SURFACE ROUGHNESS IMPROVEMENT FOR PASSENGER CAR HOOD DIE MANUFACTURING PROCESS

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การปรับปรุงความหยาบผิวสำหรับกระบวนการผลิตแม่พิมพ์ฝากระโปรงรถยนต์

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ความหยาบผิวของแม่พิมพ์เป็นปัจจัยสำคัญในการผลิตฝากระโปรงรถยนต์ให้ได้คุณภาพ วิทยานิพนธ์ฉบับนี้จึงได้ถูกจัดทำขึ้นเพื่อพัฒนากระบวนการผลิตแม่พิมพ์ให้ได้ความหยาบผิวที่น้อยลง หากกระบวนการกัดมีประสิทธิภาพไม่เพียงพอจะทำให้ใช้ระยะเวลาในการขัดมาก และอาจส่งผลให้ได้คุณภาพแม่พิมพ์ที่ไม่ตรงต่อความต้องการของลูกค้า ดังนั้นงานวิจัยนี้จึงมุ่งเน้นไปที่การแก้ปัญหาการกัดด้วยเครื่อง CNC เครื่องมือที่ใช้ในการกัดและค่าพารามิเตอร์ต่างๆ ถูกนำมาศึกษาเพื่อหาเครื่องมือและพารามิเตอร์ที่เหมาะสมที่สุดที่ใช้ในกระบวนการกัดละเอียด ปัจจุบันใช้เครื่องมือในการกัดละเอียดแบบ 1 ใบมีด ค่าพารามิเตอร์ที่ใช้ในกระบวนการคือ Cutting speed เท่ากับ 5,500 rpm Feed เท่ากับ 4,800 mm/min Dept. of cut เท่ากับ 0.1 mm และระยะ Pitch เท่ากับ 0.5 mm

ค่าพารามิเตอร์ที่ใช้ในการทดลอง ถูกออกแบบโดยโปรแกรมและป้อนลงในเครื่อง CNC เพื่อใช้ในการกัดชิ้นงานทดลองที่มีความเหมือนกับแม่พิมพ์ที่ใช้ในกระบวนการผลิตจริง ทั้งนี้การทดลองถูกออกแบบขึ้นโดยใช้วิธีการพื้นผิวตอบสนอง และใช้โปรแกรมทางสถิติในการวิเคราะห์และหาค่าพารามิเตอร์ที่เหมาะสมที่สุดเพื่อนำมาใช้งาน

หลังจากปรับปรุงความเรียบผิวของแม่พิมพ์ พบว่าการใช้ใบมีดแบบ 3 ใบ โดยใช้ค่า Cutting speed เท่ากับ 11,670 rpm Feed เท่ากับ 3,563 mm/min Dept. of cut เท่ากับ 0.1 mm และระยะ Pitch เท่ากับ 0.5 mm ให้ผลที่ดีที่สุด ซึ่งทำให้ความหยาบผิวลดลงเป็นอย่างมาก ทำให้ไม่มีความจำเป็นต้องขัดด้วยมืออีกต่อไป ส่งผลให้ระยะเวลาทั้งหมดในกระบวนการปรับความเรียบผิวรวมถึงต้นทุนในการผลิตแม่พิมพ์ลดลง

สาขาวิชา	การจัดการทางวิศวกรรม	ลายมือชื่อนิสิต ....
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Surface roughness of a die is a crucial factor for making a high-quality car hood. This research thesis is made for improving die surface quality in die manufacturing process. If the performance of milling process is not enough, it consumes a lot of time for doing polishing and might result in poor die quality that does not meet customer's need. Therefore, the purpose of this research is to improve the CNC milling process. Tools used for milling and all relate parameters are studied in order to figure out the most appropriate condition for the finish milling process. Nowadays, a 1-blade cutting tool is used with 5,500-rpm Cutting speed, 4,800-mm/min Feed, 0.1-mm Dept. of cut, and 0.5-mm Pitch for doing the finish milling process.

Parameters in each machining condition designed by the program are inputted into the CNC machine for doing the milling process with a die specimen that is the same as actual of the company. All experiments are designed by the Surface Response Methodology; all parameters are analyzed by the program in order to find out the best parameters for use.

The result from this improvement shows that using a 3-blades tool with 11,670-rpm Cutting speed, 3,563-mm/min Feed, 0.1-mm Dept. of cut, and 0.5-mm Pitch literally provides the best result. This new machining condition significant decreases the surface roughness which brings about the elimination of polishing process, total time reduction, and cost reduction.

Field of Study:	Engineering Management	Student's Signature ....
Academic Year:	2018	Advisor's Signature ....

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Worachet Onngam

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CHAPTER 1 INTROTUCTION

This chapter represents the introduction to the research project including the research's background, its significances of research area, and the overview of a research's problem together with the research objective, scope of study, assumptions of the research, and expected outcomes.

1.1 Background of study

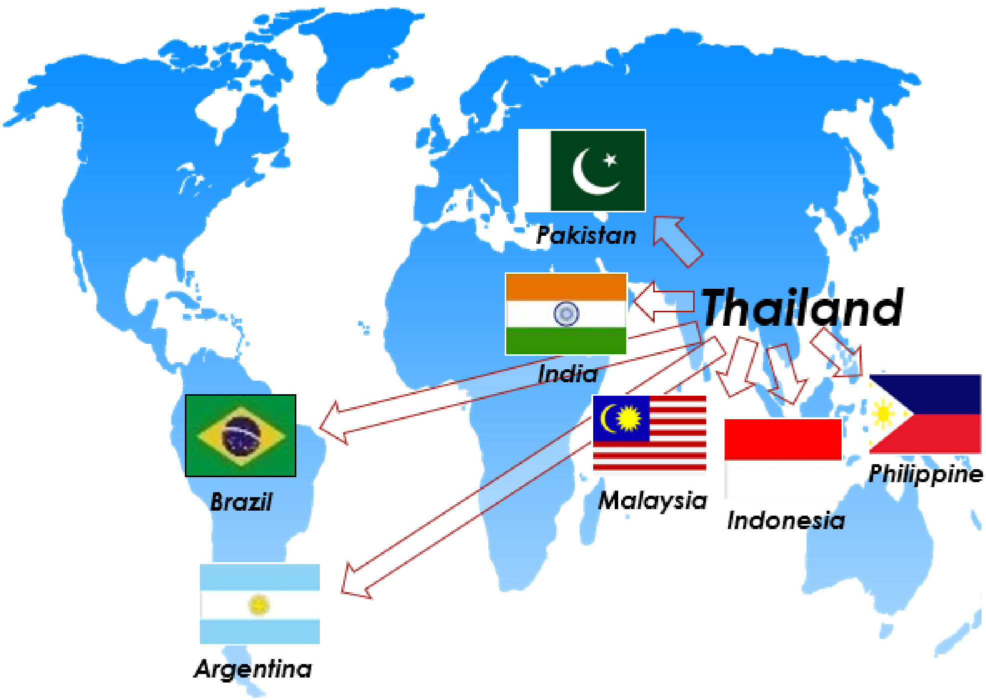


Figure 1.1 The company's international distribution

The researched firm is a leading manufacturer of medium and heavy-duty trucks across Asia Pacific Region (Hino Motors Manufacturing, 2019). As illustrated in Figure 1.1, the firm distributes lots of product for a car-leading producer in automobile industry around the world. Not only producing vehicles, the company also manufactures vehicle parts and prototyping dies as represented in Figure 1.2 and Figure 1.3 in which the products have to be optimally suited to customer needs.

Figure 1.2 Vehicle parts and Chassis

Figure 1.3 Prototyping die

1.2 Research Area

One of the most honorable products, which the company is very proud of, is a prototyping die that typically used in stamping process to make vehicle parts. Prototyping dies can be varyingly used for stamping many kinds of parts; however, the company is specialized in producing a die for stamping car hoods as depicted in Figure

1.4. Therefore, this thesis will focus on a problem related to the hood dies in the Die Production Department. The layout of the department is illustrated in Figure 1.5.

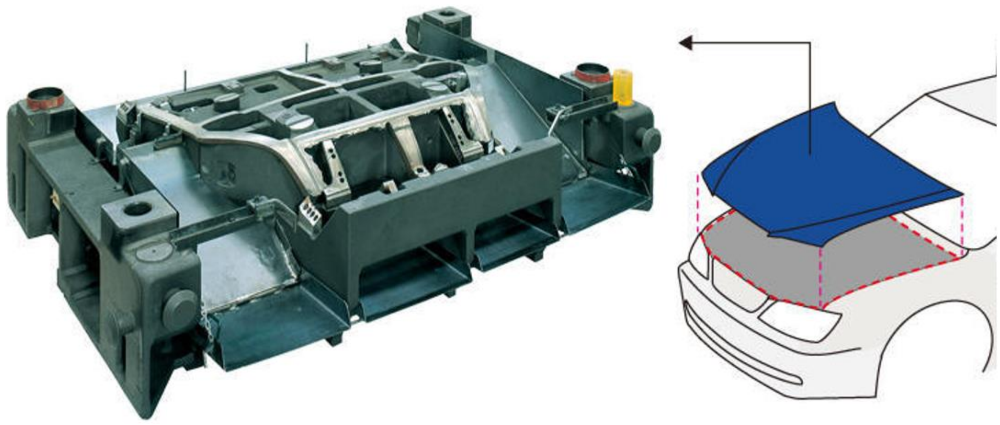


Figure 1.4 Hood Die

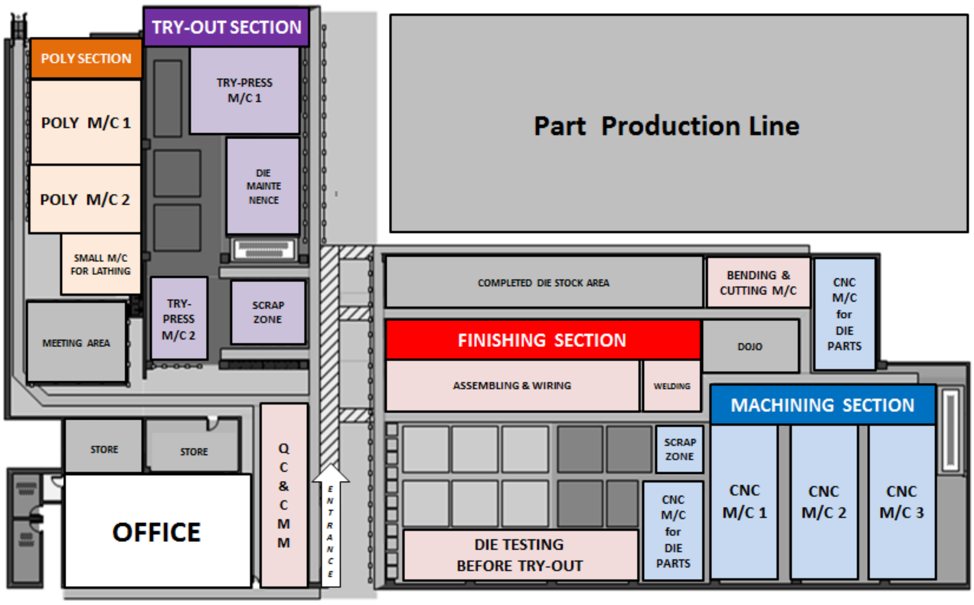


Figure 1.5 The department layout

Regarding the hood dies, there are two types of dies that typically manufactured which are a hood-inner and hood-outer die. In order to make a hood outer for use as a car hood, it is needed to produce three dies which are drawing, trimming, and flanging dies as revealed in Figure 1.6-1.8. The dies use with a hydraulic press to produce different types of parts as shown in Figure 1.9.

Figure 1.6 Drawing die

Figure 1.7 Trimming die

Figure 1.8 Flanging die

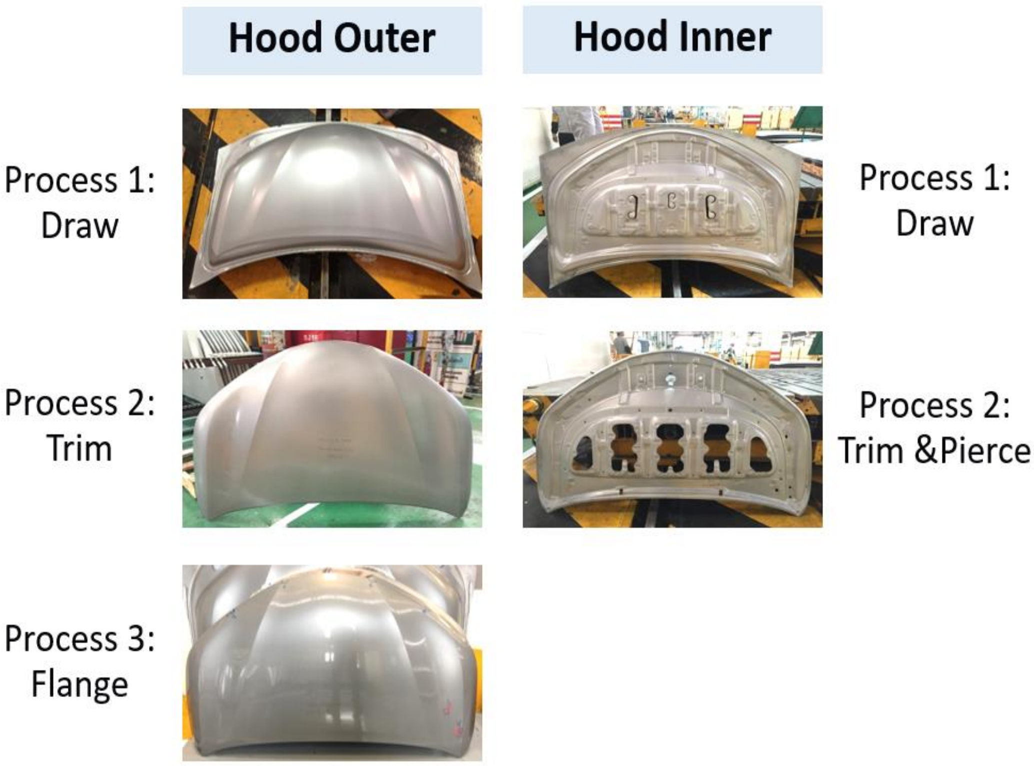


Figure 1.9 Stamping parts from each process

To manufacture dies, the department needs to schedule every die-making process, starting from designing a prototype by using CATIA program, writing CNC data for machining automated control, making prototyping foam for lost-foam casting, doing machining to ensure die accuracy, assembling die components and gleaning remain problems, and then doing the test of die performance before sending the products to customers as revealed in Figure 1.10.

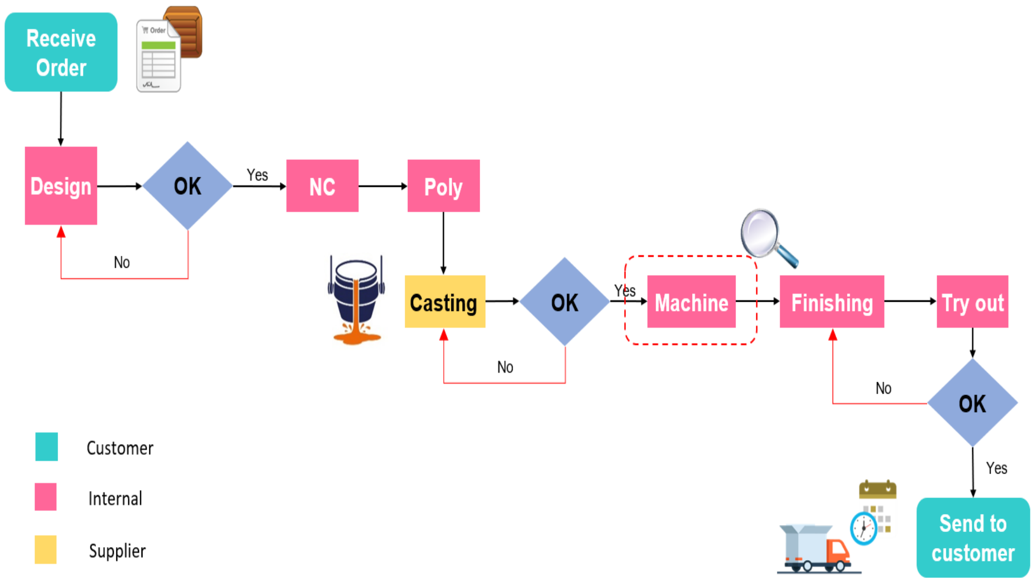


Figure 1.10 Die production flow process

In die manufacturing industry, the main production operation is regarded to the machining process. In the firm, there are three CNC machines that used for milling dies as depicted in Figure 1.11, 1.12, and 1.13. The CNC Machine 1 is normally used for angle machining. The CNC Machine 2 operates rough machining while the CNC Machine 3 is used for both semi-finish machining and finish machining.

Figure 1.11 CNC Machine 1

Figure 1.12 CNC Machine 2

Figure 1.13 CNC Machine 3

Figure 1.14 represents the overview of the machining process. The processes start after finish casting a die. The rough machining is the first process for the Machining Section. After finishing the rough machining, operators have to perform welding on the die's surface to improve the die's performance and increase the pressure tolerance of a die. Then, the welding bead is machined and blowholes are repaired in order to make the die's surface smoother. If everything is alright, the semi-finish and finish machining processes will start. After finishing all machining processes, the accuracy needs to be confirmed by the CMM as revealed in Figure 1.15. Then, the die will be sent to the Finishing Section in order to do polishing and assembling processes.

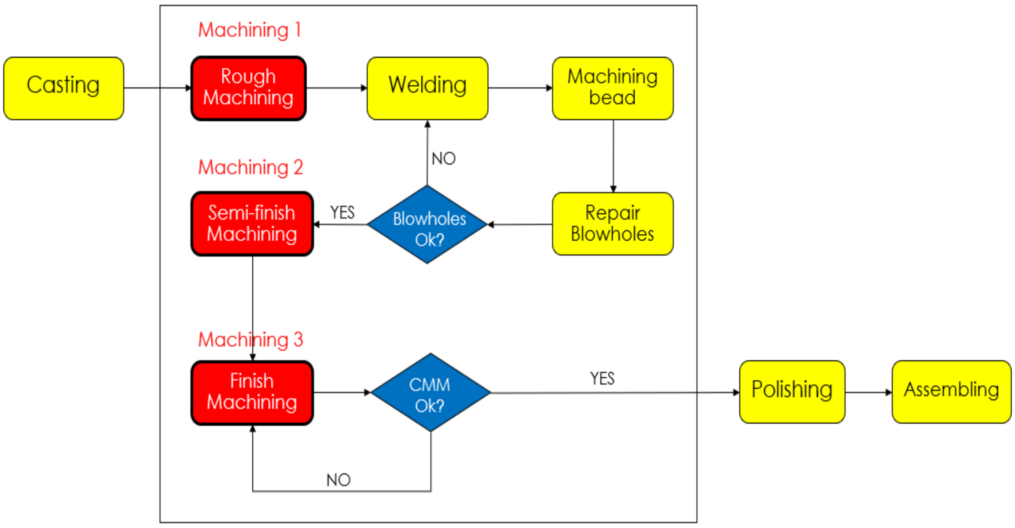


Figure 1.14 Machining flow chart

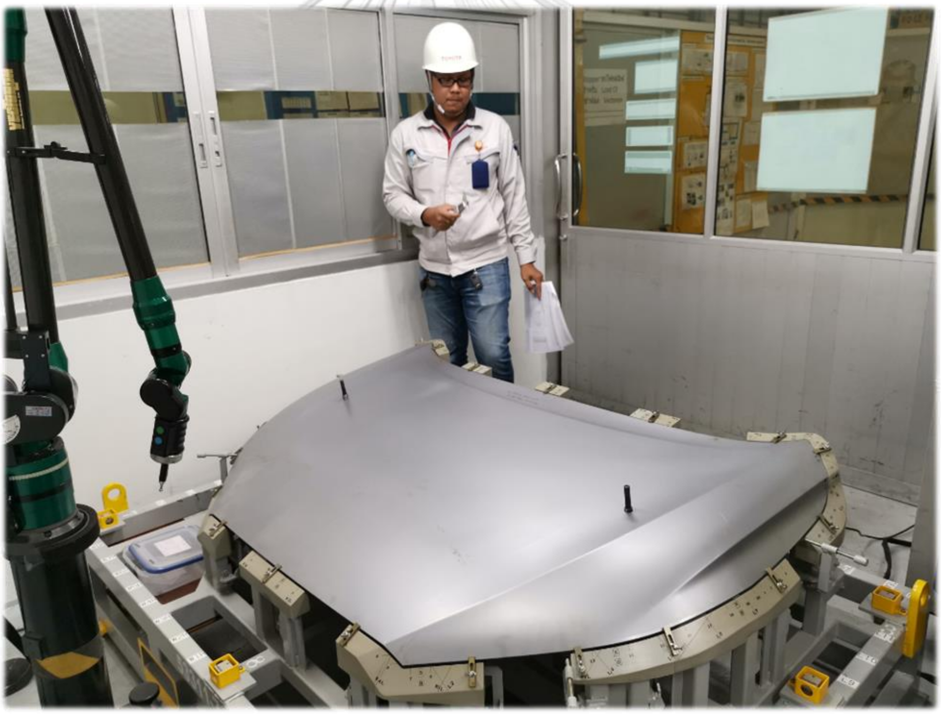


Figure 1.15 CMM check

With emphasis on the die milling process, there are two types of cutting tools that are typically used in die manufacturing, the 1-blade and 3-blades cutting tools. The 1-blade cutting tool has two cutting edges while the 3-blades cutting tools has four cutting edges as shown in Figure 1.16 and 1.17. The inserts of these tools are made from cemented carbides, type K, which normally used with FCD that is the material of the dies.

Figure 1.16 1-blade cutting tool (2 cutting edges)

Figure 1.17 3-blades cutting tool (4 cutting edges)

1.3 Statement of the Problem

In die-making process, die's surface is always unsmooth due to a machining issue as illustrated in Figure 1.18. This problem can be generally seen by looking with the naked eyes. The occurrence of it is obviously on both hood inner and hood outer die surface.

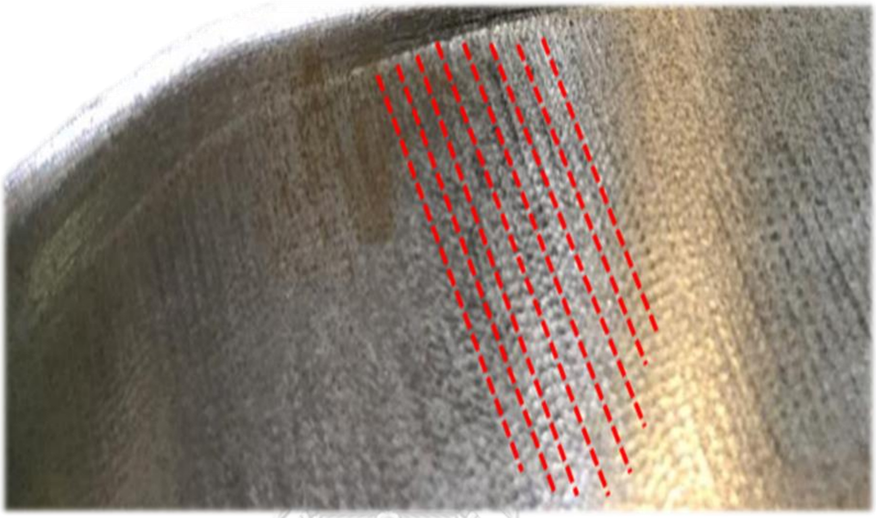


Figure 1.18 Unsmooth surface roughness

However, only the hood outer part is significantly concerned about roughness quality because it is in seeable area when assembling with a car. In other words, there is no problem with emphasis on the surface quality in the hood inner die. Regarding the hood-outer dies, there is only drawing die that affects part's surface quality due to the surface pressure and transformation as shown in Figure 1.19 while the trimming and flanging dies are cutting and folding processes that do not impact on the surface quality. As shown in Figure 1.19, 100% of hood-outer drawing dies have to be polished after finishing the machining process.

