SURFACE FINISH STUDY OF GREY CAST IRON CASTING SAMPLES FROM CONVENTIONAL & NON-CONVENTIONAL MACHINING PROCESSES.

By

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Dissertation submitted in partial fulfilment of the requirement
For the Bachelor of Engineering (Hons)
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by

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TRONOH, PERAK

MAY 2004

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 acknowledgments, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MEOR HAMZAH B. ABDULLAH SANI

ABSTRACT

The grey cast iron is considered to be unique in the great class of cast irons particularly, and irons and metals generally. In term of machining processes, the use of different machines would, from expectations from previous experiments, yield different value for the surface roughness. Although numerous studies had been done in the field of surface roughness, the use of a standard material, the grey cast iron, to compare the surface roughness produced by different machines, conventional and non-conventional would prove to be interesting.

From the study done, it had been noted that different surface finish is attainable through different machining processes. Some machining processes could in fact, yield a wide range of surface roughness, simply by varying the parameters. On the other hand, some machining processes are only capable of delivering a smaller range of surface finish. From these data, the relevant machining processes with respect to the surface finish could be chosen. However, since the range of machining parameters is so wide and vast, further studies with respect to other machining parameters to obtain other ranges of surface finishes should be considered.

ACKNOWLEDGMENT

Alhamdullillah, praise to the Lord, who had blessed me with so much. It is by the grace of the good God that I had finally succeed in preparing this report on final year project. However, though this report bears my name, various others had helped tremendously, and this is where I thank them.

To my parents, who had stood by me for the last 25 years, no words could express my gratitude and love. If I had somewhat strayed from being a dutiful son, know that it does not come from any of your fault, but all of mine. For your emotional and financial support during my stay in UTP, preparation for my presentation and my final report, my heartfelt gratitude.

To my Final Year Project supervisor, Dr. Ir. Mohd. Amin bin Abdul Majid, whose expertise and knowledge on the subject matter had been a tremendous help to me, I am greatly thankful. Having had the chance of sharing your personal experience, both in the academic and the industrial world, had been an enriching experience.

Various technicians, namely those under the manufacturing and materials department, who had shared with me their profound knowledge on the technical know-how, my sincerest thanks. Without the help of these people, this project could have never been completed.

Serope Kalpakjian, an author who had written numerous texts on manufacturing and machining processes. His writings had enabled me to better understand the principles of machining, with respect to the surface finish. Various authors for the handbooks and other materials that I had used, which are too numerous to list here, my thanks too.

This study is based upon my understanding of the information I had gathered as a mechanical engineering undergraduate student. Any errors or inaccuracy found in this report falls solely under my responsibility.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1. Background of study

The study of surface finishes for grey cast iron is not a relatively new subject; in fact, quite a lot of information could be obtained from books, journals and the Internet. However, it is considered quite an important step when are comparison between the surface finish of a sample machined with conventional machine (examples are milling and lathe), and non-conventional machines (examples are EDM Die Sinker and EDM Wirecut).

The surface finish of a part determines its appearance, affects the assembly of the part with other parts, and may determine its resistance to corrosion. No surface is smooth and flat like the straight line in an engineering drawing [1]. On a highly magnified scale it is rough, as sketched in Figure 1.1 below.

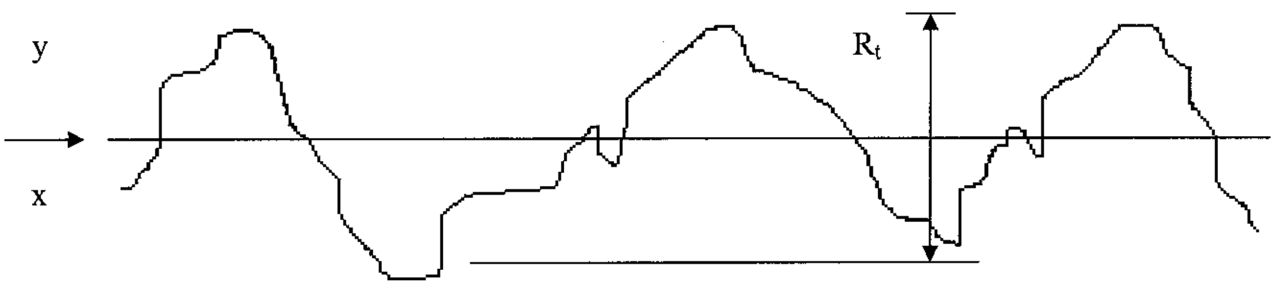

Figure 1.1 Sketch of a surface roughness profile

Surface roughness measurements typically are expressed either in micro inches or micrometer (1 μm = 0.025 μm). The detail method in calculating the surface roughness could be found under chapter 2, the literature review.

