OPTIMIZATION OF TOOL PATH PARAMETER FOR MACHINING OF FREE FORM SURFACE PROFILE OF PRE HARDEN STEEL

SITI AISHAH BINTI ARMAN

B.ENG. (Hons.)MANUFACTURING ENGINEERING

UNIVERSITY MALAYSIA PAHANG

SPLINE

SITI AISHAH ARMAN

BACHELOR OF MANUFACTURING ENGINEERING

2016

UMP

THESIS STATUS VALIDATION FORM

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's full name	: SITI AISHAH BINTI ARMAN
Identification Card No	: 930322-14-6098
Title	: OPTIMIZATION OF TOOL PATH PARAMETER FOR MACHINING OF FREE FORM SURFACE PROFILE OF PRE HARDEN STEEL
Academic Session	: 2015/2016

I declare that this thesis is classified as:

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
☐	**RESTRICTED**	(Contains restricted information as specified by the organisation where research was done)*
☑	**OPEN ACCESS**	I agree that my thesis to be published as online open access (Full text)

I acknowledge that Universiti Malaysia Pahang reserve the right as follows:

1. The Thesis is the Property of Universiti Malaysia Pahang.
2. The Library of Universiti Malaysia Pahang has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified By:

_________________________	_________________________
(Author's Signature)	(Supervisor's Signature)
SITI AISHAH BINTI ARMAN	DR. ZAMZURI BIN HAMEDON
Date:	Date:

OPTIMIZATION OF TOOL PATH PARAMETER FOR MACHINING OF FREE FORM SURFACE PROFILE OF PRE HARDEN STEEL

SITI AISHAH BINTI ARMAN

Report submitted in partial fulfillment of the requirement for the award of the Bachelor of Degree in Manufacturing Engineering

B. Eng.(Hons.) Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2016

SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project and in my opinion this project report is sufficient in terms of scope and quality for the award of Bachelor of Degree in Manufacturing Engineering.

Signature :
Name of supervisor : DR. ZAMZURI BIN HAMEDON
Position : SENIOR LECTURER
Date :

EXAMINER'S DECLARATION

I certify that the project of "Optimization of Tool Path Parameter for Machining of Free Form Surface Profile for Pre Harden Steel" is written by Siti Aishah Binti Arman and in our opinions; it is fully adequate in terms of scope and quality for award of the degree of Bachelor of Manufacturing Engineering. I here recommend that it be accepted in partial fulfilment of requirements for the degree of Bachelor of Manufacturing Engineering.

Signature	:
Name of examiner	: DR. MUHAMMED NAFIS BIN OSMAN ZAHID
Position	: SENIOR LECTURER
Date	:

STUDENT'S DECLARATION

I hereby declare that this report entitled "Optimization of Tool Path Parameter for Machining of Free Form Surface Profile for Pre Harden Steel" is result of my own except as cited in references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :
Name : SITI AISHAH BINTI ARMAN
ID Number : FA12011
Date :

MY HUMBLE EFFORT I DEDICATE TO MY LOVING
FATHER AND MOTHER

WHOSE AFFECTION AND ENCOURAGEMENT MAKE ME ABLE TO GET SUCH SUCCESS

ALONG WITH ALL HARDWORKING AND RESPECTED SUPERVISOR AND FRIENDS

ACKNOWLEDGEMENT

First of all, I am grateful to Allah, the Al Mighty God for giving me strength and motivation from everywhere to complete my research in the given time successfully. I wish to express my sincere gratitude to my supervisor, Dr Zamzuri Bin Hamedon for his guidance and motivation while conducting this research. He always willing to answer regarding the theoretical of experiment and he helps me a lot to conduct the laboratory apparatus to get the accurate results. I am proud to have him as my Final Year Project's supervisor.

Secondly, I would like to thanks to the Postgraduate Students of University Malaysia Pahang, lab's staff, friends and colleagues that guides me very well during conducting the machine, laboratory apparatus and the analysis software.

Lastly, I acknowledge to my caring and loving parents for their praised and support in love, motivation and expenses during my study in the University of Malaysia Pahang.

ABSTRACT

This project deal with the optimization of machining parameter of the free form design of pre harden steel along with the tool path strategy that classified as the hard-to-cut material. In this project, there are 2 main scope, they are tool path strategy that could machine the product to the uniformity result of the best surface roughness and low tool wear effect. The optimization machining parameter that need to be set up by specific analysis software. The tool path strategy generated in CAD CAM system in Catia software need to be study to produce the quality of product at the end of experiment and could improve the cutting tool life. In the other hand, research on the machining parameter in term of Feed Rate, Depth of Cut and Width of Cut need to be developed to find the most optimize parameter that will produce best surface finish and tool wear rate. Thus in the optimization of machining parameter, Taguchi method with 2 level and 3 factor of L_4 orthogonal array experimental set up is very important as the guide to conduct the experiment, while the mathematical ANOVA lead to the answer of the most significant factor of machining parameter that effect in each of the output of experiment in term of Ra, Rz, Pt and TW.

ABSTRAK

Projek ini membentangkan pengoptimuman parameter mesin untuk reka bentuk bebas bagi keluli pra keras dengan arah strategi alat yang diklasifikasikan sebagai bahan susah untuk dipotong. Di dalam projek ini, ada dua skop penting yang utama, iaitu arah strategi alat yang boleh memesinkan produk ke arah keseragaman keputusan yang paling terbaik untuk keadaan permukaan dan kesan terendah bagi kehausan alat. Pengoptimuman parameter mesin yang perlu di atur memerlukan analisis perisian tertentu. Arah strategi alat yang dijana di dalam sistem CAD CAM di perisian Catia perlu dikaji untuk menghasilkan produk yang berkualiti di akhir eksperimen dan boleh menambahbaik jangka hayat alat pemotong. Selain itu, kajian mengenai parameter mesin di dalam bentuk Kelajuan Pemotongan, Kedalaman Memotong dan Kelebaran Memotong perlu dikembangkan untuk mencari mesin parameter paling optimum yang akan menghasil keputusan kekemasan permukaan yang terbaik dan kesan kehausan alat yang rendah. Oleh itu di dalam pengoptimuman mesin parameter, kaedah Taguchi dengan 2 tahap dan 3 faktor iaitu aturan L_4 ortogon pelbagai eksperimen amat penting sebagai bimbingan untuk menjalankan eksperimen sementara matematik ANOVA menjurus ke arah perjawaban kesan yang paling ketara bagi parameter mesin yang mempengaruhi setiap daripada hasil eksperimen dalam bentuk Ra, Rz, Pt dan TW.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

V_c	Speed of cutting surface
ΔA	Reduction in area
A	Area of contact
ρ	Density of material
Q	Removal rate
τ	Strength of shear
Ra	Average surface roughness
Rz	Maximum surface roughness
Pt	Profile
f_z	Feed rate
a_p	Depth of cut
a_e	Width of cut
S_R	Surface roughness
T_w	Tool wear
TW	Tool wear rate

LIST OF ABREVIATION

HSM	High Speed Machine
TiC	Titanium Carbide
TiN	Titanium Nitride
ANOVA	Analysis of Varience
S/N	Signal to noise
HRC	Rockwell C Hardness
CBN	Cubic Boron Nitride
PCD	Polycrystalline Diamond Coating
PVD	Physical Vapour Deposition
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
AISI	American Iron and Steel Institute
T_L	Tool Life
SPC	Space-Filling-Curve

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE PROJECT

Recently, development of machine tool and cutting tool compatible with the manufacturing process that improved quality of product, produced the better surface finish than conventional machine and more significantly function for the hard-to-cut material machine process. The technology of the advance machining of supercritical speed increase it tool life due to minimum cutting force exerted between the cutting tool and the workpiece. Commonly the cutting tool suitable for the finishing process for the hard-to-cut material is end ball mill of coated carbide TiAlN.

In the other hand, the free form surface with waviness surface texture is one of high speed milling process with ball end nose of cutting tool. Free form surface has been applied in industry such as manufacturing of structural body for automobile and aeronautics due to it feature that lead to the optimized of airflow and ergonomics. In some cases, some of parameter of machine and tool path strategy need to be optimized to produce the smooth of free form surface.

Due to the optimization methodology, setting parameter by using Taguchi in the Minitab software could reduce number of experiment with the robust design and ANOVA will shows the parameter that give the most significant effect to the machining process.

Pre harden steel is one of the difficult-to-cut material. [J.-Y. Chen et al, 2010]. The pre harden steel selected in this project is AISI P20 steel with hardness of 45 HRC that perform in wear.

1.2 PROBLEM STATEMENT

The machining parameter is hardly to optimize for machining the free form surface profile with material of pre harden steel due to the limitation of tool path strategies and hardness of the pre harden steel.

1.3 PROJECT OBJECTIVES

1. To apply different tool path strategies of finishing process that lead to the best result of surface roughness in term of average surface roughness, Ra, maximum surface roughness, Rz and Profile, Pt and tool wear, TW

2. To optimize the machining parameter in term of feed rate, depth of cut and width of cut while machining the free form surface of the pre harden steel.

3. To obtain the result of surface roughness and tool wear rate of pre harden steel and cutting tool that lead to the best optimization of machining parameter by using Taguchi and ANOVA method.

1.4 PROJECT SCOPE

1. **CAD CAM System**

   The design, tool path strategies and parameters of machining create and computed in CAD CAM system to be transmit in the CNC milling machine system. Tool path strategies applied are zig-zag in sweeping and contour-driven process

2. **Optimized machining parameter**

   Machining parameter that based on the optimization results are depth of cut, feed rate and width of cut set up in the Taguchi design of L_4 orthogonal array in Minitab Software. Depth of cut selected are 0.3 mm and 0.4 mm, for the feed rate are 300 mm/min and 400 mm/min, while for the width of cut are 0.1 mm and 0.2 mm.

3. **Pre Harden Steel**

   The material selected in this project is AISI P20 of pre harden steel with hardness of 45 HRC after being tested under Rockwell Hardness Tester.

CHAPTER 2

LITERATURE REVIEW

2.1 CNC Milling Machine

2.1.1 Definition of CNC Milling Machine

Recently, CNC milling machine become one of the compatible manufacturing process in the industries due to the high precision of component and quality of product because while removing the rough stock of the product, efficiency is the most important process that lead to the next finishing process .(Raksiri, 2004, Vickers, 1993)

CNC milling functioning as to remove part at significant amount of material and to increase the machine productivity. (El Hofy, 2014; Derzija, 2014). As to reduce the manufacturing cost and obtain the good surface finish of the products, cutting parameter is the most important part to be optimize. (Wassila Bouzid, 2005)

Machining of a curved and free form design must through the finishing process of machining. The purpose of the finishing process is to define the expected of quality part shape. (Vickers, 1993)

2.1.2 Characteristics of CNC Milling Machine

The formulation for optimal machining process of sculptured and free form design is by improving the machining productivity in term of machining parameter and lowering the manufacturing cost in term of tool life. (Wasilla Bouzid, 2005; Vickers, 1993)

Finishing operation such as grinding, super finishing and grinding will costly at the expensive rate and consume so much time, but the development of machine tools design and present of advance cutting tool such as cubic boron nitride [CBN] and polycrystalline diamond coating [PCD] will improve the machine efficiency. (S. Ekinović, 2007)

Characterisation of milling machine mainly effect the tool wear that cause by chemical action, abrasion, corrosion etc. Thus it recommended to select the stable tool material to minimize the tool wear and to improve the productivity, the suitable cutting tool material need to be selected as the paramount of machining. (El Hofy, 2014; Y.C Shin, 2004).

2.1.3 Advantages of CNC Milling Machine

The advantages of CNC machine are better result of surface finish. In experimental conducted by S.Ekinović et. Al to compute the removal rate,Q and feed rate towards surface roughness, R_a of the steel material, they found that increasing in feed rate value will decrease the surface quality. In the other hand, instead of conducting in automated way, usage of computer-aided design [CAD] or computer-aided manufacturing [CAM] to design is faster compare to other software. (El Hofy, 2014)

2.1.4 Limitation of CNC Milling Machine

The limitation of CNC milling machine are cutting speed is limited by the tool wear during machining of difficult-to-cut materials such as titanium, hardened tool steel and others. (C.L Pu et. Al, 2015).

Besides that, knowledge and programming equipment regarding the specific process are important because it need to define the HSM process. There are several activities need to be conducted, they are define the Computer-Aided Design (CAD) model, transferring CAD model data to the Computer-Aided Manufacturing activities (El Hofy, 2014; S. Lavernhe, 2008).

2.2 Flood Lubrication

According to Pierre (2013), lubrication or coolant are very important in the machining process because of:

- it's could reduce tool wear
- it's help removing chip while machining
- it's cool the workpiece and cutting tool while machining
- it's lubricate the contact surface between the tool, chip and workpiece

2.3 Advance Cutting Tool Materials

Appropriate choosing the cutting tool material is very important as to meet the chemical and physical composition of the workpiece and machine tool capabilities. Machine tool and cutting device must balance each other to gain the productivity, finished part and toward economical use. (Erdel, 2003). Moreover to limit the manufacturing cost, to produce the good surface finish and to improve the efficiency of machine, it advisable to use the advanced cutting tool materials. (Wassila Bouzid, 2005; S. Ekinović, 2007).

2.3.1 Carbides

According to Erdel (2013), the advantages of carbide is the properties of tool that provided toughness, high impact strength and high resistance to thermal shock. The experimental conducted by the J Matter Sci, 2012 and Xiaoxiao Chen et al, 2012 on the P20 steel workpiece have used the coated, cemented carbide end ball mill of cutting tool

2.3.2 Coating

Carbide coated insert offer prolonged tool life, economical and tailored to specific machining parameter. (Erdel, 2003). The experimental conducted by the Mativenga, P. T to machine the AISI H13 steel with used of physical vapour deposition of Titanium Nitride, PVD TiN coated with carbide.

