Vol. 44, No. 3 (2022) 449-460, DOI: 10.24874/ti.1244.01.22.05

Tribology in Industry

www.tribology.rs

RESEARCH

A Fundamental Investigation of the Tribological Performance of Mahua-Castor Blend in a Four-Ball Tester

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Keywords:

Mahua-castor oil blend
Fourball tester
Accelerometer
Wear rate
Lubrication

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Received: 7 January 2022
Revised: 7 February 2022
Accepted: 16 May 2022

A B S T R A C T

The scrutinized investigation of tribological performance of castor-mahua oil blends was comprehensively studied in comparison to SAE 20W40. Better miscibility and the negligible difference in density is the prime motive for the formulation of castor-mahua oil blend. Ten different blends are assimilated in the current investigation, and two better blends are utilized for further investigations of speed variations along with pure castor oil (B0) for the reference. The effect of speed variation of 1200 rpm, 900 rpm, 600 rpm, and 300 rpm were incorporated for better blends obtained in the inquiry. Blends B2(75 wt% of castor and 25 wt% of mahua oil) and B5(50 wt% of castor and 50 wt% of Mahua) showed extremely better tribological performance with 26.19% and 32.16% diminishment in coefficient of friction (COF), respectively, in comparison to SAE20W40. The variation of wear rate with speed and surface morphology of the balls are analyzed in the research work. The effect of vibration on the tribological parameters is investigated with an accelerometer equipment. All the results obtained from the research inquiry demonstrate the fact that castor mahua oil blends are promising and potential replacements for conventional synthetic oils.

1. INTRODUCTION

Formulation of better lubricants and the development of eco-friendly alternatives is the prime requirement of the day. There is a novel need to reduce wear and coefficient of friction (COF) between two components in relative motion. This would significantly increase the efficiency and the life of the component. In order to achieve enhanced efficiency and substantially reduce the material removal rate, there is a need to utilize a proper lubricant. It is imperative to note that a high material removal rate solely substantially reduces component efficiency. Material removal or wear, in general, is a surface phenomenon that might change the surface characteristics of the material is not at all permissible in practical implications.

To comprehensively diminish wear, reduce the COF, and enhance lubrication, mineral oils were utilized in a wide variety of applications. Even though the mineral oils have intensified the friction diminishing phenomenon, but they have worked up to their limits [1]. In addition to that, mineral oils are significantly less environmental friendly [2]. It was affirmed by many researchers that the utilization of petroleum-based oils causes serious environmental threats. Crude oil-based lubricants create serious threats to environmental operations. It includes primary hazards like sawing operators, followed by secondary hazards of accumulation of oil derivative in plants, animals, and groundwater issues. It even causes extreme threats to soil fertility and significantly affects the health of human beings, causing serious health effects [3- 5]. To overcome these ill-effects, the usage of bio-oils in different applications came into the picture. It can be attributed that enhanced flash point, pour point, fire point and an optimum viscosity index of bio-based lubricants makes it a potential candidate to replace mineral-based oils [6-9]. Instead of utilizing bio-based oils independently, there are research works that used bio-based oils as a blend with mineral oils. The usage of 10% Jojoba oil with mineral oil showed an enhanced reduction in COF and wear [10]. It was also depicted by Yashvir et al. that blending bio-oils to mineral oil significantly improved the wear behavior of synthetic oils [11]. So, it can be attributed to the fact that the blend of oils is the requirement of the day not only to obtain better performance but also to protect mother nature. The two unique oils with different tribological advantages can be captured most substantially with the blend of oils. The main focus of this research article is to depict the applicability of mahua and castor oil blends, which are derived naturally for practical purposes so that it can completely replace synthetic oils.

Castor oil is basically a derivative of castor seeds chemically known to be Recinus Communis, which is a pale amber, viscous oil [12]. Sharma et al. concluded that the presence of polar ester groups makes castor oil adhere to the surface of contacting metals, thereby reducing the COF [13]. Investigations of Venu and Vaibhav affirmed that castor oil can replace synthetic oils due to its substantial flash and fire points [14]. All these aspects are pieces of evidence to confirm the applicability of castor oil in lubrication applications. Even mahua oil which is chemically known to be Madhuca-indica is known to possess better lubrication characteristics. Suresha et al. comprehensively evaluated the tribological behavior of mahua oil [15]. Many researchers noted that enhanced lubrication capability with reduced wear volume was observed with Mahua oil. In the recent past, it was observed by Yashvir et al. that the addition of mahua oil to synthetic lubricant comprehensively reduced the COF and wear scar diameter [16]. For maintenance, 5-10% of Mahua oil blend in 90T gear oil exhibited better wear reduction as outlined by Amit et al. [17]. Thus, it can be concluded that mahua oil is best suited as one of the prime blends for any base oil to obtain wear-reducing characteristics. There are significantly fewer research reports that portray the tribological behaviour of bio-based blends. There is a futuristic need to comprehensively investigate the tribological features of bio-based oils so that most of the lubrication benefits of synthetic oils can be easily obtained by the blend of oils without the further inculcation of additives.

