

PERFORMANCE OF AISI 1045 STEEL OF SIMULATION TURNING PROCESS BASE ON PREVIOUS EXPERIMENTAL RESULT





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DECLARATION

I hereby, declared this report entitled "Performance of AISI 1045 steel of simulation turning process base on previous experimental result." is the result of my own research except as cited in references.



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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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ABSTRAK

Tujuan projek ini adalah untuk mengesahkan hasil keluli AISI 1045 yang telah dikumpul daripada data eksperimen terdahulu dengan kerja simulasi yang telah dilakukan dalam projek ini. Parameter pemotongan yang dipilih dalam simulasi pusingan keluli karbon AISI 1045 ini ialah kelajuan pemotongan, kadar suapan dan kedalaman pemotongan. Data eksperimen bertindak balas yang telah dikumpul termasuk suhu pemotongan, tegasan berkesan, jumlah halaju dan kadar penyingkiran bahan. Selanjutnya, hubungan antara parameter pemotongan kepada tindak balas telah disiasat. Kemudian, respons melalui respons tunggal dan berbilang telah dioptimumkan. Analisis varians (ANOVA) digunakan untuk menentukan parameter pemotongan yang paling berpengaruh kepada tindak balas keluaran. Kotak-Behnken Kaedah Permukaan Tindak Balas (RSM) digunakan untuk menyiasat interaksi antara parameter pemotongan kepada tindak balas output. Keseluruhan larian simulasi ialah 15 larian yang ditetapkan kepada 500 langkah untuk setiap larian. Pengesahan hasil simulasi ini kepada keputusan eksperimen sebelumnya sebagai penunjuk ketepatan Perisian Simulasi Deform 3D. Parameter yang paling mempengaruhi tindak balas adalah kelajuan pemotongan dalam proses simulasi pusingan untuk keluli AISI 1045. Selepas proses pengoptimuman respons tunggal, kesemua empat respons telah ditambah baik dengan kombinasi interaksi 2 hala yang berbeza masing-masing. Sementara itu selepas proses pengoptimuman berbilang respons, respons telah dipertingkatkan dengan kombinasi parameter yang paling dikehendaki. Dalam projek ini, dapat disimpulkan bahawa semua objektif telah dicapai dengan berjaya.

ABSTRACT

The purpose of this project is to validate the result of AISI 1045 steel that has collected from previous experimental data with the simulation work that has been done in this project. The selected cutting parameters in this turning simulation of the carbon steel AISI 1045 were cutting speed, feed rate and depth of cut. The respond experimental data that has been collected including cutting temperature, effective stress, total velocity and material removal rate. Further, the relationship between cutting parameters to the responses were investigated. Then, the response through single and multiple responses were optimized. The variance analysis (ANOVA) was used to determine the most influential cutting parameters to the output responses. The Box-Behnken of the Response Surface Method (RSM) was used to investigate the interaction between the cutting parameters to the output response. The entire simulation run was 15 runs which were set to 500 steps for each run. This validation of the simulation result to the previous experimental result as an indicator the precision of Deform 3D Simulation Software. The most affecting parameter on responses was cutting speed in turning simulation process for AISI 1045 steel. After single responses optimization process, all of the four responses were improved with different combinations of 2-way interaction respectively. Meanwhile after multiple responses optimization process, the responses were improved with the most desired combinations of parameters. In this project, it can concluded that all the objectives had been achieved successfully.

DEDICATION

Only

my beloved father, Chan Chee Hun my appreciated mother, Ng Chew Khim my adored brother, Chan Wai Chong

my adored sisters, Chan Ean Eing and Jolin Chan Zhi Ying

for giving me moral support, money, cooperation, encouragement and also understandings

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LIST OF ABBREVIATIONS

AISI	-	American Iron and Steel Institute
ANOVA	-	Analysis of Variance
ASTM	-	American Society for Testing and Materials
BBD	-	Box-Behnken Design
CAM	-	Computer-aided Manufacturing
CCD	-	Central Composite Design
CCW	-	Counterclockwise
CNC	-	Computerised Numerical Control
CW	ALAYS!	Clockwise
DOE	a shirt and	Design of experiments
FKP	1. Alexandre ale	Fakulti Kejuruteraan Pembuatan
HSM		High Speed Machining
HSS	The area	High Speed Steel
ISO	- AINO	International Organization for Standardization
MRR	Al lun	Material Removal Rate
NC		Numerical Control
OFAT	UNIVERSIT	One Factor at a time LAYSIA MELAKA
RSM	-	Response Surface Method
2D	-	2-dimensional
3D	-	3-dimensional

LIST OF SYMBOLS

Vc	-	Cutting Speed
d	-	Depth of Cut
b	-	Chip Width
h	-	Chip Thickness
D	-	Diameter
Ν	-	Rotating Speed
Fr	-	Feed Rate
f	-	Feed Per Rev
m/s	-	Meter per second
m/min	- 140	Meter per Minute
mm/rev		Millimeter per Revolution
mm	TEK	Millimeter
mm/sec	E	Millimeter per second
mm^3/sec	- 33	Cubic millimeters per second
Mpa	del	Megapascals
%	ملاك	اويوم سيتي بيڪنيڪ Percentage
psi		Pounds per square inch
ksi	UNIVE	Kilopound per square inch
Gpa	-	Gigapascal
μm	-	Micrometres or microns
°c	-	Degree Celsius

CHAPTER 1 INTRODUCTION

This chapter explains the significant of the study in exploring performance of AISI 1045 steel of simulation turning process base on previous experimental result. In this chapter, the research background, problem statement, objectives, scope of the research, rational of research and project report arrangement were presented precisely.

1.1 Research Background

According to Qasim *et al.* (2015), the goal of contemporary industrial producing is to provide high-quality things in less time and at a lower cost. For this, automatic and versatile production techniques comparable to computerized numerical control (CNC) machines are used, which might cut back time interval whereas maintaining high precision. Nowsaday, the most well-known operation to remove unwanted material we used in industry is turning.

According to Nalbant *et al.* (2006), to achieve good cutting performance, it should be critical to set input (turning) parameters with higher accuracy during this operation. In most situation, the best or suitable turning parameters are create or develop based on previous experience or by following research. In this experiment, AISI 1045 mild steel will be used in turning process base on the previous simulation result.

Muñoz-Escalona *et al.* (2005) have claimed that AISI 1045 Steel is one of the most extensively used steel grades, with a wide range of applications in industrial processes due to its low cost and great machinability. In this study, the most relevant cutting parameters to the output responses will be determined using a variance analysis (ANOVA). The

relationship between the cutting parameters and the output response will be investigated using the Box-Behnken of the Response Surface Method (RSM). Cutting speed, feed rate, and depth of cut were took as consideration as cutting parameters in this carbon steel AISI 1045 turning simulation. The accuracy of the Deform 3D software simulation will be determined by comparing the testing results to the earlier experimental results.

1.2 Problem Statement

According to Kazban *et al.* (2008), the higher the cutting forces, the higher the temperature on the cutting surface. Therefore, one of the improvement required to enhance the performance of AISI 1045 steel is decrease its and tool piece surface cutting temperature during the turning process. The lower the temperature the smoother the surface of AISI 1045 steel. According to Senthilkumar *et al.* (2013), from most of the geometries to turning AISI 1045 steel, the effect of temperature at the cutting zone on wear at the flank area is examined.

Attanasio *et al.* (2009) has claimed that the tool nose radius and feed rate have the greatest influence on both maximum and lowest stresses, whereas lubrication has the least influence. The second improvement required to enhance the performance of AISI 1045 steel is reduce the effective stress formed on the carbon steel AISI 1045 during the turning process. Rech and Moisan (2003) had discovered that cutting speed was the most important element influencing residual stress level. In their investigation, cutting speed, regardless of feed rate (50 to 150 m/s), tends to increase external residual stress. The uneven surface of cutting tool which increase the surface roughness of work piece also have to take as the consideration. Dahlman *et al.* (2004) discovered that rake angle had the greatest impact on residual tensions. The compressive pressures rose as the feed rate increased. Varied cutting depths did not result in different stress levels.

Lastly, material removal rates has to take into the account during this project report is carry on. The higher the material removal rates, the shorter the time require to cut the material, hence its reduce the processing time. According to Chevrier *et al.* (2003), to achieve high material removal rates, high speed machining (HSM) is recommended which also good in reduce not processing times, use low cutting forces, higher dimensional accuracy and good surface finishing quality. Salomon *et al.* the teams who introduced the HSM concept have studied that making cutting speed higher can result in low cutting temperature after it achieve the critical value.

1.3 Objectives

The objectives are as follows:

- (a) To determine the most significant of the cutting parameter such as cutting speed, feed rate, and depth of cut towards response (cutting temperature, effective stress, total velocity and material removal rate).
- (b) To find the interaction of the cutting parameter such as cutting speed, feed rate, and depth of cut toward responses.
- (c) To optimize the response through single and multiple responses.
- 1.4 Scopes of the Research

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The scopes of research are as follows:

- (a) Design experimental matrix of tuning process parameters using response surface methodology using Minitab software.
- (b) Perform turning machining simulation using Deform 3D software for collecting data.
- (c) Perform statistical analysis "Response Surface Methodology" (RSM) and Analysis of Variance (ANOVA) using Minitab software.

1.5 Rational of Research

The rational of research as follows:

- (a) The type of material of the work piece must be available in the market. In this case, we have chose carbon steel AISI 1045.
- (b) The cutting tool should be carbide, which can easily cut the work piece. The hardness of cutting tool must be higher than the work piece.
- (c) The carbon steel AISI 1045 is chosen in this research because it is the most demand material, which is the most used material in the manufacturing sector.
- (d) The cutting parameter must be determine and optimise such as cutting speed, feed rate and depth of cut toward responses. After that, the statistical analysis "Response Surface Methodology" (RSM) must be performed by using Minitab software.

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1.6 Project Report Arrangement

The arrangement of this project is as following. Chapter 1 is start with research background, problem statement, objectives, and scope of the research, rational of research are delineated in order to better define particular aspects of AISI 1045 steel when cut by carbide cutting tool during the turning process in this project report. Chapters 2 literature review comprises previous study or research about the turning process, material carbon steel AISI 1045, cutting tool, geometry of cutting tool, defect of cutting tool, design of experiment, analysis of variance (ANOVA) and research gap and summary. Chapter 3 methodology describes all the procedures, methods, steps and precautions when carry out the simulation of turning process of carbon steel AISI 1045 with the carbide cutting tool. Different cutting speed, feed rate, depth of cut and design of experiment will apply and stated in this stage. Chapter 4 is analyze the information, data, result, statistical analysis "Response Surface Methodology" (RSM) and Analysis of Variance (ANOVA) by using Minitab software after running the cutting process through the simulation software. In Chapter 5, conclusion and recommendation about this research are examined.

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CHAPTER 2 LITERATURE REVIEW

This chapter focuses on the research, studies and theories that have been studied and found out by a lot of researchers since some times ago. Related information of previous studies are extracted as references and discussion based on their research about turning process, material carbon steel AISI 1045, cutting tool, geometry of cutting tool, defect of cutting tool, design of experiment, analysis of variance (ANOVA) and research gap and summary.

2.1 Turning process

According to Chen (2000), turning as known as a type of machining, a material removal process, which is used to make rotating parts by remove material that do not want. The turning method requires a lathe or lathe, a workpiece, a device and a reducing tool. The workpiece is a preformed piece of fabric that is attached to the system, which in turn is attached to the turning device and allowed to spin at excessive speed. The milling cutter is generally a unmarried-factor cutting tool that is additionally fixed in the system, despite the fact that some operations use a couple of-factor tools. The reducing device suits into the rotating component and cuts the material into small chips to create the preferred form. Figure 2.1 shows the process of turning using lathe machine.



Figure 2.1: Process of turning using lathe machine

2.1.1 Turning machine

Morishige & Nakada (2016) proposed that turning machine may be divided into two types: hand-operated general purpose machines and NC machines that run according to an NC programme. A general-purpose machine tool should be operated with a few handles, taking into account the best machining solution, such as tool feed and depth of cut, and requiring expertise and operator experience. CNC machine tools, on the other hand, require NC programs created using CAM software and cannot handle machining operations not supported by CAM software, Figure 2.2 shows the Haas ST30 CNC turning machine.



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Figure 2.2 : Turning Machine

2.1.2 Parameter of turning process

Davis et al. (2014) claimed that the range of parameters, including feed rate, working hardness, an unstable constructed edge, speed, depth of cut, duration cutting, and the usage of cutting fluids, have been shown to impact surface quality in turning in varied degrees. Speed, feed, and depth of cut are the three key process parameters in every basic turning operation. The spindle and the workpiece are usually mentioned when talking about speed. The feed rate refers to how quickly the tool moves along the cutting path. Rao et al. (2013) specified that in terms of surface quality, majority of them suggest that the feed rate is the most critical aspect in the turning process, followed by the cutting speed. Surface quality will decrease or become rough when the feed rate is high, but it will improves when the cutting speed is high. The thickness of the material removed by a cutting tool passing over the workpiece is referred to as the depth of cut. Sangwan et al. (2015) also claimed that for depth of cut, they noted that it is the least influential factor, it can even be considered not influential on surface roughness. Cutting parameters (feed rate, cutting speed, depth of cut, tool material qualities, and tool shape) had been observed by way of Singh & Soni (2017) to have an instantaneous effect on tool existence and tool surface finishing of machined components. Choosing the best cutting parameters for every machining operation entails balancing surface roughness minimization and material removal rate maximisation. Figure 2.3 shows the parameter of turning process.



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Figure 2.3 : Parameter of turning process (Singh & Soni, 2017)

2.1.2.1 Cutting speed

The speed at which material is removed from the tool and onto the workpiece is referred to as tool cutting speed. It's similar to the part's peripheral speed in m/min in lathe work. The calculation of cutting speed as shown in equation 2.1.

$$Vc = \frac{\pi DN}{1000}$$
(m/min) Equation 2.1

Where, Vc is cutting speed, D and N are diameter (mm) and rotating speed (rpm) of work piece respectively.

