Faculty of Mechanical Engineering

INVESTIGATION ON TRIBOLOGICAL PROPERTIES OF 3D PRINTED AND MOLDED ABS

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A thesis submitted
in fulfillment of the requirements for the degree of Master of Mechanical Engineering (Energy)

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2019

DECLARATION

I declare that this thesis entitled "Investigation on Tribological Properties of 3D Printed ABS and Molded ABS" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : NORJANNAHTUL AINAH BINTI NORASHID

Date : 12/3/2019

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Signature : .....

Name : NORJANNAHTUL AINAH BINTI NORASHID

Date : 12/3/2019

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Mechanical Engineering (Energy).

Signature : .....

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DEDICATION

Dedicated to my family especially to my beloved mother and father

ABSTRACT

Meniscus injury are one of the most common knee injury. Meniscus is a piece of cartilage between a femur and tibia that provides a cushion and stabilize the joint. It also has a function to protect the bones from wear and tear. The meniscus can be torn that caused by direct contact or pressure from a forced twist or rotation. Patient may replace the damage meniscus when injured but, it will cause the changes in the cartilage load distribution which lead to degenerative arthritis. It also can be weaken and wears thin across the time. The meniscus can be replace by using biomaterial such as ABS Polymer. Therefore in this study, 3D printed and molded ABS was used for comparison. The main purpose of this study is to determine the absorption properties and compare the tribological properties between the 3D printed and Molded ABS under a lubricated condition. The printed ABS is fabricated by using FDM technique. Surface roughness and weight gained percentage for both types of ABS also been measured. The tribological testing was conducted by using tribometer according to standard of ASTM G99-95a which is standard test for wear testing with a pin-on-disc apparatus. The test conducted by using different applied load which is between ranges of 20N to 55N with sliding speed of 100 rpm for 1000m. To determine the wear track obtained from the tribological test, a 3D non-contact profilometer had been used. The result of coefficient of friction and wear rate was obtained from the tribological testing. From the result, it shows that 3D printed ABS have higher COF but lower wear rate. It have a higher COF because of the rougher surface roughness that increases the real contact area. Besides that, it have lower wear rate because the existance of the porosity that acts as the lubricant reservoir. The absorption rate for 3d printed ABS is higher compare to molded due to pores form during the fabrication. Therefore, 3D printed ABS is suitable to be used as meniscus as it can imitate the natural meniscus.

ABSTRAK

Salah satu daripada kecederaan lutut yang sering berlaku adalah kecederaan meniscus. Meniskus adalah tulang rawan yang berada di antara femur dan tibia yang berfungdsi sebagai kusyen dan dapat menstabilkan sendi. Ia juga mempunyai fungsi untuk melindungi tulang daripada haus dan terkoyak. Meniskus boleh tercedera ataupun terkoyak disebabkan oleh sentuhan secara langsung atau tekanan yang disebabkan oleh paksaan berputar. Sekiranya tercedera, pesakit boleh menggantikan meniskus tersebut akan tetapi, ia akan menyebabkan perubahan dalam pengagihan beban tulang yang sekaligus menyebabkan arthritis degeneratif. Selain daripada itu, meniskus juga boleh menjadi haus dan nipis disebabkan faktor usia. Bahan biomaterial seperti ABS polimer juga boleh digunakan bagi mnggantikan meniskus tersebut. Oleh itu, dalam kajian ini, ABS yang bercetak 3D dan dibentuk digunakan untuk perbandingan. Tujuan utama kajian ini dilaksanakan adalah untuk memandingkan sifat penyerapan dan sifat tribologi antara ABS yang bercetak 3D dan dibentuk dengan adanya pelincir. ABS yang bercetak 3D direka menggunakan kaedah FDM. Kekasaran permukaan dan peratusan berat diperolehi kedua-dua jenis ABS juga diambil. Ujian tribologi dijalankan dengan menggunakan tribometer mengikut piawaian ASTM G99-95a yang merupakan ujian piawai untuk ujian bagi menggunakan alat pin-on-disc. Ujian dijalankan dengan menggunakan beban yang pelbagai diantara 20N hingga 55N dengan kelajuan 100rpm untuk jarak 1000m. Untuk menentukan trek haus yang didapati daripada ujian tribologi, 3D profilometer buka hubungan telah digunakan. COF dan kadar haus juga turut diperoleh daripada ujian tribologi tersebut. Berdasarkan keputusan ujikaji tersebut, ABS bercetak 3D mempunyai COF yang tinggi dan kadar haus yang rendah berbanding ABS dibentuk. Ia mempunyai COF yangtinggi kerana kekasaran permukaan yang agak kasar dan menyebabkan bertambahnya kawasan hubungan sentuh sebenar. Selain itu, ABS bercetak 3D mempunyai kadar haus yang rendah kerana mempunyai liang-liang yang bertindak sebagai penyimpan pelincir. Kadar penyerapan bagi ABS bercetak 3D lagi tinggi kerana liang-lian yang terbentuk semasa proses pembuatan yang menggunakan kaedah FDM. Oleh itu, ABS bercetak 3D sesuai digunakan bagi menggantikan meniskus yang asal kerana sifatnya yang boleh meniru meniskus yang semulajadi.

