Faculty Of Manufacturing Engineering

MULTI OBJECTIVE PERFORMANCES OPTIMIZATION OF POLY-ETHER-ETHER-KETONE (PEEK) MATERIAL BY USING ROTARY ULTRASONIC ASSISTED DRILLING

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DECLARATION

I declare that this thesis entitled "Multi Objective Performances Optimization Of Poly-Ether-Ether-Ketone (Peek) Material By Using Rotary Ultrasonic Assisted Drilling" 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	:	....
Date	:	....

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 Manufacturing Engineering (Manufacturing Engineering System)

Signature :………………...

Supervisor Name :………………………......................................

Date :……………………..

DEDICATION

To my beloved husband Muhammad Shafiq Omar and my dearest kids Muhammad Shafi Anaqi and Nur Shifa Afeeya

ABSTRACT

Polyaryletheretherketone (PEEK) materials is a semi-crystalline, high purity polymers containing of replicating monomers of two ether groups and a keytone group. PEEK is a rigid opaque material considered as a good mechanical properties retained in high temperatures with a unique mixture of properties, which include wear, exceptional chemical and electrical resistance. The accumulative use of PEEK plastics can be seen in the growth of a wide range of orthopedic applications, including spinal fusion cages, artificial discs, femoral stems and cranial implant. Compared to other implant material, polymeric material like PEEK promote better cell bone growth compared to metallic materials like Titanium because PEEK's surface topography enhance implant - bone contact. In the case of medical implants, fine surface roughness is one of the most importance requirement since the cells of surrounding tissue interact with the underlying substrate on the micro and nanometre scales. The tight tolerances in medical application for a fine surface roughness poses a major concern in conventional drilling process of PEEK implant materials. PEEK's does not dissolve heat easily and has low service temperature compared to metal and it can melt if the drilling temperature increases above of the melting point. On the others hand, PEEK also deform when the cutting force and shear stress increases during the drilling process which can lead to rough machined surface and tolerance violation. In addition, conventional drilling process towards this material tends to generate high tensile thrust that results in poor hole quality and crack propagation. Considering these facts, in this thesis a new drilling technique which assisted by the ultrasonic vibration frequency known as Rotary Ultrasonic Assisted Drilling (RUAD) is propose aim to increase the hole qualities i.e. surface roughness, hole accuracy at entry and exit surface. A set of experimental work was conducted to evaluate the effects of the RUAD parameter namely cutting speed, feed rate, ultrasonic frequency and vibration amplitude towards the hole quality. A statistical analysis of variance (ANOVA) was employed to assess the relationship between parameters and output response. Subsequently, further analysis was performed to obtain the optimum RUAD parameter that can produce the best hole quality. From the analytical results, its demonstrated that the presence of the ultrasonic vibration was able to improve the hole quality and minimize the chipping area with acceptable tolerance value. Furthermore, based on the statistical optimisation result, combination of spindle speed of 3294 rpm and feed rate of 191 mm/min will produced the best hole qualities i.e. minimum surface roughness and minimum holes error. The findings from this deliberately experimental work can be used by implant manufacturer for effectively drilling PEEK material.

