WEAR AND TEAR ANALYSIS OF CI ENGINE METAL COMPONENTS USING BIODIESEL

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Abstract: After the invention of the internal combustion engine, the major problem has been observed that the consumption of fossil fuel is increasing day by day. Study says that bio fuel can be the best partial replacement of fossil fuel but too many analyses are required like efficiency, emissions, wear etc. This study investigates the best bio fuel in terms of wear, for that tribological analysis is the method used to ascertain the wear rate/ratio of the material. To analyses the problem, Pin-on-Disc experiment was carried out in which disc made up of hardened Steel EN 31 material as per ASTM G99-95a and Pin material of Copper, Iron & Aluminum metal which plays a major role in the manufacturing of engine components. In this experiment bio fuel performed well compare to diesel which can be concluded by analyzing the wear rate, friction force, coefficient of friction, weight loss and microscopic analysis.

IndexTerms - Pin – on – Disc, Biodiesel, Wear, CoF

1.Introduction

World's demand for energy has been protruding to two times by 2050 and be more than three times by the end of the century. The human consumption of fossil fuels leads to the growing causes of international concern and agitation among some industrial nations. The reasons for which can be attributed to the rapidly consume of fossil fuels. For mainly this reason, biodiesel can be used as an alternative fuel. Biodiesel fuels have many advantages over petroleum diesel fuel, they produce less smoke and particles like NO_x & SO_x and have higher cetane number. They produce low hydrocarbon and carbon monoxide emissions and are biodegradable, non-toxic and renewable. The dynamic viscosity of vegetable oil is very much high to be directly used as diesel, so it required extraction of glycerin this process called transesterification. The flash point 52°C as specified in ASTM D975 of biodiesel makes possible its easy storage and transportation. It should be noted that the flash point of petroleum diesel fuel is vary between 52 °C and 96 °C (126°F and 205 °F) is suitable for use in a CI engine. The control of wear in movable parts of the engine is a major problem. To reduce friction, wear and heating of the engine, lubrication is used.

There are five forms of lubrications which can be categorized as follows:

A. Hydrodynamic lubrication
B. Hydrostatic lubrication
C. Elasto Hydrodynamic lubrication
D. Boundary lubrication
E. Solid film lubrication

Among these five-lubrication systems the most occurrence is seen for Hydrodynamic lubrication. In Hydrodynamic lubrication, the surface of the Pin and disc are separated by a relatively thick film of lubricant. This is used to prevent the collision of two metals. The film pressure is created by the moving surface forcing the lubricant into a wedge-shaped zone, therefore creating a pressure that separates the sliding surfaces. The Pin-on-Disc device is the most commonly used equipment in Tribology. This Tribometer serves for the investigation and stimulation of friction and wear processed under sliding condition. In the Pin-on-Disc, one part of the Pin is steady while the other part is rotating. So, in the initial stage the boundary lubrication is formed and gradually the hydrodynamic lubrication is produced. It has been observed by various Researches that the deviation of friction depends on interfacial conditions such as normal load, geometric surface, relative surface, motion, sliding velocity, surface roughness of furnishing surfaces, types of materials, system rigidity, temperature, humidity, lubrication and vibration. Among these factors normal load and sliding velocity are the major factors that play a significant role in variation of wear and friction.

2. Experimental methodology

This section describes the selection of biodiesel and selection of metal pins based on fatty acid compositions and percentage of metal alloy used in engine.

2.1 Selection of biodiesel

Despite of the proof that biodiesel can be the best replacement of mineral diesel and can overcome the thrust of current diesel engine, it is difficult to select the best biodiesel and hence, based on the availability, it's fatty acid content, it's oxidation stability and detailed analysis related to its physical and chemical properties are required. For the analysis of this, four selective biodiesels have been chosen pertaining to the criteria as per the Indian climate. For the recognition of the physical and chemical properties test has been performed in all the three fuels as mentioned in Table 1 and has been compared with this a correlation between lubricative and corrosive nature of biodiesel can be identified.

Table1: Fatty acid and Physical-chemical properties of biodiesel oils

Fatty acid composition (%)	Palm Oil	Rapeseed Oil	Jatropha Oil
Caprylic C8:0	3.3	-	-
Capric C10:0	3.4	0.01	-
Lauric C12:0	0.45	-	0.05
Myristic C14:0	1.21	0.2	1.3
Palmitic C16:0	47.8	4.9	15.5
Palmitoleic 16:1	0.6	0.21	0.7
Stearic C18:0	4.21	2	9.8
Oleic C18:1	36.8	62.8	41.1
Linoleic C18:2	9.09	19.4	32.6
Linolenic C18:3	0.28	8.9	0.2
Ricinoleic 18:1: OH	-	-	-
Arachidic C20:0	1	1.9	0.5
Gondoic C20:1	0.4	15	0.46
Behenic C22:0	0.2	2	3.62
Erucic C22:1	-	1.2	-
Lignoceric C24:0	-	2	0.11
Viscosity at 40°C (mm2/s)	40	34.7	34.9
Density(×10^3kg/m3)	0.92	0.920	0.919
Flash Point (°C)	270	321	190
Pour Point (°C)	14.8	-14.8	2.1
Cold filter plugging point(°C)	11.7	-12.8	–
Viscosity index	–	220	195.22
Cetane number	54.8	54.21	52.2
Calorific value (Mj/kg)	39.44	36.8	39.34
Acid number (mg KOH/g)	0.23	-	0.38
Sulphur (ppm) / % m/m	0.0028	-	1.3
Oxidation stability (hours)	10.21	7.48	3.17