2.1.2.2 Feed rate

In a turning operation, the feed of the cutting tool is the straight line that the tool move for each turn of the workpiece in millimetres. The material to be cut is the most important consideration when determining feed and speed. However, the tool's material, the stiffness of the workpiece, the size and condition of the lathe, and the depth of cut should all be taken into account. The calculation of feed rate as shown in equation 2.2.

$$F_r = f \frac{V}{\pi D} (mm/min) TEKNIKAL MALAYSIA MELAKA Equation 2.2$$

Where, Fr is feed rate (mm/min), V is cutting speed (m/min), D is outer diameter (mm) and f is feed per rev.

2.1.2.3 Depth of cut

Kumar *et al.* (2013) has claimed that not just feed rate and spindle speed, but the depth of cut also plays the important role as the input parameter to improve the quality of the product with the turning operation. Cutting depth refers to the perpendicular distance in millimetres between the finished machine's surface and the rough surface of the workpiece. It is the entire quantity of steel removed in line with bypass of the cutting tool. It is expressed

in mm. It is able to range and rely upon the variance of tool and work material. Mathematically, it is half of the difference of diameters. The calculation of depth of cut as shown in equation 2.3.

Depth of cut (t) =
$$(D-d/2)$$
 mm/rev Equation 2.3

Where, D =outer diameter, (mm) and d =Inner diameter (mm)

2.1.2.4 Previous study on turning parameter

There are researchers have done the simulation and machining before as shown in Table 2.1. Most of them have the different parameters and condition when carry out the turning process. Although they chose the different parameters or conditions, the type of material they used are the same, which is AISI 1045 steel. Among of this five researchers are Khadija Kimakh *et.al* (2018), Camposeco-Negrete *et.al* (2018), Nouioua *et.al* (2017), Abdulkareem *et.al* (2011), and Mishra & Gangele (2012).

rable 2.1. The your study on turning parameter							
Researcher	Type of material	Wet / Dry	Cutting Speed	Feed Rate (mm/rev)	Depth of cut (mm)		
UNI	VERSITI T	EKNIKA	(m/min)	SIA MELAKA			
Khadija Kimakh	AISI 1045	Dry	2000	0.05-0.25	0.5		
et.al							
Camposeco-	AISI 1045	Dry	355-470	0.1-0.3	0.3-0.5		
Negrete et.al							
Nouioua et.al	AISI 1045	Wet	150-350	0.08-0.16	0.2-0.6		
Abdulkareem et.al	AISI 1045	Dry	47.12-94.25	0.5-1.0	0.35-0.5		
Mishra & Gangele	AISI 1045	Dry	110-200	0.15-0.25	0.10-0.20		

 Table 2.1 : Previous study on turning parameter



Figure 2.4 : Cutting Speed Vs Feed Rate Chart

2.1.3 Machining charateristics

Dahbi *et al.* (2016) explained the most essential objective in turning is to choose the cutting parameters that will give us the best cutting results, such as surface roughness, material removal rate, tool wear, and energy consumption. Performing trials or consulting a manual to identify the needed cutting settings is a common practise, but these methods may not always result in the best cutting performance for a given machine tool and environment.

2.1.3.1 Cutting Temperature

Prediction of the temperature at the chip tool contact during the turning process was studied by L.B.Abhang *et al.* (2010). This study takes into account cutting factors such as speed, feed rate, depth of cut, and tool nose radius. Chip-to-tool contact temperature is influenced by cutting speed, feed rate, and depth of cut, with tool nose radius in a distant third place. Cutting speed, feed rate and depth of cut all raise cutting temperature, whereas increasing nose radius decreases cutting temperature. Figure 2.5 shows the simulation result of cutting process : temperature field in the cutting tool and material with meshing (a), without meshing (b).



Figure 2.5 : Simulation result of cutting process : temperature field in the cutting tool and material with meshing (a) , without meshing (b) (G. Bunga *et al.* 2007)

2.1.3.2 Effective Stress

According to Guo *et al.* (2009), a percentage of the machining energy may be recovered once the workpiece material has been liberated from its thermomechanical stress. During plastic deformation, the material experiences strains, particularly at the free ends: the surfaces. Some of this plastic deformation energy is lost. Residual stresses are those stresses in the material that persist after the loading has been eliminated. An investigation by Arunachalam *et al.* (2004) found that mixed ceramic cutting tools generated much more tensile residual stresses than CBN cutting tools. Residual stress distribution was shown to be highly influenced by tool nose radius, as demonstrated by Liu *et al.* (2004). Researchers found that the residual stress to tensile stress range. Figure 2.6 shows (a) The simplified diagram of turning process; (b) The typical distribution of residual stress along the depth direction.



Figure 2.6 : (a) The simplified diagram of turning process; (b) The typical distribution of residual stress along the depth direction. Peng.H *et al.* (2020)

2.1.3.3 Total velocity

The tangential velocity of the spinning workpiece or the revolving cutting tool is what we mean by cutting velocity. Meters per minute (m/min) is the unit of measurement, and it is given the symbol Vc. However, although the tensile stresses of cutting direction increased due to increased cutting velocity, the feed direction was unaffected. According to Cabrera J.M. *et al.* (2015), they found out cutting velocity of 500–750 m/min had an opposite impact on residual stresses, which means that there is less tension in the material as the cut velocity increases. Figure 2.7 shows the cutting velocity in turning process.



By employing Taguchi's approach, Tamizharasan and Senthilkumar (2012) investigated the material removal rate (MRR) and roughness in turning AISI 1045 steel with uncoated camented carbide cutting inserts of various ISO specified cutting tool geometries. The calculation of MRR as shown in equation 2.3.

MRR
$$\left(\frac{mm^3}{s}\right) = v x f x d$$
 Equation 2.4

Where v is cutting speed (m/s * rev), f is feed rate (mm/rev) and d is depth of cut (mm).

2.2 Material carbon steel AISI 1045

Both black and standard hot rolled forms can be told is medium-strength steel which is AISI 1045 steel. It has a Brinell hardness of 170 to 210 and a tensile strength of 570-700 MPa. Under normal and hot rolled conditions, Weldability, machinability, and high strength and impact properties are all characteristics of AISI 1045 steel.

2.2.1 Material properties

There are five elements with different percentage of content inside the AISI 1045 carbon steel. The percentage of carbon is between 0.420 % to 0.50 % while the iron is between 98.51 % to 98.98 %. There are around 0.60 % to 0.90 % of manganese and less or equal than 0.040 % of phosphorus inside the AISI 1045 carbon steel. Last but not least, the percentage of sulfur contain in AISI 1045 carbon steel is less than or equal to 0.050 %. Table 2.2 shows the material properties of AISI 1045 carbon steel and Figure 2.8 shows the microstructures of AISI 1045 Steel.

Element	Content
Carbon, C	0.420 - 0.50 %
Iron, Fe	98.51 - 98.98 %
Manganese, Mn	0.60 - 0.90 %
Phosphorus, P	≤ 0.040 %
Sulfur, S	\leq 0.050 %

Table 2.2 : Material properties of AISI 1045 carbon steel (AZO Materials, 5 July 2012)



Figure 2.8 : Microstructures of AISI 1045 Steel (Nunura et al., 2015)

2.2.2 Mechanical properties

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Through-hardening capabilities of AISI 1045 steel is limited, with only 60mm sections suggested for quenching and through-hardening. However, depending on parameters such as the size of the section, the kind of installation, and the extinguishing media used, it can be flame or induction hardened in the normalised condition, or hot rolled to achieve a surface hardness of Rc 54 to Rc 60.

The Brinell Hardness Test for AISI 1045 carbon steel is 163 while there is 184 during Knoop Hardness test. The Rockwell B Hardness Test show the result of 84 while Vickers Hardness Test show the result of 170. For the ultimate tensile strength, the data shown 565 MPa while there is 310 MPa for the yield tensile strength. At the length of 50mm, the percentage of the elongation at break is 16.0%. The percentage of reduction of area is 40.0%. The modulus of elasticity for carbon steel is 200GPa while the bulk modulus gives the data of 140Gpa. The Poissons Ratio for AISI 1045 carbon steel is 0.290 as shown. Lastly, the shear modulus of AISI 1045 carbon steel is 80GPa. Table 2.3 shows the mechanical properties of AISI 1045 carbon steel.

Mechanical Properties	Metric	Imperial
Hardness, Brinell	163	163
Hardness, Knoop (Converted from Brinell hardness)	184	184
Hardness, Rockwell B (Converted from Brinell hardness)	84	84
Hardness, Vickers (Converted from Brinell hardness)	170	170
Tensile Strength, Ultimate	565 MPa	81900 psi
Tensile Strength, Yield	310 Mpa	45000 psi
Elongation of Break (in 50mm)	16.0 %	16.0 %
Reduction of Area	40.0 %	40.0 %
Modulus of Elasticity (Typical for steel)	200 GPa	29000 ksi
Bulk Modulus (Typical for steel)	140 GPa	20300 ksi
Poissons Ratio (Typical for steel)	0.290	0.290
Shear Modulus (Typical for steel)	80 GPa	11600 ksi

Table 2.3 : Mechanical properties of AISI 1045 carbon steel (AZO Materials, 5 July 2012)

2.3 Cutting tool

With carbide, cast iron, stainless steel and etc, the cutting tool can be created for tool lathe. The cutting tool moves relative to the workpiece during the cutting process, separating part of the material from the workpiece, which is known as chips. The workpiece material loss some of it parts when cutting tool feeds toward it and it is known as cutting process. On the lathe machine, there is always can create the axis, with cutting tools on a spinning workpiece. Cutting tools are the most important component of every industrial operation. In this paper, we have choose two type of cutting tools with different materials which are stainless steel and carbide. Figure 2.9 shows the cutting tool of turning machine.



Figure 2.9 : Cutting tool of turning machine.

2.3.1 High speed steel

High speed steel (HSS or HS) is a type of lathe tool, normally will use to cut or remove material from the workpiece. It's commonly found in drill bits and power saw blades. Because it can sustain greater temperatures without losing its character, it outperforms the traditional high carbon steel tools used in the 1940s (hardness). HSS can cut quicker than high carbon steel because of this characteristic, thus the name "high speed steel." High harness is behaviour of HSS when put together with other tool such as carbon since it is high hardness (greater than Rockwell 60 hardness) and abrasion resistance (generally link to the tungsten and vanadium content which always used in HSS) at room temperature and in their should be heat treatment. Figure 2.10 shows the High Speed Steel cutting tool.



Figure 2.10 : High Speed Steel cutting tool 18

2.3.2 Carbide

Cemented carbide is a tough substance that is frequently utilised in cutting tools and other industrial applications. Carbide turning tool, in most cases, provide a better workpiece surface polish and allow for quicker cutting than HSS or other lathe tool. Carbide tools can withstand higher temperature when contact with workpiece and proceed with high speed turning operation. Hence, carbide become the main consideration to use for high speed machining. Hard materials like carbon steel and stainless steel can be cut easily by carbide, while other cutting tools may damaged or defect, such as high-volume manufacturing runs. Figure 2.11 shows the Carbide cutting tool.



2.4 Geometry of cutting tool

The form and angles at which the cutting section of a cutting tool is ground are known as cutting tool geometry. It has an impact on the kind of material handling procedure, efficiency and economy, completed product quality, and cutting tool service life (the operating time to normal dullness). As highlighted by Astakhov (2010), edge radiusing improves the cutting edge's strength and longevity without significantly increasing cutting force. The most popular of three types of geometry of cutting tools are known as rake angle, side cutting edge angle and tool nose radius.
2.4.1 Rake angle

When comes to turning processes and different type of cutting styles, the parameter will take into account is rake angle which are describing the angle of the cutting face contact with the workpiece. Using a complete factorial design, Saglam *et al.* (2007) studied the effects of rake angle, cutting tool entry angle, and cutting speed on cutting force and tool tip temperature when milling with uncoated tool inserts. Positive, zero or neutral, and negative are the main three rake angles that most of the researchers told in their studies. Figure 2.12 shows the rake angle of cutting tool on workpiece.

Positive rake: Since the face of the cutting tool slopes away from the cutting edge at inner side, we call the rake of the tool as positive rake.

Zero rake: When the cutting edge at inner side is perpendicular to the cutting tool face, the tool can tell has a zero or neutral rake.

Negative rake: When the cutting edge at outer side is slope and far away from the face of cutting tool, we can tell the tool has a negative rake angle.



Figure 2.12 : Rake angle of cutting tool on workpiece (https://en.wikipedia.org/wiki/Rake_angle)

2.4.2 Side cutting edge angle

Residual stress on workpiece surface affect by rake angle, rounded edge radius and side cutting edge angle known as characteristics of cutting tool geometry were investigated

by Ning *et al* (2009) and prove that impact load and effects the amount of feed force, back force and chip thickness have reduced by the side cutting edge angle. Figure 2.13 shows the side cutting edge angle and chip thickness.

The effect of side cutting edge angle including:

1. The side cutting edge angle and the chip contact length has been increased while the chip thickness has been decrease at the same feed rate. As a result, the cutting force is distributed over a longer cutting edge, extending tool life.

2. Increases force by make the side cutting edge angle higher. As a result, thin, lengthy workpieces might bend in some instances.

3. Decreases chip control by making the side cutting edge angle larger.

4. Increase chip width and the side cutting edge angle when the chip thickness is reduced. Thus, it is hard and difficult to breaking chips.



Figure 2.13 : Side cutting edge angle of cutting tool (https://www.mitsubishicarbide.net/)

2.4.3 Tool nose radius

The impact of machining parameters (feed rate, cutting speed, depth of cut, and tool nose radius) on the surface roughness of cast iron material machined in a turning operation was investigated by Al Bahkali *et al* (2016). Turning tools with carbide inserts and 0.4 and

0.8 mm nose radii were used. For each set of machining settings, the surface roughness was measured. To construct a model linking the machining variables to the resultant surface quality, the input parameters of three levels was used in a design of experiment. The tool nose and feed rate had the bigger impact on the machined product's surface roughness are what the results indicated. Cutting speed and depth of cut appear to have less of an impact.

