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Experimental Investigation of Tribo-Corrosive Nature of Biodiesel and its Effect on Lubricating System

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Abstract
The population of the world is growing very rapidly, which results in the increasing demand of energy in the transportation sector and a precipitous diminution in the reserve of fossil fuel. The lack of alternatives for fossil fuel and the vulnerabilities of the environment encouraged many researchers to investigate biodiesel as the most promising fuel. Biodiesel diminishes the major environmental concerns and also it will fulfil the demand energy conservation and fuel. The present investigation has been carried out to study the effect of multiple parameters governing the tribo-corrosion behaviour of aluminium in the presence of biodiesel. Experiments were conducted with three types of oil, taking bio-oil as a composition to find out the effect of corrosion in the aluminium faces. A test rig was fabricated taking ASTM standard to perform morphological analysis of the sample, and a pin-on-disc test rig is used to execute standard wear testing of it. Localised melting was observed during the experiment for the last 30 s when a load was of 20 N at a speed of 4.2 m/s in the absence of any lubrication. But in the presence of lubrication, no such melting was observed due to lesser friction and whatever frictional heat generated was taken away by the contacting fluid. Further, the experimental study concludes that the corrosion rate was found much more in vapours as compared to the condition where samples are entirely immersed in biodiesel. Hence synergism of wear, friction, and corrosion related to this experimental study plays a vital role in the performance of biodiesel.

Keywords Tribo-corrosion · Biodiesel · Aluminium material · Wear · Friction

1 Introduction

The study of relative motion between the surfaces over one another is known as tribology. It generally includes three fundamental areas, such as friction, wear, and lubrication. Friction is describing as the resistance to relative motion due to which the loss of material, i.e. wear, will occur in mating parts. To diminish friction and wear, lubrication is required in the form of liquid and solid. The analysis of material consumption-related issues (in case of tribo-corrosive study) is necessary for developing a thorough understanding of the collective and individualised behaviour of corrosion and tribology with their simultaneous interactions to determine the level of wear and tear due to various tribological factors. Corrosion is a natural phenomenon that turns refined metals into more stable chemical forms, such as sulphides, oxides, or hydroxides. This literature review provides a brief overview of the work done by various researchers in different parts of the tribo-corrosion. Special attention is specified to the effects of diesel which is trading and biodiesel. Special attention is specified to the impact of corrosive wear and tribological characteristic on numerous engineering equipment of commercial diesel and biodiesel. This dissertation summarises the following works of literature that can add specific value.

Biodiesel acts as an ideal alternative to diesel for diesel engines, as a result of its ability to perform alternative functions, replacing growing energy demand. Biodiesel is extracted from renewable resources, and it also has a lower emission rate which makes it more eco-friendly than fossil fuel. The present study focuses on the tribo-corrosion behaviour of proposed material under the biodiesel environment. Tribo-corrosion involves two significant fields of science, i.e. tribology and corrosion, so the present research is focused on studying the various factors effecting on proposed material

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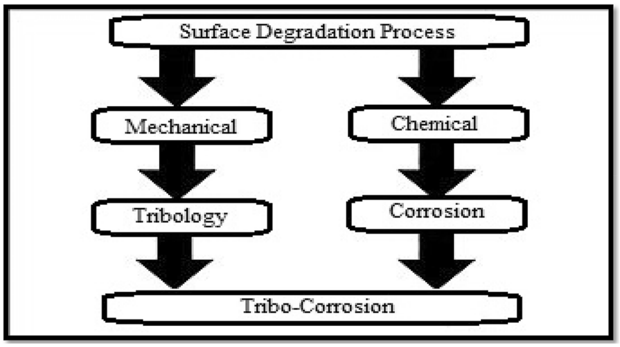


