BONDING PROPERTIES OF CARBON FIBER REINFORCED (CFR)-PEEK AND HYDROXYAPATITE (HA)-PEEK JOINED BY ULTRASONIC WELDING

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ABSTRACT

Acetabular cup is a component of hip prosthesis that replaces the acetabulum of pelvis bone in total hip arthroplasty. As shown in clinical studies, the stiffness mismatch between the implant and the bone leads to stress-shielding and bone resorption. The formation of wear debris due to contact between the acetabular cup and the femoral head can also cause adverse tissue reactions leading to massive bone loss around the implant and consequently implant loosening. This study attempted at solving the problem through the use of double-layer polymer composites. Carbon fiber reinforced polyetheretherketone (CFR-PEEK) was incorporated as the acetabular cup liner part to reduce wear rates whilst a second layer Hydroxyapatite-Polyetheretherketone (HA-PEEK) was used to create low modulus acetabular cup shell part. This new design was developed with the aim of reducing stress shielding, promote bone in-growth, and reducing wear debris from modular interfaces. The objective of this study was to prepare beam samples of the double-layer polymer composites via injection moulding process and ultrasonic welding. The strength of welding interface was evaluated by single cantilever beam (SCB) and lap shear tests. Response surface method (RSM) optimization process was used in the design of experiments in order to optimize the ultrasonic welding parameters. Coating of hydroxy-apatite on polymer composite substrate was investigated and the substrate was tested by CSM Micro scratch tester machine. SCB test showed stronger welding for partial energy director compared to those performed with whole energy director. The optimized maximum debonding force of the composite layers was achieved for 3.5 seconds welding time, 3 seconds holding time, and 8 bar pressure of ultrasonic welding parameters. Scratch test assessment showed plasma spraying as an appropriate method for coating of HA on PEEK substrate with a coefficient friction of 0.67.

ABSTRAK

Cawan acetabular adalah komponen prostesis pinggul yang menggantikan acetabulum tulang pelvis dalam pembedahan keseluruhan tulang pinggul. Seperti yang dibuktikan dalam ujian klinikal, ketidakpadanan tegasan antara implan dan tulang membawa kepada perlindungan tekanan dan penyerapan tulang. Pembentukan serpihan haus disebabkan oleh sentuhan antara cawan acetabular dan kepala femoral juga boleh menyebabkan tindak balas tisu yang membawa kepada kehilangan tulang secara besar-besaran pada keseluruhan implan dan seterusnya melongggarkan implan. Kajian ini cuba menyelesaikan masalah melalui penggunaan dua lapisan polimer komposit. Gentian karbon diperkuat polyetheretherketone (CFR-PEEK) telah digabungkan sebagai sebahagian pelapik cawan acetabular untuk mengurangkan kadar haus manakala lapisan kedua Hidroksiapatit-Polyetheretherketone (HA-PEEK) telah digunakan untuk menghasilkan bahagian cangkerang cawan acetabular yang bermodulus rendah. Reka bentuk baru ini telah dibangunkan dengan tujuan untuk mengurangkan perlindungan tekanan, menggalakkan pertumbuhan tulang dan mengurangkan puing haus antara permukaan bermodul. Objektif kajian ini adalah untuk menyediakan sampel alur dua lapisan polimer komposit melalui proses pengacuan suntikan dan kimpalan ultrasonik. Kekuatan antara muka kimpalan telah dinilai oleh rasuk julur tunggal (SCB) dan ujian pusingan ricihan. Kaedah tindak balas permukaan (RSM) telah digunakan dalam proses pengoptimuman reka bentuk eksperimen untuk mengoptimumkan parameter kimpalan ultrasonik. Salutan hidroksiapatit ke atas substrat polimer komposit telah dikaji dan substrat telah diuji dengan mesin penguji calar Mikro CSM. Ujian SCB menunjukkan kimpalan yang lebih kukuh untuk pengarah tenaga separa jika dibandingkan dengan pengarah seluruh tenaga. Daya maksimum nyahikatan bagi lapisan komposit telah berjaya dioptimumkan pada 3.5 saat untuk masa kimpalan, 3 saat untuk masa pegangan, dan tekanan 8 bar untuk parameter kimpalan ultrasonik. Penilaian ujian calar menunjukkan semburan plasma sebagai kaedah yang sesuai untuk penyalutan HA ke atas substrat PEEK dengan pekali geseran 0.67.