Al Bahkali *et al* (2016) also claimed that for a larger nose radius, the lowest roughness was achieved by using the lowest feed rate, greatest cutting speed, and shallowest cut depth. A multiobjective optimization was also used to assess process productivity, with the goal of optimising material removal rate while minimising surface roughness. A detailed examination of the surface finish under optical microscope revealed that the lower the nose radius (0.4 mm), the more likely there are graphite pullouts, which degrade the surface roughness. Figure 2.14 shows the comparison of small and large nose radius.



Figure 2.14 : Comparison of small and large nose radius

2.5 Deform 3D Simulation Software

When it comes to analysing the three-dimensional (3D) flow of complicated industrial processes, DEFORM-3D is a strong process simulation system. In large-deformation processes, DEFORM-3D is an efficient and effective technique for predicting material flow. Turning, drilling, milling, boring, and forging are among the most common uses. Finite element methods are used in DEFORM. After decades of industrial use, a

reputation for astonishment has emerged. Material flow and thermal behaviour may be accurately predicted by the powerful simulation engine.

Besides, shaping, heat treating, and meshing are all part of DEFORM-3D's integrated modelling system. Predictions made by the system include chip form, cutting force, temperature of the tool and workpiece, tool wear, and residual stress. It is possible to simulate the distortion caused by the overall part's residual stress.

In this project, the different cutting parameters were applied in Deform 3D turning simulation to obtained the output responses which were cutting temperature, effective stress, total velocity and material removal rate. Deform 3D had simulated real life turning environment with the selection of material, type of cutting tool, rake angle of cutting tool and so on to achieved accurate results as real life machining process. Figure 2.15 shows the Deform 3D simulation software user interface.



Figure 2.15 : Deform 3D simulation software user interface

2.6 Minitab software

Analysis of data may be done using Minitab, a statistical programme. It is primarily aimed at those who work in the six-sigma industry. An easy-to-use interface allows users to enter statistical data and identify the trends and patterns in their data.

Minitab software will be used in this project to randomize the cutting parameters into 15 runs with different cutting speed, feed rate and depth of cut within the range. Then, identify the cutting parameters that have the greatest impact on the output responses (ANOVA). Furthermore, by using the Box-Behnken of the Response Surface Method (RSM), the relationship between the cutting parameters and the output responses will be examine. Figure 2.16 shows the Minitab software user interface.



Figure 2.16 : Minitab software user interface

2.7 Design of experiments

Design of Experiments (DOE) is the section of applied statistics that plans, runs, analyzes, and interprets control tests to identify variables that affect the value of a parameter or combination of parameters. DOE is a versatile data collection and analysis tool that can be applied to a variety of experiments.

This allows manipulation of many input factors to determine their effect on the desired outcome (response). By modifying multiple inputs simultaneously, DOE can detect important interactions that might be overlooked when testing one component at a time. We can study all possible combinations (full factors) or only a subset of possible combinations (partial factors).

A carefully designed and run experiment can tell a lot about the effect of one or more factors on a response variable. In many studies, some variables remain constant while the values of others change. Compared to adjusting the factor levels simultaneously, this OFAT (one factor at a time) strategy is ineffective at processing knowledge.

Three parameters are applied in this turning process simulation. Cutting speed, feed rate and depth of cut at various values are checked to obtain results and responses. Feedback also clarifies the interaction of cutting parameters. Finally, single and multiple responses are optimized. After completing the AISI 1045 steel machining simulation by using Deform 3D software, the response is to develop an experimental tuning process matrix using Response Surface Methodology (RSM) BoxBehnken with Minitab software, and then perform a Surface Response Methodology (RSM) and analysis of variance (ANOVA).

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2.7.1 Box-Behnken of the Response Surface Method (RSM)

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A response surface design with no integrated factorial or fractional factorial design is known as a Box-Behnken design (BBD). A combination of midpoint or central anodization is used in Box-Behnken designs that require a minimum of three consecutive components. Figure 2.17 shows the Box-Behnken Design and table 2.4 shows the summary of the BBD generated by Minitab. The three-component configuration of Box-Behnken is shown in the diagram below. The dots in the figure represent the next run of the experiment:



Figure 2.17 : Box-Behnken Design

The researchers or students can use these designs to efficiently estimate the first and second coefficients. A Box-Behnken structure can be cheaper to create because it has fewer design points than a central composite structure with the same number of components.



2.7.2 Central Composite Design (CCD)

The most common planned response surface experiment is the central composite structure (CCD). Factorial or partial factorial designs with centroids are supplemented by groups of centroids (also called asterisks) from which curvature can be estimated. We can use CCD to efficiently estimate and predict first- and second-order terms. We can also use CCD to add centroids and centroids to previously completed factorial designs to simulate variable responses with curvature.

Furthermore, Central Composite Design (CCD) also has the desired orthogonal block properties and rotation capabilities. Orthogonal blocks use two or more blocks to create a central composite design. Orthogonal blocks can be generated using a central synthesis schema, allowing independent estimation of model conditions and block effects and reducing variability in regression coefficients. In the case of rotation, a rotatable plan at all sites equidistant from the design center will give a constant prediction deviation. Hetzner H. *et al.* (2014) claimed that schema of a central composite design with three factors, A, B and C. It consists of a full factorial design (cube points), which is extended by a center point and star points. Figure 2.18 shows a central composite design with 3 factors. Table 2.5 shows the Summary of the CCD generated by Minitab.



Figure 2.18 : Schema of a CCD with 3 factors, A, B and C. (Hetzner H. et al. (2014))

Factors	Design	Runs	Blocks	Cube blocks	Cube runs	Center points	Cube center points	Axial center points	Default alpha	Rotatable
2	Full	13	1		4	5		0	1.414	у
2	Full	14	2	1	4	6	з	з	1.414	у
з	Full	14	1		8	6		0	1.682	у
з	Full	20	2	1	8	6	4	2	1.633	n
з	Full	20	з	2	8	6	4	2	1.633	n
4	Full	31	1		16	7		0	2	у
4	Full	30	2	1	16	6	4	2	2	У
4	Full	30	з	2	16	6	4	2	2	У
5	Full	52	1		32	10		0	2.378	У
5	Full	54	2	1	32	12	8	4	2.366	n
5	Full	54	з	2	32	12	8	4	2.366	n
5	Half	32	1		16	6		0	2	У
5	Half	33	2	1	16	7	6	1	2	У
6	Full	90	1		64	14		0	2.828	У
6	Full	90	2	1	64	14	8	6	2.828	у
6	Full	SUAND	SIA .	2	64	14	8	6	2.828	у
6	Full	90	5	4	64	14	8	6	2.828	У
6	Half	53	1	2-	32	9		0	2.378	У
6	Half	54	2	P	32	10	8	2	2.366	n
6	Half	54	3	2	32	10	8	2	2.366	n
7	Full	152	1		128	10		0	3.364	У
7	Full	160	2	1	128	18	8	10	3.364	у
7	Full	160 1	з	2	128	18	8	10	3.364	У
7	Full	160	5	4	128	.18	8	10	,3.364	У
7	Half	88	ando		64	10 20	- Autuala	e, rig	2.828	У
7	Half	90 **	2 **	7	64**	12 **	8	4	2.828	У
7	Half	90	3		64	12 A)	Peta I	4 EL A	2,828	У
7	Half	90E F.C	5	4 ^{n. NII}	64	12	801A 1	4-LA	2.828	У
8	Half	154	1		128	10		0	3.364	У
8	Half	160	2	1	128	16	8	8	3.364	У
8	Half	160	з	2	128	16	8	8	3.364	У
8	Half	160	5	4	128	16	8	8	3.364	У
8	Quarter	90	1		64	10		0	2.828	У
8	Quarter	90	2	1	64	10	8	2	2.828	у
8	Quarter	90	з	2	64	10	8	2	2.828	У
8	Quarter	90	5	4	64	10	8	2	2.828	У
9	Quarter	156	1		128	10		0	3.364	У
9	Quarter	160	2	1	128	14	8	6	3.364	У
9	Quarter	160	з	2	128	14	8	6	3.364	У
9	Quarter	160	5	4	128	14	8	6	3.364	У
10	Eighth	158	1		128	10		0	3.364	У
10	Eighth	160	2	1	128	12	8	4	3.364	У
10	Eighth	160	з	2	128	12	8	4	3.364	У
10	Eighth	160	5	4	128	12	8	4	3.364	У

Table 2.5 : Summary of the CCD generated by Minitab (https://support.minitab.com/)

2.8 Analysis of variance (ANOVA)

The hypothesis that two or more population means are equal is tested by analysis of variance (ANOVA). ANOVA determines the significance of one or more variables by comparing the means of a response variable at different factor levels. The null hypothesis is that all population means (mean factor levels) are the same, but the alternative hypothesis is that at least one of them is different.

ANOVA requires a continuous response variable and at least one categorical factor with at least two levels. Analysis of ANOVA requires data from a population that is approximately normally distributed and has the same variance at the factor level. However, if one or more of the distributions are not heavily skewed or the variances are not significantly different, the ANOVA method works well even if it violates the assumption of normality. These violations can be corrected by transforming the original data set. Table 2.6 and table 2.7 show the example of ANOVA generated by researcher.

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Ta	ble 2.6 : Al	NOVA generated	l by researche	er (Davis <i>et</i> al ,2	014)
	AIND :	ANOVA TAI	BLE FOR MI	EANS	
Parameter	DF		MS	ورمسيتي	• P
Depth of Cut	/ER ₂ it	TE _{69.12} KA	4.56 A	YSI _{0:35} IEL/	AK0.420
Feed Rate	2	170.92	56.79	0.57	0.636
Spindle Speed	2	49.16	24.58	0.25	0.801
Error	2	198.31	99.16		
Total	8	487.52			

	1110	IN TABLE FOR I	
Level	Depth of Cut	Feed Rate	Spindle Speed
1	-22.32	-25.69	-23.51
2	-27.23	-18.95	-26.21
3	-22.07	-26.90	-21.81
Delta () max-min	5.16	7.95	4.40
Rank	2	1	3
	HALAYSIA MELER	كنيك	TeM اونيومرسيتي تي
L	JNIVERSITI TEK	(NIKAL MAL)	AYSIA MELAKA

Table 2.7 : ANOVA generated by researcher (Davis *et al*, 2014) ANOVA TABLE FOR MEANS

CHAPTER 3 METHODOLOGY

This chapter describes the proposed methodology of this research which consist the principles of methods that will be performed to complete the research. Following a careful examination of the specification and particulars of past research, the material selection, experiment design, machine processing, and testing will be discussed. The primary goal of methodology is to offer appropriate approaches, tools, and procedures for completing this study.

3.1 An Overview of Methodology

The purpose of the methodological preparation is to ensure that the AISI 1045 carbon steel turning process goes according to plan. The processes are built up based on the study scopes in order to acquire a cutting performance analysis. Furthermore, all operations requiring standard instruments, methods, and specimen testing are measured against the ASTM. Then, the method parameters are based on past research as well. Figure 3.1 at the next page is shows the overall process of obtaining the final result, starting with literature review, continuing into selection of parameters, follow with a design simulation matrix by RSM method, then simulation with Deform 3D, and ending with data analysis. (machining simulation preparation, continuing into the simulation process, follow with a test method, and ending with data analysis.)



Figure 3.1: Overall process of the project

3.2 Process Flow

According to Figure 3.1, the overall process flow explained the steps taken and procedures of the research in achieving the objectives stated. The sequences of the simualtion from start until the end process were expressed in details. The process started with literature review reading on the related previous journals and articles to give an overview of the research were conducted. The next step is prepare the simulation equipment of the machining preparation. This step will determine the cutting parameters which are then chosen by comparing it to the related journals. Meanwhile, the simulation matrix was designed by RSM method by using Minitab software. Then, by using Deform 3D simulation software, the turning process simulation were carried on in only one condition which is dry machining with different cutting parameters as the reference. This process had observed and investigated the cutting performances with respect to the four aspects which were cutting temperature, effective stress, total velocity and material removal rate (MRR). The analysis and results observed were recorded and examined in the next chapter.

3.3 Simulation process preparation

Before start the simulation process, the equipment preparation need to proceed first to ensure everything run as smooth as planned. The equipment preparation including the preparation of work piece material, cutting tool, cutting parameter and setup of dry machining simulation. Besides, the condition of computer used to run the simulation, need to check and examine to ensure the operation and result reading is correct and accurate. After than, the Deform 3D simulation software had been installed in computer which use to simulated the turning process of AISI 1045 steel according to the selection of turning parameters. Lastly, the Minitab software had been installed in computer which use to setup the turning parameters, proceed the analysis of Box-Behnken of the Response Surface Method (RSM) and analysis of variance (ANOVA) to determine the most significant of the cutting parameter, to find the interaction of the cutting parameter , and to optimize the response through single and multiple responses. Figure 3.2 represented the flow chart of simulation process.