Fig. 1 Basic definition of tribo-corrosion

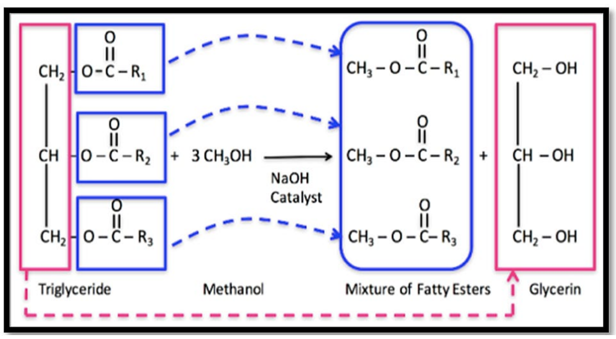


Fig. 2 Chemical process for the production of biodiesel [5]

under biodiesel environment from tribological and corrosion perspective considering a specific mahua biodiesel. In this particular study, an attempt was made to study the effect of various parameters like temperature and concentration of biodiesel in the blend on corrosive wear, considering biodiesel static immersion test which was performed for a duration of 24 days according to reference ASTM standards. Further systematic study was done to explore different tribological parameters with the help of pin-on-disc tribometer. The basic definition of tribo-corrosion is shown in Fig. 1.

Bajpai et al. and Hill et al. [1, 2] stated many of the benefits of replacing fossil fuels with biodiesel are made from vegetable oils or animal fats mostly through transesterification reaction, especially alkali-catalysed transesterification. The incomplete transesterification reaction leaves free fatty acids in biodiesel which induces the ability to absorb moisture (hygroscopic nature) in biodiesel and hence increases the corrosiveness of the fuel. Almost all biodiesels are made using base-catalysed transesterification because it is the most economical process that requires low temperature and low pressure and yields a conversion rate of 98%. The steps involved in producing methyl ester biodiesel are shown in Fig. 2. The reaction between alcohol and fat or oil is reversible. Due to that, the alcohol should be adjoined in excess to steer the response towards the right and also ensure that the conversion is completed. The final product of the above process is biodiesel which is glycerol. The familiar sources of biodiesel are presently under investigation, including soybean oil [3], linseed oil [4], *Jatropha curcas* [5], pongamiapinnata [6], madhucaindica (Mahua) [7], and palm oil [8].

Bora et al. [8] was delineating that mahua biodiesel is used as extra diesel. They found that mahua biodiesel assets within limits set by ASTMD6751-2 and IS 1448. The blending of diesel with mahua biodiesel is used to generate CO_2, CO, HC, and smoke; however, NOx emissions are significantly increased. As per experiment results, no significant reduction was observed in the engine when an engine was running a blend of diesel and biodiesel. It is noted that brake-specific fuel consumption has increased slightly and the thermal efficiency has decreased when the engine run at mahua biodiesel as compared to the pure diesel fuel. Fernandez et al. [9] proposed that the wine manufacture sector benefits from the production of biodiesel from winery waste. To conduct the accurate implementation, of 10–20% oil pleased in grape seed. Two processes, i.e. solvent extraction method and injection technique, are used to develop the oil extraction from grape seeds. Both processes are compared and concluded that the process of extraction of solvents is better because when mixed with polar and non-polar solvents, generate oil with excellent oxidation stability and even more fuel provide. The conversion of this oil to methanol and ethanol-induced good biodiesel, but ethyl esters exhibited an uncommon flow in nature compared to methyl esters. Haseeb et al. [10] deliberate copper and bronze corrosion rate at room temperature and 60 °C. For both metals, an increase in corrosion rate was observed with an increase in concentrations in the blend. It turns out that biodiesel produces more corrosion than diesel fuel. For diesel and biodiesel, the corrosion rate of each metal was more than 60 °C relative to room temperature. They measured weight loss in each case by measuring weight differences before and after testing. Haseeb et al. [11] investigated the effect of temperature on the tribological properties of palm biodiesel. They examined experiments to determine the wear and friction properties of biodiesel at four different temperatures of 30, 45, 60, and 75 °C at 40 kg/h at 1200 rpm, which was found to be a biodiesel lubricant. As friction and wear decrease, the temperature increases and the fuel content increases as the biofuel content increases. At high test temperatures, biodiesel is oxidised, and the free volume of water increases.