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LIST OF ABBREVIATIONS

3D - Triple Dimensions
ANOVA - Analysis of Variance
ASTM - American Society for Testing and Material
BGs - Bioactive Glasses
C - Centigrade
C - Compliance
CaP - Calcium Phosphates
CCD - Central Composite Design
CFRPA - Carbon Fiber Reinforced Polyamide
CFRPBT - Carbon Fiber Reinforced Polybutyleneterephthalate
CFRPEEK - Carbon Fiber Reinforced Polyetheretherketone
Co. - Company
Co-Cr - Cobalt-Chrome
CP Ti - Commercially Pure Titanium
CVD - Chemical Vapor Deposition
DOE - Design of Experiment
DSC - Differential Scanning Calorimetry
Eq. - Equation
Exp. - Experiment
F - Force
FDA - Food and Drug Administration (US)
FEM - Finite Element Method
GFR - Glass fiber Reinfoerced
GPa - Giga Pascal
HA - Hydroxyapatite
HAPE - Hydroxyapatite Polyethylene
HAPEEK - Hydroxyapatite Polyetheretherketone
HDPE - High Density Polyethylene

ISO	-	International Standards Organization
kg	-	Kilogram
kN	-	Kilo Newton
kPa.s	-	Kilo Pascal Second
L	-	Length
Ltd.	-	Limited
LVDT	-	Linear Variable Differential Transformer
max.	-	Maximum
MediTeg	-	Medical Implant Technology Group
min	-	Minute
MINT	-	Malaysian Institute of Nuclear Technology
mm	-	milimeter
MPa	-	Mega Pascal
MRI	-	Magnetic Resonance Imaging
MST	-	Micro Scratch Tester
N	-	Newton
NC	-	Numerical Control
No.	-	Number
NRC	-	National Research Council (Canada)
P	-	Penetration
PA	-	Polyamides
PE	-	Polyethylene
PVD	-	Physical Vapor Deposition
PS	-	Polysulphone
RSM	-	Response Surface Method
SCB	-	Single Cantilever Beam
sec.	-	Second
SEM	-	Scan Electron Microscopy
SIRIM	-	Standards & Industrial Research Institute of Malaysia
T	-	Temperature
Ti	-	Titanium
THR	-	Total Hip Replacement
UHMWPE	-	Ultra High Molecular Weight Polyethylene

UTM	-	Universiti Teknologi Malaysia
Wt	-	Weight

LIST OF SYMBOLS

% - Percentage

µ - Micrometer

E - Elastic Modulus

G_c - Interfacial Fracture Energy

k - Stiffness

l - Length

° - Degree

ε - Strain

G - Shear Modulus

ν - Poisson’s ratio

σ - Stress

LIST OF APPENDICES

LIST OF PUBLICATION

NO.	TITLE	Impact factor
1	Amirhossein Goharian, Ahmad Ramli Rashidi, Mohammed Rafiq Abdul Kadir, Mohd Ruslan Abdullah, and Mat Uzir Wahit; "Development of novel Polymer Composite Beam using Ultrasonic Welding Process for Acetabular Cup Prosthesis", published in the “ *Journal of Key Engineering Material, 471-472 (2011) 945-950 “.*	0.24
2	Amirhossein Goharian, Ahmad Ramli Rashidi, Mohammed Rafiq Abdul Kadir, Mohd Ruslan Abdullah, and Mat Uzir Wahit; " Optimizing The Joint Strength Of Ultrasonically Welded Composite Containing Two Bio-Reinforced Polyetheretherketone Applying Single Lap Shear Test", submitted in the “ *Journal of Advanced Manufacturing Technology”*	1.068

CHAPTER 1

INTRODUCTION

1.1 Background

Implant technology investigation has a long history. In recently decades, tissue diseases included bone, cartilage, and soft tissues have been growing fast. This is because; human has been liked to do their applications by technological tools and instruments. The activities like walking, work on field, and etc. that involve the human body bone, muscles, and all other tissues, have been going to decrease and as a result the tissues cannot deal with appropriate applying force and consequently stress.

