BIOTRIBOCORROSION PERFORMANCE OF TITANIUM ALLOY Ti-6Al-4V AND STAINLESS STEEL 316L UNDER SIMULATED BODY ENVIRONMENT

JULIAWATI BINTI ALIAS

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Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

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ABSTRACT

Tribological problems and corrosion degradation have been recognized as essential risks for total joint replacement, especially for metal arthroplasty. Degradation of the metals and alloys used in bearing surface in joint implants results from a combination of electrochemical and mechanical effects. By the increasing interest in metal-on-metal (MoM) joint implants, studies have been focused on their wear and corrosion behavior. A tribocorrosion test rig and sample of femoral head and acetabular cup for hip implant was designed and built to study and simulate the tribocorrosion condition of the biomaterials under two different simulated body fluids. By using this equipment, electrochemical tests have been conducted and reported in this thesis. The tribocorrosion behavior for two materials (Titanium alloy, Ti-6Al-4V and Stainless Steel 316L) have been analysed by using potentiodynamic polarization experiments. The corrosion rates of the alloys were then comparable.

ABSTRAK

Permasalahan dalam tribologi dan degradasi akibat karatan atau kakisan telah dikenalpasti sebagai risiko yang perlu dititikberatkan dalam gantian sendi terutamanya dalam '*arthoplasty*' logam. Degradasi logam dan aloi yang berlaku pada permukaan penyambung (bearing) dalam implan sendi terhasil dari kombinasi elektrokimia dan kesan mekanik. Dengan peningkatan minat dalam implan sendi logam-kepada-logam (*metal-on-metal*), pelbagai kajian dijalankan ditumpukan kepada kelakuan haus dan karatan bahan tersebut. Sebuah alat rig ujian '*tribocorrosion*' dan sampel '*femoral head*' dan '*acetabular cup*' dalam implan pinggang telah direka dan dibangunkan untuk mengkaji dan mensimulasikan keadaan '*tribocorrosion*' bahan bioperubatan tersebut dalam dua jenis larutan simulasi badan yang berbeza. Dengan menggunakan alat tersebut, ujian elektrokimia telah dijalankan dan dilaporkan dalam tesis ini. Kelakuan '*tribocorrosion*' dua bahan iaitu aloi titanium, Ti-6Al-4V dan keluli tahan karat, SS316L telah dianalisa menggunakan ujikaji '*potentiodynamic polarization*'. Kadar karatan kedua-dua aloi seterusnya dibandingkan.

CONTENTS

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

The application of tribology in medicine and biology is a growing and rapidly expanding field. It necessarily builds upon the fundamentals of engineering tribology, and extends well beyond conventional boundaries. Biomedical tribological systems involve an extensive range of synthetic materials and natural tissues, which often operate in complex interactive biological environments. Biomedical tribology involves natural human or animal systems and, of increasing importance, the development of replacement (prosthetic) devices to replace diseased tissues and organs. Their performance specifications and lifetimes often exceed that found in many engineering systems and frequently have to extend beyond the lifetime of the patient.

Over the last 30 years, studies of natural tissues have been used to define the functional tribological specification for prosthetic devices and biomaterials. During this period, prosthetic devices have primarily developed from an engineering science base.

The current designs of prosthetic devices, such as total replacement joints, have demonstrated clinical lifetimes of well beyond 10 years. These successes have also led to new types of problems, relating to long-term tribological and biological interactions within the human body, which can limit the lifetime of many of these devices. As the average age of the elderly population increases, their expectations of both levels of activity and quality of life increase, the fundamental specification and long-term performance requirements of biomaterials and prosthetic devices are being extended [1].

Research into tribological phenomena in an aqueous environment which called biotribology is a relatively new challenge, because historically most problems with friction and wear of materials were solved using organic lubricants. In many tribological systems, the materials that forming the tribological contact would exposed to a corrosive environment and this may cause to mechanical and chemical solicitations. Corrosion of human body metallic implants is critical as it can adversely affect the biocompatibility and mechanical integrity. Not only merely threatens the integrity of the implants, but also leads to concern about leaching of harmful metallic ions into the body.

1.2 Review of Literature.

Joint replacements have proved to be one of the most successful applications of biomaterials over the last 30 years. Currently, over 1 million devices are implanted annually in patients worldwide. There is clear evidence that many devices last well beyond 10 years. However, with prostheses now being implanted in younger patients with more active lifestyles, a life expectancy of over 20 years is required in many cases.

The primary requirement for biomaterials is biocompatibility, or the ability of a material to perform with an appropriate host response in biomedical environment. Metallic biomaterials are known to be the primarily surgical implants in the human body for orthopedic purposes. The requirements for the metals and alloys are to have high wear and corrosion resistance.

Among the metals and alloys known, stainless steels (SS), Co–Cr alloys and titanium and its alloys are the most widely used for the making of biodevices for extended life in human body. Stainless steel implants are used as temporary implants to help bone healing, as well as fixed implants such as for artificial joints. By the presence of chromium, it is mainly responsible for the high passivation ability of these alloys. An increase of Cr, as well as of Mo-content, strongly increases the resistance against localized breakdown of passivity.

