Wear Characterization Analysis of Total Knee Replacement (TKR) Implant Materials

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ABSTRACT

This study is conducted to analyse lubricated contact of biological implants using pin on disk experiment. Numerous studies proven that multiple solutions have been used as lubrication for knee implantations in order to improve the lifespan of the device. The analysis conducted using Pin on Disk Wear and Friction Test Rig and sunflower oil was used in this experiment to be compared with dry condition. The material used for the pins were Stainless Steel that polished to mirror finishing and disk was fabricated using Rapid Prototyping Machine. Three types of materials namely Polylactide (PLA), Thermoplastic Polyurethane (TPU) and Acrylonitrile Butadiene Styrene (ABS)were printed to 74mm diameter. Additionally, three different speeds were applied for the pin on disc experiment to test the effectiveness of the material and lubrication. First, 60 RPM for normal running, 90 RPM for jogging and 360 RPM for running. It is found that the experiment's results demonstrate that the higher the speed, the higher the wear rate. In comparison with dry and wet condition experiment, result with added of sunflower oil shows lesser wear rate after run for 1800 seconds. Based on the results obtained, it is proven using lubrication reduced in wear and coefficient of friction.

Keywords: *Wear and Coefficient of Friction; Lubrication; Pin on Disk; Knee Implants*

Introduction

Cartilage is a type of fibrous tissue that can be found all over the body. Cartilage is a tough and flexible substance. Cartilage injury is generally

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accompanied by joint pain, rigidity, and a rash. Cartilage degrades over time as a result of excessive motion in daily living, which can develop to Arthritis and Osteoarthritis (OA). Articular cartilage that covers the surface of joints is made up of a layer called hyaline articular cartilage, which is white and dense in a healthy joint. The articular cartilage acts as a barrier to divert the pressures that are put on joints when they move quickly. This helps the bones to better support each other [1]. The knee joint is one of the body's biggest synovial joints as these joints carry nearly a person's entire body weight, they are particularly prone to severe injury and osteoarthritis[2]. Knee osteoarthritis (OA) is widespread, and the likelihood of developing OA increases with age. According to a study, almost fifty percent of people aged 65 and above have osteoarthritis (OA), making it the most common form of joint disease in the world[3]. In Malaysia, the most often diagnosed kind of Osteoarthritis is Knee Osteoarthritis[4]. Numerous therapy options for knee OA are indicated, including pharmacological, and non-pharmacological approaches[5]. Knee Osteoarthritis is treated surgically using arthroscopy, cartilage repair, knee replacements, and knee arthroplasty, among other procedures. Patients suffering from OA, as well as the location, stage, and presence of comorbidities, all have an impact on which of these operations is the best option for them[6].

Total Knee Replacement (TKR) surgery may be the most suitable line of treatment when the pain associated with this condition is unbearable using nonsurgical methods. The goal of this operation is to replicate a knee joint that is pain-free, totally functional, and long-lasting[7]. This procedure involves the replacement of a patient's damaged knee tissue joint with a prosthetic implant. In the United States, approximately 700,000 TKR procedures are performed each year; this figure is expected to rise as the prevalence of degenerative joint illnesses such as arthritis rises, as well as the efficacy of prosthetic knee implants in enhancing a patient's function and quality of life[8]. Several aspects need to consider while performing artificial replacement or implant surgery to ensure the implant is functional for a longer duration. Friction and wear are two main factors that may affect the lifetime of an artificial implant[9]. Friction is created when surfaces come into contact with relative motion, causing undesirable heat and material wear. One possible approaches to reduce this unwanted wear is to use lubricant[10].Lubricants play a critical role in global industrial and economic development, minimising friction and wear in mechanical contacts[11]. By keeping a fluid coating between the surfaces in contact, lubricant reduces the likelihood of metal-to-metal contact[12]. Synovial fluid (SF) is formed when plasma is filtered through the capillary net and diffuses into the knee joint, where it is supplemented with locally synthesised Hyaluronic Acid(HA), which gives SF its distinctive viscosity[13]. Vegetable oils has been identified as a possible source of environmentally friendly lubricants. Sunflower oil, which types of vegetable oil reduce wear and coefficient of friction[14]. Adding the Hyaluronic Acid additive to the sunflower oil lubrication contributes in increasing the viscosity of synovial fluid to a level that is suitable for the human body to reduce the wear in the implants[15], [16].This experiment using Pin on Disk Wear Test Rig featured the application of sunflower oil lubrication and Hyaluronic Acid (HA) as additive in the TKR to indicate the wear and the coefficient of friction for the user's prosthetic knee over the course of the investigation. For several years, various forms of research and experiments have been conducted to address this issue. For the year 2021, the total number of publications identified on Google Scholar through a simple search for the phrase 'lubrication for artificial joint' is around 1,980 papers and journals from various nations.

