Friction and Wear Analysis of UHMWPE Material Using Pin-on-Disc Tester with Lubricant and Non-Lubricant

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Abstract. Ultra-high molecular weight polyethylene (UHMWPE) is a biomaterial that is widely used in the manufacture of acetabular liners for the application of artificial hip joints (AHJ). The problem that often arises from UHMWPE material is the occurrence of wear debris as a result of the mechanism of contact of UHMWPE material with its partner material on AHJ. The purpose of this research is to analyze the friction and wear behavior of UHMWPE material which is paired with AISI 316L. Wear test using a pin-on-disc tribometer in dry conditions and serum bovine lubricant. SEM-EDX analysis is used to see the phenomenon of wear track and absorption of AISI 316L metal elements that occur in UHMWPE. The results showed that the use of bovine serum significantly decreased the friction and wear rates of the UHMWPE / AISI 316 pair.

1. Introduction

Osteoarthritis (OA) is a degenerative joint disease that is most often found in elderly people. This disease is characterized by inflammation of the cartilage which will eventually lead to damage to the joint structure and damage to the cartilage itself [1]. In the normal hip joint, there is a natural lubrication in the form of synovial fluid which functions to lubricate the contact mechanism in the joint. This reduced synovial fluid results in the function of lubrication in the joints not working properly which will ultimately damage joint cartilage [2]. In the case of OA on a mild to medium scale, to maintain good joint movement and reduce pain for people with OA, it can be done by injecting hyaluronic acid (HA). However, if OA is already in a severe level, surgery must be performed to replace the natural hip joint with an artificial hip joint (AHJ) [3].

Many combinations of material pairs are used in artificial hip joints. One of them which is widely used is the pair of ultra-high molecular weight polyethylene (UHMWPE) material with metal components. In the process of using AHJ, the contact mechanism between UHMWPE material and metal components will produce UHMWPE wear particles that are separated from AHJ. It is this process that eventually causes implant failure [4]–[7]. Therefore, in order to increase the AHJ lifetime, the UHMWPE wear rate must be kept to a minimum.

To find solutions to these problems, many researchers have made various efforts so that the UHMWPE wear rate on AHJ can be minimized. One of them is by conducting UHMWPE (UHMWPE crosslinking) irradiation using gamma rays (γ). This method has been proven effective in reducing the UHMWPE wear rate, but it has the disadvantage of being able to reduce the mechanical properties of
UHMWPE such as ductile properties, tensile strength and resistance to fatigue cracks [8]–[10]. Efforts with the same objective were also carried out by several researchers to minimize the UHMWPE wear rate value by adding reinforcing material in the process of making UHMWPE (UHMWPE reinforced by filler) ram extrusion or compression moulding processes [11]–[14]. Coating technique was also carried out by researchers on metal material from AHJ to reduce the UHMWPE wear rate [15], [16].

The efforts of researchers to try to reduce the UHMWPE wear rate do not stop at the modification of UHMWPE material, but also on the lubrication side. Research has been conducted to find which lubricants produce the least wear value. Some lubricating fluids studied include bovine serum, saline solution, sesame oil, nigella sativa, hyalgan, sodium hyaluronate [7], [11], [17]–[20].

In the present study, we investigate the tribological behavior of UHMWPE against AISI 316L pins using a pin-on-disc tribometer. The tribological tests will be carried out in dry and lubricated conditions using bovine serum. The friction coefficient and wear volume of UHMWPE against metallic pins were measured and compared. Morphological and chemical analyses on metallic pins and UHMWPE were conducted after wear tests.

2. Materials and methods

2.1. Materials

In this study, AISI 316L was used as the pin material. Disc specimens are made from UHMWPE material that is made using the compression moulding process. Disc specimen consists of 4 specimens. Two specimens were used for dry testing and two specimens for testing with bovine serum lubrication. K1-NL and K2-NL specimen codes are used for disc specimens in non-lubrication (NL) tests. K1-L and K2-L codes are used for specimens in the testing for bovine serum lubrication. The dimensions of pin and disc specimens can be seen in Figure 1 and Figure 2. Lubricants in the contact mechanism of pin and disc material use bovine serum [17], [21]. This serum is obtained from the centrifuge process of cow blood obtained from Rumah Potong Hewan (RPH) Semarang-Indonesia officially.