The other crucial challenge faced by most of the components like gear, bearing, etc. is the presence of vibrations. Most of the components include friction-influenced vibrations, which play a vital role in material removal. The prime reason for the friction-induced vibration is the surface roughness of the material under consideration. This vibration in many situations plays a supreme role in the wear of the components. The presence of roughness in the bearings, tyres wheels results in excitation of vibration, which poses greater threats by abrupt material removal, which is inevitable [18]. Many researchers depicted that vibrations arising due to surface roughness are negligible, and there is no novel need to account for them, as most of the vibrations arise due to harmonic excitation of the components. The dynamic model formulated by Nayak depicts that in two contacting bodies, most of the vertical vibrations are influenced by the relative displacement of the bodies due to their shape, and surface roughness effects are fairly negligible, but it can still be considered a possible mechanism for excitation [19]. In ball bearings and spur gears, the roughness plays a significant role in generating vibrations, thereby causing a substantial wear rate [20]. Thus, capturing this effect is inevitable in predicting the tribological behaviour of the system. In order to visualize this effect a setup consisting of the accelerometer is utilized in the present inquiry. The prediction of the frequency and amplitude made by the accelerometer can be a suitable means to incarnate the wear due to vibrations. The utilization of accelerometer equipment in a four-ball tester is analogous to obtaining the wear aspects in ball bearings due to vibration. It was noted by many investigators that the accelerometer is one of the accurate means to obtain vibrations present in the system. The vibrations with a lower frequency and lower g-acceleration can be accounted for vibrations comprehensively [21]. The MEMS resonant accelerometers which are part of this study are known for their higher sensitivity and wide dynamic range [22]. Paul et al. emphasized that usage of the accelerometer in end milling applications depicted the tool wear arising from vibrations and concluded that the material removal occurring due to vibrations can be thoroughly captured by accelerometer [23]. Chaung et al. also demonstrated the wear arising due to vibrations can be accurately observed by an accelerometer [24]. Thus, by obtaining the data pertaining to wear due to vibrations, the effect of vibrations on material removal can be accurately noted, and various methods to diminish the vibrations can be formulated.

The conventional four-ball tribometer was utilized to check the tribological performance of the castor-Mahua oil blend along with an accelerometer to depict the effect of vibration on material removal. Variation of the speed of 300 rpm, 600 rpm, 900 rpm, and 1200 rpm are carried out in the present work to illustrate the lubrication performance at lower as well as at higher speeds so that the applicability of the formulated blend at speed extremities can be evaluated thoroughly. The comparative study of castor-Mahua blends with SAE20W40 and pure castor oil is carried out to evaluate the tribological similarities of Castor-Mahua blends. Thus, accounting for the lubrication aspects of the blend by comparison with synthetic oil and studying the variation of wear rate, wear scar diameter and COF and thereby presenting the complete tribological performance of castor-Mahua blend is significantly dealt in this research report.

2. EXPERIMENTATION

2.1 Extraction of oil

The Castor and Mahua oils are separately extracted by their seeds. These undergo a purification process to obtain the user-friendly oil to be utilized in various applications. The castor seeds, which are dried and dehulled, are fed into the screw extruder through the hooper, and 90% of the purified oil is obtained here. Later the purified oil undergoes a solvent extraction process to obtain pure castor oil.

In the case of mahua oil, the seeds are fed into the screw extruder to obtain the oil. Later, to remove impurities present in the oil, it undergoes a two-step purification process, coarse filtration of the extracted mahua oil is done with a 300 micron-sized filter and fine filtration with 20-micron filter is carried out. The pure oil, hence obtained is without impurities are utilized for further experimentation. The extracted oils were further taken for the purpose of blending.

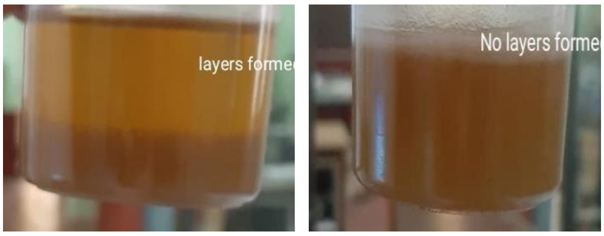
2.2 Blending of oils

The present work involves the blending of Mahua oil and Castor oil. The prime reason for blending castor and mahua oils is its extremely less density difference and better miscibility. Better Miscibility of castor-mahua oil was affirmed by Amit et al. in one of their research inquiries [25]. To check the stability of the oils, both magnetic stirring and hand stirring was performed for all ten blends. Magnetic stirring was performed for 30 min at the speed of 1200 rpm and at a temperature of 25°C. The various blends incorporated in the present work is as shown in Table1.

Table 1. Designation of blend of oils.

Sl no.	Designation	Blend wt%(CM)
1	B0	100C-0M
2	B1	80C-20M
3	B2	75C-25M
4	B3	70C-30M
5	B4	60C-40M
6	B5	50C-50M
7	B6	40C-60M
8	B7	20C-80M
9	B8	10C-90M

Both magnetic stirred and hand stirred components were kept for visual inspection for ten days. It was noted that even after ten days, there is no settling or formation of different layers for a magnetic stirred oil blend. Fig. 1 demonstrates the comparison betweenmagnetic stirred and hand stirred blends for B1.



