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The Tribology Behaviour of Polycarbonate Urethane (PCU) as Advance Material on Biomedic

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ABSTRACT

End-stage osteoarthritis of the hip can be treated by replacing the joints using an artificial hip joint. Recent research states that polycarbonate urethane (PCU) can be used as an alternative bearing in UHMWPE material because of its better properties. This study aimed to determine the value of friction coefficient, the width of wear track, The volume of wear track, wear rate, and wear particle analysis. The method used is to test the wear of the PCU material using a pin on the disc tribometer machine. The wear test was carried out for 50,000 cycles with a loading of 500 grams and variations in speed (50 Rpm, 100 Rpm, 200 Rpm). The test is carried out in conditions without lubrication. The results of this study showed that the average friction coefficient of 50NL, 100 NL, and 200NL PCU discs were 0.114, 0.116, and 0.127, respectively. The width track values of the 50NL, 100 NL, and 200NL disc specimens were 2,679 mm, 4,168 mm, and 5,211 mm, respectively. The volumetric wear values of the 50 NL, 100 NL, and 200NL disc specimens were 76,428 mm^3, 355,104 mm^3, and 1049,328 mm^3, respectively. The wear rate specimen disc values of 50NL, 100 NL and 200NL using the wear track calculation method were 1.352 x 10^{-3} mm^3 / Nm, 6.283 x 10^{-3} mm^3 / Nm, and 1.857 x 10^{-2} mm^3 / Nm, respectively.

Keywords: polycarbonate urethane (PCU), pin on the disc, coefficient of friction, wear rate

Introduction

Biomaterials are synthetic materials that are used to make medical devices and interact with biological systems in their use. One of the biomaterials applications is the treatment of osteoarthritis. Osteoarthritis is a disease that attacks the joints, caused by a series of processes ranging from structural disturbances, then spreading to the joints, and finally causing failure in the joint area (Nuki, 1999). One of the most common ways to treat osteoarthritis problems, especially in the hip, is to do a total hip replacement (THR) (Mellon, *et al.,* 2013). THR is a hip replacement medical operation in the form of cutting the head and neck of the femur and removing the acetabular cartilage which is replaced by a prosthesis (Siopack & Jergensen, 1995). In total hip replacement (THR), there are several constituent parts, including the femoral stem, femoral neck, femoral head, acetabular liner, and acetabular shell (Pruitt & Chakravartula, 2011). There are various types of bearing pairs in artificial hip joints, including metal on metal bearings, polyethylene on metal bearings, ceramic on ceramic bearings, polyethylene on ceramic bearings, and polycarbonate urethane on metal bearings (Gabarre *et al*., 2014).

One of the polymers used in the manufacture of bearings in artificial hip joints in the human body is ultra-high molecular weight polyethylene (UHMWPE). This material has been used in implants in the human body since the early 1960s and remains the best standard as a polyethylene

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on metal bearing material in total joint replacement (Kurtz, 2009). This cannot be separated from the nature of UHMWPE which is resistant to wear and pressure (Muratoglu, 2001).

In recent years, a type of polyurethane family, polycarbonate urethane (PCU), has been proposed as a suitable candidate to replace UHMWPE as a bearing material in orthopedic applications (Muratoglu, 2001). PCU materials show lower friction and wear rates than UHMWPE (Smith, Ash, & Unsworth, 2000). PCU also has good biocompatibility, which is proven by having resistance and resistance to chemical testing. Besides, the mechanical properties of PCU are also of better value than UHMWPE. These advantages allow PCU material to be aligned with UHMWPE in terms of its good biocompatibility and mechanical properties. Another study conducted by (Smith, Maghsoodpour, & Hallab, 2009) showed that PCU has the same or even better wear properties than UHMWPE due to its hydrophilic properties, and the modulus of elasticity of PCU is said to be 70 times more flexible than UHMWPE.