Titanium and its alloys are currently in use as implant materials for orthopaedic surgery. These materials possess outstanding corrosion resistance due to a dense and passive oxide film on the surface. Titanium alloys are covered with a passive film of amorphous or low-crystalline titanium oxide (TiO_2) of non-stoichiometric composition. The natural selection of titanium for implantation is determined by a combination of most favorable characteristics including immunity to corrosion, biocompatibility, strength, low modulus and density and the capacity for joining with bone and other tissues (osseointegration).

Hip joint implants endure most of the loading impacts in physiological environments, so the wear particles might potentially arise from all the contact interfaces, such as articulating joint surfaces, bone surfaces and cements. Over the last 40 years, several different bearing couples have been used in hip joint replacements such as metal on metal, ceramic on ceramic, polymer on metal and metal on ceramic. Recently, many studies reported that 10%–20% of the artificial hip joints need to be replaced within 15–20 years and aseptic loosening accounts for approximately 70% of these revisions.

The chemical environment of blood plasma is highly aggressive for many metals and alloys, due especially to the presence of a high concentration of chloride ions and their ability to induce localized corrosion. Other ions may also contribute to the corrosion process, either as accelerators or inhibitors. The pH of the aqueous will vary, depend on the amount and type of ions present and the body temperature. The body temperature also can accelerate electrochemical reactions and even change the mechanism of corrosion from that occurring at room temperature.

The performance of metal joints relies on the control of both their wear resistance (relating to nanometre-size wear debris) and corrosion resistance (relating to ion release). Metal ion release is an electrochemical process; generally denoted as corrosion. The degradation of metals and alloys used in bearing surface results from the combination of electrochemical and mechanical effects which can represents complex synergy between wear and corrosion.

From some previous research, the tribocorrosion behaviour of some materials were defined. Tribological studies of bearing surfaces should ideally be considered in conjunction with biological studies of wear debris. Corrosion of implants in the aqueous medium of body fluids takes place via electrochemical reactions. All the surgically implantable metallic materials, including the most corrosion-resistant materials, undergo chemical or electrochemical dissolution at some finite rate, due to the complex and corrosive environment of the human body. There are a number of issues that relate to the action of friction and wear to cause corrosion induced in the human body. It has been confirmed that corrosion plays a significant role and it was shown that 20–30% material loss can be attributed to corrosion-related damage, which includes pure corrosion process and wear induced / enhanced corrosion process.

As a result of corrosion, more wear debris can be created. Tribological contacts can also accelerate the corrosion rate, and released wear debris can also be corroded in the human body environment.

1.3 Significance of Studies

Research into tribological phenomena in an aqueous environment is a relatively new challenge, because historically most problems with friction and wear of materials were solved using organic lubricants. There will be a competition or a synergetic effect of both surface phenomena, wear and corrosion. To understand these mechanisms and to be able to control them favourably, there must be a better understanding of what is happening on the surface.

A renewed interest in metal-on-metal (MoM) prosthesis bearings has been considered and developed since the early 1990s. This has been mainly due to the problems of polyethylene wear debris induced osteolysis from the widely used polyethylene-on-metal (PoM) total joint arthroplasty. However, MoM joint replacements are not used by surgeons without concerns, released metal ions from MoM pairs may cause cytotoxicity. Metal ion release is an electrochemical process; generally denoted as corrosion. Corrosion is the serious problems in medical devices. For joint replacements, they perform under tribological contacts and load. Their performance (long-term durability) relies on both their corrosion resistance and wear resistance.

The performance of metal joints relies on the control of both their wear resistance (relating to nanometre-size wear debris) and corrosion resistance (relating to ion release). These two phenomena are generally closely linked. More wear debris can be created, as a result of corrosion. Tribological contacts can also accelerate the corrosion rate, and released wear debris can also be corroded in the human body environment. Such phenomena which involve the interaction between tribological and corrosion processes are often referred to as tribocorrosion. It has been proved that corrosion plays an important role in tribocorrosion systems.

1.4 Objectives

The main purpose of this project is to study the biotribocorrosion performance of biomedical grade titanium alloy, Ti-6Al-4V and stainless steel 316L, during immersion in three different simulated body fluid as functioning for orthopedic replacements devices in human body.

In such way, this study is mean to investigate experimentally, the wear corrosion behavior and performing corrosion test of these two biomedical materials. In addition, it is also to analyze the corrosion behavior and material characterization under the solution.

1.5 Scopes of the Project

In order to obtain the objectives, it should have proper arrangement of project scopes. The lists of scopes are as followed;

(1) Design, fabrication and set-up tribocorrosion test rig, by using pin-on disc principle in related with hip joint motion.

(2) Sample preparation.

(3) Material characterization (surface structure and composition of sample).

(4) Immersion of the materials in simulated body fluid such as Hank Solution, Dulbecco's Modified Essential Medium (DMEM) with addition 10 % Foetal Bovine Serum and Phosphate Buffered Saline.

(5) Corrosion analysis for respective material using 'Tafel' analysis.