Comparative Analysis of Machinability of Grey Cast Iron between Conventional and Non-conventional Machining

By

Fazmi Yuhanis bt Awang

Dissertation submitted in partial fulfillment of
the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS
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July 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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FAZMI YUHANIS BT AWANG

ABSTRACT

This report focuses on the comparative analysis on the machinability of grey cast iron using conventional and non-conventional machining. For conventional machining, a vertical milling machine was used while for non-conventional machining, an EDM wire cut machine was used. Surface finish was selected as the basis for the comparative analysis. This report analyzed the rate of machinability of grey cast iron by various machining processes. This report also includes the specific project activities which involve the machining processes which were milling and EDM wire cut. The work pieces were machined according to the specific cutting speed where the feed rate was constant. The work pieces were then subjected to surface roughness tests. Based on the results from the surface roughness comparison, it was found out that non-conventional machining produced better surface finish compared to conventional machining. Hence for the case of grey cast iron, non-conventional machining should be used in order to produce products with better surface finish.

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CHAPTER 1
INTRODUCTION

1.1 Background

Machinability of grey cast iron also known as the simplicity or the ease of grey cast iron to be machined until fit the required satisfactory surface finish. Material with good machinability will require less cutting power, less time taken to cut the materials, good surface finish and the cutting tools do not wear too much. However, the machinability is decreasing with the factors of materials performance's improvements. (Groover, Mikell P.,2007)

Few aspects that comprise machinability of a material are the strength and toughness of the materials where the increase of strength and toughness will require higher force and cutting power. The chemical composition also includes through the composition of carbon. Other than that is the increasing of thermal conductivity, the microstructure of the materials, the cutting tools geometry and the machining process parameters. The comparison of machinability of materials can be analyzed throughout the tool life, the surface finish, the cutting temperature, the tool forces and power consumptions. (Oberg, Erik; Jones, Franklin D.; McCauley, Christopher J.; Heald, Ricardo M., 2004)

For grey cast iron, carbon content between 3.1wt% to 4.0wt% while silicon content about 1.5wt% to 2.5wt% of its chemical element of grey cast iron. These types of grey cast iron have a balance good formability of complex shapes and can endure moderate shrinkage during the solidification and cooling process. (Mohd Amin Abd Majid, Othman Mamat, 2003)

1.2 Problem statement

Variation in the quality of product which is made from grey cast iron is often notified as one of big problem in machining process. The dissimilarity occurred through the machinability which is based on conventional and non-conventional machining itself. Thus cause the demand in finding the suitable and correct machining parameters in order to produce high quality product for gray cast iron.

1.3 Objective

To undertake comparative analysis machinability of grey cast iron using conventional and non-conventional machining.

1.4 Scope of Study

This project involve machining process using face milling and advanced machining process wire electro discharge machining. The scope also includes the surface technology to analyze the surface finish of the samples.

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Grey Cast Iron

Grey cast iron also known as grey flake iron. The flake was formed from free graphite in cast iron. Cast iron content about 2%-4% of carbon in its chemical composition which acts as the structure of the material and has major effect on the properties. Grey cast iron was formed by dissolved more carbon where will form Iron Carbide which is hard and brittle and also Graphite which is pure carbon with soft and little strength. Carbon takes form was determined by the rate of cooling during the solidification and also included the manipulation of other alloying elements and following thermal elements. The tensile strength of grey cast iron is three to four times less compared to the compression strength. This is due to planes of weakness generates by graphite flakes. Grey cast iron tends to brittle more compare to steel. However it is very stiff and has a little deflects before fracture. Hence the damping quality is affected. Grey cast iron also has high thermal conductivity and low modulus of elasticity thus making it to have the ability to withstand the thermal shock. (Roy Elliot, 1988) Gray cast iron is usually used as the materials for brake disc in automotive section.

The American Society for Testing Materials (ASTM) numbering system for grey cast iron was established such that the numbers correspond to the minimum tensile strength in kpsi. Thus an ASTM no. 20 cast iron has a minimum tensile strength of 20 kpsi. Note particularly that the tabulations are typical values. The properties of grey cast iron are tabulated as per table 2.1. (Thomas W. Wolf, 2006)

Table 2.1: The table below shows the properties of grey cast iron based on ASTM standards (Thomas W. Wolf, 2006)

Properties of Gray Cast Iron							
ASTM Number	Tensile Strength (Kpsi)	Compressive Strength (Kpsi)	Shear Modulus of Rupture (Kpsi)	Modulus of Elasticity (Mpsi)		Endurance Limit (Kpsi)	Brinell Hardness H_b
				Tension	Torsion		
20	22	83	26	9.6-14	3.9-5.6	10	156
25	26	97	32	11.5-14.8	4.6-6.0	11.5	174
30	31	109	40	13.0-16.4	5.6-6.6	14	201
35	36.5	124	48.5	14.5-17.2	5.8-6.9	16	212
40	42.5	140	57	16.0-20	6.4-7.8	18.5	235
50	52.5	164	73	18.8-22.8	7.2-8.0	21.5	262
60	62.5	187.5	88.5	20.4-23.5	7.8-8.5	24.5	302

2.2 Conventional machining

Conventional machining can be identified as a process which used mechanical (motion) energy. This method work using manually controlled machines such as lathe, milling and drilling. The motion of the tool is work through mechanical controls which is manually controlled. It typically using types of hardens implemented material as a cutting tool and the tool is essential to involve in direct contact between tool and work piece. (J.P. Davim, 2002) By using conventional method to machine harden metals and alloys will cause higher requirement of time and energy consumption. It also can cause the wear of tools thus will increase the cost and reduce the quality of the product due to stimulate of the residual stress during manufacturing process. Therefore, in some condition, conventional machining is not feasible. Some examples of conventional machining are milling, lathe and drilling. (Hassan El-Hofy, 2007)

2.2.1 Mechanics of cutting

There are few major independent variables in cutting which are tool materials and coating, tool shape, surface finish and sharpness, workpiece material condition, cutting speed, feed and depth of cut (DOC), cutting fluids, and characteristics of machine tools, workholding and fixturing.

There are also few of dependent variables which are types of chip produces, force and energy dissipated, temperature rise in the workpiece, tools and chip, tool wear and failure, surface finish and surface integrity of workpiece. (Serope Kalpakjian, Steven Schmid, 2006)

2.2.2 Machining parameters on machinability of Grey Cast Iron

Machining parameters of grey cast iron are selected based on the independent and dependent variables to be analyzed are as follows:

1. Surface finish and surface integrity of machined part

Surface finish can be described as the geometric features of a surface while surface integrity relates to materials properties which are highly manipulate by the nature of the surface is produced. There are few factors that influencing the surface integrity which are:

a. The temperatures produce during the process

b. Surface residual stress

c. Plastic deformation and strain hardening of the machine surface

(Serope Kalpakjian, Steven Schmid, 2006)

In producing a good and consistent surface finish, the range of tool geometries and feed rates used is restricted. The tool wear will result the end surface finish become rougher and less consistent where can limit the tool life. Basically there are two components or features in surface finish which are the ideal or geometric finish and natural finish. The ideal or geometric finish is produced in operations where the tool wear and cutting forces are low. The natural finish is hard to expect in general which result from tool wear, vibration, machine motion errors and work material effects such as inhomogeneity, built-up edge (BUE) formation and rupture at low cutting speed. It also a common components in machining inhomogeneous materials such as cast iron or machining steels and hard materials using carbide tools or in powder metals. (David A.Stephenson, John S.Agapiou, 2006)

In many cutting processes, the tool leaves feed marks on the workpiece as it travel. Thus the higher feed, *f* with smaller tool nose radius, *R*, the mark will be more prominent. This can be described through arithmetic mean value, R_a which is the schematic illustration of a rough surface. (Serope Kalpakjian, Steven Schmid, 2006)

The surface Roughness formula is:

$$R_a = f_m^{\ 2} / 8R \text{ ------------- (Equation 2.1)}$$

Thus;

$$f_m = \sqrt{Rax8R} \text{ ------------- (Equation 2.2)}$$

2. Tool wear and tool life estimation

Tool wear affected the tool life, the quality of the machined surface and its dimensional accuracy also the economics of cutting operations. Cutting tool are exposed to high localized stress at the tip of the tool, high temperatures along the rake face and sliding of the tool along the newly cut workpiece surface, hence will encourage the tool wear. (Serope Kalpakjian, Steven Schmid, 2006)

Tool wear can be categorize by the region of the tool is affected or by the physical mechanisms which produce it. However, the types of tool wear is mostly depends on the tool materials. Standardization in tool life tests is developed in order to grade the performance of cutting tool materials or the machinability of workpiece materials. There are ISO standard test for single point turning, face milling and end milling, the ASTM bar turning test and the Volvo end milling test. From this standard, we can severely identify the tools and workpiece geometry, cutting conditions, machine tool characteristic and tool life criteria. Usually, flank wear criteria are used in defining the tool life. (David A.Stephenson, John S.Agapiou, 2006)

The tool life equation is:

$$VT^n = C \text{ -------------(Equation 2.3)}$$

Where V is the cutting speed, T is the time (minutes), n is the exponent depends on the tool and workpiece and C is the constant.