2.2 Selection of Metal pins

Table 2: Elementary Analysis of CI Engine Components

	Components of CI Engine					
Elements (%)	Cylinder Liner	Exhaust Valve	Inlet Valve	Piston Ring	Piston	Connecting Rod Bearing
Zn	0.015	-	-	0.014	0.63	0.014
Cr	17.02	0.042	0.042	19.11	0.016	16.94
Ni	11.05	0.044	0.044	9.06	0.66	10.95
Fe	68.74	93.7	93.7	68.77	0.93	68.99
Cu	0.013	0.47	0.47	0.0119	1.58	0.018
Mg	0.02	-	-	0.0083	0.49	0.013
Co	0.018	-	-	0.0032	-	0.02
Al	0.023	-	-	0.0016	82.23	0.02
Mn	2.022	0.56	0.56	2.1	0.10	1.83

An engine is made up mainly of various components which are made up from metal alloys like cast iron, aluminium, brass, copper and bronze. In the initial stage of tribo-wear test based on the elementary analysis of actual engine components three metals for the pin has been selected and for disc hardened steel material as per ASTM G99-95a has been selected. The pins have a size of 25 mm in length & 8 mm in diameter & disc having diameter and thickness of 175 mm & 10 mm, the disc and metal pins compositions are mentioned in ASTM G99-95a and Table 3 respectively. After the pin material selection, the pin has been produced which were machined and polished and later these pins we're degreased using xylene-isopropanol mixture (1:1). This was weighed to an accuracy of 0.1 mg before flaunting in various synthesized biodiesel and commercial mineral diesel. The characteristics of the inter laboratory wear test Specimens for disc as per ASTM G99-95a and elemental composition of pins in Figure 1.