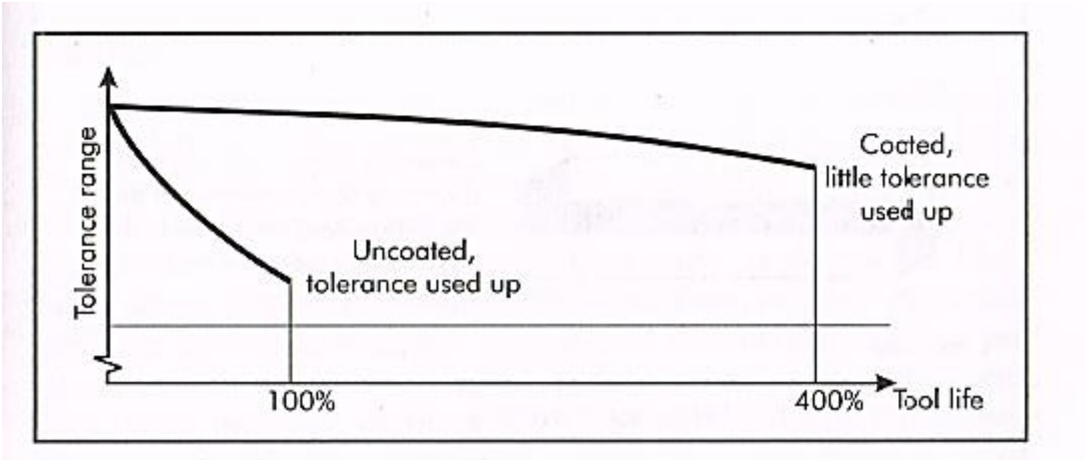


Figure 2.1: Coating VS tool life

Source: Erdel, 2003

Based on Figure 2.1 shows that the coated cutting tool provided longer tool life span compare to the uncoated cutting tool. This is due to the coated of cutting tool provided high strength from wear and corrosion compare to the uncoated tool.

2.4 Tool Wear

In machining process the limiting factor is the tool wear effect that occurred in combination of mechanism effect such as abrasion, adhesion and corrosion. (P.T Mativenga, 2005).

Tool wear depend on the cutting tool and the workpiece materials and process parameters such cutting speed, depth of cut and feed rate. (A. Attanasio et al, 2013). Factor that subjected to the tool wear are high localized stress at the cutting tool tip, high temperatures along the rake face and sliding of the cutting tool along the newly cut workpiece. (Schmid, 2010). Tool wear is due to the simultaneous combination of several wear mechanism such as abrasion, adhesion and corrosion (A. Attanasio et al, 2013).

According to H. Çalışkan, wear mechanism can be categorised as :

Wear Mechanism	Explanation
Abrasion	this type of wear cause by hard and rough surface take place between the sliding surfaces contact or between a hard, abrasive particle contact of solid body.
Adhesion	this type of wear also called as the sliding wear is when tangential force applied on the material caused the shearing take place on it.
Corrosion	also called as oxidation wear caused by chemical and electrochemical reaction between the surface and environment.

Table 2.1: Wear Mechanism

As an addition according to H. Çalışkan, type of wear occurred in form of :

Type of Wear	**Explanation**
Flank wear	occur at relief face of tool cause by rubbing of tool along workpiece (abrasion) and high temperature effect
Crater wear	high tool-chip interface temperature and chemical affinity between workpiece and cutting tool. The factor influencing flank wear may affect crater wear.

Table 2.2: Type of Wear

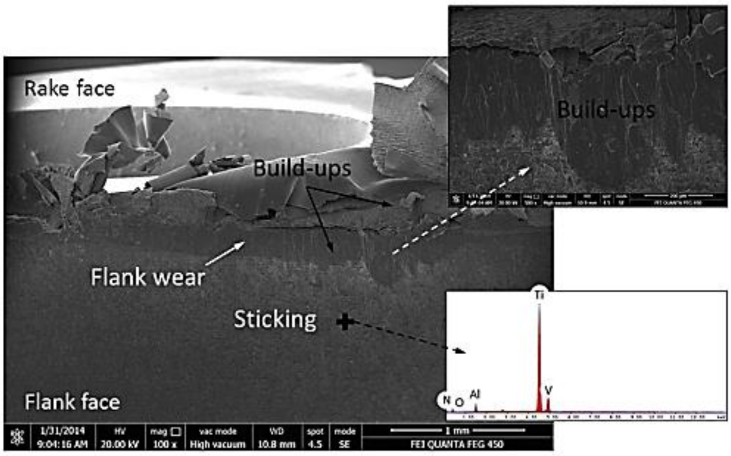


Figure 2.2 : SEM image of worn cutting tool

Source: H. Çalışkan,2015

Based on Figure 2.2 shows that image of worn cutting tool of the flank wear resulted by the rough rubbing of cutting tool and workpiece that cause the built-up edge.

2.5 Surface texture

Surface texture define as the quality of workpiece surface due to several characteristics of it, they are roughness, waviness and lay as shows in Figure 2.3. (Erdel, 2003). In the other hand, surface texture is one of criteria to determine the machinability process for product material. (C.K Toh, 2004).

Referring to the experimental conducted entitle " High Speed Turn-Milling versus Conventional Turning of Steel" resulted, good surface quality for the high speed turn milling on machined surface is better compare to the conventional turning of steel. (S. Ekinović, 2007). The parameters that will effected the surface texture are material of the product, cutting tool, machining periphery and CAD/CAM. (Erdel, 2003).

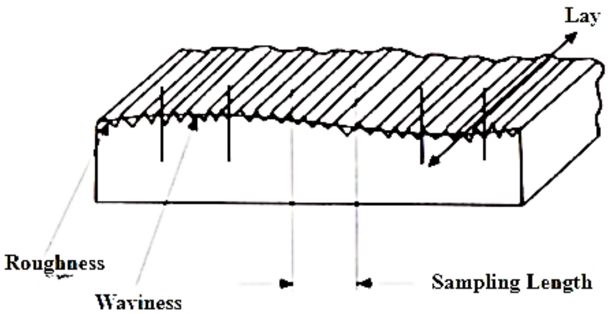


Figure 2.3: Surface texture

Source: Erdel, 2003

Roughness surface cause by the irregular process such as high feed rate will cause the rough surface. (Erdel,2003; S. Ekinović et. al, 2007). Secondly, the surface texture of the waviness surface cause by irregularities greater than sampling length such as run out. Lastly for the surface texture of lay surface cause by the surface pattern produced by the machining method such as turning.

2.5.1 Free form surface profile

The surface of free form texture categorized as the smooth shape and texture such as valley and mount (Kumazawa et al, 2015). In I.Lazonglu,2009 experiment, he applied zig-zag direction of tool path strategy for machining simulation for free form surface design as shown in Figure 2.4.

According to T.Chen (2002), to avoid the local gouging that may occurred on the free form surface, two approached suggested. Firstly, used the small radius of cutting tool that smaller than radius of workpiece curvature. Secondly, implemented the larger diameter of cutting tool and skip the region of tool interference.

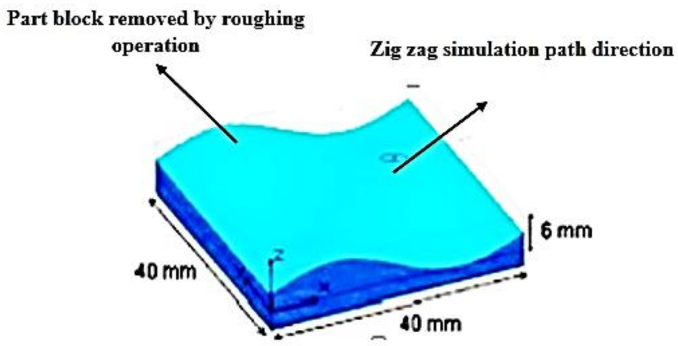


Figure 2.4: Free form surface design

Source: I.Lazonglu, 2009

2.5.2 Tool Path Strategy

The process of free form surface divided into two categories, they are design and machine activities. In design phase, some designer used CAD system to build their own product. (Duc, 1999). For geometric representation product, CAD CAM system will calculate the tool path based on planning progress that will involve machine tool, cutting tool, cutting tool geometry, machining parameter etc.

In Figure 2.5 shows the process of free form surface in machine activities. Started from the geometrical model of free form surface, it then divided into three main activities such as tool path calculation, tool path motion via NC and milling process. (Duc, 1999)

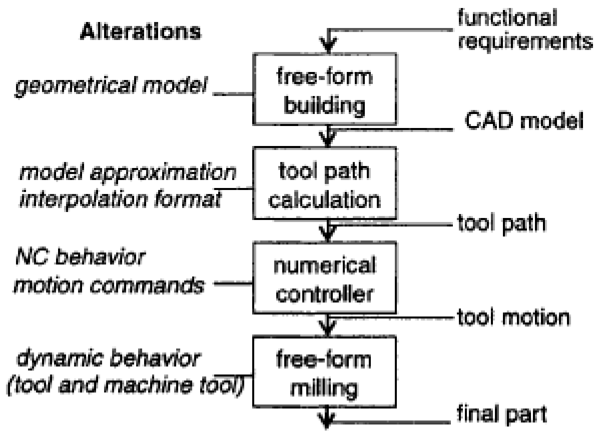


Figure 2.5: Process of free form surface

Source: Duc, 1999

One of the most critical issues in process planning of CAM system is selection of suitable tool path strategy for machining the free form surface. (I. Lazonglu, 2009). Adequate choice of tool path milling can improve production cost and surface roughness. (Adriano, 2014). As the a lot field industry required the sculptured surfaces for their geometric design of the product, the tool path optimization and calculation of machining time closer is chosen according to best cutting strategy for the CAM system possible. (Monaro et al, 2013).

In free form surface, there are three major type of tool path topologies, they are contour parallel type, direct parallel type and space-filling curve. Among three tool path topologies, the direction tool path parallel and contour parallel path widely used in industry as shown in Figure 2.6 (Z. Lin, 2015).

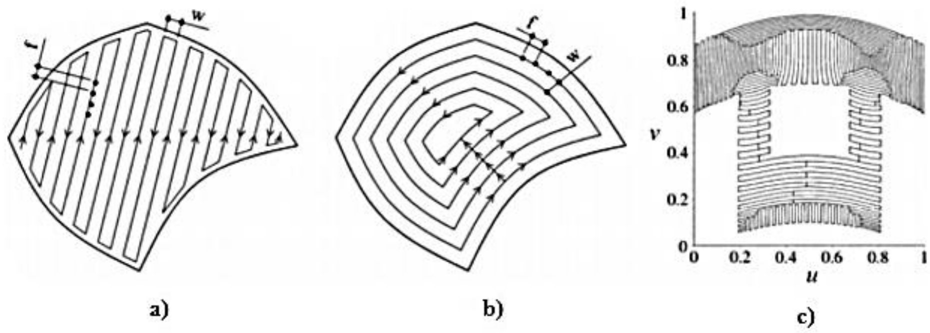
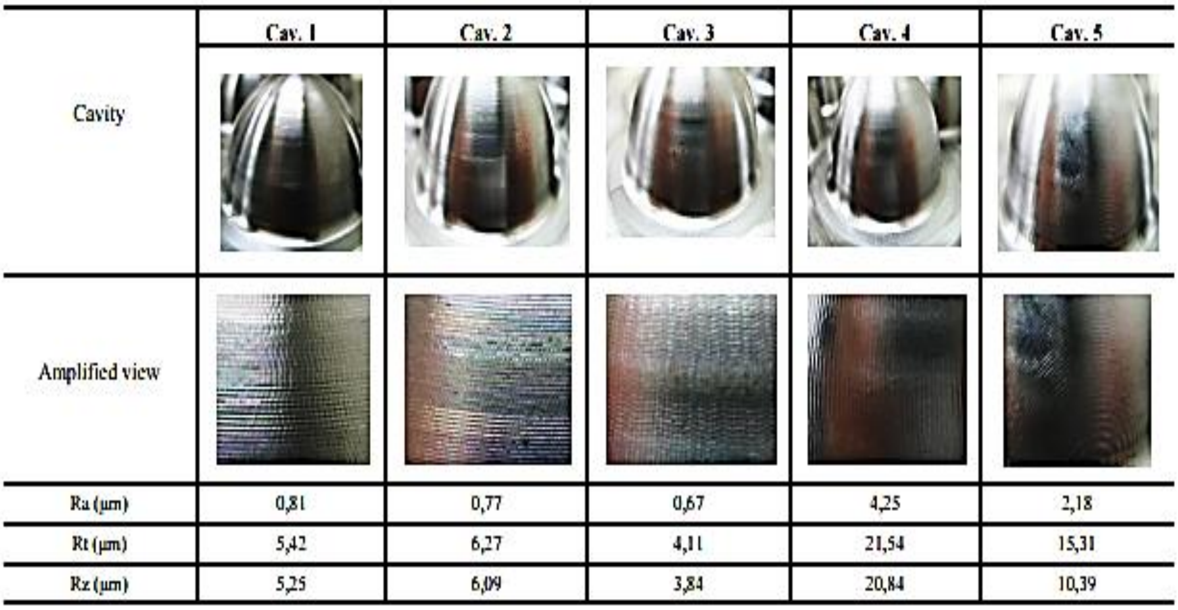


Figure 2.6: Free form surface topologies for finishing operation.

a) Directional parallel. b) Contour-parallel. c) Space-filling curve.

Source: Z. Lin, 2015

In Adriano (2014) experimental used six types tool path strategies, they are zigzag, contour curve, spiral curve, space filling curve, sequential generated curve and radial curve. He used the AISI P20 steel of 30 HRC hardness is used as the workpiece machine by 3 axis high speed milling, down cutting without coolant. The cutting tool used is a carbide ball end mill coated with titanium aluminium nitride with 6 mm diameter. The roughness of surface is measured using Taylor Hobson surface roughness.



	Cav. 1	Cav. 2	Cav. 3	Cav. 4	Cav. 5
Cavity					
Amplified view					
Ra (μm)	0,81	0,77	0,67	4,25	2,18
Rt (μm)	5,42	6,27	4,11	21,54	15,31
Rz (μm)	5,25	6,09	3,84	20,84	10,39

Table 2.3: The cavity part and result of surface roughness

Source: Adriano, 2014

Referring to Table 2.3, cavity 1 is the contour path, the tool path in a 3D offset started from the floor with step over 0.15mm. For cavity 2 is spiral curve which move in spiral path which started from top to the floor with step over 0.14 mm. As for cavity 3 is for radial curve that tool path start from the floor to the top with step over 0.81 degree. In the other hand, cavity 4 is the radial curve of tool path start from the top to the floor with step over 0.81 degree. For the cavity 5 is for zig zag curve that move one way tool path with step over 0.135mm. As the result, cavity 3 with the radial curve tool path is the best tool path strategy for the cavity design based on the smallest and smooth surface roughness in term of Ra, Rz and Rt.