3. Force and Power consumption

Identifying the cutting force and power consumption in the operation is important in order to minimize the distortion of machine part, maintaining the desired dimensional accuracy of the workpiece and also used in choosing the toolholders and workholding devices. Furthermore, the data also important in enable the workpiece to withstand the force without excessive distortion. (Serope Kalpakjian, Steven Schmid, 2006)

Cutting forces can be used in determining the machine power requirement and bearing loads, cause deflection of the part, tool or machine structure and can cause excessive cutting temperatures or unstable vibrations due to the supply energy to the machining system. For cutting forces, the measurement is often made by special design dynamometer which is the piezoelectric dynamometers that occupy quartz load measuring elements. This type of design has high stiffness, large frequency response, stable thermally and exhibit little static crosstalk between the measurement in different directions. It been placed mostly between the tool or the workpiece and the non rotating part of the machine tool. (David A.Stephenson, John S.Agapiou, 2006)

The power required for cutting is calculated through:

$$P = F_c V \text{ (ft-lb/min) -------------(Equation 2.4)}$$

Horsepower at the machine spindle:

$$Hp = F_c V / 33000 \text{ ---------------(Equation 2.5)}$$

2.2.3 Milling Process

Process of removing the materials while moving on diverge axes on the workpiece (Serope Kalpakjian, Steven Schmid, 2006) by using a rotary tool with multiple cutting edge. The criteria for milling tool is similar to turning however milling required further concern since it is an interrupted cutting process. Cutting edge on milling cutter will enter and leave the cut in each rotation. It also did the cutting process less than half of the total machining time. (David A.Stephenson, John S.Agapiou, 2006)

For basic milling process, there are three types of milling process which are slab milling, face milling and end milling. For face and end milling, most of its cutting is done by the peripheral portions of the teeth, with the face portions providing some finishing action.(E.Paul DeGarmo, JT Black, Ronald A.Kohser, 2003)

a) For slab milling, the plane of cutting is parallel to the work piece where the cutter body have allocated teeth on the side-line of its body.

b) For face milling, the cutter is mount to the spindle that is vertical to the work piece. The surface will be milled as the product of movement of the peripheral portions of the cutter teeth.

c) For end milling, the cutter rotates perpendicularly to the work piece axis. The cutter teeth are placed on the end of the tool and can cut both side and the end of the tools.

d) Figure 2.1 explained the basic cutting process involves in milling operations. (Serope Kalpakjian, Steven Schmid, 2006)

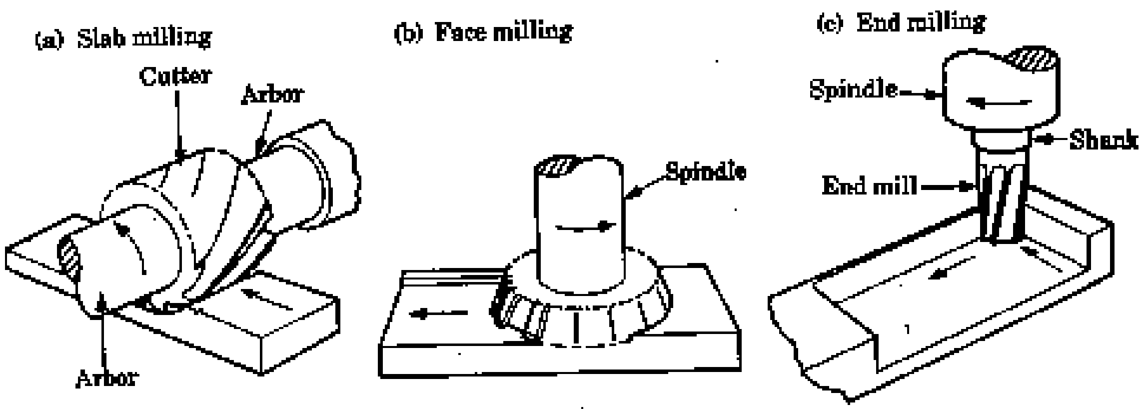


Figure 2.1: Drawing shows basic milling process operation

Design consideration for milling

1. The design should be milled by standard milling cutters
2. Pocket with sharp corners and internal cavities should be avoided because of the difficulty of milling.
3. To minimize the deflections that may occur, workpiece should be succificient.

(Serope Kalpakjian, Steven Schmid, 2006)

Cutting speed calculation for milling process:

$$V_c = 0.262\, D_m\, N_s \quad \text{-------------- (Equation 2.6)}$$

$$N_s = f_m / (n\, f_t) \quad \text{-------------- (Equation 2.7)}$$

Replacing Equation 2.7 into 2.6

Thus:

$$V_c = 0.262\ D_m\ [\ f_m / (n\ f_t)]$$ ------------- (Equation 2.8)

Where:

V_c = Cutting speed (feed/minutes)

D_m = Diameter of milling cutter (inch)

N_s = rpm value of cutter

f_m = Feed rate (inch/minutes)

f_t = Amount metal removes (feed/tooth)

n = number of teeth in cutter

(E.Paul DeGarmo, JT Black, Ronald A.Kohser, 2003)

2.3 Non-conventional machining

Non-conventional machining can be identified as a process that utilise other form of energy such as thermal, electrical and chemical energy. It is an up to date development of the conventional machining process. There are few advantages of using non-conventional machining which it can produces a high accuracy dimension of product, better surface finish and there is no direct contact between the tools and the work piece thus will result in decreasing of tool wear and increase of tool life. However non-conventional machining also has few disadvantages which is cost consuming because the set up for the machining requires competent worker to handle the job and the machines have higher complexity in setting up the machines. There are few examples of non-conventional machining which is Abrasive Jet machining, Electrical Discharge Machining and electrochemical machining. (K.L. Senthil Kumar, R. Sivasubramanian, K. Kalaiselvan, 2009)

2.3.1. Electro Discharge Machining Wire Cut

Process involves a wire travel slowly along the set trail and cut the workpiece based on the erosion of metal by spark discharges. The wire diameter used for rough cut is about 0.30mm while for finishing cut is about 0.20mm. The wire also should have high electrical conductivity, high tensile strength and the tension is about 60% from its tensile stress. The travel velocity is in constant which varies from 0.15m/min to 9m/min. Basically, it used computer controls in controlling the cutting path of the wire and the angle with respect to the work piece. (Serope Kalpakjian, Steven Schmid, 2006)

Design consideration

1. Parts should be design well so the wire can be shaped properly and economically
2. For mass production, complex and complicated design should be avoided since it is a time consuming machining process.

   (Serope Kalpakjian, Steven Schmid, 2006)

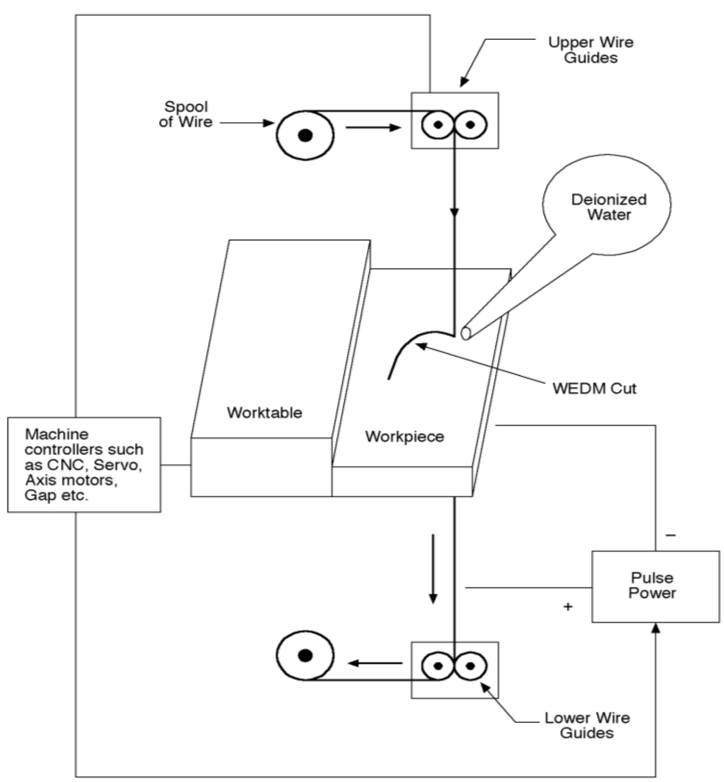


Figure 2.2: Schematic diagram of EDM wire cut operation

The material removal rate for wirecut is:

$$MRR = C\,I / T_m^{1.23} \text{------------(Equation 2.9)}$$

Where:

MRR = material removal rate (in^3/min)

C = proportionality constant value 5.08

I = Discharge current in Ampere

T_m = Melting temperature of the workpiece material °F

Thus to calculate the cutting speed, V_c, we can divide the material removal rate with area of the work piece.

$$V_c = MRR / Area \text{ ------------(Equation 2.10)}$$

2.4 Surface roughness

Roughness can be simply used as the measure texture of the surface. Surface roughness actually can be implying as the measure for the better surface irregularities in the surface texture. Well roughness plays important roles in verifying the object interaction with the environment. A rough surface usually wears rapidly and will have higher friction than the smoother surface. Thus, roughness is a good predictor of the performance of the mechanical component since any irregularities as we know could lead to cracks or any other defects in the parts and will reduce its durability. (David A.Stephenson, John S.Agapiou, 2006) A good surface finish and integrity is desirable during the machining process. However, the roughness which is undesirable is difficult and is quite expensive to control in the manufacturing process itself. The manufacturing cost will increase by increasing to the good surface finish. Thus this always cause as a swapping part in between of the manufacturing cost and the performance of the parts application. (Thomas W. Wolf, 2006)

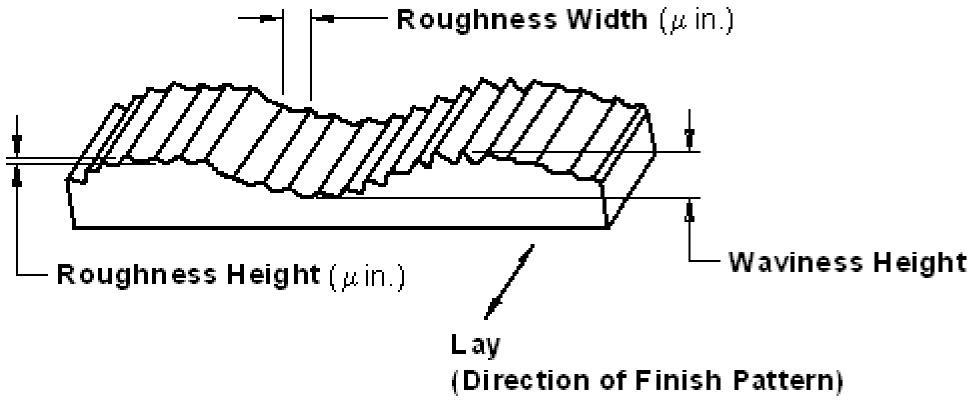


Figure 2.3: Figure show the roughness diagram on the work piece surface.

R_a is the Average Roughness. The average roughness is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length. Graphically, the average roughness is the area as per figure above between the roughness profile and its center line divided by the evaluation length where normally five sample lengths is taken with each sample length equal to one evaluation length. This is the parameter that has been used universally for many years. (Thomas W. Wolf, 2006) The European and ISO standards now more generally use R_z:

The average roughness formula is:

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i|$$ ------------------ (Equation 2.11)

As n is the ordered, the equally spaced points along the trace and y_i is the vertical distance from the mean line to the i^{th} data point. (Thomas W. Wolf, 2006)

As stated above, roughness is related directly to the friction and wear properties of the workpiece surface. A surface that has high value of R_a will have high friction and wear rapidly. (Thomas W. Wolf, 2006). Based on figure 2.4 the figure shows the range of surface roughness obtained in various machining processes.