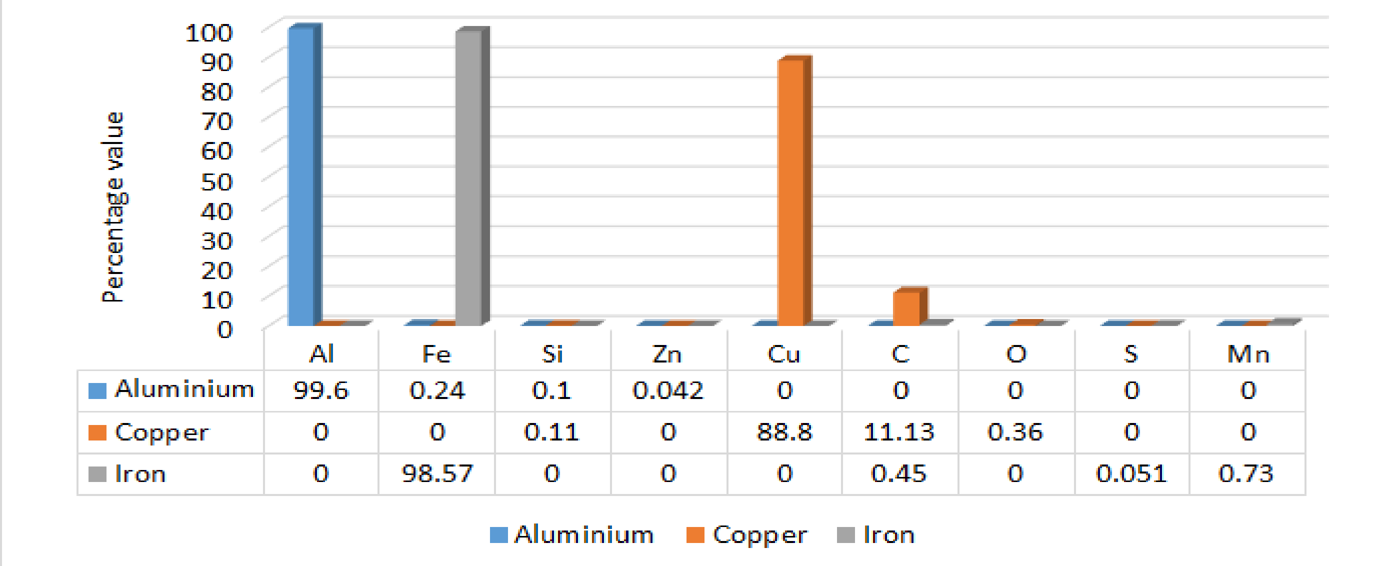


Fig. 1: Metal compositions of metal pin

3. Test Methodology

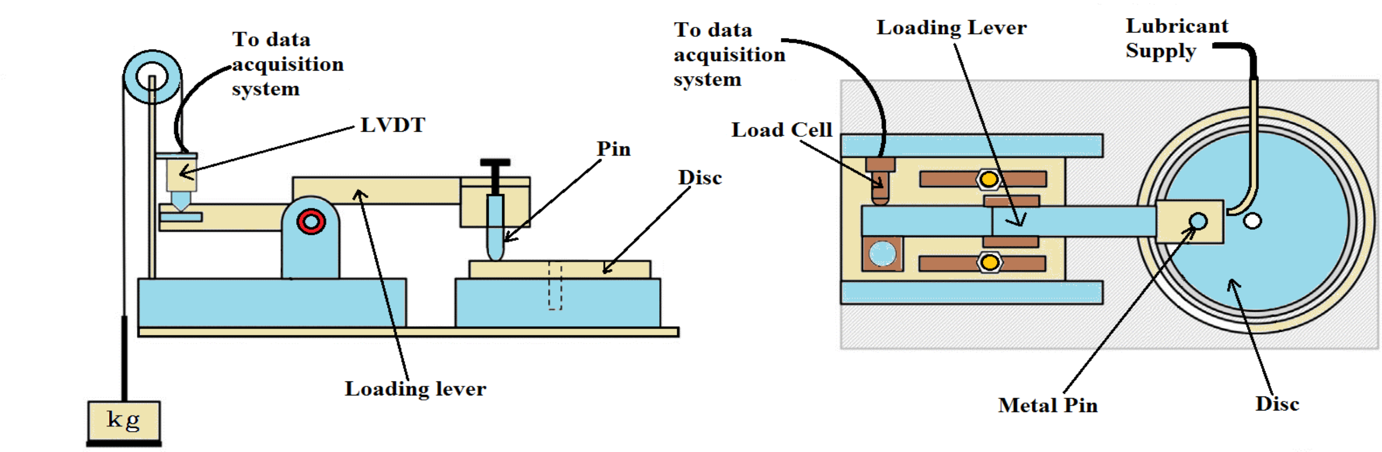


Fig. 2: Line diagram of Pin on disc apparatus

Now, to characterize the frictional properties Friction tests are carried out under pure sliding motion according to ASTM G99-95a standard with respect to the four oils Diesel, Palm, Rapeseed, Jatropha. The test is performed using a Tribometer configured for a pin-on-disc setup as shown in Figure 1. In this process, a wear disc fabricated from EN31 steel is rotated against a steady metal pin. The metal pin with radius 4mm and the wear disc are grinded to a surface roughness, R_a of 0.12 μm and R_z 0.96 μm. Prior to performing the friction test, the pin and wear disc are cleaned using xylene and then kept to dry in the room temperature. This has to be performed to remove the residuals of fluids from tools at the time of machining process. The friction test is conducted at room temperature condition (20-30°C). During the test, the pin and wear disc are kept to a constant normal load of 40 N with wear disc rotational speed, wear tracking diameter, corresponding to wear disc linear sliding velocity as mentioned in Table 3. A lubricated run-in test is conducted at different rotational speed, track diameter respect to each metal pin with a constant load of 40 N normal load in order to lower initial high surface peaks separated by deep valleys and a constant sliding speed of 5.5 m/s. With the help of this process, the contact surface lubrication is moved from elasto-hydrodynamic to mixed and then finally to boundary lubrication. During the time of this test, the tested lubricant is constantly supplied which is approximately 0.250 liter/min to the pin-disc contact wear track through a pump for sufficient lubricated connection. This helps to avoid the deprivation of lubricant that higher friction, lacking of the incites lubricant for the contact conjunction at higher rotational speeds.

Table 3: wear disc rotational speed, wear track diameter

Track Diameter	**RPM**	**Tip Velocity (m/s)**	**Lubricant Flow Rate liter/Min**	**Pin Metal**	**Metal Density g/cm^3**	**Pin (L& D)**	**Load (N)**	**Sliding Distance (m)**
115 mm	913	5.5	0.250	Aluminum	2.7	25 & 8	40	10000
125 mm	840			Copper	8.94			
135 mm	778			Iron	7.87			

3.1. Pin weight & volume loss analysis:

For the determination of weight reduction & volume reduction, earlier and later tribo-wear tests are carried out. Prior to this test, the metals are cleaned to remove all the residuals & deposits and then the pins are examined to acquire the component's weight with an accuracy level of three digits after decimal so that even a small change in weight can be jotted down and this test is conducted with weighing machine available at NABL laboratory. The volume reduction has been obtained by equation 1, provided by the ASTM standard.

$$Volume\ Loss\left(mm^3\right) = \frac{Before\ weight\ (g) - After\ weight\ (g)}{Metal\ Density\ (g/cm^3)} \times 10^{-3} \ldots\ldots (1)$$

3.2. Microscopic Examination:

Microscopic examination is carried out to study the micro-structural features of the metals. It is important to determine the properties of material which shows the capability of performance under a given application and this is conducted by SEM (Scanning Electron Microscope) Analysis. It is a type of Microscope that scans a focused electron beam over a surface to create an image. The electrons in the beam interact with the sample, producing various signals that can be used to obtain information about the surface topography and composition. SEM can achieve resolution better than 1 nanometre. Specimens are examined in high vacuum in conventional SEM, or in a low vacuum or wet conditions in variable pressure or environmental SEM, and at a wide range of cryogenic or deviated temperatures with specialized instruments.

4. Result and Discussion

In the current section results obtained during the tribowear test has been discussed which includes the wear, friction force and coefficient of friction.

