UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

OPTIMISATION OF CUTTER GEOMETRICAL FEATURE FOR MACHINING ORTHOPEDIC, TRAUMA AND SPINAL BIOMATERIALS IMPLANT

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OPTIMISATION OF CUTTER GEOMETRICAL FEATURE FOR MACHINING ORTHOPEDIC, TRAUMA AND SPINAL BIOMATERIALS IMPLANT

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2016

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Master of Science in Manufacturing Engineering.

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Date	:	....

DECLARATION

I declare that this thesis entitled “Optimisation of Cutter Geometrical Feature for Machining Orthopedic, Trauma and Spinal Biomaterials Implant” 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 : NURUL HUSNA BINTI MOHD NAWAWI

Date : ....

DEDICATION

To my beloved mother and family members

ABSTRACT

Polyetheretherketones (PEEK) are polymeric based composites that resistance to chemical and radiation, excellent stability in high temperature and biocompatible. It is a semi-crystalline polymer which consists of polyaromatic ketones that contributed to toughness and flexibility of its structure. Due to its enhanced chemical and mechanical structure, PEEK has been commercialized as implant components for orthopedic and trauma applications because it is promote non-allergic reactions compared to the metal implants. Generally, implants are fabricated by extrusion and injection molding for a larger scale. However, often for short production runs, it is not economically viable to manufacture by an injection molding. Under such circumstances, it is common to employ a machining process on the PEEK materials to form the components. The requirement for a fine surface roughness poses a major concern in machining of polymeric base materials due to its low thermal conductivity. Surface morphology is a vital factor for medical implants since the cells of the surrounding tissue interact with the underlying substrate on the micro and nanometer scales. For some application such as self-mating articulation cervical disc implants, smooth surface finish is critical so as to minimize the contact friction and wear. Machining performances such as surface roughness and cutting forces especially for polymeric material such as PEEK are directly affected by cutting tool geometry. Most of the cutter geometry employed for machining PEEK was using the same cutter as machining metal which tends to lower its machining performances. Roughed surface, premature tool wear and localized heating are defects that related with machining these polymeric materials. All of these defects are directly related with the tool geometries functions and should be methodically considered. Tool geometries such as helix angle, rake angle, clearance angle and number of flute are important in mechanics of material removal process and significantly affect the machining performances. Thus, this thesis aims to develop new cutter geometry for machining PEEK material to enhance the machining performance and productivity. To achieve the objective, Taguchi and Response Surface Methodology (RSM) experimental techniques were employed for optimizing tool cutter geometry. From the conducted experiment, it shows that a two flutes cutter geometry with a combination of 16.20° rake angle, 30.21° helix angle and 10° clearance angle was the best cutter geometry that produced the lowest resultant force and surface roughness value which are predicted to be 247.434 Newton and 0.633 µm respectively. Meanwhile, the correlation between experimental and predicted solution was significant with the ranges of percentages contribution for resultant force were 92.25% to 97.74% and for surface roughness were 91.74% to 99.52%. The good agreement value between prediction and experimental hence validate the new proposed cutter design optimize the machining performance of PEEK.