2.5.3 Application of free form surface

Free form surface widely used in the field of dies product of automobile and aeronautics industry for their characteristics of aero-fluid dynamic efficiency. (S. Lavernhe, 2008; I. Lazoglu, 2009). In the other hand, medical care industries such as surgical prostheses and electronics industries also have been applied the free form surface that give desirable ergonomics shape to the users. (Monaro et al, 2013).

2.5.4 Advantages of Free Form Surface

Free form surface give aero-fluid dynamics efficiency, ergonomic and aesthetics design that beneficially in aerospace, automotive, biomedical and die-mold industries. (I. Lazonglu, 2009; Monaro et al, 2013; Kumazawa et al, 2015)

2.5.5 Disadvantages of Free Form Surface

The ordinary tool path strategy such as zigzag, concentric and radial cannot be simply optimum to machine the free form surface. (I. Lazonglu, 2009). The user must have the knowledge regarding the tool path strategies offer by the CAM software to process the free form surface. (Adriano, 2014).

2.6 Design of Experiment (DOE)

Statistical analysis was carried out by parameter setting of Taguchi and analysis of variance [ANOVA]. Taguchi method is to find the optimum process parameter and ANOVA is to study the performance of parameter characteristics. (Gopalsamy, 2009)

2.6.1 Introduction to Taguchi Method

Taguchi has developed a methodology for the application of factorial designed experiments from statistical world and brought it into the manufacturing industry. (Gopalsamy, 2009)

In year 1970's, various of optimization approaches have been practiced to produced good quality of product, but Fong and Cheng (2006) have practiced Taguchi experiments to optimize the parameter process in turning for steel tools that include cutting speed, feed rate, depth of cut etc. that resulted to the maximum in accuracy and low of surface roughness and accurate in dimension. (Pawade, 2011)

2.6.2 Taguchi Concept

In Taguchi robust design method, process variables are classified into control, noise and signal factor. Control factor are those parameters of the system that specify by nominal values and for maintaining cost effectively. For noise factor is the cause variability in term of practical or leading to performance deterioration. Signal factor is sent into the system in response to the intent user. (Y.-F Tzeng, 2003)

P-diagram is must for every development project to define the development scope. Firstly, we must identify the signal (input) of process and response (output) of process. Next, consider the parameter or factor beyond the control of designer. Those factor are called noise factor. Later on, determine the factor that can specify the designer that called control factor. (Madhav,2015)

The effect of many different parameters on the performance characteristic in a condensed set of experiments can be examined by using the orthogonal array experimental design proposed by Taguchi. (Fraley et al, 2007). Table 2.4 shows example of L_4 orthogonal array. That shows 4 number of experiment with 3 levels. In the column of experiment is the number of experimental that will be conducted. In the table, it shows that there will 4 times of experiment will be conducted. The P symbol is mean by parameter. In the table, it shows that, in each level of experiment, there will be 3 parameter conducted denoted by symbol of P1, P2 and P3.

Experiment	**P1**	**P2**	**P3**
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	2

Table 2.4 : L_4 orthogonal array

Source: http://reliawiki.org/index.php/Taguchi_Orthogonal_Arrays

2.6.3 Taguchi Method

In the experimental conducted by Gopalsamy (2009) about " An approach for process parameters optimization of hard machining while machined hardened steel", The hardness of material used for Gopalsamy's experiment is 55 HRC. Taguchi has been used to study the effect of four input machining parameters that are cutting speed, depth of cut, feed rate and width of cut with two output that are surface roughness and tool life.

Table 2.5 shows the shows the four cutting parameters and three levels. As the result, S/N ratio is calculated for the output process for surface finish, tool wear and tool life as shown in Table 2.6.

Machining Parameter	Level 1	Level 2	Level 3
Cutting speed, m/min	100	150	204
Feed, mm/tooth	0.05	0.1	0.2
Depth of cut, mm	0.05	0.1	0.2
Width of cut, mm	0.1	0.2	0.4

Table 2.5: Machining parameters and levels

Source: Gopalsamy, 2009

Exp. No.	Surface finish, μm			Tool wear, μm			Tool life, m			Calculated S/N ratio for surface finish	Calculated S/N ratio for tool life (length of cut)
	R1	R2	R3	R1	R2	R3	R1	R2	R3		
1	0.90	0.92	0.95	110	110	105	290.20	280.00	270.03	0.6906794	48.9342726
2	0.80	0.85	0.86	120	110	100	420.00	410.03	400.10	1.54467883	52.251479
3	0.91	0.92	0.94	90	90	110	310.10	290.20	305.03	0.69203737	49.5833072
4	0.90	0.90	0.92	105	100	110	250.08	250.25	252.00	0.85057743	47.985587
5	0.92	0.93	0.70	110	95	85	300.13	310.30	302.10	1.34442021	49.6598181
6	0.80	0.70	0.90	100	90	110	448.00	409.50	406.35	1.89319525	52.4662054
7	0.61	0.62	0.70	110	95	95	437.50	446.25	439.25	3.81428972	52.8878208
8	0.41	0.42	0.43	90	85	110	910.00	918.75	915.25	7.53337318	59.2250554
9	0.85	0.90	0.75	95	100	100	782.25	784.00	780.50	1.55937227	57.866868
10	0.91	0.82	0.92	100	110	110	250.10	252.00	249.40	1.0662667	47.9759048
11	0.95	0.82	0.92	95	90	95	320.10	321.12	322.00	0.93072653	50.1320085
12	0.81	0.79	0.75	110	120	105	420.00	427.00	418.25	2.11666619	52.5000624
13	0.95	0.96	0.85	100	125	90	300.13	320.25	315.00	0.7116052	49.8674166
14	0.90	0.95	0.96	105	100	120	450.10	410.40	470.10	0.56488996	52.8964745
15	0.76	0.82	0.85	100	100	105	822.15	830.03	841.05	1.82104243	58.3916911
16	0.61	0.55	0.50	105	100	105	420.00	410.03	405.13	5.11167366	52.2891193
17	0.85	0.81	0.83	110	105	110	800.10	791.35	780.15	1.61675736	57.9570109
18	0.52	0.51	0.49	90	95	100	890.05	885.15	900.03	5.9029225	59.0041716

Table 2.6: Experimental result of tool wear, tool life and surface finish.

Source: Gopalsamy, 2009

S/N analysis and mean response provide the optimization of process. (Prosenjit, et al, 2014) S/N characteristics formulated for three different characteristics in equation (1), (2) and (3) :

Nominal the better characteristics : S/N = - 10 log ($\tilde{y}$ $/s^2y$) (1)

Lower the better characteristics : -10 log (1/n) ($\sum(y^2$) (2)

Larger is the better characteristics : -10 log (1/n) ($\sum(1/y^2$) (3)

Where $\tilde{y}$ is average observed data, s^2y is the varience and y is number of observation. (Gopalsamy, 2009)

In Gopalsamy experimental, surface roughness is the lower the better performance calculated using equation 2, while tool life is larger is the better performance calculated using equation 3.

2.6.4 Advantages of Taguchi Method

1. Improve product quality

Taguchi is the significant method approaches for optimization process and product development because of it well performance, good quality of result and cost. (Zheng et al, 2002; Gopalsamy, 2009).

2. Benefit in field of manufacturing

Taguchi performed in the manufacturing system related to the environmental, wear and machine. (A. Gupta, 2011)

2.6.5 Disadvantages of Taguchi Method

Orthogonal arrays do not test all variable combinations

Taguchi also has its own limitation which is the model system applied in the Taguchi is for the single response optimization for a single performance that effected the time and cost of process. (A. Gupta, 2011)

2.6.6 Analysis of Varience (ANOVA)

Taguchi method cannot determine the individual parameter on the entire process thus ANOVA mathematical is used investigate the parameter process. (Gopalsamy,2009). In Gopalsamy experimental is to evaluate the most optimization parameter in each level after the Taguchi method, resulted the ANOVA calculation as shown in Table 2.7.

Parameter	D.F.	Sum of Sq.	Mean Sq.	F-ratio	P-value
Surface finish					
Vc	2	37.7218	18.8609	15.47	0.00122393
fz	2	0.271912	0.135956	0.111513	0.895696
ap	2	8.53883	4.26941	3.50184	0.0750072
ae	2	12.0485	6.02423	4.94116	0.0356321
Error	9	10.9727	1.21919		
Total	17	69.5537			
Tool life					
Vc	2	128.477	64.2385	14.3520	0.00158615
fz	2	80.1955	40.0978	8.95857	0.00722706
ap	2	4.20294	2.10147	0.469506	0.639804
ae	2	8.12919	4.06459	0.908104	0.437274
Error	9	40.2832	4.47591		
Total	17	261.288			

Vc, cutting speed; *fz*, feed; *ap*, depth of cut; and *ae*, width of cut

Table 2.7: ANOVA result for S/N ratio for surface finish and tool life

Source: Gopalsamy, 2009

Parameter	Level 1	Level 2	Level 3
Cutting speed	1.17351	1.19762	4.2564*
Feed	2.04085	2.25581	2.33087*
Depth of cut	1.24486	2.57243	2.81024*
Width of cut	2.29945	3.16300*	1.16508

All cell mean = 2.20918; *Optimized level of parameters

Table 2.8: Cell mean of parameter for surface finish in ANOVA

Source: Gopalsamy et al, 2009

Based on the Table 2.8, resulted the highest cutting speed, feed rate, depth of cut and width of cut will produce low surface roughness.

In optimization result of Gopalsamy, (2009) of ANOVA , the cutting speed on the Level 3 form the best surface finish due to the optimize value confirm by ANOVA. Same as the feed rate and depth of cut at Level 3 they resulted the optimize result of machine parameter for best surface roughness, while width of cut on Level 2 resulted optimize machining parameter in this experiment.

2.7 Pre Hardened Steel of P20

The demand for pre hardened steel has greatly increased because they are more practical and greater economic efficiency compare to post-rough machining of hardened steel. One of the pre hardened steel widely used in industry is P20 steel. (J Mater Sci, 2012).

The P20 steel is a low carbon steel containing chromium and molybdenum alloying element that performed in wear and corrosion resistant because it has through the proper heat treatment. (Chen et al, 2010; J Mater Sci, 2012**).**

The machinability test were performed on the P20 steel by J Mater Sci (2012) with three axis CNC end milling by using cemented coated carbide tools as to study the relationship between the cutting force with the work hardening. Moreover it also recorded that machined process of hardened P20 with hardness of 41 HRC at relative high speed of 301-754 m/min by using TiAlN coated carbide end mills cutting tool. (Zhengwen, 2013).

2.7.1 Properties of P20 steel

The chemical composition of the steel given in Table 2.9. The steel is Uddeholm Impax HH that has been modified to AISI P20. It has been through hot rolled followed by a stress relieving treatment at 650°c for 9 hour and cooling to room temperature. It then been austenitized at 900°c, 950°c, 1000°c and 1050°c for 30 minutes to obtain different austenite grain size and lastly it been quenching in oil and double tempering at 540°c for 2x2 hour. A hardness of 42 Rockwell C Hardness (HRC) was realized after all the heat treatment process.

Chemical Composition	Percentage (%)
C	0.39
Si	0.27
Mn	1.36
P	0.017
S	0.006
Cr	1.95
Ni	1.0
Mo	0.27
V	0.06
Fe	Bal

Table 2.9: Chemical Composition of P20 Steel (wt. %).

Source: Xiaoxiao, 2011.

2.7.2 Application of P20 steel

The P20 die steel is widely used to produce plastic injection molds. The P20 tool steel is thermally hardenable through proper heat treatment that provide it good performance in wear and corrosion resistant. (Chen et al, 2010; J Mater Sci, 2012). The suitable cutting tool used to machine the P20 steel is coated, cemented carbide tool. (J Mater Sci, 2012**).**

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology contains of experimental process for testing and selection of tool path strategies along with the machining parameter. The selection of tool path strategies based on the best surface roughness and tool wear result will conducted on the next experiment, which is optimization of machining parameter. CAD CAM system has been used in for simulated the tool path strategy and conducted machining parameter through generated of NC codes.

3.2 Testing and Selection of Tool Path Strategies

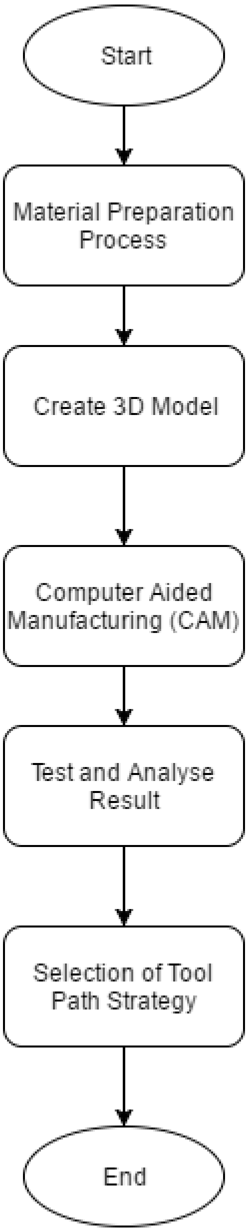


Figure 3.1: Flowchart of Testing and Selection of Tool Path Strategies

Figure 3.1 shows the flowchart of testing and selection of tool path strategies. The important of selection different tool path strategies is for testing the capability of tool motion on the free form design especially for the pre harden steel that limited in the machining process as to produce the best surface finish and low tool wear effect.

3.2.1 Material Preparation Process

Workpiece Material	Dimensional (mm)	Quantity (unit)	Hardness (HRC)
P20 Steel	50 x 50 x 50	1	45

Table 3.1: Details of P20 Steel Workpiece

Table 3.1 shows the details of P20 steel workpiece while Figure 3.2 shows the picture of P20 steel. P20 steel has been used in this experiment due to its properties of hard-to-cut material with average hardness of 45 HRC after tested under the Rockwell Hardness Tester. The size of actual workpiece is 50 mm height, 50 mm width and 50 mm length.

