

COMPARATIVE ANALYSIS OF THE TRIBOLOGICAL PERFORMANCE OF BIODEGRADABLE RICIN OIL

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Abstract. *In this study was evaluated the tribological performance of biodegradable Ricin oil compared to the commercial SAE 40 oil, by lubricated wear tests with 6261aluminum alloy and AISI 1045 steel. All tests were performed in a pin-on-cylinder test rig designed to explore the wear of the metallic samples. The normal load applied in these tests were 9 N and 20 N, the relative velocity and sliding distance were respectively 0.83 m/s and 6 Km, determined after initial exploratory experiments. The heating system due the sliding friction was monitored using thermocouples type K located to 3±0.5 mm of the contact. The metallic material was previously characterized through measures of roughness and hardness. Density measurements, viscosity and acidity were performed to characterize the oil lubricants. The wear mechanisms on metal surfaces were analyzed by scanning electron microscopy (SEM). The results of heating at 3 mm of the contact show better results for the Ricin oil.*

Keywords*: Wear, Lubrication, Biodegradable Oil, Ricin Oil, SAE 40 Oil.*

1. INTRODUCTION

Pressures from environmentalists have stimulated research aimed at expansion the application field of the vegetable oils. The waste lubricating oil fossil discarded in the environment cause negative impacts, such as: contamination of the water and soil by heavy metals, with consequent damage to the health of the population (PETROBRAS, 2009).

According to Stoeterau (2004), the ecological concerns that emerged in the 90's, and had its effects on tribology, where the need for more efficient systems, especially in terms of reducing emissions, noise emissions and consumption of lubricants, led to development of lubricants and systems lubrication friendly environmentally.

The lubricating conditions strongly influence the interaction of components and consequently the life of the systems too. In this sense, the use of lubricants in mechanical systems is intended to reduce friction, and act against the acceleration of the wear (BHUSHAN, 2001).

The lubricants have the function of introduce between the sliding surfaces a layer of material with lower shear strength. In some systems, the lubricant may not completely prevent the contact of asperities, although it may reduce the strength of joints formed (HUTCHINGS, 1992).

In addition to requirements related to its function of lubricating the system, lubricating oil, of the environmental point of view, should be biodegradable and, therefore, the search for renewable resources is increasingly important and necessary to ensure energy security and environmental protection (AGARWAL *et al.*, 2008).

Because of the ease of adapting the plant Ricinus Communis in the climate of northeast Brazil (semi-arid) and need for diversification and expansion of the energy to meet market demands, the government has encouraged its cultivation through actions directly. Thus, the growth of this plant would fulfill the roles of energy production and income generation also for poor families of semi-arid areas (SOUZA *et al.*, 2007).

The attainment of Ricin oil is obtained through pressing the seeds, containing 90% ricinoleic acid, which gives the oil its unique features, enabling wide range of industrial use. The plant has lateral roots and a taproot that can reach 1.50 meters deep. The fruit is a capsule with thorns, with three divisions and a seed in each one, as shown in Fig. 1 (DAMASCENO and DOMINGUES, 2008).

Aiming for the application of biodegradable oils as lubricating to replace mineral oils, was studied the tribological behaviour of ricin oil, derived from vegetable source (Ricinus Communis plant), comparing to SAE 40 oil used in diesel engines.

Figure 1. Fruit of Ricinus Communis

2. EXPERIMENTAL

2.1 Lubricant Oils

In this work was adopted two types of oils, as is shown in Fig. 2. The Ricin oil, a vegetable oil that comes from the *Ricinus communi*s plant, and mineral oil SAE 40 used as comparison parameters.

Oils SAE 40 (Lubrax MD 400) is an additive lubricant oil, for diesel engines, with naturally aspirated and supercharged, which meets the API CF performance level. SAE 40 was produced to control the formation of deposits in the engine and filters as well as to reduce wear and corrosion of the lubricated parts. Its additives are: anti-corrosion, anti-foaming, antioxidant, detergent, alkalinity agent and reducer pour point (PETROBRAS, 2009).