ABSTRAK

Polyetheretherketones (PEEK) ialah komposit berasaskan polimer yang tahan kepada bahan kimia dan radiasi, stabil pada suhu yang tinggi dan 'biocompatible'. Ia polimer semi-kristal terdiri daripada keton poliaromatik yang memberi kekuatan dan fleksibiliti strukturnya. Oleh sebab struktur kimia dan mekanikal yang telah dipertingkatkan, PEEK dikomersilkan sebagai komponen implan untuk aplikasi ortopedik dan trauma kerana ia menggalakkan reaksi bukan alahan berbanding dengan implan logam. Secara umumnya, implan yang dibentuk melalui penyemperitan dan acuan suntikan untuk skala yang besar. Bagaimanapun, untuk pengeluaran yang pendek, ia tidak berdaya maju dari segi ekonomi untuk menggunakan pembuatan melalui pengacuan suntikan. Dalam keadaan itu, menjadi perkara biasa menggunakan proses pemesinan pada bahan PEEK bagi membentuk komponen. Keperluan bagi kekasaran permukaan halus menimbulkan kebimbangan utama dalam pemesinan bahan asas polimer kerana kekonduksian haba yang rendah. Morfologi permukaan adalah faktor penting untuk implan perubatan sejak sel di sekitar tisu berinteraksi dengan substrat pada skala mikro dan nanometer. Bagi sesetengah aplikasi seperti implan mengawan sendiri sendi cakera serviks, kemasan permukaan licin adalah kritikal bagi mengurangkan geseran dan hakisan. Prestasi pemesinan seperti kekasaran permukaan dan daya pemotongan terutamanya bagi bahan polimer seperti PEEK dipengaruhi secara langsung dengan geometri alat pemotong. Kebanyakan geometri pemotong yang digunakan untuk pemesinan PEEK adalah menggunakan pemotong yang sama seperti pemesinan logam yang cenderung menurunkan prestasi pemesinan. Permukaan kasar, hakisan alat pra-matang dan pemanasan setempat adalah kecacatan yang berkaitan dengan pemesinan bahan-bahan polimer. Semua kecacatan ini berkait secara langsung dengan fungsi-fungsi alat geometri dan harus teratur dipertimbangkan. Geometri alat seperti sudut helik, sudut sadak,sudut kelegaan dan jumlah seruling adalah penting dalam mekanik proses pembuangan bahan dan memberi kesan ketara kepada persembahan pemesinan. Oleh itu, tesis ini bertujuan untuk membangunkan pemotong geometri baru dalam pemesinan bahan PEEK bagi meningkatkan prestasi pemesinan dan produktiviti. Bagi mencapai objektif itu, Taguchi dan Tindak Balas Permukaan Metodologi (RSM) teknik eksperimen telah digunakan untuk mengoptimumkan pemotong alat geometri. Dari eksperimen yang dijalankan, ia menunjukkan bahawa dua seruling pemotong geometri dengan gabungan 16.20 ° sudut sadak, 30.21 ° sudut helik dan 10 ° sudut kelegaan adalah geometri pemotong terbaik yang menghasilkan daya paduan terendah dan nilai kekasaran permukaan yang diramalkan masing-masing menjadi 247.434 Newton dan 0.633 μm. Sementara itu, korelasi antara eksperimen dan ramalan adalah ketara dengan julat peratusan sumbangan untuk daya paduan adalah 92.25% hingga 97.74% dan untuk kekasaran permukaan adalah 91.74% hingga 99.52%. Nilai persetujuan yang baik antara ramalan dan eksperimen dengan itu mengesahkan cadangan reka bentuk baru pemotong mengoptimumkan prestasi pemesinan PEEK.

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LIST OF ABBREVIATIONS

PEEK	-	Polyetheretherketone
PEEK CF30	-	30% Carbon Fiber Reinforced Polyetheretherketone
PEEK GF30	-	30% Graphite Fiber Reinforced Polyetheretherketone
HA	-	Hydroxyapetite
BMPs	-	Bone Morphogenic Protein
CT	-	Computer Tomography
CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
RSM	-	Response Surface Methodology
DOE	-	Design of Experiments
ANOVA	-	Analysis of Variance
FEM	-	Finite Element Method
PCD	-	Polycrystalline Diamond
HDPE	-	High Density Polyethyelene
LDPE	-	Low Density Polyethylene
MMCS	-	Metal Matrix Composite
GFRP	-	Glass Fibre Reinforced Polymer
CCD	-	Central Composite Design
S/N	-	Signal to Noise Ratio

LIST OF SYMBOLS

µm	-	micro meter
°, ° C	-	degree, degree Celcius
Pa, Mpa	-	pascal, mega pascal
mK	-	meter kelvin
g/ cm^3	-	gram per centimetre cube
kg / m^3	-	kilogram per meter cube
mm/ tooth	-	millimetre per tooth
mm/min	-	millimetre per min
mm/rev	-	millimetre per revolution
rpm	-	revolution per minute
%	-	percent
L_c	-	tool -chip contact length
∅	-	shear angle
Ra	-	arimethic roughness
n	-	number of samples
y, ȳ	-	measured data, average measured data
s^2	-	Variance
H_o	-	Null hypothesis
∝	-	alpha values

LIST OF PUBLICATIONS

1. R. Izamshah, N. Husna, M. Hadzley, M. Amran, M. Shahir, M. Amri,
   Effects of Cutter Geometrical Feature on Machining Polyetheretherketone (PEEK) Engineering Plastic, Journal of Mechanical Engineering and Sciences, 6, pp.863-872.