4.1 Wear, Friction force and Coefficient of friction analysis

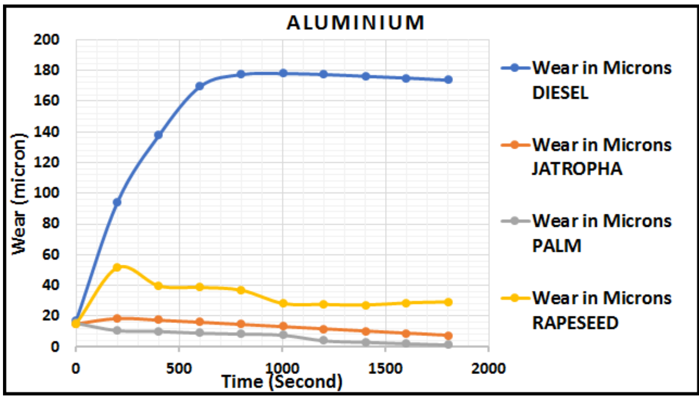


Fig. 3(a)

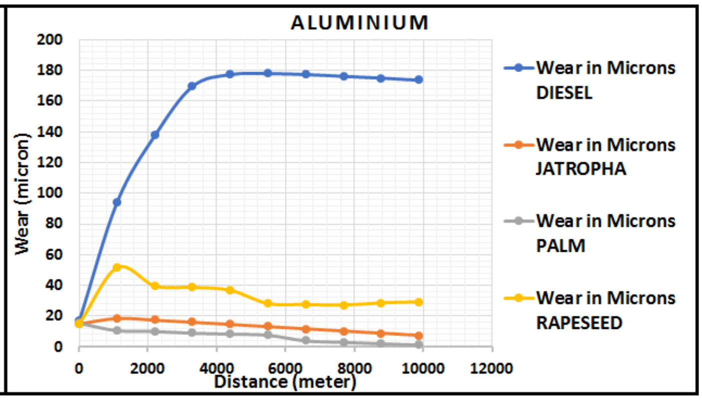


Fig. 3(b)

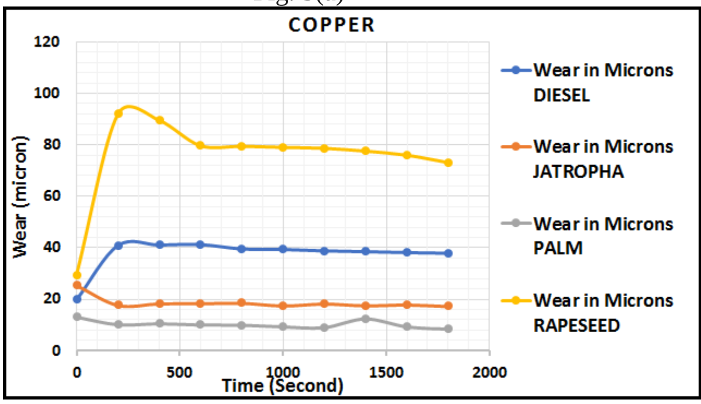


Fig. 3(c)

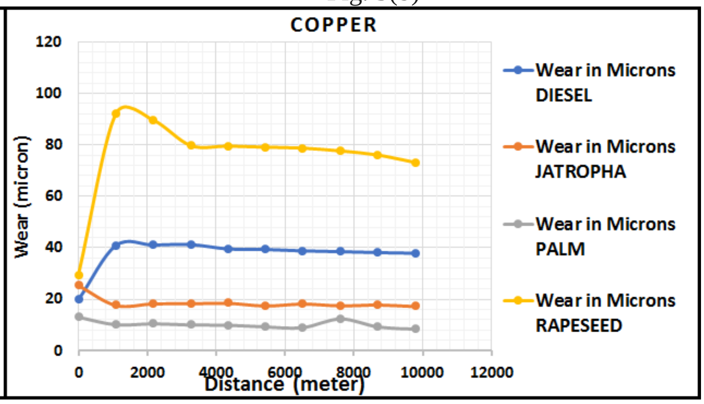


Fig. 3(d)

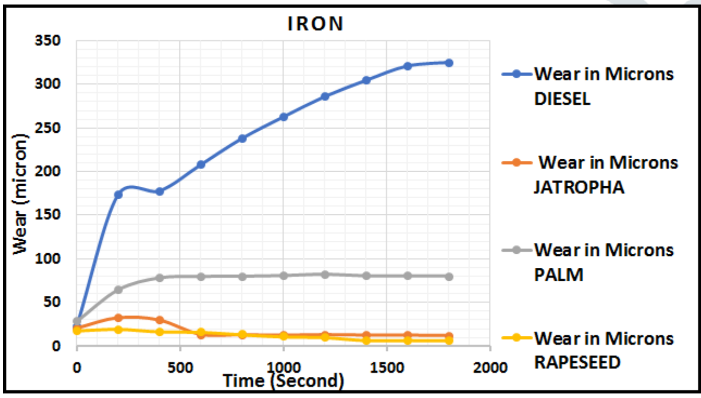


Fig. 3(e)

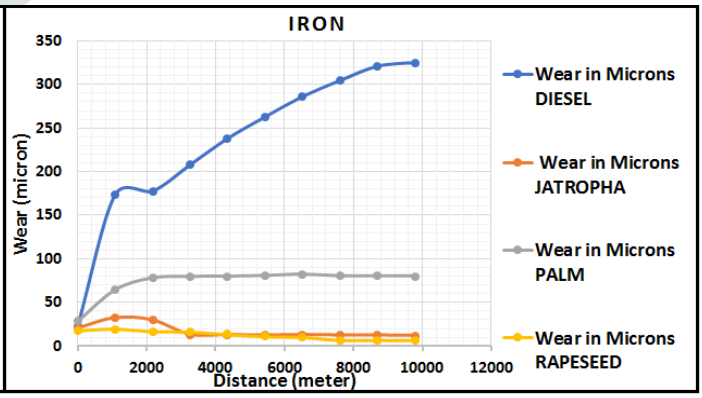


Fig. 3(f)