Figure 3.2 : Flow chart of Simulation process

3.4 Machining Simulation

First, the problem setup of cutting process was in the Deform 3D simulation software, then follow by naming the problem, in this case, "MACHINING1" was known as Run number 1. Then selected SI unit as unit system for the simulation process. For the process setup, the cutting speed, feed rate and depth of cut were inserted according to the simulation matrix which designed by the Minitab software. After that, TNMA432 was selected as the cutting tool and the side cutting angle was set to 0 degree while back rack angle and side rack angle were set to -5 degree. All the 15 runs were using the same setting of the cutting tool angle. The tool mesh size of 25000 was generated and the length of work piece was set to 10mm. The work piece mesh size of 10000 was generated then followed by the heat exhange process. Next, AISI-1045 steel was chosen as the workpiece material. The simulation step was set to 500 steps, step increment to save of 10mm and arc legth to cut of 10mm. Before the simulation start running, the multiple processor need to set up as "localhost", then the start button was clicked and the simulation process was started. If the results of analysis are out of the research gap, then the machining simulation process will be carry on again to get another analysis result. Figure 3.3 until figure 3.23 showed the Simulation steps of AISI 1045 steel turning process by using Deform 3D simulation software.

m-3D preprocessor templates		
templates		
ming	C Preform wizard	
chining[cutting]	C Inverse heat transfer wizard	
stress analysis	C Heat treatment wizard	
ape rolling	C Cogging wizard	
g rolling		
		view is availab
	e stress analysis ape rolling ng rolling	e stress analysis C Heat treatment wizard ape rolling C Cogging wizard ng rolling

Figure 3.3: Selection of problem setup

Problem Setup			>
Problem Name			
The name can be up to 80 of the problem or the purpo	characters and it on se of the simulation	can be used to provid 1.	e an explanation
Problem name			
MACHININGD			
			C

IG16 C English G System International (SI)
 English System International (SI)
System International (SI)

Figure 3.4: Setup of problem (No. of Run) name

Figure 3.5: Selection of Unit system



Figure 3.6: Selection of Cutting Parameters

	F Toolholder Setup Wizard	>
· · · · ·	Step 1- Parameters	
	Please specify Parameters for the toolho	lder.
	Side Cutting Angle (SCEA) 0	Deg
	Back Rake Angle (BR) -5	Deg
	Side Rake Angle (SR) -5	Deg

Figure 3.8: Selection of Cutting Angles

Figure 3.7: Selection of Cutting Tool

The Delete operation 🛉 Add operation 🛉 Add die stress 🕒 👶 🚑
Tool Mesh Generation
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Min element size mm
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25000
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Figure 3.9: Tool Mesh Generation



Figure 3.10: Meshing of Cutting Tool

C Curved model		Simplified	model	
Diameter(D) 50	mm	Length	10	mm
Arc angle 20	Deg	Feed amount	0.1	mm /rev
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Create geome	try	Analysis d	Uncut as lomain of surface	Advanced

Figure 3.11: Selection of Workpiece Shape



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Figure 3.14: Meshing of Workpiece

Entry	No. of nodes/ed	lges	
Deformation			
🗄 🔣 Velocity			
- Z, Fixed	157		
···· Y, Fixed	226		
X, Fixed	102		
Thermal			
🖹 🏡 Heat Exchange wi	h Env.		
ⁱ Defined	1981		
🗄 🔥 Temperature			
20	231		
Defir	e		щ н
<u>C</u> lose opr	_	< <u>B</u> ack	<u>N</u> ext >

Figure 3.15: Heat Exchange of Workpiece











Figure 3.18: Simulation Steps



Figure 3.20: Multiple Processor Set Up



Figure 3.21: Simulation option

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Epice Datase Reart		Poblem D	MACHINING/6	Pre Processor
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Figure 3.22: Simulation Running

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Figure 3.23: Simulation End

3.5 Data collection and Analysis

In this stage, the cutting temperature, the cutting temperature, effective stress, total velocity and material removal rate (MRR) were collected with the different cutting parameter such as cutting speed, feed rate, and depth of cut. After that, the collected data were proceed to analysis stage with the responses surface method (RSM) and analysis of variance (ANOVA) by using the Minitab software as mention earlier. The steps to collect the data of all responses are the same. Figure 3.24 until Figure 3.26 showed the steps of data collection. Figure 3.27 until Figure 3.30 showed the steps of data analysis.



Figure 3.25: Selection of the Output Responses



Figure 3.27: Steps to Create Response Surface Design by using Minitab Software

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1	Response: Cutting Temperature	~							
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Figure 3.29: Analysis of Contour Plot



3.6 Selected Parameters

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According to Robinson *et al.* (2013), a research gap is a topic or area where insufficient or insufficient information prevents reviewers from making judgments about a particular request. Through stakeholder interaction in prioritising, a research gap may be further expanded into research requirements.

According to the previous study and experiment by the researchers, it can be told that they have use the same material which is AISI 1045 steel and have not large difference between their depth of cut, but there are differences in cutting speed and feed rate. Therefore, a research gap and selected parameters were set between their finding to determine the most significant of the cutting parameter such as cutting speed, feed rate, and depth of cut towards responses. Figure 3.31 shows the research gap, table 3.1 shows selected parameters while table 3.2 shows box behnken matrix for simulation run.



Figure 3.31 : Research gap

Table 3.1: Selected Parameters

Process Factor	Unit	Level 1	Level 2
Cutting Speed, (v)	m/min	100	500
Feed Rate, (f)	mm/rev	0.1	0.5
Depth of Cut, (d)	mm	0.5	1.5

Table 3.2: Box Behnken Matrix for Simulation Run (15 Runs)

Run No.	Cutting Speed,	Feed Rate, f	Depth of Cut,	Cutting Temperature	Effective Stress	Total Velocity	Material Removal
	$V_c(m/min)$	(mm/rev)	a_p	(° C)	(Mpa)	(mm/sec)	Rate, MRR
			(mm)			-	(IIIII 3/sec)
1	100	0.3	0.5				
2	500	0.3	0.5				
3	100	0.3	1.5				
4	500	0.3	1.5				
5	100	0.1	1				
6	500	0.1	1				
7	100	0.5	1				
8	500	0.5	P.				
9	300	0.1	0.5				
10	300	0.1	1.5				
11	300 -	0.5	0.5				
12	300	0.5	1.5				
13	300	0.3	1				
14	300	0.3	1				
15	300	0.3	1	1 1			
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According to the findings of this chapter, the complete methodology used in this research study was elucidated and shown in detail. This simulation's cutting parameters were determined using the Box-Behnken response surface approach, which was clearly presented in the Minitab software. In addition, the turning simulation work method and FEA in DEFORM 3D turning simulation setup were described in detail so that the simulation could be performed fast and simply using the FEA DEFORM 3D machining software.

CHAPTER 4 RESULT AND DISCUSSION

In this chapter, all simulated data collecting, analysis using Minitab 18 statistical software, results or outcomes of the study, and interpretation of the importance of the findings are described in detail. For this simulation study, cutting speed, Vc, feed rate, f, and depth of cut, a_p served as independent input factors, while cutting temperature, effective stress, total velocity, and material removal rate (MRR) were examined as dependent variables or responses. Response Surface Methodology (RSM) has been used to examine the impact of these input factors on the selected responses.

4.1 Overall Simulation Results

Show all

Using the Deform 3D simulation software, a total of 15 simulation runs were done at random in accordance with the run order sequence given by Box-Behnken Experiment Design Layout. The measured values of the output parameters (cutting temperature, effective stress, total velocity and material removal rate) and their related values of the input control variables or parameters were summarised in Table 4.1.

The cutting temperature, effective stress and total velocity were measured by Deform 3D simulation software. For each simulated workpiece, fifteen measurements of cutting temperature, effective stress, and total velocity were made, and the average values of cutting temperature, effective stress, and total velocity were reported. While the material removal rate (MRR) was calculated by using Equation 4.7 as stated below.

Run	Cutting	Feed	Depth	Cutting	Effective	Total	Material
No.	Speed,	Rate, f	of Cut,	Temperature	Stress	Velocity	Removal
	$V_c(m/min)$	(mm/rev)	a_p	(°C)	(Mpa)	(mm/sec)	Rate, MRR
			(mm)				(mm^3/sec)
1	100	0.3	0.5	720	1860	2490.79	373618.5
2	500	0.3	0.5	1020	1880	12222.67	1833400.5
3	100	0.3	1.5	879	2060	2738.74	1232433
4	500	0.3	1.5	1100	2040	15296.49	6883420.5
5	100	0.1	1	691	2220	6981.87	698187
6	500	0.1	1	1040	1800	12488.73	1248873
7	100	0.5	1	940	1590	3878.16	1939080
8	500	0.5	1	1330	1830	19234.68	9617340
9	300	0.1	0.5	791	2750	8259.62	412981
10	300	0.1	1.5	930	1840	8216.44	1232466
11	300	0.5	0.5	997	1760	6872.71	1718177.5
12	300	0.5	1.5	1180	2190	13850.28	10387710
13	300	0.3	1	1080	2570	8813.92	2644176
14	300	0.3	1	1030	1700	8027.00	2408100
15	300	0.3	1	1040	1910	8518.20	2555460

Table 4.1: Cutting Temperature, Effective Stress, Total Velocity and Material Removal Rate (MRR)

4.2 Analysis Result for Cutting Temperature

Table 4.2 showed the value of the cutting temperature for each run including various parameter combinations. The cutting temperature data was derived from two sources: first, simulation software, and second, a mathematical model constructed using the response surface method and Minitab software.

Run No.	Cutting Speed, V_c (m/min)	Feed Rate, f (mm/rev)	Depth of Cut, a_p (mm)	Cutting Temperature (°C)
1	100	0.3	0.5	720
2	500	0.3	0.5	1020
3	100	0.3	1.5	879
4	500	0.3	1.5	1100
5	100	0.1	1	691
6	500	0.1	1	1040
7	100	0.5	1	940
8	500	0.5	1	1330
9	300	0.1	0.5	791
10	300	0.1	1.5	930
11	300	0.5	0.5	997
12	300	0.5	1.5	1180
13	300	0.3	1	1080
14	300	0.3	1	1030
15	300	0.3	1	1040

Table 4.2 : Cutting Temperature for the Simulation Run

Figure 4.1 below presented the line chart of cutting temperature value for each run. Run no. 5 had the lowest cutting temperature which is only 691 °C while Run no.8 obtained 1330 °C which is the highest cutting temperature among the 15 runs. From the data of Table 4.2 above, the hypothesis is made, the higher the cutting speed and feed rate, the higher the cutting temperature. Figure 4.2 and Figure 4.3 showed cutting temperature with cutting tool and cutting temperature of workpiece surface respectively.



Figure 4.2 : Cutting Temperature with Cutting Tool

Figure 4.3 : Cutting Temperature of Workpiece Surface

4.2.1 Analysis of Variance (ANOVA) for Cutting Temperature

RSM was utilised to generate the predictive mathematical quadratic model from the simulation results of cutting temperature features. ANOVA was used to evaluate the influence of turning parameters on the chosen response based on the projected regression model. Thus, analysis of variance (ANOVA) is used to assess the relevance and suitability of the suggested model.

The computed regression coefficient for cutting temperature is shown in Table 4.3. Using the R^2 value, the model's efficacy has been determined. In this study, the R^2 value is 0.9773, the adjusted R^2 value is 0.9365, and the anticipated R^2 value is 0.6851. The R^2 number is near to 1 and rather high, which is ideal. The closer R^2 is to 1, the more precise the regression model. According to Javidikia (2020), R^2 values between 85 and 98% indicate that the created models are statistically accurate and may be utilised with a high degree of confidence to predict response characteristics in the design space specified in the DoE. The R^2 result shows that the turning parameter explains 97.73 % of the variation in cutting temperatures in the present study.

Term	Coef	SE Coef	T-Value	P-Value	
Constant	1050.0	24.6	42.72	0.000	Significant
Cutting Speed (A)	157.5	15.1	10.46	0.000	Significant
Feed Rate (B)	70.1	15.1	4.66	0.006	Significant
Depth of Cut (C)	124.4	15.1	8.26	0.000	Significant
Cutting Speed * Cutting Speed (A^2)	-47.3	22.2	-2.13	0.086	
Feed Rate * Feed Rate (B^2)	-73.0	22.2	-3.29	0.022	Significant
Depth of Cut * Depth of Cut (C^2)	-2.5	22.2	-0.11	0.915	
Cutting Speed * Feed Rate (AB)	-19.8	21.3	-0.93	0.396	
Cutting Speed * Depth of Cut (AC)	10.2	21.3	0.48	0.650	
Feed Rate * Depth of Cut (BC)	11.0	21.3	0.52	0.627	
S= 42.5741 R-sq=97.73% R-sq(adj)=93.65% R-sq(pred)=68.51%					

Table 4.3: Estimated Regression Coefficients for Cutting Temperature (Quadratic)

Table 4.4 showed the ANOVA results for a cutting temperature response surface full quadratic model. P-value is less than 0.05 in Table 4.4, indicating that the model has sufficient significance at a 95% confidence level, which is desirable since it shows that the terms in the model have a significant effect on cutting temperature. Similary, the main effect of cutting speed (A), feed rate (B), depth of cut (C) and also the square effect of feed rate (BB) are significant model terms. Other model terms are not significant as shown. In this

case, the 2-way interaction of cutting speed and feed rate (AB) had the lowest P-value among others, therefore it can said that it is close to significant.

Source	DF	Adj.SS	Adj.MS	F-Value	P-Value	
Model	9	390261	43362	23.92	0.001	Significant
Linear	3	361543	120514	66.49	0.000	Significant
Cutting Speed (A)	1	198450	198450	109.49	0.000	Significant
Feed Rate (B)	1	39340	39340	21.70	0.006	Significant
Depth of Cut (C)	1	123753	123753	68.28	0.000	Significant
Square	3	26253	8751	4.83	0.061	
Cutting Speed*Cutting Speed	1	8243	8243	4.55	0.086	
Feed Rate*Feed Rate	1	19676	19676	10.86	0.022	Significant
Depth Of Cut*Depth Of Cut	1	23	23	0.01	0.915	
2-Way Interaction	3	2464	821	0.45	0.726	
Cutting Speed*Feed Rate	1	1560	1560	0.86	0.396	
Cutting Speed*Depth Of Cut	1	420	420	0.23	0.650	
Feed Rate*Depth Of Cut	1	484	484	0.27	0.627	
Error	5	9063	1813			
Lack-of-Fit	3	7663	2554	3.65	0.223	
Pure Error	2	1400	700			
Total	14	399324				

Table 4.4: ANOVA analysis of the Full Quadratic Model for Cutting Temperature

The ANOVA study of the quadratic model for the cutting temperature indicated that cutting speed, feed rate, and depth of cut, with corresponding "P-values" of 0.000, 0.006, and 0.000, had a significant impact on the cutting temperature. Cutting speed and depth of cut, with a "P-value" of 0.0000, were the cutting parameters that had the greatest influence on the output response of cutting temperature. This result is in line with the simulation research undertaken to determine the optimal process.