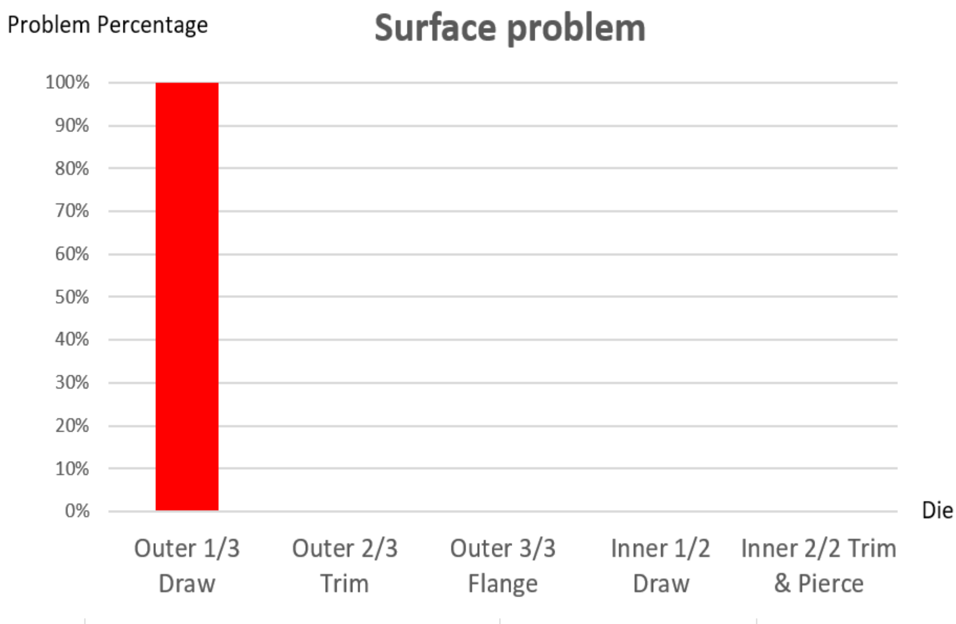


Figure 1.19 Problem percentage in each process

It has been thought that a Finishing Section (F/N) should do the polishing processes every time after machining as revealed in Figure 1.20. Nevertheless, the author realizes that the polishing processes can be eliminated to reduce production lead time if there is a decent machining procedure.

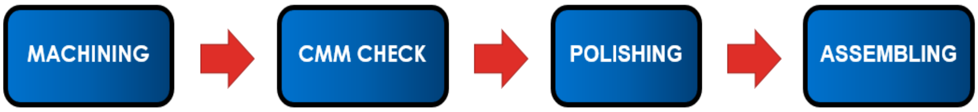


Figure 1.20 Machining flow process

Additionally, there is no collected data of surface roughness after doing machining process. Since there is no such developing implementation about surface quality, the department does not have any standards to decide whether the roughness after machine is good enough or not. Therefore, the department decides to assign this project in order to maximize customer satisfaction.

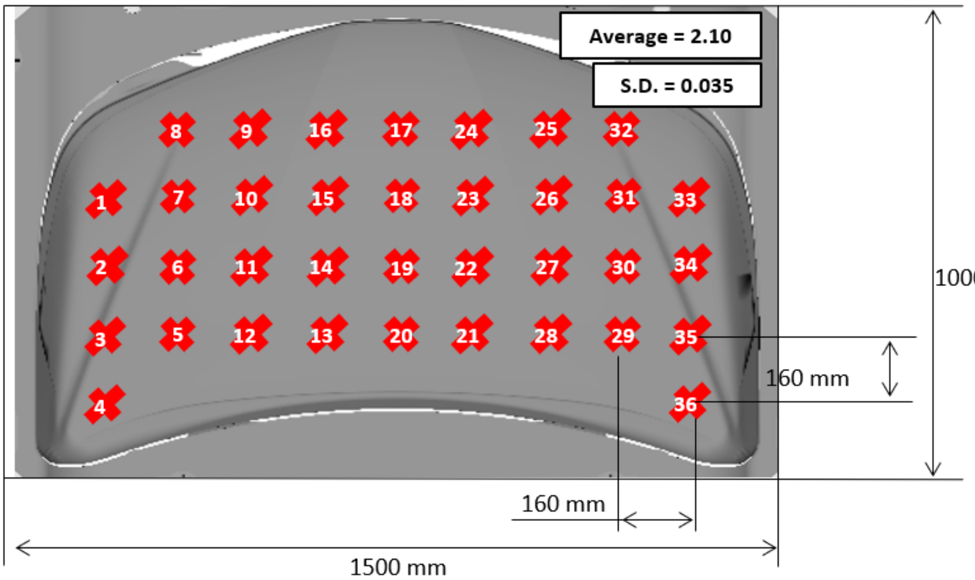


Figure 1.21 Die surface roughness after machining

After collecting surface roughness data as revealed in Figure 1.21, it is actually found out that the average surface quality of the company's die is around 2.10 micron which is lagging far behind from the surface roughness after manual polishing. To make the surface smooth, Finishing Section has to spend 540 minutes to polish a die (1000 x 1500 mm) of which the process affects the man-hour cost significantly. After polishing die surface roughness is declined to 1.10 micron as shown in Figure 1.22.

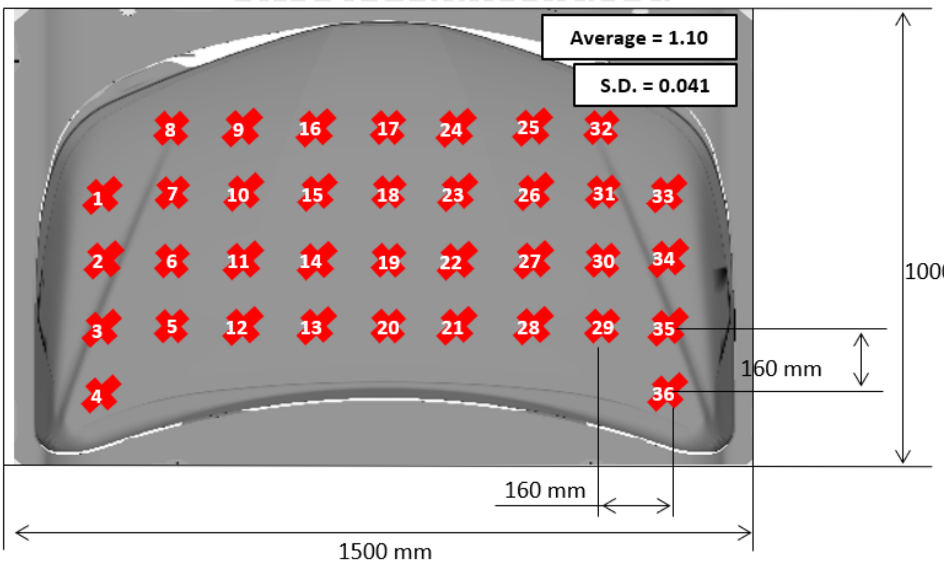


Figure 1.22 Die surface roughness after polishing

1.4 Research Objective

The objective of this research is to implement a machining standard for a die manufacturing operation to improve die surface quality and minimize lead time and cost in die production process by eliminating a polishing process.

1.5 Scope of the Research

This research project focuses on a die manufacturing company which producing prototypes for stamping vehicle parts. The research mainly involves machining process, its cutting tool and CNC data including feed, speed, pitch, and dept of cut. In this research, two types of cutting tools, which are the 1-blade and 3-blades, will be tested. The CNC Machine 3 that used for doing a finish machining which relatively affects the surface quality will be focused.

1.6 Assumption of the Study

1. The machine reaches its maximum accuracy due to machining calibration.

2. There is no error from the machine due to machining inspection and maintenance.

3. External factors cannot affect the machining operation.

1.7 Expected Benefits

The following is the summary of expected beneficial outcomes.

1. The appropriate cutting tool will be defined for finish machining process.

2. The best machining condition will be applied for use

3. The machining standard will be properly implemented.

4. The polishing processes will be eliminated.

5. Lead time in die production process will decrease.

6. Operational cost in die manufacturing will be reduced.

1.8 Methodology

In order to successfully implement the standard, it is necessary to figure out the proper CNC data and cutting tool that matches with the milling machine by following these steps.

1. Collect all relate data and measure the current die surface roughness
2. Make a die specimen that has the same condition as the current die for test
3. Do experiments to see each factor affects die surface roughness in what way
4. Use RSM to find out the optimized machining condition for the best surface roughness
5. Verify that the new machining condition can be used for the actual production
6. Implement the new milling standard for the organization

CHAPTER 2 LITERATURE REVIEW

This chapter reviews existing literatures including theories, tools, and techniques to be used in this research thesis.

2.1 Die Manufacturing for Automobile

Typically, the goal of stamping enterprises is to be the lowest cost manufacturers, with the best quality (Smith, 2001). Processes, parameters, and tools are very important points to be considered. All relate theories are explained in this chapter.

2.1.1 Type of stamping presses

According to Lim, Venugopal, and Ulsoy (2014), there are two main types of stamping presses used for sheet metal stamping process, Mechanical presses and Hydraulic Presses. They explain that "the Mechanical presses use a linked-drive powered by an electric motor to drive the punch while the Hydraulic presses use hydraulic cylinders to drive the punch". The structure of Hydraulic Presses is shown in Figure 2.1.

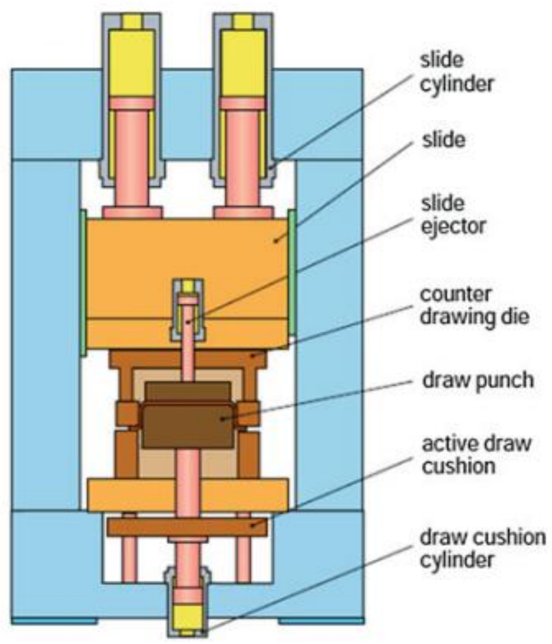


Figure 2.1 The structure of Hydraulic Presses

2.1.2 Type of dies in automotive industry

Every die is normally used for stamping a sheet material which called a blank as shown in Figure 2.2. In automotive industry, the main forming operations accomplished with press mounted dies are drawing, trimming, piercing, flanging, and hemming.

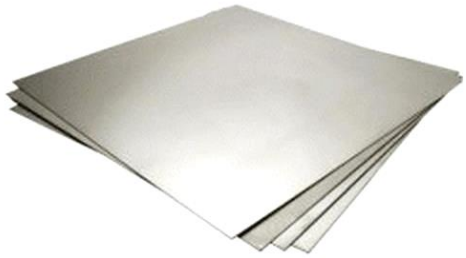


Figure 2.2 Blank for a stamping process

A blank used for producing car's parts is typically stamped by using drawing, trimming, piercing, flanging dies. The first step to make finished stamped parts is to stretch or draw a blank into the die cavity by a drawing die (Smith, 2001). After forming a blank into the die shape, the next step is to cut out unwanted material from the edges by a trimming & piercing die. Then, a trimming die is used to provide a more finished appearance, and edge strengthening. Last but not least, if a part needs to be attached with another part (For example – hood inner and hood outer), a hemming die will be used for attaching them, form smooth and rounded edges.

In fact, the *stamping* process plays a major role in determining the efficiency of *automotive* body *part* production. The key automotive parts that typically produced by stamping process are the sunroof, hoods, fender, doors, quarter, and trunk as depicted in Figure 2.3.

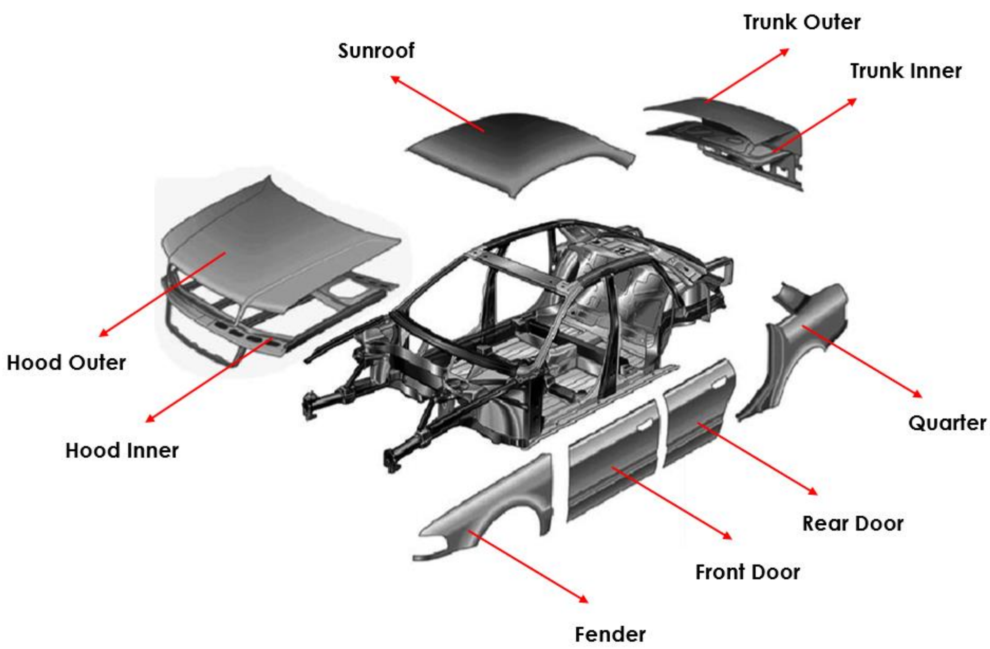


Figure 2.3 Vehicle stamping parts

2.2 Machining Parameters

Milling is one of the most operations that CNC machines usually do. It is a machining process for generating machined surfaces by removing material from the workpiece. Walsh (2002) states that "the milling process employs relative motion between the workpiece and the rotating cutting tool to generate the required surfaces". Parameters that mainly affects the operation are rotation of the cutter (cutting Speed), feed rate, and number of the cutter teeth, defined as

$$f = F_t N C_{rpm} \quad \text{------------------------- (1)}$$

where, f = feed rate, ipm

N = number of cutter teeth

Crpm = rotation of the cutter, rpm

Ft = feed per tooth (chip thickness)

2.3 Cutting tool

2.3.1 Tool materials

Davim (2008) claims that there are many kinds of tool materials used in industry nowadays such as carbide, ceramics, Cubic Boron Nitride (CBN), Polycrystalline Diamond (PCD) and Solid Film Diamond (SFD). Carbide as a tool material was first discovered with excellent wear resistance and high hot hardness for replacing expensive diamond. As a matter of fact, there are many kinds of carbide tool materials, including cermet carbides, tungsten carbides, and titanium carbides. One of the widest used carbides called cemented carbide which are classified into three grades (Smith, 2008), as depicted in Figure 2.4.

Cutting conditions	Code	Colour
Finishing steels, high cutting speeds, light cutting feeds, favourable work conditions	P01	Blue
Finishing and light roughing of steels and castings with no coolant	P10	
Medium roughing of steels, less favourable conditions. Moderate cutting speeds and feeds.	P20	
General-purpose turning of steels and castings, medium roughing	P30	
Heavy roughing of steels and castings, intermittent cutting, low cutting speeds and feeds	P40	
Difficult conditions, heavy roughing/intermittent cutting, low cutting speeds and feeds	P50	
Finishing stainless steels at high cutting speeds	M10	Yellow
Finishing and medium roughing of alloy steels	M20	
Light to heavy roughing of stainless steel and difficult-to-cut materials	M30	
Roughing tough skinned materials at low cutting speeds	M40	
Finishing plastics and cast irons	K01	Red
Finishing brass and bronze at high cutting speeds and feeds	K10	
Roughing cast irons, intermittent cutting, low speeds and high feeds	K20	
Roughing and finishing cast irons and non-ferrous materials. Favourable conditions	K30	

Figure 2.4 The classification of cemented carbide

Smith (2008) explains that the cemented carbide is categorized by the usages.

• P (blue) – "highly alloyed workpiece grades for cutting long-chipping steels and malleable irons"

• M (yellow) – "lesser alloyed grades for cutting ferrous metals with long, or short chips, cast irons and non-ferrous metals"

• K (red) – "is 'conventional' tungsten carbide grades for short-chipping grey cast irons, non-ferrous metals and non-metallic materials"

2.3.2 Tool wear

According to Davim (2008), there are 9 types of tool wear that always occur on cutting tools: 1. Flank wear 2. Crater wear 3. Plastic deformation 4. Notch wear 5. Thermal cracking 6. Mechanical fatigue cracking 7. Chipping 8. Fracture 9. BUF as illustrated in Figure 2.5.

He also explains that flank wear and crater wear are the most important measured forms of tool wear. Altintas (2012) claims that "crater wear occurs at the tool–chip contact area where the tool is subject to a friction force of the moving chip under heavy loads and high temperatures" while "flank wear is caused by friction between the flank face (primary clearance face) of the tool and the machined workpiece surface"

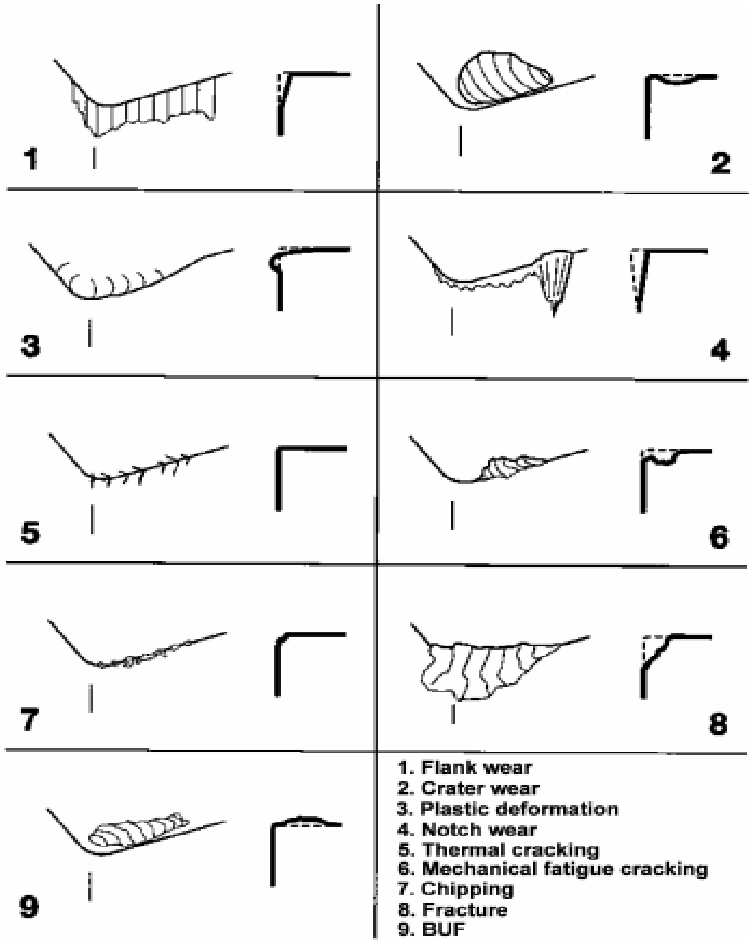


Figure 2.5 Types of tool wear on cutting tools (Davim, 2008)

2.3.3 Tool life

Almost all types of wears significantly relate to the tool life. Davim (2008) states that "Tool wear is almost always used as a lifetime criterion because it is easy to determine quantitatively". As a matter of fact, tool life is very crucial for machining processes because it significantly affects surface roughness, and the accuracy of workpieces. The Taylor's Tool Life Formula is represented as

$$V_c T^n = C \qquad \text{------------------------- (2)}$$

where, Vc is the cutting speed (m/min),

T is the tool life (min) taken to develop a certain flank wear (VBB),

n is an exponent that depends on the cutting parameters,

and C is a constant.

2.4 DOE

Nowadays, the use of statistical methods in industry is rising. One of the most beneficial improvement methods is statistical design of experiments (DOE) which is a designing method that used for identifying relationships between various input variables and output responses. (JMP, 2004). It is very beneficial for use in R & D purposes. In this research, Response Surface Method (RSM) will be focused to ensuring the experimental designs.

2.4.1 RSM

Response surface methodology (RSM) is an integration of mathematical and statistical subjects which are beneficial for the analysis of issues. In fact, it is one of the most important statistical techniques used for design and development. The method is not only beneficial for developing and improving, but it also good for optimizing processes (Myers, Montgomery, and Anderson-Cook, 2009). It is capable of establishing causal relationships between input and output variables.

For ‘n’ number of measurable input variables, the response surface can be given as –

$$Y = f(x_1, x_2, x_3, x_4 \ldots x_n) + \varepsilon \qquad \text{--------------------} \ (3)$$

Where, $x_1 \ldots x_n$ are the independent input parameters and ε is the random error.

Y is the output or response variable which has to be optimized.

In a milling operation with three input variables, the response function can be written as–

$$Y = f(x_1, x_2, x_3) + \varepsilon \qquad \text{------------------------} \ (4)$$

Where, x_1 = log V c, x_2 = log f, and x_3 = log d. Y = log Ra and ε is the random error.

RSM is generally employed through multiple regression models. Our goal is to find a suitable approximation for the response function which can be achieved by the regression models.

For example, the first order or linear multiple regression model can be used –

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \varepsilon \qquad \text{---------------------- (5)}$$

For better approximation, interaction terms can be included –

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon \qquad \text{------ (6)}$$

The second order or quadratic regression model includes the square terms–

$$Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{11} x_1^2 + \beta_{22} x_2^2 + \beta_{33} x_3^2 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \varepsilon \qquad \text{-- (7)}$$

2.5 Process Capability

Cp is process capability indice, which provides the relationships between the actual process performance and the specifications. It is used for quality assurance and process capability analysis for the last 20 years (Pearn and Kotz ,2006), defined as

$$C_p = \frac{USL - LSL}{6\sigma} \qquad \text{------------------------------ (8)}$$

where, USL is the upper specification limit,
LSL is the lower specification limit,
and σ is the process standard deviation

The Specification interval vs process spread for the normal distribution is illustrated in Figure 2.6. According to the Figure, there are lower and upper specification limits (LSL and USL). Any values outside these limits are considered as 'nonconforming' (Kotz and Johnson, 1993).