This event would be addressed by in the 19th century by the German Anatomist/Surgeon "Julius Wolff (1836-1902)" as Wolff's Law theory that states that bone in normal applications will remodel due to the loading condition. If loading apply on bone increases rather than normal application, the bone will change to become stiffer to sustain the extra effect of overloading. In contrast, if the loading decreases, the bone will become weaker [1].

In this way, two joint diseases might happen. Rheumatoid arthritis is a joint disease at which immune system cells spread in large numbers inside the joint structure. It occurs when the body's immune system invade against of joint tissues. When the immune cells attack the joint, chemical messages call bloodstream for reinforcement. This results in more new immune cells reach to the joint and enhance blood flow around the joint. These chemicals increase blood flow to the region around the joint and make the blood vessels leakier so that fluid (and immune cells) can leave the blood vessels and travel into the tissues. This response is called an inflammatory response and leaves the joint warm and swollen from the fluid accumulation. It also causes joint pain because of destruction of bone and cartilage tissue in the joint [2].

Osteoarthritis, also known as degenerative joint disease, results from wear and tear. The pressure of gravity causes physical damage to the joints and surrounding tissues, leading to pain, tenderness, swelling, or decreased function. Initially, osteoarthritis is non-inflammatory and its onset is subtle and gradual, usually involving one or only a few joints. The joints most often affected are the knees, hips, hands, and spine. Risks of osteoarthritis increase with age. Other risk factors include joint trauma, obesity, and repetitive joint use [3].

Osteoarthritis mostly affects the cartilage. Cartilage is the slippery tissue that covers the ends of bones in a joint. Healthy cartilage allows bones to glide over one another. It also absorbs energy from the shock of physical movement. In osteoarthritis, the surface layer of cartilage breaks down and wears away. This allows bones under the cartilage to rub together, causing: pain, swelling, or loss of motion of the joint. Over time, the joint may lose its normal shape. Also, bone spurs (small growths called osteophytes) may grow on the edges of the joint. Bits of bone or cartilage can break off and float inside the joint space. This causes more pain and damage. Cartilage is 65 to 80% water. Three other components make up the rest of cartilage tissue: collagen, proteoglycans, and chondrocytes [4].

The joint that was focused in this study was the hip joint. Hip pain is common problem, and it may happen because of many reasons. The diagnosis of the reason would be done to obtain the appropriate treatment. The hip pain might be as a result of arthritis, trochanteric bursitis, tendonitis, osteonecrosis, lumbar pain, snapping hip syndrome, muscle strains, hip fracture, and stress fracture. Trochanteric bursitis and tendonitis affect bursa and tendons and osteonecrosis occurs due to restriction of an area of bone by blood flow. Back and spine problems may results lumbar pain and hip region “herniated discs or sciatica" [5]. Iliotibial (IT) band, deep hip flexor snapping and cartilage tear can cause pain at hip joint. In elderly patients hip fracture is at risk and athletes who do high-impact sports may experience with stress fracture of the hip. These hip problems can cause hip pain by affecting on around tissue, cartilage or even bones. Fig. 1.1 shows the diseased hip joint.