Table 4.4 showed that the interactions between cutting speed and feed rate contribute significantly to the cutting temperature with a "P-Value" of 0.396, which is the lowest value among the three 2-way interaction parameters. However, the interaction between cutting speed and depth of cut, and feed rate and depth of cut with the "P-Value" of 0.650 and 0.627 respectively, hence they are not significantly influence the cutting temperature.

The Effects Plots were analysed to identify the factors that impact the chosen response. From the Pareto Chart of the standardize effects for cutting temperature, as shown in Figure 4.4, any effects that extend beyond the standardized effect reference line of 2.57 are statistically significant which affected the response. Therefore, in order from the largest

to the smallest effect, the main effect of cutting speed (A), feed rate (B) and depth of cut (C), and the square effect of feed rate (BB) are statistically significant at 5% significance level.



Figure 4.4 : Pareto Chart of the Standardize Effects for Cutting Temperature

The Normal Plot of the standardize effects for cutting temperature is shown in Figure 4.5. Effects that are further from 0 (on the x-axis) are more statistically significant with a larger impact on the response (Minitab, 2021). As a result, cutting speed (A), feed rate (B) and depth of cut (C), and the square effect of feed rate (BB) are statistically significant at 5% significance level. The normal plot also represents the direction of the effect. Cutting speed (A), feed rate (B) and depth of cut (C) showed the positive standardize effects, while the square effect of feed rate (BB) showed negative standardized effects. The positive effects increase and negative effects decrease the cutting temperature when the setting change from low to the high value of the factor.



Figure 4.5 : Normal Plot of the Standardize Effects for Cutting Temperature

By using the Contour and Surface Plots in terms of relationship with each process variables, the analysis of the response variable of cutting temperature can be explained. Figure 4.6 showed the influence of cutting speed and feed rate on the cutting temperature, while the depth of cut is kept at the middle level. These 3-dimensional (3D) surface and 2-dimensional (2D) countor plots represent a response surface with a simple maximum pattern. It is discovered that cutting temperature increases with the increase of cutting speed and feed rate. In this case, the lower cutting temperature is achieved with the combination of lower cutting speed and feed rate.

The cutting temperature in relation to the cutting speed, feed rate with the depth of cut is held at the middle level is presented in Figure 4.6. From the figure, it has been asserted that decreasing both cutting speed and feed rate at the same time resulted in reduction of cutting temperature. The combination of the low nearly to lower level ($\sim 110 \text{ m/min}$) of the cutting speed and the lower level ($\sim 0.11 \text{ mm/rev}$) of feed rate lead to the lowest cutting temperature.



Figure 4.6: Effect of Cutting Speed and Feed Rate on Cutting Temperature (a_p =1.0mm)

4.2.2 Mathematical Model for Cutting Temperature

Using Minitab software, a mathematical or empirical model illustrating the relationship between the parameters (cutting speed, feed rate, and depth of cut) and the desired response (cutting temperature) was produced via the response surface method. Equation 4.1 presents the mathematical model for the quadratic (or second-order) model for cutting temperature in uncoded equation.

Cutting Temperature = 199 + 1.542 Cutting Speed + 1484 Feed Rate + 205 Depth Of Cut - 0.001181 Cutting Speed*Cutting Speed-1825 Feed Rate*Feed Rate - 10.0 Depth Of Cut*Depth Of Cut - 0.494 Cutting Speed*Feed Rate + 0.102 Cutting Speed*Depth Of cut + 110 Feed Rate*Depth Of Cut Equation 4.1

By replacing the variable in Equation 4.1 with a related experimental input parameter value of cutting speed, feed rate and depth of cut, the predicted cutting temperature can be calculated. For instance, the predicted value for cutting temperature for simulation run number 8, with the combination of cutting speed, feed rate and depth of cut, of 500 m/min, 0.5 mm/rev and 1.0mm respectively, can be computed as follow :

Cutting Temperature = 199 + 1.542(500) + 1484(0.5) + 205(1.0)- 0.001181(500)(500) - 1825(0.5)(0.5) - 10.0(1.0)(1.0)- 0.494(500)(0.5) + 0.102(500)(1.0) + 110(0.5)(1.0)= 1138 °C

The predicted values of Cutting Temperature were compared with the corresponding simulation values and the percentage of error is calculated by employing Equation 4.2.

Percentage of error (% error) = $\frac{[Cutting Temp_{Simulation} - Cutting Temp_{Prediction}]}{Cutting Temp_{Simulation}} \times 100\%$ Equation 4.2

The computed percentage error for simulation run of cutting temperature values towards the predicted cutting temperature values is tabulated in Table 4.5. The highest percentage error is from simulation run number 8 and the lowest percentage error is from simulation run number 12 with a percentage of 14.43609 % and 0.03051 % respectively. The average error between simulation results and RSM model predicted results of cutting temperature is 5.079 %. The simulation values of cutting temperature were found to be very close to the predicted values. Thus, this empirical model is capable to provides reliable predictions. Figure 4.7 shows the histogram chart comparing simulation and predicted values for cutting temperature.

Run No.	Simulation Cutting Temperature (°C)	Predicted Cutting Temperature (°C)	Error (%)
1	720	729.12	1.26667
2	1020	1023.6	0.35294
3	879	957.32	8.91013
4	1100	1292.6	17.5091
5	691	682.8	1.186686
6	1040	1037.2	0.269231
7	940	862.64	8.229787
8	1330	1138	14.43609
9	791	791.44	0.05563
10	930	1018.04	9.46667
11	997	909.76	8.750251
12	1180	1180.36	0.03051
13	1080	1050.4	2.740741
14	1030	1050.4	1.98058
15	1040	1050.4	1

Table 4.5: Percentage Error between Simulation and Predicted Results for cutting temperature



Figure 4.7 : Histogram Chart for Simulation and Predicted values for Cutting Temperature

4.2.3 Optimization Parameters of Cutting Temperature

Optimization is the process of obtaining the ideal outcome under given circumstances, which may be defined as a function of assessed decision factors, with the goal of either minimising undesirable effects or maximising the intended benefit. In manufacturing, the
ultimate objective of optimising turning machining settings is to generate improved outcomes that may be used to produce high-quality products at reduced production costs.

Response surface optimization is a very useful technique for the determination of best cutting parameters in turning operation. In the present work, the goal or target is to minimize the cutting temperature. RSM optimization results for cutting temperature parameters are shown in Figure 4.8 and Table 4.6. The optimum machining parameters are found to be cutting speed of 100 m/min, feed rate of 0.10 mm/rev and depth of cut of 0.50 mm. These set of parameters possess the composite desirability of 1.000 and the predicted value of cutting temperature is equal to 576.75 °C.



Table 4.6: Response Optimization for Cutting Temperature Parameters

Optimum Conditions								
Response	Goal	Cutting	Feed Rate	Depth	Upper	Target	Pred.	Composite
_		Speed	(mm/rev)	of Cut		-	Resp.	Desirability
		(m/min)		(mm)				
Cutting	Min.	100	0.1	0.5	1330	691	576.75	1.000
Temperature								

The percentage optimization for cutting temperature

= [highest value – optimized value] / highest value x 100%

Equation 4.3

= [1330 - 576.75] / 1330 x 100%

= 56.64 %

The highest value of cutting temperature which is 1330 °C was obtained from the Deform 3D Simulation, while the optimized value of cutting temperature which is 576.75 °C was obtained from Minitab software. The percentage of optimization for cutting temperature was calculated by employing Equation 4.3 and the result is 56.64 %. The percentage of optimization indicates that the cutting temperature has been optimized by 56.64 % with the application of the optimization parameters of cutting temperature which are the cutting speed of 100 m/min, feed rate of 0.1 mm/rev and depth of cut of 0.5 mm that obtained from Minitab software.

4.3 Analysis Result for Effective Stress

For every simulation that has been done, each machined workpiece was subjected to measurement of effective stress to obtain the most accurate data. Then, the data was recorded for analysis. Table 4.7 shows the effective stress values for the simulation run with a different combination of cutting parameters were provided.

Run	Cutting Speed, V (m/min)	Feed Rate, f (mm/rev)	Depth of Cut, $q_{(mm)}$	Effective Stress
110.	C(III)IIII)	1 (11111/101)	up (IIII)	(mpa)
1	100	0.3	0.5	1860
2	500	0.3	0.5	1880
3	100 RSITIT	0.3	1.5 ALAYS	2060
4	500	0.3	1.5	2040
5	100	0.1	1	2220
6	500	0.1	1	1800
7	100	0.5	1	1590
8	500	0.5	1	1830
9	300	0.1	0.5	2750
10	300	0.1	1.5	1840
11	300	0.5	0.5	1760
12	300	0.5	1.5	2190
13	300	0.3	1	2570
14	300	0.3	1	1700
15	300	0.3	1	1910

Table 4.7: Effective Stress for the Simulation Run

Figure 4.9 below presented the line chart of Effective Stress value for each run. Run no. 7 had the lowest effective stress which is only 1590 Mpa while Run no.9 obtained 2750 Mpa which is the highest effective stress among the 15 runs. From the data of Table 4.8 above, the hypothesis is made, the higher the cutting speed, the higher the effective stress.

Figure 4.10 and Figure 4.11 showed effective stress with cutting tool and effective stress of workpiece surface respectively.



Figure 4.10 : Effective Stress with Cutting Tool

Figure 4.11 : Effective Stress of Workpiece Surface

4.3.1 Analysis of Variance (ANOVA) for Effective Stress

The computed regression coefficient for cutting temperature is shown in Table 4.8. Using the R^2 value, the model's efficacy has been determined. In this study, the R^2 value is 0.4526, the adjusted R^2 value is 0.2336, and the anticipated R^2 value is 0.000. The R^2

number is near to 0.5 and rather moderate, which is acceptable. The closer R^2 is to 1, the more precise the regression model. The R^2 result shows that the turning parameter explains 45.26 % of the variation in effective stress in the present study.

Term	Coef	SE Coef	T-Value	P-Value	
Constant	2000.0	72.2	27.69	0.000	Significant
Cutting Speed (A)	-22.5	98.9	-0.23	0.825	
Feed Rate (B)	-15.0	98.9	-0.15	0.882	
Depth of Cut (C)	-155.0	98.9	-1.57	0.148	
Feed Rate * Depth of Cut (BC)	335	140	2.40	0.038	Significant
S= 279.723 R-sq=45.26% R-s	q(adj)=23.3	6% R-sq	(pred)=0.00%	ό	

Table 4.8: Estimated Regression Coefficients for Effective Stress (Quadratic)

Table 4.9 showed the ANOVA results for a effective stress response surface full quadratic model. P-value is less than 0.05 in Table 4.9, indicating that the model has sufficient significance at a 95% confidence level, which is desirable since it shows that the terms in the model have a significant effect on effective stress. Elimination process is carry out to remove square of the parameters and some 2-way interaction. This is due to the high value of "P-value" at the "model" row, which is 0.522 and not significant. After elimination process, the P-value of model reduce to 0.160, which is close to significant. In this case, the 2-way interaction of feed rate and depth of cut (BC) had the lowest P-value among others, therefore it can said that it is significant. Other model terms are not significant as shown.

Source	DF	Adj.SS	Adj.MS	F-Value	P-Value		
Model	4	646950	161738	2.07	0.160	Close to	
						significant	
Linear	3	198050	66017	0.84	0.501		
Cutting Speed (A)	1	4050	4050	0.05	0.825		
Feed Rate (B)	1	1800	1800	0.02	0.882		
Depth of Cut (C)	1	192200	192200	2.46	0.148		
2-Way Interaction	1	448900	448900	5.74	0.038	Significant	
Feed Rate*Depth Of Cut	1	448900	448900	5.74	0.038	Significant	
Error	10	782450	78245				
Lack-of-Fit	8	370250	46281	0.22	0.950		
Pure Error	2	412200	206100				
Total	14	1429400					

Table 4.9: ANOVA analysis of the Full Quadratic Model for Cutting Temperature

The ANOVA study of the quadratic model for the effective stress indicated that cutting speed, feed rate, and depth of cut, with corresponding "P-values" of 0.825, 0.882, and 0.148, had some impact on the effective stress. Depth of cut, with a "P-value" of 0.148, was the cutting parameters that had the greatest influence on the output response of effective

stress since it is the lowest P-value among the 3 parameters. This result is in line with the simulation research undertaken to determine the optimal process.

Table 4.9 showed that the interactions between feed rate and depth of cut contribute significantly to the effective stress with a "P-Value" of 0.038, which is the lowest value among the three 2-way interaction parameters after the elimination process is carried out. However, the other models are exceed 0.05, hence they are not significantly influence the effective stress.

The Effects Plots were analysed to identify the factors that impact the chosen response. From the Pareto Chart of the standardize effects for effective stress, as shown in Figure 4.12, any effects that extend beyond the standardized effect reference line of 2.228 are statistically significant which affected the response. Therefore, only the 2-way interaction of feed rate and depth of cut (BC) is statistically significant at 5% significance level.



Figure 4.12 : Pareto Chart of the Standardize Effects for Effective Stress

The Normal Plot of the standardize effects for cutting temperature is shown in Figure 4.13. Effects that are further from 0 (on the x-axis) are more statistically significant with a larger impact on the response (Minitab, 2021). As a result, the 2-way interaction of feed rate

and depth of cut (BC) is statistically significant at 5% significance level. The normal plot also represents the direction of the effect. The 2-way interaction of feed rate and depth of cut (BC) showed the positive standardize effects. The positive effects increase the effective stress when the setting change from low to the high value of the factor.