2. R. Izamshah, N. Husna, M. Hadzley, M. Amran, M. Shahir, M. Amri,
   Determination on Effect of Cutter Geometrical Feature for Machining Polyetheretherketone (PEEK) Using Taguchi Method, Applied Mechanics and Materials, 699,pp.192-197. (SCOPUS Indexed)

3. R. Izamshah, N. Husna, M. Hadzley, M. Amran, M. Shahir, M. Amri,
   Optimisation of Cutter Geometrical Feature to Minimise Force on Polyetheretherketone (PEEK) Engineering Plastic, Proceedings of the 3rd International Conference on Design and Concurrent Engineering (IDECON), 22-23 September 2014

CHAPTER 1

INTRODUCTIONS

1.1 Backgrounds

Poly-ether-ether-ketone (PEEK) are thermoplastic polymer consisted of aromatic ring structure bridging with ketone group and two ether linkages (Sagomonyants et al., 2008). This structure gives stiffness, flexibility and toughness on this material. In addition, its bio-compatibility to the human bodies has made it as an alternative material for medical implant to replace metal based implant such as stainless steel and titanium alloy (Kurtz and Devine, 2007). The increasing use of PEEK plastics can be seen in the development of a wide range of orthopaedic applications, including spinal fusion cages, artificial discs and femoral stems as shown in Figure 1.1.

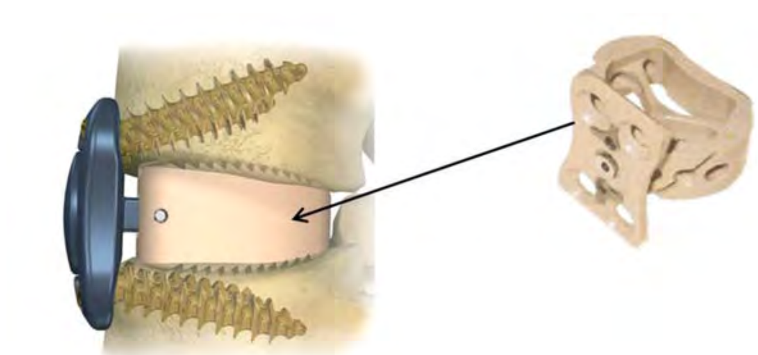

Figure 1.1: Orthopaedic PEEK plate cage for cervical spinal bone (Anonymous, 2013)

Processing for some plastics can be easily scaled up to meet the increasing demand for product parts. Incorporating plastic technologies (for example, injection molding) means that the economics of production are viable on a larger scale, while complex shapes can be formed as required to aid device fabrication. However, often for prototype designs or short production runs such as patient specific implant, it is not economically viable to manufacture injection molding tool. Under such circumstances, it is common to employ a machining process on the PEEK polymer from a solid block material to form the components.

However, the technique acquired from metal machining cannot be directly transplanted to the polymeric material without considering the peculiar material response on the cutting performances. Polymers are relatively soft if compared to metal and this can create manufacturing problems related to machining. Machining performances such as surface roughness, tool wear, part accuracy and cutting forces are directly affected by several factors namely machining parameters, material properties, cutting tool geometry, jig and clamping fixture. Above all the factors mentioned, cutting tool geometry is the most crucial factor affecting the machining performances especially for polymeric material (Shih et al., 2004). To the best of author's knowledge, most of the latest cutting tools geometry employed for machining PEEK were using the same cutting tool as metal machining which can cause some problems. Severe tool wear and rough machined surface were obtained during machining and finishing operations conducted on these polymeric materials.

Surface roughness is a vital factor for medical implants since the cells of the surrounding tissue interact with the underlying substrate on the micro and nanometer scales (Krishna Alla et al., 2011). For some application, such as self-mating articulation cervical disc implants smooth surface finish is critical so as to minimize the contact friction and wear. Nevertheless, the bone-cell adhesion is directly related with the surface integrity of the implant. The requirement for a fine surface roughness poses a major concern in machining of polymeric base materials due to its low material of thermal conductivity.

The optimization of ball nose cutter geometry is purposely studied in this thesis. The project involved a full collaboration with Medical Devices and Technology Group (MediTeg), Faculty of Biosciences and Medical Engineering, Universiti Teknologi Malaysia and funded by Malaysia Ministry of Education. The workpiece material is Poly-ether-ether-ketone (PEEK) thermoplastic which are used for all of the components. The milling process of PEEK thermoplastic for patient specific implants is generally employed in medical practices. During milling process of this component, large volumes of materials are removed with the risk of instability and tolerance violation. Traditionally, the cutting tool geometry used in machining PEEK material are employed by a similar cutting tool that cuts metal, which tends to lower the machining performances.

