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Friction and wear characteristics of tire pyrolysis oil

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KEYWORDS

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ABSTRACT

The demand for alternative fuels has seen an exponential rise due to increased fuel prices and environmental impacts. In addition to being a source of energy, these are also frequently used as a lubricant due to their plentiful availability and low cost. Using the four-ball tester, this research investigates the wear and friction properties of waste tire pyrolysis oil (WTPO) as a lubricant. The tribological characteristics were compared with the diesel and biodiesel fuel. The experiment was performed on ASTM D2266 standard during 3600 s on a load of 40 kg, constant speed of 1200 rpm and with a temperature of 27 °C for all fuels. The wear scar diameter was calculated using an optical microscope and then examined through a scanning electron microscope. The coefficient of friction of WTPO is 22.3% and 10.6% lower than the diesel and biodiesel fuel, respectively. The surface morphology of the WTPO displays the smaller worn surfaces than the biodiesel fuel. Overall, the tribological performance of WTPO as a lubricant is observed to be better than the other samples due to its low coefficient of friction and worn surfaces.

1.0 INTRODUCTION

Because of the fast depletion of fossil fuels (Rashid et al., 2021), climate change (Sher et al., 2020), economic issues, and energy demand increase (Murugesan et al., 2009; Dhar et al., 2014; Qaisrani et al., 2021; Yaqoob, Teoh, Goraya, et al., 2021), alternative fuel have proliferated in a diesel engine (Yaqoob, Teoh, Sher, Ashraf, et al., 2021). Alternative fuels (Food based) such as soybean, rapeseed, palm oil, sunflower, and others, have been criticized around the world for

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deforestation, particularly the food vs fuel issue. As a result, it is suggested that the conversion of food to fuel will result in a global food crisis (Lam et al., 2009). As a result, waste to fuel conversion offers significant potential for producing alternative fuels, reducing the need for conventional fuel, and reducing waste (Duan et al., 2015; Yaqoob, Teoh, Sher, Jamil, Murtaza, et al., 2021). Solid waste is a big issue that causes environmental and financial issues (Mokhtar et al., 2012). Open disposal of tires produces a serious environmental issue and contributes to climate change and global warming (Al-Juboori et al., 2020; Ameen et al., 2021; Verma et al., 2018; Zhang et al., 2019).

The EAMA (European Association of Automotive Manufacturers) predicts that 1.35 billion road vehicles are present on the world road (ACEA, 2016), with 2 billion anticipated for 2035 (Voelcker, 2014). According to reports, 1 billion waste tires are wasted each year, with an estimated four billion in storage and dumpsites around the world (Shulman, 2004). The waste tires are processed to yield 49% weight oil, 44% weight char, and 7% weight pyrolytic gases (Li et al., 2016). Following that, ~44.5% of WTPO can be purified into fuel (M.Z.H. Khan, Md. Ikram Hossain, Pobitra Kumar Halder, Md. Rafiul Hasan, 2016).

One of the principal waste tire compounds is WTPO, which is created during the pyrolysis of waste car tires. The potential use of TPO in boilers (García-Contreras et al., 2015), furnaces (Karagoz et al., 2020; Pinto et al., 2019; Pote et al., 2019; Solmaz et al., 2018), and CI engines as a renewable fuel (Sharma et al., 2015) has piqued the interest of researchers. WTPO has a similar kinematic viscosity, calorific value, and density to DF, but its sulfur concentration is substantially higher (Singh et al., 2017). However, one disadvantage of TPO appears to be that it can be mixed with diesel up to 90%. Tire pyrolysis oil can be utilized in diesel engines to operate in dual-fuel mode (Murugan et al., 2018). Without modification, a 10% TPO fuel blend in diesel fuel may be utilized in the diesel engine (Yaqoob, Teoh, Jamil, et al., 2021).