(a) (b)

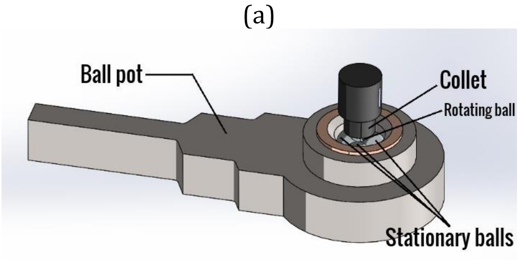
Fig. 1. B1 blend, (a) Magnetic stirred, (b) Hand stirred.

As there is better dispersion stability with magnetic stirred blends, all the further tests are conducted by taking the magnetic stirred blends.

2.3 Wear performance investigation tests

The entire inquiries of tribological performance of the blend of oils are carried out in a Four-ball tester as per ASTM D 4172 standards [26]. Fig. 2 (a) depicts the four-ball tester equipment utilized in the present investigation.

(a)



(b)

Fig. 2. (a) Four ball tester, (b) Ball pot assembly.

Fig. 2(b) renders the assembly utilized within the four-ball tester. The ball pot is the component that contains three balls, the motion of the balls is arrested by means of the lock nut. Once the assembly is done, the oil samples are poured into the ball pot so that all the balls are completely dipped in the oil samples. The fourth ball is attached to the top, which is motor driven, and after assigning the load, it is made to rotate in a specified direction. This rotation would generate torque, and opposing that torque, there is resistance which is generated by friction, and the resisting torque can be called frictional torque, this would result in the material removal and the data of COF is obtained, which can be employed for further discussions. The oil samples used in the present inquiry are tested for wear preventive characteristics in a four-ball tester procured from Magnum Engineers, Bangalore. The balls utilized are of diameter 12.7 mm made of 100Cr6steel material with mirror finish, having a Rockwell hardness of 64-66 HRC. Ten oil samples, including pure Castor and SAE20W40, were tested for wear preventive characteristics. The samples were run for 1 hour each with a temperature of 75o C, constant load of 392.4 N and speed of 1200 ± 0.2 rpm. Once the initial tests were carried out in accordance with the standards, for the wear rate values and co efficient of friction, two better samples were selected, and speed variations of 300 rpm, 600 rpm, 900 rpm were further performed to depict the better lubricant by comparing it to SAE 20W40 and base castor oil. Once the test is completed, all the balls were cleaned with Acetone and then an optical camera is employed in obtaining the wear scar diameter.

After the completion of the tests, average values of wear scar diameter of the three stationary balls were taken and are substituted in the eqn. 1, to obtain the volumetric wear rate.

$$k = \frac{\pi}{32t}\left(R - \sqrt{(R^2 - a^2)}\right)^2 \left(2R + \sqrt{(R^2 - a^2)}\right)$$

R is the radius of the steel balls considered depicted in mm. Wear scar diameter in mm is shown by a. t is the time required for sliding shown in seconds. k is the volume wear rate.

2.4 Vibration study

The vibrations that are arising in the four-ball tester plays a key role in material removal and abrupt wear. To account for the vibrations in the entire equipment, accelerometer is utilized. The present research work uses an accelerometer procured from PCB piezotronics. The Z-axis Vibration in the vertical direction is determined in the current work as the vibrations in X and Y directions are negligible. The piezoelectric crystal is placed on the top on ball pot. The accelerometer has a sensitivity of 10.2 mV (m/s2). It has a measuring range of ± 490m/s2. The frequency measuring range is observed to be 2-5000 Hz.

3. RESULTS AND DISCUSSIONS

3.1 Selection of optimum blend

The mean value of the COF (COF) of various samples assessed in the entire work with 1200 rpm is depicted in Fig. 3.

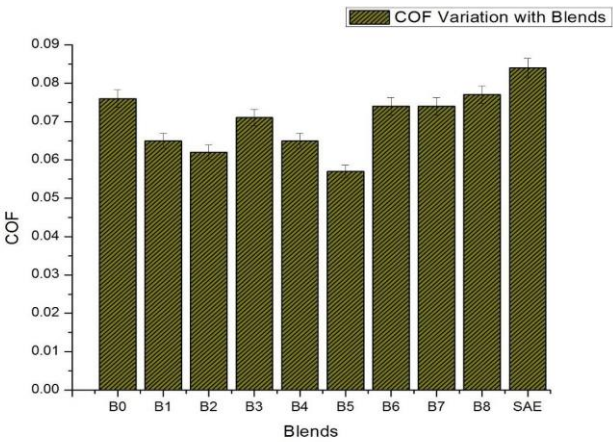


Fig 3. Variation of COF with different blends.