Fig. 3 Metal pin wear vs time (3a, 3c & 3e) and metal pin wear vs distance (3b, 3d & 3f)

The experiment has been done under the constant velocity of 5.5 m/s under wet lubrication, maintaining constant oil flow of 0.250 liter per minute. In Fig 3 it can be seen that in almost all the above-mentioned cases the trend of wear has increased drastically till 1000 m of pin travelling distance, after that the wear has increased in linear manner in the case of iron and copper. There is a shift of drastic wear increase with respect to travelling distance in the case of aluminum pin having a value of 3000 m. It can be observed from the figure that with the diesel as a lubricant the wear is found to be very huge in compare to biodiesels. The probable reason behind this is due to absence of fatty acid and self-lubricating properties in diesel. Palm biodiesel has shown lowest wear with aluminum and copper pins and in the case of iron pin rapeseed-based biodiesel has shown lowest wear. Trend of wear about aluminum and it can be clearly observed that the least wear found in Palm oil which was started from 10.86 micron and decreased till 1.5 micron. This trend is followed by Jatropha which was 18.76 microns in starting but decreased and stopped on 7.4 microns. The massive wear found in Diesel which was started from 17.22 microns but because of bad lubrication property it increased gradually up to 178 microns.

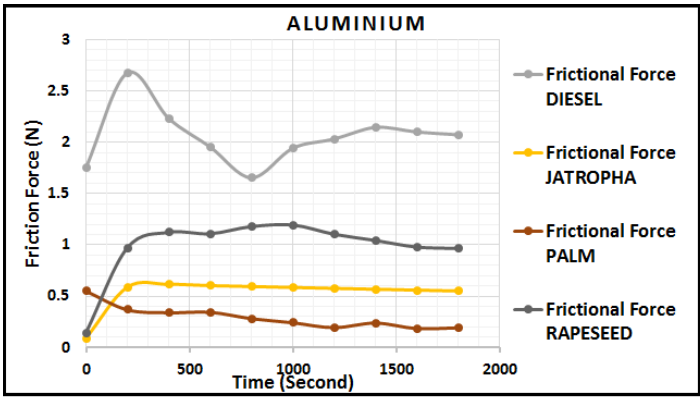


Fig. 4(a)

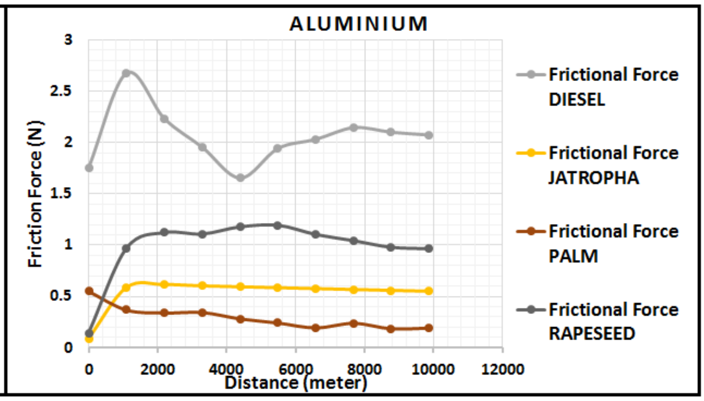


Fig. 4(b)

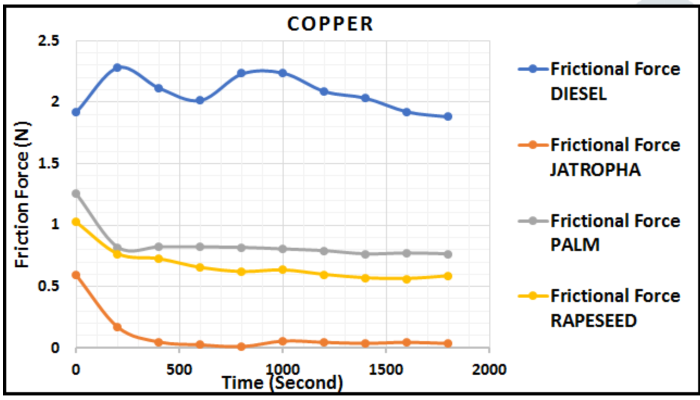


Fig. 4(c)

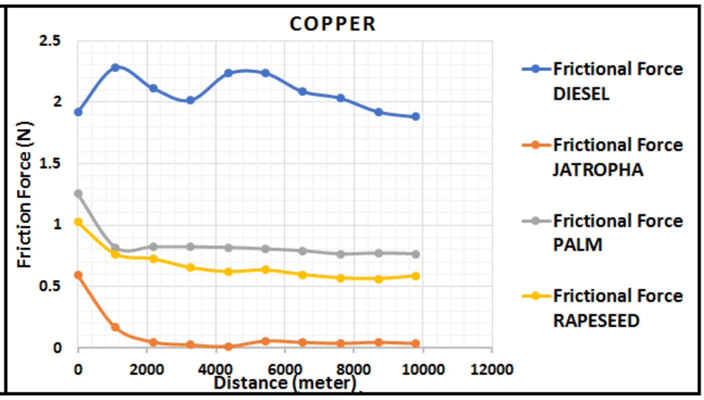


Fig. 4(d)