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LIST OF ABBREVIATIONS

3D	Three Dimensional
ABS	Acrylonitrile-Butadiene-Styrene
AM	Additive Manfacturing
ASTM	American Society for Testing and Materials
CAD	Computer Aided Design
FDM	Fused Deposition Method
FFF	Fused Filament Fabrication
OA	Osteoahrtritis
PE	Polyethylene
SLA	Stereolitography
SLS	Selective Laser Sintering
UHMWPE	Ultra High Molecular Weight Polyethylene

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CHAPTER 1

INTRODUCTION

1.1 Background of Project

In a human body, knee joint is one of the most important and strongest joints. The meniscus is a commonly injured fibrocartilage vital for knee function due to sport. The number of adults that involve in this incidence is approximately 9/1000 and 4.2/1000 for men and women respectively. The meniscus is a fibrocartilage tissue that found within the knee joint as shown in Figure 1. 1.

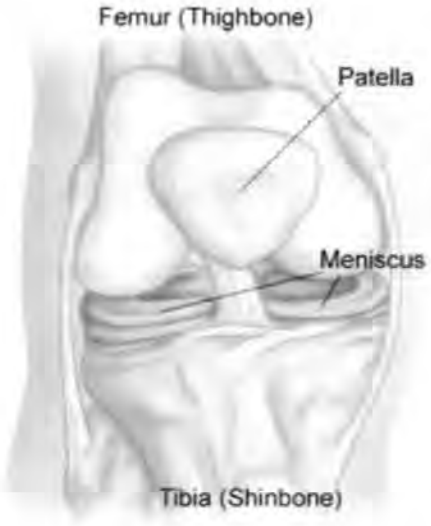

Figure 1. 1: Location of Meniscus

The tissue plays an important role for shock absorption, transmission of load and stability within the knee joint. It can be damaged by tears or degenerative process and if this happen, deterioration of articular cartilage can occur. Meniscus cell is heterogeneous and it can be replaced by using other cell sources (Makris et al., 2011). However, there are lack of people research on the tissue engineer compare to other musculoskeletal tissues such a bone (Sweigart & Athanasiou, 2001).

ABS (Acrylonitrile Butadiene Styrene) is one of the most successful polymer composites with an unequalled variety of forms and range of application. It is composed of three monomer which is acrylonitrile, butadiene and styrene. Therefore, it makes the plastic having a good impact resistance and rigidity. Besides that, the ABS is relatively harmless and doesn't have any known carcinogens so there is no adverse health effected related to ABS (Arcos et al., 1988).

ABS has low melting temperature which makes it ideal for injection molding and other application such as 3D printing. 3D printing and injection molding are really competing technologies so much as they are complementary. Both can theoretically be used for manufacturing and both can technically be used for rapid prototype generation. Therefore, in this study, the tribological properties of 3D printed ABS using FDM technique and molded ABS will be compared.