2.4.1 Surface roughness calculation

For surface roughness equation from cutting speed for this analysis:

By replacing Equation 2.2 into Equation 2.8

$$V_c = 0.262\ D_m\ [\sqrt{Ra8R}\ /\ (n\ f_t)]$$ ------------ (Equation 2.12)

Simplifying Equation 2.12 for surface roughness, Ra:

$$Ra = [\ (V_c\ n\ f_t) /\ 0.262\ D_m]^2\ /\ 8R$$ ------------ (Equation 2.13)

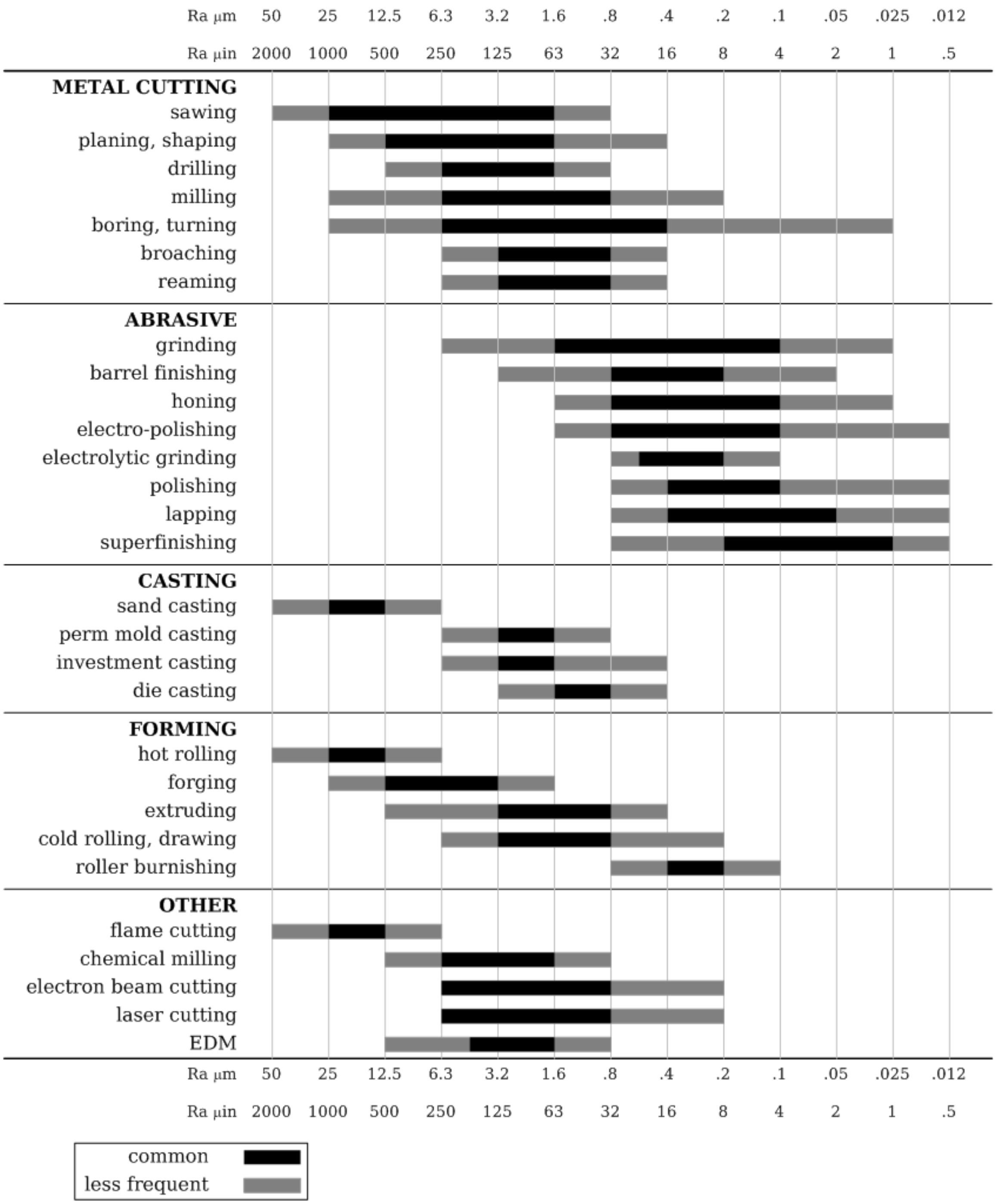


Figure 2.4: The figure shows the range of surface roughness obtained in various processes (Serope Kalpakjian, Steven Schmid, 2006)

2.4.2 Surface roughness test

A surface profilometer is a modern surface measuring devices which use to measure and record surface roughness. It consists of a stylus that have a small diamond tip gauge or transducer, a traverse datum and a processor. The surface was measured by moving the stylus across the surface. As the stylus moves up and down along the surface, the transducer converts this movement into a signal which is then exported to a processor which converts this into a number and usually a visual profile. The stylus must be moved in a straight line to give accurate readings. (Serope Kalpakjian, Steven Schmid, 2006)

Surface roughness also can be observed through an optical or scanning electron microscope. For three dimensional views of surfaces and surfaces roughness, a stereoscopic photograph can be used. (Serope Kalpakjian, Steven Schmid, 2006)

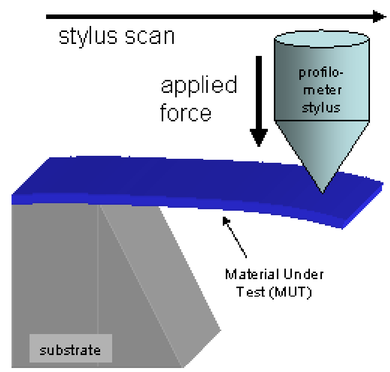


Figure 2.5: Diagram of surface roughness testing machine (Thomas W. Wolf, 2006)

Table 2.2 : The table shows the surface roughness parameters involved as the result from the surface roughness test

Surface roughness parameters	Description
Ra	Arithmetical mean roughness, section of standard length from the line
Rz	Ten-point mean roughness
Rq	The root mean squared of the length from the line
Rp	The maximum peak height
Rt	The maximum height of the profile

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

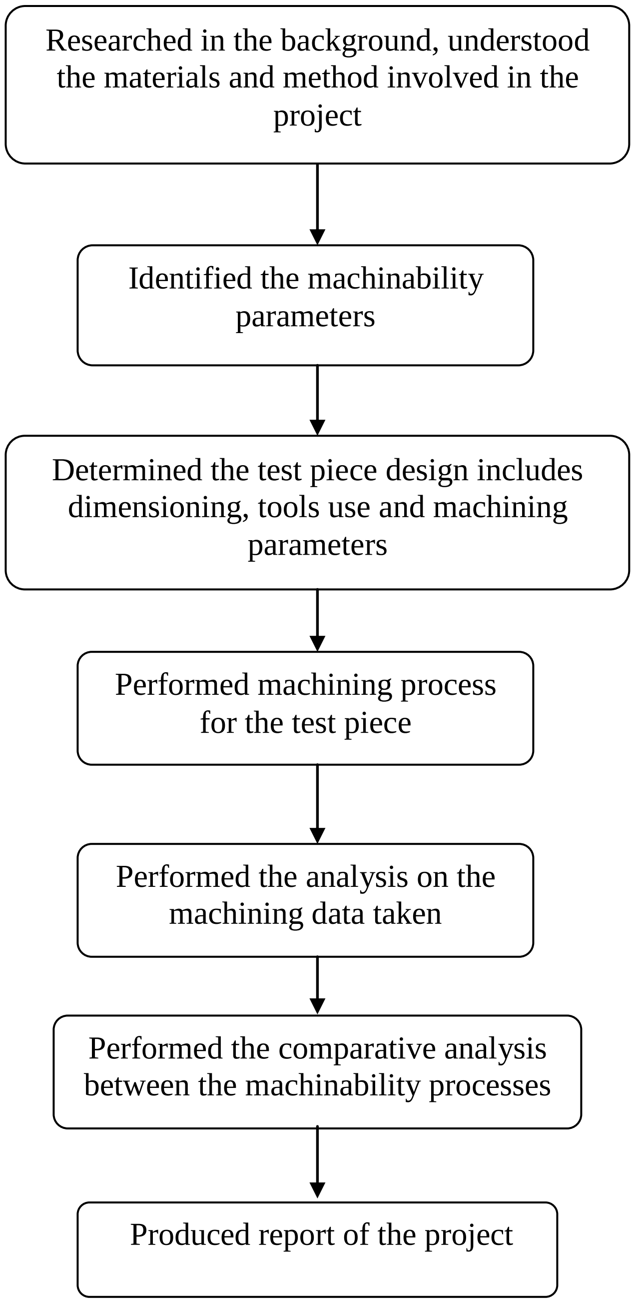


Figure 3.1: The flow diagram of the project

3.2 Specific project activities

i. The background of grey cast iron, its composition and its machinability had been researched by referred to journals and reference books on the characteristic and the mechanics of cutting.
ii. Identified the materials and methods involved in the project with reference to the literature reviewed
iii. Identified the machinability parameters from the data gathering process by deciding the parameters that were used in the data analysis later on.
iv. Machinability parameters were selected and used in calculating the prediction of the analysis result.
v. Produced the procedures for coming activities.
vi. Performed the machining and surface roughness tests.
vii. Produced result analysis based on predicted result analysis.

3.3 Procedures and equipment used

a. Milling process had been done on the work piece by varying the cutting speed and sustaining the feed rate. There are six work pieces that were used in order to vary the surface roughness which were resulted from varying cutting speed on the work piece.

b. Parameters that had been used in the machining process are shown in Table 3.1 while carbide insert type had been used as the cutting tool.

Table 3.1: Table shows the parameters that had been used for the milling process

Work piece	Spindle Speed (rpm)	Feed (manual) mm/rev
A	600	70
B	1000	70
C	1400	70
D	1800	70
E	2200	70
F	2600	70

c. Procedures used for conventional milling machining:

i. The cutting tool was set up as per requirement and the cutting tool was clearly checked for sharpness and in a good condition
ii. The work piece had been prepared according to the allowable dimension
iii. The work piece was clamped to the chuck and make sure it is tight and to avoid vibration on the work piece later on
iv. The cover was closed and locked for proper safety
v. The spindle speed and depth of cut as the specific parameter above were set up
vi. The machining process began from lower spindle speed to the higher
vii. After the machining process were completed, the work piece is taken out
viii. The work pieces were ready for surface roughness test
ix. Steps 3 to 7 were repeated for all the work pieces.

Figure 3.2: Figure shows the process during the milling machining operation

Figure 3.3: Sparks form from the work piece which undergo higher cutting speed

d. For EDM wire cut, there are few parameters that could be used in controlling the cutting speed as per equation 2.10 which is the material removal rate (MRR). However, the machining time is taken in order to produce the graph based on the surface roughness of the surface finishing.

