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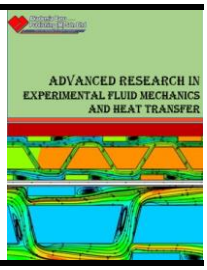

Tribological Characterisation of Biofluid Using Four Ball Experiment

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ABSTRACT

This study presents the tribological characterisation of biofluid that uses plant-based oil namely sunflower oil and olive oil that has been blended with hyaluronic acid as an additive. Plant-based oil is a type fluid that is not harmful to humans and the hyaluronic acid helps the based fluid in absorption shock and distribution of forces. This project aims to measure the performance of this biofluid as an artificial synovial fluid in terms of its coefficient of friction, frictional torque and the wear scar diameter produced. Three different composition volumes of hyaluronic acid were used which are 0%, 5% and 10% in the fluid sample. This sample of biofluid is tested by using four ball tribological testing under one of the conditions which was wear preventive condition. To obtain the coefficient of friction and frictional torque for the biofluid by using the 3D Surface Measurement Systems, we measure the wear scar diameter produced at the ball bearings. The results acquired for this study are the average coefficient of friction and frictional torque that were directly proportional to the volume composition of additives. However, for the average wear scar diameter, it depends on the suitability of volume additives that have been added. Pure sunflower oil has the lowest coefficient of friction which is 0.065940. While, for average wear scar diameter, olive oil with 10% hyaluronic acid recorded the lowest value which is 0.64828mm. It shows that pure plant-based oil has the best lubricant ability which is producing lower coefficient of friction and frictional torque compared to it going to be blend with hyaluronic acid. This result of this project might give benefits to the medical engineering nowadays that related to the case that need the usage of artificial synovial fluid.

Keywords:
Four ball; sunflower oil; olive oil; artificial synovial fluid; hyaluronic acid

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1. Introduction

Synovial fluid is one of the main biofluids in human body. It contains physiological serum, hyaluronic acid, proteins which are albumin and globulin and lipids [1]. Synovial liquid is created as a ultrafiltrate of blood plasma and is fundamentally made of hyaluronan, lubricin, proteinase, collagenases, and prostaglandins. This fluid helps to ensure the smoothness of our joint motion in the body and could absorb shock. According to the medical dictionary, synovial fluid is a clear thixotropic fluid that serves as a lubricant in joints. At sub-atmospheric pressures of about 50 µm, the fluid forms a thin microscopic layer of fluid on the surface of cartilage, filling all joint empty spaces [2]. In addition, synovial fluid also acts as natural lubrication in human body that could reduce friction

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in any movement of our body joint such as knee and hip. However, composition of synovial fluid could increase if the people adopt a healthy diet which is by taking food that contains a lot of good nutrients. Synovial fluid produces a layer of membrane between the fluid and inner articular cartilage. This membrane plays it important responsibility to manage the joint movement in our body and pressure of the cartilage [3,4]. The membrane layer or film also could be destructed when extreme pressure such as high force and temperature been applied to this synovial fluid. However, osteoarthritis affects to the failure of the synovial fluid in human joint to maintain its functions in human joint such as knee caused by smaller volume of the synovial fluid been degenerating in the joint such in Figure 1 [5]. As a result, osteoarthritis causes the patients suffering in musculoskeletal disorders, pain, and mobility limitations, lowering the patient's independence and overall quality of life. In osteoarthritis, hyaluronic acid is easily broken down, resulting of decreasing the effectiveness in the viscous and elastic characteristics of synovial fluid [6]. Therefore, the synovial fluid for the human that is suffering this type of disease has lower viscosity compared to the normal viscosity resulting in reducing the volume composition [7]. From Figure 1, it could clearly be seen that the volume of synovial for healthy joint is greater than the person that facing osteoarthritis. This type of disease usually occurs in older people.