On a four-ball tribometer, Yaqoob et al. (Yaqoob et al., 2020) examined the tribological properties of tire pyrolysis oil and its mixture with palm oil biodiesel. BT10 (90% biodiesel-10% TPO) outperforms BT20 (80% biodiesel-20% TPO), TPO, and biodiesel in terms of tribological performance. The lubricity of B30 + ethanol-gasoline declines, whereas friction and wear improve, according to Mujtaba et al. (Mujtaba et al., 2020). The smallest wear scar diameter (WSD) was found in B30 + dimethyl carbonate (DMC), and the maximum performance was found in B30 + nanoparticle TiO_2, which had the lowest wear scar diameter (WSD) and coefficient of friction (COF). TPO's tribological properties and their combination with diesel fuel were investigated by Yaqoob et al. (Yaqoob, Teoh, Sher, Jamil, Nuhanović, et al., 2021). The DT10 (90% diesel-10% TPO) outperforms the DT20, TPO, and diesel fuel in terms of wear and friction. Plastic pyrolysis oil exhibited an excellent lubricity property in terms of lowest friction coefficient as compared to polyalphaolefin 8 and trimethylpropane trioleate (Sharul et al., 2020). The tribological properties of the jatropha oil + graphene nanoparticles were examined and the best results were shown at graphene 0.5% which lessened the rate of wear by 43.7% and friction coefficient by 44% as compared to jatropha oil (Mushtaq et al., 2021). A fourball tribometer was used to test tribological properties at a load of 785 N. When compared to SAE-40, 10% cotton bio lubricant added to the blend resulted in the lowest friction and wear, while greater than 10% volume of cotton bio lubricant in the blend significantly increased wear and friction, as measured by both HFRR and four-ball tribometer (Gul et al., 2020).

With rapid industrialization and technical growth, fuel provided energy and served as a lubricant (Chauhan et al., 2012; Fayaz et al., 2021). The lubricity of the engine has a significant impact on its longevity. The lubricity of the engine minimizes friction between moving parts, resulting in lower friction strength and energy consumption (Tung et al., 2004). Fuel input temperature (>60 °C) determines engine fuel lubrication (Sarvi et al., 2008). To our knowledge, there is a substantial amount of literature on the engine performance of tire oils in diesel engines. (Hamzah et al., 2019; Hürdoğan et al., 2017; Karagoz et al., 2020; Pinto et al., 2019; Pote et al., 2019; Sharma et al., 2015; Solmaz et al., 2018; Thangavelu S et al., 2020; Vihar et al., 2015), however, no technical investigation of WTPO's tribological properties has been done.

To focus on the gap, a recent study evaluates the wear and friction properties of waste tire pyrolysis oil (WTPO), diesel (DF), and biodiesel (BD) under various testing conditions. This research looks into WTPO, DF, and BD. The fourball Tester (FBT) is used in this study to investigate the experimental examination of friction and wear characteristics of various fuels.

2.0 MATERIALS AND METHODS

2.1 Tested Fuels

Automobile tires are stripped of steel wires and fibers before being shredded into little bits. In a chamber, the pyrolysis method was employed on discarded tire fragments.

Malaysian industries provided the waste tire pyrolysis oil, biodiesel, and diesel. In this experiment, the WTPO, DF, and BD are used as test fuels, and the important physical properties are shown in Table 1.

Table 1: The physical properties of the different fuels.

Tested Fuels	Density (g/l) 15 °C	Kinematic viscosity (cSt) 40 °C
WTPO	927	4.74
DF	845.3	3.36
BD	875.5	4.45

2.2 Test System

A fourball tester was utilized in this investigation to support develop and examine novel lubricants in tribology. The sample was analyzed in four balls; however, three balls were held in the fuel sample tube and one ball rotated at the top end by a constant set of electric motor spindles. Figure 1 shows a diagram of the FBT as well as the experimental setup. After the fuel tub had been examined, fuel was placed in it. The fourball tester's features are listed in Table 2.

The frictional torque was calculated using an adjustable arm and the friction recording tool's spring, and the load was applied to the bottom-locked balls using the lever. Steel carbon-chromium balls were used in this experiment, and the characteristics of the balls are provided in Table 3.

Figure 1: Fourball tester.