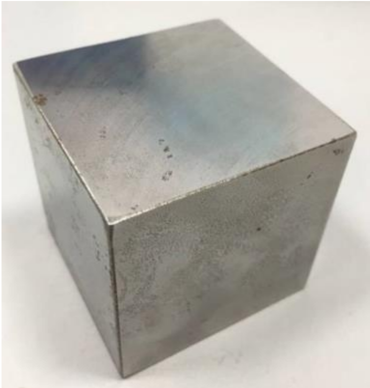


Figure 3.2: P20 Steel Workpiece

Type of Cutting Tool	Dimensional (mm)	Quantity (unit)	No. of Flute
Ball end mill of coated carbide of TiAlN	6.0	12	2

Table 3.2: Details of Cutting Tool for Finishing Process

Table 3.2 shows the details of the cutting tool used for the finishing process in this experiment.

Figure 3.3: Ball end mill of coated carbide of TiAlN

Type of cutting tool used in this experiment is ball end mill of coated carbide of TiAlN with dimensional of 6.0 mm. Total quantities of cutting tool used in this experiment are 12 units. Figure 3.3 shows the picture of ball end mill of coated carbide of TiAlN with 6.0 mm diameter.

3.2.2 Create 3D Model

3D model of free form design created in the Catia V5R21 software. Figure 3.4 shows the free form design sketched with 22.0 mm radius of concave and convex surface and 50.0 mm length.

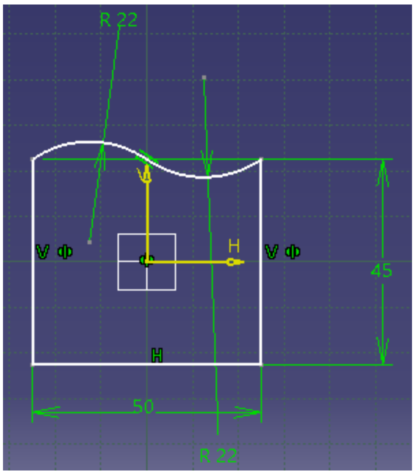


Figure 3.4: Free form design sketched

The design has been extruded to 50.0 mm width according to the actual size of workpiece that has length of 50.0 mm and width of 50.0 mm as shows in Figure 3.5.

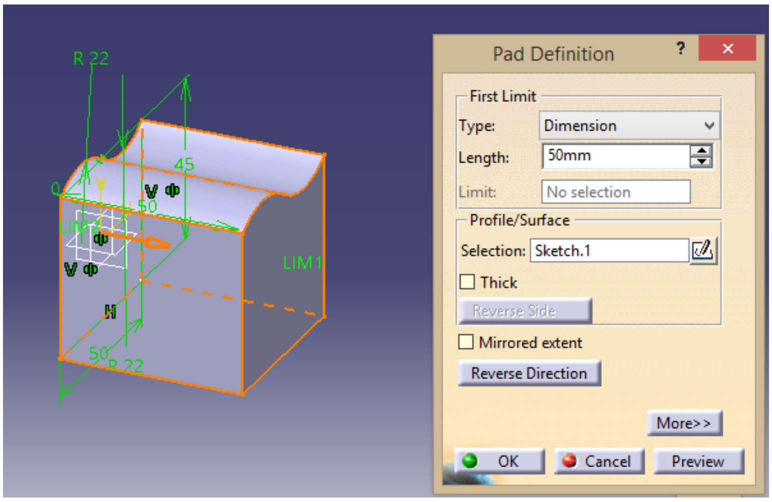


Figure 3.5: Design extruded by 50.0 mm width

3.2.3 Computer Aided Manufacturing (CAM)

Computer aided manufacturing function as to generated NC codes of the tool path strategy with machining parameter set up from the software to be transmitted to the CNC milling machine system as shows in Figure 3.6.

Figure 3.6: CNC milling machine

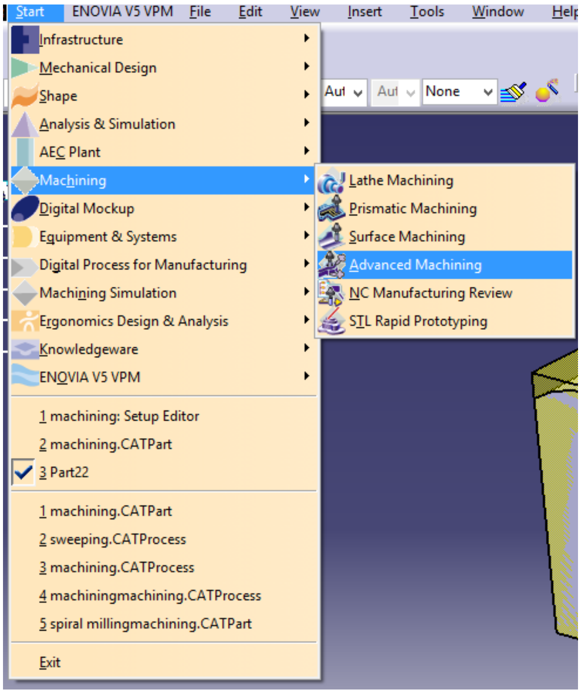


Figure 3.7: Advance machining selection

In Figure 3.7 shows the advance machining selection in CATIA software for the initial step of generated CAM system

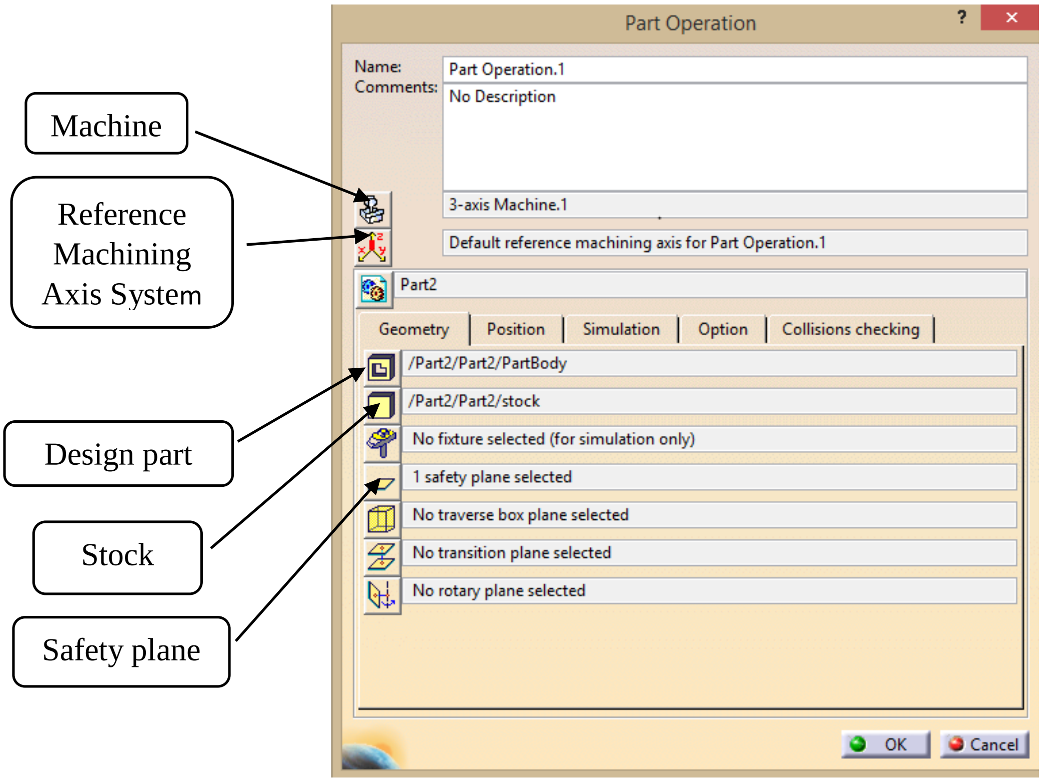


Figure 3.8: Part Operation

Based on Figure 3.8 shows part operation need to be set up before begin the simulation of tool path. Selection of “Machine” is 3 axis milling machine, “Reference Machining Axis System”, “Design Part”, “Stock” and “Safety Plane” is selected at the design of free form.

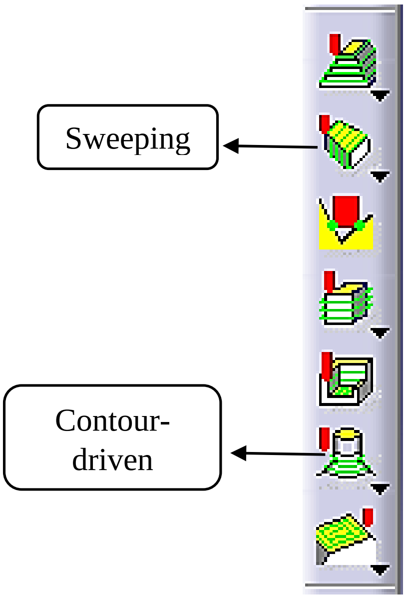


Figure 3.9: Tool path strategy of finishing process

The tool path of finishing process conducted in this experiment are contour-driven and sweeping. This is because this two finishing process have similar tool path motion and machining parameter set up that suitable for the free form design. Figure 3.9 shows the tool path strategies of finishing process are selected.

Tool path strategies have been conducted on concave and convex surface separated because to test the uniformity of surface roughness and tool wear result at the end of selection.

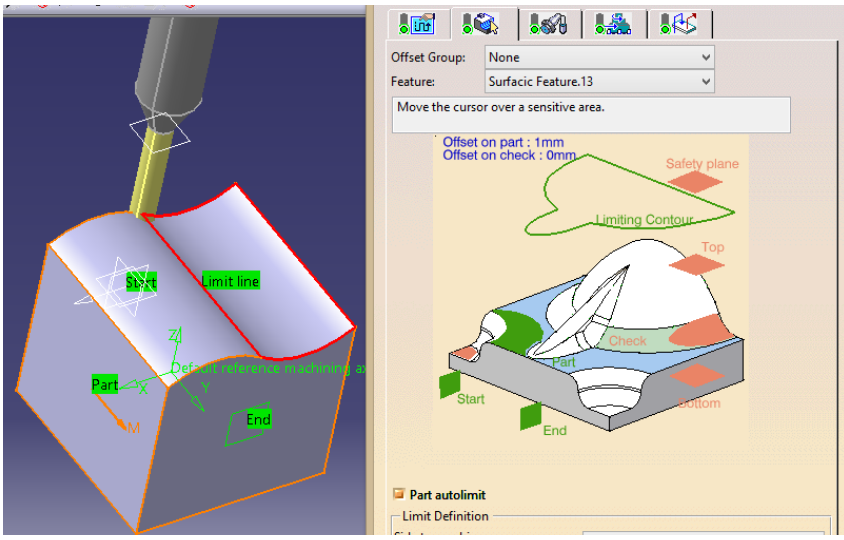


Figure 3.10: Surface feature of finishing process

Figure 3.10 shows surface feature of finishing process selected. For the first experimental conducted, the tool path strategy will be generated on the convex surface of sweeping process. Next, the tool path strategy will be conducted on the concave surface of sweeping process. The same steps will be conducted on the contour-driven process.

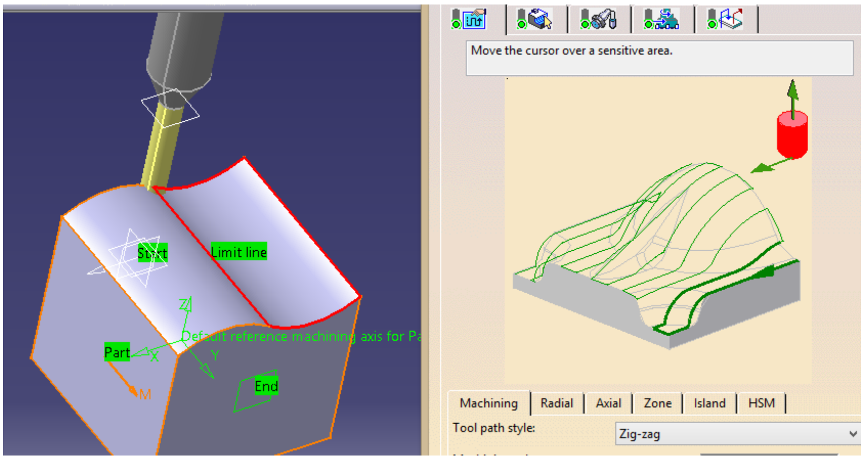


Figure 3.11: Zig-zag tool motion

Figure 3.11 shows the zig-zag tool motion conducted in the sweeping process, same also with the contour-driven, zig-zag motion is applied.

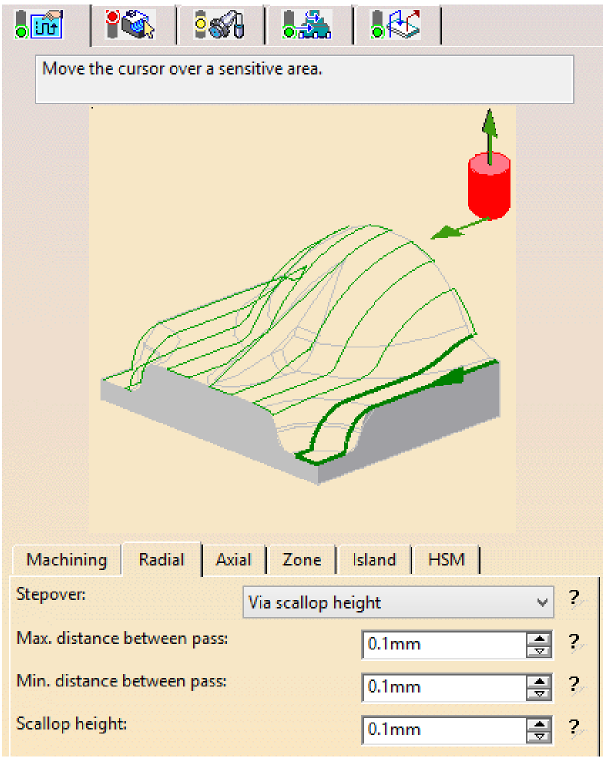


Figure 3.12: Radial parameter set up

Figure 3.12 shows the radial width of cut set up. Type of stepover chosen is via scallop height with maximum, minimum distance and scallop height between pass is 0.1 mm.