From some of the descriptions of the explanation above, it can be concluded that polymers, especially PCU, are a material that can support implant prosthesis tools because of the many properties of PCU which are suitable for the manufacture of implant prosthesis tools, especially bearing material. Besides, the properties of PCU are of better value than the previous bearing material, namely UHMWPE, so that it can improve the quality of prosthetic bearings. As a bearing material, an understanding of the tribology of the material must be made, especially the wear and friction coefficient of the bearing material (Cowie *et al*., 2019). It is necessary to analyze the number, size distribution, and volume of wear particles produced to determine the level of wear (Elsner *et al*., 2010). This can be done by testing using a tribometer, namely, a pin on the disc. The pin on disc tribometer is a machine that can simulate movement in the joints because the contact form on the tool is in the form of rotation (ASTM, 2000) which resembles joint motion. Also, the final result is influenced by the presence of a lubricant or without lubrication, because the results obtained will be different even in the same lubricating conditions but different lubricants are used. The purpose of this study was to determine the tribology phenomenon of PCU materials by carrying out wear testing using a pin on the disc tribometer machine. The test was carried out in dry conditions (without lubrication) with variations in the speed of 50 Rpm, 100 Rpm, and 200 Rpm. The results of the test are the friction coefficient and the wear rate.

Research Method

The research begins by literature review to study matters related to research. The next step is to make a disc and pin specimen. The materials used in this study were PCU for disc specimens and SS 316L for pin specimens. Disc specimens are manufactured using compression molding, whereas pins are manufactured by turning machines. The wear test was carried out using a pin on disc tribometer engine in dry conditions (without lubrication). Each test was carried out with variations in rotational speed, namely 50 Rpm, 100 Rpm, and 200 Rpm. The fixed variables in this test are the same loading value of 500 grams, and the number of cycles used is 50.000 cycles. After the wear test is carried out, the wear track geometry is measured using a surface roughness tool to determine the width, depth and volumetric area of the resulting wear track. The existing wear track geometry data is then used in calculating the wear rate according to the wear track calculation method. The flow chart of the PCU material wear testing in this study is shown in Figure 1.

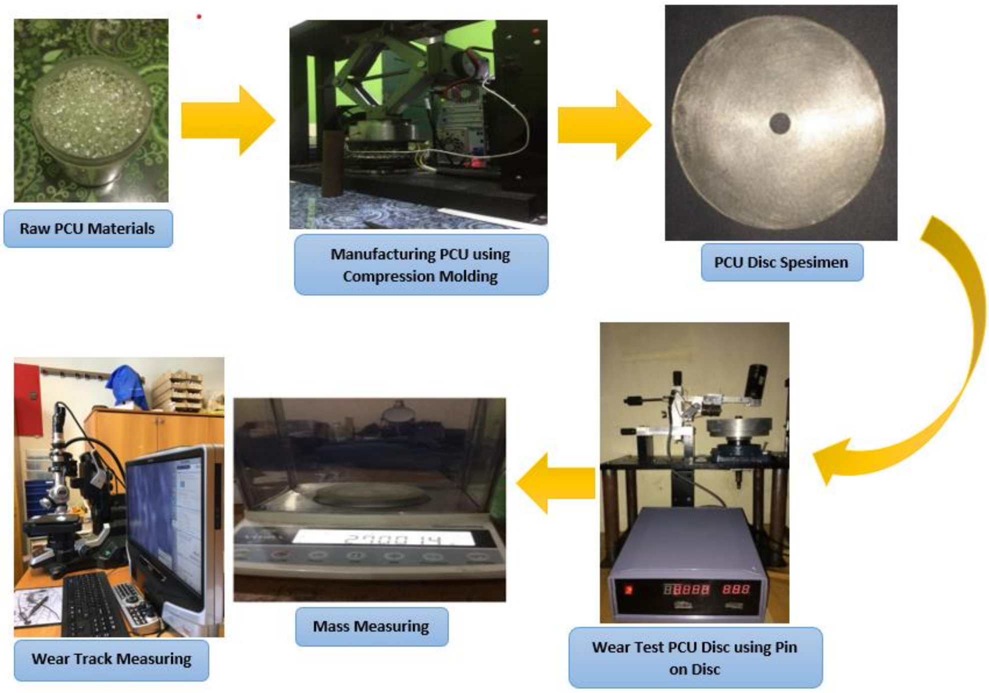


Figure 1. The flow chart of PCU material wear test using the pin on disc machine

Results and Discussion

Tribological testing is carried out to determine tribological phenomena such as friction, wear on the contact mechanism between the SS 316 L pin and the PCU disc. The pin on the disc test is performed in dry conditions (dry test). The test was carried out using a pin on disc tribometer. The results obtained from these tests are mass reduction after testing, friction coefficient, and wear track geometry profile of PCU disc specimens. Mass measurement in this study was conducted to determine the mass value of the disc before and after the pin on the disc, the test was carried out. This measurement was carried out because during the test there was a reduction in size and volume in the form of frictional pieces called wear particles. The results of PCU mass measurement are shown in Table 1.