ABSTRAK

Bahan Polyaryletheretherketone (PEEK) adalah polimer tulen yang semi-kristal, yang mengandungi monomer mereplikasi dua kumpulan eter dan kumpulan keytone. PEEK adalah bahan legap kaku yang dianggap sebagai sifat mekanik yang baik yang disimpan dalam suhu tinggi dengan campuran sifat unik, yang termasuk memakai, rintangan kimia dan elektrik yang luar biasa. Penggunaan plastik PEEK yang terkumpul dapat dilihat dalam pertumbuhan berbagai macam aplikasi ortopedik, termasuk sangkar gabungan tulang belakang, cakram buatan, batang femoral dan implan tengkuk. Berbanding dengan bahan implan lain, bahan polimer seperti PEEK memjadikan pertumbuhan tulang sel yang lebih baik berbanding dengan bahan logam seperti Titanium kerana topografi permukaan PEEK meningkatkan sentuhan implan tulang. Dalam kes implan perubatan, kekasaran permukaan halus adalah salah satu keperluan yang paling penting kerana sel-sel tisu sekeliling berinteraksi dengan substrat yang mendasari skala mikro dan nanometer. Toleransi yang kecil dalam aplikasi perubatan untuk kekasaran permukaan halus menimbulkan kebimbangan utama dalam proses penggerudian konvensional bahan implan PEEK. PEEK tidak membubarkan haba dengan mudah dan mempunyai suhu perkhidmatan yang rendah berbanding dengan logam dan ia boleh mencairkan jika suhu penggerudian meningkat di atas titik lebur. Di sisi lain, PEEK juga berubah apabila tekanan pemotongan dan tegasan ricih meningkat semasa proses penggerudian yang boleh mengakibatkan permukaan machined kasar dan pelanggaran toleransi. Di samping itu, proses penggerudian konvensional ke arah bahan ini cenderung untuk menghasilkan teras tegangan yang tinggi yang menyebabkan kualiti lubang yang lemah dan penyebaran retak. Memandangkan fakta ini, dalam tesis ini, teknik penggerudian baru yang dibantu oleh frekuensi getaran ultrasonik yang dikenali sebagai Rotary Assisted Drilling Rotary (RUAD) adalah bertujuan untuk meningkatkan kualiti lubang iaitu kekasaran permukaan, ketepatan lubang di permukaan masuk dan keluar. Satu set kerja eksperimen dijalankan untuk menilai kesan parameter RUAD iaitu kelajuan pemotongan, kadar suapan, kekerapan ultrasonik dan amplitud getaran ke arah kualiti lubang. Analisis statistik varians (ANOVA) digunakan untuk menilai hubungan antara parameter dan tindak balas output. Seterusnya, analisis selanjutnya dilakukan untuk mendapatkan parameter RUAD optimum yang boleh menghasilkan kualiti lubang terbaik. Dari hasil analisis, ia menunjukkan bahawa kehadiran getaran ultrasonik dapat meningkatkan kualiti lubang dan meminimumkan kawasan kerepotan dengan nilai toleransi yang dapat diterima. Selain itu, berdasarkan hasil pengoptimuman statistik, gabungan kelajuan gelendong 3294 rpm dan laju suapan 191 mm / min akan menghasilkan kualiti lubang terbaik iaitu kekasaran permukaan minimum dan ralat lubang minimum. Penemuan dari kerja percubaan yang sengaja ini boleh digunakan oleh pengilang implan untuk menggerudi bahan PEEK dengan berkesan.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

LIST OF FIGURE

LIST OF FIGURE

LIST OF APPENDICES

LIST OF ABBREVIATIONS

PEEK	Polyetheretherketones
PAEK	Polyaryletherketone
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CT	Computer Tomography
RUAD	Rotary Ultrasonic Assisted Drilling
MRR	Material Removal Rate
Ra	Surface Roughness
CMM	Coordinate Measurement Machine
DOE	Design of Experiment
RSM	Response Surface Methodology
CCD	Central Composite Design
ANOVA	Analysis of Variance

CHAPTER 1

INTRODUCTIONS

1.1 Background

Polyaryletheretherketone (PEEK) materials is a semi-crystalline high purity polymers containing of replicating monomers of two ether groups and a keytone group. PEEK is a rigid opaque material considered as a good mechanical properties retained in high temperatures with a unique mixture of properties, which include wear, exceptional chemical and electrical resistance. The accumulative use of PEEK plastics can be seen in the growth of a wide range of orthopedic applications, including spinal fusion cages, artificial discs, femoral stems and cranial implant according to the picture at figure below.

