UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

FEA ANALYSIS OF THE LATHE MACHINING ON MACHINING CHARACTERISTICS TOWARDS ALUMINIUM ALLOY USING RSM METHOD

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in fulfillment of the requirements for the degree of Master of
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DECLARATION

I declare that this thesis entitled "FEA analysis of the lathe machining on machining characteristics towards aluminium alloy using RSM method" 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

To my beloved father and mother

My beloved siblings

For giving me the moral support, financial support, and encouragement

Thank you so much

ABSTRACT

This project focuses on the simulation of the turning process by using the finite element analysis (FEA) machining Deform 3D software based on the Box-Behnken of response surface method (RSM) experimental matrix. Based on the Box-Behnken design matrix, there were 13 simulation runs with one centre point in order to analyze the influence of the cutting parameters on the output responses of the turning process such as cutting temperature, effective stress and material removal rate. The selected cutting parameters in this turning simulation of the aluminium alloy 7075 were cutting speed (200 m/min – 250 m/min), feed rate (0.1 mm/rev – 0.25 mm/rev) and depth of cut (0.5 mm – 0.6 mm). The analysis of variance (ANOVA) was used to determine the most influential cutting parameters on the output responses. The Box-Behnken of response surface method was employed to investigate the interactions between the cutting parameters on the output responses and to optimize the cutting parameters setting of the turning process. From the results, it is found that the depth of cut is the most influential cutting parameter for the cutting temperature. Meanwhile, the feed rate is the most significant cutting parameter for effective stress. For the material removal rate, the most influential cutting parameter is the feed rate. Furthermore, the interaction between cutting speed and depth of cut is the predominant interaction that gives a significant effect on the cutting temperature, which shows that the cutting temperature increases with the increase in depth of cut and decrease in cutting speed. In the meantime, the interaction between cutting speed and feed rate is the major interaction that gives the most influential impact on the effective stress, which shows that the effective stress increases with the increase in both of the cutting speed and feed rate. The most influential interaction that gives a significant effect on the material removal rate is the interaction between feed rate and depth of cut, which shows that the material removal rate increases with the increase in both of the feed rate and depth of cut. Moreover, after the optimization process, the cutting temperature gives the minimum value of 401.89 ℃. Further, the effective stress gives the minimum value of 792.14 MPa. While the material removal rate gives the maximum value of 5126375 mm^3/s. Overall, all the objectives of this project are achieved. Thus, a decrease in both of the cutting temperature and effective stress with the increase of material removal rate, therefore the defect of the wear on the cutting tool can be reduced.

