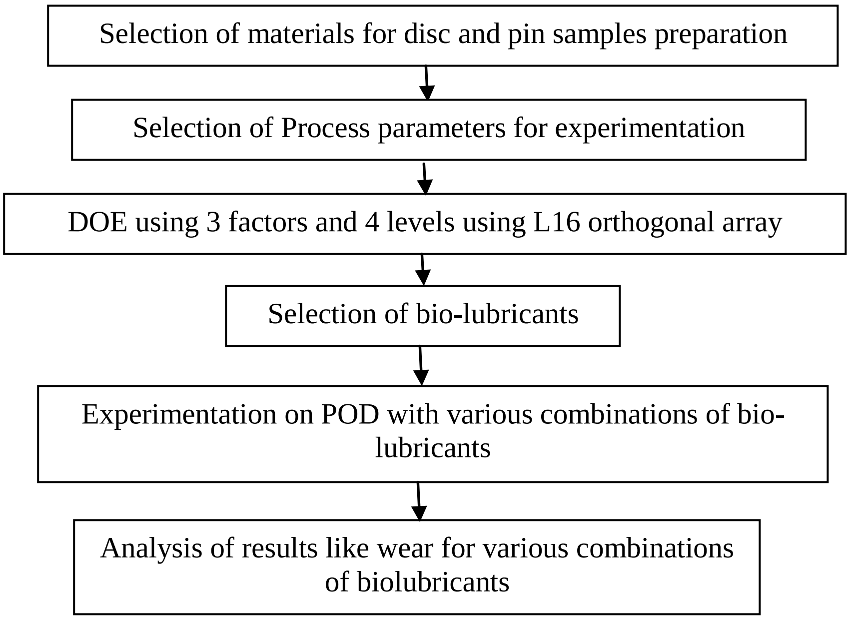

Figure 1 Experimental Methodology

Table 2 Taguchi DOE

Experiment No	Speed N (rpm)	Load P (N)	Track diameter D (mm)
1	200	19.61	20
2	200	39.22	40
3	200	58.83	60
4	200	78.45	80
5	400	19.61	40
6	400	39.22	20
7	400	58.83	80
8	400	78.45	60
9	600	19.61	60
10	600	39.22	80
11	600	58.83	20
12	600	78.45	40
13	800	19.61	80
14	800	39.22	60
15	800	58.83	40
16	800	78.45	20

Table 3 Technical specifications of Wear tester used for experimentation

Parameter	Range
Normal load (kg)	1-10
Disc rotational speed (rpm)	100-1000
Wear (Max) (µm)	2000
Wear track diameter (mm)	8 (Min); 80 (Max)
Wear disc size (mm)	100 (dia), 6–8 (thickness)
Specimen pin size (mm)	4–8 (dia) in steps of 2, 20–30 (length)