After a thorough literature review, it has been observed that no such relevant literature was available that could be given a concrete idea to study significantly. Past researchers only have studied the tribo-corrosion aspect without considering samples partially immersed or in vapours of biodiesel. This categorical fact of the research gap has motivated us to retake this type of study for the benefit of the research in the area of tribo-corrosion, considering as a reference mahua biodiesel. The present work gives a detailed experimental investigation about the tribo-corrosion effect of mahua biodiesel.

2 Theoretical Study of Material Selection

In this study, various parameters taken into consideration while making a selection of material such as cost, mechanical properties, end-use, local availability, and chemical composition are discussed in details. In order to study the tribo-corrosion (combined effect of corrosion and wear) aspects of biodiesel, the current study is divided into two parts, i.e. corrosion of aluminium [12] in the presence of biodiesel and wear of aluminium when biodiesel is being used as one of the lubricants. As the proposed end-use of biodiesel is in automotive engines, aluminium material is selected for the present study as aluminium is used in the manufacture of components of an engine. Krishi Global supplied the Mahua biodiesel used in this study.

3 Corrosion Study of Material Under Biodiesel

The corrosion of metals is conditioned by its physical and chemical properties as well as by the nature of the environments. In the present investigation, the corrosion of aluminium is studied in an immersed condition. The principal factors governing corrosion, in this case, are the composition of the alloy, the nature of the corroding medium, and conditions like temperature, etc. To elucidate the mechanism of corrosion in an immersed state completely, it would be necessary to conduct investigations on several lines. The usual and most convenient method of studying the damage by corrosion is to determine the loss in weight of the specimen and the analysis of the corroding media. A specimen, when immersed in a corroding medium, may gain or lose weight depending upon whether the product is an adherent substance or a soluble one.

4 Experimental Setup

Experimental Apparatus shown in Fig. 3 was set up according to ASTM Standards with Designation: NACE TM0169/G31 – 12a (Standard Guide for Laboratory Immersion Corrosion Testing of Metals).

All samples were prepared according to ASTM standards with Designation: G1 – 03 (Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens).

The formula calculates the average corrosion size:

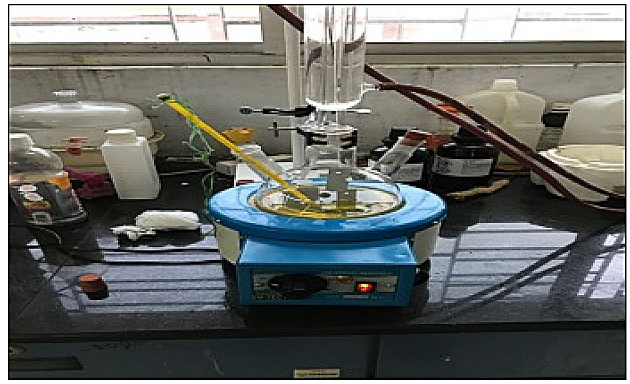


Fig. 3 Experimental setup

$$\text{Rate of corrosion} = \frac{KW}{TAD}$$

where W is mass loss in g, to nearest 1 g (corrected for any loss during cleaning), K is proportionality constant, T is time of exposure in hours to the nearest 0.01 h, A is area in cm^2 to the nearest 0.01 cm^2, D is density in g/cm^3.

5 Experimental & Tribological Study of Material Under Biodiesel

This study provides details about the experimental setup and methodology used for the preparation of samples to study the effect of biodiesel on the tribological aspects (wear + friction + lubrication). Wear and friction tests were performed on a tribometer (Model TR-20LE-M5), which was used to slipping against the hardened steel discs of material (EN31), and the hardness of 62HRC is identified in Tribology lab at NIT Agartala. The Ducom Pin-on-Disc Tribometer is a test instrument designed for accurate and repeatable tribological characterisation of bulk materials, coatings, and lubricants. Easily changeable holders allow users to quickly change the nature of tribological contact to something relevant to the application**.** Test specimen is with a diameter of 6 mm. The height of 40 mm were drawn from the S block. 6063 Polished metal for rectangular and polished wear. Before testing, the surface of the disc was polished with CD-150 grade. A digital weighing machine is used to identify needles before and after the examination. To take into consideration all the significant parameters projected in the literature affecting the wear, different experiments were done with varying load, speed, distance, and lubrication.