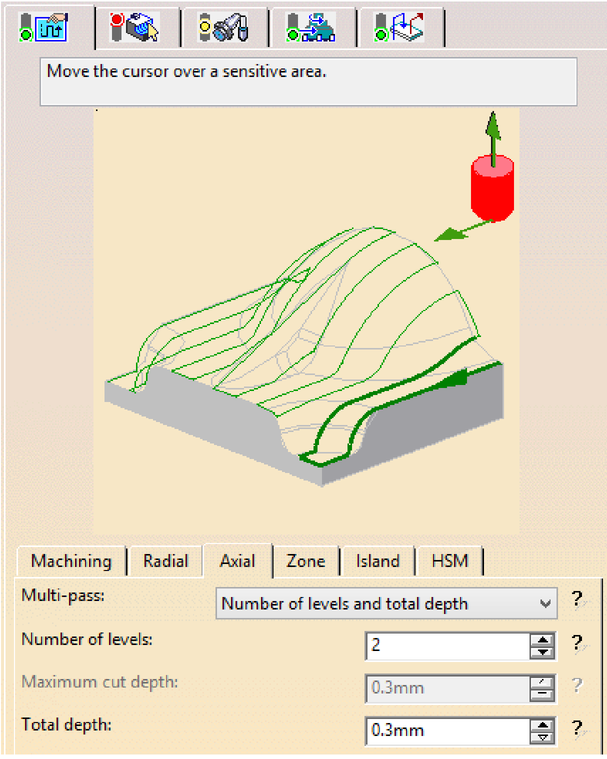


Figure 3.13: Axial parameter set up

Figure 3.13 shows the axial depth of cut set up. The multi-pass selected is number of level and total depth with 0.3 mm total depth of cut and 2 times of cutting levels.

3.2.4 Test and Analyse Result

Test result of surface roughness in term of average surface roughness, Ra, maximum surface roughness, Rz and profile, Pt of each process of surface profile have been conducted with surface roughness tester as shown in Figure 3.14. 3 times of each level of surface was recorded with 40.0 mm evaluation length.

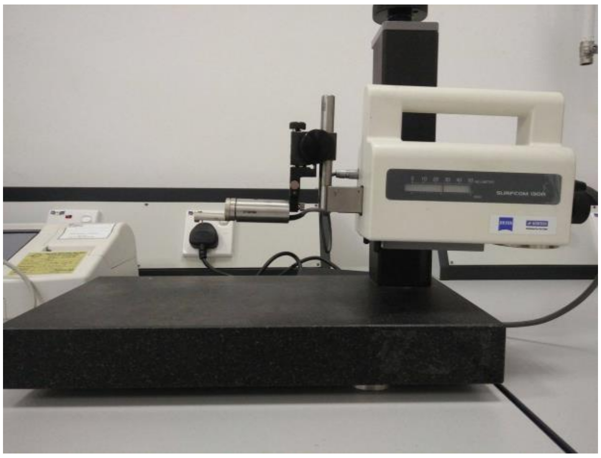


Figure 3.14: Surface Roughness Tester

Figure 3.15: Measuring profile surface

Figure 3.15 shows the ways of the Surface Roughness Tester measuring the profile of free form surface by placing a roll of plaster sink to ease the measurement method on the slope surface.

Meanwhile, tool wear result have been tested under the Video Measurement System as shown in Figure 3.16. Six point of tool wear result measured and captured with 3.5 times magnification to get the result of tool wear and to determine the mechanism of tool wear from the surface part at the tip of cutting tool.

Figure 3.16: Video Measurement System

The result of Ra, Rz, Pt and TW have been average calculated and recorded in the Table 3.3, table result of surface roughness and tool wear.

Tool Path Strategy	**Surface Profile**	**Ra (μm)**	**Rz (μm)**	**Pt (μm)**	**Tw (mm)**
Sweeping	Concave				
Sweeping	Convex				
Contour-driven	Concave				
Contour-driven	Convex				

Table 3.3: Table result surface roughness and tool wear

3.2.5 Selection of Tool Path Strategy

Selection of tool path strategy is based on the uniformity result of Ra, Rz, Pt and TW for convex and concave surface. Analysis of result will be presented in the bar graph chart.

3.3 Optimization of Machining Parameter

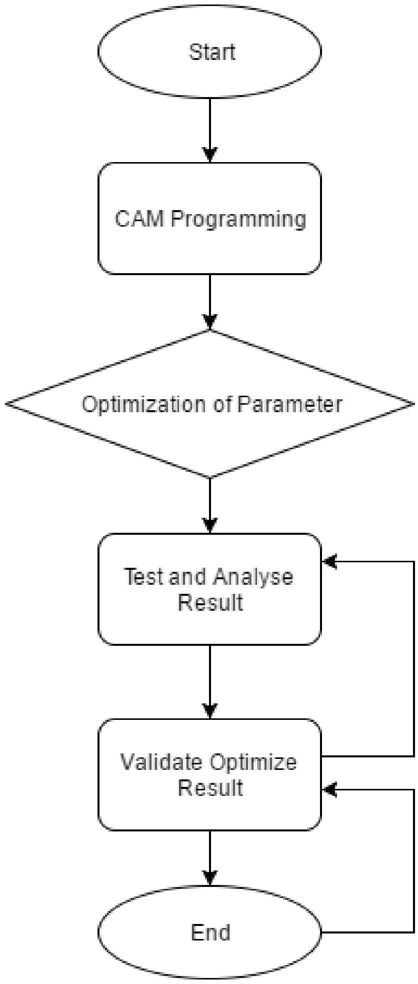


Figure 3.17: Flowchart machining optimization

Figure 3.17 shows the flowchart of machining optimization. The main setting of the machining parameter is on the CAM system based on the Taguchi method. The optimize result will be conclude in the cell mean of Taguchi and mathematical ANOVA will detecting machining parameter that give the most significant effect to the optimize result.

‘

3.3.1 CAM Programming

Machining parameter have been set up in the Taguchi system. 3 factor and 2 level of Taguchi design set up based on the machining parameter selected, that is Feed Rate of 300 mm/min and 400 mm/min, Axial depth of cut of 0.3 mm and 0.4 mm and Radial width of cut of 0.1 mm and 0.2 mm as shows in Table 3.4. L_4 Orthogonal array of experimental as shown in Table 3.5 is the experimental that has been set up in the Taguchi.

Factor/ Level	**1**	**2**
Axial Depth of Cut (mm)	0.3	0.4
Feed Rate (mm/min)	300	400
Radial Width of Cut (mm)	0.1	0.2

Table 3.4: Machining parameters and levels

Experiment No.	Machining Parameters		
	Axial Depth of Cut (mm)	**Feed Rate (mm/min)**	**Radial Width of Cut (mm)**
1	0.3	300	0.1
2	0.4	300	0.2
3	0.3	400	0.2
4	0.4	400	0.1

Table 3.5: L_4 Orthogonal array of experimental

Feed rate, axial depth of cut and radial width of cut of each experimental level generated in the CAM system. Figure 3.18, Figure 3.19 and Figure 3.20 is the examples of machining parameter set up for experiment number 1. Figure 3.18 shows the radial width of cut set up is 0.1 mm. Figure 3.19 shows the axial depth of cut set up is 0.3 mm and Figure 3.20 shows the feed rate set up is 300 mm/min with constant spindle speed that is 3000 RPM. Every each of parameter according to the number of experimental will be generated in form of NC codes.

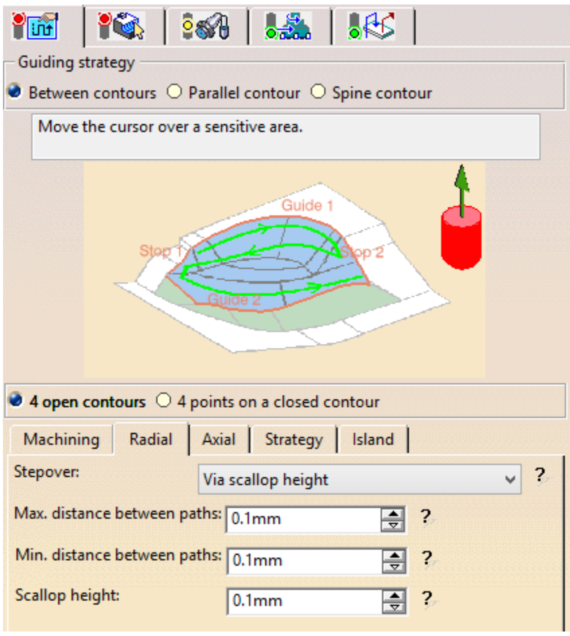


Figure 3.18: Radial width of cut

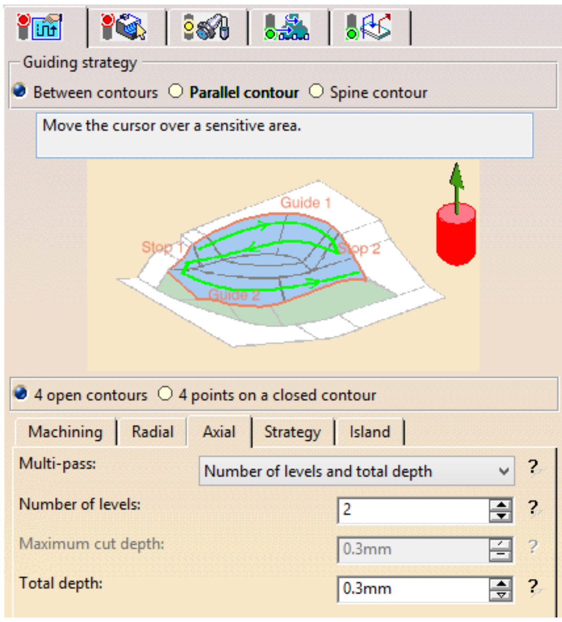


Figure 3.19: Axial depth of cut

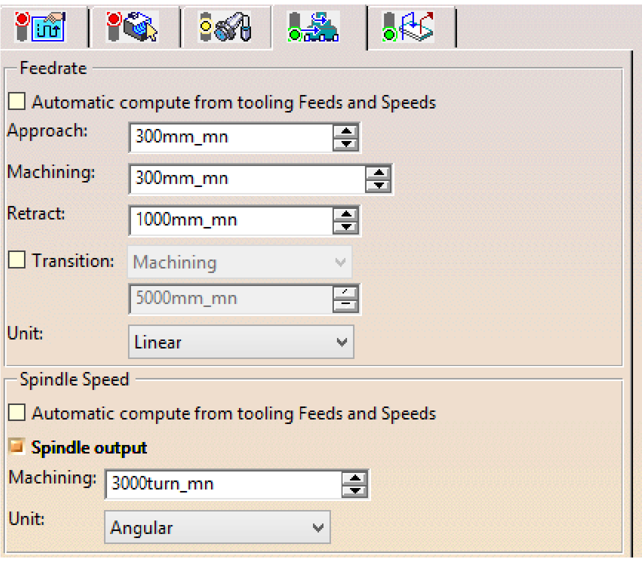


Figure 3.20: Feed rate setting

3.3.2 Optimization of Machining Parameter

After every of each experimental completed, the machining time is recorded to calculate with the tool wear in form of mm/hrs as shows in Table 3.6. The result of surface roughness in term of Ra, Rz and Pt recorded in the table of Taguchi with S/N ratio and mean calculated in statistical as shows in Table 3.7, Table 3.8, Table 3.9 and Table 3.10.

Exp. No	Machining Parameter			Tool Wear, mm	Machining Time, Hours (mm/hrs)
	FR	D.O.C	W.O.C		
1	300	0.3	0.1		
2	300	0.4	0.2		
3	400	0.3	0.2		
4	400	0.4	0.1		

Table 3.6: Machining time and tool wear

Exp. No	Machining Parameter			Average Surface Roughness, Ra (μm)	S/N Ratio	Mean
	FR	D.O.C	W.O.C			
1	300	0.3	0.1			
2	300	0.4	0.2			
3.	400	0.3	0.2			
4	400	0.4	0.1			

Table 3.7: Table result of Ra with S/N ratio and mean

Exp. No	Machining Parameter			Maximum Surface Roughness, Rz (μm)	S/N Ratio	Mean
	FR	D.O.C	W.O.C			
1	300	0.3	0.1			
2	300	0.4	0.2			
3	400	0.3	0.2			
4	400	0.4	0.1			

Table 3.8: Table result of Rz with S/N ratio and mean

Exp. No	Machining Parameter			Profile, Pt (μm)	S/N Ratio	Mean
	FR	D.O.C	W.O.C			
1	300	0.3	0.1			
2	300	0.4	0.2			
3	400	0.3	0.2			
4	400	0.4	0.1			

Table 3.9: Table of result of Pt with S/N ratio and mean

Exp. No	Machining Parameter			Tool Wear Rate, TW (mm/hrs)	S/N Ratio	Mean
	FR	D.O.C	W.O.C			
1	300	0.3	0.1			
2	300	0.4	0.2			
3	400	0.3	0.2			
4	400	0.4	0.1			

Table 3.10: Table of result of TW with S/N ratio and mean

3.3.3 Test and Analyse Result

Taguchi will analyse in S/N ratio calculation and will shows the optimize result of machining parameter graphically in form of lower the better according to the result of the surface roughness and tool wear that resulted to the lowest is the best output of process.

3.3.4 Validate the Optimize Results

Taguchi will recommended parameter that need to be validate for the better result of experimental performed before as shows in Table 3.11 for Ra, Table 3.12 for Rz, Table 3.13 for Pt and Table 3.14 for TW. While mathematical ANOVA will calculated in form of P-Value that give the most significant effect of the optimize parameter as shows in Table 3.14 for Ra, Rz, Pt and TW.