ANALISA FEA PADA PEMESINAN LARIK KEATAS CIRI-CIRI PEMESINAN PADA ALUMINIUM ALOI MENGGUNAKAN CARA RSM

ABSTRAK

Projek ini adalah untuk menfokuskan pada simulasi proses melarik dengan menggunakan analisis unsur terhingga (FEA) pemesinan perisian Deform 3D berdasarkan matriks eksperimen Box-Behnken pada response surface method (RSM). Berdasarkan matriks reka bentuk Box-Behnken, terdapat 13 ujian simulasi dengan satu titik tengah untuk menganalisis pengaruh parameter pemotongan terhadap tindak balas keluaran dari proses melarik seperti suhu pemotongan, tekanan efektif dan kadar penyingkiran bahan. Parameter pemotongan yang dipilih dalam simulasi melarik aloi aluminium 7075 ini adalah kecepatan pemotongan (200 m/min - 250 m/min), kadar suapan (0.1 mm/rev - 0.25 mm/rev) dan kedalaman pemotongan (0.5 mm - 0.6 mm). Analisis varians (ANOVA) digunakan untuk menentukan kesan parameter pemotongan yang paling ketara terhadap tindak balas keluaran. Kaedah permukaan respons Box-Behnken digunakan untuk menganalisis interaksi antara parameter pemotongan pada tindak balas keluaran dan untuk mengoptimumkan pengaturan parameter pemotongan dari proses melarik. Dari keputusanya, kedalaman pemotongan adalah parameter pemotongan yang paling berpengaruh untuk suhu pemotongan. Sementara itu, kadar suapan adalah parameter pemotongan yang paling signifikan untuk tekanan efektif. Untuk kadar penyingkiran bahan, parameter pemotongan yang paling berpengaruh adalah kadar suapan. Selanjutnya, interaksi antara kelajuan pemotongan dan kedalaman pemotongan telah menghasilkan pengaruh yang signifikan terhadap suhu pemotongan, dimana suhu pemotongan meningkat dengan peningkatan kedalaman pemotongan dan penurunan kelajuan pemotongan. Sementara itu, interaksi antara kelajuan pemotongan dan kadar suapan telah menghasilkan kesan paling berpengaruh pada tekanan efektif, dimana tekanan efektif meningkat dengan peningkatan kedua-duanya kelajuan pemotongan dan kadar suapan. Interaksi yang paling berpengaruh yang memberikan kesan yang signifikan terhadap kadar penyingkiran bahan adalah interaksi antara kadar suapan dan kedalaman pemotongan, dimana kadar penyingkiran bahan meningkat dengan peningkatan pada kedua kadar suapan dan kedalaman pemotongan. Selepas operasi pengoptimuman, nilai minimum suhu pemotongan adalah 401.89 ℃. Nilai minimum parameter pengoptimuman tekanan efektif adalah 792.14 MPa. Manakala nilai maksimum parameter pengoptimuman kadar penyingkiran bahan adalah 5126375 mm^3/s. Secara keseluruhan, semua objektif projek ini telah tercapai. Dengan itu, penurunan suhu pemotongan dan tekanan efektif manakala peningkatan kadar penyingkiran bahan, maka masalah mata hakisan pemotongan dapat dikurangkan.

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D	-	Diameter
d	-	Depth of cut
F	-	Feed rate
Fm	-	Feed
N	-	Spindle speed
Vc, V	-	Cutting speed

LIST OF ABBREVIATIONS

AA	-	Aluminium Alloy
AISI	-	American Iron and Steel Institute
ANOVA	-	Analysis of Variance
BBD	-	Box-Behnken Design
CCD	-	Central Composite Design
CNC	-	Computer Numerical Control
DF	-	Degree of Freedom
DOE	-	Design of Experiment
EN	-	European Union
FEA	-	Finite Element Analysis
MRR	-	Material Removal Rate
RSM	-	Response Surface Methodology
TNMA	-	Triangle, Negative Rake, Lapped Top and Bottom with Hole
UNS	-	Unified Numbering System

CHAPTER 1

INTRODUCTION

This chapter explains the background of study, problem statement, objectives, scope of study, significant of study, and the project organization. Furthermore, there is information related to the simulation of the turning process on the aluminium alloy by using the FEA machining Deform 3D software.

1.1 Background of Study

In the last decades, aluminium alloy has been used as the raw material increasingly due to its brilliant mechanical properties and technological properties (Horvath et al., 2015). Aluminium alloy 7075 is the aluminium alloy with the 7000 series which alloyed with zinc (Sahithi et al., 2019). Furthermore, aluminium alloy 7075 has strength as good as several steels and it has supreme fatigue strength and strong (Allamraju and Rao, 2017). As mentioned by Patel et al. (2019), the utmost proper material for the transport application especially the airplane components is the aluminium alloy with 7000 series due to its extreme mechanical properties such as ductile, low density, and fatigue strength. There are various material removal processes to machine the aluminium alloy 7075 such as milling, turning, drilling, and water jet cutting. While the most common material removal process to machine the aluminium alloy 7075 is the turning process.