Methodology

This experiment started from choosing the suitable material for disc and pins which can be suit to the human body. The disc designed using SOLIDWORKS software. Afterwards, choosing the finest lubrication that suit the criteria of knee condition which include other parameters such as material, load, speed and time. Next, the process of preparing the samples, followed by experiment process and lastly, obtained and record the results.
The material chosen among the thermoplastics which are accessible for 3D printing, Polylactic acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) as in Table 1, which are the most common filament materials [17] while Thermoplastic Polyurethane(TPU) discs were fabricated from TPU sheet. For TPU material, multiple sheets of TPU measuring 600 mm wide, 650 mm long, and 4 mm in thickness were ordered from Euroshore Sdn Bhd. The sheet was then cut round with a 74 mm diameter and a 4 mm thickness. For TPA and ABS material, the discs were produced using 3D printing machine

Discs Preparation

Table 1: Material Properties for Disc

Materials Used	Value of Poisson Ratio	Young Modulus (N/mm^2)	Yield Strength (MPa)
Polylactic Acid (PLA)[18]	0.387	2410	21
Acrylonitrile Butadiene Styrene (ABS)[19]	0.36	3500	70
Thermoplastic Polyurethane (TPU)[20]	0.38	2240	20

The dimension for the disk was obtained from the disk designed at the SOLIDWORK software as in Figure 3. Ultimate Cura in STL format used to customize the disc model's infill density and layout. Printing process began by setting the plastic filament up to 185 degrees Celsius. The bed temperature has been set to 45 degrees Celsius. The printing can start right away as soon as it reaches the preheat setting. During PLA printing, the temperature of the nozzle must be 200 degrees Celsius and 60 degrees Celsius to make sure the melted filaments can flow out of the nozzle and stick to the 3D printer.

Once the disc is printed, there are print lines have been detected on the surface of the disk that need to be removed. Tetrahydrofuran Chemical has been applied using brush to rub on the surface of the disk to diminish the print lines for PLA disc. Rubbing process is completed as in which must be done in the fume chamber at the material laboratory because the chemical smell was too strong which can affect respiration system.

Pin Preparation

A 1-meter-long pin purchased at a hardware store is cut into several pieces using the cutting tool which was abrasive cutter. The pin chosen was made of stainless-steel material. The requirement for the pin to be used in the pin on disk experiment is 25mm in length and 8mm in diameter. The number of pins needed were 18 pins. After the pin is cut into pieces, the pin will go through the grinding process to ensure a good finishing. The last process for pin production to produce a mirror-like pin is the Polishing Process. Pins polished using 9- micron Alumina powder to produce mirror-like surface.

Lubrication Preparation

Based on several research works conclude that sunflower seed oil has an excellent tribological properties. Thus, this oil is use as lubricant to mimic the synovial fluid in the knee implantation to test the effectiveness to reduce wear during the experiment. 5ml hyaluronic acid has been blend with 1.5L of sunflower oil as the additive and to determine its effect on the wear of PLA, ABS and TPU disc.

Pin on disk Tribometer Test

Pin on Disc Wear and Friction test rug machine operated to investigate wear and friction analysis. The load that has been applied was constantly 7.5kg and but with different speed which were 60 RPM, 90 RPM and 360 RPM which represents different kind of motions. The lubrication applied was sunflower oil. For all experiments, the sliding time set at 30 minutes. The disk will rotate and come into contact with the pins. This process creates wear on the disc surfaces.

Result and Discussion

The effect of polymers was discussed after it undergo three different activities as in Table 2 for 1800 seconds.

Table 2: The activity and the utilize speed

Activity	Speed utilizes
Walking	60 RPM
Jogging	90 RPM
Running	360 RPM

Effect of load to the Wear

For the graph at Figure 1, shows material PLA exhibit the highest wear compared to TPU and ABS. However, as the sliding time increase, the value slowly reduced. TPU material shows negative results, due to the flexibility material itself. Before the experiment started to run, the stainless pin pressed the TPU disk when the load applied, this has created a mini slope and uneven surface thus produce negative value to the during the run. For 90 and 360 RPM speed, both graphs illustrate ABS material has the highest line followed by PLA as shown in Figure 2 and Figure 3. This similarity may due to similar method approaches in producing the disc which is through the 3D printing method. ABS has the weak characteristic compared to these two materials. Thus, during the experiment, ABS creates the highest wear which explains on the reasons it gives the highest value of wear against sliding time.