Table 3.2: Table shows the machining parameters result from the EDM wire cute machining

Workpiece	Machining Time	Feed Rate	Wire
G	1:15:51	1.648	0.4

Procedures used for non-conventional EDM Wire Cut machining

i. Inspected the machine for safety purpose
ii. Checked wear alignment on the machine
iii. Checked taper specification index
iv. Position were set up by placing the work piece to the position and clamp it
v. Adjusted upper nozzle displacement for fluid flow rate
vi. The data was set as input by transferring the drawing to the EDM machine
vii. The set up of the machining process was done by the technician. The following were the steps involved.
    1. The file was loaded
    2. Z-height for the outline stampling was set up
    3. The drawing to 2D CAM was transferred
    4. Machine program was made by selecting the 1st element based on the drawing
    5. NC program for the machining was executed
    6. NC program for the machining was viewed as per table 3.3
    7. NC data had been executed
    8. The program had been checked
    9. Wire path against the original solid drawing was then viewed
    10. NC program in check mode had been executed

e. Started the machining process of EDM wirecut

Table 3.3: Table shows the G-code programming and the task execute for EDM machining

G-code Programming	Task execute
N0001 M80	To delete the rest of distance from the axis measuring input
N0002 M82	
N0003 M84	
N0004 G90	Fixing the cycle or simple cycle for roughning (z-axiz emphasis)
N0005 G92 X0 Y0	Register the position from the tool tip to 0 coordinate
N0006 G41 G01 X0 Y-4	Define the tool radius compensation left and linear interpolation for the machining process to X0 Y-4
N0007 G01 X30 Y-4	Linear interpolation for the machining process to X30 Y-4
N0008 G01 X30 Y-34	Linear interpolation for the machining process to X30 Y-34
N0009 G01 X-0 Y-34	Linear interpolation for the machining process to X-0 Y-34
N0010 G01 X-0 Y-4	Linear interpolation for the machining process to X-0 Y-4
N0011 M01	Conditional stop of the machining operation
N0012 G40 G01 X0 Y0	Path compensations "off" together with linear interpolation with feed rate to X0 Y0
N0013 G23	Beginning of new routine path

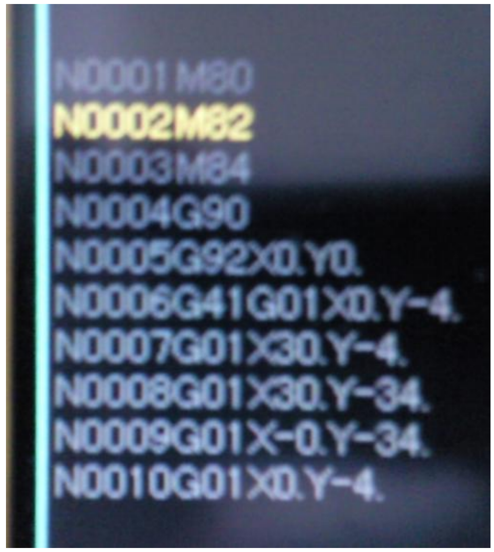


Figure 3.4: G-code programming during data executing

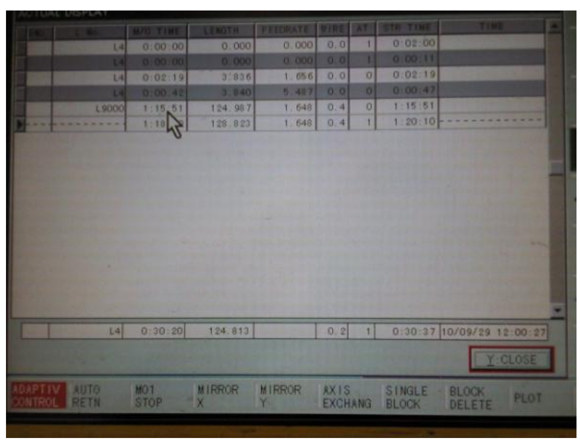


Figure 3.5: The machining data preview on the screen

3.4 Surface Roughness Test

For surface roughness testing, the test used a Perthometer Concept machine. Procedures for surface roughness testing:

i. Checked the dongle whether it is connected to the parallel port
ii. Switched on the computer and double clicked on the CONCEPT icon program on the desktop
iii. Selected the “Configuration of measure station” when the dialog box pop up
iv. Clicked “OK” on the dialog box
v. Clicked on FILE and then clicked on the OPEN FORM. Form was choosed based on how many parameters needed.
vi. Changed the measurement setting by go to SETTING and then clicked on “MEASURING CONDITION”
vii. Set up the required measuring condition. Then clicked on OK to confirm
viii. The red button was twisted and pulled up to ON the machines
ix. Clicked on the “Measurement station view”
x. Placed the work piece on the stage and under the sensor.
xi. Pressed the arrow button down to lower the sensor and stopped it before it touch the work piece
xii. Clicked on the initialize icon
xiii. Choose multiple measurements
xiv. Clicked on the “Start measurement” icon and “Close” icon
xv. The measurement had been started
xvi. After the first measurement, moved the ample a bit so that new surface can be measured
xvii. Clicked on the “Measurement station view” again and repeated the procedure
xviii. Clicked on “Off” on the multiple measurement icon after all measurement is taken
xix. Double clicked on the profile info, clicked on Edit, Roughness Parameter and then clicked confirmed with OK
xx. Clicked on the form and all the measurement was saved

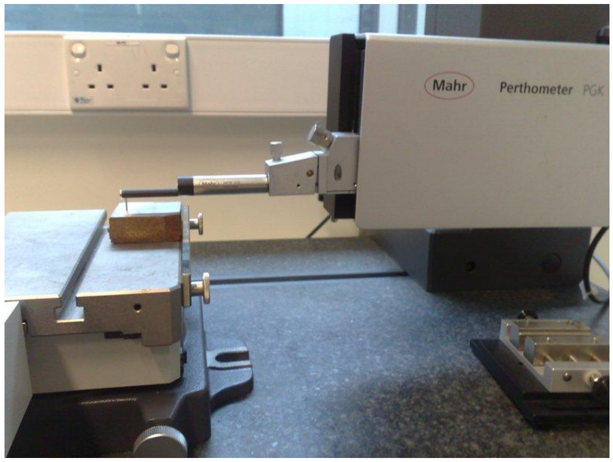


Figure3.6: Picture above shows the workpiece during surface roughness analysis was done

Figure3.7: Picture above shows the surface roughness analysis machine

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Data gathering and theoretical analysis

From the literature review, it was noted that there were few conditions in determined the surface finish based on the studies on the analytical result of the figure below:

1. Decrease the feed rate and maintaining the cutting speed will result in decreasing the surface roughness
2. Constant the feed rate and increasing the cutting speed will result in decreasing the surface roughness
3. By decreasing the feed rate and increasing the cutting speed will result in decreasing surface roughness.

High Ductility Materials: have more than 18% elongation and less than Rc32. They include: annealed steel, stainless steel, aluminum, brass, bronze and malleable iron. Low Ductility Materials: have less than 18% elongation and a maximum hardness of Rc40. They include: gray iron, nodular iron, heat-treated steel, magnesium alloys and hard copper alloys.

The analytical result from varying the cutter revolution is tabulated based on the earlier formula equation below.

$$V_c = 0.262\, D_m\, N_s \quad \text{----------- (Equation 2.6)}$$

$$N_s = f_m / (n\, f_t) \quad \text{------------ (Equation 2.7)}$$

$$V_c = 0.262\, D_m\ [\, f_m / (n\, f_t)] \quad \text{------------- (Equation 2.8)}$$

$$V_c = 0.262\, D_m\, [\sqrt{Ra 8R} / (n\, f_t)] \quad \text{------------ (Equation 2.12)}$$

From the calculation for surface roughness, Ra from Equation 2.13

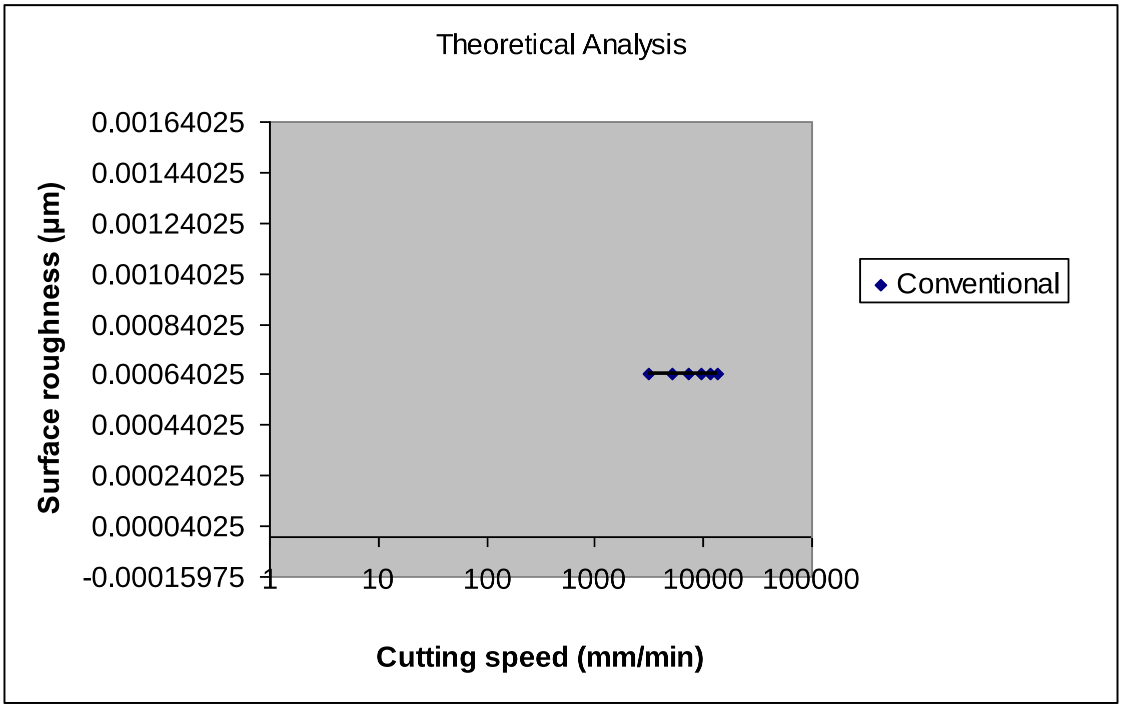
$$Ra = [\,(V_c\, n\, f_t)/\, 0.262\, D_m]^2 \,/\, 8R$$

By calculating using the conventional milling process formula, taking gray cast iron as the materials, the data as per Table 4.1 was obtained from the calculation.