Table 2: Specifications of the fourball tester (Yaqoob et al., 2020).

Specifications	Details	Accuracy
Model	Make: DUCOM	
Software	Winducom 2010	
Spindle Speed	300-3000 rpm	1
Temperature of Oil	25-100 °C	0.5
Load (Maximum)	10,000 N	0.5
Scar range	100–4,000 μm	0.5
Diameter of the ball	12.7 mm	
Power	380/50/3/2000 (V/Hz/VA)	

2.3. Test Process

For the four-ball test, acetone was used to clean the oil cup and the four steel balls. The 3 steel balls were tightly tightened into the oil tube and the test oils were poured into the oil tub until the three steel balls were fully immersed. A single steel ball is collected and attached to the tool. In the instrument, an oil bath was introduced, and a controlled wire was attached. For this experiment, the ASTM D2266 standard was applied, with a fixed speed of 1200 rpm, 40 kg weights, and 27 °C oil temperature of 3600 seconds. Several parameter values have been computed and reviewed by the program. The requirements for Fourball testing are shown in Table 4. The three balls in a cup were collected after the conclusion of the test to be used for the optical microscope and the SEM analysis to determine the wear scar diameter.

2.3.1. Friction Analysis

The mean friction coefficient was measured using the software "Winducom 2010," and equation (1) was used to calculate it. The frictional torque is determined using the load cell (IP-239 standard, 1986). Habibullah et al. (Habibullah, H.H. Masjuki, et al., 2015), Mosarof et al. (Mosarof et al., 2016), and Zulkifli et al. (Zulkifli et al., 2014) all employed the same technique. Where r is 3.67 mm, that is the distance between the axis of rotation and the contact surface center on the lowest balls, T is frictional torque (Nm), W is load (N) and μ is coefficient of friction.

Table 3: Features and operating conditions of the experiment.

Test Conditions	Details
ASTM Standard	D2266
Applied Load	40 kg
Duration	1 hour
Fuel Temperature	27 °C
Spindle Speed	1200 rpm
Material of the ball	Carbon–chromium steel (SKF)
Material hardness	62 HRc
Diameter of the Ball	12.7 mm
Material surface roughness	0.1 C.L.A µm

$$\mu = \frac{T \times \sqrt{6}}{r \times 3 \times W} \quad (1)$$

2.3.2. Wear Analysis

An optical microscope would be used to analyze the wear scar diameter (WSD) on steel balls with a resolution of 0.01 mm, according to ASTM D4172. The optical microscope made use of computer software to capture the image of the wear scar. Furthermore, the software is used to compute the WSD, therefore this operation is repeated for each fuel test.

2.3.3. Flash Temperature Parameter Analysis

Flash Temperature Parameter (FTP) is measured by using the equation (2). In which F is Load (kg) and D is average wear scar diameter (mm).

$$\text{FTP} = \frac{F}{D^{1.4}} \quad (1)$$

3.0 RESULTS AND DISCUSSION

3.1. Friction Analysis

Because of the experiment's time gap, the recorded friction behavior was not stable at the beginning of testing. The stabilized friction behavior, also called steady-state condition, was recorded after a few seconds. The average friction coefficient of the different tested fuels in the test duration (3600 s) is shown in Figure 2.

The average coefficient of friction of diesel fuel is higher than that of other test fuel samples. In comparison to diesel fuel and biodiesel, the WTPO has a stronger friction protection behavior. WTPO shows a 22.3% and 10.6% lower coefficient of friction than the diesel and biodiesel fuel, respectively.

The viscosity of the lubricating oil is the key component that impacts the film thickness dividing the surfaces and, as a result, defines the friction behavior at the boundary lubrication condition as the adopted testing conditions (Zulkifli et al., 2016). The significance of considered viscosity of lubricating oil, high temperatures had been reported at the fourball contact configuration, increasing average friction coefficient, and decrease of oils viscosity. The biodiesel has a better coefficient of friction, which is mostly owing to its increased viscosity and oxygen content (Wain et al., 2005).