Table 1. PCU disc mass measurement results

No.	Name of PCU disc	Before	After
1.	50 NL	27,088 g	27,001 g
2.	100 NL	27,083 g	26,691 g
3.	200 NL	27,057 g	25,883 g

Friction coefficient

The coefficient of friction data obtained from the three PCU disc specimens as much as 150,000 data. The data is then processed using statistical data processing software to determine the trendline of the friction coefficient value of each PCU disc. The graph that shows the results of the trendline value of the PCU disc friction coefficient can be seen in Figure 2. Based on the friction coefficient graph, it can be seen that the three PCU disc specimens show almost the same trendline friction coefficient. The three specimens, namely the PCU 50NL, 100NL, and 200 NL disc specimens, had a large trendline at the beginning then increased slowly to the highest point, ending with a decrease at the end of the cycle. The average value of the friction coefficient of the three PCU disc specimens was analyzed using ANOVA with a significance level of 5% in the statistical data processing software. Based on the analysis, the results showed that the 50NL specimen had an average friction coefficient of 0.114. The 100NL specimen has an average friction coefficient of 0.116. The 200NL specimen has an average friction coefficient of 0.127.

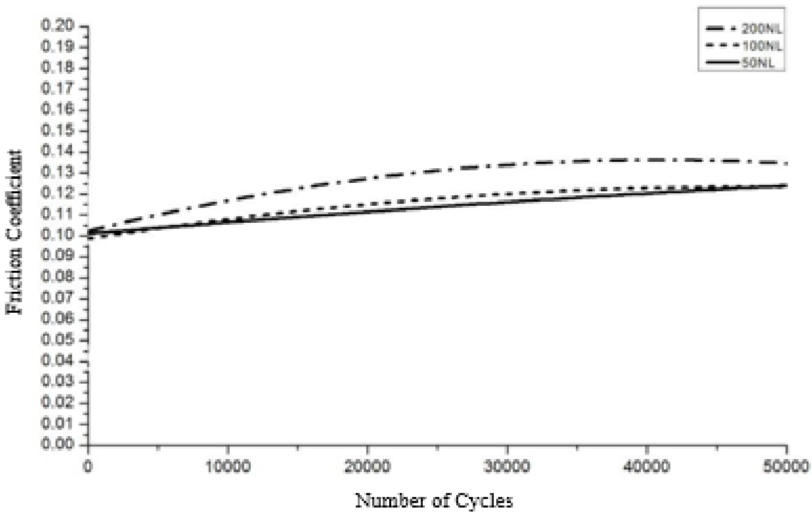
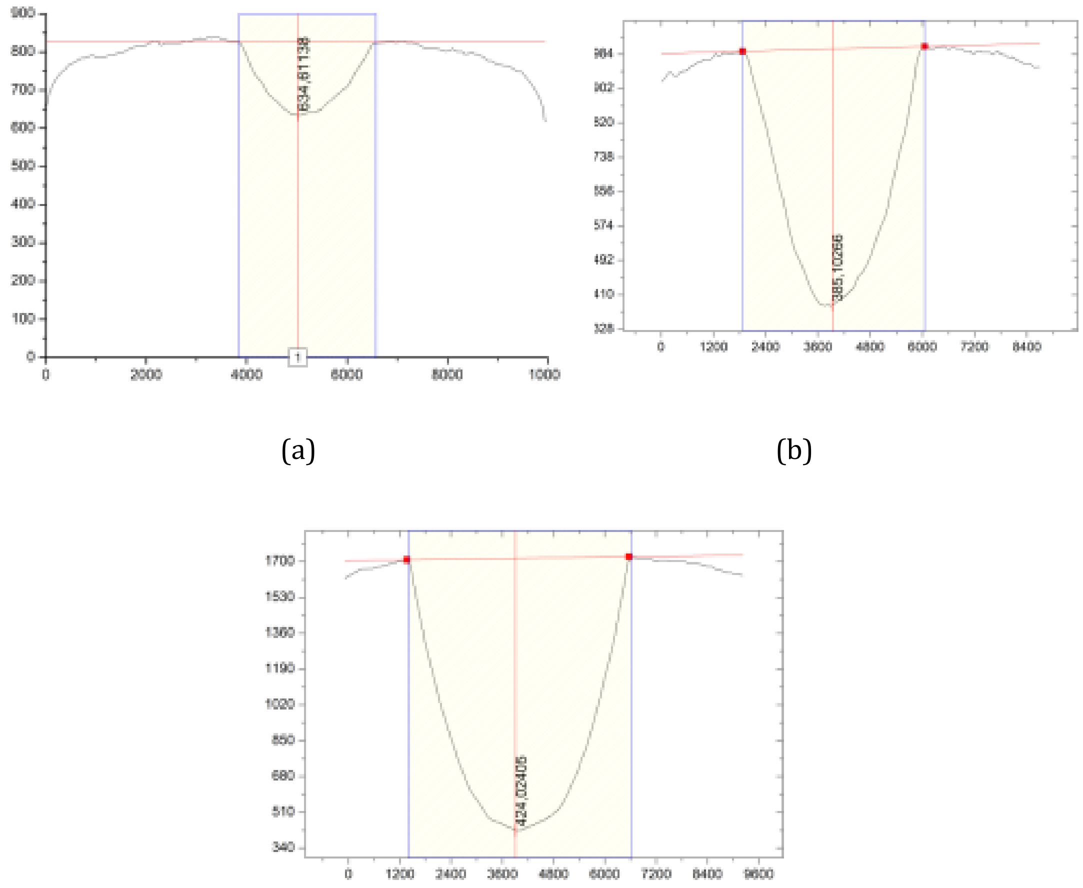