The turning process is a broadly used machining process and it is significant in many manufacturing industries and as well as in research and development. This turning process is broadly used in the aerospace, automobile, die, and bearing industries. Turning is a significant process used to make the cylindrical part such as the shaft of the aircraft, where the cutting tool moves in a linear way to remove material from the surface of the revolving cylinder-shaped workpiece to acquire the desired contour (Saravanakumar et al., 2018). Nowadays, the finite element analysis has predominantly become the major instrument for simulating the metal machining processes. The finite element analysis is applied for modeling the 3D machining process has become a part of present research activity due to the substantial cost-saving and gives vision into the process which is not easily measured in the experiments (Bhoyar and Kamble, 2013).

There are various software finite element programs to simulate the metal machining processes such as SUPERFORM, FORGE, HYPEREXTRUDE, ABACUS, DEFORM 3D, and LS-DYNA, and the precision of the simulation results are determined by the accurateness of the finite element analysis (Francy et al., 2019). Furthermore, the finite element analysis machining Deform 3D software is used to simulate the turning process, in order to analyze the influence of the cutting speed, feed rate and depth of cut on the output responses of the turning process such as the effective stress, material removal rate and cutting temperature. Nowadays, the main challenges faced by many machining industries are to enhance the quality of the machined part and to improve the machining time. Especially for the aircraft industry which required extremely good dimensional accuracy due to the rigorous requirement of the assembly tolerance for the aircraft's shaft.

The machining industry has to machine an advanced quality of the machined part, and at the same time has to improve the machining time which is to improve the material removal rate. Many manufacturing industries desired a high material removal rate to manage mass production without surrendering the quality of the product in a shorter period (Jayaraman and

Kumar, 2014). The material removal rate is an important factor in the machining processes due to its significant influence on the manufacturing economy (Ramudu and Naga, 2012). Furthermore, the high material removal rate in the turning process prominently depends on the increase of the cutting parameters like the cutting speed, feed rate, and depth of cut to cope with the mass fabrication (Patel et al., 2019). It is supported by Moganapriya et al. (2018) stated that the material removal rate increases with the increasing of the cutting speed, feed rate, and depth of cut.

The high material removal rate in the turning process is achieved with the increasing of the cutting speed. However, a high cutting speed would induce a high cutting temperature which results in dimensional inaccuracy, deviation of the assembly tolerance of the machined parts, and the machined surface quality. Furthermore, the high cutting temperature has a significant impact on the subsurface of the machined surface (Ezilarasan et al., 2014). Moreover, the effect of the cutting temperature is directly reflected on both of the surface integrity of the machined components and the accuracy of the machining process. Thus, the cutting temperature in the machining process has become a significant study in attaining the extreme machining performance (Suhin et al., 2013). The cutting temperature is important in the machining processes since it is the prominent factor for the quality of the machined parts, tool life, and chip morphology (Ezilarasan et al., 2014).

The cutting parameters especially the depth of cut has the most significant influence on the cutting temperature, in which a rise in the depth of cut would induce a rise in the cutting temperature due to the occurrence of the large plastic deformation at the tool and workpiece interface (Kiprawi et al., 2017). In fact, the cutting temperature is greatly responsive to the variation of the cutting parameters in the machining processes. Likewise, the effective stress is also very responsive to the variation of the cutting parameters in the machining processes.

According to Ezilarasan et al. (2014), the increase in both of the cutting speed and feed rate would induce a rise in the effective stress in the primary deformation region where there is an interface of the tool and workpiece in the turning process.

Stress gives a significant impact on the machined region of the workpiece and the cutting edge of the cutting tool (Pradhan, 2019). Normally, the high effective stress is located in the primary deformation zone which is the contact between the cutting tool and workpiece (Charitha et al., 2018). Furthermore, the high effective stress affects the surface finished of the machined parts which results in the poor quality of the machined parts. Moreover, the enhancement in the properties of the machined parts such as the assembly tolerance, thermal resistance, wear rate and tear rate can be achieved with a superior quality of the turning surface (Jayaraman and Kumar, 2014). In order to achieve a high material removal rate with the minimum cutting temperature and minimum effective stress, the selection of suitable cutting parameters has a vital role in the efficiency of the turning process.