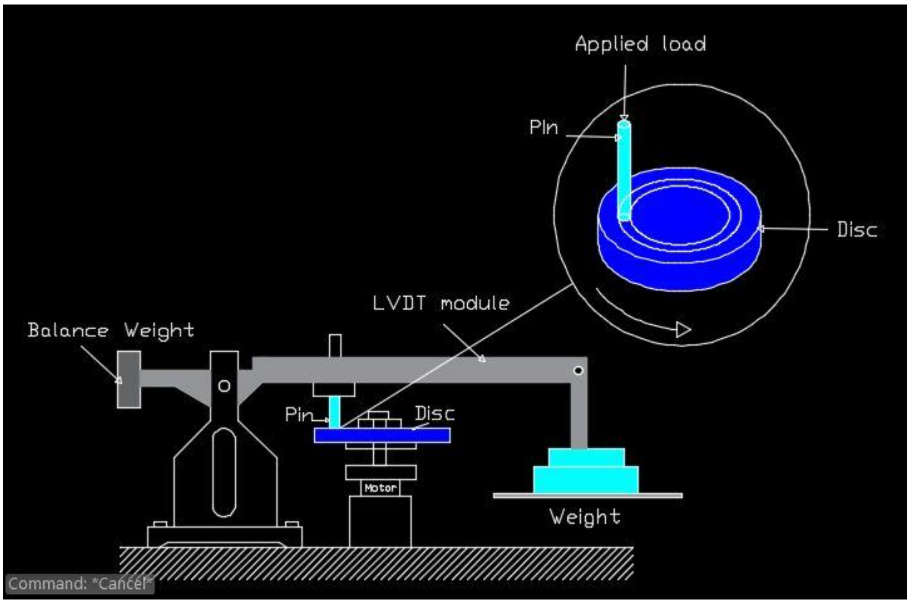

Figure 2 Pin-and-Disc arrangement (Auto-CAD diagram)

The Pin-on-Disc (POD) experimental setup consists of a machine, controller, weights and a connected PC. All these are connected via cables and the values of the controller are fed directly into the PC. Figure 3 shows a view of the set up.

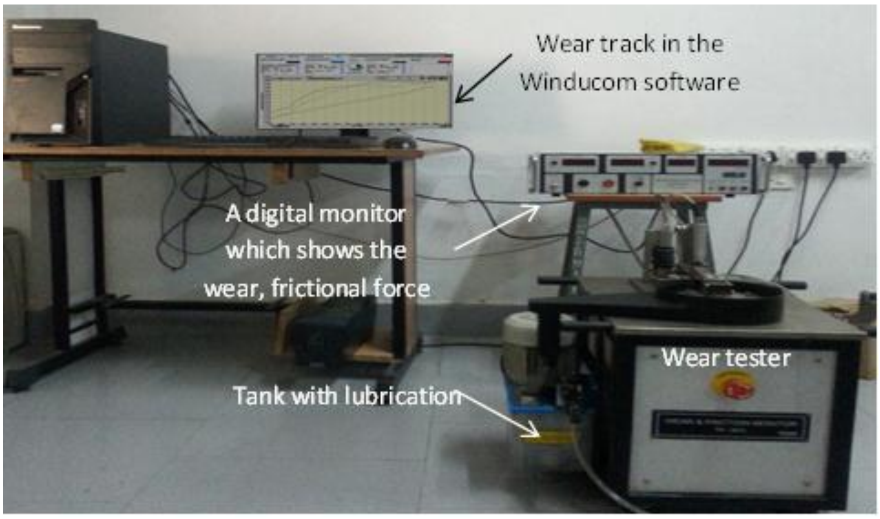

Figure 3 Photographic view of experimental setup

3.2. Design of Disc and Pin

3.2.1. Design of disc

For conducting experiments on the POD machine, a disc specimen made of AISI 1040 Steel material has been utilized. The disc is made according to the standard dimensions to incorporate it into the space provided in the machine. The design details of the disc are shown in Figures 4 and 5.