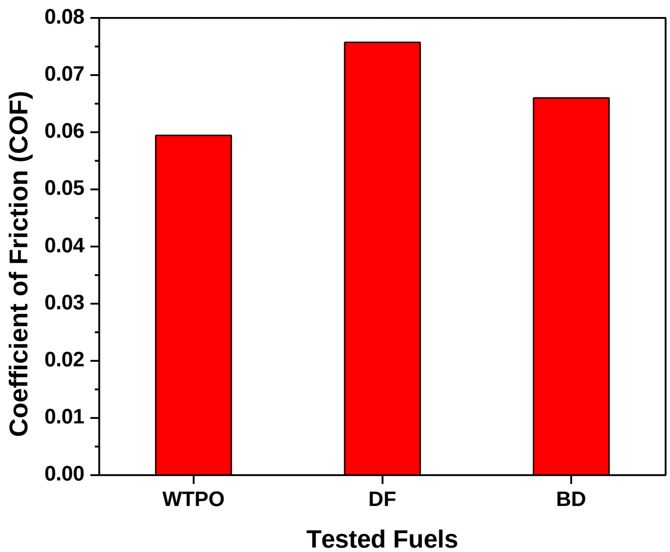

Figure 2: Waste tire pyrolysis oil, diesel fuel, and biodiesel coefficient of friction performance.

3.2. Wear Analysis

Metal-to-metal contact happens under the conditions of boundary lubrication, causing interacting tribo-pairs to wear. Figure 3 depicts the wear behavior of all of the fuels studied. WTPO exhibits lower antiwear characteristics as compared to DF and BD. WTPO exhibits lower antiwear characteristics as compared to DF and BD. The WSD of WTPO was 16.6% and 3.9% respectively higher relative to diesel and biodiesel. But at high loads, pure TPO shows better antiwear characteristics (Yaqoob et al., 2020; Yaqoob, Teoh, Sher, Jamil, Nuhanović, et al., 2021). The high sulfur concentration of WTPO reduces wear, and its combination with diesel improves lubricant properties (Nikanjam et al., 1993; Yaqoob et al., 2020). Low sulfur concentration in diesel creates lubricity issues, although Mello et al. (Silva e Mello et al., 2014) discovered that increasing sulfur concentration improves lubricity. Tire Pyrolysis Oil has a better capacity of load carrying, implying that it can bear bigger loads and be employed in high-pressure conditions (Yaqoob et al., 2020). The amount of oxygen in biodiesel will be reduced due to wear and friction between the surface contacts (Mosarof et al., 2016). In this manner, thermal energy was generated in sliding the interacted surfaces, which the protective layers were able to reduce, and lubricity was improved (Knothe et al., 2005). The stability of the lubricating layer between rubbing surfaces is strongly affected by speed, applied load, fluid viscosity, nanoparticle dispersion, fuel fatty acid content, and temperature (Maleque et al., 2000).

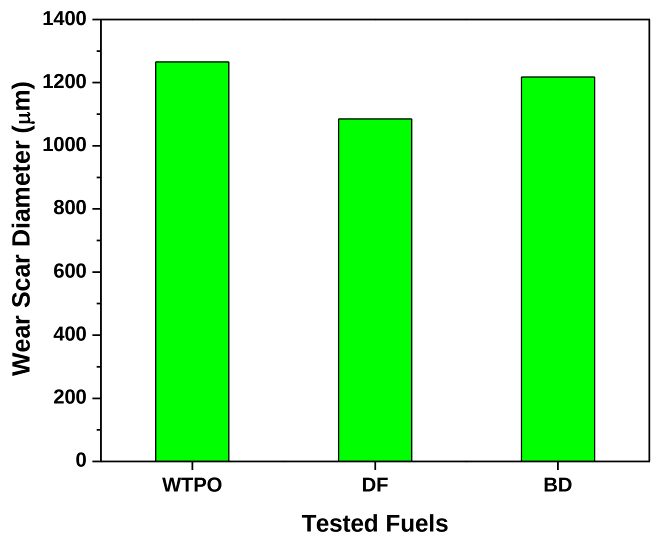

Figure 3: Waste tire pyrolysis oil, diesel fuel and biodiesel wear scar diameter.