Fig. 3 comprehensively depicts the different blend variations with COF. It is imperative to note that SAE 20W40 showed a significantly higher COF. The chief reason for enhanced COF is that, at elevated temperature and speed, there is a substantial decrement in the viscosity of oil and thereby resulting in the larger relative shearing between the top rotating ball and the lubricating film. It was also affirmed Dinesh et al. in their research report [27]. An elevated high value COF is observed with the B0 sample. It can be noted that at uplifted temperature and speed, the film thickness reduces significantly, and it would cause lubricant film breakage, thereby causing a higher value of COF. Similar observations were seen by Wang et al. [28]. B5 blend has an extremely low COF in comparison to all other oil samples under consideration. Around 32.16% decrement in the value of COF is observed with the B5 blend relative to SAE20W40, and a 24% reduction in COF is seen when compared to B0. Similarly, the B2 sample exhibited a 26.19% diminishment of COF in comparison to SAE20W40 and17.33% relative to B0. Attainment of significantly lower COF stabilizes the fact that B5 and B2 blend shows better film thickness holding capability under standard conditions. It can also be concluded that the addition of a specific wt% of Mahua oil increases the viscosity of the blends. As the viscosity increases, the film thickness increases, and hence reduced COF is observed. Apart from B5 and B2 all the other oils showed comparable COF and just had extremely less differences of B5 and B2 are considered for the further speed variations and compared with B0 and SAE20W40 so that key tribological characteristics can be deduced.

3.2 Variation of COF with speed

Four different speed iterations, namely 1200 rpm, 900 rpm, 600 rpm and 300 rpm, are incorporated in the current research work. The chief motive for choosing the aforementioned speed variations is to check the accountability of the blends at extremely low as well as with extremely high speed. It was depicted from the obtained results that with the increment in the speed, there is a comprehensive reduction in the COF. Figure 4 Renders the variation of COF with speed for four different oil samples.

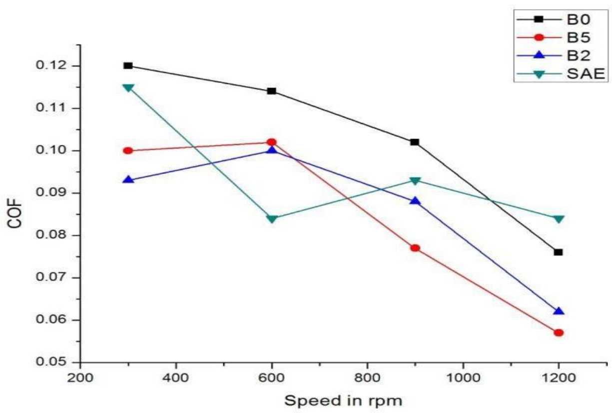


Fig 4. Variation of COF with speed in rpm.

It is noteworthy to emphasize the fact that the trend of decreasing COF with increasing speed was seen with all the oil samples under consideration. It can be concluded that the presence of long-chain fatty acids in the blends because of the pronounced miscibility of two oils resulted in the higher film thickness, and even at higher speeds, it was possible to maintain the film thickness as the oil samples behave as a fluid with lower viscosity at increased speed. The above observation of the effect of fatty acid chain in reduction of COF was emphasized by Syahrullail et al. while investigating the key tribological aspects of RBD palm olein [29]. The key reason for the higher COF at lower speeds is that at lower speeds, continuous contact of asperities of top ball and bottom ball takes place, due to which there will be contact between the balls for a longer duration of time. Thus, there is a noteworthy increase in the COF. With the increased speed, there will be lesser and lesser asperity contacts, and at higher speeds, the oil is diffused in the interface between the balls, so comprehensive reduction in the COF is noted. Many researchers in the recent past encountered a similar mechanism of variation of COF with the speed [30,31]. Thus, it can be concluded that the blending of oils reduced COF with increasing speed more beneficially in comparison with SAE20W40 so that it can be a potential and more stable replacement for synthetic oils.

3.3 Variation of speed with wear rate

Wear rate calculation of the samples is done by applying Eqn (1). The figure 5 Shows the wear rate of oil samples varying with speed.

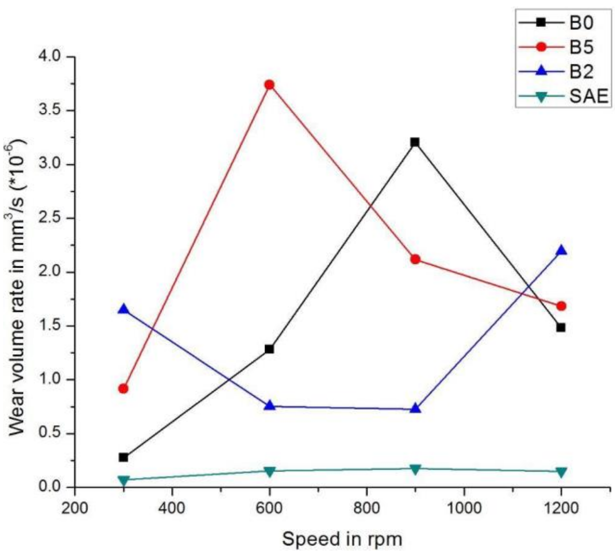


Fig 5. Wear volume rate variation with speed.