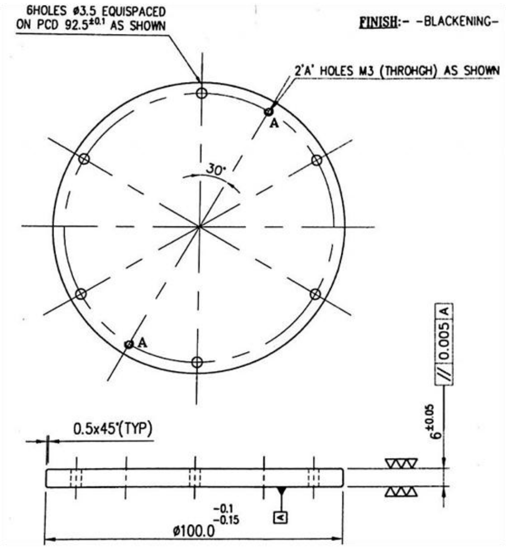

Figure 4 Sectional view of the plate

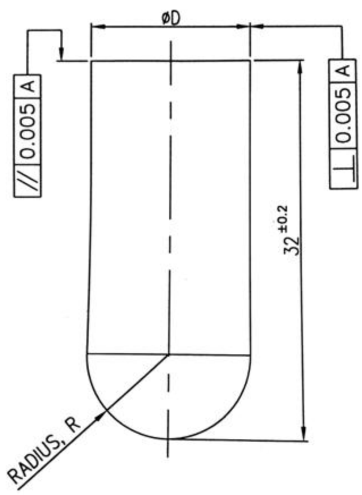

Figure 5 Sectional view of pin

There are 6 holes arranged in a sequence as shown in the Figure 4. These holes are drilled according to the said dimensions of the nut and bolt assembly to be used in clamping the disc.

3.2.2. Design of pin

The pin is an 8 mm to 10 mm diametric pin, having a hemispherical shape at one end as shown in Figure 5. The hemispherical shape allows the pin to make a single point contact with the rotating disc. But with time, speed and load, the single point contact does not stay as it is. The dimensions, surface roughness and tolerances have been depicted in the figure, which are followed during casting and machining.

3.3. Experimentation

3.3.1. Preparation of bio lubricant samples

A total of 11 combinations of blended oils of 1 litre are prepared as shown in Table 4. Each Sample (Figure 6) is mixed thoroughly using the magnetic stirrer with a heater (Figure 7). The maximum temperature of heating is much less than the Flash and Fire point of the oils. The duration time of stirring was 30 minutes.

Table 4 Percentages of Mahua oil and Palm oils for experimentation

Sample No	% of Mahua oil	% of Palm oil
1	10	90
2	20	80
3	30	70
4	40	60
5	50	50
6	60	40
7	70	30
8	80	20
9	90	10
10	Pure palm oil	
11	Pure Mahua oil	

4. RESULTS AND DISCUSSION

4.1. Tribological Performance of AISI 1040 Steel under Various Combinations of Bio-lubricants

Tribological characteristics of the specimens were observed by conducting a wear test on the Pin-On Disk machine for all combinations of blended bio-lubricants (Table 4) under all Taguchi Design of Experiment tests. After each test, the response variables like co-efficient of friction, wear and frictional force are observed from the in-built WINDUCOM software (as shown in Figure 8) and the values for each one of the samples was tabulated in Table 5.

