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Wear and Frictional Performance of Metals under Dry/Waste Cooking Oil Lubricant Conditions

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Jasem Alotaibi
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Abstract

The development of recycled, renewable and sustainable products to replace fossil products is a vital concern from industrial, environmental and academic viewpoints. Lubricants are one of the synthetic products widely used in numerous fields of the manufacturing and industrial sectors. Furthermore in 2005, more than 38 million metric tons of oils were used in the lubrication techniques of various industrial applications in the United States (US). In other words, the need for alternative friendly lubricants needs to increase by about 36 billion gallons to meet expected demands in 2022. This need motivates the current investigation of the potential use of waste cooking oil as a lubricant for tribological applications. A review of the available literature reviewed no work related to this topic. However, many works have been conducted on vegetable oils and their potential as lubricant. The current study establishes the basis for the research in the area of waste cooking oil as a lubricant; focusing on the oil and its blend characteristics and applications in journal bearings.

At the first stage of this study, comprehensive experiments were conducted on the wear and the frictional behaviour of brass, aluminium and mild steel metals sliding against a stainless steel counterface under dry contact condition for comparison purposes with the lubricant results. Furthermore, predicting the tribological performance of materials is a very complex task and many attempts to model the wear and frictional behaviour of materials have failed. In this study, the artificial neural networks approach is used as a tool to predict wear, roughness, interface temperature and the frictional behaviour of metals under different operating parameters.

For the wear experiments under dry contact conditions, the wear and frictional performance of brass, aluminium and mild steel metals was investigated at different operating parameters: sliding distances (0 – 10.8 km) and applied loads (0 – 50 N) against a stainless steel counterface at a sliding velocity of 2.8 m/s. Experiments were performed using a block-on-ring (BOR) machine. To categorise the wear mechanism and damage features on the worn surfaces and the collected debris, scanning electron microscopy was used. A thermal imager was used to measure the interface temperature between the contacted bodies.

The results of the dry tests revealed that the operating parameters significantly influence the wear and frictional behaviour of all the metals. Brass metal exhibited better wear and frictional behaviour compared to the other metals tested. This is mainly due to the presence of 4% of Pb which helped reduce the aggressiveness of the material removal. Three different wear mechanisms were observed: two-body abrasion (brass), three-body abrasion (mild steel) and adhesive (aluminium). Friction coefficient trends were almost steady for brass and mild steel, however, aluminium/stainless steel exhibited slight fluctuations due to the modifications of the worn surface due to the sliding.

A biolubricant extracted from waste cooking oil (WCO) was developed in this study. Different blends of lubricant were prepared: fully synthetic 100%SO, 75%SO+25%WCO, 50%SO+50%WCO 25%SO+75%WCO and 100%WCO. The prepared waste cooking oil was blended with 5% (wt) of EVA copolymer and 2%

(wt) of EC and synthetic oils. Viscosity, pour point and flash points of the blends were examined and compared with industrial lubricants, (10W-50, 15W-40, 5W-40, and 5W-30).

The possibility of using WCO with its blend as a lubricant was tested using two techniques. First, a new tribology machine was designed and fabricated locally to study the wear and frictional performance of brass, aluminium and mild steel under lubricant conditions considering different sliding distances (up to 10.8 km), applied loads (10 N – 40 N) and sliding speed of 2.8 m/s at different lubricant temperatures (22ºC, 40ºC, 80ºC). For consistent comparison purposes with the dry data, 113 kPa applied pressure was used as the dry contact condition was conducted mainly on 50N applied load which is equivalent to 113 kPa.

This study found promising potential for the use of WCO as a lubricant from a viscosity viewpoint. The viscosity of the waste cooking oil was significantly enhanced with the addition of 5% (wt) of EVA copolymer and 2% (wt) of EC. Blending the waste cooking oil with the fully synthetic oil also showed good improvement in performance. Based on the viscosity data, it is found that the pure waste cooking oil is very comparable with W5-30 oil which is recommended for gasoline and diesel engines. Increasing the applied load reduced the specific wear rate due to the presence of the lubricant which assisted to absorb the heat in the interface and clear (polish) the rubbed surfaces. The lubricant temperature was the key in determining the wear behaviour of the materials. Increasing the temperature reduced the viscosity, leading to less lifting during the experiments (i.e. a high specific wear rate). Conversely, the lubricant temperature showed no remarkable influence on the frictional behaviour. This is mainly due to the chemical adsorption of the fatty acids on the worn surfaces which acted as coated layer. From the journal bearing testing results, the waste cooking oil and its blends exhibited a similar trend in oil pressure values to the ones obtained for the fully synthetic oil, thus demonstrating the potential of waste cooking oil and its blends for journal bearing applications.

The complexity of predicting the wear and frictional performance of the materials motivates the tribologist to adopt an artificial neural network (ANN) approach, as it can be used to make such predictions with caution. In developing an ANN for this study, training function, performance and adopting functions were found to be the keys to predicting wear, roughness and interface temperature. The large input data of the friction coefficient (12009 x 3 x 3) made the prediction of friction coefficient difficult and led to poor ANN performance. Using individual inputs for each parameter and training the ANN in several steps improved the performance. About 95.5% prediction performance was recorded, particularly for the wear, roughness and interface temperature.

List of Publications

Alotaibi, J, Yousif, B & Yusaf, T 2014, ‘Wear behaviour and mechanism of different metals sliding against stainless steel counterface’, *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*, p. 1350650114527072.

Alotaibi, J, Yousif, B & Yusaf, T (in press), ‘Brass, aluminium, and mild steel sliding against stainless steel under dry conditions’, *International Journal of Precision Technology, Inderscience*.

Alotaibi, J, Yousif, B & Yusaf, T (under review), ‘Review on biolubricants and the potential of waste cooking oil’, *Renewable and Sustainable Energy Review*.

Alotaibi, J, Yousif, B & Yusaf, T (forthcoming), ‘The potential of using waste cooking oil as lubricant’, paper to be presented at Wear of Materials (WOM), Toronto, Canada, 12–16 April 2015.

Alotaibi, J, Yousif, B & Yusaf, T (in progress), ‘Designing a new lubrication tribology machine and the possibility of using waste cooking oil as lubricant, paper to be submitted to *Tribology Letter*.

Certification of Thesis

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this thesis are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Jasem Alotaibi
0061039057

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Signature of Candidate	Date

Endorsement

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Signature of Principal Supervisor	Signature of Associate Supervisor
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Date	Date

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List of Abbreviations

ASTM D97-02	Standard Test Method for Pour Point of Petroleum Products
BOR	block-on-ring
DITA	Di-Isotridecyl Adipate
DSC	differential scanning calorimetry
DSRW	dry sand rubber wheel
EC	ethyl cellulose
EVA	ethylene-vinyl acetate
FE	finite element
POD	pin-on-disc
PUFA	polyunsaturated fatty acid
SEM	scanning electron microscope
SO	synthetic oil
TAG	triacylglycerol
US	United States
USQ	University of Southern Queensland
WCO	waste cooking oil
WSRW	wet sand rubber wheel