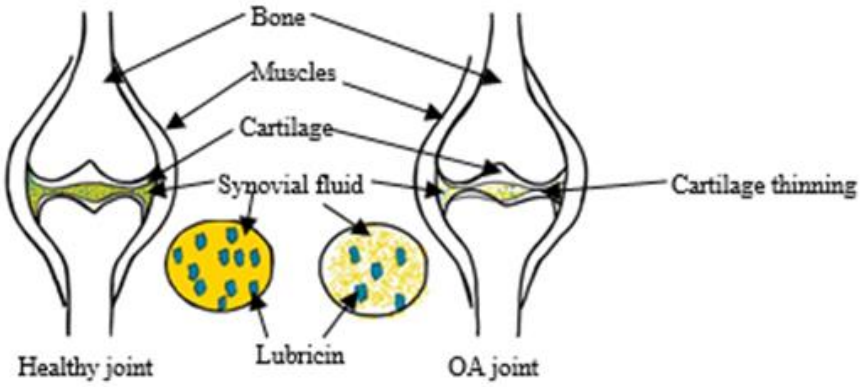

Fig. 1. Comparison volume of synovial fluid

From observation, many medical industries nowadays are treating this type of disease by injecting high volume of hyaluronic acid into the articular cartilage that helps to reduce the pain [8,9]. However, some of the patients who are suffering from this type of disease experience allergies with the high concentration of hyaluronic acid. This will cause patients to face other types of disease in their body such as pseudogout [10,11]. Due to the soaring price of high concentration of hyaluronic acid in the global market, the medical industry is looking towards new ways to overcome this problem [12]. Other than the hyaluronic acid, the combination of alginic sodium acid and lambda-carrageenan could be used as additives because it gives the smaller value coefficient of friction and have been tested by using pin on disc experiment comparing with the one type of additive only [13]. Since there are many demands in the medical sector to help implement the artificial synovial fluid, immediate research and work needs to be run to achieve the objective. Unfortunately, only a small number of researchers that studied the usage of plant-based oil as biofluid for replacement of the synovial fluid in human body joint. In order to produce the artificial synovial fluid, the biofluid with the less viscosity need to be used to produce less friction between the biofluid and the articular cartilage in human joint. This type of biofluid could be replaced by using the plant-based oil that having lower viscosity such as olive and sunflower oil as a based medium and it going to blend with suitable additives such as hyaluronic acid that could produce the membrane layer at the cartilage. Furthermore, the pure plant-based oil does not contain any harmful substances and suitable with the human body [14]. The

presence of suitable additives leads to the success of artificial synovial fluid caused it could increase the viscosity of the biofluid until achieve the best viscosity that reliable to the actual synovial fluid. In past review states that the increasing viscosity going to decrease the shear rate of the biofluid [15,16].

Sunflower seed oil is the non-volatile oil crushed from seeds of sunflower (Helianthus annuus) [17]. Sunflower oil regularly contains 69 percent linoleic acid, 20 percent oleic acid, and 11 percent saturated fatty acids, but a variety of strategies have been used to present an advanced range of sunflower oils with increased oleic acid, stearic acid, linoleic acid, palmitic acid, and low saturated acid [18,19]. It is also viewed as plentiful in minerals like magnesium, iron, copper, calcium, zinc, sodium, potassium, phosphorus, selenium and manganese [20]. These fundamental unsaturated fats are pivotal in cell film development and for support of body formative exercises [21,22]. In research, it was found that the sunflower oil facing the transition phase to form the double crystal phase when it been applied by the pressure in the range of 440 to 500 MPa in duration of 170 hours [23]. On the other hand, graphene reinforced sunflower oil in the form of nanoparticle produced better surface metrology compared to other lubricating fluids [24].

Other than sunflower oil, it was found that pure olive oil could also act as the based-fluid in producing an artificial synovial fluid. Olive oil is the oil produced from the olive tree (Olea europaea sativa) without having been exposed to control or any treatment [25,26]. Olive oil is principally shaped by fatty substances and different a few mixtures in little amounts. Olive oil for the most part comprises of triacylglycerols (98-almost 100%). Triacylglycerols (TGA) are an assorted gathering of glycerol esters with various unsaturated fats [27]. Among the glyceride division, olive oil shows a high content of unsaturated fats and especially, a raised extent of monounsaturated unsaturated fats (MUFA). Unsaturated acids ultimately depend on 85% of its synthesis, because it is highly saturated in oleic acid (C18:1), which could run between 70-85% and other unsaturated fats as linoleic or palmitoleic acid [28]. In a study, by usage of olive oil diet give beneficial in medical therapy which is to forestall osteoarthritis illness to safeguard the articular ligament and afterward the whole joint [29]. The unsaponifiable fraction from the olive oil also reduces joint pains while improving the mobility of the patients that experienced osteoarthritis [30]. Hydroxytyrosol in extra virgin olive oil is a powerful antioxidant that can influence specific signal transduction in chondrocytes that preventing from the inflammation and cartilage degradation [31].

In this study, the sunflower oil and olive oil were blended with hyaluronic acid and tests were carried out using a Fourball Tribotester and 3D Surface Measurement Systems (Alicona). Thus, the purpose of this study is to investigate the tribological properties which are the coefficient of friction, friction and also the wear scar diameter of the solution of biofluid.