The Fig. 5 clearly states that SAE 20W40 showed substantially less wear rate, and also, the amount of wear volume rate remains nearly constant at almost all the speeds. Thus, it can be concluded that the wear volume rate in the case of SAE 20W40 is independent of speed. There is no definite trend of wear volume rate with speed. It can be noted that the highest wear volume rate is observed for B5 is at 600 rpm and for B0 is at 900 rpm. It is interesting to note that not even a single peak wear rate is observed with B2. It is obvious that at higher speeds, all the blends under consideration are showing a reduced wear volume rate. At lower speed, it can be hypothesized that a stable lubricant film is maintained and at some threshold speed, there is the removal of material at a higher rate, and again when the speed increases, the asperity contact decreases, so the oil flows in between the two contacting surfaces thereby preventing material removal. It was concluded by Spânu et al. about the speed and wear volume rate variation in a similar manner [32]. Thus, it can be scrutinized that B2 blends work similar to SAE 20 W 40, and further characterization can comprehensively diminish the wear volume rate.

3.4. Effect of vibrations

The vibration performance of all other blends is depicted by considering the SAE20W40 oil as the benchmark with all speed variations. Figure 6 represents the frequency versus acceleration graph at 1200 rpm.

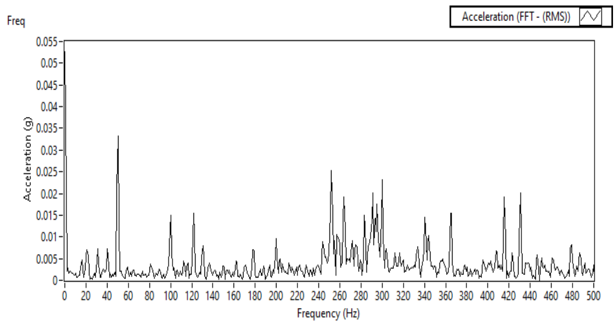


Fig 6. Acceleration vs frequency graph for SAE 20W40.

The present study makes a thorough comparison of vibration performance by considering pure castor oil also at 1200 rpm. The graph pertaining to pure castor oil is portrayed in Fig. 7.

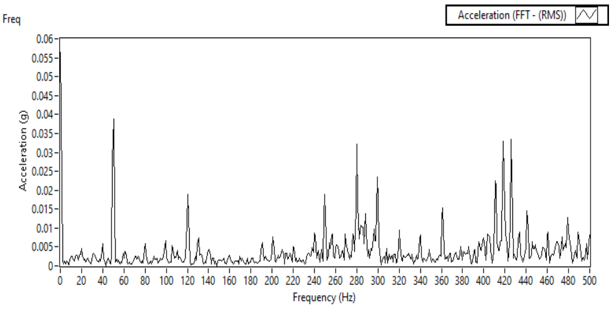
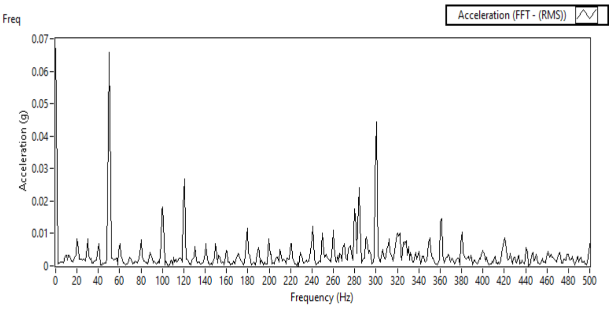
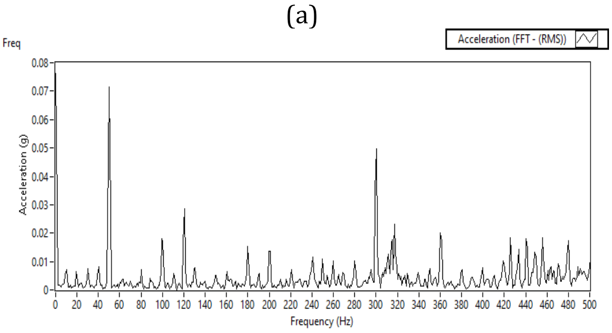


Fig 7. Acceleration vs frequency graph for pure Castor oil.

The vibrations that are encountered in the four- ball tester is of minute level. To evaluate its effect on material removal, the accelerometer is utilized. Two kinds of readings are noted to demonstrate the tribo-dynamic evaluation of different oil blends. Initial reading is obtained after 10 seconds, and another reading was taken at the end of the test at 60 min as it was noteworthy to emphasize that COF increases abruptly at the initial stage. To capture that effect, readings have been taken at 10sec. The average COF settles at the end of the 1hour test. To elucidate that effect, reading is taken at the time just before the end of the test. It was noted that the vibrations have a greater influence on the lubrication behaviour of the blend of oils. The graphs pertaining to 1200 rpm and 75^{0}C of B2, B5 is rendered in Fig. 8. The prime reason for selecting two blends is that B5 and B2 are the blends with extremely less COF and wear rate. So, to comprehensively evaluate the effect of vibration on better blends, these studies are rendered.