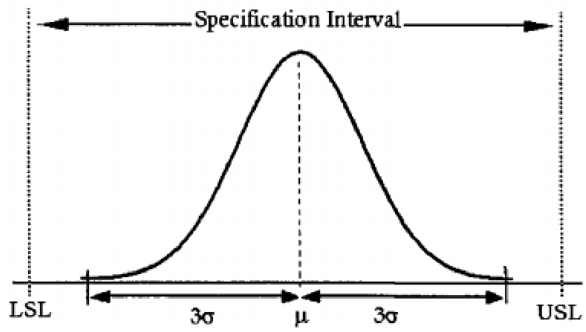


Figure 2.6 Specification interval vs process spread for the normal distribution (Pearn and Kotz ,2006)

Cp is very useful for analysis; however, Pearn and Kotz (2006) state that "it cannot reflect the tendency of process targeting and gives no indication of the actual process performance", meaning that it has some drawbacks when applying for the actual use. Polhemus (2018) claims that Cp has two major drawbacks which are 1. Cannot be calculated when dealing with one-sided specifications 2. Possible to get acceptable although much of the data is out of spec. Due to these disadvantages, *Cpk*, whichever

specifiation limits are presented, is more proper for use. *Cpk* is defined as:

$$C_{pk} = \min\left\{\frac{USL-\mu}{3\sigma}, \quad \frac{\mu-LSL}{3\sigma}\right\} \qquad \text{----------------------(9)}$$

where, USL is the upper specification limit,

LSL is the lower specification limit,

μ is the process mean

and σ is the process standard deviation

CHAPTER 3 RESEARCH METHODOLOGY

This chapter provides an overview of a methodology used to achieve research objectives and also the way to set up experiments, collect data, and doing analysis. Additionally, all relate information is also provided in this chapter, including specimen's chemical composition, tool's limitation and machine's limitation.

3.1 Collect data and measure surface roughness

Table 3.1 Current machining condition

Condition	Tool	Cutting Speed (rpm)	Feed (mm/min)	Dept. (mm)	Pitch (mm)	CT (minute)	Ra (micron)	S.D. (Ra)
Current	**1-Blade**	5500	4800	0.1	0.5	208	2.10	0.035

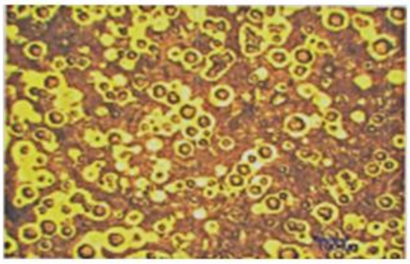
Table 3.1 shows the current machining condition that used for the finish machining process.

3.2 Making the die specimen

Figure 3.1 Die specimen for machining test

According to Figure 3.1, a die specimen is prepared for doing the machining test following the experimental conditions. The materials and chemical compositions are exactly the same as the current die conditions produced by the company (FCD 540) as illustrated in Table 3.2.

Table 3.2 Die chemical compositions

MATERIAL			PART NAME : HOOD		
Chemical Composition (%)	**Standard**	**Actual**	**Mechanical Properties**	**Standard**	**Actual**
C	3.000 - 4.000	3.404	Tensile Strength (N/mm2)	540 Minimum	565
Si	1.800 - 3.000	2.072			
Mn	1.000 Maximum	0.517	Hardness (HS, Casting)	28 - 39	30
P	0.120 Maximum	0.001			
S	0.020 Maximum	0.002	Elongation (%)	3.00 Minimum	4.95
Mg	0.030 - 0.090	0.060			
Microstructure	**Standard**	**Actual**			
Pearlite (%)	-	80%			
Ferrite (%)	-	20%			
Graphite Type	Spheroidal	Spheroidal			
Nodularity (%)	80% Minimum	90%			
Matrix Structure	Pearlite-Ferrite	Pearlite-Ferrite			

3.3 Do experiments to see factor's effect

Machine Limit

M/C Limit	Speed	Feed
Max	12,000	15,000
Min	500	500
	(rpm)	mm/min

Figure 3.2 Machine limitation

There are two types of tools which are the 1-bade and 3-baldes for use in this experiment. To make a proper machining condition for the test, the tools' feed and speed should not be over their limits and machine limits. The maximum and minimum feed and cutting speed of the machine and tools are revealed in Figure 3.2 and 3.3.

Limit Speed (rpm)		
Tool types	Min	Max
1 Blade	1,810	7,640
3 Blades	5,940	11,670

Limit Feed (mm/min)		
Tool types	Min	Max
1 Blade	2,170	9,170
3 Blades	4,750	11,670

Figure 3.3 Feed and speed limitation of tools

In order to figure out which factors affect the surface roughness and which tool has superior performance, both cutting tools need to test in the same condition. The main purposes of this experiment are to see the factor's effect and cut out some factors that are not significant to the surface roughness. Since both 1-blade and 3-baldes tools are tested in the same condition through their limitations, another experiment will be required for finding the best machining condition optimized by RSM.

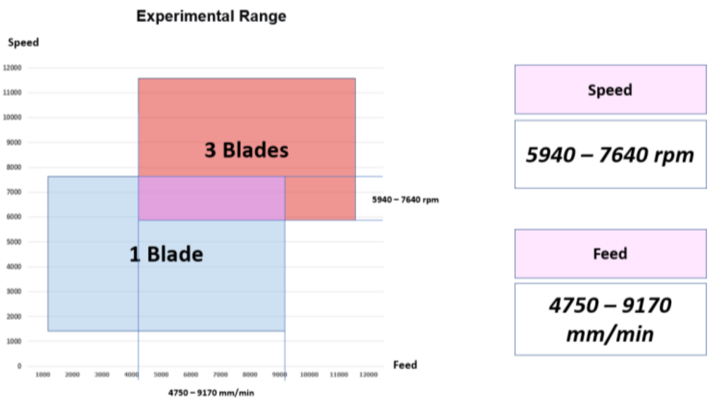


Figure 3.4 Feed and speed used in the 1 blade VS 3 blades experiment

According to Figure 3.4, these cutting tools will be tested at the speed from 5,940 rpm to 7,640 rpm and the feed from 4,750 mm/min to 9,170 mm/min.

Figure 3.5 Surface roughness measuring

Surface roughness is precisely measured by a QC engineer, using a profilometer as shown in Figure 3.5. Every measured position in the experiment will be done by this person only to ensure that the human error will not be affect to the operation.

After doing each machining test, the surface roughness will be measured and collected for use to analyze as shown in Figure 3.6.

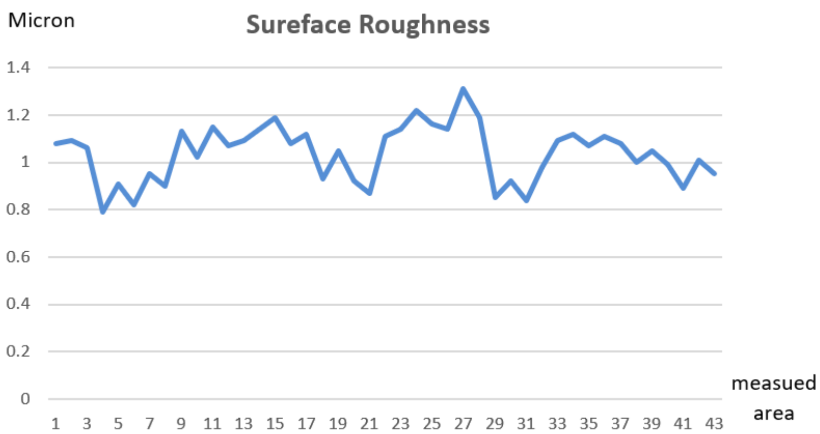


Figure 3.6 Surface roughness analysis

If the roughness does not remarkably increase, it can be concluded that the milling process causes very small tool wear. Hence, there is no need to measure the tools. However, if the roughness tends to increase, the cutting tool's measurement is required.

3.4 Use RSM to optimize machining condition

After knowing the effect of each factor and cutting out some factors that are not significant to the surface roughness, another experiment is outlined by using MINITAB to make the design of experiment for the machining test. After doing the design of experiment and preparing everything, the next steps are machining following each experimental condition and collect the surface roughness results to see which tool is more effective for the operation. The program will help analyze the best machining condition that is most appropriate for the finish machining process.

3.5 Verify the new machining condition

In order to confirm that the new machining condition can be use in the actual production, it is very needed to apply the new condition to test with the die specimen for many times to ensure that the results of the new condition will be the same and not over specification limits.

3.6 Implement the new milling standard

The last step after verifying that the new condition can use with the actual production is to set it as a new milling standard. An appointment needs to be arranged in order to make everyone understand about the purpose of this implementation and work in the same direction. All relate persons including managers and supervisors have to be able to manage this new procedure, applying it throughout the organization.

CHAPTER 4 DATA COLLECTION & RESULTS

In this chapter, a preparation for an experiment is described to illustrate experimental conditions and surroundings before doing the experiment and collect data. All related factors are analyzed in order to figure out the potential influences when parameters change.

4.1 Preparation for experiments

4.1.1 A die specimen

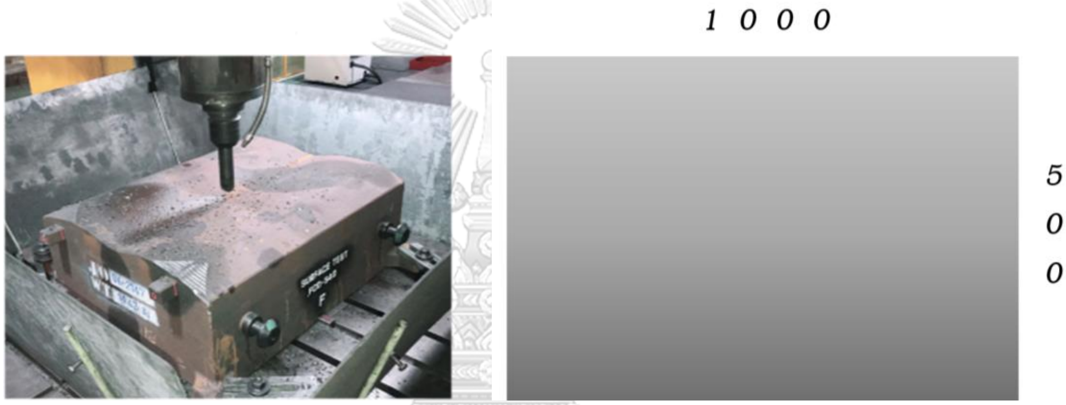


Figure 4.1 The die specimen, size 500x1000 mm

Prior to do experiments and collect data, a die specimen is made following the current die conditions. The specimen size is 500x1000 mm, three times smaller than the actual die as depicted in Figure 4.1. The material compositions and shape of this specimen is quite the same as the actual die.

As aforementioned in Figure 1.16 and 1.17, there are only two types of milling tools to be considered, the 1-balde and 3-blades, due to their worthwhile quality, price, and performance. These two tools are from the same suppliers and have made from the same chemical compound, carbide.

4.1.2 Parameters and experimental condition

Parameters that might be related to the die surface roughness are cutting speed, feed, dept. of cut, pitch, and cutting angle. However, these two tools have the same cutting angle, so that there is no need to consider about it. Hence, there are five factors to be analyzed in this analysis, cutting tool, cutting speed, feed, dept. of cut, and pitch.

According to Figure 3.4, the tool's limits of both tools are not the same; in order to analyze the factors efficiently, it is very needed to set both tools in the same condition. All factors and their ranges to be analyzed are shown in Table 4.1.

Table 4.1 Factors and common ranges to be analyzed in the analysis

Factor name		MAX	MIN	UNIT	Factor type
1	Tool Types (cutting blade)	3	1	Pcs	Qualitative
2	Speed	7640	5940	rpm	Quantitative
3	Feed	9170	4750	mm/min	Quantitative
4	Dept. of cut	0.2	0.1	mm	Quantitative
5	Pitch	1	0.5	mm	Quantitative

According to Table 4.1, there are one qualitative factor which is tool types (1, 3 blade) and four quantitative factors, cutting speed (5,940-7,640 rpm), feed (4,750-9,170 mm/min), dept. of cut (0.1, 0.2 mm), and pitch (0.5, 1 mm). The experimental conditions are carried out by using a full factorial design as illustrated in Table 4.2. Since the 2^k refers to the basis of this design, the total numbers of conditions in this experiment is 32 (2^5). The purpose of this experiment is to know the tendency of surface roughness when the parameters change.

Table 4.2 1-balde VS 3-blades experimental conditions

No.	blade	speed	feed	Feed per tooth	Dept.	pitch
1	1	5940	4750	0.40	0.1	0.5
2				0.40		1
3				0.40	0.2	0.5
4				0.40		1
5			9170	0.77	0.1	0.5
6				0.77		1
7				0.77	0.2	0.5
8				0.77		1
9		7640	4750	0.31	0.1	0.5
10				0.31		1
11				0.31	0.2	0.5
12				0.31		1
13			9170	0.60	0.1	0.5
14				0.60		1
15				0.60	0.2	0.5
16				0.60		1
17	3	5940	4750	0.20	0.1	0.5
18				0.20		1
19				0.20	0.2	0.5
20				0.20		1
21			9170	0.39	0.1	0.5
22				0.39		1
23				0.39	0.2	0.5
24				0.39		1
25		7640	4750	0.16	0.1	0.5
26				0.16		1
27				0.16	0.2	0.5
28				0.16		1
29			9170	0.30	0.1	0.5
30				0.30		1
31				0.30	0.2	0.5
32				0.30		1
		(rpm)	(mm / min)	(mm / tooth)	(mm)	(mm)

4.2 The 1-balde VS 3-blades experiment

After preparing the specimen, tools and conditions, the experiment is started. While doing the experiments, operators have to adjust parameters and change tools, following the conditions in Table 4.2 as represented in Figure 4.2.

Figure 4.2 Machining operation and parameter adjustment

After finishing each condition, a QC person has to measure of the 12 points of surface roughness as revealed in Figure 4.3, including cycle time of each operation for use in the analysis.

Figure 4.3 Surface Roughness Measurements

Table 4.3 Data collection from "the 1-balde VS 3-blades experiment"

No.	blade	speed	feed	Feed per tooth	Dept.	pitch	CT	Ra	SD
1	1	5940	4750	0.40	0.1	0.5	211	**2.06**	0.033
2	1	5940	4750	0.40	0.1	1	105	**2.47**	0.019
3	1	5940	4750	0.40	0.2	0.5	211	**2.26**	0.043
4	1	5940	4750	0.40	0.2	1	105	**2.50**	0.020
5	1	5940	9170	0.77	0.1	0.5	109	**2.70**	0.016
6	1	5940	9170	0.77	0.1	1	55	**2.88**	0.016
7	1	5940	9170	0.77	0.2	0.5	109	**2.80**	0.014
8	1	5940	9170	0.77	0.2	1	55	**2.94**	0.013
9	1	7640	4750	0.31	0.1	0.5	211	**1.39**	0.032
10	1	7640	4750	0.31	0.1	1	105	**2.03**	0.012
11	1	7640	4750	0.31	0.2	0.5	211	**1.69**	0.040
12	1	7640	4750	0.31	0.2	1	105	**2.29**	0.017
13	1	7640	9170	0.60	0.1	0.5	109	**2.18**	0.014
14	1	7640	9170	0.60	0.1	1	55	**2.60**	0.018
15	1	7640	9170	0.60	0.2	0.5	109	**2.51**	0.016
16	1	7640	9170	0.60	0.2	1	55	**2.77**	0.011
17	3	5940	4750	0.20	0.1	0.5	211	**2.28**	0.026
18	3	5940	4750	0.20	0.1	1	105	**2.52**	0.012
19	3	5940	4750	0.20	0.2	0.5	211	**2.39**	0.042
20	3	5940	4750	0.20	0.2	1	105	**2.58**	0.018
21	3	5940	9170	0.39	0.1	0.5	109	**2.54**	0.014
22	3	5940	9170	0.39	0.1	1	55	**2.80**	0.016
23	3	5940	9170	0.39	0.2	0.5	109	**2.68**	0.016
24	3	5940	9170	0.39	0.2	1	55	**2.75**	0.015
25	3	7640	4750	0.16	0.1	0.5	211	**1.83**	0.030
26	3	7640	4750	0.16	0.1	1	105	**2.36**	0.013
27	3	7640	4750	0.16	0.2	0.5	211	**1.92**	0.037
28	3	7640	4750	0.16	0.2	1	105	**2.50**	0.018
29	3	7640	9170	0.30	0.1	0.5	109	**2.05**	0.017
30	3	7640	9170	0.30	0.1	1	55	**2.38**	0.012
31	3	7640	9170	0.30	0.2	0.5	109	**2.21**	0.016
32	3	7640	9170	0.30	0.2	1	55	**2.65**	0.012
		(rpm)	(mm / min)	(mm / tooth)	(mm)	(mm)	(Min)	(Micron)	

Table 4.3 reveals the results of cycle time, average surface roughness, and standard deviation (S.D.) of roughness in each experimental condition. Performance of the 1-blade and 3-blades tools seem to be different when parameters change; however, it is still not clear which factors affect to the surface roughness and in what way. Therefore, every entire factor needs to be analyzed in order to clarify the surface roughness trends.

4.3 The 1-balde VS 3-blades experiment analysis

Figure 4.4-4.12 show the surface roughness trends of 1-blade and 3-blades tools when cutting speed, feed, dept. of cut, and pitch change.