1.2 Advantages of PEEK in Medical Application

PEEK offers a lot of advantages compared to metal implant; biocompatible and does not release metallic ions to human body which can trigger the allergic reactions in certain patients. PEEK also able to withstand the corrosion in the human-biological environment which is important to prolong the life span of implant (Ramakrishna et al., 2010). In addition, it also offers greater strength, lightweight and translucent; which are similar in properties with human bone. Like metal, surface coating technologies can also be applied towards PEEK. For example, 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). Furthermore, this coating property can also induce the new bone growth that stabilizes the fixation of PEEK implants at human fractured - bone. Figure 1.2 indicates the stiffness of PEEK material in relation with human bone. The correspond pattern of PEEK's stiffness with bone elastic modulus at 16Gpa is imperative in reducing the stress shielding which can cause weakening of bony region around the implants and ultimately lead to implant loosening (Green and Schlegel, 2001).

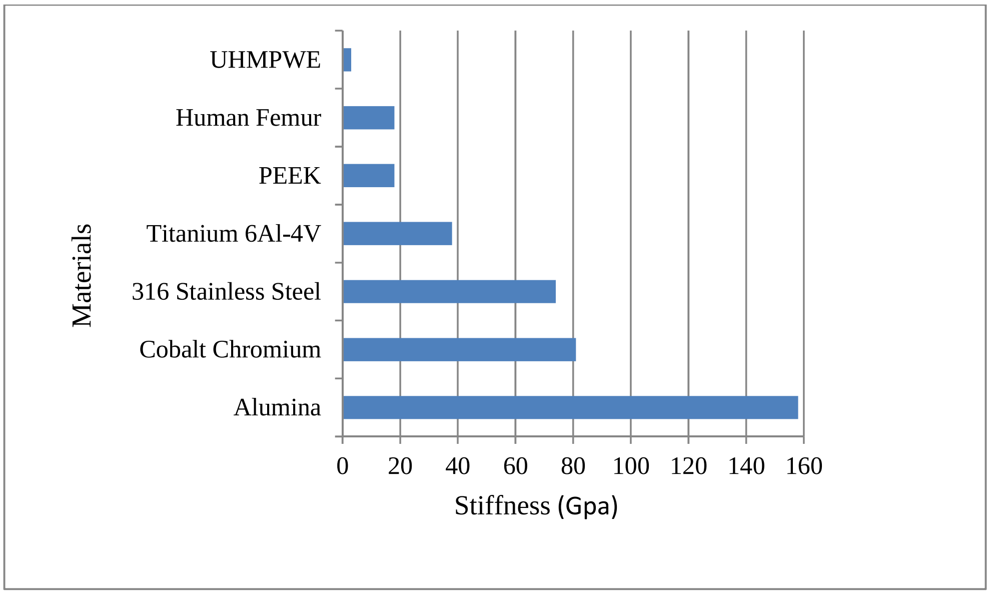

Figure 1.2: Stiffness property of implant materials compared with human femur bone (Green and Schlegel, 2001)

1.3 Medical Implant Fabrication Technique

In manufacturing production of conventional medical implants, a large scale of injection molding and extrusion are involved (Kurtz, 2012). However, the main drawback of this near shape process is that it only produced standard size implant. However, the human bones are derived in many size and contour according to gender, age and ethnic. Therefore, the reconstruction method during surgery needs to be carried out to fit 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). Through the development of Computer Aided Design (CAD) technology, the patient specific implant designs are emerging into the alternative technique to solve the problem.

Patient specific implants are designed to customize a particular orthopedic patient. It is produced through the integration of advance technique design based on Computer Tomography (CT) scan data and machining process. The production of patient specific implants started with the CT scan data containing of implant prescription by the surgeon. Then, based on the CT scan data, manufacturer will reconstruct the design into a CAD model and create the CAM code to generate the machine tool path. After the machining process, the implants will be sterilized before being sent back to the hospital for implantation (Fadda et al., 1998). One of the main advantages of using this procedure isthat it can fit perfectly to the patient's bone and reduce the complication due to the reconstruction (Harryson et al., 2007). In addition, this technique is more sustainable in terms of time and cost compared to the conventional implant procedure. Figure 1.3 depicted the production cycle for patient specific implants.