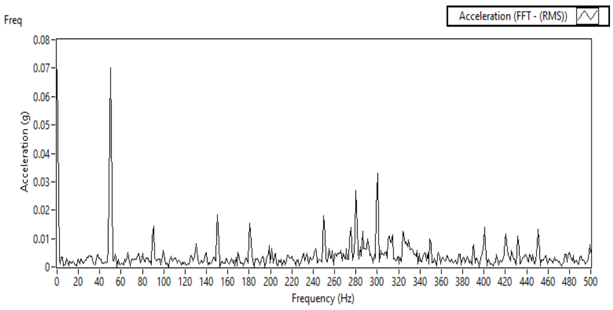
(a)



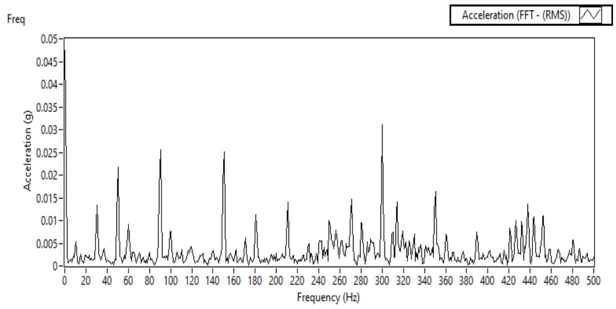
(b)

Fig 8. (a) Vibration plots B5 blend, (b) Vibration plots of B2 blend.

From the graph (Fig. 8), it can be interpreted that the peak amplitude is visualized at 50 Hz in both blend samples. Initially, an extreme peak is obtained, which can be attributed to the fact that when the sudden load falls, extreme frictional torque is generated due to which sudden contact of the component occurs. Thus, generated vibrations generated result in abrupt material removal, making the ball surface rougher. The more comprehensive model was proposed by researchers, which claims that whenever there is a relative motion, it would result in the displacement of the natural frequencies in tangential and normal directions towards each other, at the point called Hopf bifurcation point, where both the frequencies become equal. The static equilibrium point becomes completely unstable, and it would result in oscillations, these oscillations result in the material removal [32]. As this point of Hopf bifurcation appears at 50Hz, the peak of acceleration amplitude is seen at this frequency and later it reaches an almost steady- state and lesser material removal takes place. Thus, it can be emphasized that the material removal rate is high initially and, later, it goes on decreasing. Figure 9 depicts the variation of peak acceleration at different stages of the wear preventive test for a B5 blend at 900 rpm. As most of the vibration is seen in the initial stage of the test where the unsteady state of wear is seen, the comparative study as depicted in Fig. 10 is done by taking peak acceleration at 10 seconds after the initiation of the test. The steady-state wear is attained after a certain span of time during the test. It is pertinent from Fig. 9(a) that the peak acceleration amplitude is very high of the order of 0.07g, initially, at 10 seconds of the test, and it diminishes to 0.022g at the end of the test as depicted by Fig 9(b).

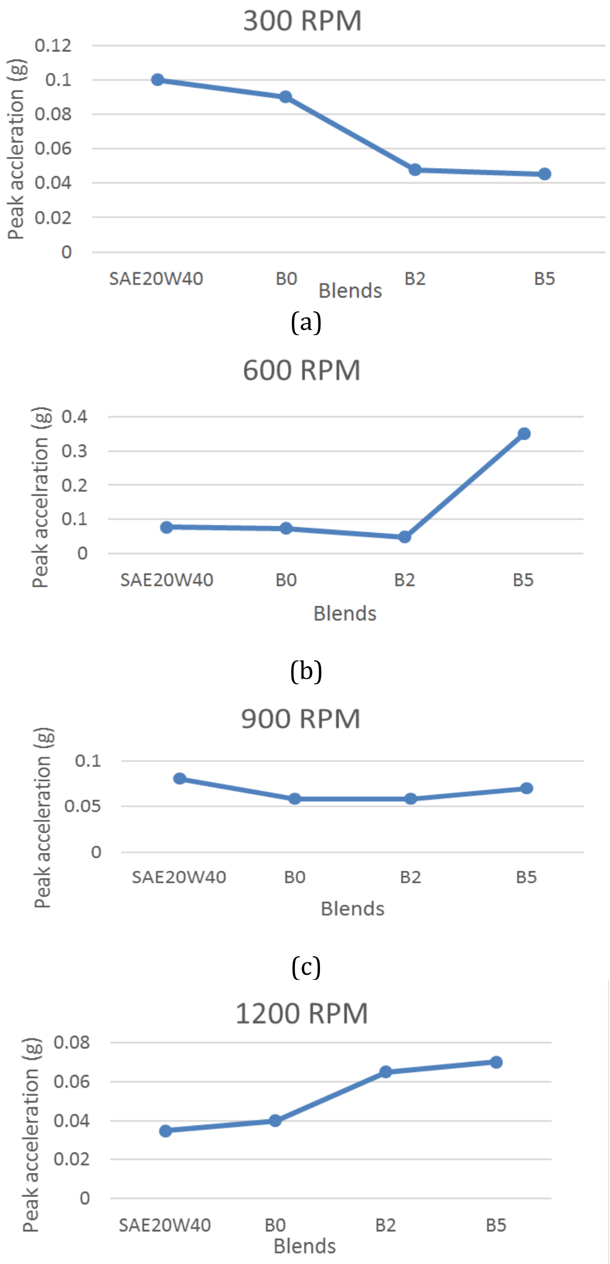


(a)



(b)

Fig 9. Attainment of steady state at (a) Initiation of the test, (b) End of the test.