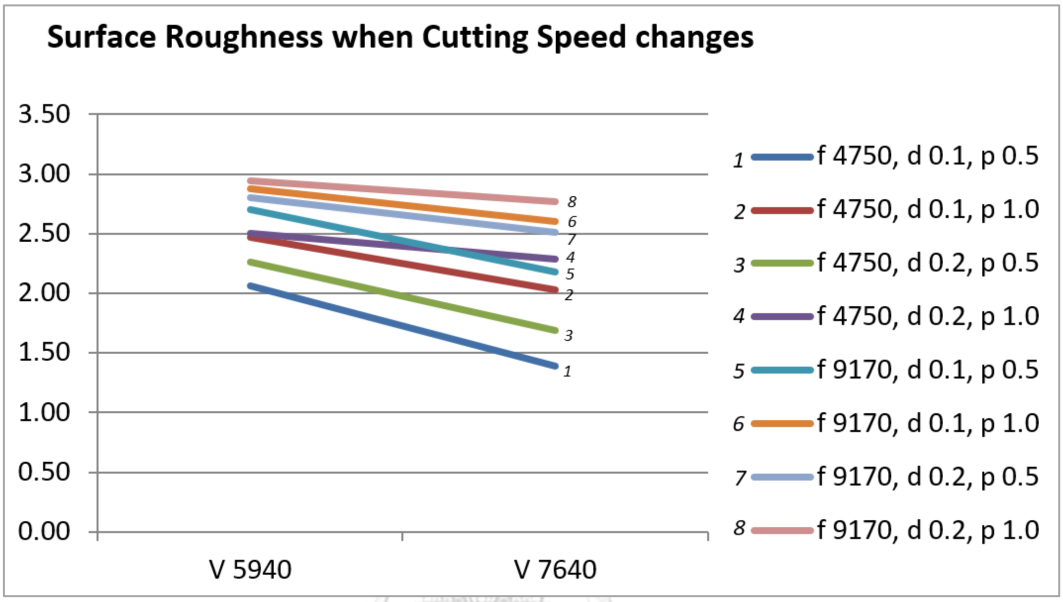


Figure 4.4 1-blade surface roughness trends when cutting speed changes

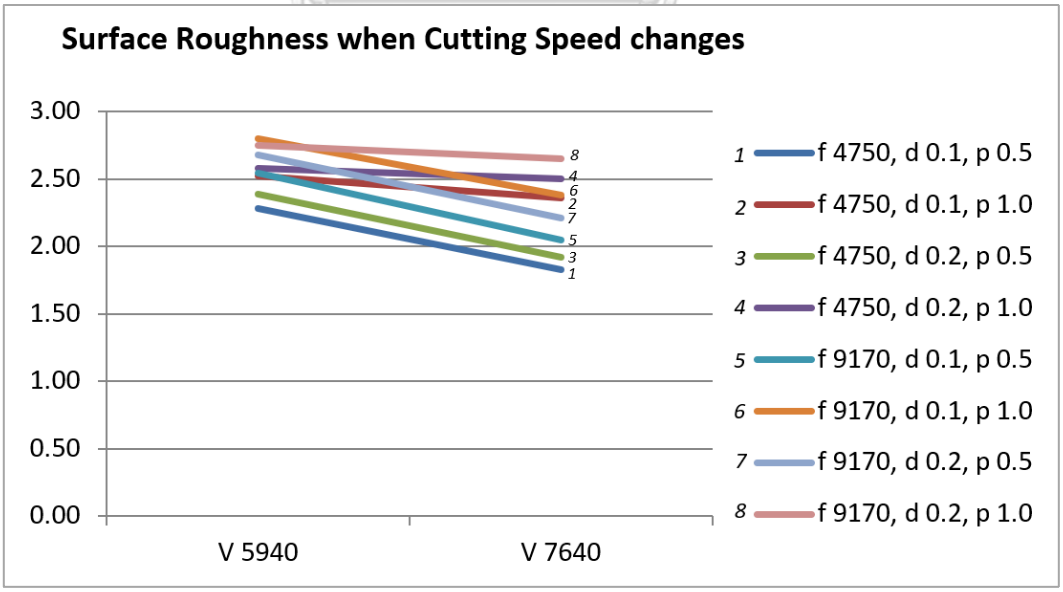


Figure 4.5 3-blade surface roughness trends when cutting speed changes

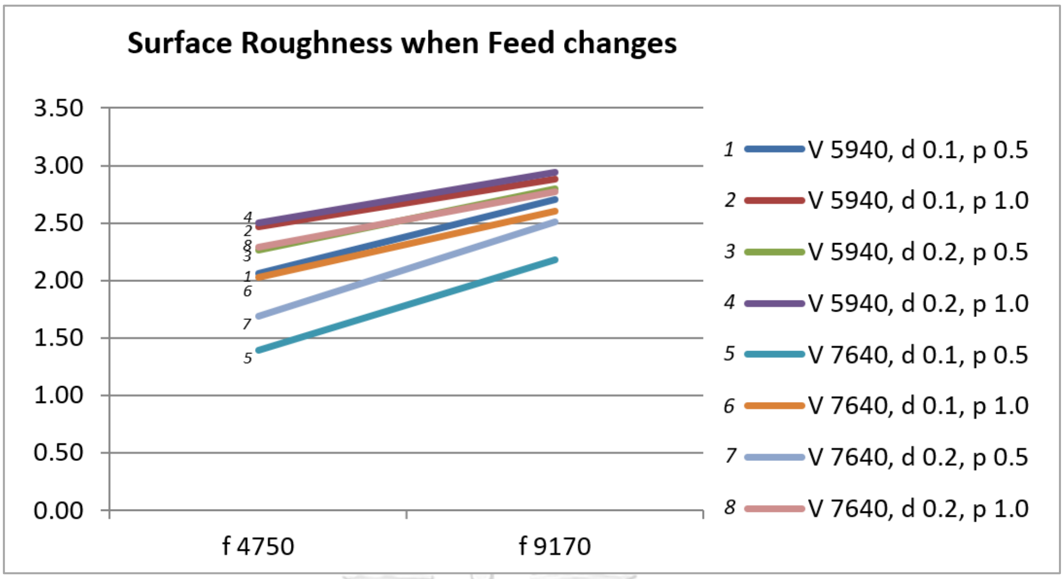


Figure 4.6 1-blade surface roughness trends when feed changes

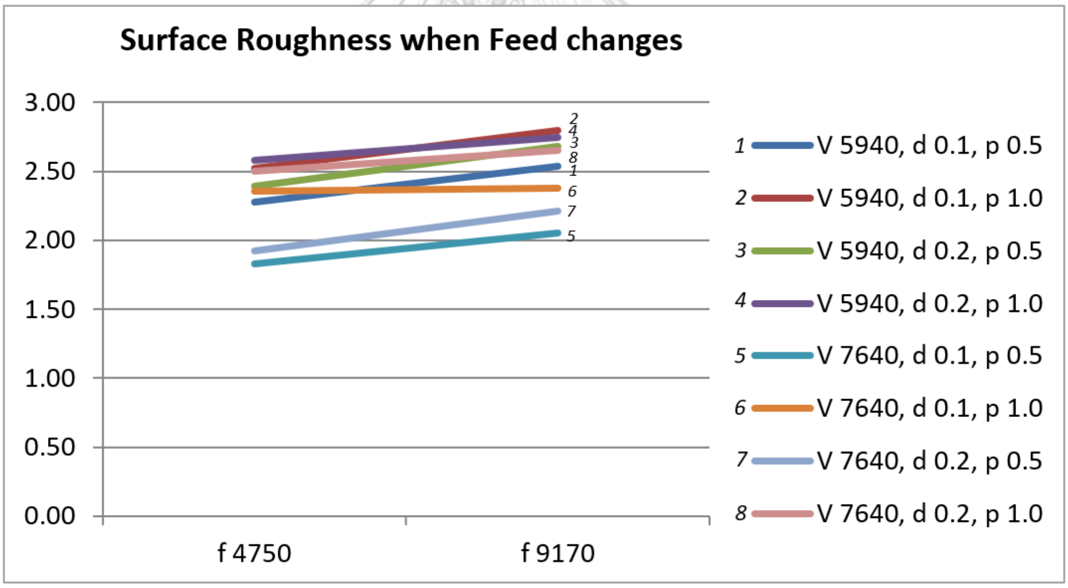


Figure 4.7 3-blade surface roughness trends when feed changes

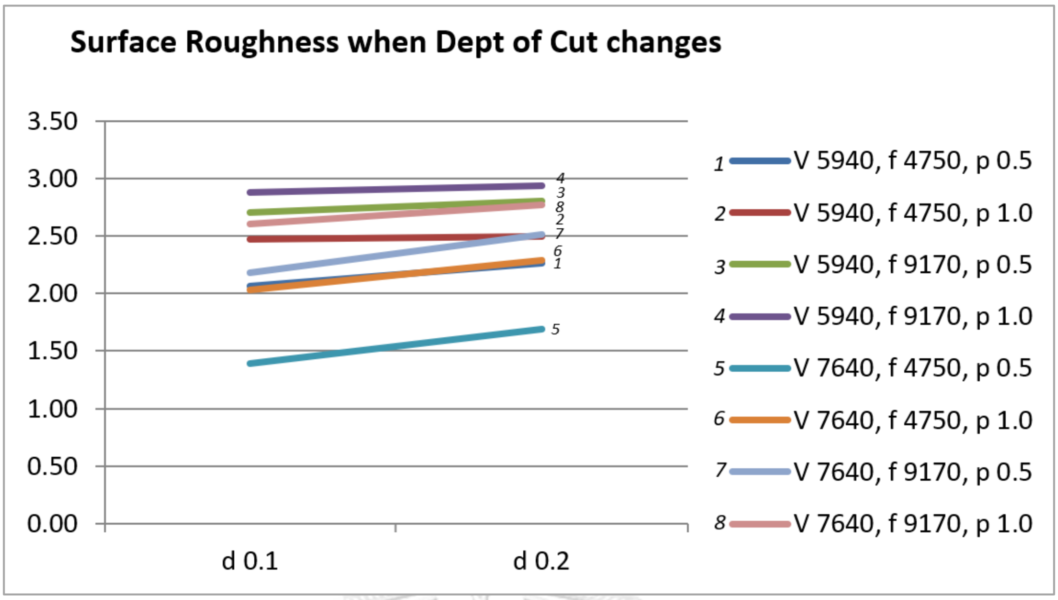


Figure 4.8 1-blade surface roughness trends when dept. of cut changes

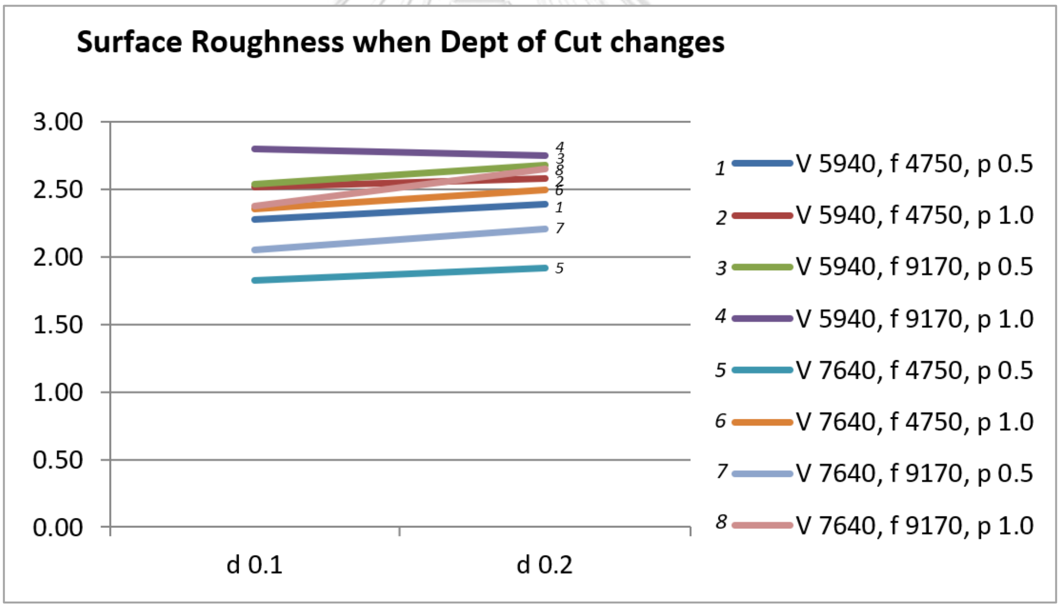


Figure 4.9 3-blade surface roughness trends when dept. of cut changes

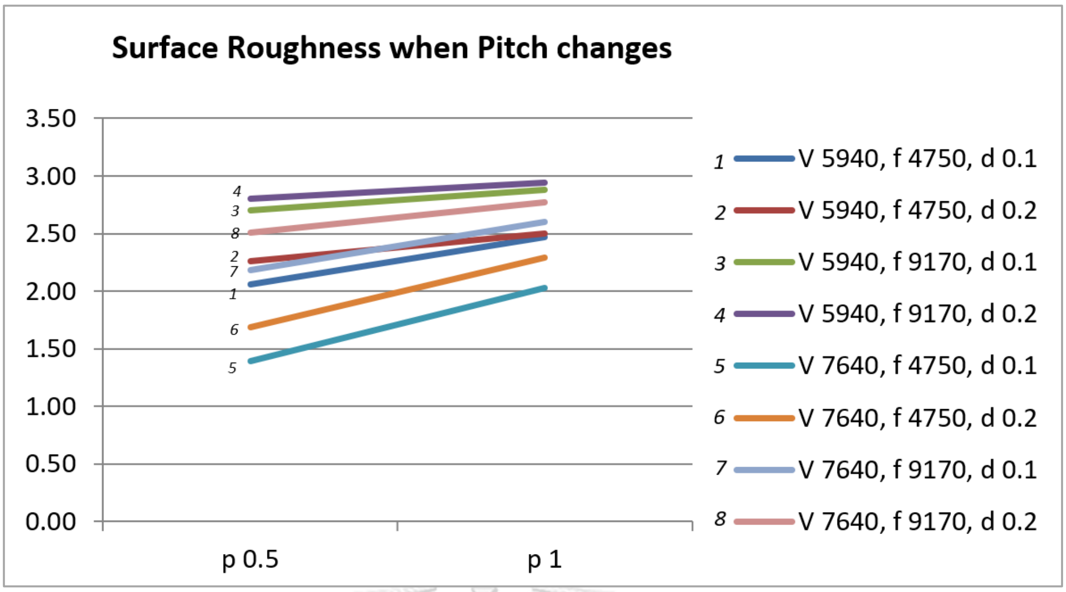


Figure 4.10 1-blade surface roughness trends when pitch changes

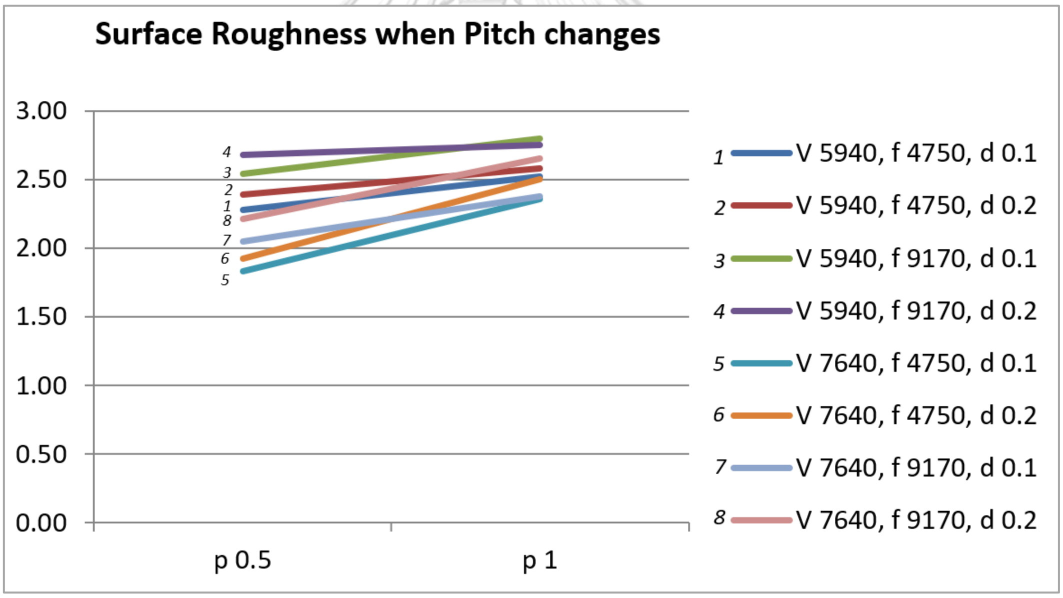


Figure 4.11 3-blade surface roughness trends when pitch changes

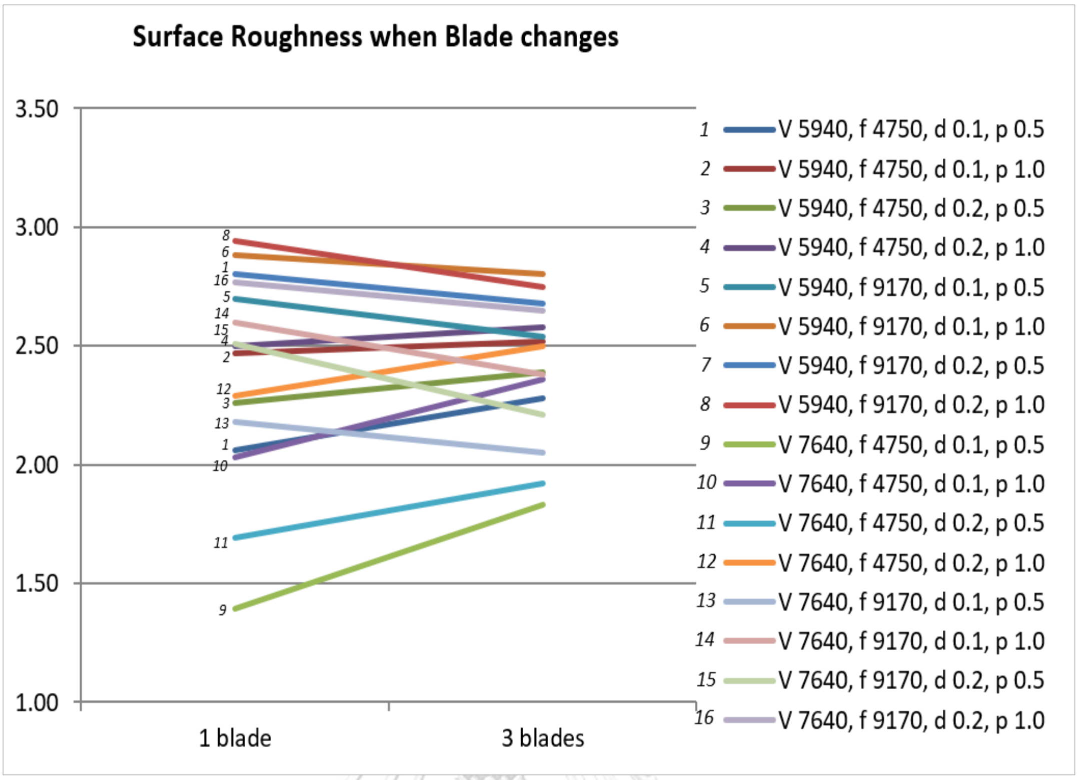


Figure 4.12 Surface roughness trends when blade changes

Figure 4.4 and 4.5 represent surface roughness trends of 1-blade and 3-blades tools when the cutting speed changes from 5940 rpm to 7640 rpm. Figure 4.6 and 4.7 illustrate surface roughness trends when feed changes from 4,750 mm/min to 9,170 mm/min. In the same way, Figure 4.8 and 4.9 also show the trends when dept. of cut changes from 0.1 mm to 0.2 mm while the trends when pitch changes from 0.5 mm to 1.0 mm are shown in Figure 4.10 and 4.11. Last but not least, the surface roughness trends when cutting blades change from 1-blade to 3-blades tool are depicted in Figure 4.12.

Table 4.4 Summarization of surface roughness when factors increase

FACTOR	Ra (1 blade)	Ra (3 blades)
Cutting Speed ↑	↓	↓
Feed ↑	↑	↑
Dept. of Cut ↑	↑	↑
Pitch ↑	↑	↑

Surface roughness trends in this experiment are summarized as illustrated in Table 4.4. Literally, the surface roughness declines when cutting speed rises. On the other hand, it rises when feed, dept. of cut, and pitch increase. Therefore, it can be concluded that the surface roughness varies inversely as cutting speed but directly as feed, dept. of cut, and pitch (slightly for dept. of cut).

According to Figure 4.13, the p-value of cutting speed, feed, dept. of cut, and pitch are less than 0.05. Therefore, these factors are significant to the surface roughness at a significant level of 0.05. The trends of each graph in Figure 4.4 to 4.12 are in the same direction; however, they sometimes do not have the same pattern (the lines are not parallel). This is caused by the 2-Way Interaction of cutting blade*feed, cutting speed*dept. of cut, cutting speed*pitch, and feed*pitch as illustrated in Figure 4.13.

Response Surface Regression: Ra versus b, v, f, d, p

The following terms cannot be estimated and were removed:
b*b, v*v, f*f, d*d, p*p

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	15	3.98857	0.26590	59.34	0.000
Linear	5	3.45112	0.69022	154.02	0.000
b	1	0.00428	0.00428	0.95	0.343
v	1	1.04763	1.04763	233.78	0.000
f	1	1.26803	1.26803	282.96	0.000
d	1	0.17553	0.17553	39.17	0.000
p	1	0.95565	0.95565	213.26	0.000
2-Way Interaction	10	0.53746	0.05375	11.99	0.000
b*v	1	0.00813	0.00813	1.81	0.197
b*f	1	0.28313	0.28313	63.18	0.000
b*d	1	0.00878	0.00878	1.96	0.181
b*p	1	0.00195	0.00195	0.44	0.519
v*f	1	0.00300	0.00300	0.67	0.425
v*d	1	0.03578	0.03578	7.98	0.012
v*p	1	0.13390	0.13390	29.88	0.000
f*d	1	0.00000	0.00000	0.00	0.979
f*p	1	0.05528	0.05528	12.34	0.003
d*p	1	0.00750	0.00750	1.67	0.214
Error	16	0.07170	0.00448		
Total	31	4.06027			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0669421	98.23%	96.58%	92.94%

(When b = no. of cutting blade, v = cutting speed, f = feed, d = dept. of cut, and p= pitch)

Figure 4.13 Response surface regression of the 1-balde tool VS 3-blades experiment

Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.3909	0.0118	202.04	0.000	
b	0.0116	0.0118	0.98	0.343	1.00
v	-0.1809	0.0118	-15.29	0.000	1.00
f	0.1991	0.0118	16.82	0.000	1.00
d	0.0741	0.0118	6.26	0.000	1.00
p	0.1728	0.0118	14.60	0.000	1.00
b*v	0.0159	0.0118	1.35	0.197	1.00
b*f	-0.0941	0.0118	-7.95	0.000	1.00
b*d	-0.0166	0.0118	-1.40	0.181	1.00
b*p	-0.0078	0.0118	-0.66	0.519	1.00
v*f	0.0097	0.0118	0.82	0.425	1.00
v*d	0.0334	0.0118	2.83	0.012	1.00
v*p	0.0647	0.0118	5.47	0.000	1.00
f*d	-0.0003	0.0118	-0.03	0.979	1.00
f*p	-0.0416	0.0118	-3.51	0.003	1.00
d*p	-0.0153	0.0118	-1.29	0.214	1.00

Regression Equation in Uncoded Units

Ra = 4.023 + 0.254 b - 0.000633 v + 0.000197 f - 2.26 d - 0.606 p + 0.000019 b*v
- 0.000043 b*f - 0.331 b*d - 0.0313 b*p + 0.000000 v*f + 0.000787 v*d + 0.000304 v*p
- 0.000003 f*d - 0.000075 f*p - 1.225 d*p

(When b = no. of cutting blade, v = cutting speed, f = feed, d = dept. of cut, and p= pitch)

Figure 4.14 Ra regression equation of the 1-balde tool VS 3-blades experiment

The adjusted R-square is at 96.58% which means only 3.42% of observed variation cannot be explained by the model's input. The surface roughness equation from Figure 4.14 is

$$Ra = 4.023 + 0.254b - 0.000633v + 0.000197f - 2.26d - 0.606p + 0.000019b*v - 0.000043b*f - 0.331b*d - 0.0313b*p + 0.000787v*d + 0.000304v*p - 0.000003f*d - 0.000075f*p - 1.225d*p \qquad \text{----- (10)}$$

On the other hand, number of cutting blades does not significantly affect to the die surface roughness. However, in this experiment, both tools are tested in the same ranges; in other words, they still do not reach their max-min feed/speed limitations and is crucial to be observed in the next experiments.

In fact, the purpose of this experiment is to cut out some factors that do not affect to the surface roughness; however, the experimental result shows that these four factors are all significant to the surface roughness. Therefore, all these factors will be used for the next analysis in Chapter 5.

CHAPTER 5 TECHNICAL DATA ANALYSIS

This chapter describes the design of experiment framework and also optimized results of each cutting tools from the program. Each condition is tested with specimen to see whether the result is the same as the simulation or not in order to figure out the best condition for finish machining.

In chapter 4, the analysis shows that cutting speed, feed, dept. of cut, and pitch significantly relate to surface roughness results. When dept. of cut and pitch are decreased, the surface roughness literally declines. Hence, the lowest dept. of cut and pitch will be used in next experiments. Cutting speed and feed also remarkably affects to the surface roughness; however, it still cannot be assumed which numbers lead to the best result since the first experiment is tested at the common speed and feed rages of the 1-blade and 3-blades tools. The next experiments will separately test the 1-blade and 3-blades in their own max-min ranges. Therefore, there are other two experiments for test, a 1-blade experiment and a 3-blades experiment.

Since the process needs high estimation accuracy and there are only quantitative factors, cutting speed and feed to be analyzed, the Central Composite Design (CCD) is very appropriate for use to plan experimental conditions.

5.1 Setting up the 1-blade experiment

Table 5.1 1-blade cutting speed and feed rages

Factor	Name	Low	High
A	V	1810	7640
B	f	2170	9170

(When v = cutting speed and f = feed)

Table 5.1 shows 1-blade cutting speed and feed rages, using as max-min parameters for putting in the program. The max-min cutting speed is 1,810 – 7,640 rpm while the max-min feed is 2,170 – 9,170 mm/min.

Table 5.2 1-blade experimental conditions

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	PtType	Blocks	V	f		
1	1	1	1	1	1810.00	2170.0		
2	2	2	1	1	7640.00	2170.0		
3	3	3	1	1	1810.00	9170.0		
4	4	4	1	1	7640.00	9170.0		
5	5	5	-1	1	602.57	5670.0		
6	6	6	-1	1	8847.43	5670.0		
7	7	7	-1	1	4725.00	720.3		
8	8	8	-1	1	4725.00	10619.7		
9	9	9	0	1	4725.00	5670.0		
10	10	10	0	1	4725.00	5670.0		
11	11	11	0	1	4725.00	5670.0		
12	12	12	0	1	4725.00	5670.0		
13	13	13	0	1	4725.00	5670.0		

(When v = cutting speed and f = feed)

After setting max-min rages for parameters in the program, the experiment is planned following the CDD method. Table 5.2 reveals the experimental conditions that the program plans; there are 13 conditions in total.

5.2 Experimental results of the 1-blade experiment

Table 5.3 Data collection from "the 1-blade experiment"

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	PtType	Blocks	V	f	CT	Ra
1	1	1	1	1	1810.00	2170.0	461	1.99
2	2	2	1	1	7640.00	2170.0	461	1.19
3	3	3	1	1	1810.00	9170.0	109	4.20
4	4	4	1	1	7640.00	9170.0	109	2.18
5	5	5	-1	1	602.57	5670.0	176	3.95
6	6	6	-1	1	8847.43	5670.0	176	1.43
7	7	7	-1	1	4725.00	720.3	1388	1.15
8	8	8	-1	1	4725.00	10619.7	94	4.77
9	9	9	0	1	4725.00	5670.0	176	2.17
10	10	10	0	1	4725.00	5670.0	176	2.19
11	11	11	0	1	4725.00	5670.0	176	2.17
12	12	12	0	1	4725.00	5670.0	176	2.18
13	13	13	0	1	4725.00	5670.0	176	2.16

(When v = cutting speed and f = feed)

Then, an operator adjusts parameters and operates CNC machine following each condition. After completing the experiment, cycle time and surface roughness of each condition are collected. Then, the cycle time and average surface roughness are entered into the program as illustrated in Table 5.3.

5.3 Analysis of the 1-blade experiment

5.3.1 Analysis of variance of the 1-blade experiment

Response Surface Regression: Ra versus V, f

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	14.7690	2.95381	22.75	0.000
Linear	2	13.7458	6.87290	52.95	0.000
V	1	5.0941	5.09414	39.24	0.000
f	1	8.6517	8.65166	66.65	0.000
Square	2	0.6511	0.32556	2.51	0.151
V*V	1	0.1550	0.15496	1.19	0.311
f*f	1	0.5621	0.56207	4.33	0.076
2-Way Interaction	1	0.3721	0.37210	2.87	0.134
V*f	1	0.3721	0.37210	2.87	0.134
Error	7	0.9087	0.12981		
Lack-of-Fit	3	0.9081	0.30272	2328.58	0.000
Pure Error	4	0.0005	0.00013		
Total	12	15.6777			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.360291	94.20%	90.06%	58.80%

(When v = cutting speed and f = feed)

Figure 5.1 Response surface regression of the 1-blade experiment

According to Figure 5.1, both cutting speed and feed are significant at a significant level of 0.05 (P-Value less than 0.05). The adjusted R-square is at 90.06% which means only 9.94% of observed variation cannot be explained by the model's input.

5.3.2 Reliability of the 1-blade experiment analysis

In order to summarize that the result from the analysis is accurate, it is necessary to check the correctness of the data in the analysis. Here, there are three statistical methods used in this analysis, normality test, test of independence, and variance stability test as depicted in Figure 5.2-5.4.

5.3.2.1 Normality test of the 1-blade experiment

In order to do the normality test, a normal probability plot as shown in Figure 5.2 is required. According to the figure, the residuals are normally distributed in an approximate straight line; this means the information from the analysis is accurate.