Furthermore, the cutting parameters like cutting speed, feed rate, and depth of cut have a significant influence on the cutting temperature, effective stress, and the material removal rate of the turning process, so it is significant to select the cutting parameters in the turning process for aluminium alloy. Selecting the optimal cutting parameters in the turning process is important to obtain a better performance and quality product. The appropriate cutting parameters which are determined by experience or by theory does not guarantee that the selected cutting parameters have an optimum performance (Saravanakumar et al., 2018). Nowadays, it is important to select the optimal cutting parameters in turning of aluminium alloy before mass production. The optimal cutting parameters can be obtained by carrying out the experimental trials, however, the experimental trials are costly and time-inefficiency.

Therefore it is wise to apply the process simulation system of Deform 3D and to reduce the number of simulation runs by applying the design of experiments (DOE) to obtain the optimal cutting parameters. Furthermore, the analysis of variance (ANOVA) with a 95% confidence limit is employed to analyze the most significant influence of the cutting parameters on the output responses such as the cutting temperature, effective stress, and material removal rate. Regarding Montgomery (2009), the response surface methodology (RSM) is a mathematical and statistical approach that is used for the analysis of the effect of various variables on the experimental responses and the aim is to optimize those responses. Additionally, the RSM is a design of experiments, in which to acquire the optimum output responses of the turning process after the turning simulation work is done on the aluminium alloy is completed.

The response surface methodology comprises an experimental design to determine an approximate model between the input and output variables and to optimize the responses (Pandiyan and Prabaharan, 2019). The input variable is the cutting parameters like cutting speed, feed rate, and depth of cut, while the output variable is the output responses like cutting temperature, effective stress, and material removal rate. The simulation run in this study is designed by employing the Box-Behnken design. Furthermore, Box-Behnken design requires less number of runs, for example, an optimal mathematical model can be selected and the tests at every level of the experimental factors can be analyzed (Arunangsu et al., 2018). As mentioned by Ferreira et al. (2007), Box-Behnken design is a type of rotatable and closely rotatable second-order design based on the incomplete factorial designs with three levels.

The aim of this project is to focus on the simulation of the turning process using the FEA machining Deform 3D software to attain the high material removal rate with the minimum cutting temperature and minimum effective stress. Furthermore, the interactions between the cutting parameters such as cutting speed, feed rate, and depth of cut on the output responses such as the cutting temperature, effective stress, and material removal rate are investigated by applying the RSM method. Moreover, the ANOVA analysis method is employed to determine the most significant parameters that affected the output responses of the turning process.

1.2 Problem Statement

Nowadays, achieving high quality, high productivity, and low cost are the major challenges faced by many manufacturing industries in order for them to compete for the market advantages with their competitors. The turning process is the greatest common material subtraction process and it is broadly utilized to fabricate the cylindrical product. Especially in the aerospace manufacturing industry, the turning process is utilized to machine the aircraft's shafts which required a highly close assembly tolerance. Furthermore, the quality of the surface is a significant performance characteristic to assess the machined surface (Jayaraman and Kumar, 2014). In fact, the uneven machined surface obtained from the turning process results in imperfect contact between the two uneven surfaces of the aircraft's shaft, and this raises a serious quality problem in the aerospace industry.

The uneven machined surface is actually caused by the high cutting temperature and high effective stress. It is supported by Ezilarasan et al. (2014), the subsurface of the machined surface is significantly affected by the high cutting temperature that results in the poor quality machined parts. Additionally, stress contributes a significant impact on the machined region of the workpiece (Pradhan, 2019). Actually, the cutting temperature and effective stress are the prominent elements in influencing the dimensional accuracy and the quality of the machined parts. Furthermore, the cutting parameters like cutting speed, feed rate, and depth of cut possessed a significant influence on the cutting temperature, effective stress, and material removal rate. Therefore, it is important to analyze the cutting parameters in the turning of