(d)

Fig 10. Variation of amplitude peaks at 50 Hz withoil blends at 1200, 900, 600 and 300 rpm respectively after 10s test

It can be noted from Fig. 10(a) that B0 is having a lesser amplitude at 50 Hz peak with 1200 rpm when compared with the other blends. It is clear that the amplitude of peak acceleration raised with an increase in mahua oil concentration. The standard oil SAE 20W40 showed the least peak acceleration of around 0.032 at 1200 rpm after 10 s of initial experimentation. The COF trend showed the least value for the B5 blend and increased for B2 and B0, and increment of the value for SAE oil. At 900rpm, B0 and B2 portrayed the least acceleration peak of 0.058g when compared with the B5 blend. In addition to this, SAE standard oil ensued an elevated peak acceleration value. Fig. 10(b) depicts the variation at 900 rpm. At the reduced speed of 600 rpm, the B2 blend gave a diminished peak acceleration of 0.0475, whereas this value was around 0.35 for the B5 blend. Running the test at 300 rpm showed a least acceleration peak for B5 oil and value for SAE oil. Fig. 10(c) and 10(d) respectively portray the changes in the trend of peak acceleration at 600 rpm and 300 rpm.

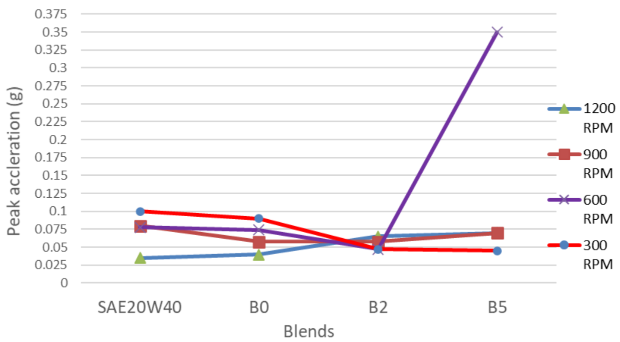
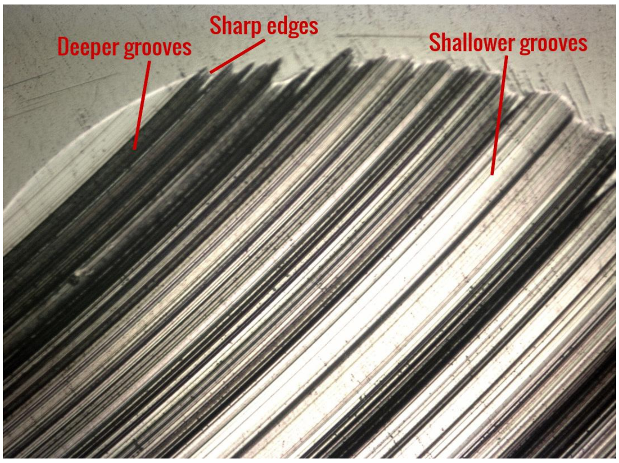


Fig 11. Comparison of blend oils with SAE oil at different speeds.

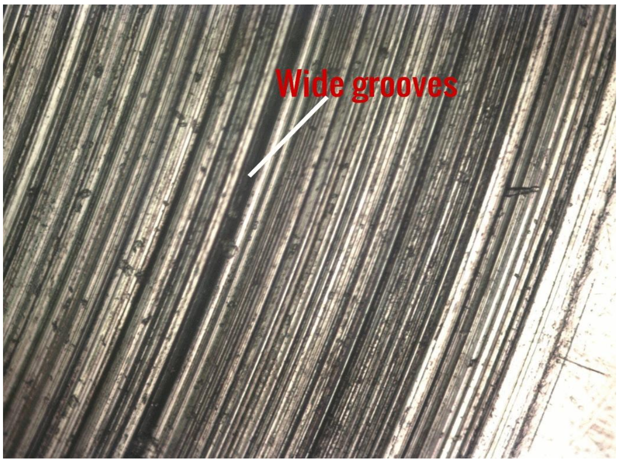
In Fig. 11, the above results are piled up to clearly understand the vibration behaviour of the blends as compared to SAE oil with the variation of speeds. It is pertinent to note that the SAE standard oil at 1200 rpm gave the best result by showing the lowest acceleration peak of 0.032g. B0 came up with the lowest acceleration peak at 900 rpm. Similarly, B2 and B5 gave the best results at 600 rpm and 300 rpm, respectively. It can also be noted that the B5 blend followed an unexpected unsteady behaviour by showing a peak acceleration of 0.35g at 600 rpm. The values of wear volume rate and the friction coefficients are also higher for this blend at this speed. This is due the fact that, the application of this blend at 600 rpm gave the rougher surface under the running condition. A similar trend is seen for SAE oil, at 900 rpm. It can be attributed that the higher the concentration of castor oil with mahua oil, the viscosity of oils decreases. As a result of this, the number of shearing layers decreases. This would result in the contact of the rotating top ball and the shearing layers of the oils, and also bottom ball would directly come in contact with the top ball. The relative motion would cause vibrations, and the amplitude of vibration peaks uplifts abruptly.