Figure 4.13 : Normal Plot of the Standardize Effects for Effective Stress

By using the Contour and Surface Plots in terms of relationship with each process variables, the analysis of the response variable of cutting temperature can be explained. Figure 4.14 showed the influence of feed rate and depth of cut on the effective stress, while the cutting speed is kept at the middle level. These 3-dimensional (3D) surface and 2-dimensional (2D) countor plots represent a response surface with a simple maximum pattern. It is discovered that effective stress increases with the decrease of feed rate and depth of cut at a certain level. In this case, the lower effective stress is achieved with the combination of lower feed rate and higher depth of cut.

The effective stress in relation to the feed rate, depth of cut with the cutting speed is held at the middle level, which is 300m/min is presented in Figure 4.14. From the figure, it has been asserted that decreasing the feed rate and increasing the depth of cut at the same time resulted in reduction of effective stress. The combination of the low nearly to lower level ($\sim 0.1 \text{ mm/rev}$) of the feed rate and the higher level ($\sim 1.50 \text{ mm}$) of depth of cut lead to the lowest effective stress.



Surface Plot of Effective Stress vs Depth Of Cut, Feed Rate Cutting Speed 300

4.3.2 Mathematical Model for Effective Stress

Equation 4.4 presents the mathematical model for the quadratic (or second-order) model for effective stress in uncoded equation.

Equation 4.4

By replacing the variable in Equation 4.4 with a related experimental input parameter value of cutting speed, feed rate and depth of cut, the predicted effective stress can be calculated. For instance, the predicted value for effective stress for simulation run number

11, with the combination of cutting speed, feed rate and depth of cut, of 300 m/min, 0.5 mm/rev and 0.5 mm respectively, can be computed as follow :

Effective Stress =
$$3371 - 0.112(300) - 3425(0.5) - 1315(0.5)$$

+ $3350(0.5)(0.5)$
= 1804.9 Mpa

The predicted values of Effective Stress were compared with the corresponding simulation values and the percentage of error is calculated by employing Equation 4.5.

Percentage of error (% error) = $\frac{[E.stess_{Simulation} - E.stress_{Prediction}]}{E.stress_{Simulation}}$ x 100% Equation 4.5

The computed percentage error for simulation run of effective stress values towards the predicted effective stress values is tabulated in Table 4.10. The highest percentage error is from simulation run number 7 and the lowest percentage error is from simulation run number 12 with a percentage of 26.2453 % and 1.146119 % respectively. The average error between simulation results and RSM model predicted results of effective stress is 11.81213 %. The simulation values of effective stress were found to be very close to the predicted values. Thus, this empirical model is capable to provides reliable predictions. Figure 4.15 shows the histogram chart comparing simulation and predicted values for effective stress.

Run	Simulation Effective	Predicted Effective	Error (%)
No.	Stress (Mpa)	Stress (Mpa)	
1	1860	2177.3	17.0591
2	1880	2132.5	13.4309
3	2060	1867.3	9.354369
4	2040	1822.5	10.66176
5	2220	2037.3	8.22973
6	1800	1992.5	10.6944
7	1590	2007.3	26.2453
8	1830	1962.5	7.24044
9	2750	2504.9	8.912727
10	1840	1524.9	17.125
11	1760	1804.9	2.55114
12	2190	2164.9	1.146119
13	2570	1999.9	22.18288
14	1700	1999.9	17.6412
15	1910	1999.9	4.70681

Table 4.10: Percentage Error between Simulation and Predicted Results for Effective Stress



Simulation versus Predicted Value for Effective Stress

Figure 4.15 : Histogram Chart for Simulation and Predicted values for Effective Stress

4.3.3 Optimization Parameters of Effective Stress

Optimization is the process of obtaining the ideal outcome under given circumstances, which may be defined as a function of assessed decision factors, with the goal of either minimising undesirable effects or maximising the intended benefit. In manufacturing, the ultimate objective of optimising turning machining settings is to generate improved outcomes that may be used to produce high-quality products at reduced production costs.

Response surface optimization is a very useful technique for the determination of best cutting parameters in turning operation. In the present work, the goal or target is to minimize the effective stress. RSM optimization results for effective stress parameters are shown in Figure 4.16 and Table 4.11. The optimum machining parameters are found to be cutting speed of 500 m/min, feed rate of 0.10 mm/rev and depth of cut of 1.50 mm. These set of parameters possess the composite desirability of 1.000 and the predicted value of effective stress is equal to 1502.5 Mpa.



Figure 4.16: Optimization Plot for Effective Stress

Fable 4.11: Response Op	otimization for Eff	fective Stress Pa	arameters
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Optimum Conditions								
Response	Goal	Cutting	Feed Rate	Depth	Upper	Target	Pred.	Composite
	14	Speed	(mm/rev)	of Cut			Resp.	Desirability
	X	(m/min)	10. I	(mm)				
Effective	Min.	500	0.1	1.5	2750	1590	1502.5	1.000
Stress	2		22					
The percentage optimization for effective stress								
= [highest value – optimized value] / highest value x 100% Equation 4.6								
= [2750 – 1502.5] / 2750 x 100%								
= 45.36 %	LIMIVE	ERSITI	TEKNIK		I AVS		ΔΚΔ	

The highest value of effective stress which is 2750 Mpa was obtained from the Deform 3D Simulation, while the optimized value of effective stress which is 1502.5 Mpa was obtained from Minitab software. The percentage of optimization for effective stress was calculated by employing Equation 4.6 and the result is 45.36 %. The percentage of optimization indicates that the effective stress has been optimized by 45.36 % with the application of the optimization parameters of effective stress which are the cutting speed of 500 m/min, feed rate of 0.1 mm/rev and depth of cut of 1.5 mm that obtained from Minitab software.

4.4 Analysis Result for Total Velocity

Table 4.12 showed the value of the total velocity for each run including various parameter combinations. The total velocity data was derived from two sources: first, simulation software, and second, a mathematical model constructed using the response surface method and Minitab software.

Run	Cutting Speed,	Feed Rate,	Depth of Cut,	Total Velocity
No.	$V_c(m/min)$	f (mm/rev)	a_p (mm)	(mm/sec)
1	100	0.3	0.5	2490.79
2	500	0.3	0.5	12222.67
3	100	0.3	1.5	2738.74
4	500	0.3	1.5	15296.49
5	100	0.1	1	6981.87
6	500	0.1	1	12488.73
7	100	0.5	1	3878.16
8	500	0.5	1	19234.68
9	300	0.1	0.5	8259.62
10	300	0.1	1.5	8216.44
11	300	0.5	0.5	6872.71
12	300	0.5	1.5	13850.28
13	300	0.3	1	8813.92
14	300	0.3	1	8027
15	300	0.3	1	8518.2
27	Amme,	- un	$=\omega,\omega$	او دوم س

Table 4.12 : Total Velocity for the Simulation Run

Figure 4.17 below presented the line chart of total velocity value for each run. Run no. 1 had the lowest total velocity which is only 2490.79 mm/sec while Run no.8 obtained 19234.68 mm/sec which is the highest total velocity among the 15 runs. From the data of Table 4.12 above, the hypothesis is made, the higher the cutting speed, feed rate and depth of cut, the higher the total velocity. Figure 4.18 and Figure 4.19 showed total velocity with cutting tool and total velocity of workpiece surface respectively.



Figure 4.17 : Total Velocity against the Simulation Run Number



Figure 4.18 : Total Velocity with Cutting Tool



4.4.1 Analysis of Variance (ANOVA) for Total Velocity

The computed regression coefficient for total velocity is shown in Table 4.13. Using the R^2 value, the model's efficacy has been determined. In this study, the R^2 value is 0.9927, the adjusted R^2 value is 0.9796, and the predicted R^2 value is 0.8976. The R^2 number is near to 1 and rather high, which is ideal. The closer R^2 is to 1, the more precise the regression model. The R^2 result shows that the turning parameter explains 99.27 % of the variation in total velocity in the present study.

Term	Coef	SE Coef	T-Value	P-Value	
Constant	8453	387	21.84	0.000	Significant
Cutting Speed (A)	5394	237	22.76	0.000	Significant
Feed Rate (B)	1282	237	5.41	0.003	Significant
Depth of Cut (C)	986	237	4.16	0.009	Significant
Cutting Speed * Cutting Speed (A^2)	540	349	1.55	0.182	
Feed Rate * Feed Rate (B^2)	-806	349	-2.31	0.069	
Depth of Cut * Depth of Cut (C^2)	1653	349	4.74	0.005	Significant
Cutting Speed * Feed Rate (AB)	706	335	2.11	0.089	
Cutting Speed * Depth of Cut (AC)	2462	335	7.35	0.001	Significant
Feed Rate * Depth of Cut (BC)	1755	335	5.24	0.003	Significant
S= 670.425 R-sq=99.27% R	-sq(adj) = 97.	96% R	-sq(pred) = 89.7	76%	

Table 4.13: Estimated Regression Coefficients for Total Velocity (Quadratic)

Table 4.14 showed the ANOVA results for a total velocity response surface full quadratic model. P-value is less than 0.05 in Table 4.14, indicating that the model has sufficient significance at a 95% confidence level, which is desirable since it shows that the terms in the model have a significant effect on total velocity. Similary, the main effect of cutting speed (A), feed rate (B), depth of cut (C) and also the square effect of feed rate (CC) are significant model terms. Other model terms are not significant as shown. The 2-way interaction of cutting speed and depth of cut, and feed rate and depth of cut have the P-Value of 0.001 and 0.003 respectively. In this case, the 2-way interaction of cutting speed and depth of cut (AC) had the lowest P-value among others, therefore it can said that it is the most significant.

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Table 4.14: ANOVA	analysis of the Fu	ll Quadratic M	Iodel for	Total Velocity

Source	DF	Adj.SS	Adj.MS	F-Value	P-Value	
Model	9	306452509	34050279	75.76	0.000	Significant
Linear	3	253701262	84567087	188.15	0.000	Significant
Cutting Speed (A)	1	232772784	232772784	517.88	0.000	Significant
Feed Rate (B)	1	13148602	13148602	29.25	0.003	Significant
Depth of Cut (C)	1	7779875	7779875	17.31	0.009	Significant
Square	3	14178178	4726059	10.51	0.013	Significant
Cutting Speed*Cutting Speed	1	1077136	1077136	2.40	0.182	
Feed Rate*Feed Rate	1	2398552	2398552	5.34	0.069	
Depth Of Cut*Depth Of Cut	1	10085294	10085294	22.44	0.005	Significant
2-Way Interaction	3	38573068	12857689	28.61	0.001	Significant
Cutting Speed*Feed Rate	1	1996385	1996385	4.44	0.089	
Cutting Speed*Depth Of Cut	1	24253951	24253951	53.96	0.001	Significant
Feed Rate*Depth Of Cut	1	12322733	12322733	27.42	0.003	Significant
Error	5	2247348	449470			
Lack-of-Fit	3	1931358	643786	4.07	0.203	
Pure Error	2	315990	157995			
Total	14	308699857				

The ANOVA study of the quadratic model for the total velocity indicated that cutting speed, feed rate, and depth of cut, with corresponding "P-values" of 0.000, 0.003, and 0.009, had a significant impact on the total velocity. For the 2-way interaction, cutting speed and depth of cut, with a "P-value" of 0.001, were the cutting parameters that had the greatest influence on the output response of total velocity. This result is in line with the simulation research undertaken to determine the optimal process.

Table 4.14 showed that the interactions between cutting speed and depth of cut contribute significantly to the cutting temperature with a "P-Value" of 0.001, which is the lowest value among the three 2-way interaction parameters. However, the interaction between cutting speed and feed rate, and feed rate and depth of cut with the "P-Value" of 0.089 and 0.003 respectively, hence they are not the most significantly influence the total velocity.

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The Effects Plots were analysed to identify the factors that impact the chosen response. From the Pareto Chart of the standardize effects for total velocity, as shown in Figure 4.20, any effects that extend beyond the standardized effect reference line of 2.57 are statistically significant which affected the response. Therefore, in order from the largest to the smallest effect, the main effect of cutting speed (A), cutting speed and depth of cut (AC), feed rate (B), feed rate and depth of cut (BC), square effect of depth of cut (CC) and depth of cut (C) are statistically significant at 5% significance level.



Figure 4.20 : Pareto Chart of the Standardize Effects for Total Velocity

The Normal Plot of the standardize effects for total velocity is shown in Figure 4.21. As a result, cutting speed (A), feed rate (B) and depth of cut (C), and the square effect of feed rate (BB) are statistically significant at 5% significance level. The normal plot also represents the direction of the effect. Cutting speed (A), feed rate (B), depth of cut (C), cutting speed and depth of cut (AC), feed rate and depth of cut (BC) and the square effect of depth of cut (CC) showed the positive standardize effects. The positive effects increase the total velocity when the setting change from low to the high value of the factor.



Figure 4.21 : Normal Plot of the Standardize Effects for Total Velocity

By using the Contour and Surface Plots in terms of relationship with each process variables, the analysis of the response variable of total velocity can be explained. Figure 4.22 showed the influence of cutting speed and depth of cut on the total velocity, while the feed rate kept at the middle level. These 3-dimensional (3D) surface and 2-dimensional (2D) countor plots represent a response surface with a simple maximum pattern. It is discovered that total velocity increases with the increase of cutting speed and depth of cut. In this case, the higher total velocity is achieved with the combination of higher cutting speed and depth of cut.

The total velocity in relation to the cutting speed, depth of cut with the feed rate is held at the middle level is presented in Figure 4.22. From the figure, it has been asserted that

increasing both cutting speed and depth of cut at the same time resulted in increment of total velocity. The combination of the high nearly to higher level (~ 500 m/min) of the cutting speed and the higher level (~ 1.50 mm) of depth of cut lead to the higher total velocity.



Figure 4.22: Effect of Cutting Speed and Depth of Cut on Total Velocity

4.4.2 Mathematical Model for Total Velocity

Equation 4.7 presents the mathematical model for the quadratic (or second-order) model for total velocity in uncoded equation.