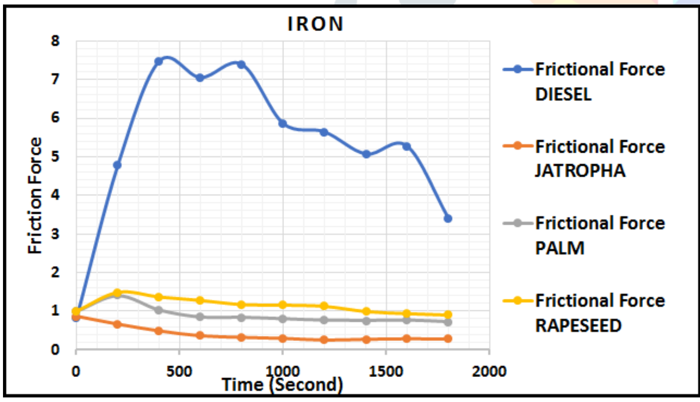


Fig. 4(e)

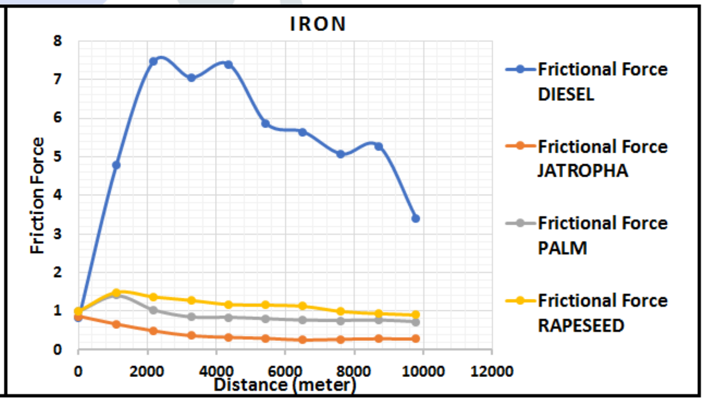


Fig. 4(f)

Fig. 4 Metal pin friction force vs time (4a, 4c & 4e) and metal pin friction force vs distance (4b, 4d & 4f)

Figure 4 shows the friction force of the metal pin with respect to the metal pins. From the figure it can be observed that with jatropha and palm-based biodiesel the friction force is found to be minimum. With diesel the friction force variation is quite high with respect to time and distance, in remaining biodiesel this trend is quite smooth and linear which shows biodiesel superior lubricating properties in compare to diesel. In case of aluminum pin throughout the experiment palm oil shows highest lubricating property by showing lowest friction force between pin and disc which was followed by jatropha oil then after rapeseed oil but highest friction force found in diesel. In case of copper pin lowest friction force found in jatropha oil which was followed by rapeseed oil and then after palm oil but like aluminum pin, highest friction force found in diesel. In case of Iron pin also lowest friction force found in jatropha oil which was followed by palm oil and then after rapeseed oil but similar to aluminium and copper pin highest friction force found in diesel.

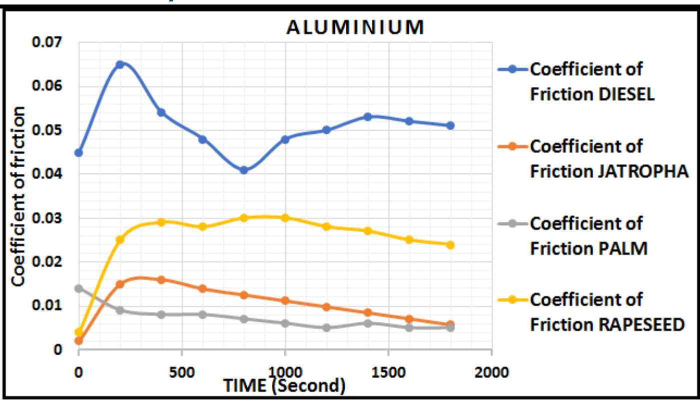


Fig. 5(a)

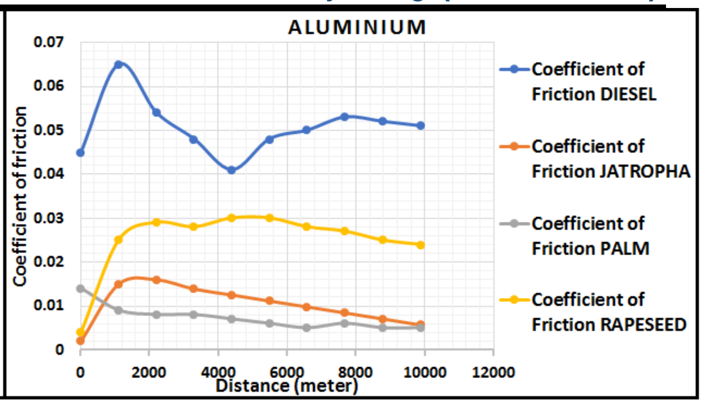


Fig. 5(a)

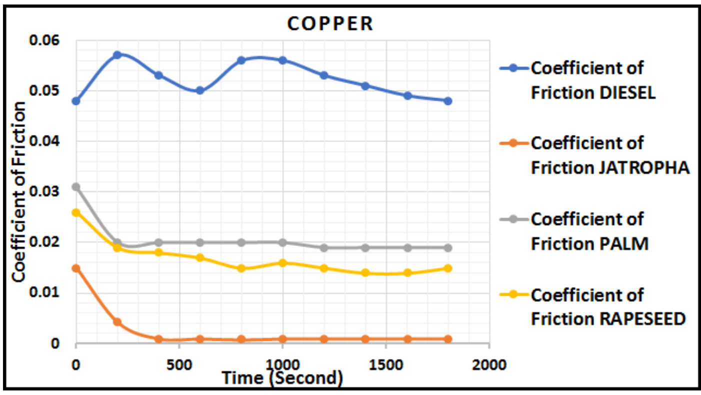


Fig. 5(c)