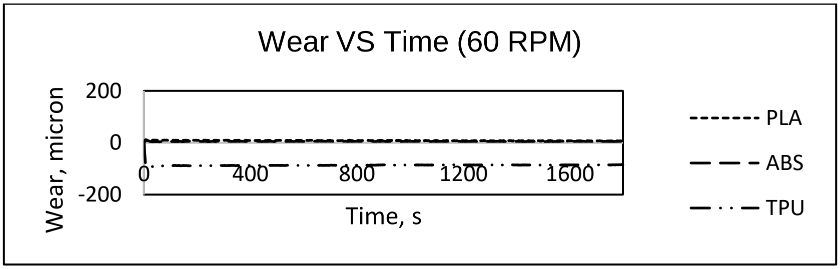

Figure 1: Wear VS Sliding Time for 60 RPM

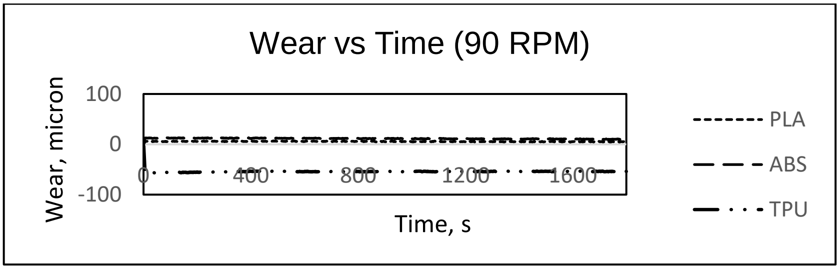

Figure 2: Wear VS Sliding Time for 90 RPM

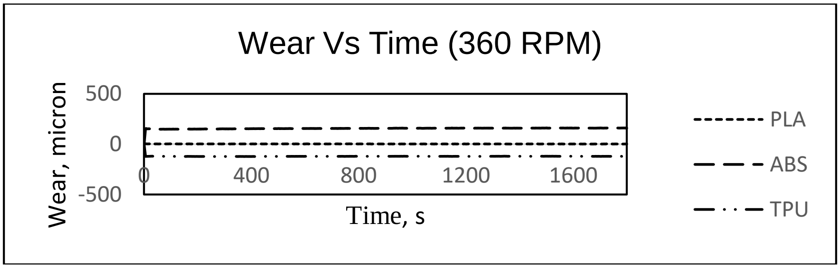

Figure 3: Wear VS Sliding Time for 360 RPM

Next, the experiment continued with wet conditions by blending the sunflower oil with 1.5ml of Hyaluronic Acid (HA) which function as the additive to reduce the wear and friction in the material. At 60 RPM, PLA exhibit the highest wear as in Figure 3. This is due during the continuous run, high temperature developed in between the pin and disc surfaces. Thus, it weakens the bond of PLA materials which create to highest wear. However, at speed of 90 and 360 RPM, ABS shows the highest wear compared to TPU and PLA as in Figure 4 and Figure 5. This explains on the limitations of the materials where, ABS suffers from stress cracking in the presence of greases or lubrication that led to highest wear [21]. ABS has poor resistance to any aromatic hydrocarbons, halogenated hydrocarbons and alcohols [22].