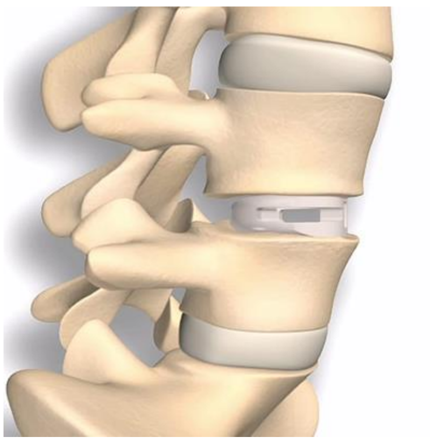

Figure 1.1: Spinal implant

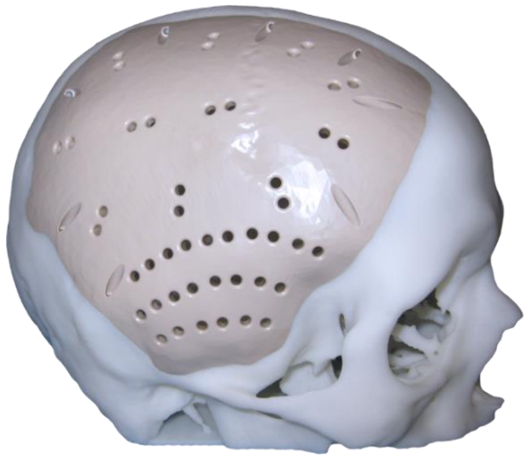

Figure 1.2: Cranial implant

Worthy of its biocompatibility, requirements on PEEK start to increase especially on medical application. PEEK offers a lot of compensations compared to metal implant; biocompatible and doesn't unleash metallic ions to body which may trigger the aversions in certain patients. PEEK also able to endure the corrosion in the human-biological environment which is significant to prolong the life span of implant (Alla et al.,2010). Furthermore, it also offers greater strength, translucent and lightweight; which are equivalent in properties with human bone. Comparable with metal, surface coating technologies can also can applied towards PEEK. For instance, PEEK is coated with hydroxyapetite (HA) or titanium which can be integrated with bone morphogenic protein (BMPs) to enhance the cartilage and bone development (Green and Schlegel, 2001) Moreover, this coating property can also encourage the new bone growth that stabilizes the fixation of PEEK implants at human fractured - bone.

1.2 Implant Fabrication Techniques

In massive scale production of standard medical implants, injection moulding and extrusion are utilized in the fabrications. Nevertheless, the main downside of these processes is that, it only produces standard size implant. Therefore, the reconstruction method during surgery needs to be carried out to fit the standard. Up until now, the human bones are derived in many size and contour according to gender, age and ethnic. Therefore, the reconstruction methodology throughout surgery must be applied to suit the standard- implant to human bones anatomy. However, the procedure is quite expensive and time-consuming due to the abnormality of human joint-anatomy to be faced in the operation (Mahoney et al., 2010)

Throughout the helps from the computer aided design (CAD) technology, patients' specific implant design technique was introduced as another technique to unravel the matter. Patient specific implants are designed to customise a specific orthopaedic and the assembly of patient specific implants started with the computer tomography (CT) scan information containing of implant prescription by the surgeon. The CT scan data will then be reconstructed by the manufacturer into a CAD model and creates the Computer Aided Manufacturing (CAM) code for machining purposes (Fadda et al., 1998). The main advantages of using this procedure is that it can fit perfectly to the patient's bone and condense the complication due to the reconstruction (Harrysson et al., 2007). On top, this technique is more sustainable in terms of time and cost compared to the conventional implant procedure.

1.3 Challenges in Machining Peek Implant / Problem Statement

To remain competitive, manufacturer is usually seeking for product improvement and qualities by manufacturing 'right initial time' machined element. Machining processes are required once there's a requirement for prototype or custom created or advanced shapes for the implants. However, the exceptional physical properties and wear characteristics of those materials will create a difficult to machining process.

On the other side, traditional manufacturing methods associated with metallic implants are commonly not satisfactory for polymeric materials. Polymers are moderately soft when compared with implant alloys and it can create manufacturing problems connected to machining, deburring, and cleaning operations. Extra data i.e optimum machining parameter is required in order to provide high qualities PEEK biomaterials implants.

In the case of medical implants, fine surface roughness is an importance factor since the cells of surrounding tissue interact with the underlying substrate on the micro and nanometer scales. Compared to application, polymeric material like PEEK promote better cell bone growth compared to metallic materials like Titanium because PEEK's surface topography enhance implant - bone contact (Sagomonyants et al., 2008). The constraint of a fine surface roughness poses a major concern in machining/drilling PEEK implant materials. PEEK's does not dissolves heat easily and has low service temperature compared to metal and it can melt if the machining/drilling temperature increases above of the melting point (Paper et al., 2016). On others hand, PEEK also deform when the cutting force and shear stress increases during the machining/drilling process which can lead to rough machined surface and imprecise tolerance of the implants.

In fabricating PEEK of cranial implant, important criteria are the drainage holes because it's not only provides access to the insides of the implant, but at the same time its available for dura and temporalis muscle suspension. Thus, the drilling process to fabricate implants is studied in this thesis by implementing the ultrasonic drilling compared with the conventional drilling process.

1.4 Objective

The objectives of this research are;

1. To investigate on the effects of Rotary Ultrasonic Assisted Drilling (RUAD) parameters namely speed and feed rate on the hole performances (hole accuracy and surface roughness) for PEEK material.
2. To develop a mathematical model on the relationship between each machining performance associated with RUAD parameters.
3. To optimize the RUAD parameters based on multi objective performances criteria namely minimize hole error and surface roughness value.