Ricin oil is belonging to the family Euphorbiaceae of origin African-Asiatic, and can be found on Brazilian territory due to ease of adaptation to different conditions of soil and climate (DESER, 2007). The abrupt changes in temperature does not change their characteristics, for this reason is essential its application in aviation (CARVALHO, 1991 *apud* COSTA, 2006).

Ricin oil consists of a mixture of esters of glycerol, fatty acids whose chain contains 8 to 20 carbon atoms (SILVA, 2006).

Figure 2. Visual appearance of the turbidity of the Ricin and SAE 40 oils.

Table 1 shows the physicochemical analyses as density, viscosity and acidity that characterized the lubricant oils used in this study. The density was measured using a densimeter of the Anton Paar DMA 4500M mark that follows the ASTM D 4052 standard. The acidity was measured using a pHmeter mark Digimed MD-23 that follows the ASTM D664. The kinematic viscosity was determined according to ASTM D445 using an equipment ISL mark, TVB 445 Tamson Inside model, with a Cannon Fenske tube, series 150 with constant equal to 0.03892 mm^2/s^2 at 100 °C.

Table 1. Some physicochemical properties of lubricant oils

Oil	Oil base	Density (g/cm^3)	Viscosity (cSt) at 100 °C	Acidity
SAE 40 Oil	Mineral	0.890±0.0003	17.086	5.21
Ricin Oil	Vegetable	0.956±0.0002	21.367	6.28

According Scholz and Silva (2008), the kinematic viscosity of the ricin oil presents variation with heating *i.e,* higher heating promote low viscosity.

2.2 Metal

In this work were machined pins and rods of 6261 aluminum alloy and AISI 1045 steel, respectively. Figure 3(a) shows the AISI 1045 steel rod with 12.2 mm diameter and 9 sections of 18 mm length.

The metallic materials were characterized through tests of the roughness (Ra, Rq), waviness (Wa, Wq) and Rockwell C and Brinell hardness.

The roughness and waviness tests on the surfaces of the metallic materials were applied using the Taylor Hobson Precision Surtronic 25 equipment with the following criteria: seven measures on the pin samples and four measures on the longitudinal positions of the rods according Fig. 3(b); and their values are shown on the Tab. 2.

Figure 3. (a) Geometry and (b) longitudinal directions (12h, 3h, 6h and 9h) of roughness and waviness measurement on the AISI 1045 steel rod.

Table 2. Roughness and waviness of the pin and rod.

Form	Materials	Roughness		Waviness	
		Ra	Rq	Wa	Wq
Pin	Aluminum 6261	0.217±0.16	0.369±0.51	0.535±0.72	0.574±0.77
Rod	AISI 1045 Steel	0.180±0.06	0.247±0.08	0.341±0.21	0.344±0.22

The Rockwell hardness (HRC) of the counterbody (rod) was measured seven times, with a hardness tester of the Panambra® and using a pre-load of 10 Kgf and then 150 Kgf, showed on the Tab. 3.

The Brinell hardness of the sample (pin) was measure seven times, using Equation (1), where the diameter of the calotte formed by the indenter was measured on a profile projector:

$$HB = \frac{2F}{\pi.D(D-\sqrt{D^2-d^2})} \tag{1}$$

where:

F = applied load (kgf);
D = ball diameter (mm);
d = printing diameter (mm).

Table 3. Hardness of the metallic materials

Material	Form	Rockwell C Hardness (average value)	Brinell Hardness (average value)
AISI 1045 Steel tempered and quenched	Rod	49.0 ± 7 HRC	464 ± 1.3 HB
6261 Aluminum alloy	Pin	----------------	71.98±0.34 HB

2.3 Tribology tests

In this study, were conducted tests of sliding lubricated to evaluate the performance of Ricin oil in relation to the SAE 40 oil. For that were used tribological couples from different metallic materials: aluminium (used as pin) and AISI 1045 steel tempered and quenched (used as rod).