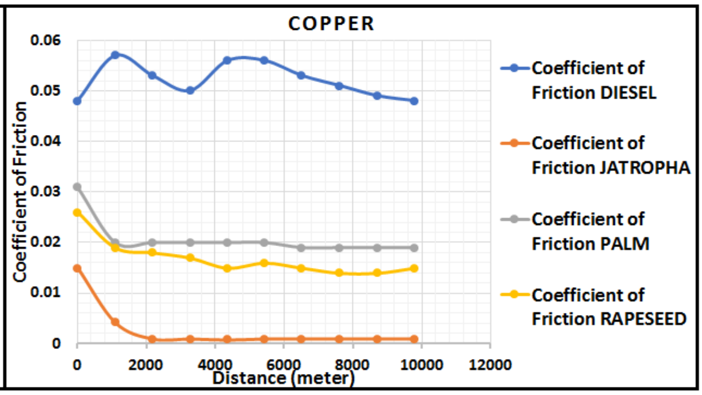
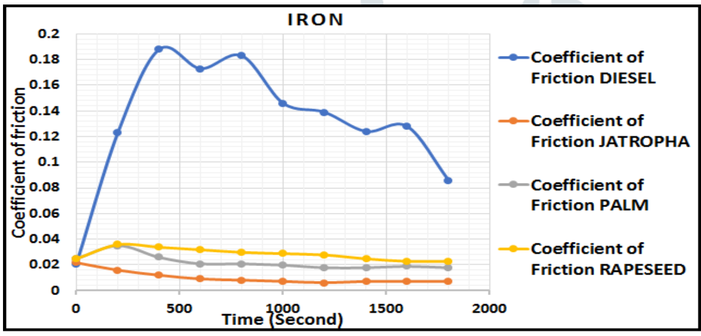


Fig. 5(d)



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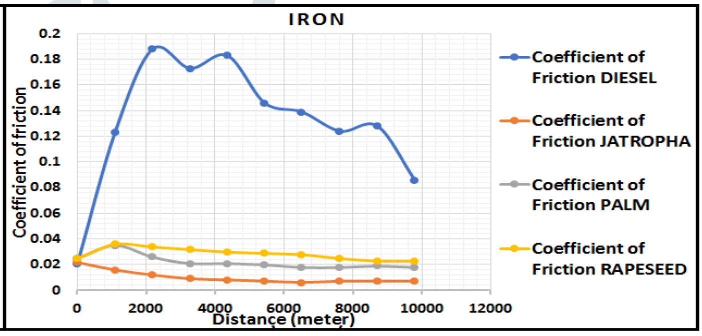

Fig. 5(f)

Fig 5. Metal pin CoF vs time (5a, 5c & 5e) and metal pin CoF vs distance (5b, 5d & 5f)

Figure 5 shows the coefficient of friction generated between pin and disk during wet lubrication, from the figure it can be observed that as similar to the previous cases of friction force and wear the diesel shows highest CoF in compare to biodiesels. The probable reason behind this result is nothing but the absence of dissolved oxygen and the bond between hydrogen and oxygen in diesel. The CoF values of all the pin with respect to fuel are quite linear and smooth except diesel where a clear deviation of trend can be observed. Palm and rapeseed-based biodiesel shows lowest friction force in compare to all the fuels.

4.2 Weight loss analysis

Weight loss of metal pin between the starting and ending of tribo-wear test has been identified with the help of high precise weighting machine. From the table 4 it can be clearly observed that a massive loss in weight is found in pin made from iron with diesel, apart from this in almost all the cases a minor loss of metal can be detected, which ultimately reflects the self-lubricating properties of biodiesel in compare to diesel.

Table 4. Weight loss analysis of all metal pins

Metal	Oil	Initial weight (mg)	After weight (mg)	Weight loss (mg)
Aluminum	Diesel	32120	32109	11.00
	Rapeseed	32120	32119	1.00
	Jatropha	32120	32118	2.00
	Palm	32120	32118.2	1.80
Copper	Diesel	106352	106350	2.00
	Rapeseed	106352	106342	10.00
	Jatropha	106352	106351	1.00
	Palm	106352	106351.6	0.40
Iron	Diesel	93622.8	93521	101.80
	Rapeseed	93622.8	93622	0.80
	Jatropha	93622.8	93622	0.80
	Palm	93622.8	93616	6.80

4.2 Microscopic Analysis:

Microscopic analysis of any material is very crusial for the proper study of surface properties, for that the metal pins made from aluminium, copper and iron were examined under a scanning electron microscope at a magnification of 250 X as shown in Figure 6. During the observation it has been observed that due to friction between pin and disc abrasive, delemination and grooves types of wear are obtained. Diesel and palm are only focused due to considering diesel as our reference and palm as our lowest wear fuel, in which heavy abrasive wear and ploughing of metal surfaces with metal debris can be easely seen but in the case of palm the wear are almost negligable in compare to diesel which shows that Palm is effectively good in wear resistance property.