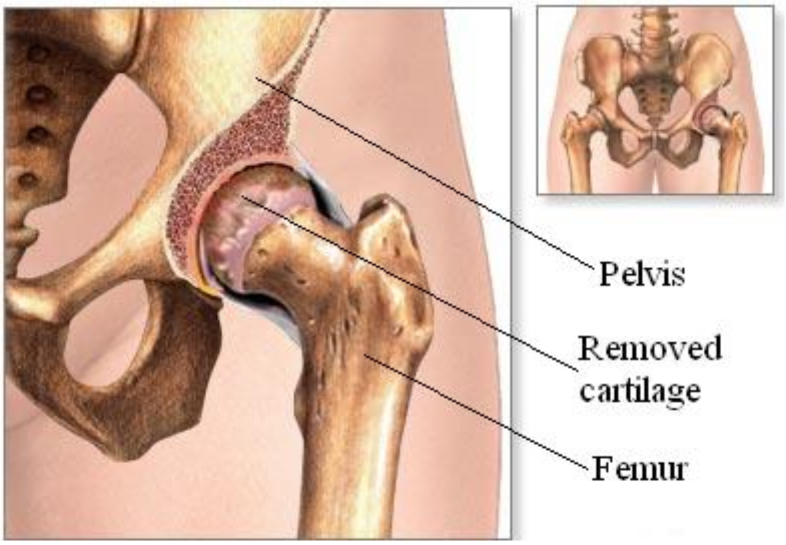

Fig. 1.1 Diseased Hip Joint

Total Hip Replacement (THR) is the last treatment of hip joint pain if other treatments would not be able to heal the problem. The hip surgeons consider the intensity of pain as apposed of application. They mostly evaluate the activities at which the patient is under pain or not. Daily activities like normal walking, climbing stairs or entertainment activity like traveling, shopping, and exercising are some factors in this way. Patients who experience severe pain in their hip at daily applications or normal activities are advised to do THR.

Nowadays millions of people around the world suffer from their hip joint injury. In United States more than 250,000 THR surgeries currently are performed annually and it is predicted that it goes to more than 500,000 surgery per year at 2030 [6]. Although, this surgery is so difficult for either surgeon or patient, but it is observed that many patients who are affected by hip joint pain, are pursuing to do THR. The difficulty of THR is related to tissue cares. Surgeon should pass away the tissues around the hip joint to reach to the head of fumer and acetabulum of pelvis bone (Fig. 1.2). Recovery process and tissue-integration of hip implant are two hard challenging matters that should be performed at good biological manner.

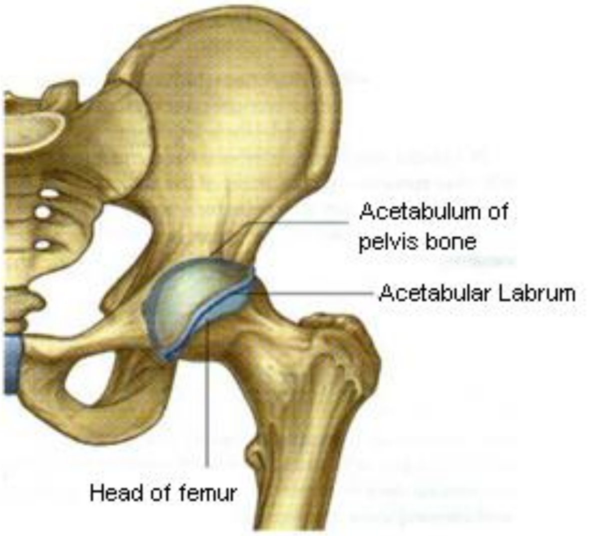

Fig. 1.2 The connection of acetabulum of pelvis bone and head of femur

The hip implant that is applied to overcome the severe hip pain or severe hip problems needs various processes to reach to the desired component to insert at the human body. First of all, biological requirements are considered. In this regard, chemical, physical, and mechanical reactions of implant against joint tissues make implant biocompatibility issues. In addition of using surgery techniques and cements to insert the implant within the hip joint, it is attempted that the implant connects biologically to hip joint tissues as well as normal and healthy hip joint.