Validate Exp.	Machining Parameter			Average Surface Roughness, Ra (μm)
	FR	D.O.C	W.O.C	
1				

Table 3.11: Table of validate experiment for Ra

Validate Exp.	Machining Parameter			Maximum Surface Roughness, Rz (μm)
	FR	D.O.C	W.O.C	
1				
2				
3				
4				

Table 3.12: Table of validate experiment for Rz

Validate Exp.	Machining Parameter			Profile, Pt (μm)
	FR	D.O.C	W.O.C	
1				
2				
3				
4				

Table 3.13: Table of validate experiment for Pt

Validate Exp.	Machining Parameter			Tool Wear Rate (mm/hrs)
	FR	D.O.C	W.O.C	
1				
2				
3				
4				

Table 3.14: Table of validate experiment for TW

Parameter	Degree of Freedom	Sum of Square	Mean Square	P-Value
FR				
DOC				
WOC				

Table 3.15: Table of ANOVA result

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Chapter 4 shows the results for selection of the best tool path strategy from the testing and the optimization of machining parameter that have been conducted. The best selection of tool path strategy is based on the result of surface roughness and tool wear that shows to the most uniformity result conducted on concave and convex surface. The optimization of machining parameter is based Taguchi setting and validate result, while the most significant parameter that give effect to the output is analyse with mathematical ANOVA.

4.2 Result for Selection of Tool Path Strategy

Tool Path Strategy	Surface Profile	Ra (μm)	Rz (μm)	Pt (μm)	TW (mm)
Sweeping	Concave	0.663	4.971	12.415	0.050
Sweeping	Convex	3.451	15.185	18.066	0.056
Contour-driven	Concave	0.249	1.603	12.153	0.041
Contour-driven	Convex	0.331	2.607	9.83	0.046

Table 4.1: Average result for selection of tool path strategy

Table 4.1 shows the average result for selection of tool path strategy. From the Table 4.1 it shows value of Ra, Rz, Pt and TW process by sweeping and contour-driven for concave and convex surface. From overall result, sweeping process conducted on the concave and convex surface resulted bigger Ra, Rz, Pt and TW value compare to the contour-driven process conducted on the concave and convex surface.

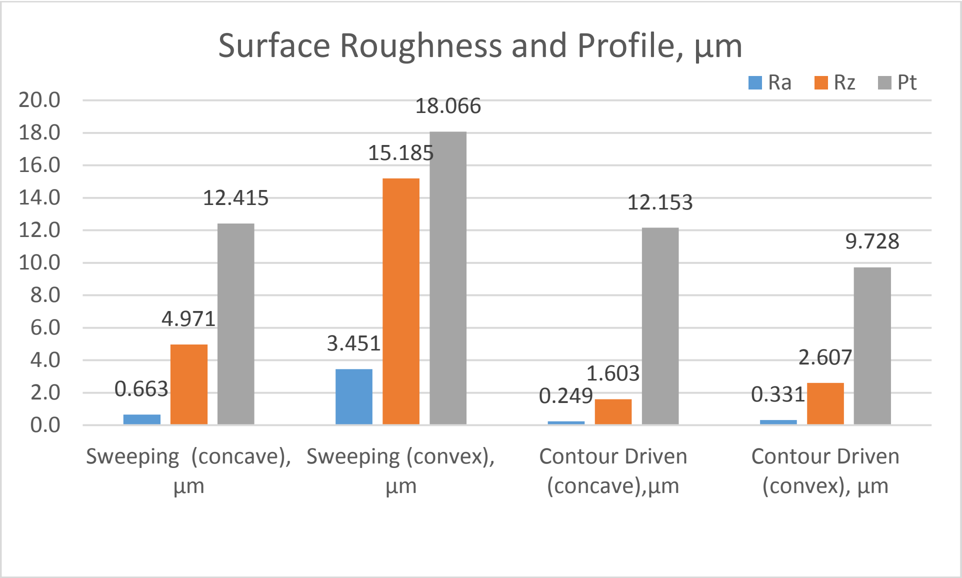


Figure 4.1: Result of Surface Roughness

From Figure 4.1 shows the result of surface roughness for sweeping and contour driven process for concave and convex surface surface. From figure shows that value of Ra, Rz and Pt for sweeping process conducted on the both surfaces is higher compare to Ra, Rz and Pt for contour-driven conducted on the both surfaces. This shows, surface roughness of contour-driven process is better compare to the sweeping process. In the other hand, the result of Ra, Rz and Pt for both surfaces of contour-driven process performed to the almost uniformity result compare to the sweeping process.

Thus, contour-driven is selected based on the best surface roughness formed in term of Ra, Rz, Pt and TW, in the same time it could perform on concave and convex surface to the almost uniformity result.

4.2.1 Surface Structure of Process

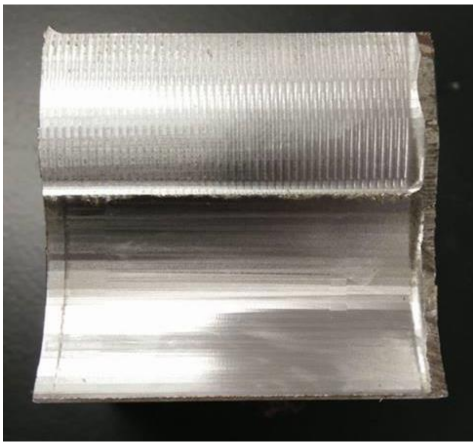


Figure 4.2: Surface structure of sweeping process

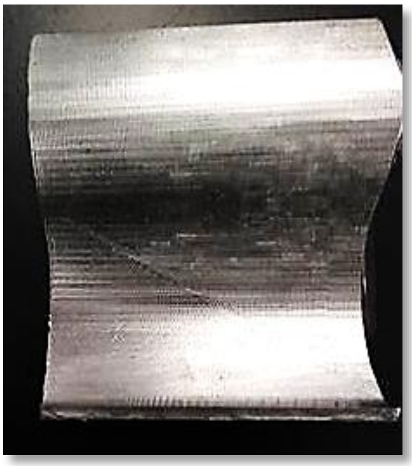


Figure 4.3: Surface structure of contour driven process

From Figure 4.2 and Figure 4.3 shows surface structure formed from sweeping and contour-driven process. In sweeping process, the surface roughness of workpiece at the concave part is not smooth enough compare to the convex part surface. Differ to the contour-driven process, the surface roughness for concave and convex surface are almost too similar. This proved that, contour-driven process suitable for machining the free form surface of hard-to-cut material.

4.2.2 Tool Wear Result

Tool wear result at the end tip of the cutting tools has been observed through the Video Measurement System. Figure 4.4 shows the chips of steel sticks and melts on the cutting tool even the cutting tool has been clean several time. This mechanism of wear is called adhesion while sweeping process conducted.

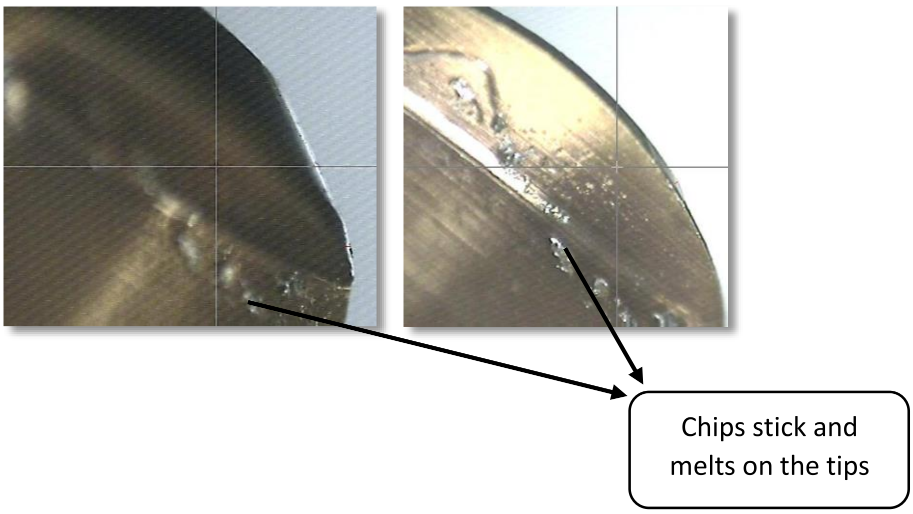


Figure 4.4: Adhesion

Figure 4.5 shows at the tip of cutting tool, the coated of TiAlN have been eroded due to rough contact between the cutting tool and the workpiece. This mechanism of wear called abrasion while contour-driven process conducted.

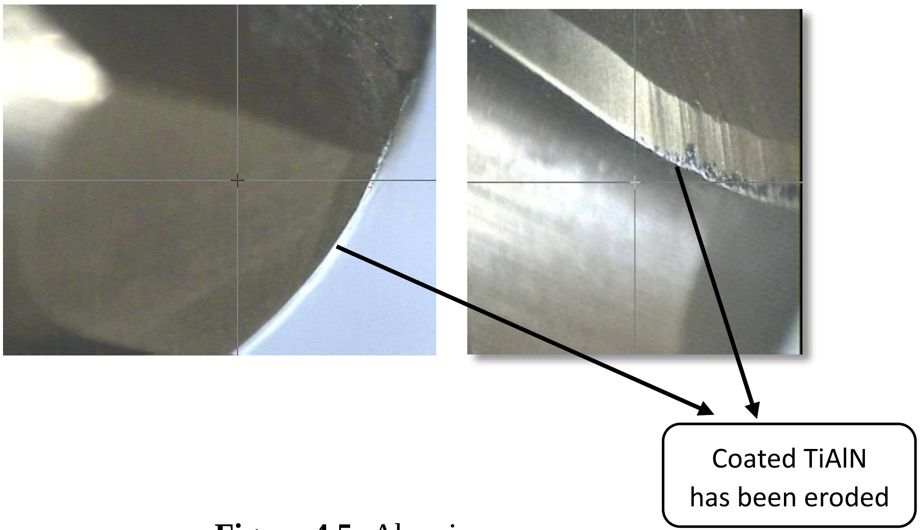


Figure 4.5: Abrasion

4.3 Result of Machining Optimization

Experimental of machining optimization have been conducted based on the L_4 orthogonal array of Taguchi set up. Besides of Ra, Rz and Pt result, machining time of each experimental level were recorded to measure the tool wear rate as shows in Table 4.2.

Exp. No	Machining Parameter			Tool Wear, mm	Machining Time, Hours
	FR	D.O.C	W.O.C		
1	300	0.3	0.1	0.490	22 H, 38 Min
2	300	0.4	0.2	0.564	12 H, 57 Min
3	400	0.3	0.2	0.246	8 H, 42 Min
4	400	0.4	0.1	1.110	15 H, 35 Min

Table 4.2: Tool wear and machining time

From Table 4.2 shows the tool wear and machining time, it shows that on the 4th experimental recorded the longest time of machining time with Feed rate, 400 mm/min, Depth of cut, 0.3 mm and Width of cut, 0.1 mm. Meanwhile the shortest time of machining time is on the 2nd experimental with Feed rate, 300 mm/min, Depth of cut, 0.4 mm and Width of cut, 0.2 mm. The largest tool wear resulted on the 4th experimental while the shortest tool wear resulted on the 3rd experimental.

Exp. No	Machining Parameter			Average Surface Roughness, Ra (μm)	S/N Ratio	Mean
	FR	D.O.C	W.O.C			
1	300	0.3	0.1	1.310	-2.3454	1.310
2	300	0.4	0.2	1.615	-4.1635	1.615
3.	400	0.3	0.2	1.794	-5.0765	1.794
4	400	0.4	0.1	1.300	-2.2789	1.300

Table 4.3: Result S/N ratio and mean for Ra

Based on Table 4.3, result S/N ratio and mean for Ra, the optimize parameter result will affect to the S/N Ratio value. Based on the S/N Ratio value, the best Ra value is 1.300 μm resulted to the biggest S/N Ratio, which is -2.2789. Thus the optimize parameter for Ra is feed rate, 400 mm/min, depth of cut, 0.4 mm and width of cut, 0.1 mm.

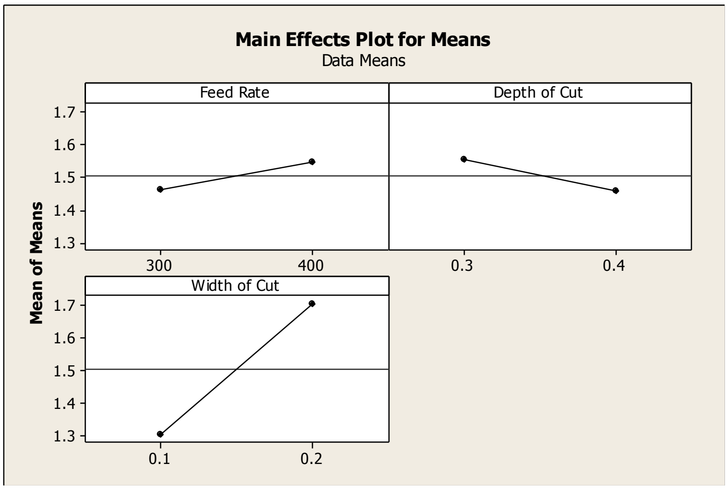


Figure 4.6: Data mean of recommend experiment for Ra

Based on statically data mean of lower the better shows in Figure 4.6, the recommended parameter to obtain the best Ra are feed rate, 300 mm/min, depth of cut, 0.4 mm and width of cut, 0.1 mm.

Exp. No	Machining Parameter			Maximum Surface Roughness, Rz (μm)	S/N Ratio	Mean
	FR	D.O.C	W.O.C			
1	300	0.3	0.1	5.757	-15.2039	5.575
2	300	0.4	0.2	8.528	-18.617	8.528
3	400	0.3	0.2	7.874	-17.924	7.874
4	400	0.4	0.1	5.689	-15.101	5.689

Table 4.4: Result S/N ratio and mean for Rz

Based on Table 4.4, the optimize parameter result will affect to the S/N Ratio value. Based on the S/N Ratio value, the best Rz value is 5.689 μm resulted to the biggest S/N Ratio, which is -15.101. Thus the optimize parameter for Rz is feed rate, 400 mm/min, depth of cut, 0.4 mm and width of cut, 0.1 mm.