Table 4.1: The calculation from varying the spindle speed of the cutter for non-conventional machining process

Ns(rpm)	Dm (mm)	fm (m/min)	n (tooth number)	Ft (mm/tooth)	Vc (mm/min)	Ra (μm)
600	20	0.0032	8	6.66667E-07	3144	0.00064000
1000	20	0.0032	8	0.0000004	5240	0.00064000
1400	20	0.0032	8	2.85714E-07	7336	0.00064000
1800	20	0.0032	8	2.22222E-07	9432	0.00064000
2200	20	0.0032	8	1.81818E-07	11528	0.00064000
2600	20	0.0032	8	1.53846E-07	13624	0.00064000

Figure 4.1: The graph show the theoretical result based on calculation for varying cutting speed for non-conventional machining

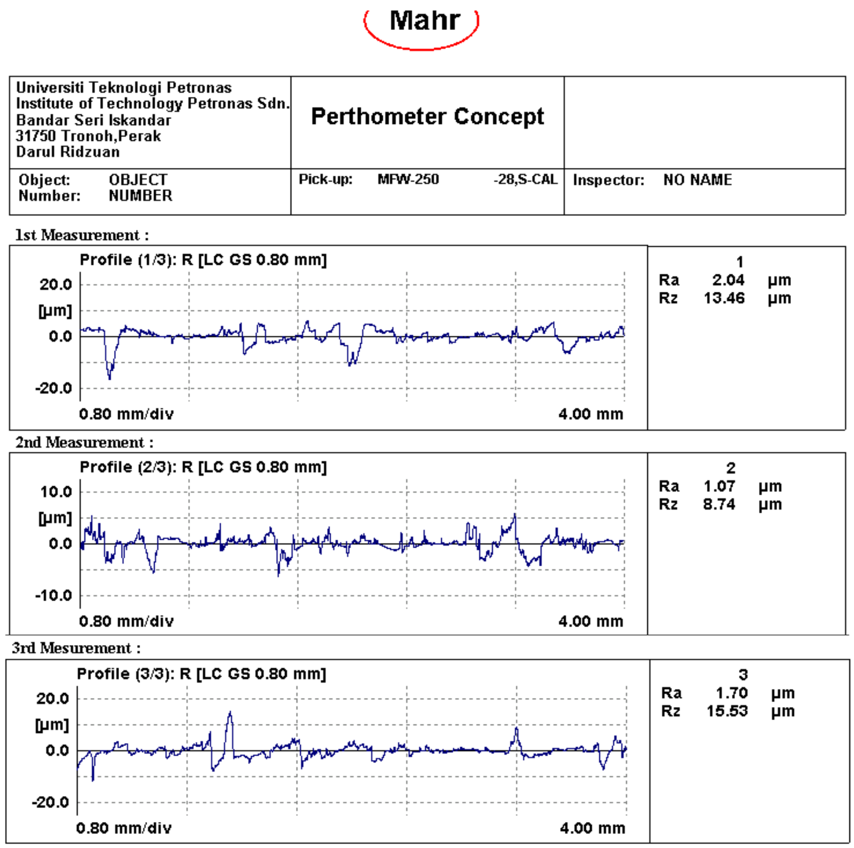


As per table 4.1, the data had been calculated based on the equation stated earlier. By replacing the equation from cutting speed to get the surface roughness, hence varying the cutting speed and keep other parameter constant will produce an increasing surface roughness since it is directly proportional to the surface roughness. However by using the log graph in order to achieve more accurate result, the result had been produced as according to the graph above where the surface roughness for varying the cutting speed is constant. This meant that surface roughness should be the same for the coming experimental result which will be determined later. For correlation between the two graphs, there were none of any types of the graph in correlating the two variables. Thus, based on the calculation and graph above cutting speed and surface roughness did not correlate to each other.

4.2 Experimental Result Analysis

1. Conventional Machining

The work piece was machined to the shape as shown in the Appendices. For milling operation, the surface analysis was based on the surface roughness testing that had been done through MAHR roughness tester. The data from the roughness testing were as in Figure 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7 below:

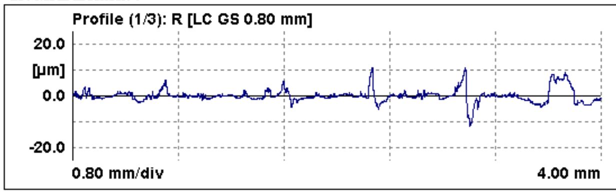


1: Ra	2.04	µm
1: Rz	13.46	µm
1: Rq	3.03	µm
1: Rp	4.62	µm
1: Rt	22.66	µm
2: Ra	1.07	µm
2: Rz	8.74	µm
2: Rq	1.55	µm
2: Rp	4.33	µm
2: Rt	12.21	µm
3: Ra	1.70	µm
3: Rz	15.53	µm
3: Rq	2.56	µm
3: Rp	8.28	µm
3: Rt	26.89	µm

Figure 4.2: Surface roughness result for Workpiece A and the description of the parameters can be referred to Table 2.2

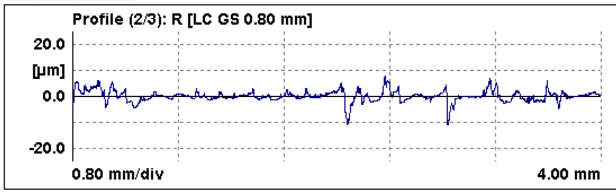
Universiti Teknologi Petronas Institute of Technology Petronas Sdn. Bandar Seri Iskandar 31750 Tronoh,Perak Darul Ridzuan	**Perthometer Concept**	
Object: OBJECT Number: NUMBER	Pick-up: MFW-250 -28,S-CAL	Inspector: NO NAME

1st Measurement :



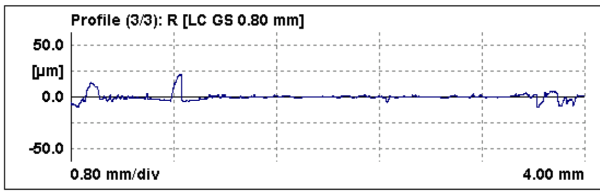
1		
Ra	1.55	µm
Rz	13.49	µm

2nd Measurement :



2		
Ra	1.44	µm
Rz	12.48	µm

3rd Mesurement :



3		
Ra	1.90	µm
Rz	15.56	µm

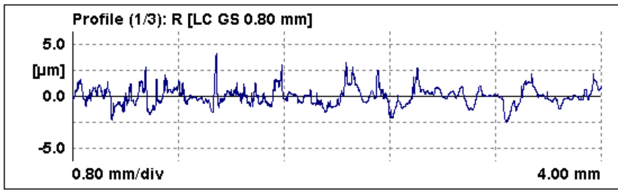
1: Ra	1.55	µm
1: Rz	13.49	µm
1: Rq	2.52	µm
1: Rp	8.46	µm
1: Rt	22.30	µm
2: Ra	1.44	µm
2: Rz	12.48	µm
2: Rq	2.14	µm
2: Rp	5.94	µm
2: Rt	18.75	µm
3: Ra	1.90	µm
3: Rz	15.56	µm
3: Rq	3.55	µm
3: Rp	9.31	µm
3: Rt	32.31	µm

Figure 4.3: Surface roughness result for Workpiece B and the description of the parameters can be referred to Table 2.2

Mahr

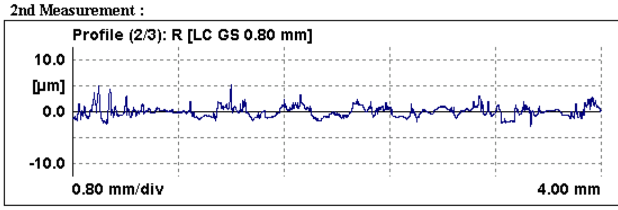
Universiti Teknologi Petronas Institute of Technology Petronas Sdn. Bandar Seri Iskandar 31750 Tronoh,Perak Darul Ridzuan	Perthometer Concept	
Object: OBJECT Number: NUMBER	Pick-up: MFW-250 -28,S-CAL	Inspector: NO NAME

1st Measurement :



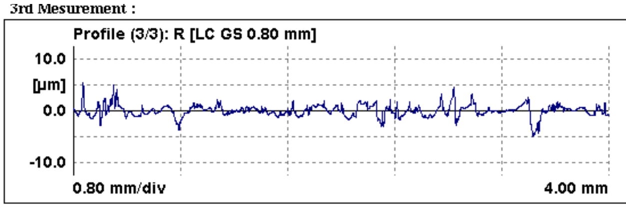
1		
Ra	0.66	µm
Rz	5.10	µm

2nd Measurement :



2		
Ra	0.81	µm
Rz	6.00	µm

3rd Mesurement :



3		
Ra	0.83	µm
Rz	6.77	µm

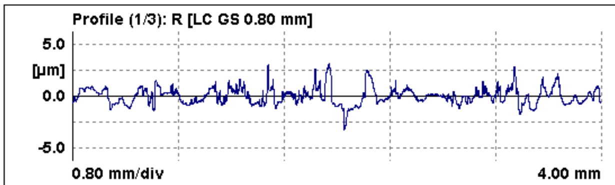
1: Ra	0.66	µm
1: Rz	5.10	µm
1: Rq	0.87	µm
1: Rp	3.04	µm
1: Rt	6.63	µm
2: Ra	0.81	µm
2: Rz	6.00	µm
2: Rq	1.05	µm
2: Rp	3.88	µm
2: Rt	7.99	µm
3: Ra	0.83	µm
3: Rz	6.77	µm
3: Rq	1.15	µm
3: Rp	3.39	µm
3: Rt	10.24	µm

Figure 4.4: Surface roughness result for Workpiece C and the description of the parameters can be referred to Table 2.2

Mahr

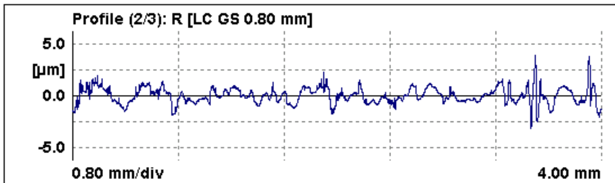
Universiti Teknologi Petronas Institute of Technology Petronas Sdn. Bandar Seri Iskandar 31750 Tronoh,Perak Darul Ridzuan	**Perthometer Concept**	
Object: OBJECT Number: NUMBER	Pick-up: MFW-250 -28,S-CAL	Inspector: NO NAME

1st Measurement :