1.2. Problem statement

To date, there has been many study conducted on the study of surface finish due to different types of machining. The basic assumption seems to be that non-conventional machining process would most of the time yield a better surface roughness than conventional process. However, there are exceptions to the rule, since the surface roughness itself is influenced by many factors; among them are tools used, feed rate, and depth of cut. Most manufacturing books and journals provide users with the range where the average roughness would be; however, since most of the literary information are from the west, it would be significant to either approve or disprove the range given.

The problem statement for this project is, " to conduct a surface finish study of grey cast iron casting samples from conventional and non conventional machining processes, and to compare them with available data from various books and journals."

1.3. Objective & Scope of Study

1.3.1. Objectives

The objectives of the project are as follows:

- To conduct surface roughness testing on samples of grey cast iron machined with different conventional and non-conventional machines.
- To provide comparison between the surface finish measurements of different types of machining processes.

1.3.2. Scope of Study

The scope of this project would evolve around conducting the machining process using conventional methods and non-conventional methods, with the grey cast iron as the material. Given the availability of equipment and the suitable time frame, it is feasible for the student to complete the project.

2.0 LITERATURE REVIEW

2.1. Grey Cast Iron Properties

Iron-carbon alloys with more than 2.11% carbon are known as cast irons. Grey cast iron, which is the least expensive, are the most common variety. Typical composition of the grey cast iron ranges from 2.5 to 4.0% carbon, 1.0 to 3.0% silicon, and 0.4 to 1.0% manganese [2].

Grey cast iron is normally sold by "class", with the class number corresponding to the minimum tensile strength in thousands of pounds per square inch. Class 20 iron (minimum tensile strength of 20,000 psi) consists of high carbon-equivalent metal with ferrite mix. High strength, up to class 40, are obtainable with lower carbon equivalent and a pearlite mix. Grey cast irons can be obtained up through class 80, but this usually result in extremely low ductility.[2]

A summary of the properties of the grey cast is tabulated in Table 2.1, Table 2.2, and Table 2.3. Note that some property is dependent on the grade of the grey cast iron.

Table 2.1 : Mechanical Property of Grey Cast Iron. [4]

SAE Grade	Hardness, HB	Min. Transverse Load, kg		Min. Deflection		Min. Tensile Strength		Poisson's Ratio
		kg	lb	Mm	in.	MPa	ksi	
G1800	187 max	780	1720	3.6	0.14	118	18	0.24 (softest iron) to 0.27 (high-strength)
G2500	170 to 229	910	2000	4.3	0.17	173	25	
G3000	187 to 241	1000	2200	5.1	0.20	207	30	
G3500	207 to 255	1110	2450	6.1	0.24	241	35	
G4000	217 to 269	1180	2600	6.9	0.27	276	40	

Table 2.2 Property and Typical Applications of Cast Irons[5]

Type	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Elongation in 50 mm (%)	Typical Applications
Ferritic	170	140	0.4	Pipe, sanitary ware
Pearlitic	275	240	0.4	Engine blocks, machine tools
Martensitic	550	550	0	Wearing surfaces

Table 2.3 Hardness Property of Grey Cast Iron according to different grades

ASTM A48 Class 150 [11]	Hardness		SAE Grade[12]	Hardness		A436 [13]	Hardness	
	HB	HRB		HB	HRB		HB	HRB
20	156	81	G1800	187 max	87 max	Type 1	131 – 183	74 – 183
25	174	86	G2500	170 – 229	85 – 96	Type 1b	149 – 212	79 – 93
30	210	93	G3000	187 – 241	89 – 98	Type 2	118 – 174	70 – 86
35	212	93	G3500	207 – 255	92 – 100	Type 2b	171 – 248	85 – 99
40	235	97	G4000	217 - 268	94 - 102	Type 3	118 – 159	70 – 82
50	262	101				Type 4	149 – 212	79 – 94
60	302	109				Type 5	99 – 124	64 – 72

The grey cast iron is considered to be one of the unique classes of cast irons. This is due to the fact that there is a wide range of applications of this metal, in numerous industries. Different grades of the cast iron are suitable for different applications. Table 2.4 shows some automotive applications of grey cast iron, with respect to its grade.