Figure 2. Graph of the friction coefficient for the three PCU disc specimens

The friction speed affects much higher than the applied pressure. The friction between the materials results in the formation of heat at high temperatures and hence increases the temperature at the friction surface of the two materials. The higher the friction speed the higher the temperature increases, and as the temperature reaches the polymer softening point, the adhesive component increases leading to a higher friction coefficient value (Unal *et al*., 2004). It can be concluded that the higher the rotational speed used, the higher the coefficient of friction. From the results obtained, the value of the PCU disc friction coefficient is smaller than the coefficient friction value of the UHMWPE disc for dry lubrication conditions.

Wear rate

Specimens that have been tested for the pin on disc wear are then measured for their wear profile using a Mitutoyo SJ-210 surface roughness tool. The results of measuring the wear track profile of each PCU disc specimen can be seen in Figure 3. From the predetermined pin on the disc test, several values were found that can be used to calculate the wear rate (Ka). The volumetric wear value in this method is calculated from the track wear profile. The calculation of the wear rate (Ka) can be done using equation (1). The load is given (P) is 500 grams. The value of the sliding distance on a PCU disc with a diameter can be calculated by equation (2).



(a) (b)

(c)

Figure 3. PCU disc specimen wear profile (a) 50 NL, (b) 100 NL, (c) 200 NL

$$Ka = \frac{V}{Fn\ S} \qquad (1)$$

S = Circumference 1 Turn x Number of Cycles (2)

