MACHINING OF BONE: AN ANALYSIS OF CUTTING FORCE, SURFACE INTEGRITY AND CHIP MORPHOLOGY

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ABSTRACT

In orthopedic surgery, a damage bone is removed by method of machining in order to enable implant fixation. This requires high precision tools and techniques to prevent mistakes such as overcut and to avoid injuries to the surrounding tissues. This project involved the turning process where bovine bone samples were turned based on experimental conditions suggested by the response surface methodology (RSM) with a view of determining the optimum condition within the range investigated. At the same time an initial investigation on the cutting mechanism fundamentals for bone material was undertaken. The experiments were performed under dry cutting conditions. Cutting speed, depth of cut and feed rate were the main factors investigated while the main cutting force and surface roughness were the responses. Experiments were performed at cutting speeds ranging from 55 to 130 mm/min, with depths of cut in the range of 0.1–0.3mm, and feed rate from 0.04 to 0.09 mm/rev. The experimental plan was based on the central composite design (CCD). Chips after machining were observed and analyzed in order to see the influence of cutting conditions. The proposed mathematical models are adequately accurate to predict the performance indicators within the experimental range investigated. The most influencing factor on the cutting force is depth of cut, followed by feed rate, cutting speed and depth of cut interaction, depth of cut and feed interaction, and cutting speed respectively. Feed rate has the most effect on surface roughness while the cutting speed and feed rate^2 factors presented secondary contribution on the surface roughness response. The partially continuous chips were observed at the cutting condition of 55 mm/min speed, 0.3mm depths of cut and 0.09 mm/rev feed rate indicating the possible occurrence of ductile mode machining on bone.

ABSTRAK

Dalam pembedahan ortopedik, tulang yang rosak dikeluarkan dengan kaedah pemesinan untuk membolehkan pemasangan implan. Pembedahan ini memerlukan peralatan berkeupayaan tinggi dan teknik untuk mengelakkan kesilapan pemotongan dan mencegah kecederaan tisu di sekitarnya. Projek ini dilakukan secara eksperimen ke atas sampel tulang lembu dengan menggunakan kaedah tindak balas permukaan (RSM) untuk menilai keadaan pemesinan optimum pada julat pemesinan yang disiasat. Pada masa yang sama kajian awal mengenai asas mekanisme pemotongan untuk bahan tulang dilakukan. Ujikaji telah dijalankan secara pemotongan kering. Kadar kelajuan, kedalaman pemotongan dan kadar suapan adalah faktor utama yang dikaji manakala tindak balasnya adalah daya pemotongan dan kekasaran permukaan. Kadar kelajuan semasa memotong adalah dalam julat 55-130 mm / min, kedalaman pemotongan dalam julat 0.1 - 0.3mm, dan kadar suapan dalam julat 0.04-0.09 mm / rev. Eksperimen ini adalah berdasarkan kepada reka bentuk pusat komposit (CCD). Selepas eksperimen dilakukan, cip dikaji dan dianalisis berdasarkan kepada keadaan pemotongan. Secara matematik, ianya adalah bersesuaian dan tepat untuk meramalkan prestasi bagi pelbagai faktor yang telah dikaji. Faktor yang paling mempengaruhi daya pemotongan adalah kedalaman pemotongan, diikuti oleh kadar suapan, interaksi kelajuan pemotongan dan kedalaman pemotongan, interaksi kedalaman pemotongan dan kadar suapan dan kelajuan pemotongan. Kadar suapan mempunyai kesan besar ke atas kekasaran permukaan manakala kelajuan pemotongan dan kadar suapan^2 memberi sumbangan sekunder kepada kekasaran permukaan. Cip separa berterusan diperhatikan pada kelajuan pemotongan 55 mm/min, kedalaman pemotongan 0.3 mm dan kadar suapan 0.09 mm/rev menunjukkan kemungkinan berlakunya pemesinan mod mulur pada tulang.

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LIST OF SYMBOLS

A	-	First factor or input variable investigated —cutting speed (m/min)
Adeq precision	-	Adequate precision
Adj R^2	-	Adjusted R^2
B	-	Second factor or input variable investigated —dept of cut (mm)
C	-	Third factor or input variable investigated —feed rate (mm/rev)
Cor. total	-	Totals of all information corrected for the mean
CV	-	Coefficient of variation
d.f.	-	Degrees of freedom
Fc	-	Main cutting force - tangential force (N)
Pred. R^2	-	Predicted R^2
Prob.>F	-	Proportion of time or probability you would expect to get the stated F value
PRESS	-	Predicted residual error sum of squares
Ra	-	Surface roughness of the turned surface (µm)
R^2	-	Coefficient of determination
S.D.	-	Square root of the residual mean square
V	-	Cutting speed (m/min)

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CHAPTER 1

INTRODUCTION

1.1 Background

Machining is well known as a manufacturing process for removing unwanted material in the form of chips by the use of machine tools into the desired shape, with size and finish as specified to fulfill design requirements. The majority of manufacturing applications involving machining involve metals i.e. aluminum, steel, stainless steel, copper, etc. Although theoretical analysis of the metal cutting processes is complex, the application of these processes in the industrial world is widespread. Not only metal, machining processes can be further used to produce components from various types of materials such as polycarbonate, plastic, fiberglass, acrylic as well as brittle materials such as glass, ceramic, cast iron, silicon, and bone etc. For a broad range of materials, machining processes are able to perform on a wide variety of machine tool and variation of the combination of machining condition.