Biology scientists try to simulate the action of various kinds of tissues in joints and reaction of body tissues and body fluid by designing and performing various kind of in-vivo and in-vitro simulated testing. Then material and chemical investigators attempt to compound or synthesis new biocompatible material that are called "biomaterial". Then implants, tissue scaffolds, or other artificial prosthesis made from biomaterial and inserted inside the body. Some influence of body reaction to prosthesis takes long time to appear. This may because body systems are all actively regenerative. Therefore, firstly body tissues remodel to balance the anti-biological consequences of artificial prosthesis. After passing time, if this process would not be successful, the prosthesis become as an external component inside the body that fail the application of the joint.

Hip implant is composed of three main parts (Fig. 1.3). Femoral stem, femoral head, and acetabular cup. In this research, acetabular cup prosthesis was focused to be investigated. This part of hip implant is considered as cartilage on the acetabulum of pelvis bone. Commercial available acetabular cup are thick and composed of two parts; liner, shell. The shell is metal based material and the liner is made of biopolymer. But in recent years, composite polymer materials were addressed to produce a lightweight and thin acetabular cup.

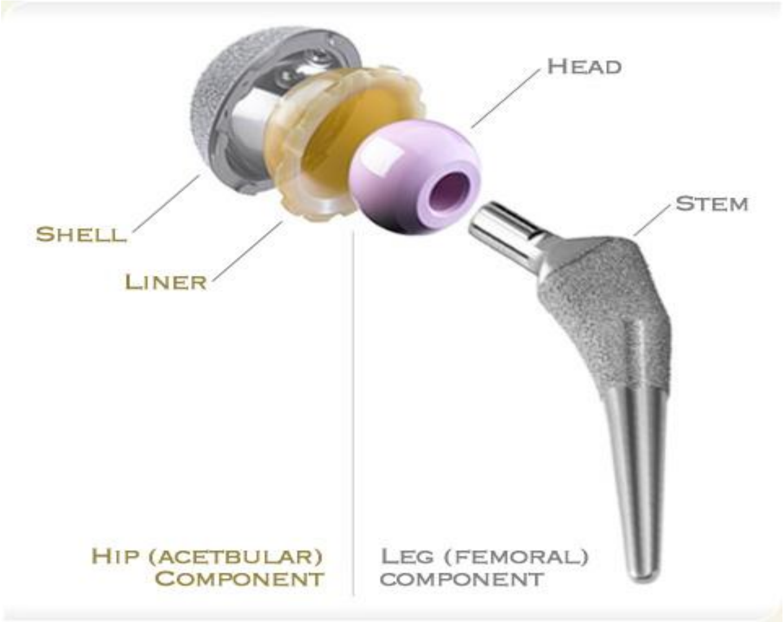

Fig. 1.3 Commercially Hip Implant components

1.2 Problem Statement

The hip joint is a synovial joint formed by the articulation of the rounded head of the femur and the cup-like acetabulum of the pelvis. Hip prosthesis is an implant that is inserted in femur bone and connected to pelvis bone.

Acetabular cup is one part of hip prosthesis component. This would be hip joint part to pelvis bone. Due to the existence of cartilage and lunate surface and other body joint compositions at acetabulum, the connection between hip prosthesis or in particular connection between acetabualr cup and pelvis is considerable in terms of load transferring, bio-connection.

Cartilage is an incompressible, neo-Hoboken, hyper elastic material with shear modulus G=6.8MPa [7, 8]. This kind of material absorbs energy when it is deformed elastically and then upon unloading this energy recovered. An example of a cartilage which has a high resilience is articular cartilage, the substance lining the ends of bones in articulating joints such as the knee and hip.

Hip join mostly related to cartilage removing by aging. Transferring load within the joint between bones is done via cartilage. In fact, acetabular cup is seated at the acetabulum instead of cartilage. Fig. 1.4 displays the articular surface of the acetabulum.

Mechanical properties, biocompability, and osteointegration of acetabular cup are issues that should be investigated to fabricate the implant. In Chapter 2 various kinds of acetabular cups that are currently commercial or under clinical research have been exhibited.