3.3. Flash Temperature Parameter Analysis

Figure 4 depicts the impact of various fuel samples on flash temperature characteristics at various temperatures. As the temperature of the fuel rises, the parameter of the flash temperature of various fuels drops.

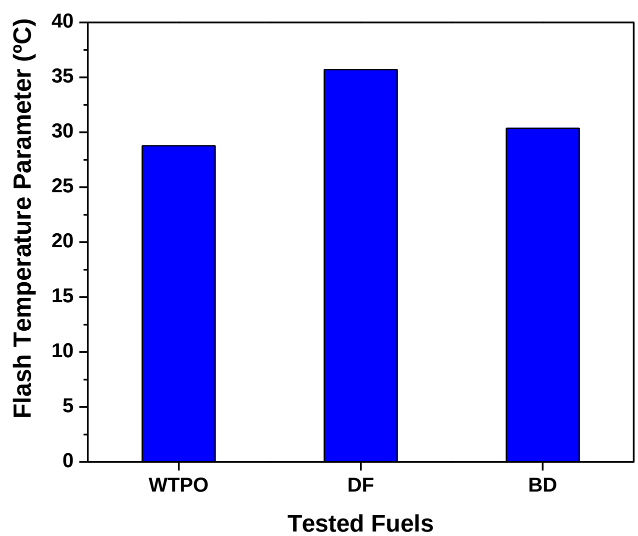

Figure 4: Waste tire pyrolysis oil, diesel fuel, and biodiesel flash temperature parameter.

The wear scar diameter is inversely proportional to the flash temperature parameter. WTPO displays the lowest flash temperature parameter 28.8 °C as compared to diesel fuel and biodiesel. Diesel fuel shows the highest FTP 35.7 °C. Higher parameters of flash temperature levels improve the efficiency of lubrication, while lower parameters of flash temperature levels cause films of lubrication to break down (Habibullah, Masjuki, et al., 2015). The oxidation process has been shown to have an impact on lubricating performance (Tsuchiya et al., 2006). When compared to diesel fuel, WTPO has a larger oxygen concentration (Verma et al., 2018). Furthermore, the oxidation process improves lubricating efficiency in a relatively short amount of time (Tsuchiya et al., 2006).

3.4 SEM ANALYSIS

A scanning electron microscope was used to describe the damaged interface of the tested balls to better understand the antiwear behavior of the oil samples (SEM). SEM was used to examine the worn surfaces. SEM micrographs of damaged edges of investigated balls for tested fuels are shown in Figure 5(a)-(i). The micrographs of the WTPO (Figure 5(a)-(c) exhibit more adhesive wear and a rough surface than those of the DF (Figure 5 (d)-(f)). Similarly, Figures 5(d)-(f) indicate the least amount of material removal compared to Figures 5(g)-(i) and 5(a)-(c).

The oxidation process increases the performance of lubricating, whereas the higher sulfur concentration increases anti-wear qualities. TPO has a higher oxygen and sulfur concentration (Tsuchiya et al., 2006; Verma et al., 2018; Wain et al., 2005). The interaction between the treated material and the additives in the given atmosphere causes tribofilm production. On the tested surfaces, Tribofilm is also known as protective film (Chou et al., 2010) (Viesca et al., 2011).