For bone material, methodology of machining bone in surgery which is developed in means of medicine has existed since when people start to heal other people and animal. Up to now people still used conventional method in bone machining such as sawing, drilling and milling to repair the broken or inflame part of bone in the best possible way. In orthopedic surgery, fracture repair is performed by placing the bone in the proper position and is then fixated by attaching screws, pins, or plates to the bone. In order to attach these fixating devices, bone needs to be machined (i.e., by drilling) in multiple locations. Another form of bone machining is performed during dental implantation, where small amount of bone is removed by machining (i.e., drilling) to provide a space for placing dental implant in the jaw bone.

Bone machining actually induces new wound damage to the bone tissue. This requires the process to be performed gently not to over damage the surrounding healthy tissue. There are some effects which may occur due to the influencing factors during bone operation. First is the thermal necrosis, the temperature occurred during machining causes tissue damage which results in infection, implantation failure, delayed recovery period, and severe pain. Bone necrosis was reported to occur when the machining temperature reaches 56°C for over 10 seconds [1]. Second is machining force, the excessive force have an effect on the penetration of surgical instruments, the surgeon can control the instrument smoother when force is minimum and more precision operation is achieved. Thus when these effect need to be controlled within this limit by optimum parameter of bone machining to achieve the best possible shortest time and avoid the thermal damage on machined bone.

As the modern surgery medicine, the cooperation between the technical and medicine scientific is growing daily. However the study on bone machining and especially in the surface integrity and chip morphology analysis area is still very rare. Due to the limited data of bone machining, brittle material such as silicon etc. which can accomplish ductile mode machining over brittle mode machining is studied due to its characteristic is similar to bone to find out the optimum setting parameters in bone machining. The chip formation which can be used to indicate the ductile mode machining in brittle material is also considered. Since when the brittle mode machining is transform to ductile removal machining, the high-quality surface finish and smaller cutting energy are produced. These results are required in orthopedic surgery.

Thus the project's goal is to study parameters and influence factors focusing on these two approaches in bone turning process. It is believed that the result from this study can convert to determine the optimum setting to achieve the best possible result for usual bone machining in medicine surgery

1.2 Problem Statement

For surgical bone in medicine, most of processes which have been done are drilling and milling. Some of researches proposed the influenced factors and optimum parameters for bone machining on thermal distribution and force during machining. Some results presented the guide line of cutting condition but the fundamental understanding of bone machining process and chip formation mechanism are still unclear. Moreover very few studies in literature focus on surface integrity on machined bone, however the good quality surface finish is desirable for bone machining. Since the machined surface result can indicate by the chip formation and cutting force, the phenomena occurred due to theses effect can be related and described by compare to the results which have been proposed by other studies.

Brittle characteristic of bone may cause the fracture during machining. In this case, the ductile mode machining is considered due to it can be achieved through continuous chip formation and good surface integrity under significant cutting condition in brittle material. However the analysis of surface integrity and chip morphology for bone machining by employing usual surgical bone process such as drilling and milling, there is complicated method to determine the optimum parameters for machining and examine chip formation via these processes. Therefore tuning process will be used in this project since it is easier method to conduct the experiment and approach the analysis of result in chip morphology.

1.3 Objectives of the Study

The purpose of this research was to observe effect of various cutting parameter on Surface integrity and chip morphology of cortical bone. The following objectives were to be achieved in this research:

- To explore the effect of various process parameters on various machinability criteria.
- To develop mathematical models which relate various process parameters on various machinability criteria.
- To study chip morphology as a function of cutting parameters.

1.4 Scope of the Study

The femur bones form adult bovines were chosen for the turning experiment. Samples were prepared to be machined using turning process (using CNC lathe machine). Three set of cutting parameters (cutting speed, feed rate and depth of cut) were controlled and performed on the experiment. The experiment plan was designed by using response surface methodology (RSM). Cutting force of turning was captured simultaneously when bone was machined. Next surface integrity was investigated on the external topography of surfaces (surface roughness) and then chip morphology was analyzed.

1.5 Thesis Organization

The thesis is divided into six chapters. Chapter 1 provides a general overview of the study. Chapter 2 was organized to summarize the literature reviews of the related topic to guide the study towards achieving the objective. The experimental set up and techniques used are explained in Chapter 3. All the experiment data and result are presented in Chapter 4. In Chapter 5, the results are discussed and the comparisons are made to the work done in previous research. The conclusions of the study and the recommendations for future work are given in Chapter 6.

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