![Figure 1](image1.png)  
Figure 1. Specimen dimension of pin (mm).

![Figure 2](image2.png)  
Figure 2. Specimen dimension of disk (mm).

2.2. Methods

2.2.1 Tribological test

Tribology tests were performed using a pin on disc tribometer as shown in the Figure 3. Before the tribology test is carried out, the UHMWPE disc specimen is first cleaned using ethanol [18]. During the testing process, the specimen pin is attached to the specimen holder and the UHMWPE disc continuously rotates at 50 rpm. Normal load is set to 20 N. This value is considered on the basis of
previous research [22], [23]. The number of cycles was fixed at 50,000 cycles which is equal to a total sliding distance of 12,560 m.

After the tribology testing process is complete, the next step is to measure the wear track profile on the UHMWPE specimen. Tool for measuring UHMWPE wear track profiles using Mitutoyo SJ-210 surface roughness tool. The measurement of wear track profiles aims to determine the dimensions of UHMWPE material track wear due to wear that occurs during tribology tests. Examples of wear track profiles can be seen in the Figure 4. The red area in the Figure 4 will be used as data for the calculation of wear rate.

To calculate the wear rate (K) used (equation 1). The average volumetric wear ΔV (mm) was then calculated by multiplying cross-sectional surface by 12,560 m (the total sliding distance of wear track). where $F_N$ (N) is the applied normal load and $L$ (m) is the total sliding distance [18], [24].

$$K = \frac{\Delta V}{F_N L}$$  

(1)

2.2.2 Characterization techniques

Testing using a scanning electron microscope (SEM) aims to see the phenomenon of wear on UHMWPE. With the SEM test, it can be seen more clearly wear track and plastic deformation phenomena that occur as a result of the contact of AISI 316L material with UHMWPE. Tests using an energy dispersive x-ray spectroscopy (EDX) tool are intended to look at the elemental composition of the UHMWPE specimen, especially those found at the wear track location. Is there absorption of metal elements from AISI 316L or not. SEM and EDX testing uses JEOL JSM-6510LA. In this
research, a tool to measure the UHMWPE wear track profile uses the Mitutoyo SJ-210 surface roughness tool. Wear track profile data from Mitutoyo SJ-210 is processed using graph analysis software to calculate the wear volume of UHMWPE.

2.2.3 Statistical analysis
The results of tribology tests on the pin on disc tribometer will produce friction coefficient data of 50,000 for each UHMWPE specimen. Even though there are 4 times of specimen tests (2 times of dry conditions specimens and 2 times of lubrication conditions specimens), so there are a total of 200,000 data that must be processed. In analyzing this data, analysis of variance (ANOVA) was used with a significance level of 5%. This analysis aims to determine how significant the effect of serum bovine lubrication on the coefficient of friction coefficient of UHMWPE specimens. Data analysis software and scientific charts are used to calculate ANOVA analysis. The type of ANOVA analysis used is one-way analysis. Some researchers have also used ANOVA analysis to test how significantly an independent variable affects the dependent variable of a test, in this case the UHMWPE tribology test [9], [12], [24]–[26].

3. Results and discussion

3.1. Statistical analysis
ANOVA analysis of 200,000 datas from 4 (four) tribology test specimens was performed to obtain an analysis of the significance of the data. Based on the results of ANOVA analysis with a significance level of 5% that has been done, it shows that bovine serum lubrication has a significant effect on the value of the resulting friction coefficient.