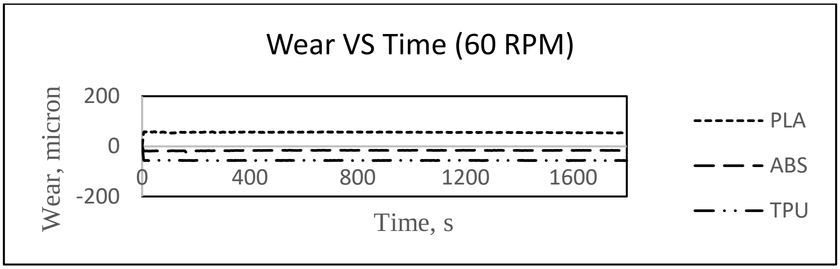

Figure 4: Wear VS Sliding Time for 60 RPM and 5%HA

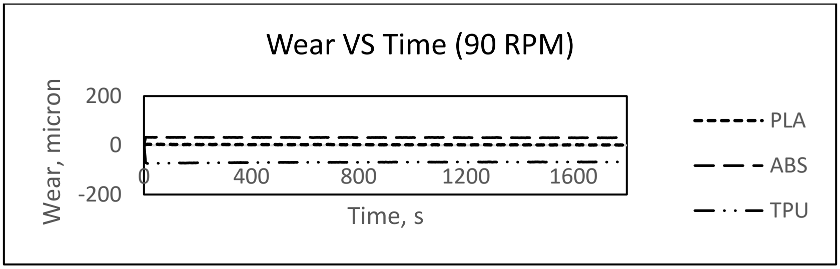

Figure 5: Wear VS Sliding Time for 90 RPM and 5%HA

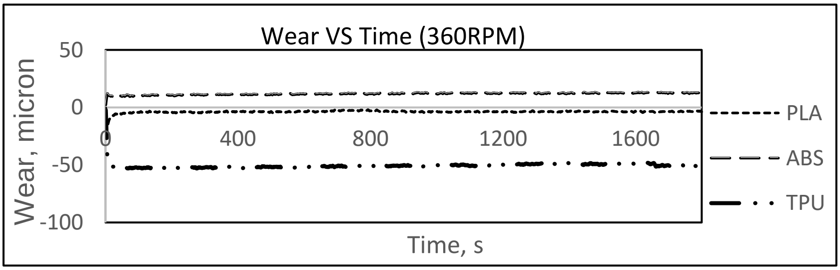

Figure 6: Wear VS Sliding Time for 360 RPM and 5%HA

Wear Comparison

The graph shown in Figure 7 are the comparison of the wear in present research which is oil lubrication vs dry lubrication which own by previous student, Nadiah et. al (2020). At the speed of 60 RPM, dry lubrication obtained higher wear compared to sunflower oil lubrication, which has lower value in wear in a range of differences which are 18% percent. It is proven that by adding lubrication, it able to reduce friction between pin and disc surfaces and reduce the wear rate of the disc. By increasing the load causes the asperities' surfaces to flatten at a fix contact area may result in reducing the wear and friction [23].

While as the sliding velocity increases, it causes the surface temperature to rise and adhesive forces between the contact surface to decrease [24].

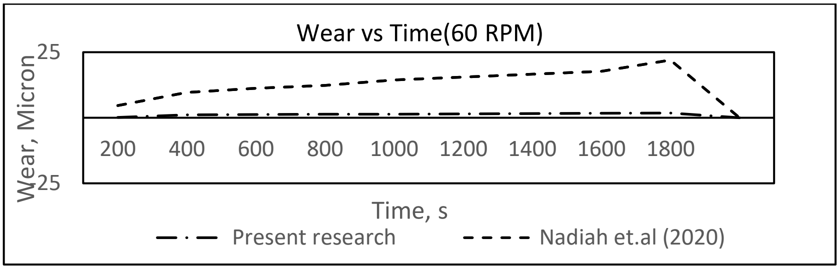

Figure 7: Wear vs Sliding Time for dry lubrication vs oil lubrication

Coefficient of Friction Comparison

The coefficient of friction, μ, used for describing the amount of friction between two surfaces which are pin and disc. A low value coefficient of friction meaning less load required to cause the motion compared to the high coefficient of friction. Based on the graph at Figure 8, a significant difference is observed between both two curves. The coefficient of friction for oil lubrication very low compared to the coefficient of friction for dry lubrication. Likewise, wear rate for dry condition peaked at the initial of the experiment and continue to progress with higher sliding speed regardless the load applied.

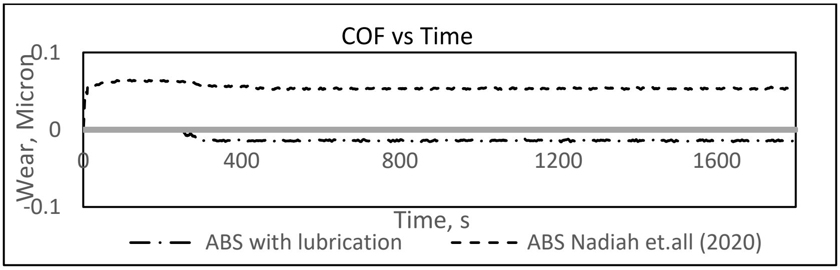

Figure 8: Comparison of COF at 90 RPM speed

As known, dry sliding condition process started with the form of debris initial. Debris formation piled up as load increased and this is known as ploughing. Compared to result with added lubrication, zero value for coefficient of friction indicates using oil as the lubrication minimising the friction between the pin and disc. This clearly indicate that sunflower oil absorbs and dissipate heat generated on the disc interface which indirectly reduces friction to greater extend. Hence, this conclude the amount of wear is low in wet sliding condition compared to dry sliding condition.

Conclusion

In a nutshell, the wear and coefficient of friction in dry test and oil lubrication using pin on disk experiment were obtained. From this study, it is found that the characteristic of materials such as PLA, ABS and TPU can mimic natural cartilage for the knee implants. It was tested under lubricated conditions of biological implants on different speed. These speed pattern results show that using lubrication has reduced the wear and coefficient of friction. The value for wear for six results are below 100 micron which are a low value compared to dry lubrication that have highest value of wear up until 2000 micron. Lastly, the wear percentages difference between present research which is oil lubrication compared to dry lubrication are 18 percent.

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