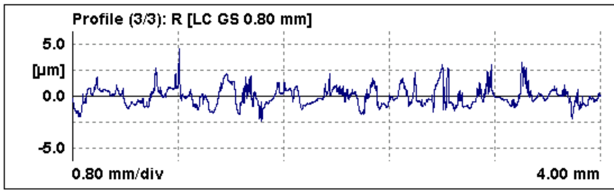
1
Ra 0.62 µm
Rz 4.19 µm

2nd Measurement :



2
Ra 0.61 µm
Rz 3.90 µm

3rd Mesurement :



3
Ra 0.70 µm
Rz 5.07 µm

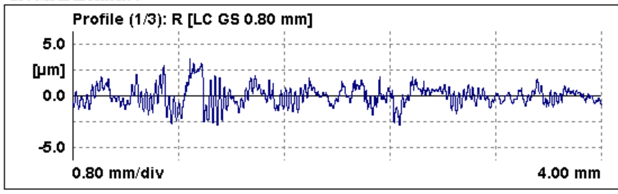
1: Ra	0.62	µm
1: Rz	4.19	µm
1: Rq	0.81	µm
1: Rp	2.44	µm
1: Rt	6.50	µm
2: Ra	0.61	µm
2: Rz	3.90	µm
2: Rq	0.78	µm
2: Rp	2.11	µm
2: Rt	6.97	µm
3: Ra	0.70	µm
3: Rz	5.07	µm
3: Rq	0.90	µm
3: Rp	3.16	µm
3: Rt	6.98	µm

Figure 4.5: Surface roughness result for Workpiece D and the description of the parameters can be referred to Table 2.2

Mahr

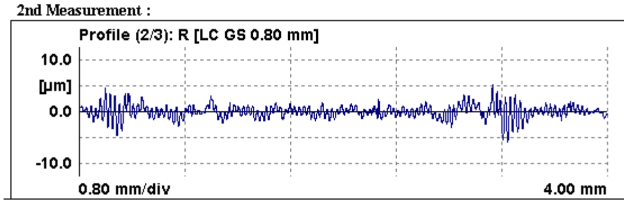
Universiti Teknologi Petronas Institute of Technology Petronas Sdn. Bandar Seri Iskandar 31750 Tronoh,Perak Darul Ridzuan	Perthometer Concept	
Object: OBJECT Number: NUMBER	Pick-up: MFW-250 -28,S-CAL	Inspector: NO NAME

1st Measurement :



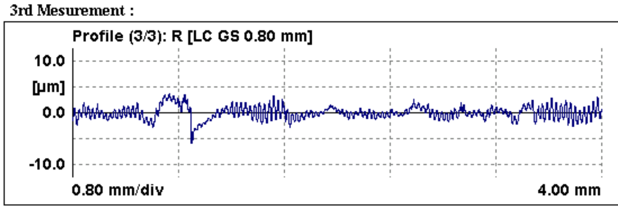
1		
Ra	0.73	µm
Rz	4.64	µm

2nd Measurement :



2		
Ra	0.91	µm
Rz	7.07	µm

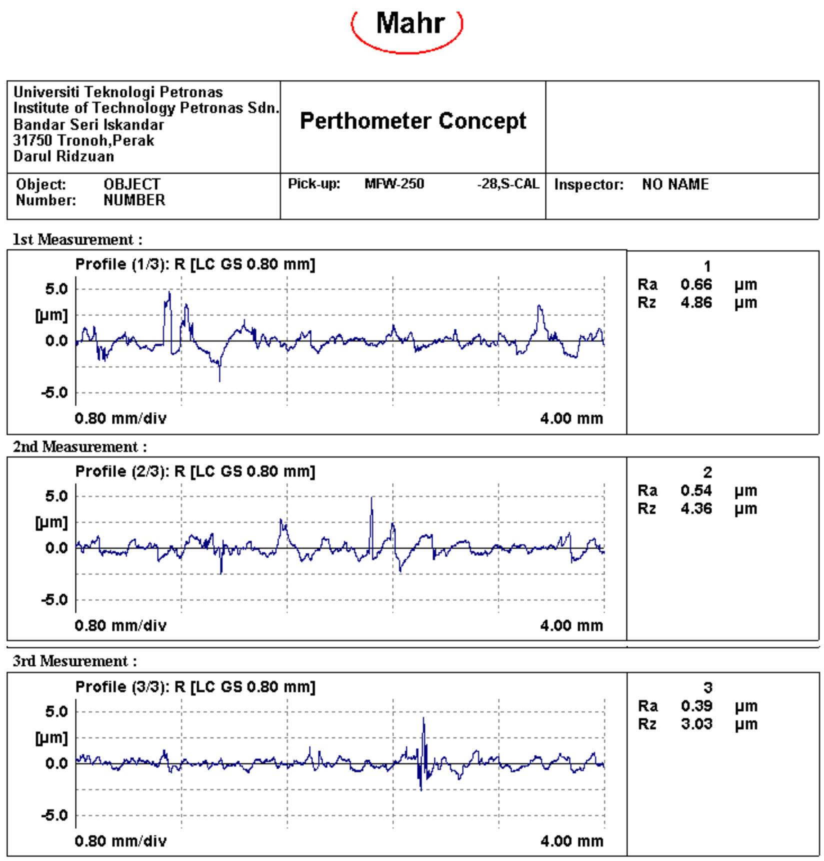
3rd Mesurement :



3		
Ra	0.96	µm
Rz	6.02	µm

1: Ra	0.73	µm
1: Rz	4.64	µm
1: Rq	0.95	µm
1: Rp	2.38	µm
1: Rt	6.42	µm
2: Ra	0.91	µm
2: Rz	7.07	µm
2: Rq	1.24	µm
2: Rp	3.63	µm
2: Rt	10.99	µm
3: Ra	0.96	µm
3: Rz	6.02	µm
3: Rq	1.24	µm
3: Rp	2.86	µm
3: Rt	9.44	µm

Figure 4.6: Surface roughness result for Workpiece E and the description of the parameters can be referred to Table 2.2



1: Ra	0.66	µm
1: Rz	4.86	µm
1: Rq	0.94	µm
1: Rp	2.91	µm
1: Rt	8.65	µm
2: Ra	0.54	µm
2: Rz	4.36	µm
2: Rq	0.72	µm
2: Rp	2.59	µm
2: Rt	7.41	µm
3: Ra	0.39	µm
3: Rz	3.03	µm
3: Rq	0.53	µm
3: Rp	1.83	µm
3: Rt	7.07	µm

Figure 4.7: Surface roughness result for Workpiece F and the description of the parameters can be referred to Table 2.2

From the test result, this could be illustrated by observing the test values which were varied according to the increasing cutting speed assigned. The trend of the result was more likely to decrease as increasing the cutting speed. Thus this will produce a negative slope for the graph.

From equation 2.6, cutting speed was calculated based on the spindle speed. Thus the result of the cutting speed calculation and the surface roughness result from the testing were tabulated in the table below:

Table 4.2: The data based on the conventional milling machining where the Ra values were based on the surface roughness result for milling process

Workpiece	Ns(rpm)	Vc(mm/min)	Ra(µm)
A	600	6.98754	1.603
B	1000	11.6459	1.63
C	1400	16.30426	0.767
D	1800	20.96262	0.643
E	2200	25.62098	0.867
F	2600	30.27934	0.53

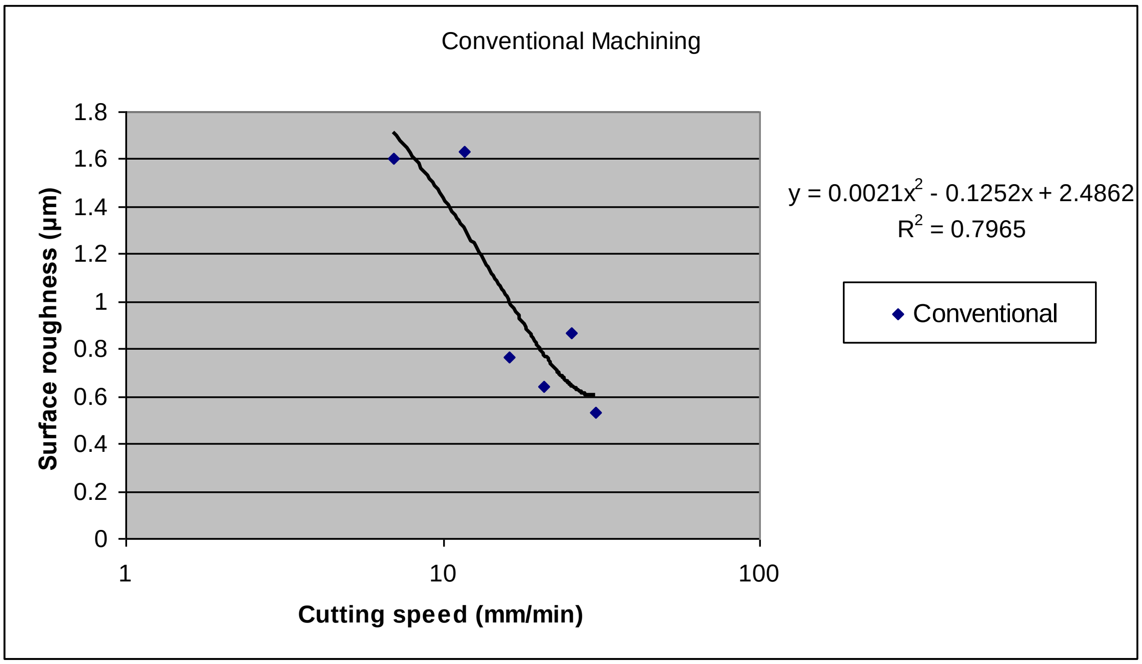
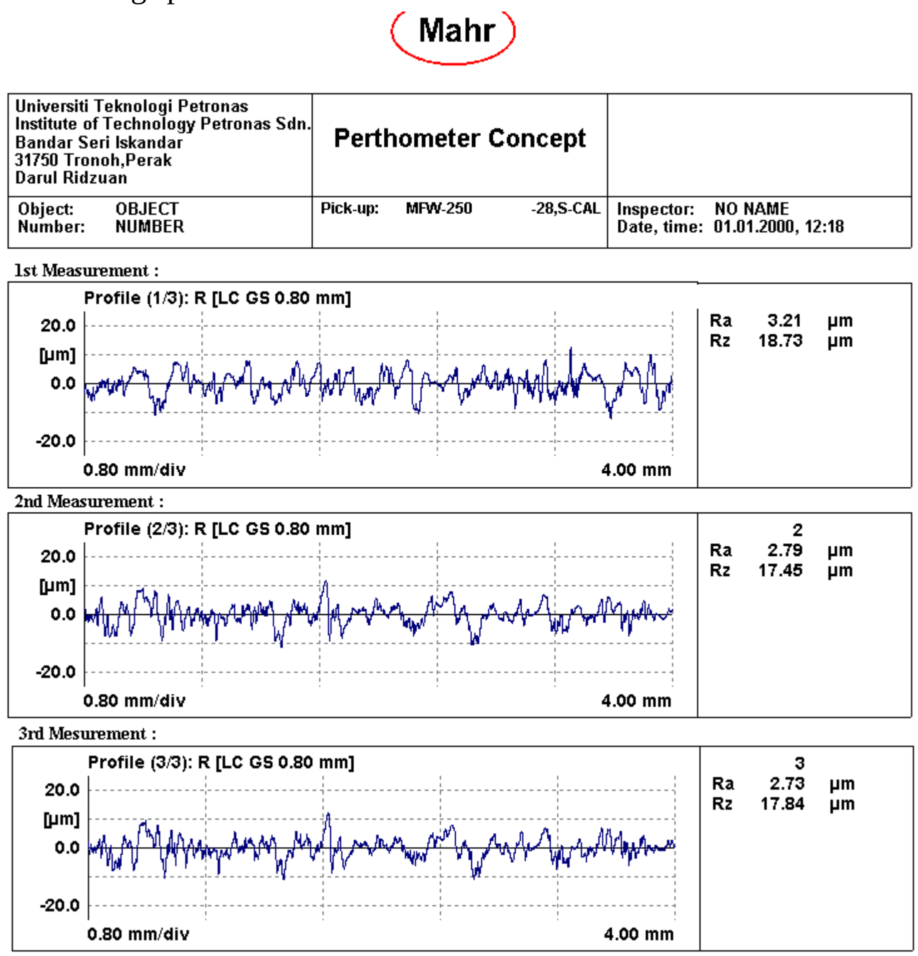