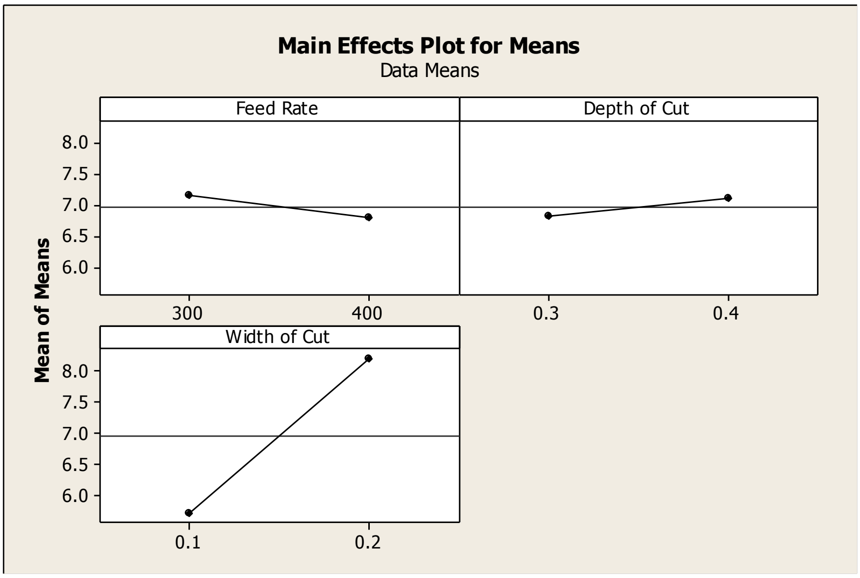


Figure 4.7: Data mean of recommend experiment for Rz

Based on statically data mean of lower the better shows in Figure 4.7, recommended parameter to obtain the best Ra are feed rate, 400 mm/min, depth of cut, 0.3 mm and width of cut, 0.1 mm.

Exp. No	Machining Parameter			Profile, Pt (μm)	S/N Ratio	Mean
	FR	D.O.C	W.O.C			
1	300	0.3	0.1	8.760	-18.8501	8.760
2	300	0.4	0.2	8.829	-18.918	8.829
3	400	0.3	0.2	8.540	-18.629	8.540
4	400	0.4	0.1	8.960	-19.047	8.960

Table 4.5: Result S/N ratio and mean for Pt

Based on Table 4.5, the optimize parameter result will affect to the S/N Ratio value. Based on the S/N Ratio value, the best Pt value is 8.540 μm resulted to the biggest S/N Ratio, which is -18.629. Thus the optimize parameter for Pt is feed rate, 400 mm/min, depth of cut, 0.3 mm and width of cut, 0.2 mm.

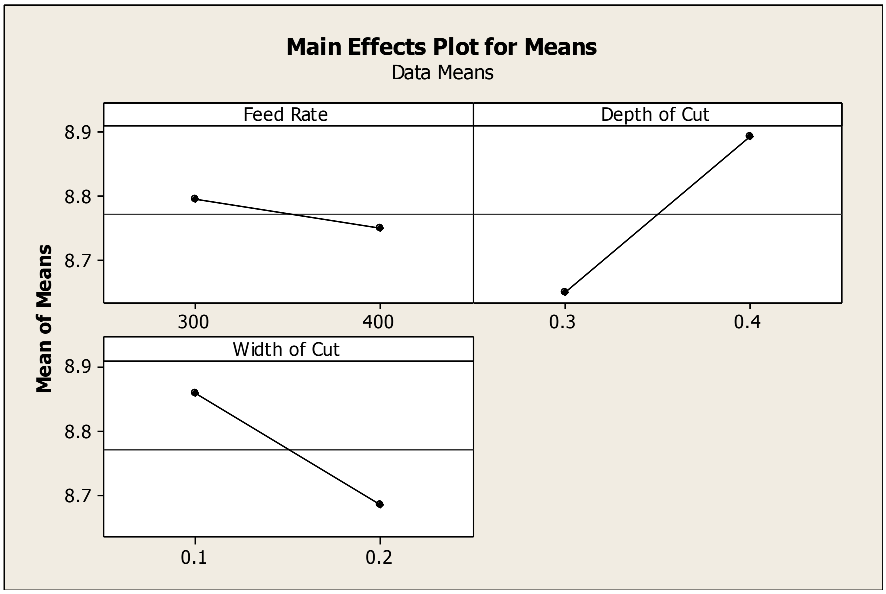


Figure 4.8: Data mean of recommend experiment for Pt

Based on statically data mean of lower the better shows in Figure 4.8, recommended parameter to obtain the best Ra are feed rate, 400 mm/min, depth of cut, 0.3 mm and width of cut, 0.2 mm.

Exp. No	Machining Parameter			Tool Wear Rate, TW (mm/hrs)	S/N Ratio	Mean
	FR	D.O.C	W.O.C			
1	300	0.3	0.1	0.022	33.152	0.022
2	300	0.4	0.2	0.045	26.936	0.045
3	400	0.3	0.2	0.029	30.752	0.029
4	400	0.4	0.1	0.072	22.853	0.072

Table 4.6: Result S/N ratio and mean for TW

Based on Table 4.6, the optimize parameter result will affect to the S/N Ratio value. Based on the S/N Ratio value, the best Tw value 0.022 resulted to the biggest S/N Ratio, which is 33.152. Thus the optimize parameter for Pt is feed rate, 300 mm/min, depth of cut, 0.3 mm and width of cut, 0.1 mm.

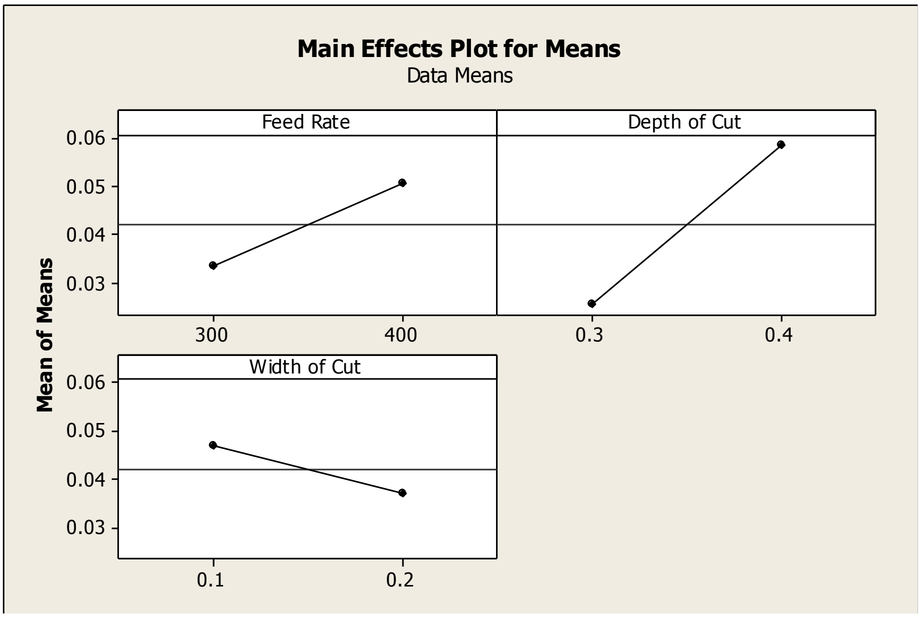


Figure 4.9: Data mean of recommend experiment for TW

Based on statically data mean of lower the better shows in Figure 4.9, recommended parameter to obtain the best Ra are feed rate, 300 mm/min, depth of cut, 0.3 mm and width of cut, 0.2 mm.

4.3.1 Validate Results

Validate Exp.	Machining Parameter			Average Surface Roughness, Ra (μm)
	FR	D.O.C	W.O.C	
1	300	0.4	0.1	1.115

Table 4.7: Validate Result for Ra

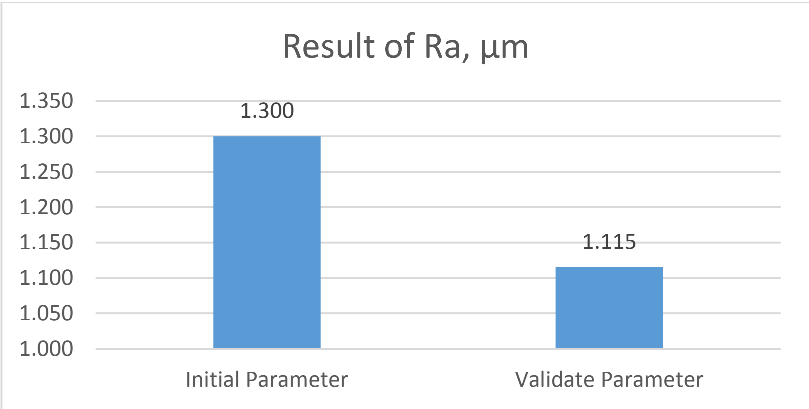


Figure 4.10: Comparison result of Ra

Table 4.7 shows the validate parameter result recommended by Taguchi for Ra with machining parameter of Feed Rate, 300 mm/min, Depth of cut, 0.4 mm and Width of cut, 0.1 mm. Figure 4.10 shows comparison result Ra of the initial parameter with the validate parameter. It shows that validate result perform better Ra value that is 1.115 µm than setting parameter that is 1.300µm

Validate Exp.	Machining Parameter			Maximum Surface Roughness, Rz (μm)
	FR	**D.O.C**	**W.O.C**	
1	400	0.3	0.1	5.651

Table 4.8: Validate Result for Rz

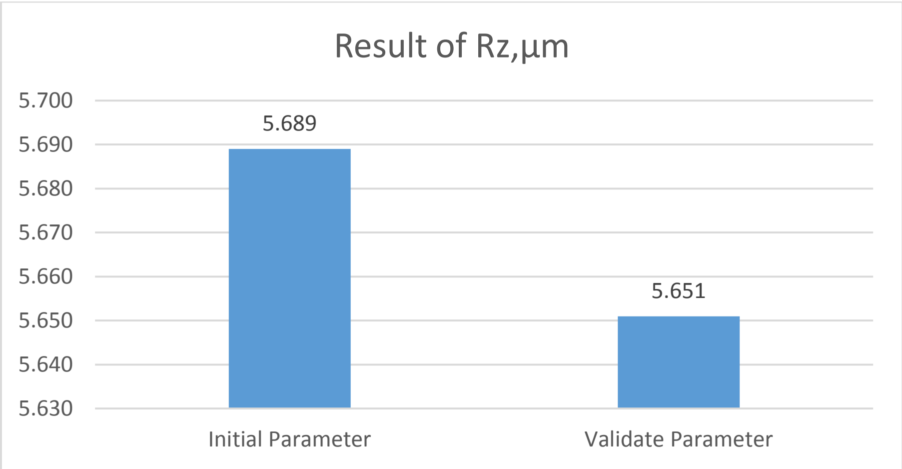


Figure 4.11: Comparison result of Rz

Table 4.8 shows the validate parameter result recommended by Taguchi for Rz with machining parameter of Feed Rate, 400 mm/min, Depth of cut, 0.3 mm and Width of cut, 0.1 mm. Figure 4.11 shows comparison result Rz of the initial parameter with the validate parameter. It shows that validate result perform better Rz value that is 5.651 µm than setting parameter that is 5.689 µm

Validate Exp.	Machining Parameter			Profile, Pt (μm)
	FR	D.O.C	W.O.C	
1	400	0.3	0.2	8.214

Table 4.9: Validate result of Pt

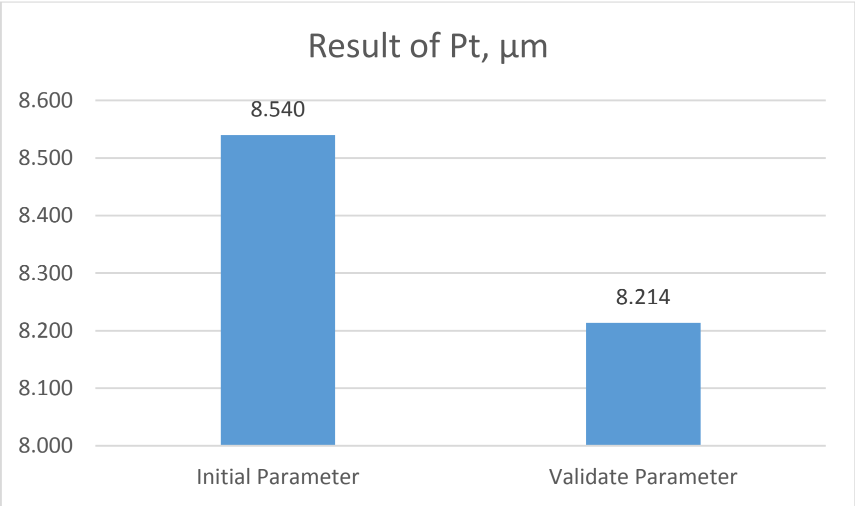


Figure 4.12: Comparison resulf of Pt

Table 4.9 shows the validate parameter result recommended by Taguchi for Pt with machining parameter of Feed Rate, 400 mm/min, Depth of cut, 0.3 mm and Width of cut, 0.2 mm. Figure 4.12 shows comparison result Pt of the initial parameter with the validate parameter. It shows that validate result perform better Pt value that is 8.540 µm than setting parameter that is 8.214 µm

Validate Exp.	Machining Parameter			Tool Wear Rae, TW (mm/hrs)
	FR	D.O.C	W.O.C	
1	300	0.3	0.2	0.026

Table 4.10: Validate result of TW

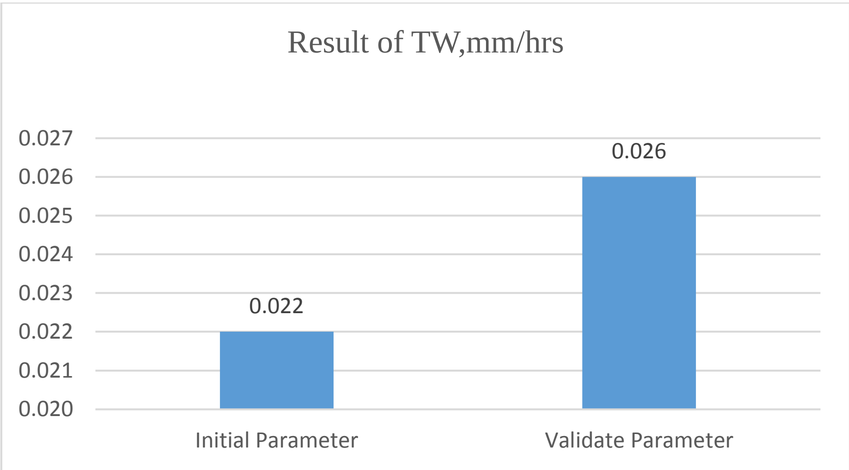


Figure 4.13: Comparison result of TW

Table 4.10 shows the validate parameter result recommended by Taguchi for TW with machining parameter of Feed Rate, 300 mm/min, Depth of cut, 0.3 mm and Width of cut, 0.2 mm. Figure 4.13 shows comparison result TW of the initial parameter with the validate parameter. It shows that initial result perform better TW value that is 0.022 mm/hrs than validate parameter that is 0.026 mm/hrs

4.3.2 Analysis of Varience (ANOVA)

Taguchi method cannot determine the individual parameter on each on the process, thus ANOVA function is to determine the most influencing of machining parameter that give effect in the experiment. In mathematical ANOVA, Degree of Freedom mean how many times of experimental was conducted. Sum of square and Mean of square mean related to the effects of experiment to the parameter.