Figure 6 A bio-lubricant sample with 20% Mahua oil + 80% palm oil

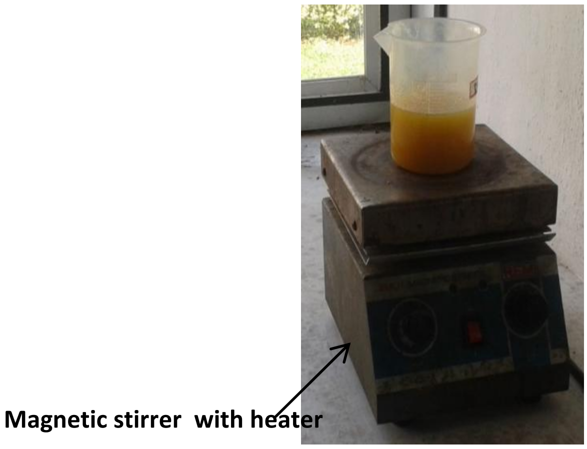

Figure 7 Oil sample on the magnetic stirrer

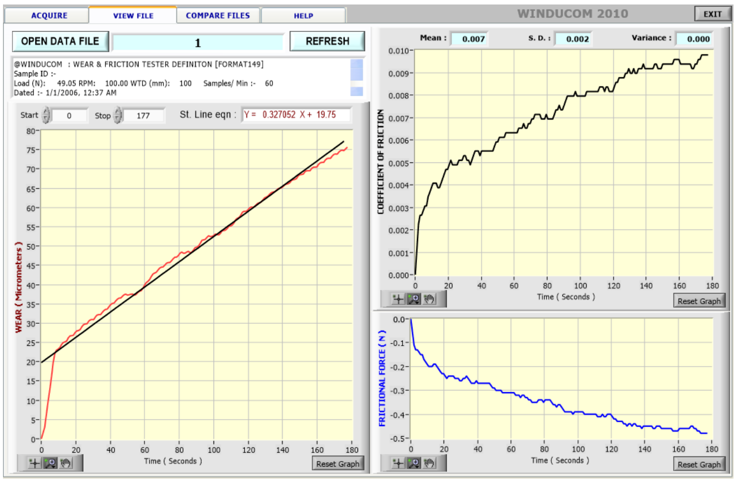

Figure 8 Graph showing variation of wear, coefficient of friction and frictional force

4.2. Experimental Results

Based on the experimental results, graphs are plotted to observe the variation of wear for all blended oil samples individually and one of them is shown in Figure 9.

4.3. Variation of Total Wear for All Blended Oil Samples

From the experimental results, the total wear for each sample is summarized and plotted as depicted in Figure 10.

Table 5 Wear characteristics for sample-1 (10% Mahua + 90% Palm oil)

Experiment No	Speed N (rpm)	Load P (N)	Track diameter D (mm)	Coefficient of friction (μ)	Frictional Force F (N)	Wear (μm)
1	200	19.61	20	0.007	1.2	76
2	200	39.22	40	0.279	3.9	190
3	200	58.83	60	0.138	5.7	449
4	200	78.45	80	0.126	8.1	504
5	400	19.61	40	0.034	1.3	170
6	400	39.22	20	0.115	2.9	97
7	400	58.83	80	0.105	5.3	538
8	400	78.45	60	0.093	4.6	86
9	600	19.61	60	0.080	1.1	217
10	600	39.22	80	0.045	1.8	334
11	600	58.83	20	0.118	2.6	64
12	600	78.45	40	0.080	5.3	4.7
13	800	19.61	80	0.020	0.6	173
14	800	39.22	60	0.041	1.7	175
15	800	58.83	40	0.070	2.6	185
16	800	78.45	20	0.121	6.3	92