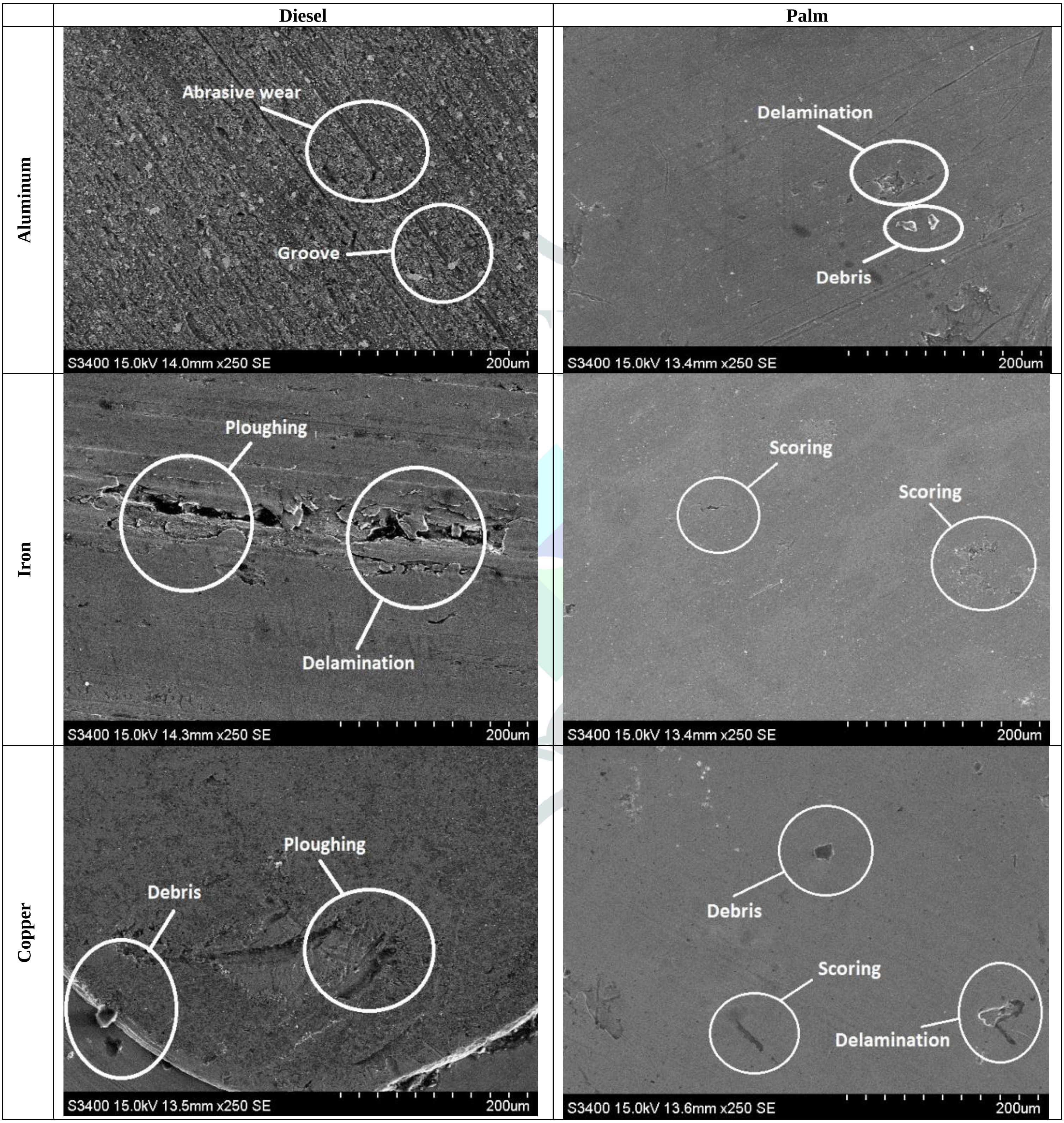

Fig. 6 Microscopic analysis of metal pins tip with diesel and palm.

8. Conclusion

The results of the current study have led to the following conclusions:

- The massive pin weight loss of around 102 mg was found in iron with diesel, almost in every case it has been observed that diesel has the lowest tendency towards lubrication except copper pin.
- Palm and Jatropha oil has shown lowest weight and volume loss in comparison to other fuels.
- The Palm and Jatropha oil shows lowest CoF and Friction Force values as compared to most of the cases, this is due to the presence of fatty acids which are responsible for enhancement of lubricity.
- The Palm and jatropha oil shows lowest wear as compared to all cases, this is because of the presence of thick hydrodynamic film provided by these.

Reference

1. Victor, V., Luiz, A., 2016, “Lubricated sliding wear of SAE 1045 and SAE52100 steel against alumina in the presence of biodiesel, diesel and a 50:50 blend of those fuels”
2. Hamdan, S., H., Chong, W., W., F., 2016, “A study of the tribological impact of biodiesel dilution on engine lubricant properties”
3. Anil, K., Pavani, P., 2017, “The Effect of Lubrication on Tribological Properties of Bearing Materials Using Pin on Disc” M. Anil Kumar, PNL Pavani
4. Hamdan, S., H., Chong, W., W., F., 2016, “Influence of fatty acid methyl ester composition on tribological properties of vegetable oils and duck fat derived biodiesel”
5. Kiran, D., Lalita, A., Manoj, H., 2015, “Testing of Wear Rate Frictional Force and Coefficient of Friction Computationally Using Pin on Disk”
6. Alessandro, R., Roberto, D., 2017, “Tribological Characterization of Vegetal Lubricants: Comparative Experimental investigation on Jatropha Curcas L. oil, Rapeseed Methyl Ester oil, Hydrotreated Rapeseed oil”