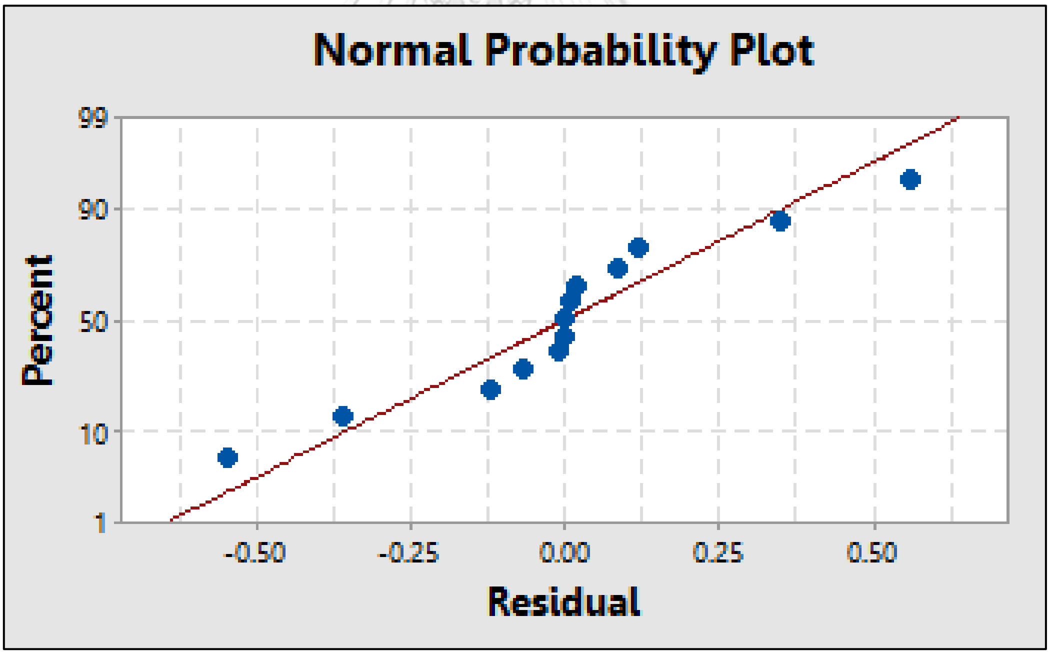


Figure 5.2 Normal probability plot of the 1-blade experiment

5.3.2.2 Variance stability test of the 1-blade experiment

The variance stability test focuses on the distribution of the residuals on the y-axis and the fitted values on the x-axis. According to Figure 5.3, the residuals are randomly distributed with no recognizable patterns; this means the information has variance stability.

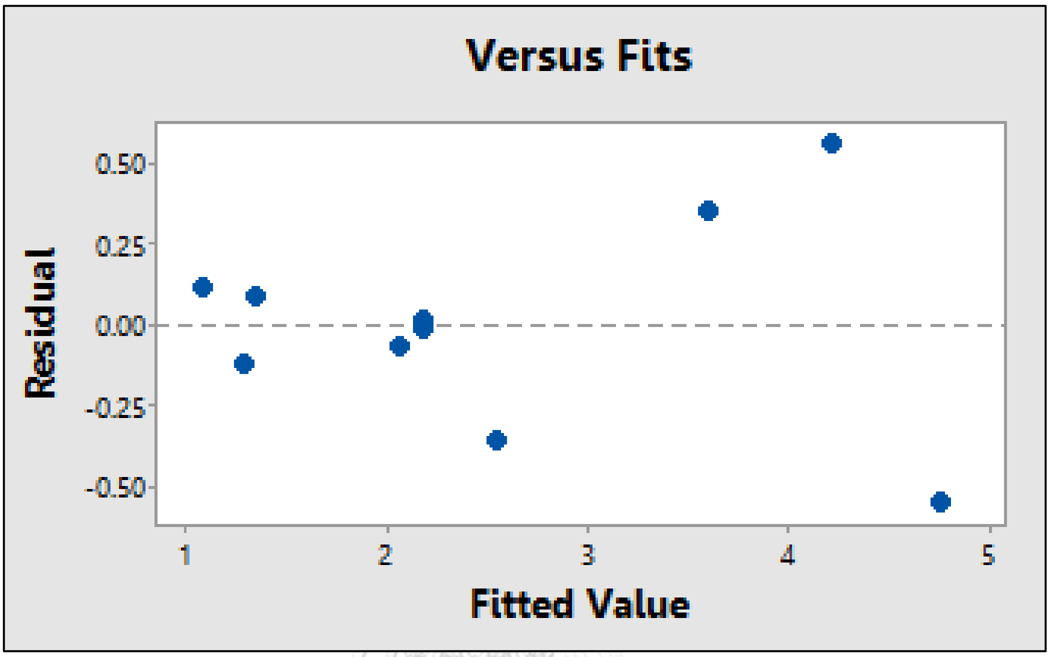


Figure 5.3 Versus fits of the 1-blade experiment

5.3.2.3 Test of independence of the 1-blade experiment

The versus order as shown in Figure 5.4 illustrates the residuals in the order that the data is collected. According to the figure, there is no pattern or trend when arranged in time order; this means the residuals are independent from one another.

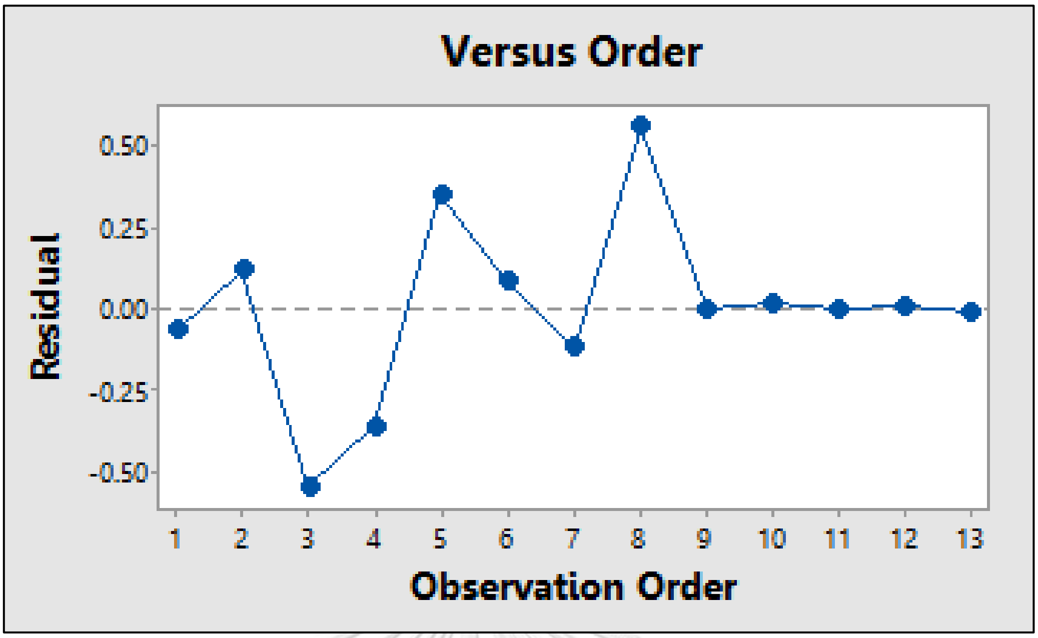


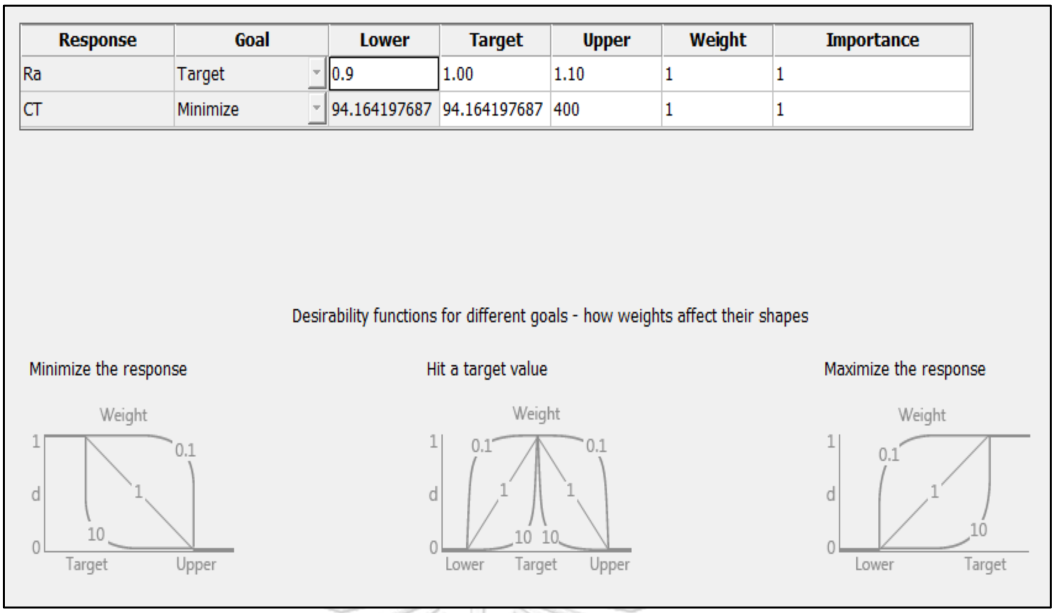
Figure 5.4 Versus order of the 1-blade experiment

5.4 Optimization of the 1-blade experiment

Response	Goal	Target
Ra	Target	1.00
CT	Minimize	

Figure 5.5 The 1-blade experiment target setting

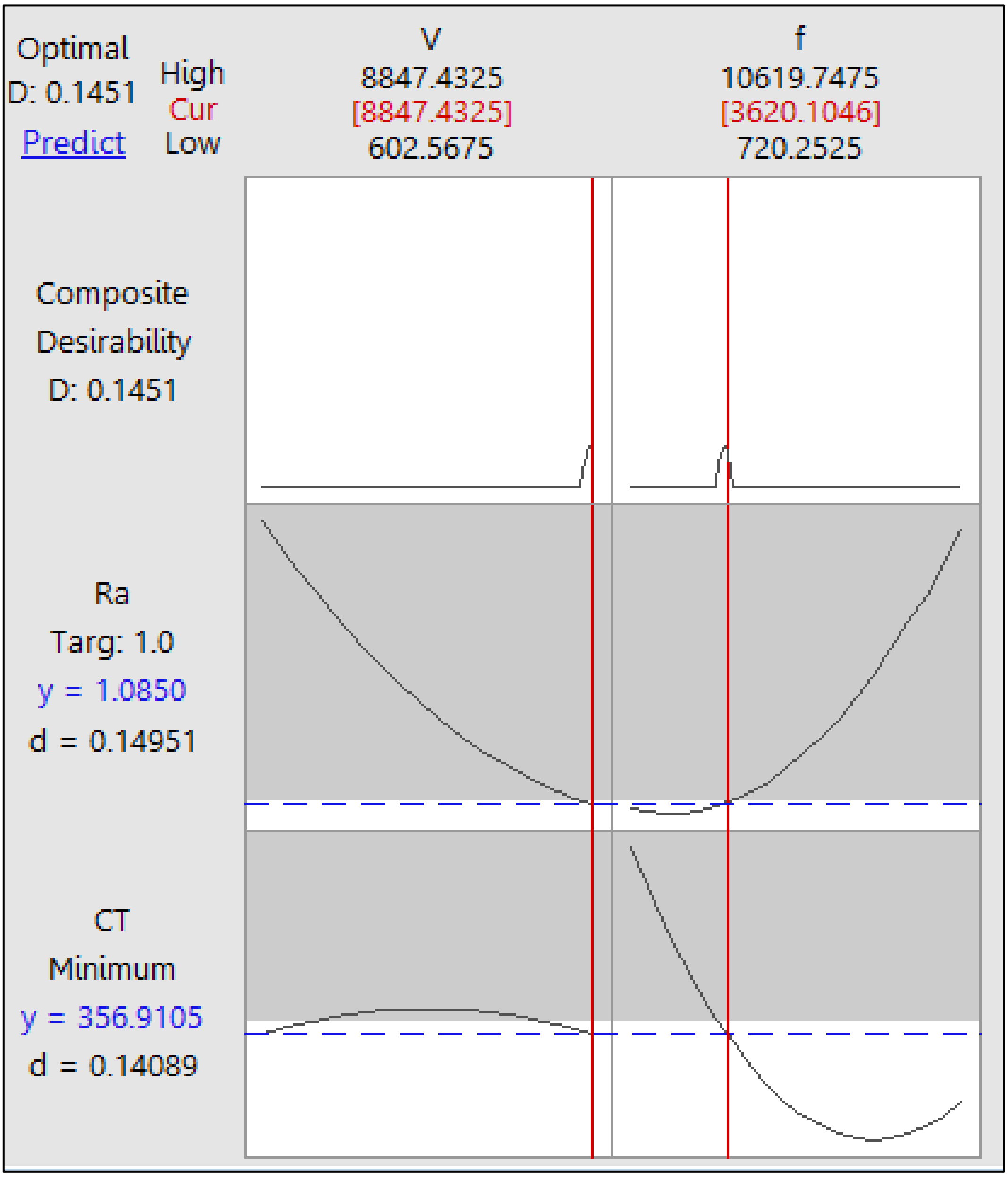
Prior to optimize the best condition of the 1-balde tool, it is needed to consider about surface roughness and machining cycle time target in order to use them to set up the program. Since the expectation of this project is to eliminate the polishing process by making the surface roughness after machining less than the current surface roughness after polishing (1.10 micron as revealed in Figure 1.22) while minimizing machining cycle time, the goal of the Ra is set as “Target” and the CT is set as “Minimize” as illustrated in Figure 5.5.



Response	Goal	Lower	Target	Upper	Weight	Importance
Ra	Target	0.9	1.00	1.10	1	1
CT	Minimize	94.164197687	94.164197687	400	1	1

Figure 5.6 The 1-blade experiment response set up

According to Figure 5.6, the Ra upper limit is set as 1.10 micron so that the optimized result will not be over 1.10 micron. Nowadays, the finish machining process takes around 1 day (10 hours including OT) to finish 1000x15000-mm die. However, there still be a capacity left in machining operation; the maximum capacity for finish machining is 2 days (20 hours or 1,200 minutes). Since the specimen size is three times smaller than the actual die, the expected time for this optimization should be divided by three. Therefore, the machining cycle time upper limit is set as 400 minutes.



(When v = cutting speed and f = feed)

Figure 5.7 The 1-blade optimization plot

After the targets including lower limits and upper limits are set, the best condition of the 1-balde tool is optimized as shown in Figure 5.7. The program forecasts that the best condition to get less-than-1.10-micron surface roughness with the smallest time is when using 8,847 rpm of cutting speed and 3,620 mm/min. of feed.

The predicted surface roughness is at 1.085 micron while the cycle time of the operation is 357 minutes.

5.5 Setting up the 3-blades experiment

Table 5.4 3-blades cutting speed and feed rages

Factor	Name	Low	High
A	V	5940	11670
B	f	4750	11670

(When v = cutting speed and f = feed)

The 3-blades cutting speed and feed rages, using as max-min parameters for putting in the program is represented in Table 5.4. The max-min cutting speed is 5,940 – 11,670 rpm while the max-min feed is 4,750 – 11,670 mm/min.

Table 5.5 3-baldes experimental conditions

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	PtType	Blocks	V	f		
1	1	1	1	1	5940.0	4750.0		
2	2	2	1	1	11670.0	4750.0		
3	3	3	1	1	5940.0	11670.0		
4	4	4	1	1	11670.0	11670.0		
5	5	5	-1	1	4753.3	8210.0		
6	6	6	-1	1	12856.7	8210.0		
7	7	7	-1	1	8805.0	3316.8		
8	8	8	-1	1	8805.0	13103.2		
9	9	9	0	1	8805.0	8210.0		
10	10	10	0	1	8805.0	8210.0		
11	11	11	0	1	8805.0	8210.0		
12	12	12	0	1	8805.0	8210.0		
13	13	13	0	1	8805.0	8210.0		

(When v = cutting speed and f = feed)

Table 5.5 shows the 13 experimental conditions that the program plans following the CDD method.

5.6 Experimental results of the 3-baldes experiment

Table 5.6 Data collection from "the 3-blades experiment"

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	PtType	Blocks	V	f	CT	Ra
1	1	1	1	1	5940.0	4750.0	211	2.28
2	2	2	1	1	11670.0	4750.0	211	1.09
3	3	3	1	1	5940.0	11670.0	86	3.15
4	4	4	1	1	11670.0	11670.0	86	1.95
5	5	5	-1	1	4753.3	8210.0	122	2.63
6	6	6	-1	1	12856.7	8210.0	122	1.52
7	7	7	-1	1	8805.0	3316.8	301	1.40
8	8	8	-1	1	8805.0	13103.2	76	3.78
9	9	9	0	1	8805.0	8210.0	122	1.72
10	10	10	0	1	8805.0	8210.0	122	1.72
11	11	11	0	1	8805.0	8210.0	122	1.74
12	12	12	0	1	8805.0	8210.0	122	1.75
13	13	13	0	1	8805.0	8210.0	122	1.73

(When v = cutting speed and f = feed)

After planning conditions for test, the CNC machine is operated following each condition. The same as 1-blade experiment, cycle time and surface roughness of each condition are collected and entered into the program as illustrated in Table 5.6.

5.7 Analysis of the 3-blades experiment

5.7.1 Analysis of variance of the 3-blades experiment

Response Surface Regression: Ra versus V, f

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	6.21901	1.24380	17.01	0.001
Linear	2	5.20591	2.60296	35.61	0.000
V	1	1.95998	1.95998	26.81	0.001
f	1	3.24593	3.24593	44.40	0.000
Square	2	1.01307	0.50653	6.93	0.022
V*V	1	0.09645	0.09645	1.32	0.288
f*f	1	0.97957	0.97957	13.40	0.008
2-Way Interaction	1	0.00003	0.00003	0.00	0.986
V*f	1	0.00003	0.00003	0.00	0.986
Error	7	0.51172	0.07310		
Lack-of-Fit	3	0.51104	0.17035	1002.03	0.000
Pure Error	4	0.00068	0.00017		
Total	12	6.73072			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.270375	92.40%	86.97%	45.99%

(When v = cutting speed and f = feed)

Figure 5.8 Response surface regression of the 3-blades experiment

According to Figure 5.8, both cutting speed and feed are significant at a significant level of 0.05 (P-Value less than 0.05). The adjusted R-square is at 86.97% which means only 13.03% of observed variation cannot be explained by the model's input.

5.7.2 Reliability of the 3-blades experiment analysis

Not only 1-blade experiment, the 3-blades experiment is also required some statistical test to verify that the information from the analysis is accurate. The normality test, test of independence, and variance stability test of the 3-blades experiment are depicted in Figure 5.9-5.11.

5.7.2.1 Normality test of the 3-blades experiment

The normal probability plot is shown in Figure 5.9. The information from the analysis is accurate because the residuals in this plot are normally distributed in an approximate straight line.

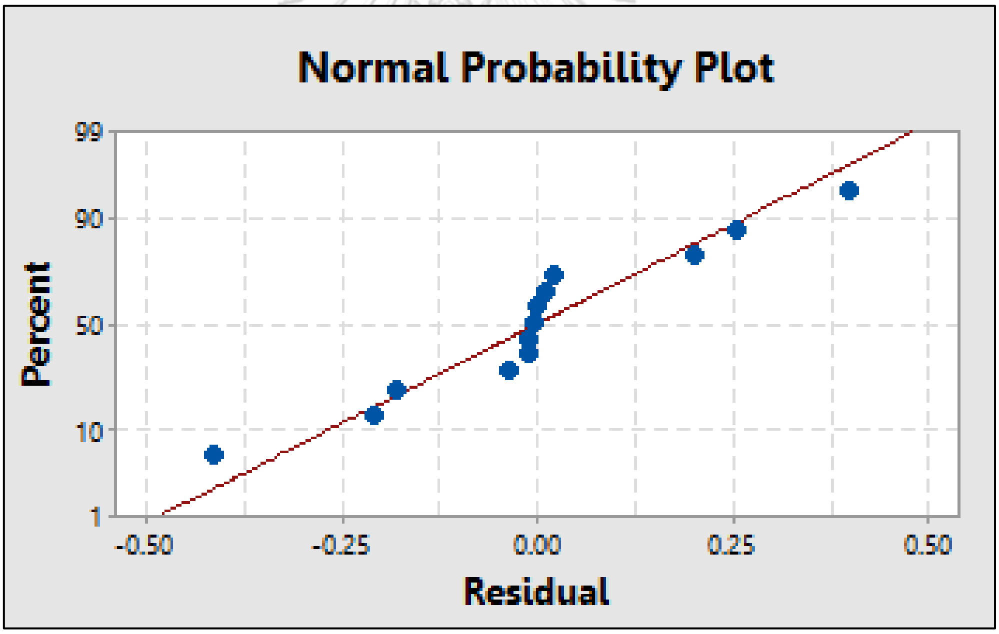


Figure 5.9 Normal probability plot of the 3-blades experiment

5.7.2.2 Variance stability test of the 3-blades experiment

According to Figure 5.10, the distribution of the residuals on the graph is randomly distributed with no recognizable patterns; this means the information has variance stability.

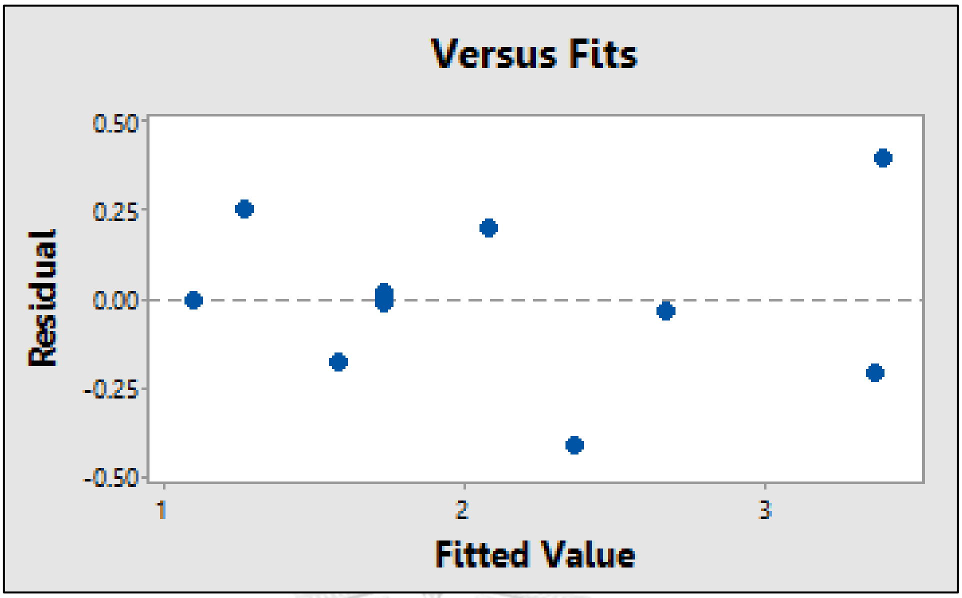


Figure 5.10 Versus fits of the 3-blades experiment

5.7.2.3 Test of independence of the 3-blades experiment

The test of independence illustrated as the versus order as shown in Figure 5.11 describes the residuals in the order, which the data is collected, have no pattern or trend when arranged in time order, meaning that the residuals are independent from one another.