Two values from normal load were applied, 9 N and 20 N. The relative velocity and the sliding distance were maintained constant in: 0.83 m/s and 6 Km, respectively.

The flow of lubricating oil in the contact of the tribological couples occurred every one minute and performed one repetition to each set of pairs of sliding adopted.

On the table 4, is shown the parameters of the sliding tests, as well as materials and lubricants used.

Table 4. Parameters of the sliding tests

Conditions	*Lubricant*	*Normal Load (N)*	*Tribology Couple*	
Velocity (1300 RPM) *Relative Velocity (0.83 m/s)* *Sliding Distance (6 Km)*	*Ricin*	*9*	AISI 1045 Steel	6261 Aluminum alloy
			AISI 1045 Steel	6261 Aluminum alloy
	SAE 40	*9*	AISI 1045 Steel	6261 Aluminum alloy
			AISI 1045 Steel	6261 Aluminum alloy
	Ricin	*20*	AISI 1045 Steel	6261 Aluminum alloy
			AISI 1045 Steel	6261 Aluminum alloy
	SAE 40	*20*	AISI 1045 Steel	6261 Aluminum alloy
			AISI 1045 Steel	6261 Aluminum alloy

Temperatures collected during the tests were obtained at an acquisition rate of 1 second. Before and after the tests, the pieces were washed in a solution of isopropyl alcohol and weighed on a digital scale. The wear rate was calculated using the Archard Equation (2), which relates the mass change due to wear and density of materials:

$$\kappa = {}^{v}/_{(W.L)} \tag{2}$$

where:

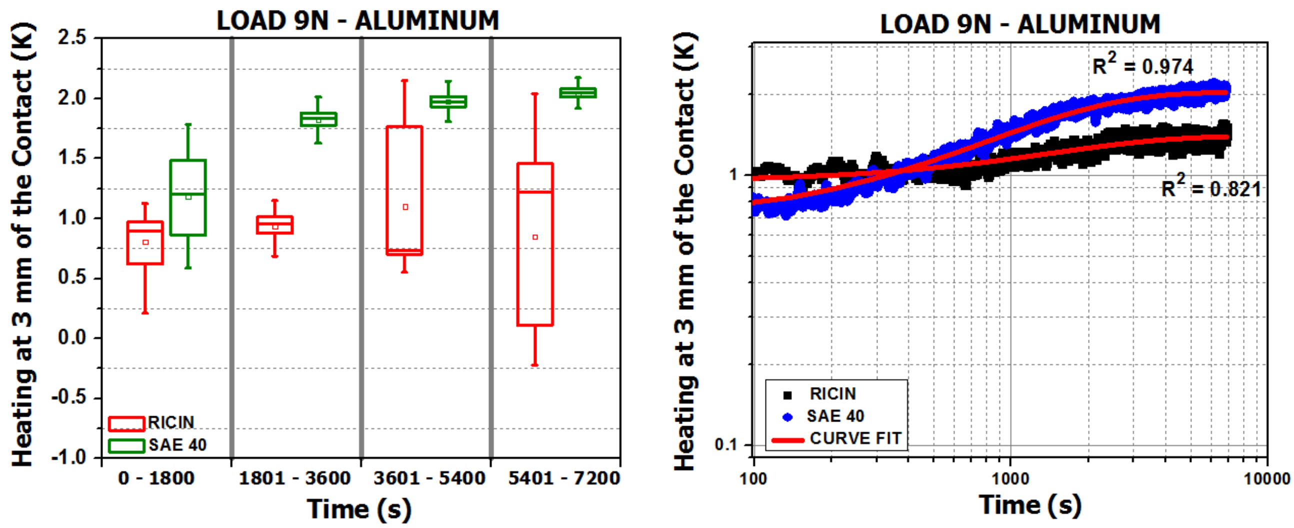
- ***v*** = volume of material worn (m^3);
- ***W*** = normal load applied (N);
- ***L*** = total of the sliding distance (m).