2. Methodology

2.1 Apparatus and Procedures

For this research, Fourball Tribotester have been used by following the standard of the ASTM D4172 which is a test method to study about the wear preventive characteristics of lubricating fluid. Figure 3 shows the machine of Fourball Tribotester that is being used while Figure 2 shows the schematic diagram for the position of all four balls that have been used in which 3 balls were located at the bottom in the ball pot and another one ball was located at the top at the spindle [32]. The ball pot has been tightened through torque wrench of 50 lb-ft. In this study, a new set of four balls been used for every sample that is going to be tested and it will soak in the N-Heptane to ensure the cleanliness of every balls. The ball pot containing 10ml of the sample fluid which will drown the balls at the bottom and it will be pressed by a ball at the top with force around 40kg (392.2N) and rotating

at the speed of 1200rpm. In addition, the sample fluid will be heating up to 75°C and this experiment is going to run in 60 minutes. Table 1 shows the specifications of balls that been used in this study [33]. Other that Fourball Tribotester, 3D Surface Measurement System (Alicona) with the usage of the optic IFM G4 10x have also been used in this research in order to measure the wear scar diameter that is being produced at the three balls at the bottom. By using this system, the surface of wear scar can be seen clearly in term of its surface characteristics in 3-dimension view. Figure 4 shows the Alicona System that have been used in this research. When using the system, it must be ensured that the usage of suitable optic such as in this study, IFM G4 10x have been used and the specimen was also clean from any droplets of the test lubricant. Other than that, every optic has their range values of vertical resolution that must be set up in order to obtain a clear sight of the surface that needs to be observed. In addition, the position of the microscope needs to be adjusted until the suitable distance between the specimen and the microscope. The brightness and contrast settings also play important roles to get clear view of sight of the wear scar when using 3D Surface Measurement System.

Table 1
Specification of balls [33]

Item	Specification
Material	Chrome alloy steel (AISI E-52100)
Diameter (mm)	12.7
Extra polish (EP) grade	25
Rockwell hardness (HRC)	64 - 66
Chemical composition	A high carbon, chromium containing low alloy steel that has been hardened

2.2 Frictional Torque and Coefficient of Friction

The data for the frictional torque was obtained from the Fourball Tribotester machine directly. This data increases rapidly in early few minutes before it going to be in a steady state condition. Based on the IP-239, the coefficient of friction calculated as in Eq. (1).

$$\mu=(T\sqrt{6})/3Wr \quad (1)$$

This method of calculation have also been used by other researchers [34,35]. However, in this research, both values of frictional torque and the friction coefficient were calculated automatically by the system of the Fourball Tribotester machine.

2.3 Test Lubricants

There are 2 types of lubricants from the plant-based oil which are sunflower seed oil and olive oil as the medium-based oil. The plant-based oils are well-known in Malaysia for food industrial usage. These types of oils are going to blended with the additives which is hyaluronic acid with three different volume composition and the total volume of the biofluid was 10 ml that will put inside the ball pot. Three volume compositions are 0%, 5% and 10% of hyaluronic acid. The tests for different samples of biofluid were labelled from Sample 1 until Sample 12 as shown in the Table 2.

Based on the ingredients in these two types of plant-based oil, it was containing almost the same nutrient especially fat. It was found that the monounsaturated fat, polyunsaturated fat, saturated fat and also trans fatty acid in both olive oil and sunflower seed oil. In order to ensure all of the nutrients were there, the plant-based oil that have been used should not exceed its expiry date. All of the sample of both oil and hyaluronic acid had been measured of its volume by using different syringe. It caused the more accurate volume going to be used and followed all of the blending composition as the scope of work in this study. The usage of different syringe for three different fluids which are olive oil, sunflower oil and hyaluronic acid was to prevent the mixing of unwanted blending. The blending process was done by using a glass beaker in the fume hood.

Table 2
Test lubricant's labels

Test (run)	Sample	Type of lubricants
1st	1	Olive oil + 0% ml HA
2nd	2	
1st	3	Olive oil + 5% ml HA
2nd	4	
1st	5	Olive oil + 10% ml HA
2nd	6	
1st	7	Sunflower oil + 0% ml HA
2nd	8	
1st	9	Sunflower oil + 5% ml HA
2nd	10	
1st	11	Sunflower oil + 10% ml HA
2nd	12	

2.4 Wear Scar Diameter

With the help of 3D Surface Measurement System, every scar produced after the wear preventive test had been done is going to be measured. By using the high resolution and optical microscope which is IFM G4 10x, the surface characteristics such as diameter was captured. In addition, the vertical resolution of the microscope also been set up to 500 nm to obtain a clear sight of the wear scar characteristics. Every three balls at the bottom in every test had been measured. Nonetheless, the average of the diameters been calculated to reduce the error value.