Parameter	Degree of Freedom	Sum of Square	Mean Square	P-Value
FR	1	0.0071	0.0071	0.798
DOC	1	0.0089	0.0089	0.775
WOC	1	0.1596	0.1596	0.047

Table 4.11: ANOVA result for Ra

Based on Table 4.11 of mathematical ANOVA, all of machining parameter give significant effect to Ra because P-value below than 0.05, but the most optimize parameter is width of cut because it resulted the lowest P-value that is 0.047. Largest value of Sum of square and mean of square resulted to the most significant effect for the parameter.

Parameter	Degree of Freedom	Sum of Square	Mean Square	P-Value
FR	1	0.13	0.13	0.857
DOC	1	0.09	0.09	0.884
WOC	1	6.140	6.140	0.017

Table 4.12: ANOVA result for Rz

Based on Table 4.12 of mathematical ANOVA, width of cut is the most optimize parameter for Rz because the P-value is below than significant value, $P < 0.05$ and resulted the lowest P-value that is 0.017. Largest value of Sum of square and mean of square resulted to the most significant effect for the parameter.

Parameter	Degree of Freedom	Sum of Square	Mean Square	P-Value
FR	1	0.0020	0.0020	0.854
DOC	1	0.0598	0.0598	0.196
WOC	1	0.0308	0.0308	0.423

Table 4.13: ANOVA result for Pt

Based on Table 4.13 of mathematical ANOVA, there no optimize machining parameter to Pt because there no P-value below than 0.05, but the parameter that give large significant effect for Pt is depth of cut because it recorded the lowest P-value that is 0.196. Largest value of Sum of square and mean of square resulted to the most significant effect for the parameter.

Parameter	DF	SS	MS	P
FR	1	0.003	0.003	0.558
DOC	1	0.001	0.001	0.142
WOC	1	0.0001	0.0001	0.740

Table 4.14: ANOVA result for TW

Based on Table 4.14 of mathematical ANOVA, there no optimize machining parameter for TW because there no P-value below than 0.05, but the parameter that give large significant effect for TW is depth of cut because it recorded the lowest P-value, that is 0.142. Largest value of Sum of square and mean of square resulted to the most significant effect for the parameter.

4.4 Discussion

Tool path strategy selected for the free form surface of P20 steel is contour-driven due to the better result compare to the sweeping process and uniformity result of Ra, Rz, Pt and low tool wear effect for concave and convex profile.

The most optimize machining parameter to form best surface roughness in term of Ra is along parameter of feed rate, 300 mm/min, depth of cut, 0.4 mm and width of cut, 0.1 mm. As to form best Rz with the optimized parameter are feed rate, 400 mm/min, depth of cut, 0.3 mm and width of cut, 0.1 mm. Meanwhile to form best Pt are by conducted optimized parameter of feed rate, 400 mm/min, depth of cut, 0.3 mm and width of cut, 0.2 mm. In the other hand, the 4th experiment set in the L_4 orthogonal array of experiment by using optimized parameter of feed rate, 400 mm/min, depth of cut, 0.4 mm and width of cut, 0.1 mm will form low tool wear rate.

According to the ANOVA result from the P-Value, the most optimize parameter that give large significant effect for Ra and Rz is width of cut, while for the Pt and TW, the machining parameter still does not optimize due to the P-value result that higher than the significant value, but depth of cut resulted the lowest P-value for Pt and TW, so depth of cut give large effect to them in the experimental.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

Chapter 5 shows the conclusion and some recommendation for the research and experiments that have been done.

5.2 Conclusion

As the nutshell, the overall objectives for this experimental had achieved. The tool path strategy for machining the pre harden steel that resulted to the smooth surface roughness with the low tool wear effect has been found that is contour-driven as result shown in Table 4.1 and Figure 4.1.

As an addition, the optimize machining parameter in term of feed rate, axial depth of cut and radial width of cut could be set up in Taguchi method with least number of experimental due to the limited time to conduct the Final Year Project 2. The validate result of machining parameter recommended by the Taguchi have proved the result for Ra, Rz and Pt is better compare to the machining parameter set up in the L_4 orthogonal array of experimental. Percentage of validated Ra value is 14.23%, and for percentage validate Rz value is 0.67%, for percentage validate Pt value is 3.81% and for percentage of validate TW value is -18.18% From percentage validate of result for the TW recommended by the Taguchi doesn't prove the result of given better TW effect, it might due to the lack of precise Video Measurement System in measuring the length of tool wear or during conducting the experiment, the coolant from the machine has been stop suddenly that stressed the contact of cutting tool and the workpiece that resulted to the greater abrasion effect.

Improvement in the optimization after validate result shows that to get the best Ra value is by implemented machining parameter of Feed Rate, 300mm/min, Depth of Cut, 0.4 mm and Width of Cut, 0.1 mm. In the other hand, to get the best Rz value is by implemented machining parameter of Feed Rate, 400mm/min, Depth of Cut, 0.3 mm and Width of Cut, 0.1 mm. Besides that, to get the best Pt value is by implemented machining parameter of Feed Rate, 400mm/min, Depth of Cut, 0.3 mm and Width of Cut, 0.2 mm. As for improve the tool life of cutting tool, the optimize machining parameter that need to be implemented are Feed Rate, 300mm/min, Depth of Cut, 0.3 mm and Width of Cut, 0.1 mm

5.3 Recommendations

In this experimental, there are some recommendation could be make:

a. For further study in the tool wear result, research on the microstructure of cutting chip recommend as it could give the better answer for the reason of the mechanism and type of tool wear. In this experiment, measuring wear by using Video Measurement System does only limit to the outer part surface of cutting tool but the reason that lead to the wear cannot precisely answered.

b. During machining process in this experiment, cutting force between the cutting tool and the workpiece does not being measured due to the limited tool to measure the cutting force. So as the recommendation, while conducted the experiment, there need to measure the cutting force so that we can measure the chatter effect that lead to the reason of surface roughness and tool wear effect.

c. Taguchi method only provided to the robust design of the experimental, but it does not provided to the most optimize and validate parameter in once conducting experiment. As the recommendation, Design of Experiment in Minitab Software could improve the optimization methodology in this experiment.

d. Along conducting the experiment, the machining time generated in the Catia software and the actual machining time does not give the same result and synchronize even the override of the machining has been turn to 100%. As the recommendation for generating the future CAD CAM process using the CNC Makino Milling Machine, some other software should be used to get the same result of machining time resulted in the software and the actual machining time.

REFERENCES

Attanasio, A., Ceretti, E., Giardini, C., & Cappellini, C. Tool wear in cutting operations: Experimental analysis and analytical models. Journal of Manufacturing Science and Engineering, 135(5), (2013).

Barry, J., & Byrne, G. The mechanisms of chip formation in machining hardened steels. Journal of Manufacturing Science and Engineering, 124(3), (2002). 528-535.

Bhattacharya, A., Das, S., Majumder, P., & Batish, A. Estimating the effect of cutting parameters on surface finish and power consumption during high speed machining of AISI 1045 steel using Taguchi design and ANOVA. Production Engineering, 3(1), (2009).31-40.

Broniszewski, K., Wozniak, J., Czechowski, K., Jaworska, L., & Olszyna, A. Al 2 O 3–Mo cutting tools for machining hardened stainless steel.Wear, 303(1), (2013).87-91.

Chen, J. Y., Conlon, K., Xue, L., & Rogge, R. Experimental study of residual stresses in laser clad AISI P20 tool steel on pre-hardened wrought P20 substrate. Materials Science and Engineering: A, 527(27), (2010).7265-7273.

Chen, Tao, and Peiqing Ye. "A tool path generation strategy for sculptured surfaces machining." Journal of Materials Processing Technology 127.3 (2002): 369-373.

Chen, X., Zhao, J., Li, Y., Han, S., Cao, Q., & Li, A. Investigation on ball end milling of P20 die steel with cutter orientation. The International Journal of Advanced Manufacturing Technology, 59(9-12), (2012). 885-898.

.

Das, P., Samanta, S. K., Das, R., & Dutta, P. Optimization of degree of sphericity of primary phase during cooling slope casting of A356 Al alloy: Taguchi method and regression analysis. *Measurement*, *55*, (2014). 605-615.

Dolinšek, Slavko, Sabahudin Ekinović, and Janez Kopač. "A contribution to the understanding of chip formation mechanism in high-speed cutting of hardened steel." *Journal of Materials Processing Technology* 157 (2004): 485-490.

Duc, E., Lartigue, C., Tournier, C., & Bourdet, P. A new concept for the design and the manufacturing of free-form surfaces: the machining surface. CIRP Annals-Manufacturing Technology, 48(1), (1999). 103-106.

Duchosal, A., Serra, R., Leroy, R., & Hamdi, H. Numerical optimization of the Minimum Quantity Lubrication parameters by inner canalizations and cutting conditions for milling finishing process with Taguchi method. *Journal of Cleaner Production*, *108*, (2015). 65-71.

El-Hofy, H. A. G. Fundamentals of machining processes: conventional and nonconventional processes. (2013). CRC press.

Erdel, Bert P. High-speed machining. Society of Manufacturing Engineers, 2003.

Faverjon, Pierre, Joël Rech, and René Leroy. "Influence of minimum quantity lubrication on friction coefficient and work-material adhesion during machining of cast aluminum with various cutting tool substrates made of polycrystalline diamond, high speed steel, and carbides." Journal of Tribology 135.4 (2013): 041602.

Gopalsamy, Bala Murugan, Biswanath Mondal, and Sukamal Ghosh. "Taguchi method and ANOVA: An approach for process parameters optimization of hard machining while machining hardened steel." Journal of scientific & industrial research 68.8 (2009): 686-695.

Hoseiny, H., et al. "The effect of the martensitic packet size on the machinability of modified AISI P20 prehardened mold steel." Journal of Materials Science 47.8 (2012): 3613-3620.

http://reliawiki.org/index.php/Taguchi_Orthogonal_Arrays. (2016)

Ibrahim, R. N., et al. "Monolayer TiAlN and multilayer TiAlN/CrN PVD coatings as surface modifiers to mitigate fretting fatigue of AISI P20 steel." Engineering Fracture Mechanics 137 (2015): 64-78.

Kalpakjian, S., Schmid, S. R., & Kok, C. W. (2008). Manufacturing processes for engineering materials. Pearson-Prentice Hall.

Kumazawa, Guillermo H., Hsi-Yung Feng, and M. Javad Barakchi Fard. "Preferred feed direction field: A new tool path generation method for efficient sculptured surface machining." Computer-Aided Design 67 (2015): 1-12.

Lavernhe, Sylvain, Christophe Tournier, and Claire Lartigue. "Optimization of 5-axis high-speed machining using a surface based approach." Computer-Aided Design 40.10 (2008): 1015-1023.

Lazoglu, I., C. Manav, and Y. Murtezaoglu. "Tool path optimization for free form surface machining." CIRP Annals-Manufacturing Technology 58.1 (2009): 101-104.

Lin, Zhiwei, et al. "Tool path generation for multi-axis freeform surface finishing with the LKH TSP solver." *Computer-Aided Design* 69 (2015): 51-61.

Mativenga, P. T., and K. K. B. Hon. "An experimental study of cutting forces in high-speed end milling and implications for dynamic force modeling." Journal of manufacturing science and engineering 127.2 (2005): 251-261.

Monaro, R. L. G., A. L. Helleno, and K. Schützer. "Evaluation of Dynamic Behavior of Machine Tools for Sculptured Surface Manufacturing." Procedia CIRP 7 (2013): 317-322.

Sutter, G., and A. Molinari. "Analysis of the cutting force components and friction in high speed machining." Journal of Manufacturing Science and Engineering 127.2 (2005): 245-250.

Toh, C. K. "Surface topography analysis in high speed finish milling inclined hardened steel." Precision Engineering 28.4 (2004): 386-39

Vickers, G. W., Z. Dong, and H. Li. "Optimal rough machining of sculptured parts on a CNC milling machine." Journal of Engineering for Industry, Transactions of the ASME 115.4 (1993): 424-432.

APPENDIX

GANTT CHART FINAL YEAR PROJECT 1

No	Task	Action	Week													
			W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Verify the project title	P														
		A														
2	Verify the project objective and scope	P														
		A														
3	Search of literature source	P														
		A														
4	Study of CADCAM system	P														
		A														
5	Study of methodology	P														
		A														
6	Progress report (Chapter 1-3)	P														
		A														
7	Submit milestone 1	P														
		A														
8	Presentation of FYP 1 proposal	P														
		A														
9	Submit milestone 2	P														
		A														
10	Final report progress	P														
		A														
11	Submit final report (milestone 3)	P														
		A														

GANTT CHART FINAL YEAR PROJECT 1

No	Task	Action	Week													
			W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Material Preparation	P														
		A														
2	CAD/CAM	P														
		A														
3	Testing and analysis	P														
		A														
4	Validate experiment	P														
		A														
5	Chapter 4 (Result and Analysis) progress	P														
		A														
6	Chapter 5 (Conclusion and Recommendation) progress	P														
		A														
7	Preparation of Final Year Project Thesis	P														
		A														
8	Presentation of Final Year Project 2	P														
		A														
9	Submission of Final Year Project Thesis	P														
		A														