1.5 Scope

The scopes of this project are to evaluate the hole accuracy of PEEK material at the entry and exit by using ultrasonic drilling and conventional drilling toward the machining performance with varied drilling parameter.

CHAPTER 2

LITERATURE REVIEWS

Literature review was conducted in order to attain the objectives of this analysis. It contains the data associated with Polyetheretherketones (PEEK) materials, ultrasonic drilling machine, performance observations and modelling by response surface methodology. All the information presented in this chapter served as a reference and guidelines for this study.

2.1 Polyetheretherketones (PEEK)

Polyetheretherketones also called as PEEK polymer is available in two basic grades which are industrial and medical. PEEK with Industrial-grade has a strong thermoplastic characteristic that keep its mechanical properties even at high temperatures. The flame-retardant material is abrasion resistant, has high impact strength and a low coefficient of friction. Industrial-grade PEEK is normally used in the electronics, automotive, petroleum, chemical, aerospace, food and beverage industries.

Oppositely, medical-grade PEEK has the same physical properties but with the improvement of biocompatibility and high chemical resistance, it is compatible with different sterilization methods. PEEK biomaterials implant is biocompatible polymer with its bio-stability analysis is conducted according to ISO 10933 (Biological Evaluation of Medical Devices). It is nontoxic substance, inert and compatible to the living systems (Green et al., 2001) .PEEK also as organic substances that easily infers with surface modification technology to convalesce direct blood contact in human body. The additional benefit of PEEK is it can be design and shaping with various plastic processing technology as well as machining applications.

PEEK is imitative from PAEK (Poly-aryl-etherketone) polymer family which was invented in 1978 at UK Laboratories of Imperial Chemical Industries. This thermoplastic polymer was primarily used as cable-insulation material due to its toughness and high in temperature resistant. As per commercialization at 1981 afterwards, PEEK material also had recognized with an excellent mechanical properties and thermal stability which can be used as material for moulding and extrusion in high performance applications. In recent times, it is widely used in electrical, automotive, medical, chemical and other engineering plastics industries. Standard PEEK has been produced such as; KetaSripe and AvaSpire from Solvay and Victrex PEEK from Victrex. Generally, PEEK is integrated by polymerization or constant refinement of PAEK in certain type of solvents and temperatures. PEEK has several advantages over other material, such as;

1) High melting point temperature (Tm) of PEEK allows it to be used for extreme condition which involves hard-hitting chemical reaction in elevated temperature. The attack of chemical reaction can induce wear particle and contaminated the conventional composite polymer material. In spite of this, by using advanced thermoplastic like PEEK, service operation temperature can increase up to 260°C and reducing the wear particle problems.

2) High toughness of PEEK make it resistant to extreme hydrolysis and could maintain its stability in effects of ionising radiation. It is a progressive thermoplastic that does not give ionic allergic reactions to human compared to metal.

3) The diffusion of water in PEEK resin followed the Fickian's Law of Diffusion. According to the theory, the diffusion coefficient for absorption, desorption and reabsorption are equally even to the solubility of water increases. (Boinard et al., 2000). It shows that PEEK is highly resistant to dissolution in most common solvents and can be used in typical of manufacturing process; such as sintering, phase separation and rapid-prototyping (Kurtz, 2012)

4) The study by Kurtz and Devine examined that PEEK is a semi-crystalline polymer which its crystallinity can be increased from 30% to 35% upon thermal processing or annealing. The mechanical properties of PEEK are influenced by its degree of crystallinity. By increasing the crystallinity, the elastic modulus and yield strength of PEEK polymer would increase. (David Joseph Jaekel, 2012)

2.1.1 Mechanical Properties of PEEK

The Standard Specification for PEEK Polymers for Surgical Implant Applications according to ASTM International shows that the mechanical and thermal properties of PEEK has high tensile strength ranging between 97.22 to 99.97 Mpa and has Young's Modulus at 3502.537 Pa. . High tensile strength and low of young modulus properties imply that PEEK has similar attributes of human bones which possess good strength and lightweight features. (Sagomonyants et al., 2008). Other than that, PEEK can achieve stability even though temperature increases up to 300 ◦C. This indicates that PEEK poses good bio- compatibility properties and have high resistant towards hot temperatures (Converse et al., 2010) Table 2.1 shows the mechanical and thermal properties of natural PEEK.