Faculty of Manufacturing Engineering

PREDICTION OF TOOL WEAR CHARACTERISTICS IN TURNING ON INCONEL 718: EXPERIMENTATION AND SIMULATION

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A thesis submitted in fulfilment of the requirements for the degree of Master of Manufacturing Engineering (Industrial Engineering)

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DECLARATION

I declare that this thesis entitled "Prediction of Tool Wear Characteristics in Turning on Inconel 718: Experimentation and Simulation" 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 (Industrial Engineering).

Signature :………………………………….

Supervisor Name :………………………………….

Date :……………………………….........

DEDICATION

In the Name of Allah, Most Gracious, Most Merciful.Praise be to Allah S.W.T. because with His permission I capable to complete my thesis with the title of “Prediction of Tool Wear Characteristics in Turning on Inconel 718: Experimentation and Simulation”. This thesis is dedicated to my beloved parents Sir Abd Aziz bin Hashim and Madam Miskiati binti Mohd Som. Highly gratitude and thank you to my family and friends for the continuous supports, encouragements and sacrifices The huge appreciation for my supervisor, lecturers and assistant engineer that involved in this study. The advice and guidance from Assoc. Prof. Dr Md Nizam bin Abd Rahman and Dr Mohd Shahir bin Kasim and Sir Mohd Taufik bin Abd Aziz as my reference in order to accomplished this thesis.

ABSTRACT

Inconel 718 is a superalloy that has very strong mechanical properties due to an excellent yield strength at elevated temperature, capable to withstand thermal shock and corrosion resistance. In this study, the turning process is chosen as material removal operation. A bar stock of Inconel 718 and uncoated tungsten carbide were used as workpiece and cutting tool respectively. The turning operation evaluation was conducted in two different techniques which are experimental machining and simulation modelling. The input parameters selected in this study were spindle speed, depth of cut and feet rate. The chosen spindle speed parameters are 717 rpm, 876 rpm, 1035 rpm and 1194 rpm. The other two parameters which are depth of cut and feet rate parameters remain fixed as 1.0 mm and 0.1 mm/rev. Each set of cutting parameter underwent four repetitions of machining operation in order to access variability in this study. The aim of study is to establish and evaluate correlation between spindle speed and tool wear characteristics for both experimental machining and simulation modelling techniques in turning of Inconel 718 operation. The equipment used in this study was CNC lathe machine for experimental machining, thermal imager for capturing thermogram image of temperature distribution during turning process for maximum values. Besides, tool maker microscope and optical microscope were used for analysing and observing physical and structural changes of tool wear characteristics on the cutting tool edge. For the simulation modelling technique, DEFORM 3D software used in order to predict the tool wear characteristics that occurred after simulation process is completely done. The output response obtained from DEFORM 3D software is in terms of graphical image, graph chart and numerical values. The pre processor, simulator and post processor were generated based on the actual experimental machining characterizations which were mechanical properties, geometry dimensions and cutting conditions. The data analysis method for this study were regression and correlation analysis by using Minitab software. The hypothesis of this study is stated that the tool wear characteristics increase as the spindle speed increased. The tool wear characteristics generation are influenced by spindle speed as heat generated between contacted area of cutting tool and workpiece. The positive results obtained from the experimental machining and simulation modelling which indicated that rising in spindle speed tends to increase tool wear characteristics. In the experimental machining, result shows that flank wear length, notch wear length, crater wear length, chip formation and maximum temperature increased due to rising in spindle speed. Besides, the simulation modelling also determines that maximum temperature, total velocity, tool wear-interface temperature, tool wear-interface pressure, tool wear-sliding velocity, effective strain rate, effective strain, nodal heat, total force, folding angle, effective stress, tool wear-wear rate, tool wear-total wear depth, minimum distance, surface area, surface expansion ratio, damage and maximum shear stress increased due to rising in spindle speed.