1.2 Problem Statements

Meniscal injuries due to sport and ageing are the most common knee injury. The damage meniscus needs to be removed when it comes to severe meniscus tear and it lead to early osteoarthritis. By using a new technology in develop a temporary scaffolds to stimulate the knee to grow new meniscus, the synthetic meniscus was served (Fong, 2014). Besides that, 9.3% of Malaysian adult undergoes knee pain and half of them examined had clinical evidence of OA according to study of Community Oriented Program for the control of Rheumatic Disease (COPCORD) in Malaysia which initiated by ILAR and WHO (Malaysia Health Technology Assessment Section (MaHTAS) Medical Development Division, Ministry of Health Malaysia, 2013). The meniscus plays important role within the knee joint because it aids in joint stability, helps protects ligaments against force and it also provides lubrications.

Besides, this study is also conducted due to limited number of literatures available regarding to meniscus replacement. Meniscus replacement remains an incessantly popular topic in the scientific literature. This is because, most of research that had been conducted is regarding to musculoskeletal tissue such as bone (Sweigart & Athanasiou, 2001).

Polymers have a high tendency to replace the meniscus. Some of the polymer that is biocompatibility is UHMWPE and PE. The friction of the material is low but somehow have their limitations, they create large wear debris and causing inflammation in joint and osteolysis (bone loss) (Brown & Clarke, 2006). For this study, ABS (Acrylonitrile Butadiene Styrene) was used because of it properties that lightweight, shock absorbent and has strong resistance towards corrosive chemicals and physical impacts (Halonen, 2016 ; Olivera et al., 2016) so, it have high tendency to imitate the meniscus. Furthermore, ABS is relatively

harmless and doesn't have any known carcinogens. Hence, there is no adverse health effect related to ABS (Arcos et al., 1988).

1.3 Objectives

The objectives of this study are:

i. To determine the absorption properties of 3D printed ABS and molded ABS.

ii. To compare the wear and friction properties of 3D printed ABS and molded ABS under lubricated condition.

1.4 Scopes of Project

To give more clearly to the critical point of view, the study had been narrowed down to be more specific. The material used to fabricate the disc sample is ABS material. The applied load for the tribological test is within the range of 20N to 55N with a sliding speed of 100 rpm and with temperature surrounding of 27°C. The ball material used for the test is SKD II. The constraint for the tribological test is the availability of the knee fluid (synovial fluid), so, it was replaced with paraffin oil.

CHAPTER 2

LITERATURE REVIEW

2.1 Bio-tribology

Word had been derived from old Greek word "tribos" which gives a meaning rubbing or the literally translation would be "the science of rubbing". In 1966, the word tribology was first reported by H. Peter Jost. The committee in the submitted report had suggested bringing along all activities regarding to friction, wear and lubrication will be under tribology (Woodberry, 1964). By dictionary, tribology is defined as the science and technology of interacting surfaces in relative motion and of related subjects and practices (Bhushan, 2013). In other words, tribology deals with lubrication, friction and wear, which involved the basic engineering subjects such as solid mechanics, fluid mechanics, lubricant chemistry, material science and heat transfer (Zhou & Jin, 2015).

In engineering, the importance of tribology was clear since almost all engineering components and system was involved with relative motion. The common examples included the ball bearings, gears and tyres. In biological system, tribology also has their importance. Since 1960s, the tribology study had focused on solving the immediate industrial problem regarding to wear and friction. Since the immediate problem had been solved, the research had shifted the focused on newly area such as nanotechnology and bio-tribology (Stachowiak & Batchelor, 2014). The term bio-tribology was introduced by Dowson and Wright which stated that bio-tribology is those aspects of tribology that concerned to

biological system. The application of tribology in human body can be seen as shown in Figure 2. 1.