Total Velocity = 16722 - 11.05 Cutting Speed - 4351 Feed Rate - 23902 Depth Of Cut + 0.01350 Cutting Speed*Cutting Speed - 20150 Feed Rate*Feed Rate + 6611 Depth Of Cut*Depth Of Cut + 17.66 Cutting Speed*Feed Rate + 24.62 Cutting Speed*Depth Of Cut + 17552 Feed Rate*Depth Of Cut Equation 4.7

By replacing the variable in Equation 4.7 with a related experimental input parameter value of cutting speed, feed rate and depth of cut, the predicted total velocity can be calculated. For instance, the predicted value for total velocity for simulation run number 4, with the combination of cutting speed, feed rate and depth of cut, of 500 m/min, 0.3 mm/rev and 1.5 mm respectively, can be computed as follow :

Total Velocity =
$$16722 - 11.05(500) - 4351(0.3) - 23902(1.5) + 0.01350(500)(500)$$

- 20150(0.3)(0.3) + 6611(1.5)(1.5) + 17.66(500)(0.3)
+ 24.62(500)(1.5) + 17552(0.3)(1.5)
= 19487.35 mm/sec

The predicted values of Total Velocity were compared with the corresponding simulation values and the percentage of error is calculated by employing Equation 4.8.

Percentage of error (% error) =
$$\frac{[T.velocity_{Simulation} - T.velocity_{Prediction}]}{T.velocity_{Simulation}} \times 100\%$$
 Equation 4.8

The computed percentage error for simulation run of total velocity values towards the predicted total velocity values is tabulated in Table 4.15. The highest percentage error is from simulation run number 1 and the lowest percentage error is from simulation run number 15 with a percentage of 170.137 % and 0.763072 % respectively. The average error between simulation results and RSM model predicted results of total velocity is 26.1502 %. The simulation values of total velocity were found to be very close to the predicted values. Thus, this empirical model is capable to provides reliable predictions. Figure 4.23 shows the histogram chart comparing simulation and predicted values for total velocity.

Run	Simulation Total	Predicted Total	Error (%)
No.	Velocity (mm/sec)	Velocity (mm/sec)	
1	2490.79	6728.55	170.137
2	12222.67	12591.75	3.01963
3	2738.74	3776.15	37.8791
4	15296.49	19487.35	27.3975
5	6981.87	2218.2	68.22914
6	12488.73	11592.6	7.175509
7	3878.16	3369	13.12891
8	19234.68	15569	19.05766
9	8259.62	8787.55	6.3917
10	8216.44	7248.75	11.77749
11	6872.71	7840.75	14.0853
12	13850.28	13322.75	3.808804
13	8813.92	8453.2	4.092617
14	8027	8453.2	5.30958
15	8518.2	8453.2	0.763072

Table 4.15: Percentage Error between Simulation and Predicted Results for Total Velocity



Figure 4.23 : Histogram Chart for Simulation and Predicted values for Total Velocity

4.4.3 Optimization Parameters of Total Velocity

Optimization is the process of obtaining the ideal outcome under given circumstances, which may be defined as a function of assessed decision factors, with the goal of either minimising undesirable effects or maximising the intended benefit. In manufacturing, the ultimate objective of optimising turning machining settings is to generate improved outcomes that may be used to produce high-quality products at reduced production costs.

Response surface optimization is a very useful technique for the determination of best cutting parameters in turning operation. In the present work, the goal or target is to maximize the total velocity. RSM optimization results for total velocity parameters are shown in Figure 4.24 and Table 4.16. The optimum machining parameters are found to be cutting speed of 500 m/min, feed rate of 0.50 mm/rev and depth of cut of 1.50 mm. These set of parameters possess the composite desirability of 1.000 and the predicted value of total velocity is equal to 22426.2 mm/sec.



Table 4.16: Response Optimization for Total Velocity Parameters

Optimum Conditions									
Response	Goal	Cutting	Feed Rate	Depth	Lower	Target	Pred.	Composite	
-		Speed	(mm/rev)	ofCut		Ũ	Resp.	Desirability	
		(m/min)		(mm)					
Total	Max.	500	0.5	1.5	2490.79	19234.7	22426.2	1.000	
Velocity									

The percentage optimization for total velocity

= [lowest value – optimized value] / lowest value x 100%

= [2490.79 - 22426.2] / 2490.79 x 100%

= 800.36 %

Equation 4.9

The lowest value of total velocity which is 2490.79 mm/sec was obtained from the Deform 3D Simulation, while the optimized value of total velocity which is 22426.2 mm/sec was obtained from Minitab software. The percentage of optimization for total velocity was calculated by employing Equation 4.9 and the result is 800.36 %. The percentage of optimization indicates that the total velocity has been optimized by 800.36 % with the application of the optimization parameters of total velocity which are the cutting speed of 500 m/min, feed rate of 0.5 mm/rev and depth of cut of 1.5 mm that obtained from Minitab software.

4.5 Analysis Result for Material Removal Rate (MRR)

Table 4.17 showed the value of the material removal rate (MRR) for each run including various parameter combinations. The material removal rate data was derived from two sources: first, MRR formula, and second, a mathematical model constructed using the response surface method and Minitab software.

For the MRR calculation, the total velocity obtained from the Deform 3D simulation software is used with the various feed rate and depth of cut as shown in the Equation 4.10.

Material Removal Rate = 1000 x Total Velocity x Feed Rate x Depth of Cut

Equation 4.10

By replacing the variable in Equation 4.10 with a related simulation input parameter value of feed rate, depth of cut and total velocity, the predicted MRR can be calculated. For instance, the predicted value for MRR for simulation run number 9, with the combination of feed rate, depth of cut and total velocity, of 0.1 mm/rev ,0.5 mm and 8259.62 mm/sec respectively, can be computed as follow :

Material Removal Rate = $1000 \times 8259.62 \times 0.1 \times 0.5$ Material Removal Rate = $412981 \text{ mm}^3/\text{sec}$

Run	Cutting Speed,	Feed Rate,	Depth of Cut,	Total Velocity	MRR
No.	$V_c(m/min)$	f (mm/rev)	a_p (mm)	(mm/sec)	(<i>mm</i> ³ /sec)
1	100	0.3	0.5	2490.79	373618.5
2	500	0.3	0.5	12222.67	1833401
3	100	0.3	1.5	2738.74	1232433
4	500	0.3	1.5	15296.49	6883421
5	100	0.1	1	6981.87	698187
6	500	0.1	1	12488.73	1248873
7	100	0.5	1	3878.16	1939080
8	500	0.5	1	19234.68	9617340
9	300	0.1	0.5	8259.62	412981
10	300	0.1	1.5	8216.44	1232466
11	300	0.5	0.5	6872.71	1718178
12	300	0.5	1.5	13850.28	10387710
13	300	0.3	1	8813.92	2644176
14	300	0.3	1	8027	2408100
15	300	0.3	1	8518.2	2555460

Table 4.17 : MRR for the Simulation Run

Figure 4.25 below presented the line chart of material removal rate (MRR) value for each run. Run no. 1 had the lowest MRR which is only 373618.5 mm^3 /sec while Run no.12 obtained 10387710 mm^3 /sec which is the highest MRR among the 15 runs. From the data of Table 4.17 above, the hypothesis is made, the higher the cutting speed and feed rate, the higher the material removal rate.



Material Removal Rate (mm^3/sec)

Figure 4.25 : MRR against the Simulation Run Number

4.5.1 Analysis of Variance (ANOVA) for Material Removal Rate (MRR)

The computed regression coefficient for material removal rate (MRR) is shown in Table 4.18. Using the R^2 value, the model's efficacy has been determined. In this study, the R^2 value is 0.9872, the adjusted R^2 value is 0.9641, and the predicted R^2 value is 0.7976. The R^2 number is near to 1 and rather high, which is ideal. The closer R^2 is to 1, the more precise the regression model. The R^2 result shows that the turning parameter explains 98.72 % of the variation in material removal rate (MRR) in the present study.

Table 4.18: Estimated Regression Coefficients for MRR (Quadratic)

Term	Coef	SE Coef	T-Value	P-Value	
Constant	2535912	353788	7.17	0.001	Significant
Cutting Speed (A)	1917464	216650	8.85	0.000	Significant
Feed Rate (B)	1924732	216650	8.88	0.000	Significant
Depth of Cut (C)	2508725	216650	11.58	0.000	Significant
Cutting Speed * Cutting Speed (A^2)	-8579	318900	-0.03	0.980	
Feed Rate * Feed Rate (B^2)	53385	318900	0.17	0.874	
Depth of Cut * Depth of Cut (C^2)	848537	318900	2.66	0.045	Significant
Cutting Speed * Feed Rate (AB)	1047801	306389	3.42	0.019	Significant
Cutting Speed * Depth of Cut (AC)	1781893	306389	5.82	0.002	Significant
Feed Rate * Depth of Cut (BC)	1962512	306389	6.41	0.001	Significant
S= 612778 R-sq=98.72% R-sq	(adj)= 96.4	1% R-sq	(pred) = 79.76	5%	

Table 4.18 showed the ANOVA results for a total velocity response surface full quadratic model. P-value is less than 0.05 in Table 4.18, indicating that the model has sufficient significance at a 95% confidence level, which is desirable since it shows that the terms in the model have a significant effect on total velocity. Similary, the main effect of cutting speed (A), feed rate (B), depth of cut (C) and also the square effect of feed rate (CC) are significant model terms. Other model terms are not significant as shown. The 2-way interaction of cutting speed and feed rate, cutting speed and depth of cut, and feed rate and depth of cut have the P-Value of 0.019, 0.002 and 0.001 respectively. In this case, the 2-way interaction of feed rate and depth of cut (BC) had the lowest P-value among others, therefore it can said that it is the most significant.

Source	DF	Adj.SS	Adj.MS	F-	P-Value	
				Value		
Model	9	1.44577E+14	1.60641E+13	42.78	0.000	Significant
Linear	3	1.09400E+14	3.64666E+13	97.12	0.000	Significant
Cutting Speed (A)	1	2.94134E+13	2.94134E+13	78.33	0.000	Significant
Feed Rate (B)	1	2.96367E+13	2.96367E+13	78.93	0.000	Significant
Depth of Cut (C)	1	5.03496E+13	5.03496E+13	134.09	0.000	Significant
Square	3	2.67894E+12	8.92979E+11	2.38	0.186	
Cutting Speed*Cutting Speed	1	271735206	271735206	0.00	0.980	
Feed Rate*Feed Rate	1	10522873399	10522873399	0.03	0.874	
Depth Of Cut*Depth Of Cut	1	2.65852E+12	2.65852E+12	7.08	0.045	Significant
2-Way Interaction	3	3.24979E+13	1.08326E+13	28.85	0.001	Significant
Cutting Speed*Feed Rate	1	4.39155E+12	4.39155E+12	11.70	0.019	Significant
Cutting Speed*Depth Of Cut	1	1.27006E+13	1.27006E+13	33.82	0.002	Significant
Feed Rate*Depth Of Cut	1	1.54058E+13	1.54058E+13	41.03	0.001	Significant
Error	5	1.87749E+12	3.75497E+11			
Lack-of-Fit	3	1.84905E+12	6.16349E+11	43.35	0.023	Significant
Pure Error	2	28439125344	14219562672			
Total	14	1.46454E+14				

Table 4.19: ANOVA analysis of the Full Quadratic Model for MRR

The ANOVA study of the quadratic model for the material removal rate indicated that cutting speed, feed rate, and depth of cut, with corresponding "P-values" of 0.000, had a significant impact on the material removal rate. For the 2-way interaction, feed rate and depth of cut, with a "P-value" of 0.001, was the cutting parameters that had the greatest influence on the output response of material removal rate. This result is in line with the simulation research undertaken to determine the optimal process.

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Table 4.19 showed that the interactions between feed rate and depth of cut contribute significantly to the material removal rate with a "P-Value" of 0.001, which is the lowest value among the three 2-way interaction parameters. However, the interaction between cutting speed and feed rate, and cutting speed and depth of cut with the "P-Value" of 0.019 and 0.002 respectively, hence they are not the most significantly influence the MRR.

The Effects Plots were analysed to identify the factors that impact the chosen response. From the Pareto Chart of the standardize effects for material removal rate, as shown in Figure 4.26, any effects that extend beyond the standardized effect reference line of 2.57 are statistically significant which affected the response. Therefore, in order from the largest to the smallest effect, the main effect of depth of cut (C), feed rate (B), cutting speed and depth of cut (AC), cutting speed and

feed rate (AB) and square effect of depth of cut (CC) are statistically significant at 5% significance level.



The Normal Plot of the standardize effects for total velocity is shown in Figure 4.27. As a result, cutting speed (A), feed rate (B) and depth of cut (C), and the square effect of depth of cut (CC), feed rate and depth of cut (BC), cutting speed and depth of cut (AC), cutting speed and feed rate (AB) are statistically significant at 5% significance level. The normal plot also represents the direction of the effect. Cutting speed (A), feed rate (B), depth of cut (C), cutting speed and feed rate (AB), cutting speed and depth of cut (AC), feed rate and depth of cut (C), cutting speed and feed rate (AB), cutting speed and depth of cut (AC), feed rate and depth of cut (BC) and the square effect of depth of cut (CC) showed the positive standardize effects. The positive effects increase the material removal rate when the setting change from low to the high value of the factor.



Figure 4.27 : Normal Plot of the Standardize Effects for MRR

By using the Contour and Surface Plots in terms of relationship with each process variables, the analysis of the response variable of material removal rate can be explained. Figure 4.28 showed the influence of feed rate and depth of cut on the material removal rate, while the cutting speed kept at the middle level. These 3-dimensional (3D) surface and 2-dimensional (2D) countor plots represent a response surface with a simple maximum pattern. It is discovered that MRR increases with the increase of feed rate and depth of cut. In this case, the higher material removal rate is achieved with the combination of higher feed rate and depth of cut.

The MRR in relation to the feed rate, depth of cut with the cutting speed is held at the middle level is presented in Figure 4.28. From the figure, it has been asserted that increasing both feed rate and depth of cut at the same time resulted in increment of material removal rate. The combination of the high nearly to higher level (~ 0.5 mm/rev) of the feed rate and the higher level (~ 1.50 mm) of depth of cut lead to the higher material removal rate.