3. RESULTS AND DISCUSSION

In Figure 4, is shown the heating graphics measured at 3 mm of the contact area, and the correlation between the heating of the Ricin oil and SAE 40, of testing with a load of 9 N.

The heating analysis to the steel - aluminum contact, through the distribution of time windows (Fig.4a), it is observed that the distribution of quartiles when the Ricin oil is used provides greater data dispersion. However, the heating of the contact lubricated with Ricin oil is less than the lubricated with SAE 40.

The quality of the heating results was evaluated through the correlation graphics (Fig. 4b), obtained from the data that fall outside the period of softening (running). It is noted that the SAE 40 oil has R^2 = 0.974 indicating that the quality of their data are better than castor oil with R^2 = 0.821.



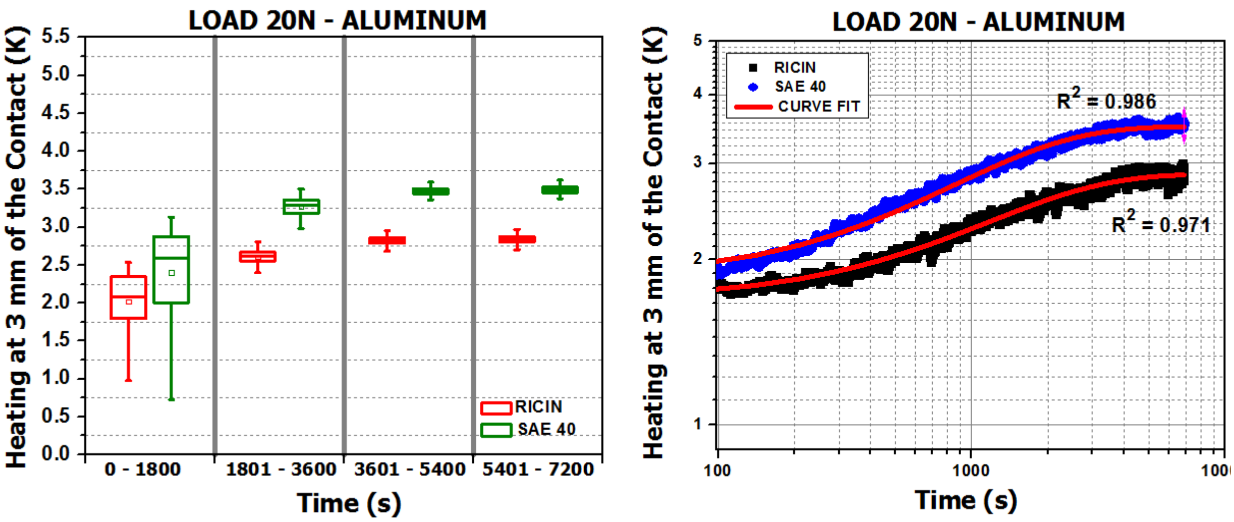
a) (b)

Figure 4. Heating at 3 mm distance of the contact (a) in function of time windows and (b) exponential correlation, load of 9 N, and sample of 6261aluminum alloy lubricated with Ricin oil and SAE 40 oil.

In Figure 5, is shown the heating graphics measured at 3 mm of the contact area, and the correlation between the heating of the Ricin oil and SAE 40, of testing with a load of 20 N.

In the time windows (Fig. 5a), for heating the contact made with a load of 20 N, is observed that the distribution of the quartiles for the two oils have higher dispersions only during period of softening (running).

However, the heating of the contact lubricated with Ricin oil is less than the lubricated with SAE 40 oil, as occurred for the load of 9 N. In the graphic of correlation (Fig. 5b) is observed that the SAE 40 oil has R^2 = 0.986 indicating that the quality of their data are better than Ricin oil with R^2 = 0.971.



(a) (b)

Figure 5. Heating at 3 mm distance of the contact (a) in function of time windows and (b) exponential correlation, load of 20 N, and sample of 6261aluminum alloy lubricated with Ricin oil and SAE 40 oil.