ABSTRAK

Inconel 718 adalah aloi terkuat yang mempunyai sifat mekanik yang kuat kerana kekuatan hasil yang cemerlang pada suhu tinggi, mampu menahan kejutan haba dan rintangan kakisan. Dalam kajian ini, proses larik dipilih sebagai operasi penyingkiran bahan. Stok bar Inconel 718 dan karbida tungsten yang tidak bersalut akan digunakan sebagai alat kerja dan alat pemotong. Operasi larik akan dijalankan dalam dua teknik yang berbeza iaitu pemesinan eksperimen dan pemodelan simulasi. Parameter input yang terpilih dalam kajian ini adalah kelajuan gelendong, kedalaman potongan dan kadar kaki. Parameter kelajuan gelendong yang dipilih adalah 717 rpm, 876 rpm, 1035 rpm dan 1194 rpm. Dua lagi parameter iaitu kedalaman potongan dan kadar suapan seperti 1.0 mm dan 0.1 mm / rev. Setiap set parameter memotong akan menjalani empat operasi pemesinan pengulangan untuk kebolehubahan akses dalam kajian ini. Tujuan kajian adalah untuk menubuhkan dan menilai hubungan antara kelajuan gelendong dan ciri kehausan mata alat untuk kedua-dua teknik pemesinan dan pemodelan dalam operasi larik Inconel 718. Peralatan yang akan digunakan dalam kajian ini adalah mesin CNC larik untuk teknik pemesinan, pengimejan termal untuk menangkap imej termogram pengedaran suhu semasa proses larik untuk nilai maksimum. Selain itu, mikroskop pembuat alat dan mikroskop optik digunakan untuk menganalisis dan memerhatikan perubahan fizikal dan struktur kehausan mata alat. Untuk teknik pemodelan simulasi, perisian DEFORM 3D akan digunakan untuk meramalkan ciri-ciri haus alat yang berlaku selepas proses simulasi selesai sepenuhnya. Tanggapan pengeluaran akan diperoleh dari perisian DEFORM 3D adalah dari segi grafik, dan nilai berangka. Pra pemproses, simulasi dan pemproses pasca dihasilkan berasaskan situasi pemesinan sebenar yang sifatnya mekanikal, dimensi geometri dan keadaan pemotongan. Analisis data yang akan digunakan dalam kajian ini adalah analisis regresi dan korelasi dengan menggunakan perisian Minitab. Hipotesis kajian ini menyatakan bahawa ciri haus alat akan meningkat apabila kelajuan gelendong meningkat. Hasil positif diperolehi daripada model pemesinan dan pemodelan simulasi yang menunjukkan bahawa peningkatan dalam kelajuan gelendong akan cenderung meningkat dalam ciri-ciri pakaian alat. Dalam pemesinan eksperimen, hasil menunjukkan bahawa memakai panjang memakai, panjang memakai takik, panjang memakai kawah, pembentukan cip dan suhu maksimum meningkat disebabkan peningkatan dalam kelajuan gelendong. Selain itu, pemodelan simulasi juga menentukan suhu maksimum, jumlah halaju, suhu pakai alat antara muka, tekanan pakai antara muka alat, halaju gelongsor alat, kadar ketegangan berkesan, ketegangan yang berkesan, haba nod, kekuatan keseluruhan, sudut lipatan, tekanan berkesan, kadar pakai pakai alat, kedalaman memakai jumlah pakai alat, jarak minimum, kawasan permukaan, nisbah pengembangan permukaan, kerosakan dan tegasan ricih maksimum dinaikkan kerana kenaikan kelajuan gelendong.

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LIST OF ABBREVIATIONS

CNC	-	Computer Numerical Control
FEM	-	Finite Element Model
3D	-	Three Dimensional
ISO	-	International Standards Organization
WC	-	Tungsten Carbide
MDI	-	Manual Data Input

LIST OF EQUATIONS

CHAPTER 1

INTRODUCTION

This chapter presents the background of project, problem statement, objectives, scope and significance of the study. Besides, it briefs about the data accuracy issues between experimental machining and simulation modelling of turning Inconel 718 operation. Then, the relationship between cutting parameters and tool wear characteristics of Inconel 718 will be determined.

1.1 Background

Turning is one of the metal removal cutting operation which has been used widely in various type of manufacturing industries. The machining process of turning produced a cylindrical parts or products. Metal cutting operations has been representing the largest class of manufacturing operations that make turning process is the most commonly employed in material removal process (Swamy et al., 2012). As the basic form, turning process could be defined as the machining of an external surface of work piece as it is rotating at a specific cutting or spindle speed. The advances in lathe CNC machining technologies has been boosting the productivity of the turning machining process. The three main variables in any basic turning operation are cutting speed or spindle speed, depth of cut and feed rate. Other variable also has a significant in operating turning process such as type of work piece material and type of tool. Tool of turning operation are insert and tool holder. The material either coated or coated of insert also make a different during turning process. However, these three variables have a large influence in turning operation that could be changed and controlled by adjusting the manipulated variable. As the curiosity of the effect of cutting parameters towards the result of turning operation; then it became one of the encouragement in order to have a thorough study about this issues.