4.5.2 Mathematical Model for Material Removal Rate (MRR)

Equation 4.11 presents the mathematical model for the quadratic (or second-order) model for material removal rate in uncoded equation.

MRR = 8840898 - 15961 Cutting Speed - 18660745 Feed Rate - 13004060 Depth Of Cut

- 0.21 Cutting Speed*Cutting Speed + 1334622 Feed Rate*Feed Rate

- + 3394147 Depth Of Cut*Depth Of Cut + 26195 Cutting Speed*Feed Rate
- + 17819 Cutting Speed*Depth Of Cut + 19625119 Feed Rate*Depth Of Cut

Equation 4.11

By replacing the variable in Equation 4.11 with a related experimental input parameter value of cutting speed, feed rate and depth of cut, the predicted MRR can be calculated. For instance, the predicted value for MRR for simulation run number 12, with the combination of cutting speed, feed rate and depth of cut, of 300 m/min, 0.5 mm/rev and 1.5 mm respectively, can be computed as follow :

$$\begin{split} \text{MRR} &= 8840898 - 15961 \ (300) - 18660745 \ (0.5) - 13004060 \ (1.5) \\ &\quad - 0.21 \ (300)(300) + 1334622 \ (0.5)(0.5) \\ &\quad + 3394147 \ (1.5)(1.5) + 26195 \ (300)(0.5) \\ &\quad + 17819 \ (300)(1.5) + 19625119 \ (0.5)(1.5) \\ &= 9834361 \ mm^3/sec \end{split}$$

The predicted values of MRR were compared with the corresponding simulation (formula from Deform 3D) values and the percentage of error is calculated by employing Equation 4.12.

Percentage of error (% error) = $\frac{[MRR_{Simulation} - MRR_{Prediction}]}{MRR_{Simulation}} \times 100\%$ Equation 4.12

The computed percentage error for simulation run of MRR values towards the predicted MRR values is tabulated in Table 4.20. The highest percentage error is from simulation run number 9 and the lowest percentage error is from simulation run number 15 with a percentage of 134.256 % and 0.743382 % respectively. The average error between simulation results and RSM model predicted results of MRR is 47.88872 %. The simulation values of total velocity were found to be very close to the predicted values. Thus, this empirical model is capable to provides reliable predictions. Figure 4.29 shows the histogram chart comparing simulation and predicted values for MRR.

Run	Simulation MRR	Predicted MRR	Error (%)	
No.	(<i>mm</i> ³ / <i>sec</i>)	(mm^3/sec)		
1	373618.5	731665.08	95.8321	
2	1833401	1004065.08	45.23482	
3	1232433	2185334.78	77.3187	
4	6883421	9585334.78	39.2525	
5	698187	213581.38	130.5909	
6	1248873	1527018.62	22.2717	
7	1939080	1540277.5	20.56658	
8	9617340	7472077.5	22.30619	
9	412981	967432.42	134.256	
10	1232466	2059878.32	67.1347	
11	1718178	891867.5	48.09224	
12	10387710	9834361	5.326958	
13	2644176	2536463.18	4.073587	
14	2408100	2536463.18	5.33048	
15	2555460	2536463.18	0.743382	

Table 4.20: Percentage Error between Simulation and Predicted Results for Total Velocity



Figure 4.29 : Histogram Chart for Simulation and Predicted values for MRR

4.4.3 Optimization Parameters of Material Removal Rate

Optimization is the process of obtaining the ideal outcome under given circumstances, which may be defined as a function of assessed decision factors, with the goal of either minimising undesirable effects or maximising the intended benefit. In manufacturing, the ultimate objective of optimising turning machining settings is to generate improved outcomes that may be used to produce high-quality products at reduced production costs.

Response surface optimization is a very useful technique for the determination of best cutting parameters in turning operation. In the present work, the goal or target is to maximize the material removal rate. RSM optimization results for total velocity parameters are shown in Figure 4.30 and Table 4.21. The optimum machining parameters are found to be cutting speed of 500 m/min, feed rate of 0.50 mm/rev and depth of cut of 1.50 mm. These set of parameters possess the composite desirability of 1.000 and the predicted value of material removal rate (MRR) is equal to $14572383 \ mm^3/sec$.



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Table 4.21: Response Optimization for MMR Parameters

Optimum Conditions										
Response	Goal	Cutting Feed Rate Depth Lower Target Pred. Com								
		Speed	(mm/rev)	of Cut			Resp.	Desirability		
		(m/min)		(mm)			_	_		
MRR	Max.	500	0.5	1.5	373619	10387710	14572383	1.000		

The percentage optimization for material removal rate

= [lowest value – optimized value] / lowest value x 100%

Equation 4.13

= [373619 - 14572383] / 373619 x 100%

= 3800.33 %

The lowest value of material removal rate which is 373619 mm³/sec was obtained from the Deform 3D Simulation, while the optimized value of material removal rate which is 14572383 mm³/sec was obtained from Minitab software. The percentage of optimization for material removal rate was calculated by employing Equation 4.13 and the result is 3800.33 %. The percentage of optimization indicates that the material removal rate has been optimized by 3800.33 % with the application of the optimization parameters of material removal rate which are the cutting speed of 500 m/min, feed rate of 0.5 mm/rev and depth of cut of 1.5 mm that obtained from Minitab software.

4.6 Multiple Response Optimization

The primary goal of multiple response optimization is to determine the most optimal variable settings for the process and product while concurrently considering various replies. In this study, the objective of the multiple optimization is to reduce (better) the cutting temperature and effective stress while simultaneously maximising (better) the total velocity and material removal rate in turning AISI 1045 carbon steel. Table 4.22 displays the objective and constraint for the input cutting parameters and output responses.

Input cutting parameter/response	MALAYS Target/Constraints
Cutting Speed	In Range
Feed Rate	In Range
Depth of Cut	In Range
Cutting Temperature	Minimize
Effective Stress	Minimize
Total Velocity	Maximize
Material Removal Rate (MRR)	Maximize

Table 4.22: Target and Constraint for Cutting Parameters and Responses

Figure 4.31 shows RSM multiple response optimization plot for cutting temperature, effective stress, total velocity and material removal rate, while Table 4.23 summarizes the optimization parameters of the multiple responses. The optimum machining parameters for the multiple responses are cutting speed of 500 m/min, feed rate of 0.5 mm/rev and depth of cut of 1.1315 mm. The individual desirability for cutting temperature of 0.24137, effective stress of 0.63805, total velocity of 0.86972 and material removal rate of 0.87886, were

combined yielding overall or composite desirability of a multiresponse system of 0.5857 which is close to 1 denoting the accurrence of an optimal solution. The predicted value of cutting temperature is 1175.77 °C, effective stress is 2009.86 Mpa, total velocity is 17053.3 mm/sec and material removal rate is 9174617 mm³/sec.

 Table 4.23: Multiple Response Optimization for Cutting Temperature, Effective Stress, Total

 Velocity and Material Removal Rate

	Optimum Conditions									
Response	Goal	Cutting	Feed	Depth	Lower	Upper	Target	Pred.	Comp.	
_		Speed	Rate	of Cut			_	Resp.	D.	
		(m/min)	(mm	(mm)						
			/rev)							
Cutting	Min.					1330	691	1175.77	0.24137	
Temp.										
Effective	Min.	500	0.5	1.1315		2750	1590	2009.86	0.63805	
Stress										
Total	Max.				2491		19235	17053.3	0.86972	
Velocity										
MRR	Max.	MALAY	NA .		373619		10387710	9174617	0.87886	



Figure 4.31: Multiple Response Optimization Plot for Cutting Temperature, Effective Stress, Total Velocity and Material Removal Rate

By appling the equations from the previous pages, the percentage of multiple responses optimization were calculated. After multiple responses optimization, cutting temperature reduced from 1330 °C to 1175.77 °C, which is 11.60% of improvement. Effective stress reduced from 2750 Mpa to 2009.86 Mpa, which improve to 26.91%. Total velocity increased from 2491 mm/sec to 17053.3 mm/sec, which is the huge improvement with the percentage of 584.60%. MRR increased from 373619 mm³/sec to 9174617 mm³/sec, which is 2355.61% of improvement. All responses had been optimized with the application of the optimization parameters which are the cutting speed of 500 m/min, feed rate of 0.5 mm/rev and depth of cut of 1.1315 mm that obtained from Minitab software.



CHAPTER 5 CONCLUSION AND RECOMMENDATION

In this chapter, the conclusion of the whole project was based on the 3 objectives, the result and discussion and findings. The result obtained in chapter 4 was used as proof and evidence to support the conclusion. Besides, the recommendation about the project also was provided to improve the study of this project.

5.1 Conclusion

The first objective of this research is to determine the most significant of the cutting parameter such as cutting speed, feed rate, and depth of cut toward response. It is evident that turning process of AISI 1045 steel was influenced by the cutting parameters. By using ANOVA analysis, Pareto chart has showed that cutting speed had the highest standardized effect among the others towards the cutting temperature and total velocity responses. Meanwhile, 2-way interaction of feed rate and depth of cut had the highest standardized effect towards the effective stress responses. Furthermore, for the material removal rate response, depth of cut play the most important role which influenced the response the most. Hence, the most significant of cutting response where the cutting speed is the most parameter which affect the responses.

The second objective is to find interactions of the cutting parameters such as cutting speed, feed rate and depth of cut toward responses. To obtain lower cutting temperature, lower cutting speed and feed rate were applied to the turning process. To obtain lower effective stress on the AISI 1045 steel during turning process, the combination nearly to lower level ($\sim 0.1 \text{ mm/rev}$) of the feed rate and the higher level ($\sim 1.50 \text{ mm}$) of depth of cut must be applied. For the total velocity, it can increase by using the combination nearly to

higher level (~ 500 m/min) of the cutting speed and the higher level (~ 1.50 mm) of depth of cut. The fourth response is material removal rate (MRR), the higher the feed rate (~ 0.5 mm/rev) and the higher the depth of cut (~ 1.50 mm) lead to the higher material removal rate. In addition, in term of interaction of the cutting parameter towards responses, it shows that cutting speed still the parameter which influenced all the responses the most.

The third and last objective is to optimize the responses through single and multiple responses. By applied the single responses optimization, all of the four responses which are cutting temperature, effective stress, total velocity and material removal rate were improved with different combinations of 2-way interaction respectively. After multiple responses optimization, cutting temperature reduced from 1330 °C to 1175.77 °C, which is 11.60% of improvement. Effective stress reduced from 2750 Mpa to 2009.86 Mpa, which improve to 26.91%. Total velocity increased from 2491 mm/sec to 17053.3 mm/sec, which is the huge improvement with the percentage of 584.60%. MRR increased from 373619 mm³/sec to 9174617 mm³/sec, which is 2355.61% of improvement. Therefore, the single and multiple responses optimization process did help to improve the output and result of current work. In conclusion, all the objectives in this project had been achieved successfully.

5.2 Recommendation UNIVERSITI TEKNIKAL MALAYSIA MELAKA

In the end of this project, there are some recommendations are suggested to apply in the future study of the similar project :

- In term of machining or simulation preparation, it may carry out with the wet machining method such as apply of coolant to obtain better outcome of responses. Besides, different types of cutting tools such as stainless steel and high speed steel can be used in this experiment or simulation to obtain different results for the future study.
- In term of process improvement, the measurement of the surface roughness and tool wear after different value of the cutting parameters are apply on the turning process of AISI 1045 steel can be proceed. The surface roughness may examined

by measuring at 3 angle which are 0° , 120° and 240° after different value of cutting parameters are applied. Then, the average surface roughness is calculated to determine which parameters will not cause a lot of roughness on the surface of workpiece. The tool wear of cutting tool may examine after certain times of turning process to determine which parameters damaged the cutting tool the most and how strong the different types of cutting tools are.



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APPENDICES

A Gantt Chart FYP 1

								SEN	AESTE	ER 1	(WE	EK)					
No.	ACTIVITIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	PSM title registration								М								
2.	First briefing of title								I D								
3.	Searching for related journals/ articles																
4.	Chapter 1 Introduction	190							S E								
5.	Chapter 2 Literature Review	Ň	R.Y.A				-		М			-					
6.	Chapter 3 Methodology								ES			1					
7.	Abstract								ТЕ	4							
8.	Table of Content	0	4	/	R	- <	~	2	R			نيە	91				
9.	References								9.		v	- 10 m					
10.	Log book submission	TE	ΕK.	MI	(A	L 1	AΛ	LA	YSI/	A A	IEL	Ak	A				
11.	Poster Presentation								R E								
12	EVD 1 Papart Submission								A								
12.	1°11 1 Report Submission								K								

Plan
Actual

B Gantt Chart FYP 2

		SEMESTER 2 (WEEK)															
No.	ACTIVITIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.	Review PSM 1 report								М								
2.	Simulation preparation								I								
2	D 1 1 1																
3.	workpiece and tool.									-							
4.	Start turning simulation									-							
									S								
5.	Collect data from simulation								Ш								
									7								
6.	Compare the result from								Λ								
	experimental								Π								
7.	Determine the most significant of the cutting								S								
	parameter	8							Т								
8.	Find the interaction of the	Ň	F														
	cutting parameter		2						Ш			1					
0	Ontimize the response		-						R								
9.	Opumize the response									7							
	" Alter				-				-								
10.	Complete FYP 2 report		-														
	4 Maluel		4		5.	<		1.1	в								
11.	Log book submission 2	6	7					-	S	-	5	7	2				
									~								
12.	Video Presentation 2	ΓE	KV	IK	AL	M	AL	A۱.	'ন্দা/	A N	IEL	AM.	A				
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13.	FYP 2 Report Submission																
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Plan
Actual

Cutting Temperature Simulation С

























Run 13

Run 14



D Effective Stress Simulation















Run 8



Run 9



Run 10



Run 13

Run 14



E Total Velocity Simulation









Run 8

102











Run 13

Run 14