3.2. Friction behaviour
The results of tribology testing can be seen in Figure 5. This graph displays the relationship between the coefficient of friction and the number of test cycles. Different trend lines are seen for testing under dry conditions and with bovine serum lubricating. In the non-lubrication conditions (K1-NL), it can be seen that the trend line from the friction coefficient graph of the UHMWPE specimen is small at the initial stage of the test and becomes larger at the transition stage, before the friction coefficient value is finally stable at the end of the test. This behavior is consistent with the results of previous studies [7], [23]. Although the K1-NL and K2-NL specimens have slightly different coefficient of friction values, they remain at a reasonable value based on data from previous studies [22], [23], [27].

Graphs K1-L and K2-L show the value of the coefficient of friction of UHMWPE material against AISI 316L material under conditions of lubricating bovine serum fluid. In the graph, it can be seen that the trend line of the coefficient of friction of the K1-L and K2-L specimen are large at the initial stage of testing and becomes smaller at the transition stage, before the friction coefficient value is finally stable at the end of the test. This is consistent with what has been done by previous researchers [7], [18], [23].
Figure 5. The friction coefficient of UHMWPE under lubrication and non-lubrication conditions.

3.3. Wear behaviour

Figure 6 shows the results of the UHMWPE specimen wear rate values for non-lubricating (NL) and lubricated (L) conditions. The blue color in the graph shows the wear rate value for non-lubricated specimens and the red color shows the wear rate value for specimens that are lubricated. The results of the calculation of the average wear rate of each specimen can be seen in Figure 6. In the picture, it can generally be seen the phenomenon of decreasing wear rate values for all UHMWPE specimens from non-lubricating conditions (NL) to lubricated conditions (L). Based on Figure 6 it can also be seen the positive effect of using bovine serum as a contact lubricant mechanism between UHMWPE material and AISI 316L in terms of increased wear resistance. This increase in wear resistance is closely related to the protein content found in serum bovine, namely albumin and \( \gamma \)-globulin. Formation of this protein layer on the contact mechanism of UHMWPE and AISI 316L will reduce the occurrence of friction which results in a significantly decreased UHMWPE wear rate value [21], [28].

Figure 6. Wear rate of UHMWPE.

In the SEM results of the K1-NL specimen (Figure 7a), the wear mechanism can be seen including ploughing and plastic deformation. Whereas the SEM results of K1-L specimen (Figure 7b) can be seen using the mechanism such as ironing, scratching, ploughing and plastic deformation. Of the four
types of wear mechanisms, it appears that the most dominant are ironing and scratching. The dominant ironing mechanism is a material characteristic that has good wear resistance. Whereas the dominant plastic deformation mechanism will contribute to the decrease in UHMWPE wear resistance [27]. This difference in the wear mechanism causes the K1-NL specimen wear rate to be greater than the K1-L specimen.

![Figure 7. SEM images of UHMWPE (a) K1-NL specimen (b) K1-L specimen (I) Ironing. (II) Scratching. (III) Ploughing. (IV) Plastic deformation.](image)

The EDX test results for K1-NL and K1-L specimens can be seen in Figure 8. In the figure there are four main elements to be compared, namely elements C, Fe, Cr and Ni. Element C is the main constituent of UHMWPE. While the elements of Fe, Cr and Ni are the three largest elemental compositions found in AISI 316L material. Figure 8 shows that the composition of element C in the K1-NL and K1-L specimens was 99.87% and 98.58%, respectively. A positive result is that no Fe and Cr elements enter the UHMWPE material structure, both under non-lubricating conditions (K1-NL) and under lubricated conditions (K1-L). There is a Ni element content of 0.04% in the K1-L specimen. Nickel content must be wary because it can cause local irritation to the tissue and necrosis [29].

![Figure 8. EDX test result of UHMWPE.](image)
4. Conclusion
After testing and analyzing the results of tribology testing both in conditions without lubricating and lubricating bovine serum, the following conclusions are obtained: (i) the use of bovine serum as a lubricant has a significant impact on wear resistance in all UHMWPE specimens; (ii) the amount of metal element from AISI 316L material absorbed into UHMWPE material both in dry conditions and serum bovine lubricant is still relatively safe for the human body.

5. References
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