The wear rate was determined according to the Archard equation. Figure 6 shows the wear rate of the bodies used in test lubricated with Ricin oil and SAE 40 for the load of 9 N. In Figure 7, is shown the wear rate for loads of 20 N.

The aluminum-steel contact for 9 N loads, presents a high wear rate for the contact lubricated with SAE 40 oil, but with less dispersion when compared to Ricin oil.

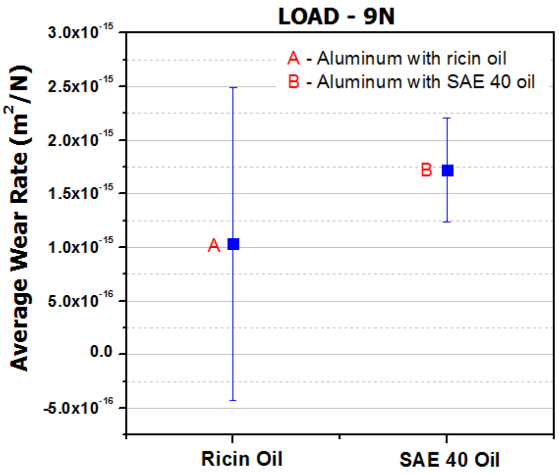


Figure 6. Wear rate of the 6261 aluminum alloy sample at load of 9 N lubricated with Ricin oil and SAE 40 oil.

For loads of 20 N, the SAE 40 oil offered lower wear rate and dispersion than ricin oil. According to Smith (1994) lower values than 10^{-16} $m^2 N^{-1}$ indicating mild wear and, values higher than 10^{-14} $m^2 N^{-1}$ indicating severe wear.

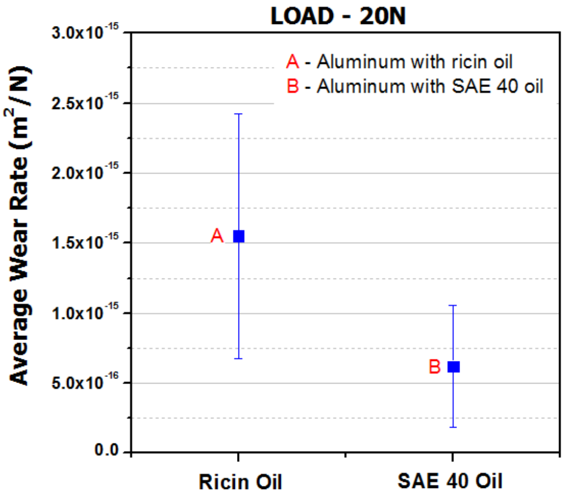
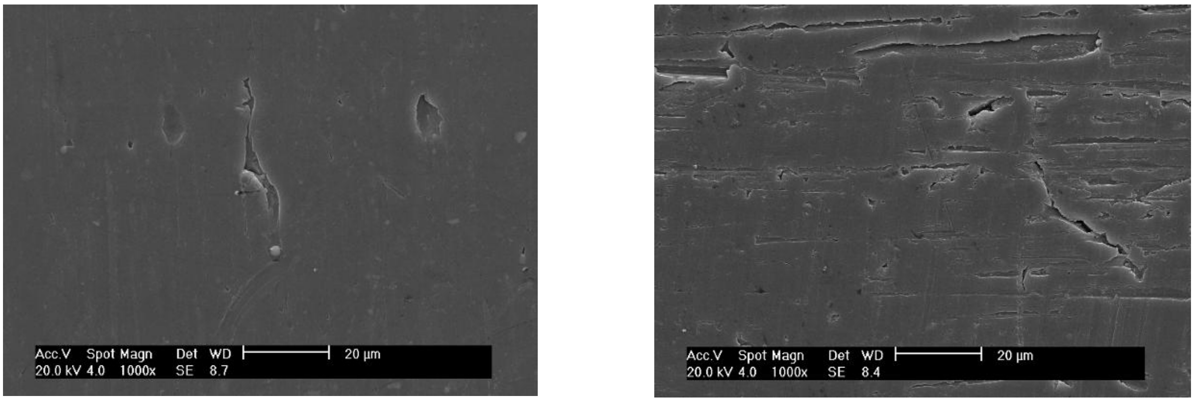


Figure 7 – Wear rate of the 6261 aluminum alloy sample at load of 20 N lubricated with Ricin oil and SAE 40 oil.