The use of composite material in orthopaedic surgery offers a variety of new implant designs. As shown by clinical studies, the mismatch of stiffness between the implant and the bone leads to stress-shielding and bone resorption and is one of the contributing factors to implant failure. Fiber-reinforced composite materials are light weight and have high specific strength. They also could be designed with desire performance and therefore reduce the mismatch of stiffness between bone and implant. In this research, carbon fiber reinforced polyetheretherketone (CFR/PEEK) as the liner and hydroxyapatite polyetheretherketone (HA/PEEK) as the shell were utilized to decrease bone and implant stiffness mismatch.

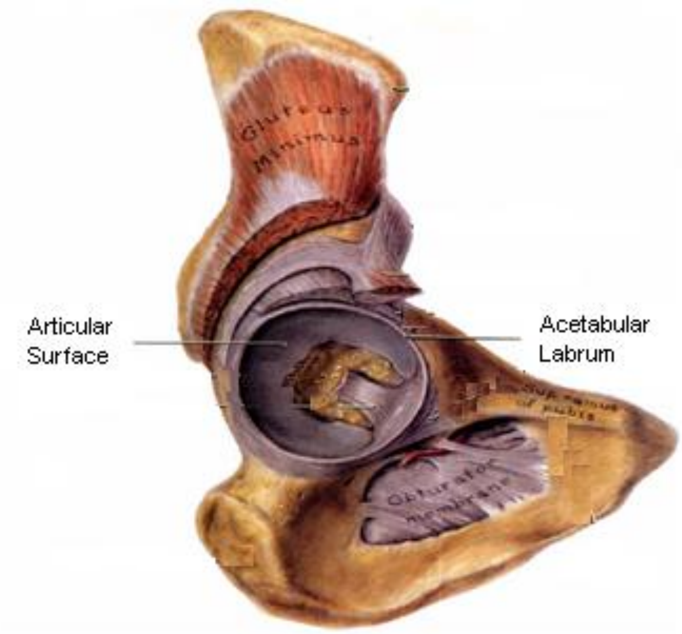

Fig. 1.4 Articular surface of the acetabulum

1.3 Research Objectives

1. To fabricate a suitable kind of lightweight polymer composite and low friction material with relevant composition using for acetabular cup that could satisfy the mechanical and biological requirements of the acetabular cup.
2. To examine the fabricated composition by using mechanical testing.
3. To evaluate the coating processing of bioactive material on the composition.

1.4 Significance of Study

It could be mentioned that hip joint is the main joint of the body that plays an important role to connect the upper part of the body to the bottom part. If this area would affect by any problem, the whole body would be out of movement.

By in-growing the THR surgeries in the world and the problems of the currently commercial acetabular cup, it is needed to develop the new composition acetabular cup applying the new biomaterials that were developed for joints implants.

1.5 Research Scopes

This study would propose a light weight acetabular cup that there would be low friction between ball (femoral head) and acetabular cup interfaces. Carbon Fiber Reinforced PolyetheretherKetone (CFR/PEEK) will be incorporated to reduce wear rates whilst Hydroxyapatite-PEEK (HA/PEEK) coated by HA creating low modulus backing.

The methods used in the manufacturing of the component (Injection Molding, Ultrasonic welding, Plasma Spraying) will be utilized to joint two composite material "HA/PEEK & CFR/PEEK" and coating HA on HA/PEEK.

1.6 Research Report Organization

This report has been organized in to the 5 chapters. Chapter 1 considers the introduction of this investigation. The background of diseases that motivate the investigator to do this research is explained and then the problem statement, objectives, and scope of the study are determined.

In Chapter 2, the previous investigations regarding to the problem statement are considered. In this chapter, the material and methods that could be applied for performing this research were elaborated.

Chapter 3 displays the methodology and specifies the way that this research was done. This chapter explains the methodology of applying the material and methods that have addressed in chapter 2.

The attained results of the research according to the research methodology are exhibited in chapter 4. The results will discuss to evaluate the research methodology. Chapter 5 is included the conclusion of the whole research and suggest the further research to develop the project.

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