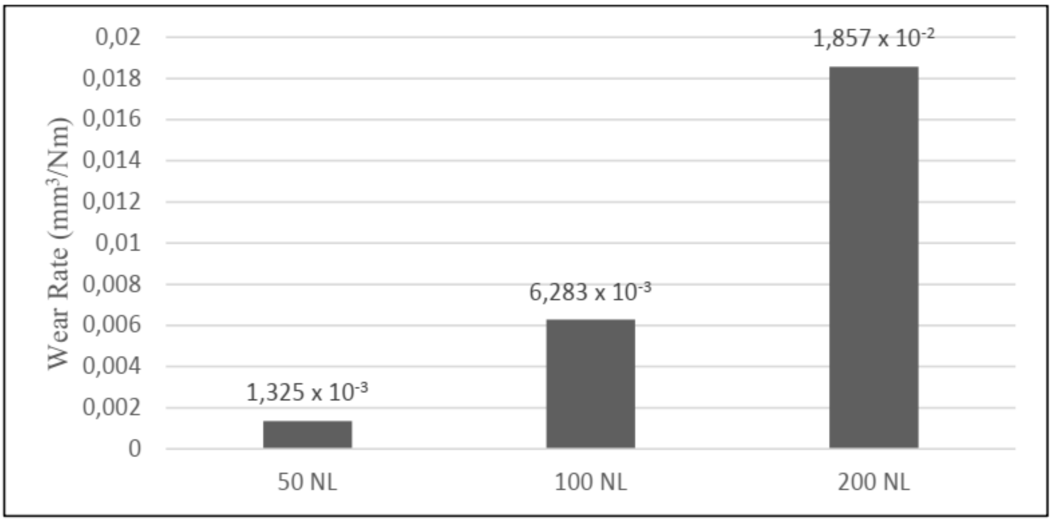
Where,
Radius = 0.036 m
Circumference 1 Turn = 2πR = 2 x 3.14 x 0.036 m = 0.22608 m
Number of Cycles = 50,000 Cycles

V = A x S (3)

Where:
Ka = wear rate (mm3 / Nm)
V = Volumetric wear (mm3)
Fn = Load given (N)
S = Sliding distance (m)
A = cross sectional area (mm2)

From the results of the above calculations, the value of the sliding distance (X) can be obtained. amounting to 11.304 m. The method for calculating the wear rate is with calculates the volumetric wear of the PCU disc wear track. Volumetric wear can be obtained by multiplying the cross-sectional area of the wear track by the sliding distance for one turn. The equation used is equation (3). By using the calculation results and equation (3), the wear rate value for each PCU disc specimen can be found.

The wear rate values for the three PCU disc specimens were obtained using the volumetric wear calculation method using a wear track. In the volumetric area calculation method using the wear track, data such as track width, track depth for each specimen, volumetric area, and wear rate values are obtained. The results of these calculations are then discussed and compared with existing studies to determine the validation of the values obtained. In this study, the smallest track width value is 2.679 mm which is owned by the 50 NL PCU disc specimen. This was followed by the PCU 100 NL disc specimen with a track width of 4.168 mm. The largest track width value is owned by the PCU 200 NL disc specimen, which is 5.211 mm. Similar to the track width, the smallest track depth in this study is also owned by the PCU 50 NL disk specimen, which is 0.193 mm. This was followed by a 100 NL PCU disc specimen with a track depth of 0.612 mm, and the largest depth was owned by a 200 NL PCU disc specimen of 1.292 mm.



Gambar 4. The wear rate value for each PCU disc specimen

The results of the calculation of the volumetric wear value showed that the PCU 50 NL disc specimen had the smallest value, which was 76.428 mm^3. Furthermore, the PCU 100 NL disc specimen had a value of 355.104 mm^3, and the largest volumetric wear value was found in the PCU 200 NL disc specimen of 1049.328 mm^3. The results of the wear rate calculation in this study are shown through a graph in Figure 4.Based on the graph, it can be seen that the 50NL disc specimen has the smallest wear rate of 1.352 x 10^{-3} mm^3 / Nm, followed by the 100NL specimen which has a wear rate of 6.283. x 10^{-3} mm^3 / Nm. The highest wear rate is owned by the 200NL disc specimen, which has a wear rate of 1.857 x 10^{-2} mm^3 / Nm.

Conclusion

Based on the results of the PCU material wear test using a pin on the disc tribometer machine, the following conclusions are obtained.

1. 50NL, 100 NL, and 200NL specimens had an average coefficient of friction of 0.114, 0.116, and 0.127, respectively. The value of the friction coefficient is smaller when compared with the UHMWPE friction coefficient value.
2. Disc specimen track width values of 50NL, 100 NL and 200NL respectively 2,679 mm, 4,168 mm and 5,211 mm. The volumetric wear value specimen disc 50 NL, 100 NL and 200NL respectively 76,428 mm^3, 355,104 mm^3 and 1049,328 mm^3.

3. The wear rate of the specimen disc is 50NL, 100 NL and 200NL respectively 1.352 x 10^{-3} mm^3 / Nm, 6,283 x 10^{-3} mm^3 / Nm and 1,857 x 10-2 mm^3 / Nm.

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