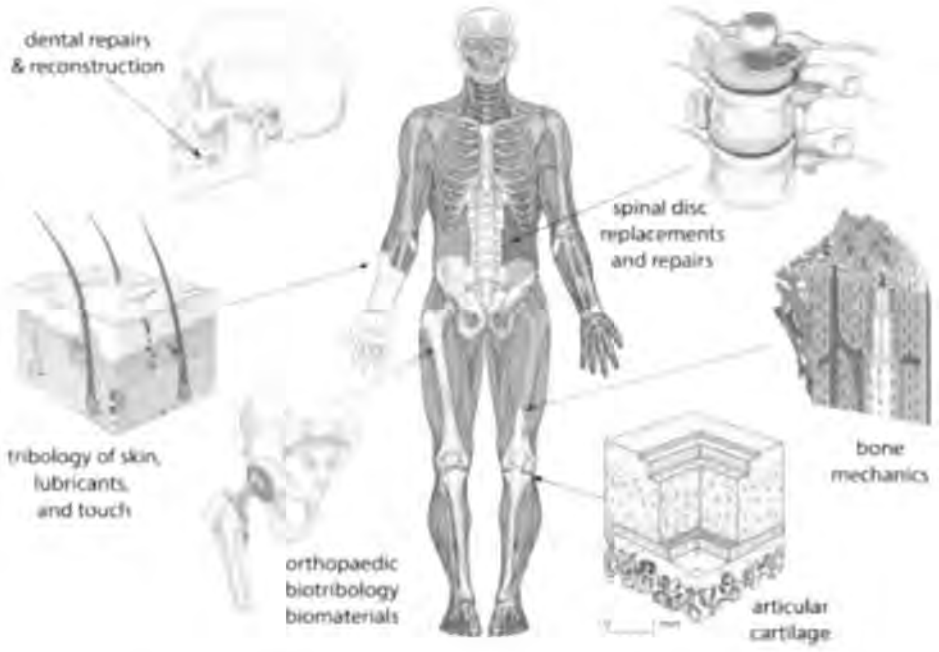

Figure 2. 1: Application of Tribology related to Human Body

Originally, the biotribology was applied to natural synovial joint which shows an effort to understand the mechanical function of joints and the failure mechanism with the hope in reducing the osteoarthritis (OA). Therefore, many physician, physiologist, biochemist, rheumatologist, biologist, rheology and engineer had joined the force in order to understand the lubrication of synovial joints and more important is how the joint being compromised with by OA.

Biotribology had applied the principles of lubrication engineering with an attempt to understand how the body lubricates its articulating bearings or synovial joints. The analysis of human joints is not complete as compare to mechanical bearing analysis because biochemistry and surface chemistry play a vital role than the mechanical part (Dowson, 1990).

For human body, the artificial replacements are supposed to last about 15 to 25 years. However, generation of wear debris make the implant life shorter for infection or instability and revision surgery is needed (Baena et al., 2015). Therefore, biotribology also study and focus on increasing and prolong the lifetime of the artificial joints. Historically, patients were trying the new bearing material (Charnley, 1966 ; Fisher, 2000). As for the consequences from incorrect design and material selection and subsequent failure, that means, an extensive pre-clinical requirement for evaluation of materials to implantation is needed (Fisher, 2000).

2.1.1 Tribological study of performance of natural synovial joints

There are numerous of study regarding to natural synovial joint lubrication and the design, manufacture and performance of various total joint replacement is one of the example of bio-tribology. In engineering view, the synovial joints are remarkable bearing. Human joints is a remarkable bearing that have low coefficient of friction which is 0.002 (Jones, 1934 ; Hills & Crawford, 2003) and it was expected to survive the dynamic loading, at least 70 years associated with normal activities life. Its function is to facilitate articulating motion of a creature that internal skeleton supporting. For humans and animals, wear of bearing surfaces can result to pain and restricted movement. Therefore, the consequences of excessive wear of bearing material which is articular cartilage in synovial joints are well-known.

The articular cartilage as bearing material is elastic and porous. Like the conventional bearing, it is mounted on a hard backing (bone). Synovial fluid as the lubricant is a highly non-Newtonian fluid which is placing within the joint space by the synovial membrane. In the synovial fluids, it contents are dialysate blood plasma with varying amount of protein.

The joints experience most of the lubrication modes familiar to tribologists, hydrodynamic, elastohydrodynamic, mixed and boundary together with unique squeeze film based on theoretical and experimental studies. In some activities, the range of loading support by the joint is considerable and peak load more than ten times of body weight can anticipate.