6 Results and Discussions

The corrosion rate of the sample (AA6063) at 80 °C and room temperature is changed, when the conditions of samples are (a) entirely submerged, (b) partially immersed, and (c) surrounded by vapour mixed (blend). It is seen that when the temperature increases, the rate of corrosion also increases, which might be due to the dissolution of more oxygen from the atmosphere into the fuel at high temperature owing to the activating surface immersed in blend (c) samples in vapours of the blend. It can also be concluded that corrosion rate is much more in vapours as compared to the condition where samples are entirely immersed in Biodiesel; this may be due to the availability of oxygen in the environment to assist in corrosion. In contrast, even samples which are partially submerged in blends have higher corrosion rate as compared to samples which were utterly immersed in biodiesel. Thus, it might be suggested that during the storage of biodiesel in metal tanks, the most critical area with respect to corrosion is the portion of the tank is above the uppermost layer of the biodiesel.

Figure 4 shows the EDS results of the surface exposed to B30 at room temperature and 80 °C compared with as-received AA6063. It can be observed that there is only 0.93% oxygen present on the surface of as-received material which is increased to 20.82% when the material was exposed to B30 at room temperature.

In the optical images of samples which were partially immersed in fuel as shown in Fig. 5a–c it can be seen that there are the formation of minimum 2 (two) layers on the surface of the material with severe corrosion on the portion of the sample which was in the vapours of the fuel. Optical images of the samples which were immersed entirely in fuel during the duration of test as shown in Fig. 5d and e, it can be observed that corrosion layer is uniform on the surface of the material, whereas Fig. 5e shows the optical image of a fresh specimen.

The total acid number (before and after the metal at room temperature) of the various fuels is shown in Fig. 6.

From Fig. 7a, it can be seen that at a speed of 1.25 m/s (an optimum speed for observing the characteristics), wear mass loss decreases drastically to almost half of its value when diesel is used as lubricant which further decreased when diesel was replaced with B30.

A similar trend can be seen when speed was 4.2 m/s from Fig. 7b, but wear mass loss is more at high speed; this may be due to the softening of material due to more heat generation at high speed due to friction.

The SEM micrographs of the worn surfaces of the AA6063 at speed of 4.2 m/s covering a distance of 1260 m with no lubrication and in the presence of B0, B15, and B30 are shown in Fig. 8.