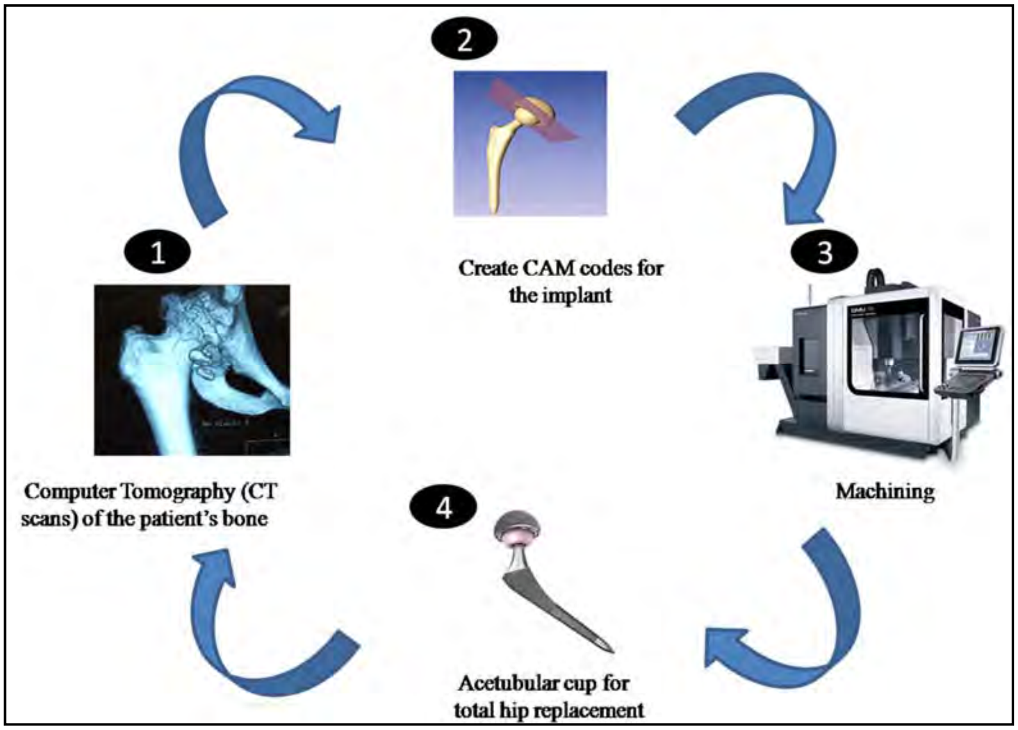

Figure 1.3: Production cycle of a patient–specific implant (Fadda et al., 1998)

1.4 Challenges in Machining PEEK Implant / Problem Statement

The machining of polymeric materials has been increasingly used and made necessary when the quantity of precious items does not justify the cost of tooling for mould or extrusion dies, or when a product needs a costly dimensional accuracy, such as polymer implants. It is a well-known fact that machining of polymeric plastic can create several problems due to its low thermal resistance, greater thermal expansion, low mechanical characteristics and poor creep resistance. Too much heat input in the component can lead to high stress levels and thus to warping or fracture. In addition, excessive heat input can cause expansion of the plastic which make it difficult to control the required tolerances of machined parts. On the other hand, inadequate fixation may lead to deformation during machining which will lead to part rejection. However, due to its gummy condition, severe tool wear and rough machined surface are obtained during machining operations were conducted on these polymeric materials.

In the case of medical implants, fine surface roughness is a vital factor since the cells of surrounding tissue interact with the underlying substrate on the micro and nanometer scales. For some application, polymeric material like PEEK is promote better cell bone growth compared to metallic materials like Titanium because PEEK's surface topography enhance implant - bone contact (Sagomontyant et al., 2008). Other medical device, such as self-mating articulation cervical disc implants smooth surface finish is critical so as to minimize the contact friction and wear. Nevertheless, the bone-cell adhesions are directly related with the surface integrity of the implants. The requirement for a fine surface roughness poses a major concern in machining PEEK implant materials. PEEK's does not dissipates heat easily and has low service temperature compared to metal. PEEK can melt if the machining temperature increases above of the melting point (Fetecau et al., 2008; Mata et al., 2009). PEEK also deform when the cutting force and shear stress increases during machining which can lead to rough machined surface and inaccurate tolerance of the implants.

Machining performances such as surface roughness, tool wear, accuracy and cutting forces are directly affected by several factors namely machining parameters, material properties, cutting tool geometry, jig and clamping fixture. Despite all of the factors, cutting tool geometry is the most critical criteria affecting the machining performances especially for polymeric material (www.sdplastics.com/pdf/machng.pdf access on 27 October 2013). To the best of author's knowledge, most of the latest cutting tools geometry employed for machining PEEK are similar to the cutting tool used for metal machining which tend to lower its machining performances. Rough machined surface, premature tool wear and localized heating are among few of the synonym defects when machining these