3.5 Surface topography of steel balls

It is crucial to investigate the surface morphological characteristics of steel balls to determine the wear that occurred during the experimentation. Optical micrographs that are obtained from an optical microscope which is coupled to the four-ball tester, is utilized to depict the surface morphology of steel balls. All the steel balls, including the top rotating ball that are involved in the testing, are checked with wear scar using the aforementioned equipment. The top rotating ball with an annular wear track is subjected to the highest wear, close to thrice of that of bottom stationary balls. This is visualized on all oil sample tested balls. Fig. 12(a) depicts the deeper and shallower grooves with bright and dark colour contrast. It can be depicted that deeper grooves and shallow grooves are the characteristics of abrasive wear, as concluded by Suresha et al. [33]. These are also visualized in all oil samples and one with better picture quality is depicted here. The surface of the top ball as seen in fig. 12(b) has with deeper and wider grooves when compared to bottom balls. The sharper edges of the stationary balls correspond to the fact that whenever the top ball and stationary balls come in contact with each other, there would be a material removal taking place. This removed particle further circulates back to the interface of the balls; this would result in the three-body abrasion, which is practically inevitable. Ing et al. affirmed the reason for the formation of the sharper edges [34]. The formation of pits is another noteworthy outcome from the surface study of the balls. It was noticed that at lower speeds, pits are formed. The supreme reason for the formation of the pits is that at lower speed, the top ball contacts only confined contact area due to which larger material removal takes place in the specific location, due to which pits are formed. Fig. 12(c) renders the pits formed in the balls. The other reason for the formation of the pits is that, as bio-based oils have lower oxidative stability when the part of the oil is exposed to oxygen, the hydroperoxide group directly attacks the steel material, thereby causing the formation of pits [35,36]. Also, premature fatigue combined with adhesive wear due to temporary load variations can be considered for another reason for the formation of pits. Thus, it can be stated that excessive material removal is seen in blends in comparison to that resulted when using SAE20W40 oil.



(a)



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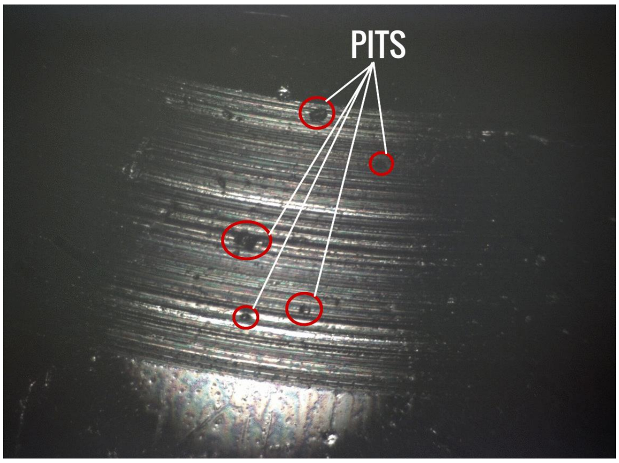

(c)

Fig. 12 (a) Formation of deeper and shallower grooves along with sharp edges in stationary balls, (b) Deeper and wider grooves in top rotating ball, (c) Pits formation.

4. CONCLUSIONS

The present work is mainly intended to comprehensively depict the tribological performance of mahua-castor blends. The key outcomes are the followings.

- The better miscibility and negligible density difference of mahua and castor oils are the key advantage for the formulation of a better oil blend.
- The formulation of oil samples with magnetic stirring showcased better dispersion stability and longer shelf life. The enhanced shelf life of the oil samples can be attributed to the effective mixing mechanism inculcated with magnetic stirring.
- The reduced COF is the main criterion for evaluating the applicability of a better blend in this study as the main outcome from the testing equipment is COF. From values of the COF, it can be deduced that there is not much variation in the COF, when testing the blends under consideration4. Utilization of any blend with suitable additives could yield to comprehensive results.
- B2 and B5 blends, which exhibit a better COF (lower and stable) were further considered for speed variation tests. It is imperative to note that, with the increase in speed, the COF decreased as a result of fewer asperities asperity contact of steel balls due to fully film lubrication regime.
- SAE20W40 showed a significantly lower wear volume rate of stationary balls in comparison to all other blends. B5 and B0 samples depicted the threshold value of speed where high wear volume rate is obtained. B2 sample showed promising results with reduced wear volume rate noted on balls.
- The accelerometer equipment used in the current inquiry demonstrated the effect of vibrations on material removal and the effect of peak values on severe material removal.
- The presence of grooves in the surface morphology of steel balls illustrates the fact that abrasive wear is more predominant in four-ball tester. The formation of pits is mainly due to the hydroperoxide group attacking the surface of the ball and also the local adhesive wear due to temporary load variations.
- It is also obvious to note that, from the present study B2 is the potential oil blend that may replace the existing synthetic oil.
- Furthermore, incorporation of additives to obtain better blends would comprehensively challenge to replace synthetic oil.

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