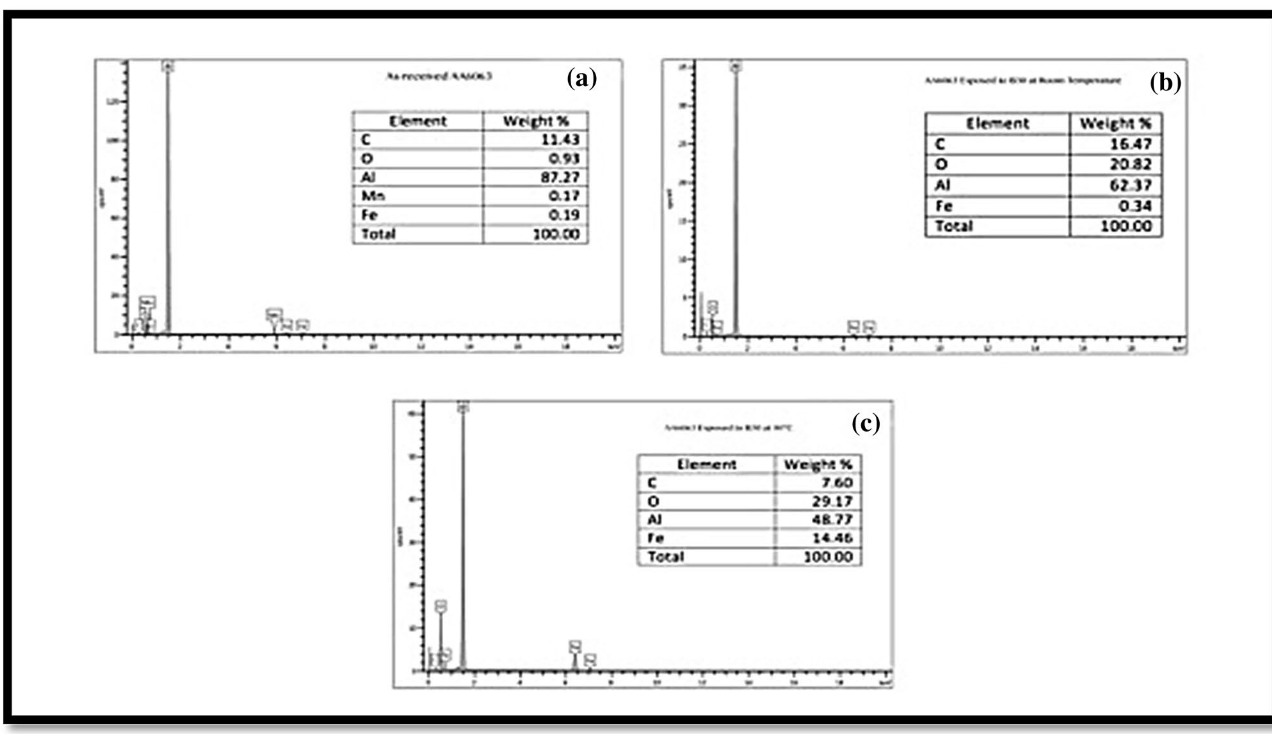


Fig. 4 EDS Analysis of **a** as-received AA6063, **b** AA6063 exposed to B30 at room temperature, **c** AA6063 exposed to B30 at 80 °C