3. Results

3.1 Effect on Frictional Torque and Coefficient of Friction

From the result of frictional torque, the value increases for a few seconds in the early stage of the Fourball Tribotester testing before it remains in a steady state condition. Frictional torque was the torque produced from the applied force which is about 392.2 N when the ball on the top was in contact with three balls at the bottom. The result of frictional torque for every sample of test lubricant based on the medium-based oil obtained is illustrated in Figure 2 (a) and (b). The coefficient of friction (COF) for olive-based oil is depicted in Figure 3(a) and for the sunflower-based oil, the Figure 3(b).

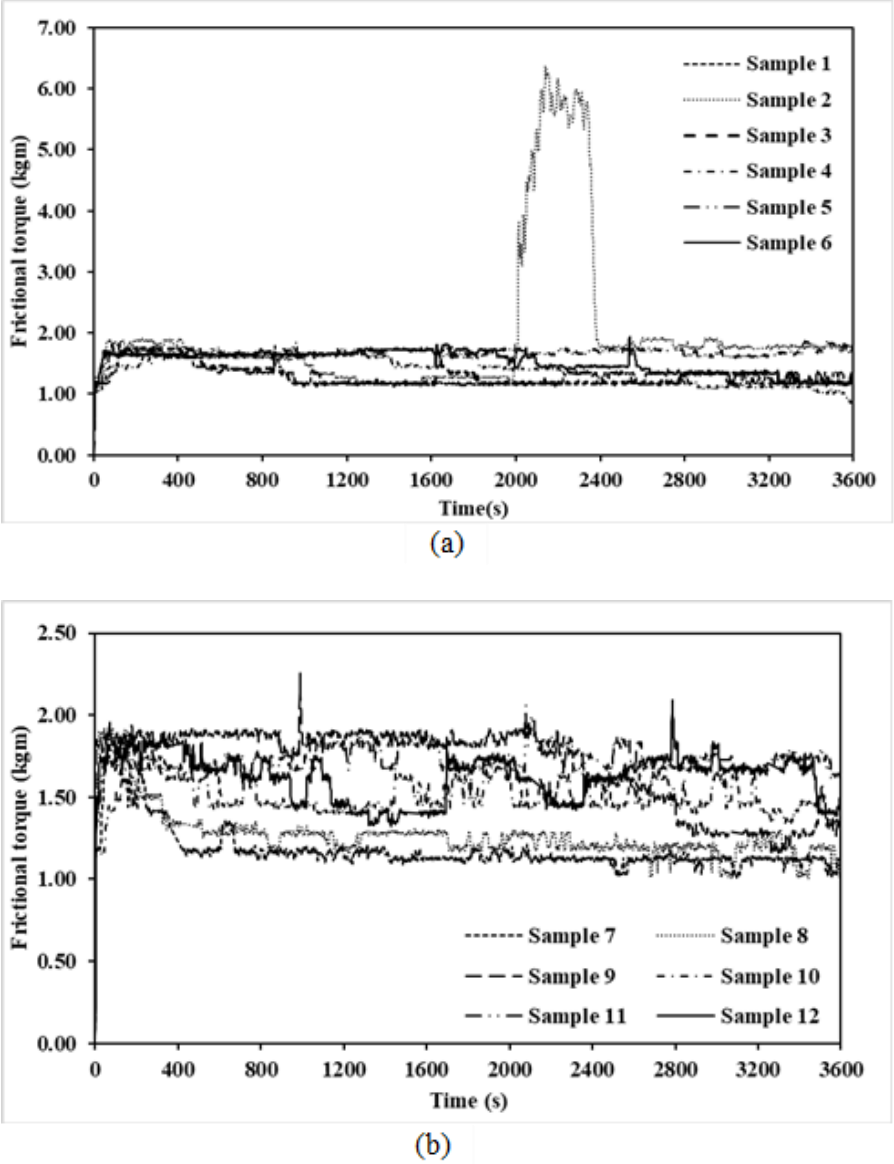

Fig.2. Fictional torque of (a) olive oil (b) sunflower oil

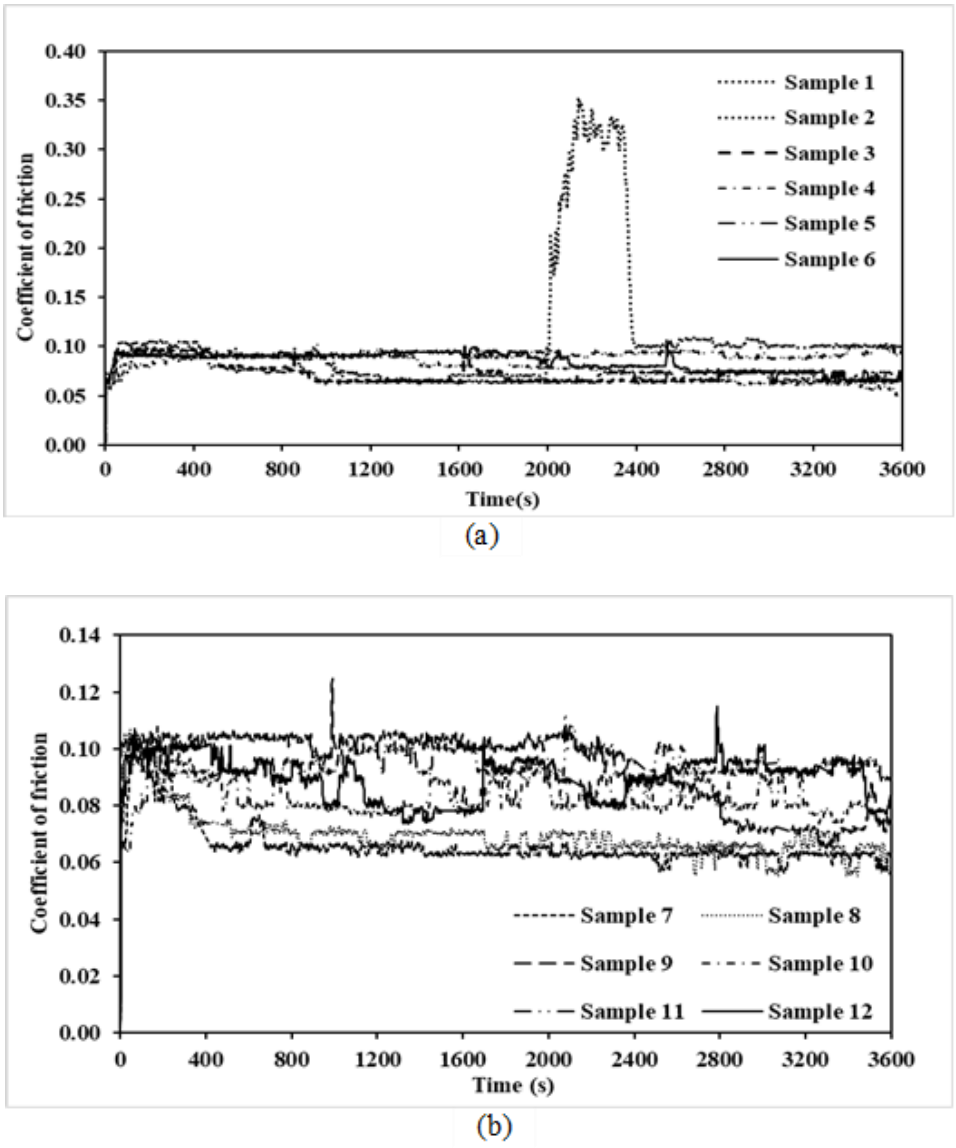

Fig. 3. Coefficient of friction (COF) of (a) olive-based oil (b) sunflower-based oil

4. Conclusions

In summary, the additive of hyaluronic acid was not suitable to blend with the plant-based oil which are olive oil and sunflower oil. This is due to the increase of the coefficient of friction and producing larger wear scar diameter. Pure plant-based oil has the better lubricant ability compared with the blended oil. However, for the olive oil, it is suitable to be blended with 10 percent volume composition of hyaluronic acid which produce smallest average wear scar diameter which is 0.64828mm that seen to be a lubricant that having higher preventive conditions. While, pure sunflower oil which is Sample 7 producing the smallest average coefficient of friction and frictional torque which is 0.065940 and 1.17495818727008kgm respectively. All in all, with the aid of the hyaluronic acid, olive oil as medium-based oil has better result in term of it tribological characteristics compared to sunflower oil. It is clearly seen on the results, where with the based- medium of olive oil produce less frictional torque, coefficient of friction and also smaller wear scar diameter. As a result, it is expected that the contribution of this chapter would be advantageous not only to the defined lubricant outline, but also to the general academic and tribology community.

Acknowledgement

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