According to Hutchings (1992), the abrasive wear happens when two bodies in sliding contact have the dissimilar hardness values (less than 20 % of the harder body). In this case, the 6261aluminum alloy is less 16 % than to 1045 steel.

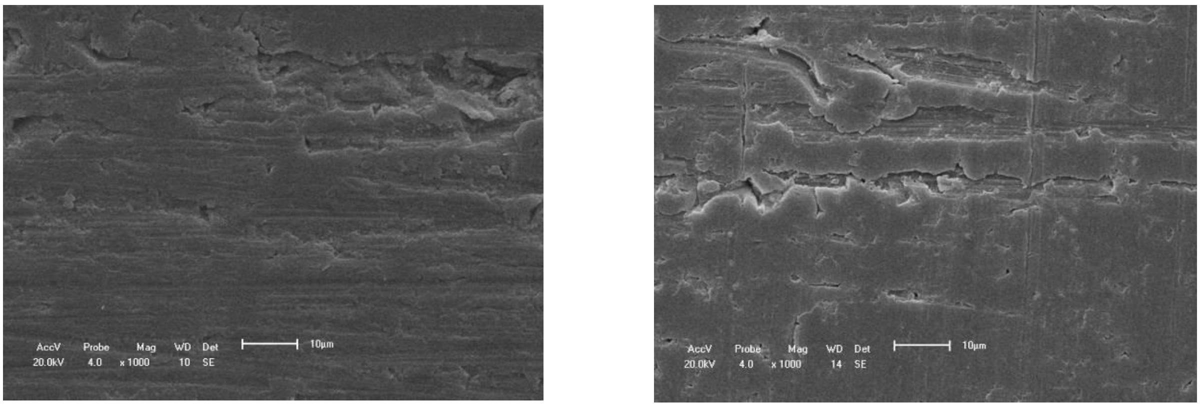
Figure 8 shows the surfaces of aluminum, analyzed by SEM, which was tested with 9 N lubricated with ricin and SAE 40 oil. Observe that surfaces lubricated with ricin oil show lower wear that surfaces lubricated with SAE 40 oil. The wear mechanisms obtained were: plastic deformation, ploughing and grooves.



(a) **(b)**

Figure 8 – SEM of the 6261 aluminum alloy sample at load of 9 N lubricated with Ricin oil (a) and SAE 40 oil (b).

Figure 9 shows the surfaces of aluminum, analyzed by SEM, which was tested with 20 N lubricated with ricin and SAE 40 oil. The main wear mechanism obtained was plastic deformation.



(a) **(b)**

Figure 9 – SEM of the 6261 aluminum alloy sample at load of 20 N lubricated with Ricin oil (a) and SAE 40 oil (b).

4. CONCLUSIONS

The graphics of the heating with loads 9 N and 20 N, displayed that ricin oil presents lower values of the heating than SAE 40 oil.

The wear rate exhibited a nonlinear relationship when compared to heating of the pin-cylinder contact. This can be explicated due the reduction of the kinematic viscosity with increase of the heating by higher load (20 N).

According to Scholz and Silva (2008), the kinematic viscosity of the ricin oil presents variation with heating *i.e*, higher heating promote low viscosity, which promoted the formation of a thin lubricating film, resulting in friction and consequently wear.

It was observed that the 6162 aluminum alloy lubricated with ricin and SAE 40 oils exhibited mild wear, as mentioned by Smith (1994).

The correlations plots, the curve settings for the SAE 40 oil have better quality, maintaining a low dispersion of their values.

The wear mechanisms obtained in this work were grooves, plastic deformation and ploughing.

5. ACKNOWLEDGEMENTS

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