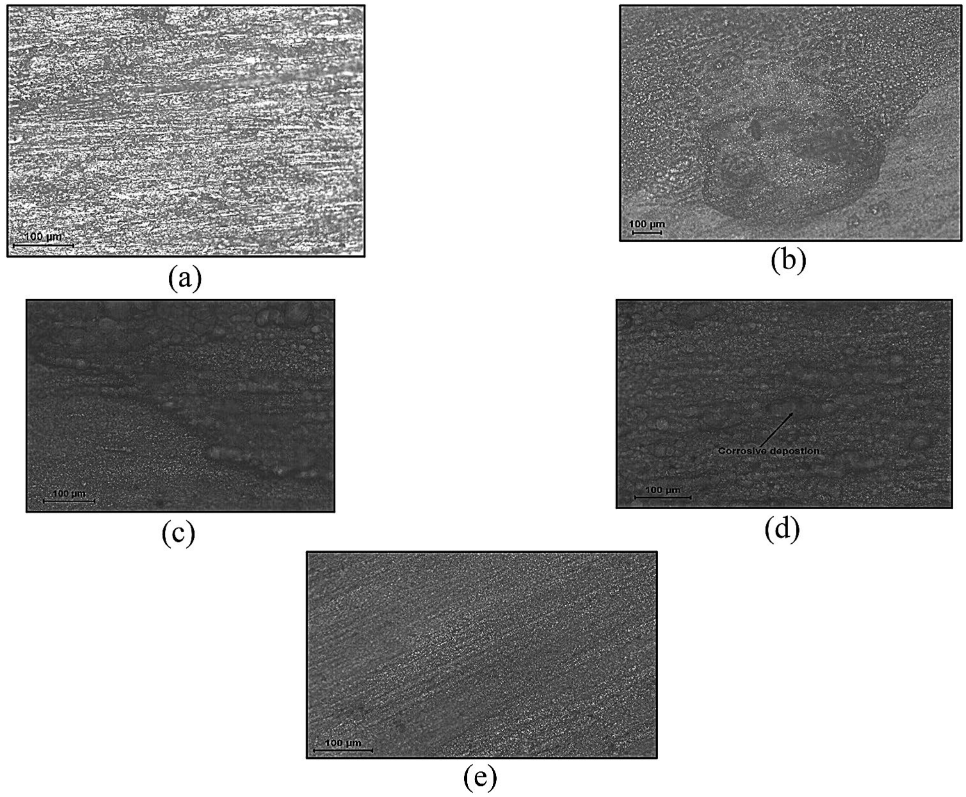


Fig. 5 Optical images of different samples

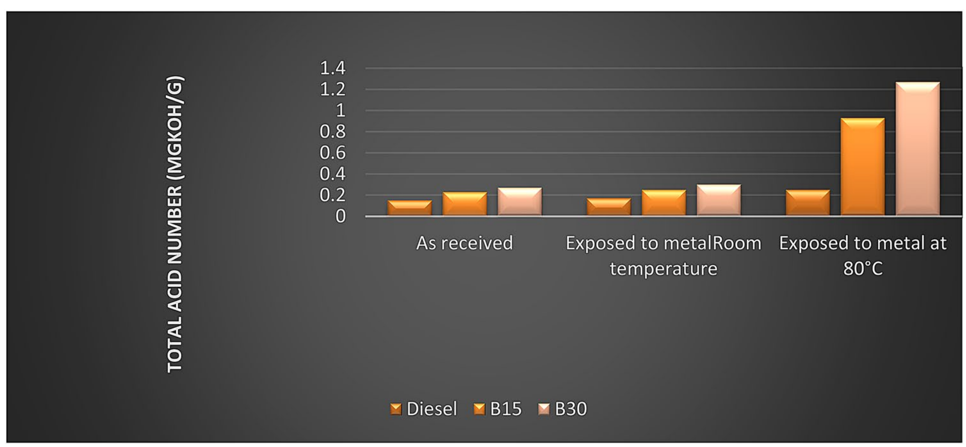
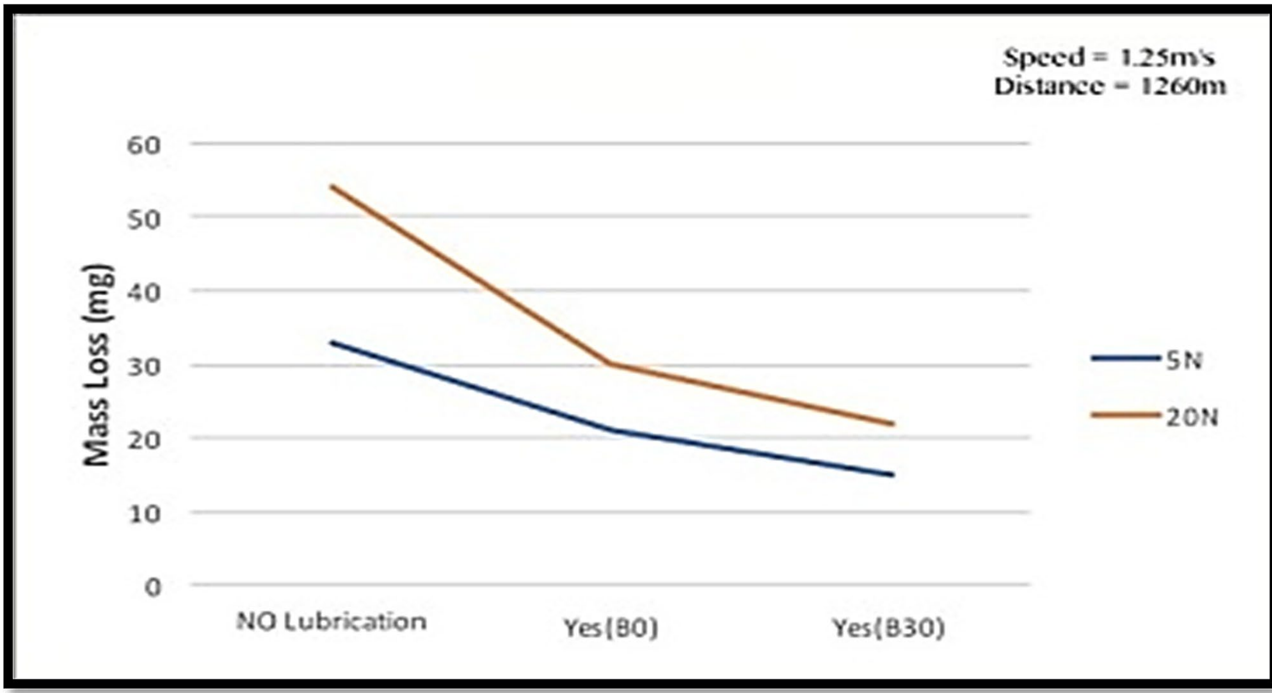