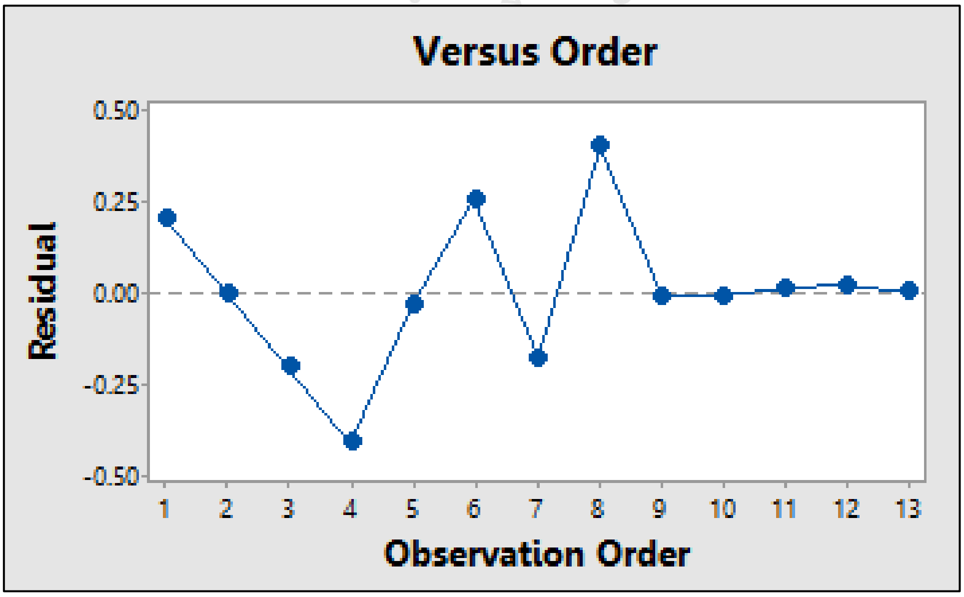
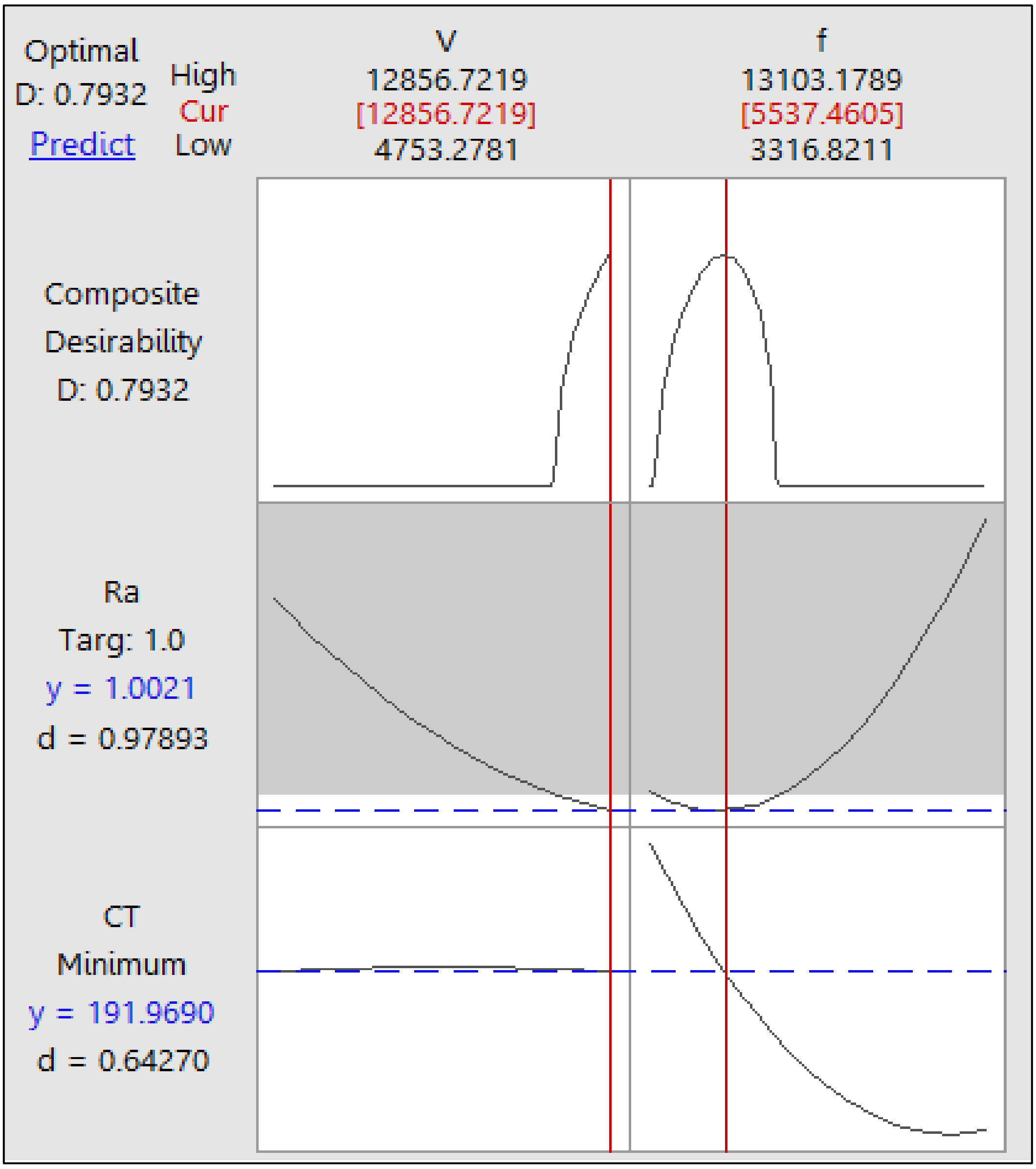


Figure 5.11 Versus order of the 3-blades experiment

5.8 Optimization of the 3-blades experiment

As aforementioned in Figure 5.5 and 5.6, the goal of the Ra is set as "Target" and the CT is set as "Minimize". Since everything is the same as the 1-blade experiment, the Ra upper limit is set as 1.10 micron and the CT upper limit is set as 400 minutes.



(When v = cutting speed and f = feed)

Figure 5.12 The 3-blades optimization plot

According to Figure 5.12, the best condition of the 3-baldes tool is when using 12,857 rpm of cutting speed and 5,537 mm/min. of feed. The predicted surface roughness is at 1.002 micron while the cycle time of the operation is 192 minutes.

5.9 Select the best machining condition

After getting the optimized conditions of the 1-blade and 3-blades tools from the program, it is necessary to test that the optimized conditions from the program are the best conditions to get the best surface roughness. The actual result after testing is revealed in Table 5.7.

Table 5.7 Optimized and actual results of the 1-blade and 3-blades tools

Tool	Cutting Speed	Feed	Dept.	Pitch	Program		Actual		
					CT	Ra	CT	Ra	SD
1 blade	8847	3620	0.1	0.5	**357**	**1.085**	**357**	**1.12**	**0.021**
3 blades	12857	5537	0.1	0.5	**192**	**1.002**	**192**	**1.23**	**0.018**
	(rpm)	(mm./min)	(mm)	(mm)	(minutes)	(micron)	(minutes)	(micron)	

According to the table, the cycle time of the optimized conditions and actual results are the same; the 1-blade tool can finish machining a die faster than the 3-blades tool if these conditions are applied to the machine. The actual result of 1-blade surface roughness is 1.12 micron, slightly different from the optimized results, 1.085 micron, from the program. However, the actual result of 3-blades surface roughness is remarkably different from the simulation. The root cause of this might be from using too high cutting speed in the operation.

5.9.1 The 3-blades cutting speed experiment

According to Figure 3.3 and 3.4, the CNC machine's maximum speed is at 12,000 rpm and maximum speed that the 3-blades tool can tolerate is at 11,670 rpm.

This optimized cutting speed, 12,857 rpm, is supernumerary both machine and tool's limitations; therefore, it might be the cause to worsen the surface roughness.

To verify that this is right, another experiment is planned in order to check surface roughness results when cutting speed changes. The experimental conditions and results of this experiment are shown in Table 5.8. All data is plotted on the graph as illustrated in Figure 5.13, showing that the trend of surface roughness drops when cutting speed rises and ends up rebounding when reaching an approximate 11,670 rpm cutting speed.

Table 5.8 Surface roughness results when cutting speed changes

Tool	Cutting Speed	Feed	Dept.	Pitch	Ra
3 blades	6,000	4,750	0.1	0.5	**2.28**
3 blades	6,500	4,750	0.1	0.5	**2.15**
3 blades	7,000	4,750	0.1	0.5	**1.97**
3 blades	7,500	4,750	0.1	0.5	**1.83**
3 blades	8,000	4,750	0.1	0.5	**1.70**
3 blades	8,500	4,750	0.1	0.5	**1.64**
3 blades	9,000	4,750	0.1	0.5	**1.55**
3 blades	9,500	4,750	0.1	0.5	**1.47**
3 blades	10,000	4,750	0.1	0.5	**1.36**
3 blades	10,500	4,750	0.1	0.5	**1.25**
3 blades	11,000	4,750	0.1	0.5	**1.14**
3 blades	11,500	4,750	0.1	0.5	**1.09**
3 blades	12,000	4,750	0.1	0.5	**1.12**
3 blades	12,500	4,750	0.1	0.5	**1.20**
3 blades	13,000	4,750	0.1	0.5	**1.29**

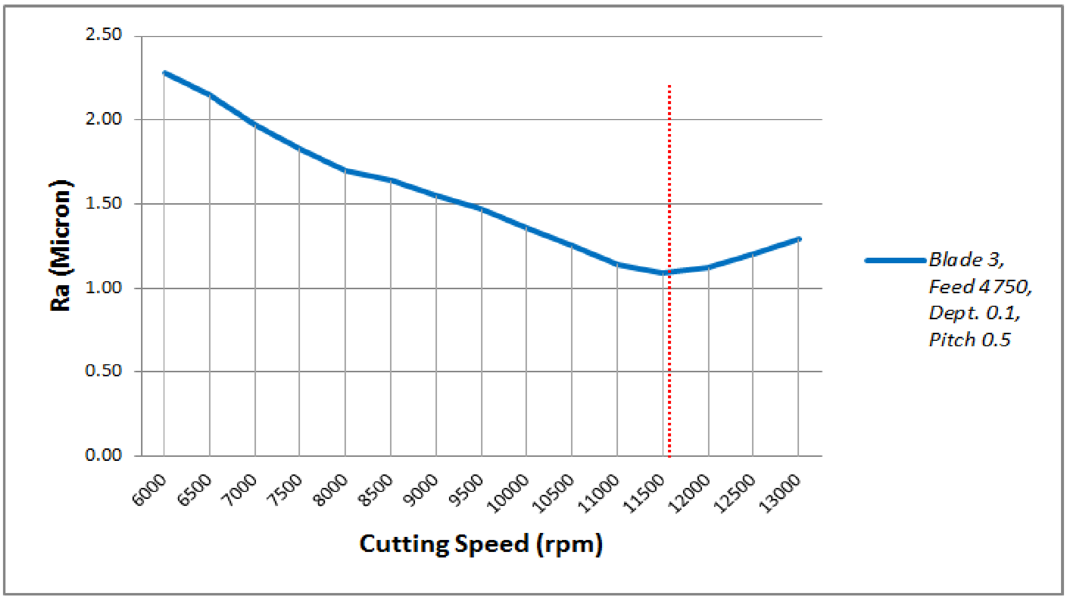


Figure 5.13 Surface roughness trend when cutting speed changes

According to the actual results from the optimized conditions in Table 5.7, the actual result of 1-blade tool is better than the result of 3-blade tool. However, the optimized condition of the 3-blades is still not the best condition that the tool can do.

Table 5.9 Comparison between the best Ra condition from the experiment and optimized condition from the program.

	Tool	Cutting Speed	Feed	Dept.	Pitch	Result		
						CT	Ra	SD
Best Ra condition from the experiment	**1 blade**	4725	720	0.1	0.5	**1388**	**1.15**	**0.019**
	3 blades	11670	4750	0.1	0.5	**211**	**1.09**	**0.017**
Optimized condition from the program	**1 blade**	8847	3620	0.1	0.5	**357**	**1.12**	**0.021**
	3 blades	12857	5537	0.1	0.5	**192**	**1.23**	**0.018**
		(rpm)	(mm./min)	(mm)	(mm)	(minutes)	(micron)	

The comparison between the best Ra conditions from the experiment (Table 5.3 and Table 5.6) and the actual results of optimized condition from the program is represented in Table 5.9. The best condition in this table is when using 3-blades tool with 11,670-rpm speed and 4,750-mm/min feed; this is better than the optimized condition due to machine and tool's cutting speed limitation. Base on the results of both cycle time and surface roughness from each experiment, it can be concluded that the 3-blades tool can achieve better surface roughness than the 1-blade tool.

The surface roughness of the best Ra condition from Table 5.9 is at 1.09 micron; however, there is 0.017 SD which is the variation that makes the data differs from the Mean. Since the target is 1.10 micron, there is a very high possibility that the surface roughness result will be over the target. In order to make the surface roughness less than the target, it is crucial to find out other machining conditions that lead to better results.

5.9.2 New methods to improve surface quality

Base on the results from each analysis, cutting speed, feed, dept. of cut, and pitch are significant to the die surface roughness. According to Table 4.4, the surface roughness declines when cutting speed increases and when feed, dept. of cut and pitch decrease. Now, the best condition now is when using 3-blades tool with 11,670-rpm speed, 4,750-mm/min feed, 0.1-mm dept. of cut, and 0.5-mm pitch. Since the cutting speed and pitch has already reached the limitation at 11,670 rpm and 0.5 mm, other factors to be considered is feed and dept. of cut. To figure out a new condition that can achieve target, methods to improve surface quality are set for test as illustrated in Table 5.10.

Table 5.10 Methods to improve surface quality

Method	Description
1	*Decrease feed 25% (4,750 mm/min -> 3,563 mm/min)*
2	*Decrease feed 50% (4,750 mm/min -> 2,375 mm/min)*
3	*Decrease dept. of cut 50% (Do finish machining 2 times)*

The first and second methods are regarded to feed while the third method is regarded to dept. of cut. The aim of the first method is to decrease 25% of the best condition feed, so that the feed used for test is 3,563 mm/min. In the same way, the feed is decreased up to 50% from 4,750 mm/min to 2,375 mm/min in the second method. Last but not least, the third method is to decrease 50% of dept. of cut in order to see whether the lower dept. of cut results in the better surface roughness or not.

Table 5.11 Results from the methods

Condition	Tool	Cutting Speed	Feed	Dept.	Pitch	CT	Ra	S.D. (Ra)
Best Ra	**3-Blades**	11670	4750	0.1	0.5	211	1.09	0.017
Method 1	**3-Blades**	11670	3563	0.1	0.5	281	1.04	0.016
Method 2	**3-Blades**	11670	2375	0.1	0.5	421	1.03	0.013
Method 3	**3-Blades**	11670	4750	0.05	0.5	421	1.06	0.012
		(rpm)	(mm/min)	(mm)	(mm)	(minute)	(micron)	

The results of each method are represented in Table 5.11. Literally, feed and dept. of cut remarkably affect to the die surface roughness; all methods are able to improve the die surface quality. Additionally, the results of every method are able to achieve the target (less than 1.10 micron). According to Table 5.11, method 2 brings about the best surface roughness result. However, it takes very long time and there is only a slight difference when comparing to the method 1. As aforementioned when describing Figure 5.6, the capacity of finish machining for this specimen size is 400 minutes. Since the method 2 and 3 is over the capacity, the method 1 can be considered as the best way to improve surface roughness.

5.9.3 The 3-blades feed experiment

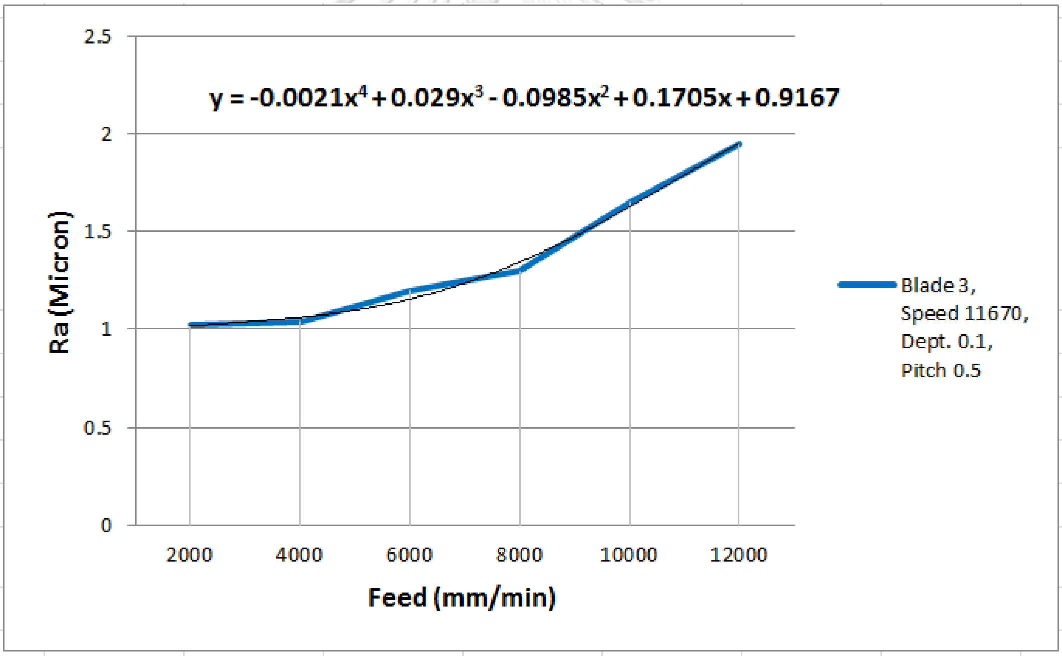


Figure 5.14 Surface roughness trend when feed changes

To verify that there is no other better condition, the feed-change graph is made as illustrated in Figure 5.14. It is noticeable that the surface roughness slightly drops and ends up being stable when feed tends to approach 0. The polynomial equation of surface roughness trend is

$$y = -0.0021x^4 + 0.029x^3 - 0.0985x^2 + 0.1705x + 0.9167 \quad \text{------- (11)}$$

(When x = 1, feed = 2,000 mm/min)

Table 5.12 The forecast when feed approaching zero

Feed	CT	Ra
5000	200	1.10
4500	222	1.08
4000	250	1.06
3500	286	1.05
3000	333	1.04
2500	400	1.03
2000	500	1.02
1500	667	1.00
1000	1000	0.98
(mm/min)	(minute)	(micron)

The forecast from this equation is revealed in Table 5.12. According to the table, when feed is less than 5,000 mm/min, feed reduction can slightly improve surface roughness. Even though the maximum capacity of 400 minutes is used at feed 2,500 mm/min, the result of surface roughness will be the same as the method 1 at 1.03 micron. Therefore, it can be concluded that the selected condition that will result in the best surface roughness and minimized time is the method 1.

5.9.4 Select the new machining condition

Base on the results from all experiments, the machining condition that should be selected for use in finish machining process is 11,670-rpm cutting speed, 3563-mm/min feed, 0.1-mm dept. of cut, and 0.5-mm pitch. The comparison between the current condition and the selected condition (method 1) is illustrated in Table 5.13.

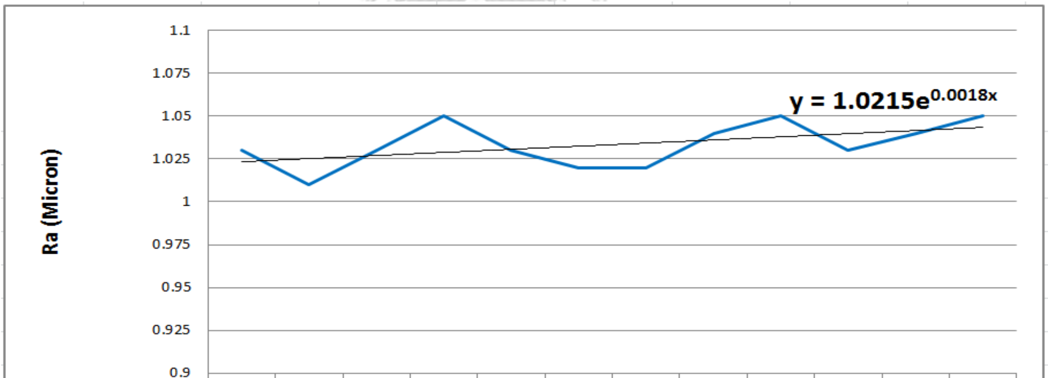
Table 5.13 The comparison between the current condition and selected condition

Condition	Tool	Cutting Speed	Feed	Dept.	Pitch	CT	Ra	S.D. (Ra)
Current	1-Blade	5500	4800	0.1	0.5	208	2.10	0.035
New (Method 1)	3-Blades	11670	3563	0.1	0.5	281	1.04	0.016
		(rpm)	(mm/min)	(mm)	(mm)	(minute)	(micron)	

According to the table, the new condition is much better than the current condition. As a matter of fact, it can reduce the die surface roughness by half and does not cause over-capacity problems.

5.10 Testing the new condition

After machined by the new condition, the measurement results of specimen's surface areas are collected as usual (in Figure 4.3) and plotted as a graph as revealed in Figure 5.15.



	1	2	3	4	5	6	7	8	9	10	11	12
Blade 3, Speed 11670, Feed 3563, Dept. 0.1, Pitch 0.5	1.03	1.01	1.03	1.05	1.03	1.02	1.02	1.04	1.05	1.03	1.04	1.05

Figure 5.15 New condition's Ra

According to the graph, the length of machining time affects to the surface roughness since tool wear occurs during the operation. The Ra exponential equation of the new condition is

$$y = 1.0215e^{0.0018x} \qquad \text{---------- (12)}$$

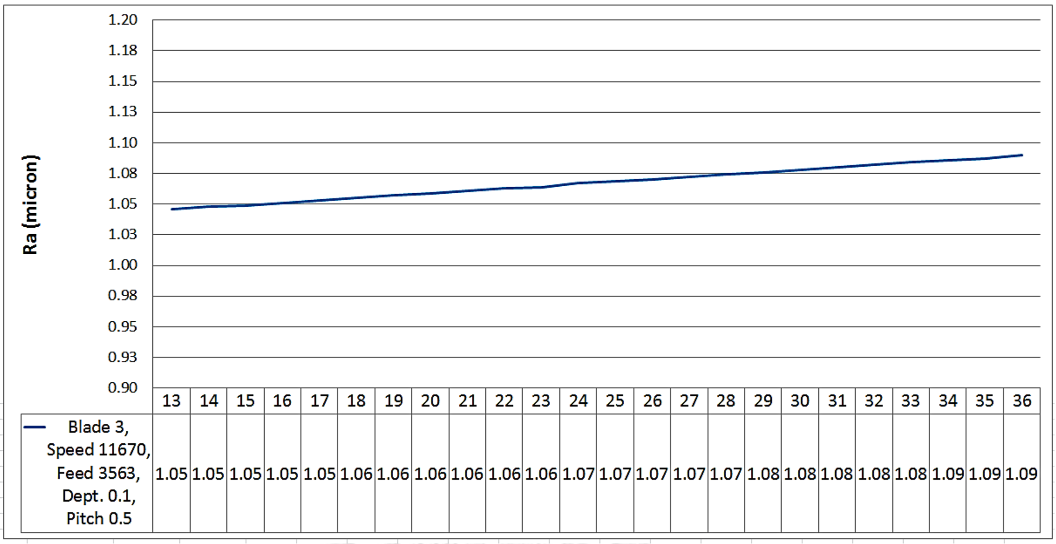


Figure 5.16 The forecast of new condition's Ra

According to Figure 5.16, Ra of the new condition is forecasted following the equation (12) in order to confirm that all areas of the actual die will have the surface roughness lower than 1.10 micron. Base on the forecast, it is noticeable that the Ra will not reach 1.10 micron after machining the actual die.