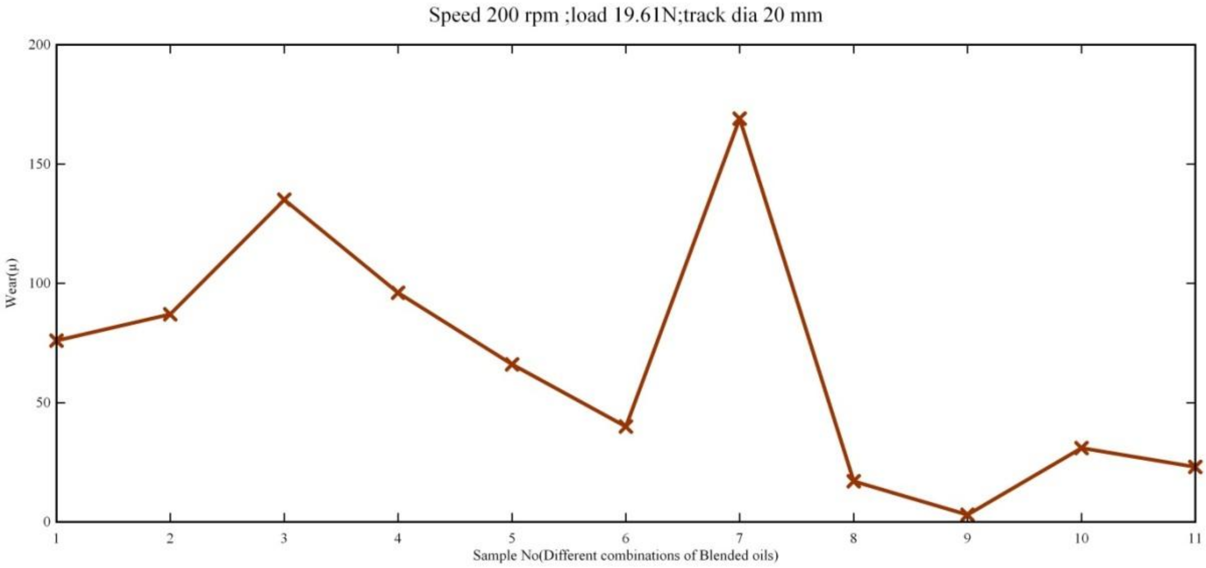

Figure 9 Variation of wear of different samples at speed 200 rpm, load 19.61 N, track dia 20 mm

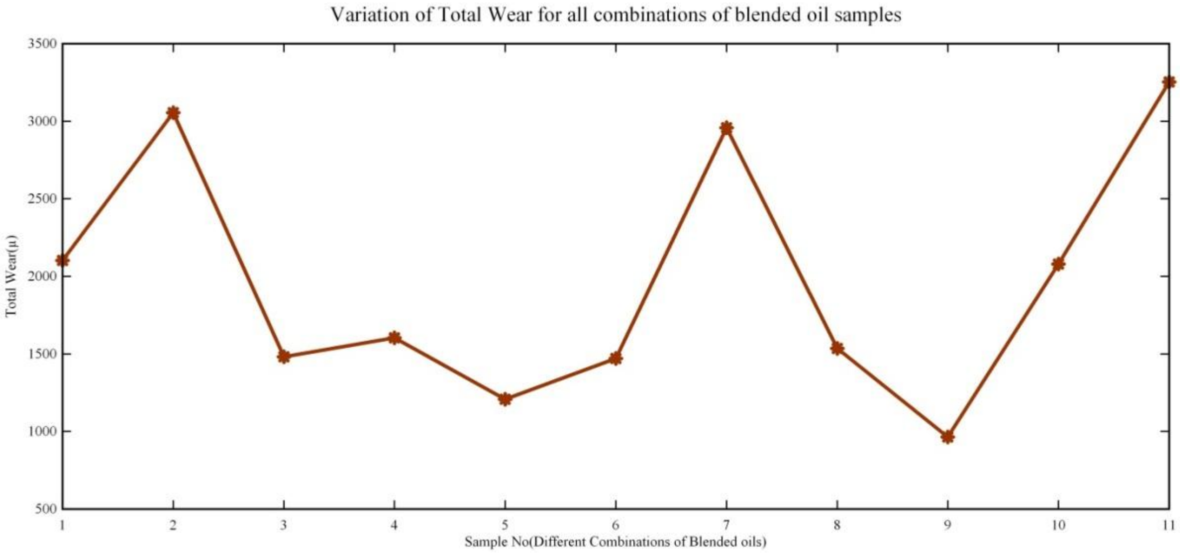

Figure 10 Variation of total wear for all blended oil samples

5. CONCLUSION

The objective of the present study was to investigate effects of bio-lubricant and optimization of process parameters in order to reduce the wear using the Taguchi Design of Experiments. Taguchi methodology was useful in identifying the best combination of blended Palm and Mahua bio-lubricants. It was also useful in the preparation of bio-diesel from the best combination of blended Palm and Mahua oil samples. Based on the results of these experimental investigations, the following conclusions were made: (1) The results of the present study using blended vegetable oils have shown an improvement in reducing the wear and coefficient of friction compared to the commercially available lubricants; (2) The blended bio-lubricants can be used as an alternative to the commercially available lubricants and it would be an added advantage to gain the lubricating properties of two individual vegetable oils; (3) At a 90% Mahua and 10% Palm blended oil combination; total wear of the test specimens under all machining conditions was found to be minimum; (4) Taguchi methodology was found to be useful in identifying the best combination of minimizing the repetitions in the combination of machining parameters.

The analysis of experimental results would be useful in the selection of best combinations of blended bio-lubricants which can be further used in the preparation of bio-diesel.

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