Inconel 718 is the nickel based alloy that have been used widely as an engineering material in space vehicles, aircraft gas turbines, nuclear reactors, reciprocating engines, petroleum industries and thermal exchangers applications (Olovsjö et al., 2012). Inconel 718 has a low machinability characteristic that makes a turning process become a challenging machining operation due to excessive of tool wear as the result of excessive heat generation and poor surface finish (Khidhir and Mohamed, 2010). The power required for turning operation of Inconel 718 is normally fed through a central power of the distribution system (Zhu et al., 2013). The cutting force is an essential component needed to perform the metal removal cutting operation (Vijayaraghavan et al.,2016). Various combination of turning process parameters will result many different of mechanical properties such as tool wear, surface roughness temperature and so on. The effectiveness of a material removal cutting process is depending on the large extend on the machinability characteristics of the material (Olovsjö et al., 2012). Thus, the machinability of Inconel 718 in not only based on cutting parameters but it is also depending on the cutting tool properties which will determine the quality of finished product or component. So as stated by previous studies, cutting tool properties also is an important matter in this study.

In order to understand tool wear mechanisms, tool insert either coated or uncoated, material of insert used, machining process monitoring and tool holder and insert geometry are the crucial factors need to be understand (Vijayaraghavan et al., 2016). Apart from the study, Finite Element Model (FEM) analysis is one of the method could be used to analyse the mechanical properties of Inconel 718. FEM analysis capable to predict the machining characteristics in turning operation of Inconel 718 (Lorentzon and Järvstråt, 2006). Lorentzon & Järvstråt (2006) studied the wear models and its impact on the wear profiles generated from the FE model. Moreover, Vijayaraghavan et al. (2016) stated that FE models has been used widely in order to understand and analyse the machining operation of Inconel 718 in an efficient way compared to the expensive machining experimental in the laboratory conditions. FEM analysis serves a better alternative as it has advantages of less time consuming and more precise and accurate results in determining effect of wear mechanisms and chip formations (Senthilkumaar et al., 2012). FEM is an efficient tool to predict material removal process variables such as temperature field which is difficult to be determined by performing experimental of turning operation. Yang et al. (2011) indicated that the maximum temperature in the cutting zone is located on the rake face at the distance of about 0.01 mm from the insert tip. As the cutting speed or spindle speed of turning machine and feet rate increase, the maximum temperature in the cutting are also increases. Moreover, the cutting speed or spindle speed has a significant impact on the cutting temperature compared to the depth of cut variable (Yang et al., 2011). Even though there is some of previous researchers has been studied about the effect of cutting speed in turning operation. But the studies in the temperature distribution and tool wear still not enough as the technology of machining keep changing and become more advances in future.

According to Sandeep et al., (2017) experimental method need high cost and wastages; there is a strong necessity to have another approach such as simulation model. Simulation modelling could be done in two options which are two dimensional and three dimensional models. One of the previous research which is Vincent et al., (2014) stated that two dimensional model is used because of fast computing time compared to three dimensional model which is more complex. However, data collected from three dimensional model have high accuracy towards the exact experimental machining result. It has been proven by Ceretti et al., (2000), a three dimensional modeling is capable to simulate a FEM analysis in their study. Besides, simulation modeling by using DEFORM 3D software is able to predict the effect of various process variables as the machining performance indicator such as cutting force, surface accuracy, machining forces, temperature variations, chip flow and so on (Bhoyar and Kamble, 2013). Nevertheless, the experimental machining still the real operation that need help and information from the simulation approach to have an optimum cutting parameter in order have a good and better result with a minimum cost required.

1.2 Problem Statement

The assessment of Inconel 718 superalloy machinability has been a topic of research over the last three decades. The previous studies have been put a lot of efforts that directed towards the assessment of cutting tool life and disclosing tool wear mechanisms in machining operation of Inconel 718 (Costes et al., 2007). The inappropriate and wrong selection of material removal cutting parameters such as cutting speed, feed rate and depth of cut for turning Inconel 718 process might cause the insert of cutting tool to wear rapidly and has a tendency to break apart, which is leads to imperfect surface quality and anti-fatigue performance of Inconel 718 (Ezugwu and Bonney, 2004). Yang et al. (2011) analysed that the cutting forces in x and y directions decrease as the cutting speed increases. The tool wear characteristics has been increased with the increased of cutting speed. Then, the increasing of cutting speed leads to the decreasing of deformation coefficient and friction coefficient of the Inconel 718 material which minimize the cutting forces. Based on Yang et al. (2011) studies, the value of tool wear characteristics is increased according to the increased cutting speed which varies from 629 °C at 15 m/min to 902 °C at 60 m/min in the turning of Inconel 718 operation. Then, it explains that cutting speed or spindle speed is one of the most