Table 5.14 New standard for the finish machining process

Die type	Machining Tool	Cutting Speed	Feed	Dept.	Pitch	CT	Ra
Hood Outer	*3-Blades*	*11670 rpm*	*3560 mm/min*	*0.1 mm*	*0.5 mm*	**843 minutes**	**1.05±0.05 micron**
Hood Inner							

(Actual Die)

After verifying that the new condition can be applied to the process, the next step is to implement a new standard for used in the finish machining operation. To make it more suitable, the feed 3,563 mm/min is adjusted to 3,560 mm/min. The standard result of the new condition is 843-minutes CT (CT of specimen x 3) and 1.05 ± 0.05-micron Ra when using the new condition with typical hood dies (1000x1500 mm) as shown in Table 5.14.

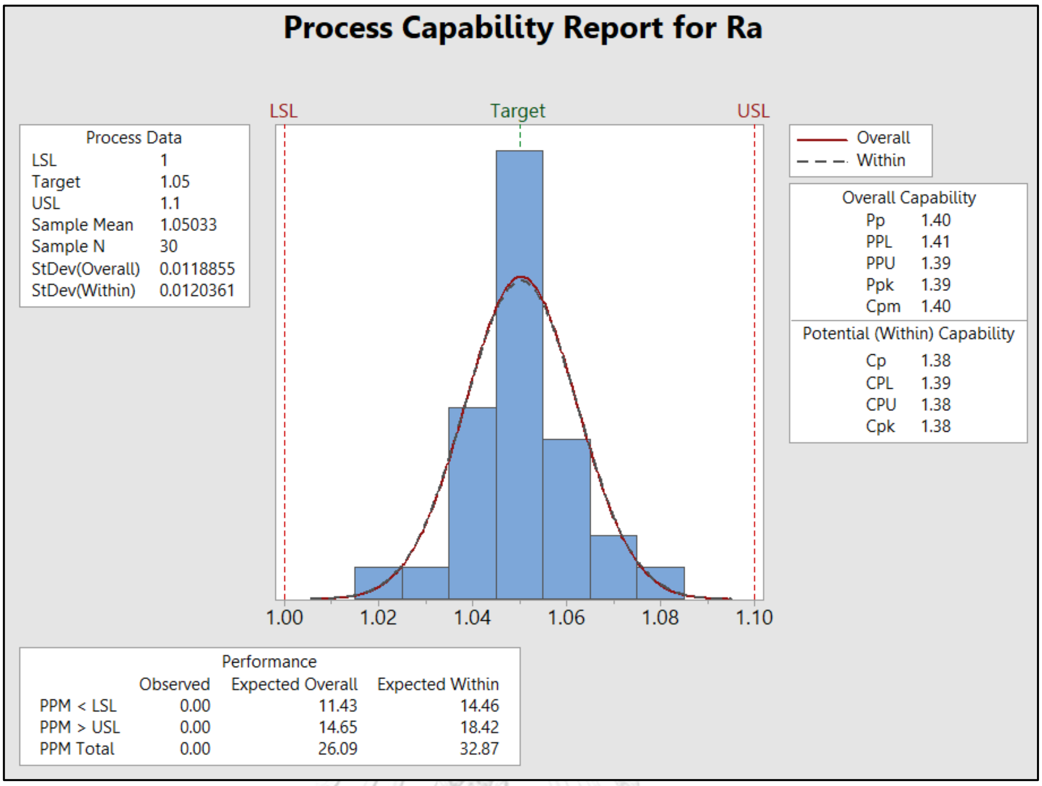


Figure 5.17 Cp and Cpk of the new condition

The new machining condition is applied to test with the die specimen in order to see if it can bring about the same rage of result every time. The process capability as shown in Figure 5.17, measured in Cp and Cpk, illustrates a process's ability to meet specifications. As a result, the Cp and Cpk from the test are at 1.38 which is high enough to say that the process is good with a small spread within the tolerance width. If gap between Cp and Cpk is close, the average of data approaches the target value. The result from this test shows that Cp and Cpk are equal, meaning that the average of data is equal to the target value. This can be concluded that the new condition will definitely result in good surface roughness within the targeted rage.

5.11 Implementation

A meeting is arranged for clearing up the procedure of finish machining process. Managers, supervisors, and staffs in the department are invited to join the meeting to make sure everyone is all on the same page. The 1-blade tool is not used in the finish machining process anymore, but still used in rough and semi-finish machining processes. The 3-blades tool is considered as the suitable tool for use in finish machining instead of the 1-blade tool. The appropriate parameters are 11,670-rpm cutting speed, 3,560-mm/min feed, 0.1-mm dept. of cut, and 0.5-mm pitch in which the result will be 843-minutes CT (281x3) and 1.05 $\pm$ 0.05-micron Ra. This new condition is going to be used with the actual hood dies in the next project in December 2019.

CHAPTER 6 DISCUSSION

This chapter provides important points and summarization of the study, including methods and processes to succeed implementation and fulfill the entire research thesis objectives and also advantages from the improvement.

6.1 Summarization from each experiment

In this research, 6 experiments are launched to see the potential of machining cycle time and surface roughness. Table 6.1 represents the result from each experiment.

Table 6.1 The experimental result from each experiment

No.	Experiment	Result
1	1-balde VS 3-blades	Cutting speed, Feed, Dept of cut, Pitch -> Significant
2	Optimized 1-blade	Optimized Ra = 1.085 , Actual Ra = 1.12
3	Optimized 3-blades	Optimized Ra = 1.002 , Actual Ra = 1.23
4	3-blades Cutting speed	Ra decreases when speed rises, but increases when speed over 11,670 rpm
5	Method 1, 2, 3	Method 1 can achieve both CT and Ra Target
6	3-blades Feed	Ra tends to be stable when Feed approaching 0

The 1st experiment: The purpose of the first experiment is to find out which factors significantly affect to the die surface roughness and what the best tool is. The result shows that cutting speed, feed, dept. of cut, and pitch are significant to the surface roughness at a significant level of 0.05. However, it is very hard to consider which tool is better than another one since both tools are tested at the common cutting speed and feed ranges which still do not reach their max-min limitations. Hence, the 2nd and 3rd experiment are planned to find out the optimized conditions that suited for each tool.

The 2nd experiment: In this experiment, the 1-blade tool is tested in its own max-min ranges. The experiment is planned by the program, using the Central Composite

Design (CCD) method. After all cycle time and surface roughness are collected, the program is used for doing analysis following the Surface Response Methodology. The result of the 1-balde optimized condition is 1.085-micron Ra with 357-minutes CT. After applying this optimized condition to the machine, the actual result is 1.12-micron Ra. Therefore, the best surface roughness that the 1-blade can do is at 1.12 micron which does not achieve the target.

The 3rd experiment: The aim of this experiment is exactly the same as the 2nd experiment, but the 3-baldes tool is tested in its own max-min ranges instead of the 1-blade tool. After planning experimental conditions by the program and machining following those conditions, all results are collected and analyzed. The result of the 3-baldes optimized condition is 1.002-micron Ra with 192-minutes CT. After applying this optimized condition to the machine, the actual result is 1.23-micron Ra. Since there is a huge difference between the simulation and the actual result, the root cause of this problem needs to be found out (as tested in the 4th experiment).

As matter of fact, the actual surface roughness of the 3-blades optimized condition is higher than some conditions in the 3rd experiment. The lowest-Ra condition provides only 1.09-micron Ra with 0.017 SD. Since there is 0.017 SD and the result is very close the target (1.10 micron), it is necessary to figure out the methods (in the 5th experiment) to make sure that the result will be able to achieve the target as depicted in Table 14.

The 4th experiment: The purpose of this experiment is to see the potential of the surface roughness when using the 3-blades tool and varying cutting speed (fix other parameters). Basically, the Ra decreases when cutting speed rises. However, the Ra tends to increase when cutting speed is over the maximum tool limitation at 11,670 rpm. Base on the result of this experiment, the recommend cutting speed is at 11,670 rpm.

The 5th experiment: This experiment is set for machining the specimen following the method 1, method 2 and method 3. As the result, the method 2 brings about the best Ra but cannot achieve CT target. On the other hand, the method 1 can achieve both CT and Ra target and has only a slight different Ra when compare to method 1. It can be concluded that the method 1 is the best machining condition when comparing to other methods.

The 6th experiment: To make sure that the method 1 is the most appropriate condition for the process, this experiment is set to see the potential of Ra when feed varies. As the result, Ra becomes stable when feed approaches 0. Therefore, there is no need to use feed lower than this because the surface roughness will not be different from the result from method 1 condition and CT will increase.

Table 6.2 reveals the new condition for the finish machining process. The 3-blades tool is used instead of the 1-blade tool and the parameters used for the process are changed to 11,670-rpm cutting speed, 3,560-mm/min feed, 0.1-mm dept. of cut, and 0.5-mm pitch. By applying the new condition to a die, the result will be 1.05±0.05 micron with 562 minutes per square meter.

Table 6.2 New condition for the finish machining process

	Tool	Cutting Speed	Feed	Dept.	Pitch	CT/m2	Ra
New condition	3-Blades	11670 rpm	3560 mm/min	0.1 mm	0.5 mm	562 minutes	1.05 ± 0.05 micron

6.2 Discussion

This study provides a lot of advantages for the department; the total time in die manufacturing process is reduced while decreasing the production cost which includes a variety of expenses as explained in 6.2.1-6.2.5.

6.2.1 Eliminate polishing process

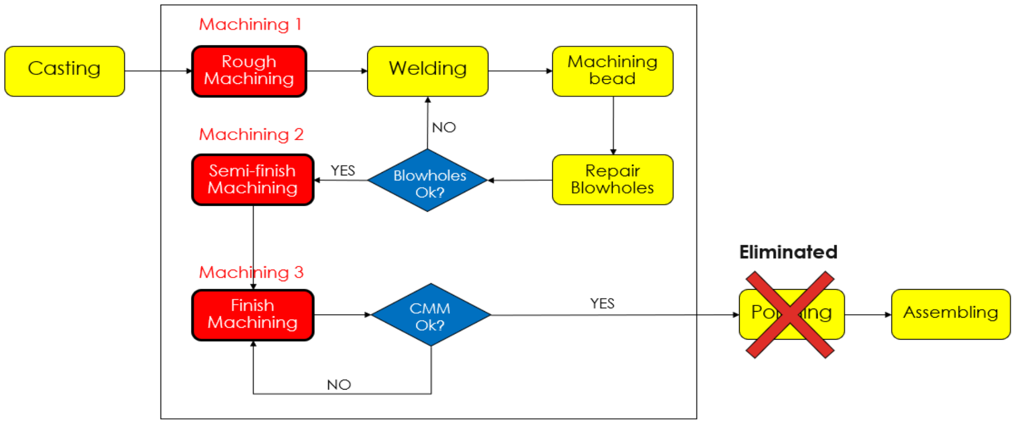


Figure 6.1 New flow chart for die production process

As a matter of fact, the surface roughness of the current machining condition is 2.10 micron after machining and 1.10 micron after polishing. Since the die surface quality after machining of the new machining condition is able to achieve the target of 1.1 micron, there is no need to do polishing anymore. Therefore, the die can be directly sent to assemble after the finish machining and CMM check as depicted in Figure 6.1.

6.2.2 Reduce time in finish machining operation

Table 6.3 Total CT of milling and polishing processes

Condition	CT / m2 (minute)			Ra (micron)
	Milling	Polishing	Total	
Current	*416*	*360*	**776**	**1.10**
New	*562*	-	**562**	**1.04**

Table 6.3 illustrates the CT per square meter of total milling and polishing time. Since the CT when using the current condition for milling the specimen (500 x 1000 mm) is 208 minutes, the CT per square meter is 562 minutes. Regarding the polishing process, the time for polishing the actual die is 540 minutes, calculated as 360 minutes per square meter. Hence, the total CT per square meter is 776 minutes.

With emphasis on the new condition, the total CT per square meter is only 562 minutes since the polishing process is eliminated. Even though there is no polishing process, the new condition can result in better surface roughness at 1.04 micron.

6.2.3 Reduce man power

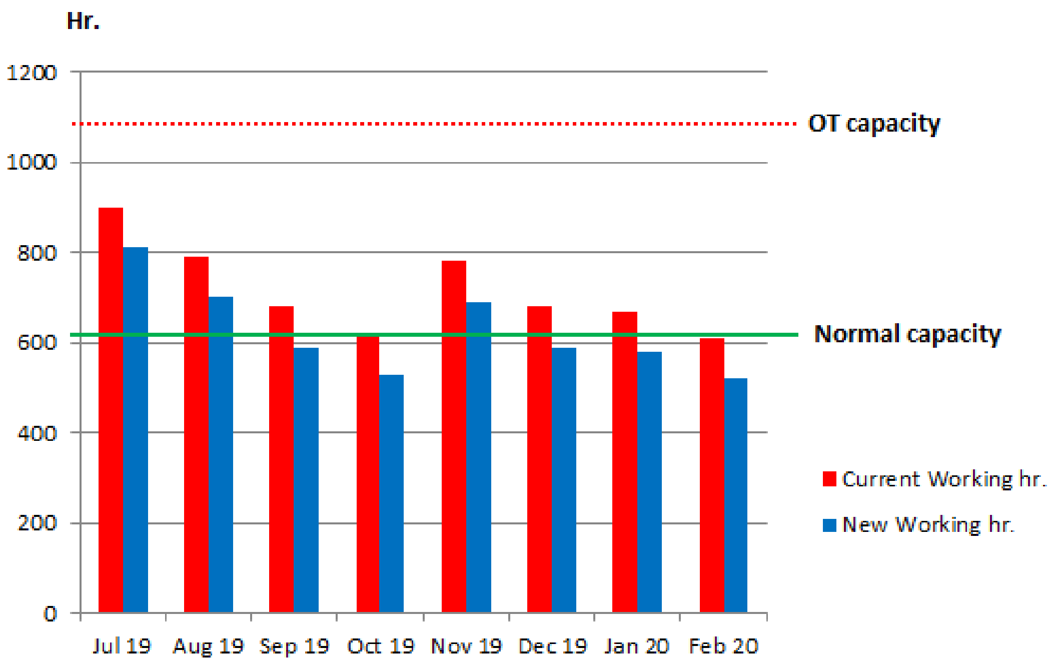


Figure 6.2 Capacity of the Finishing Section

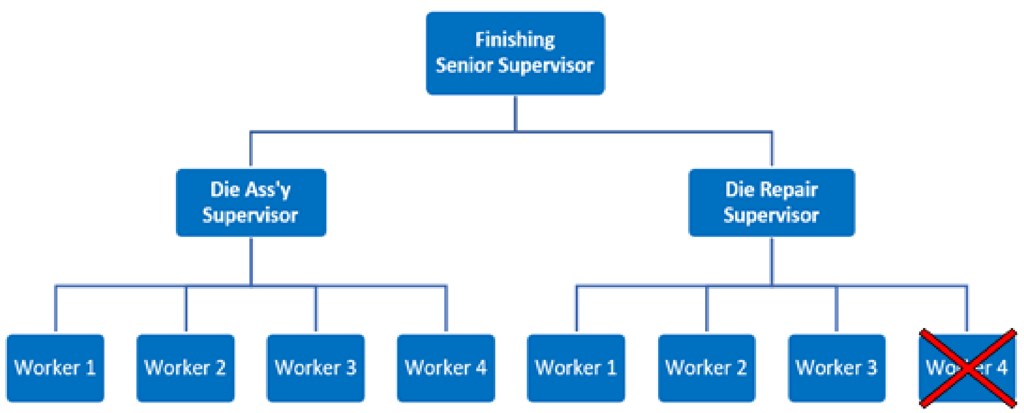


Figure 6.3 New organizational chart of the Finishing Section

According to Table 6.3, the machining time slightly increases while the total polishing time drops to zero. Since the polishing process literally requires man power in the operation, total man hour in the Finishing Section reduces a lot when the polishing process is eliminated. This improvement actually helps reduce working time for 540 minutes/die, making the Finishing Section have capacity left. As represented in Figure 6.2, the new working hours, which is the working hours after eliminating the polishing process, is under the normal capacity line in some months, meaning that there will be idle time in the operation. In other word, this improvement can help reduce the number of workers as illustrated in Figure 6.3.

6.2.4 Reduce equipment cost

Figure 6.4 Equipment used for polishing

Not only saving time, but this study also helps reduce cost in the operation. Tools and equipment that mainly relate to polishing process is an orbital sander and sand paper as shown in Figure 6.4. Basically, the orbital sander is used for flat areas while the curved areas are polished by hand. Since the polishing process is eliminated, the orbital sander and sand papers will not be used anymore.

6.2.5 Increase working area

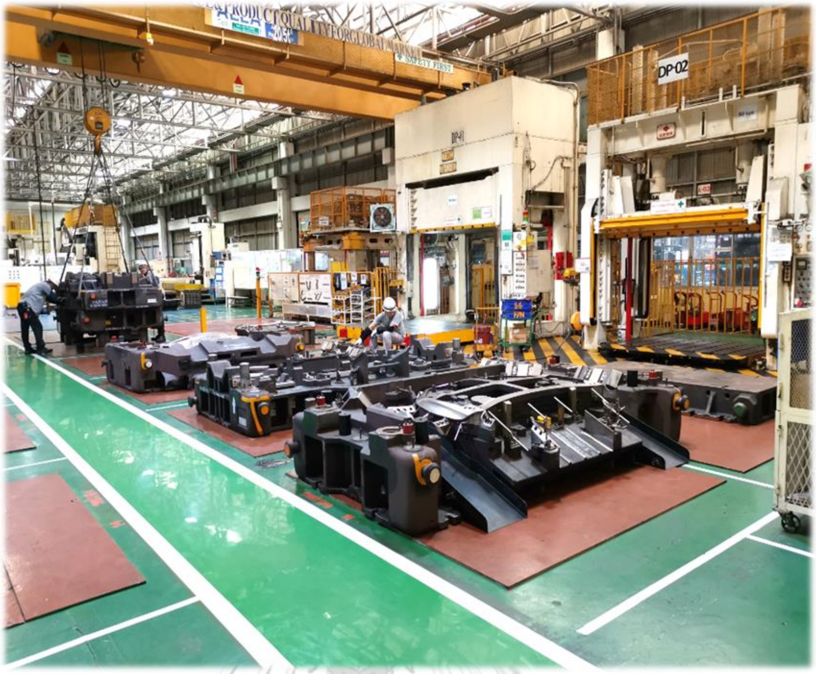


Figure 6.5 Working area in the Finishing Section

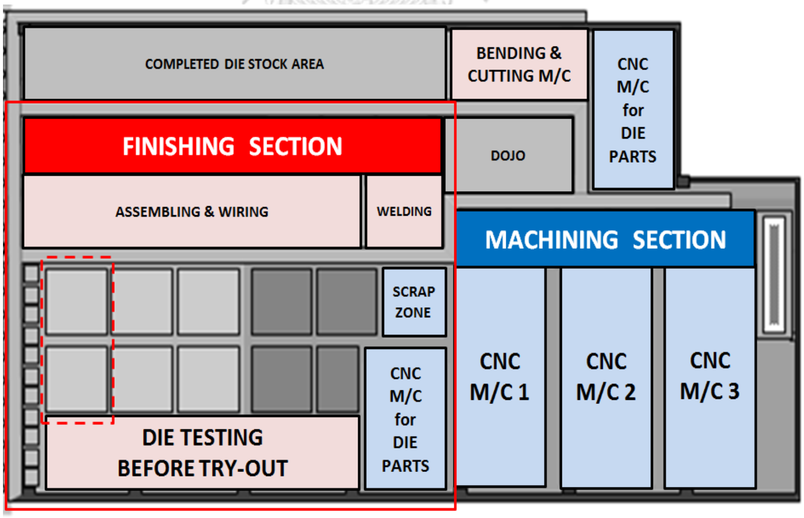


Figure 6.6 Finishing-section working area layout

Figure 6.5 and 6.6 illustrate the working area and layout of Finishing Section. Since there is no polishing process anymore, the areas that used to be for polishing will not be used. Hence, there will have some area left in the section, readying to be utilized for other purposes.

CHAPTER 7 CONCLUSION

In this chapter, the result and conclusion, which are drawn from the study, are revealed, along with the research limitations. Prospective points for the future work are also described for improving the future die manufacturing process.

7.1 Conclusion

In conclusion, this research studies about machining tools and parameters with emphasis on the car hood dies production. The main purpose of this research is to eliminate a polishing process and implement the new machining standard for improving die surface quality. As a result, the cutting tool is changed from 1-blade type to 3-blade type while the parameters are adjusted from "5,500-rpm cutting speed, 4,800-mm/min feed, 0.1-mm dept. of cut, and 0.5-mm pitch" to "11,670-rpm cutting speed, 3,560-mm/min feed, 0.1-mm dept. of cut, and 0.5-mm pitch". After optimizing the best machining condition, the new machining standard is determined for use in the operation.

The research brings about multifaceted benefits for the organization. It does not only result in the improvement of die surface quality, but also reduce the lead time and cost in the operation. The summarization of the research benefits is listed as below;

1. The surface roughness after the finish machining is reduced by 50.5%.
2. The lead time to complete the die surface shows a 27.6% decline.
3. The number of men in the Finishing Section is reduced by 12.5%
4. The costs for equipment and tools used for polishing are totally cut.
5. The working area is saved up to 20%.

7.2 Research limitation

The new machining condition is developed based on the program simulation result that is highly dependent on its own basis. In each experiment, the parameters are set into the machine by operators and the surface roughness is measured by the QC person who is beyond the project developer's direct control.

The CNC machine used for the finish machining process was selected and installed by a company's in-charge person in which the capabilities of the machine is regarded to a limitation for this research project. All suppliers who provide the tools used with the CNC machine are filtered and chosen by a purchaser of the company; contract, agreement, and strong relationship are considered as the heart of business for Japanese corporations.