2.1.2 Anatomy of Synovial Joint

Synovial joints can be found at the articulations of the long bones of the skeleton such as hip, knee, shoulder and finger. Synovial joint refers to joint structure, articular surfaces that covered with hyaline cartilage, connected by ligaments and lined by a synovial membrane to create joint cavity filled with synovial fluid.

Synovial joint allow movement between the articulating bones. Without failure, the synovial joint can experienced load that are complex and variable exceeding 100 million cycles within the life time. For example, during walking, our joints experiencing high loading (5 to 6 times from body weight) meanwhile, very low load at maximum surface velocity such as swing phase (Unsworth, 1978).

One of the synovial joint is knee. However, in this section we will discuss on meniscus within the knee. There are three articulations within the knee, Figure 2. 2 shows the diagram structure of the knee.

i. Two condyloid joints
ii. One between each condyle of the femur and corresponding meniscus and condyles of the tibia.
iii. Between patella and the femur

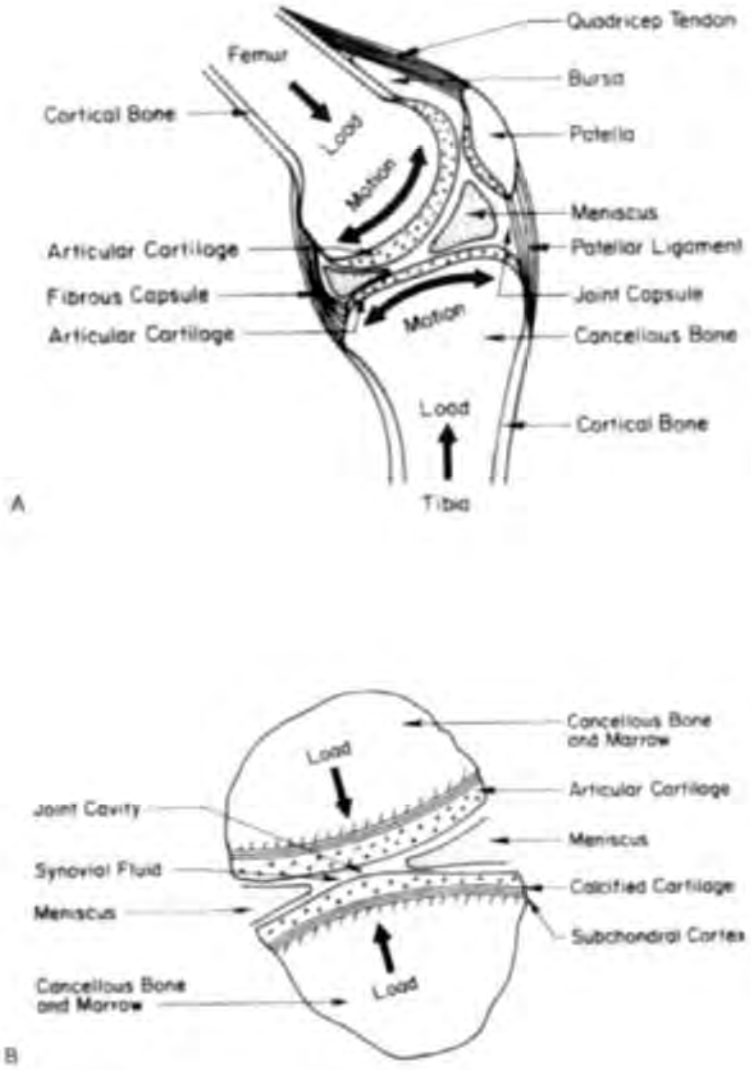

Figure 2. 2 (a) (b): Diagram Structure of Knee

(Source: Gale, 2007)

In each knee joint, there are two menisci. The menisci or semilunar fibrocartilage are found on the articular surface of the tibia and improve articulation with condyles of the femur, enlarging the contact area hence aiding articular cartilage in load transmission and distribution (Gale, 2007). Meniscus is a piece of cartilage between a femur and tibia that provides a cushion and stabilize the joint. It also has a function to protect the bones from wear and tear.