Figure 4.8: The graph shows the cutting speed versus surface roughness for conventional machining

Plot in Figure 4.8 indicates that there was a correlation between the cutting speed and surface roughness since the R^2 value is greater than 0.5 which is 0.7965. This signified that surface roughness decreased with increased the cutting speed.

2. Non-conventional machining

For non conventional machining, only one work piece was used for the testing surface roughness. Since the ampere for this machining has not been varied, the distance traveled and machining time for the current distance is taken in order to calculate the cutting speed.



1: Ra	3.21	µm
1: Rz	18.73	µm
1: Rq	3.96	µm
1: Rp	8.86	µm
1: Rt	24.48	µm
2: Ra	2.79	µm
2: Rz	17.45	µm
2: Rq	3.63	µm
2: Rp	8.03	µm
2: Rt	23.23	µm
3: Ra	2.73	µm
3: Rz	17.84	µm
3: Rq	3.54	µm
3: Rp	8.38	µm
3: Rt	22.91	µm

Figure 4.9: Surface roughness result for Workpiece G that undergo EDM wire cut machining and the description of the parameters can be referred to Table 2.2

Table 4.3: The data based on the non-conventional milling machining where the Ra values were based on the surface roughness result for EDM wire cut process

Workpiece	Cutting time(min)	Distance(mm)	Ra(μm)
G	18.856	30	3.21
	37.57	60	2.79
	56.11	90	2.73

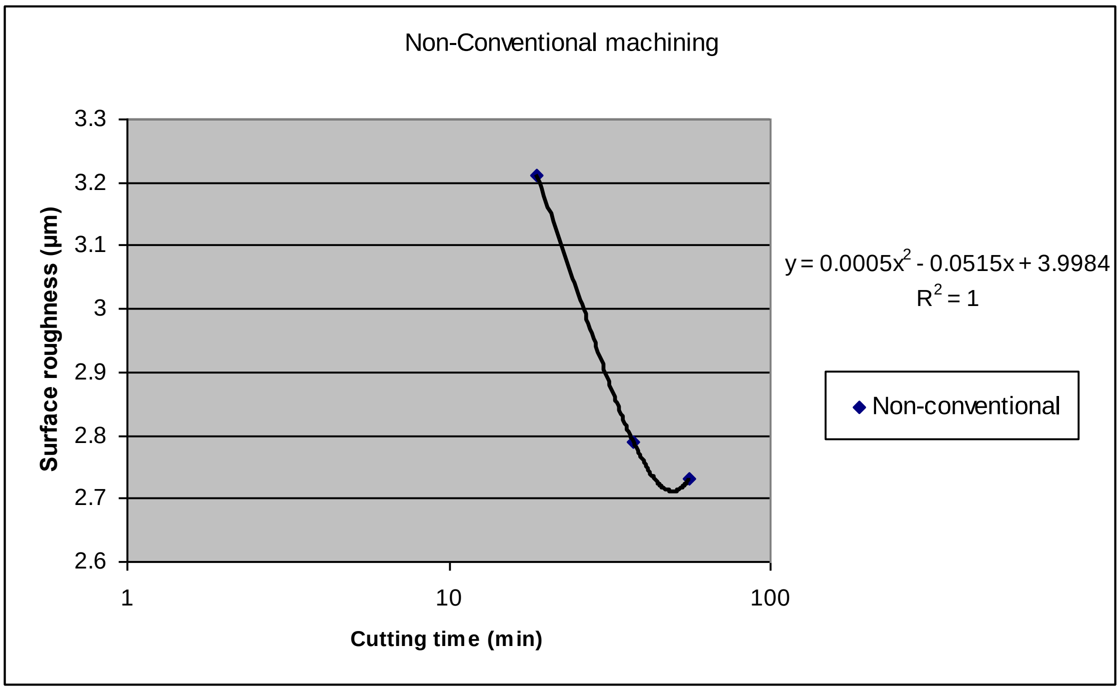


Figure 4.10: The graph shows the machining time versus surface roughness for non-conventional machining.

Plot in Figure 4.10 indicates that there was a correlation between the surface roughness and cutting time since the cutting value of R^2 is greater than 0.5 which is 1. Thus this signified that surface roughness decreased as increased the cutting time.

4.3 Discussion

Both conventional and non-conventional graph indicate that by increasing the cutting speed produced in decreasing surface roughness.

a. Conventional machining

. R^2 is the coefficient of determination which can be used as a forecast of the future result. The value ranged from 0 to 1. From the conventional machining graph, the best fit for the graph for R^2 is 0.7965 which near to 1 value. Thus this meant the conventional machining graph could be used in indicated the relationship of surface roughness to cutting speed. R^2 value should be higher than 0.5 in orders for the graph to have a correlation between both parameters.

Plot in Figure 4.8 indicated that there was a correlation between the cutting speed and surface roughness since the R^2 value is greater than 0.5 which is 0.7965. This signified that surface roughness decreased with increased the cutting speed.

The slope value was large for conventional machining because of the average surface roughness that has larger variation in its value. The steeper slope meant the larger value of the slope. Thus the steepness of the slope was used in determined the effectiveness of the machining. The larger slope value shows the cutting parameters were less effective in the machining process.

For conventional machining, by increasing spindle speed will increase the cutting speed. From the theoretical analysis, the surface roughness at any value of cutting speed should be the same. However, based on the experimental analysis, the surface roughness is decrease by increasing the cutting speed. As in the literature review, there are few factors that contribute into poor surface finish of the work piece which are the feed applied is too high, the tool is dull, cutter did not have enough teeth and the most important point is the cutting speed is too low. Thus, it is proven that poor surface finish which is higher surface roughness is caused by lower cutting speed.

b. Non-conventional machining

The value of coefficient of determination for non-conventional machining is 1. The closest the value to 1 meant that the graph is more accurate in predicting the relationship of cutting time to cutting speed. Thus, from R^2 value, non-conventional shows higher value which is closer to 1. The non-conventional graph illustrates highest accuracy in predicting the surface roughness.

Plot in Figure 4.10 indicates that there was a correlation between the surface roughness and cutting time since the cutting value of R^2 is greater than 0.5 which is 1. Thus this signified that surface roughness decreased as increased cutting time.

Slope value used in determining the effectiveness of the machining type. Steeper slope which means the slope that have higher slope value. From the graph, non-conventional machining has smaller slope value. Thus, this meant that non-conventional machining is more effective to be used.

For EDM wire cut, there are few factors that influence the cutting time which are wire types, wire diameter, wire tension and nozzle distance. A coated types wire will increase the cutting speed. A larger size of wire diameter will faster the machining time. Loose wire tension will reduce the time taken for machining and far distance of nozzle will increase the cutting speed however high spark discharge from the machining will worsen the surface finish of the work piece.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The machinability comparison was done on grey cast iron to compare the better surface roughness between conventional and non-conventional machining. Thus from the experiment results, where the overall average for conventional is 2.91μm while non-conventional is 1.00 μm. Thus, conventional machining by using face milling showed higher surface roughness compared to the non-conventional machining by using EDM wire cut. This indicated that non-conventional machining was better to be used in machining the grey cast iron from the surface finish view. However, the suitability of machining for grey cast iron in large volume of production should also considered other types of production parameters such as cost in production of the products and accuracy that were required. As for conclusion, the surface roughness decreases with increasing cutting speed for conventional machining and increases with the longer cutting time taken for non-conventional machining.

5.2 Recommendation

The result could not be so much reliable since for non-conventional machining the cutting speed did not involved. This will produce less error in the result. So, it is recommended that the non-conventional machining was actually done with a machining that can be varied clearly according to the cutting speed. So this will ease in comparing the result for surface roughness between both types of machining.

The comparative analysis also should be done based on the other types of machining parameters which stated such as tool wear and tool life estimation also force and power consumption. These kind of machining parameters also play an important roles in determining the machinability of grey cast iron between both machining.