Fig. 6 Total acid number

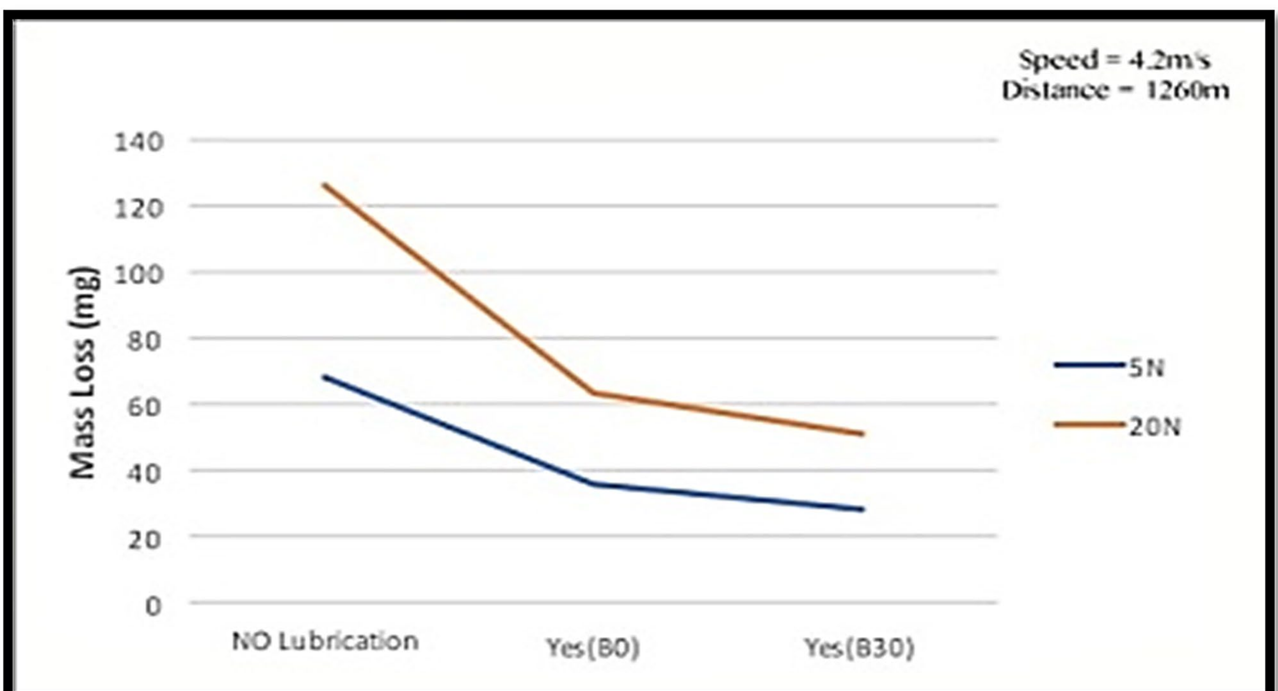
7 Conclusion and Future Scope

Experiments were conducted with three types of oil taking bio as a composition to find out the effect of corrosion in the aluminium faces. A test rig was fabricated taking ASTM standard, and thereafter, morphological analysis has been done; besides, standard wear testing is done in a standardised test rig (pin-on-disc). Based on the results, the following cautious conclusions were given:

1. Corrosion rate increases with an increase in temperature. This might be due to the dissolution of more oxygen from the environment due to the high rate of condensation.
2. Corrosion rate increases with the concentration of biodiesel in the blend.
3. The corrosion rate is much high in vapours than in totally immersed conditions due to the abundant amount



(a)



(b)

Fig. 7 Variation in the wear mass loss with different fuel for a sliding distance of 1260 m at a speed of **a** 1.25 m/s, **b** 4.2 m/s

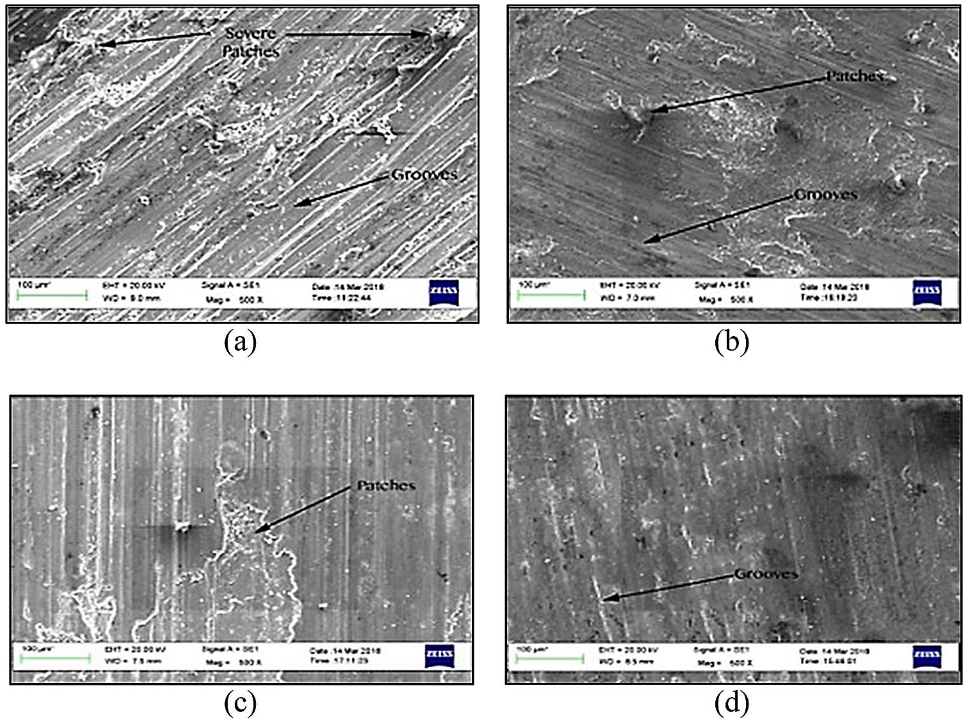


Fig. 8 SEM micrograph of the worn surface of **a** AA6063 without lubrication, **b** AA6063 in the presence of diesel, **c** AA6063 in the presence of B15, **d** AA6063 in the presence of B30

of oxygen available to assist in corrosion reactions in the environment.

4. The concentration of oxygen on the surface of metal increases with the increase of temperature. The increased concentration of oxygen indicates the formation of oxide compounds on the surface of the material. Wear of the material is reduced when biodiesel is used in the system and works as an efficient lubricant due to the presence of free fatty acids and monoacylglycerols.

Studies can be done to find additives that can be added to biodiesel to reduce its corrosive action and improve its lubrication properties. Also, parametric optimisation can be done to find the percentage of additive to be inserted to achieve the best possible solution considering all parameters responsible for corrosion and wear.

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Data Availability The data used in this research work have been placed in its appropriate place.

Code availability No code is used to pursue this work.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflicts of interest.

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