7.3 Future suggestions

Future suggestions for this organization are mainly for manufacturing process which requires further researches to improve production process and increase production efficiency. Three main considerations regarding the production process are recommended as further studies. Suggestions for the organization include:

1. The optimization of a new machining condition for reducing cycle time in rough machining and semi-finish machining processes
2. The study of welding procedures for increasing stamping efficiency in die manufacturing process, considering environmental and commercial factors
3. Supplier selection with emphasis on die casting and chemical composition for stamping process improvement

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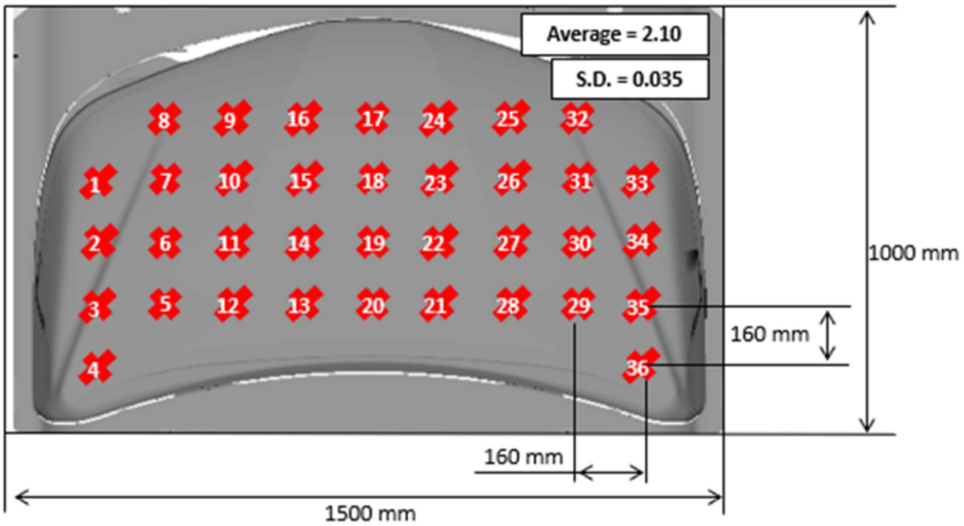
APPENDIX

APPENDIX A: Surface roughness of the die before improvement

A1. Surface roughness after machining by current condition



Unit : Micron

Point	1	2	3	4	5	6	7	8	9
Ra	2.04	2.02	2.06	2.03	2.07	2.05	2.07	2.08	2.08

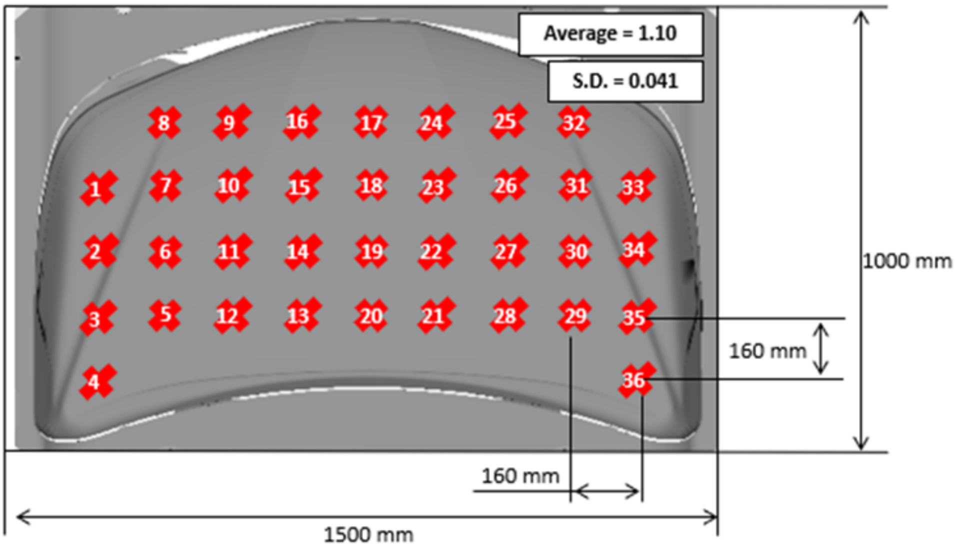
Point	10	11	12	13	14	15	16	17	18
Ra	2.05	2.09	2.07	2.06	2.08	2.10	2.11	2.08	2.09

Point	19	20	21	22	23	24	25	26	27
Ra	2.10	2.12	2.09	2.09	2.09	2.11	2.13	2.11	2.14

Point	28	29	30	31	32	33	34	35	36
Ra	2.13	2.14	2.12	2.13	2.14	2.16	2.13	2.12	2.15

Figure A1 Surface roughness after machining by current condition

A2. Surface roughness after polishing the surface machined by the current condition



Unit : Micron

Point	1	2	3	4	5	6	7	8	9
Ra	1.12	1.08	1.16	1.13	1.09	1.06	1.14	1.14	1.09

Point	10	11	12	13	14	15	16	17	18
Ra	1.07	1.15	1.14	1.18	1.13	1.09	1.12	1.16	1.11

Point	19	20	21	22	23	24	25	26	27
Ra	1.14	1.09	1.06	1.01	1.09	1.07	1.13	1.15	1.13

Point	28	29	30	31	32	33	34	35	36
Ra	1.08	1.03	1.09	1.05	1.04	1.11	1.05	1.08	1.14

Figure A2 Surface roughness after manual polishing the surface machined by the current condition

APPENDIX B: Surface roughness of the die specimen during the experiments

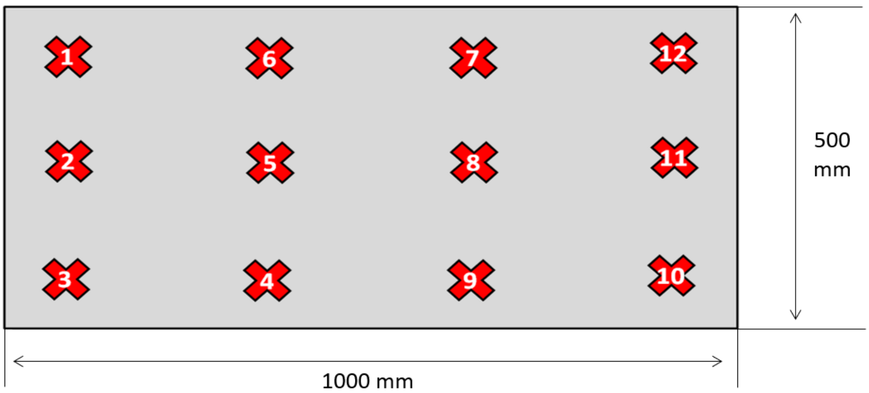


Figure B1 The points of measurement on the die specimen

B1. The 1-balde VS 3-blades experiment

Table B1.1 Data collection from "the 1-balde VS 3-blades experiment"

No.	blade	speed	feed	Feed per tooth	Dept.	pitch	CT	Ra	SD
1	1	5940	4750	0.40	0.1	0.5	211	**2.06**	0.033
2				0.40		1	105	**2.47**	0.019
3				0.40	0.2	0.5	211	**2.26**	0.043
4				0.40		1	105	**2.50**	0.020
5			9170	0.77	0.1	0.5	109	**2.70**	0.016
6				0.77		1	55	**2.88**	0.016
7				0.77	0.2	0.5	109	**2.80**	0.014
8				0.77		1	55	**2.94**	0.013
9		7640	4750	0.31	0.1	0.5	211	**1.39**	0.032
10				0.31		1	105	**2.03**	0.012
11				0.31	0.2	0.5	211	**1.69**	0.040
12				0.31		1	105	**2.29**	0.017
13			9170	0.60	0.1	0.5	109	**2.18**	0.014
14				0.60		1	55	**2.60**	0.018
15				0.60	0.2	0.5	109	**2.51**	0.016
16				0.60		1	55	**2.77**	0.011
17	3	5940	4750	0.20	0.1	0.5	211	**2.28**	0.026
18				0.20		1	105	**2.52**	0.012
19				0.20	0.2	0.5	211	**2.39**	0.042
20				0.20		1	105	**2.58**	0.018
21			9170	0.39	0.1	0.5	109	**2.54**	0.014
22				0.39		1	55	**2.80**	0.016
23				0.39	0.2	0.5	109	**2.68**	0.016
24				0.39		1	55	**2.75**	0.015
25		7640	4750	0.16	0.1	0.5	211	**1.83**	0.030
26				0.16		1	105	**2.36**	0.013
27				0.16	0.2	0.5	211	**1.92**	0.037
28				0.16		1	105	**2.50**	0.018
29			9170	0.30	0.1	0.5	109	**2.05**	0.017
30				0.30		1	55	**2.38**	0.012
31				0.30	0.2	0.5	109	**2.21**	0.016
32				0.30		1	55	**2.65**	0.012
		(rpm)	(mm / min)	(mm / tooth)	(mm)	(mm)	(Min)	(Micron)	

Table B1.2 Each point of measurement from "the 1-balde VS 3-blades experiment"

Unit : Micron

Condition	Ra													
	1	2	3	4	5	6	7	8	9	10	11	12	Avg	SD
1	2.03	2.02	2.06	2.03	2.05	2.05	2.04	2.05	2.09	2.10	2.12	2.10	**2.06**	**0.033**
2	2.48	2.45	2.46	2.44	2.47	2.44	2.50	2.47	2.49	2.46	2.47	2.49	**2.47**	**0.019**
3	2.24	2.24	2.21	2.23	2.22	2.25	2.25	2.26	2.30	2.34	2.32	2.31	**2.26**	**0.043**
4	2.49	2.47	2.52	2.51	2.48	2.50	2.49	2.50	2.52	2.54	2.51	2.52	**2.50**	**0.020**
5	2.72	2.69	2.70	2.69	2.71	2.73	2.69	2.70	2.67	2.71	2.69	2.70	**2.70**	**0.016**
6	2.88	2.85	2.89	2.87	2.90	2.88	2.89	2.87	2.88	2.88	2.91	2.87	**2.88**	**0.016**
7	2.78	2.80	2.81	2.78	2.79	2.78	2.81	2.79	2.82	2.80	2.78	2.80	**2.80**	**0.014**
8	2.95	2.93	2.97	2.95	2.94	2.94	2.93	2.92	2.93	2.94	2.95	2.94	**2.94**	**0.013**
9	1.37	1.36	1.34	1.38	1.37	1.39	1.37	1.42	1.44	1.40	1.43	1.43	**1.39**	**0.032**
10	2.01	2.03	2.02	2.05	2.03	2.01	2.03	2.02	2.04	2.01	2.03	2.02	**2.03**	**0.012**
11	1.68	1.64	1.66	1.65	1.64	1.69	1.66	1.70	1.73	1.75	1.72	1.74	**1.69**	**0.040**
12	2.28	2.28	2.26	2.27	2.28	2.29	2.28	2.27	2.29	2.31	2.32	2.29	**2.29**	**0.017**
13	2.20	2.17	2.18	2.19	2.20	2.17	2.18	2.16	2.19	2.17	2.16	2.19	**2.18**	**0.014**
14	2.58	2.58	2.60	2.59	2.63	2.61	2.60	2.60	2.57	2.62	2.58	2.59	**2.60**	**0.018**
15	2.53	2.51	2.50	2.53	2.50	2.49	2.51	2.53	2.52	2.48	2.50	2.51	**2.51**	**0.016**
16	2.76	2.77	2.77	2.75	2.78	2.77	2.76	2.76	2.79	2.77	2.78	2.76	**2.77**	**0.011**
17	2.25	2.27	2.25	2.27	2.26	2.25	2.29	2.28	2.27	2.29	2.33	2.32	**2.28**	**0.026**
18	2.52	2.52	2.54	2.53	2.50	2.52	2.51	2.51	2.53	2.54	2.52	2.52	**2.52**	**0.012**
19	2.37	2.33	2.34	2.36	2.39	2.35	2.40	2.39	2.43	2.46	2.42	2.44	**2.39**	**0.042**
20	2.58	2.56	2.56	2.58	2.57	2.59	2.60	2.57	2.57	2.59	2.61	2.61	**2.58**	**0.018**
21	2.55	2.54	2.53	2.53	2.56	2.54	2.55	2.53	2.56	2.52	2.55	2.56	**2.54**	**0.014**
22	2.81	2.79	2.81	2.82	2.80	2.78	2.82	2.79	2.77	2.80	2.81	2.81	**2.80**	**0.016**
23	2.68	2.66	2.66	2.69	2.68	2.70	2.67	2.71	2.66	2.68	2.69	2.68	**2.68**	**0.016**
24	2.77	2.77	2.74	2.75	2.78	2.74	2.73	2.75	2.76	2.74	2.76	2.75	**2.75**	**0.015**
25	1.81	1.81	1.80	1.79	1.81	1.84	1.87	1.83	1.85	1.88	1.84	1.87	**1.83**	**0.030**
26	2.38	2.35	2.36	2.34	2.37	2.38	2.35	2.34	2.36	2.37	2.36	2.36	**2.36**	**0.013**
27	1.90	1.87	1.90	1.89	1.88	1.92	1.96	1.93	1.95	1.98	1.94	1.97	**1.92**	**0.037**
28	2.50	2.51	2.48	2.50	2.50	2.49	2.50	2.48	2.53	2.51	2.54	2.51	**2.50**	**0.018**
29	2.06	2.05	2.07	2.05	2.04	2.05	2.03	2.03	2.06	2.05	2.08	2.08	**2.05**	**0.017**
30	2.36	2.39	2.39	2.38	2.38	2.36	2.37	2.39	2.37	2.38	2.38	2.36	**2.38**	**0.012**
31	2.21	2.21	2.21	2.18	2.19	2.22	2.21	2.23	2.20	2.18	2.22	2.22	**2.21**	**0.016**
32	2.66	2.64	2.64	2.66	2.64	2.65	2.66	2.63	2.65	2.64	2.67	2.66	**2.65**	**0.012**

B2. The 1-balde experiment

Table B2.1 Data collection from “the 1-blade experiment”

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	PtType	Blocks	V	f	CT	Ra
1	1	1	1	1	1810.00	2170.0	461	1.99
2	2	2	1	1	7640.00	2170.0	461	1.19
3	3	3	1	1	1810.00	9170.0	109	4.20
4	4	4	1	1	7640.00	9170.0	109	2.18
5	5	5	-1	1	602.57	5670.0	176	3.95
6	6	6	-1	1	8847.43	5670.0	176	1.43
7	7	7	-1	1	4725.00	720.3	1388	1.15
8	8	8	-1	1	4725.00	10619.7	94	4.77
9	9	9	0	1	4725.00	5670.0	176	2.17
10	10	10	0	1	4725.00	5670.0	176	2.19
11	11	11	0	1	4725.00	5670.0	176	2.17
12	12	12	0	1	4725.00	5670.0	176	2.18
13	13	13	0	1	4725.00	5670.0	176	2.16

(When v = cutting speed and f = feed)

Table B2.2 Each point of measurement from “the 1-blade experiment”

Unit : Micron

Condition	Ra													
	1	2	3	4	5	6	7	8	9	10	11	12	Avg	SD
1	1.96	1.99	2.01	1.97	2.04	1.97	1.98	1.97	2.00	2.03	2.00	2.01	**1.99**	**0.025**
2	1.20	1.18	1.16	1.21	1.15	1.20	1.20	1.18	1.19	1.22	1.20	1.23	**1.19**	**0.023**
3	4.10	4.15	4.12	4.13	4.18	4.25	4.19	4.22	4.27	4.25	4.28	4.30	**4.20**	**0.068**
4	2.16	2.14	2.19	2.17	2.18	2.16	2.19	2.21	2.17	2.22	2.20	2.21	**2.18**	**0.024**
5	3.91	3.89	3.90	3.92	3.91	3.97	3.96	3.94	3.98	3.96	4.02	3.99	**3.95**	**0.041**
6	1.43	1.42	1.43	1.43	1.42	1.44	1.42	1.42	1.45	1.44	1.44	1.46	**1.43**	**0.013**
7	1.14	1.12	1.16	1.12	1.15	1.14	1.17	1.16	1.13	1.18	1.14	1.15	**1.15**	**0.019**
8	4.70	4.73	4.69	4.75	4.72	4.79	4.75	4.78	4.80	4.80	4.85	4.84	**4.77**	**0.052**
9	2.15	2.17	2.16	2.16	2.18	2.15	2.17	2.19	2.16	2.15	2.18	2.18	**2.17**	**0.014**
10	2.16	2.18	2.15	2.15	2.19	2.17	2.20	2.22	2.21	2.24	2.20	2.19	**2.19**	**0.028**
11	2.15	2.18	2.16	2.19	2.18	2.18	2.16	2.17	2.16	2.18	2.19	2.17	**2.17**	**0.013**
12	2.17	2.14	2.18	2.17	2.16	2.17	2.20	2.18	2.18	2.19	2.17	2.20	**2.18**	**0.017**
13	2.16	2.19	2.18	2.19	2.19	2.15	2.16	2.16	2.12	2.14	2.16	2.16	**2.16**	**0.021**

B3. The 3-baldes experiment

Table B3.1 Data collection from "the 3-blades experiment"

↓	C1	C2	C3	C4	C5	C6	C7	C8
	StdOrder	RunOrder	PtType	Blocks	V	f	CT	Ra
1	1	1	1	1	5940.0	4750.0	211	2.28
2	2	2	1	1	11670.0	4750.0	211	1.09
3	3	3	1	1	5940.0	11670.0	86	3.15
4	4	4	1	1	11670.0	11670.0	86	1.95
5	5	5	-1	1	4753.3	8210.0	122	2.63
6	6	6	-1	1	12856.7	8210.0	122	1.52
7	7	7	-1	1	8805.0	3316.8	301	1.40
8	8	8	-1	1	8805.0	13103.2	76	3.78
9	9	9	0	1	8805.0	8210.0	122	1.72
10	10	10	0	1	8805.0	8210.0	122	1.72
11	11	11	0	1	8805.0	8210.0	122	1.74
12	12	12	0	1	8805.0	8210.0	122	1.75
13	13	13	0	1	8805.0	8210.0	122	1.73

(When v = cutting speed and f = feed)

Table B3.2 Each point of measurement from "the 3-blades experiment"

Unit : Micron

Condition	Ra													
	1	2	3	4	5	6	7	8	9	10	11	12	Avg	SD
1	2.27	2.28	2.24	2.26	2.29	2.28	2.26	2.31	2.32	2.28	2.30	2.28	**2.28**	**0.022**
2	1.08	1.07	1.10	1.08	1.06	1.11	1.09	1.11	1.08	1.09	1.11	1.10	**1.09**	**0.017**
3	3.14	3.11	3.13	3.18	3.12	3.14	3.16	3.13	3.17	3.18	3.20	3.19	**3.15**	**0.030**
4	1.93	1.96	1.95	1.92	1.94	1.96	1.97	1.95	1.93	1.95	1.94	1.98	**1.95**	**0.017**
5	2.58	2.62	2.60	2.63	2.61	2.59	2.64	2.63	2.67	2.62	2.65	2.66	**2.63**	**0.027**
6	1.52	1.50	1.49	1.51	1.52	1.50	1.50	1.52	1.54	1.52	1.53	1.54	**1.52**	**0.016**
7	1.40	1.37	1.38	1.38	1.40	1.41	1.40	1.43	1.43	1.42	1.41	1.41	**1.40**	**0.019**
8	3.73	3.75	3.77	3.74	3.76	3.76	3.80	3.79	3.82	3.84	3.84	3.81	**3.78**	**0.038**
9	1.69	1.71	1.69	1.68	1.72	1.71	1.71	1.73	1.72	1.74	1.74	1.75	**1.72**	**0.022**
10	1.71	1.69	1.69	1.68	1.70	1.73	1.71	1.72	1.72	1.74	1.76	1.73	**1.72**	**0.023**
11	1.73	1.74	1.72	1.74	1.74	1.72	1.71	1.75	1.73	1.76	1.74	1.74	**1.74**	**0.014**
12	1.74	1.72	1.72	1.73	1.75	1.74	1.76	1.75	1.75	1.77	1.78	1.76	**1.75**	**0.019**
13	1.70	1.73	1.72	1.73	1.74	1.74	1.74	1.72	1.74	1.71	1.73	1.75	**1.73**	**0.014**

B4. The cutting speed experiment

Table B4.1 Surface roughness results when cutting speed changes

Unit : Micron

Condition	Tool, Feed, Dept., Pitch	Speed	Ra													
			1	2	3	4	5	6	7	8	9	10	11	12	Avg	SD
1	Tool Type 3 Blades Feed 4,750 mm/min Dept. 0.1 mm Pitch 0.5 mm	6,000 rpm	2.26	2.27	2.24	2.26	2.26	2.28	2.28	2.29	2.27	2.30	2.28	2.31	**2.28**	**0.019**
2		6,500 rpm	2.11	2.14	2.11	2.15	2.13	2.14	2.16	2.15	2.15	2.18	2.17	2.15	**2.15**	**0.021**
3		7,000 rpm	1.95	1.98	1.96	1.99	1.96	1.97	1.98	1.99	1.96	1.96	1.98	2.00	**1.97**	**0.016**
4		7,500 rpm	1.83	1.81	1.80	1.81	1.81	1.83	1.84	1.84	1.87	1.86	1.84	1.85	**1.83**	**0.022**
5		8,000 rpm	1.70	1.69	1.68	1.70	1.71	1.70	1.71	1.68	1.69	1.73	1.68	1.71	**1.70**	**0.015**
6		8,500 rpm	1.60	1.65	1.63	1.64	1.63	1.61	1.64	1.63	1.65	1.66	1.66	1.64	**1.64**	**0.018**
7		9,000 rpm	1.54	1.54	1.56	1.55	1.54	1.52	1.56	1.56	1.58	1.56	1.57	1.57	**1.55**	**0.017**
8		6,000 rpm	1.43	1.45	1.46	1.44	1.45	1.46	1.46	1.49	1.50	1.48	1.49	1.48	**1.47**	**0.022**
9		6,000 rpm	1.35	1.38	1.37	1.35	1.34	1.34	1.35	1.36	1.37	1.36	1.36	1.37	**1.36**	**0.013**
10		6,000 rpm	1.22	1.21	1.25	1.22	1.26	1.21	1.25	1.26	1.26	1.27	1.28	1.25	**1.25**	**0.024**
11		6,000 rpm	1.13	1.11	1.11	1.15	1.12	1.16	1.14	1.13	1.13	1.17	1.16	1.16	**1.14**	**0.021**
12		6,000 rpm	1.08	1.09	1.07	1.07	1.09	1.10	1.09	1.11	1.09	1.11	1.10	1.12	**1.09**	**0.016**
13		6,000 rpm	1.09	1.08	1.11	1.09	1.12	1.13	1.14	1.11	1.12	1.14	1.13	1.15	**1.12**	**0.022**
14		6,000 rpm	1.18	1.17	1.20	1.19	1.18	1.18	1.20	1.23	1.23	1.21	1.24	1.22	**1.20**	**0.023**
15		6,000 rpm	1.27	1.28	1.26	1.26	1.29	1.31	1.28	1.30	1.31	1.32	1.33	1.30	**1.29**	**0.023**

B5. Result from method 1,2, and 3

Table B5.1 Results from the methods

Condition	Tool	Cutting Speed	Feed	Dept.	Pitch	CT	Ra	S.D. (Ra)
Best Ra	**3-Blades**	11670	4750	0.1	0.5	211	1.09	0.017
Method 1	**3-Blades**	11670	3563	0.1	0.5	281	1.04	0.016
Method 2	**3-Blades**	11670	2375	0.1	0.5	421	1.03	0.013
Method 3	**3-Blades**	11670	4750	0.05	0.5	421	1.06	0.012
		(rpm)	(mm/min)	(mm)	(mm)	(minute)	(micron)	

Table B5.2 Each point of measurement from the methods

Unit : Micron

Method	Ra													
	1	2	3	4	5	6	7	8	9	10	11	12	Avg	SD
1	1.05	1.04	1.02	1.05	1.02	1.03	1.07	1.04	1.04	1.06	1.05	1.06	**1.04**	**0.016**
2	1.03	1.04	1.02	1.03	1.01	1.04	1.03	1.03	1.05	1.06	1.03	1.04	**1.03**	**0.013**
3	1.05	1.03	1.04	1.06	1.06	1.05	1.05	1.06	1.07	1.07	1.06	1.07	**1.06**	**0.012**

B6. The feed experiment

Table B6.1 Surface roughness results when feed changes

Condition	Tool, Speed, Dept., Pitch	Feed	Ra													
			1	2	3	4	5	6	7	8	9	10	11	12	Avg	SD
1	Tool Type 3 Blades Feed 4,750 mm/min Dept. 0.1 mm Pitch 0.5 mm	2,000 mm/min	1.01	1.02	1.03	1.03	1.02	1.04	1.02	1.00	1.03	1.02	1.04	1.03	**1.02**	**0.012**
2		4,000 mm/min	1.04	1.02	1.03	1.01	1.03	1.03	1.05	1.04	1.03	1.06	1.05	1.04	**1.04**	**0.014**
3		6,000 mm/min	1.18	1.19	1.17	1.20	1.21	1.20	1.18	1.19	1.19	1.22	1.21	1.23	**1.20**	**0.018**
4		8,000 mm/min	1.28	1.26	1.28	1.28	1.29	1.31	1.30	1.30	1.28	1.33	1.31	1.33	**1.30**	**0.022**
5		10,000 mm/min	1.64	1.62	1.65	1.66	1.66	1.63	1.63	1.67	1.66	1.66	1.68	1.66	**1.65**	**0.018**
6		12,000 mm/min	1.92	1.95	1.93	1.95	1.94	1.96	1.96	1.95	1.97	1.96	1.97	1.99	**1.95**	**0.019**

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