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APPENDICES

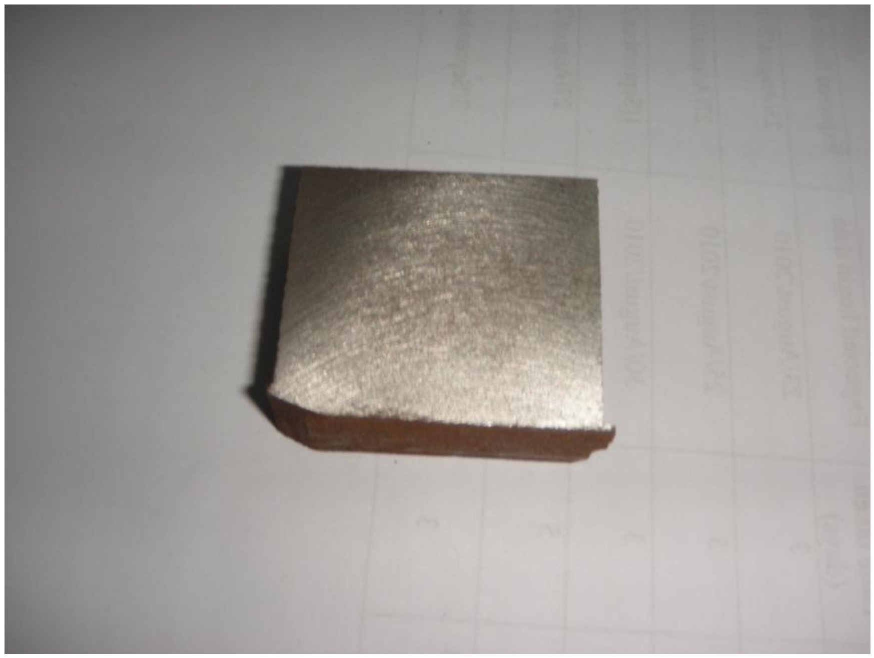

Figure 1: Workpiece A

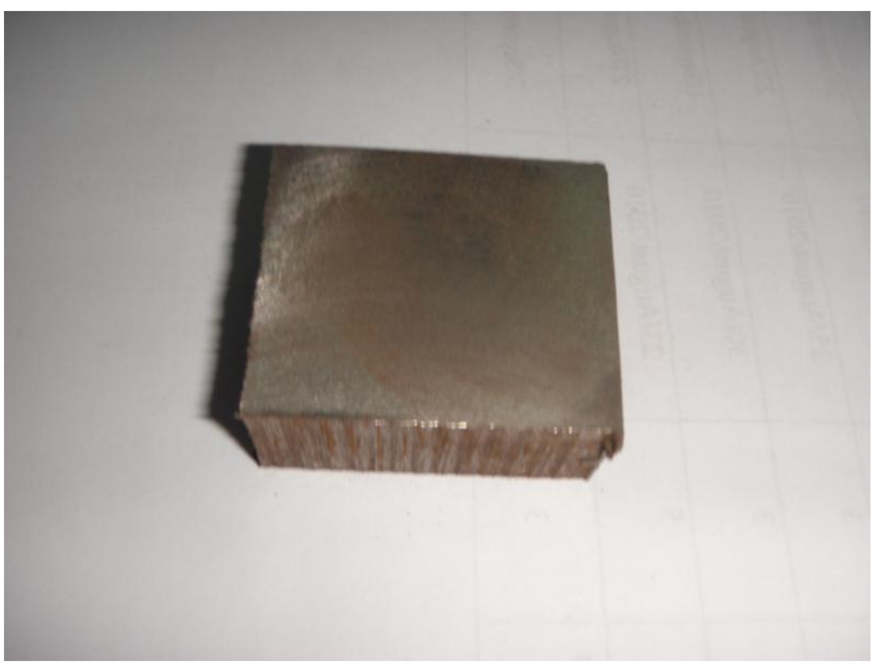

Figure 2: Workpiece B

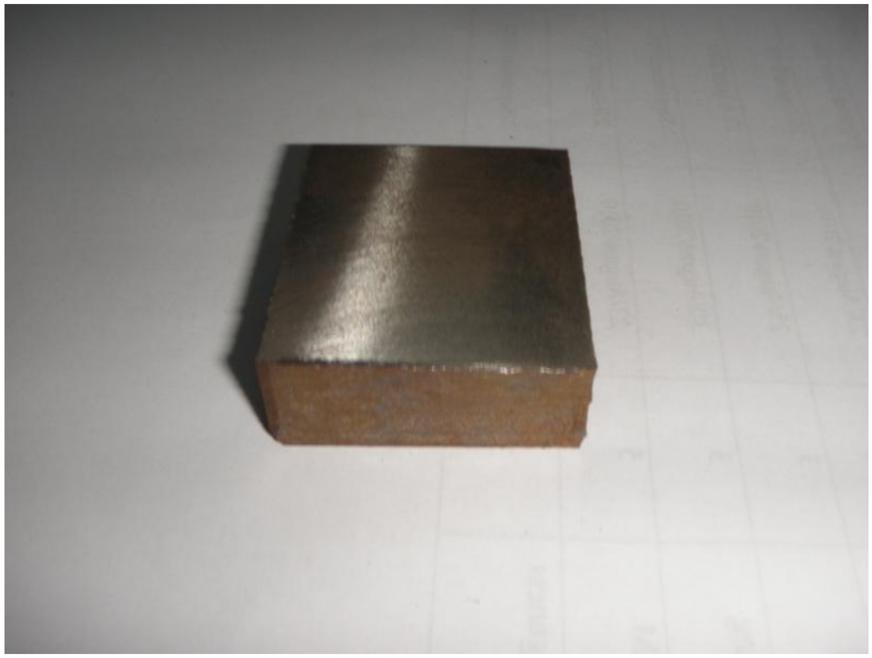

Figure 3: Workpiece C

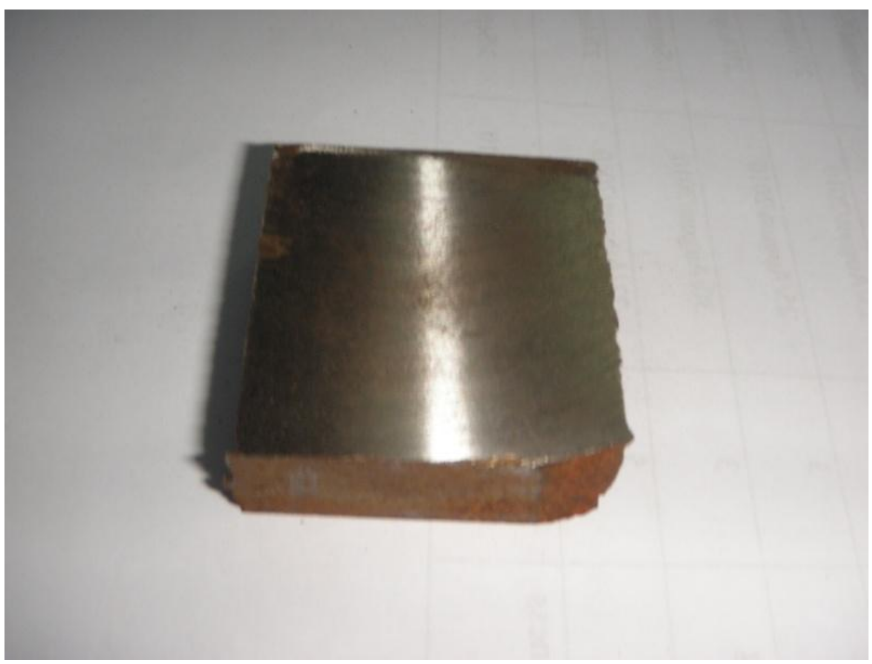

Figure 4: Workpiece D

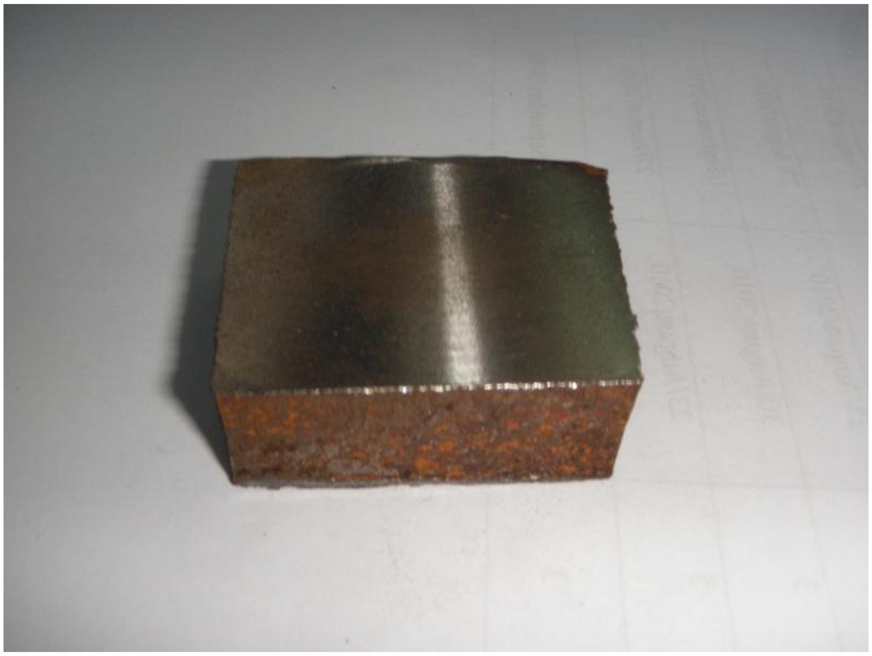

Figure 5: Workpiece E

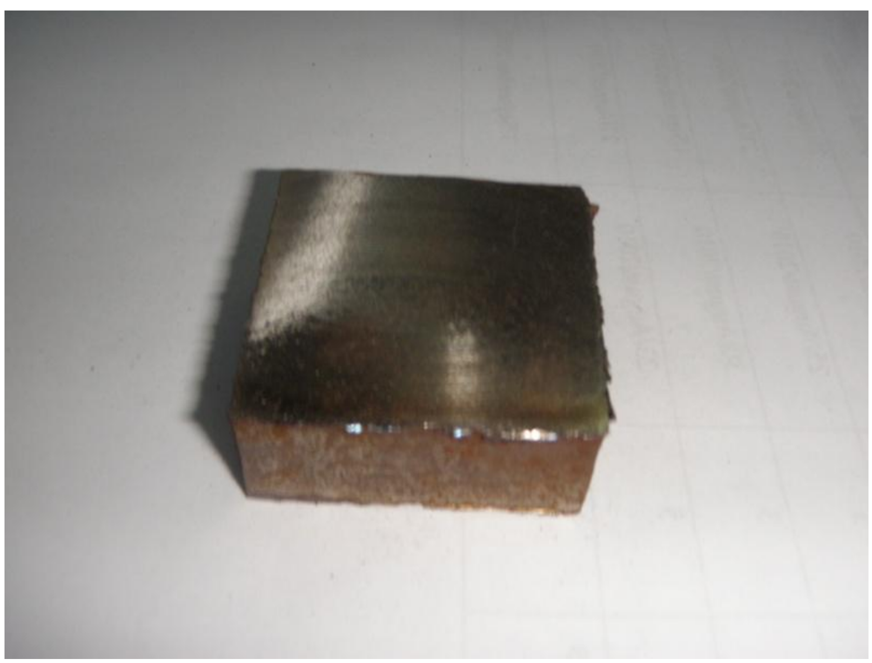

Figure 6: Workpiece F