CONCLUSION

The tribological performance of waste tire pyrolysis oil, diesel fuel, and biodiesel is determined using a fourball tester in this experiment. The ASTM D2266 standard was used to test all of the fuels for 3600 seconds at 40 kg load, fixed speed (1200 rpm), and 27 °C temperature. The tribological performance of WTPO was in comparison to that of diesel and biodiesel fuel. The four-ball tribometer is a popular research tool in lubricant manufacturing for developing lubricants. As a result, it's used to investigate the tribological performance of a DF, biodiesel and WTPO. WTPO displays a 22.3% and 10.6% lower coefficient of friction than the diesel and biodiesel fuel respectively. WTPO exhibits lower antiwear characteristics as compared to DF and BD. The WSD of WTPO was 16.6% and 3.9% respectively higher relative to diesel and biodiesel. WTPO displays the lowest flash temperature parameter 28.8 °C as compared to diesel fuel and biodiesel. Diesel fuel shows the highest FTP 35.7 °C. The WTPO and DF fuels had less metal extrusion than the BD fuel, according to SEM micrographs. Finally, it is concluded that DF has the best results in terms of wear, whereas WTPO has the best results in terms of friction. As a future recommendation, the purification of the WTPO by using the distillation process and blend with diesel/biodiesel can exhibit better antiwear characteristics.

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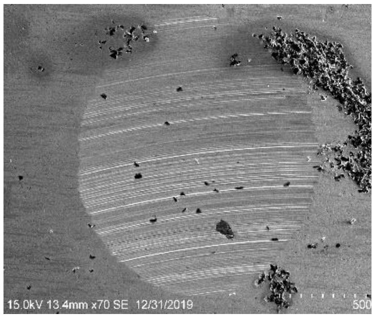
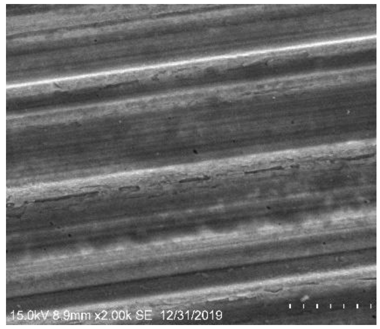
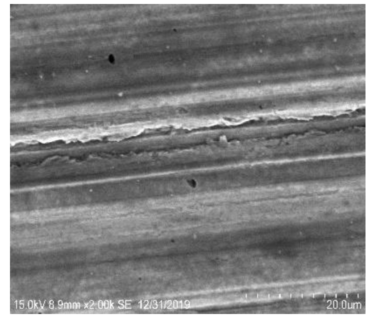


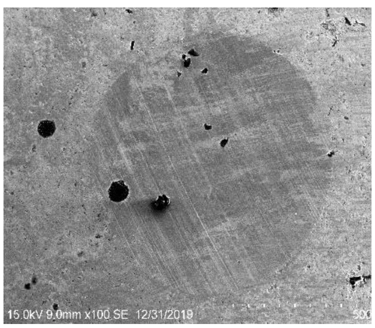
(a) WTPO-70x



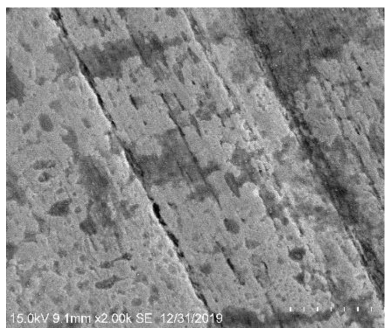
(b) WTPO-2.00kx



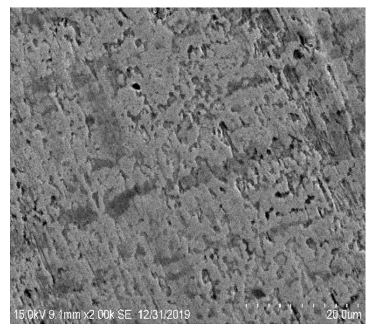
(c) WTPO-2.00kx



(d) DF-100x

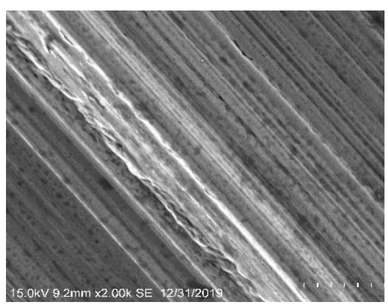


(e) DF-2.00kx



(f) DF-2.00kx

(g) BD-90x



(h) BD-2.00kx

(i) BD-2.00kx

Figure 5: SEM analysis of worn surfaces of the tested steel balls.

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