Table 2.4 : Automotive Applications of Grey Cast Iron

Class	Typical Applications	Class	Typical Applications
G1800	Miscellaneous, where strength is not primary consideration.	G 3500	Diesel engine blocks, heavy flywheels, tractor transmission cases, heavy gearboxes.
G2500	Small cylinder blocks, cylinder heads, pistons, clutch plates, transmission cases, gearboxes, light duty brake drums.	G 3500b	Brake drums and clutch plates where resistance to heat checking and higher strength is a must.
G 2500a	Brake drums and clutch plate for moderate service requirements, where high carbon iron is desired to minimize heat checking.	G 3500c	Brake drums for heavy service.
G 3000	Automobile and diesel cylinder blocks, cylinder heads, flywheels, pistons.	G 4000	Diesel engine castings, cylinders and pistons.

2.1.1. Basic Processing of Grey Cast Iron.

The traditional method of casting metals is in sand moulds and has been used for millennia.[5] For grey cast iron, the method most frequently used for the basic processing of the grey cast iron is sand casting. Basically, sand casting consists of (a) placing a pattern having the shape of the desired casting in sand to make a print, (b) incorporating a gating system, (c) filling the resulting cavity with molten metal, (d) allowing the metal to cool until it solidifies, (e) breaking away the sand mould, and (f) removing the casting.[5] The production steps for typical sand casting are shown in the figure below.

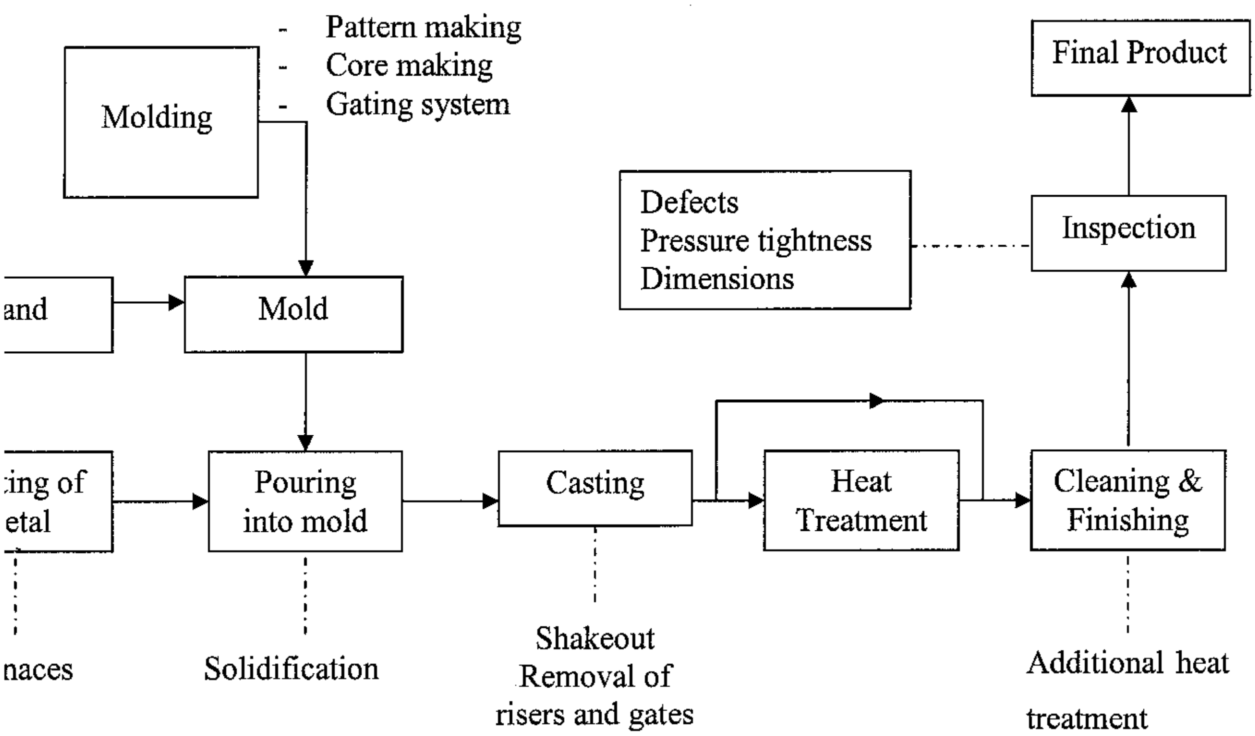

Figure 2.1 : Outline of Production Steps In a typical sand-casting operation

2.1.2. Secondary Operation of Grey Cast Iron

Most of the time, the final product of the grey cast iron is not suited for usage, more so if the requirement is of high surface finish or tolerance. Thus, there is a need for another set of operation, which is the secondary operation, which prepares the grey cast iron for usage. In other word, the basic processing, which is the sand casting, is only for the forming of the general shape of the final product itself. For finishes and tolerances, including final dimensions, those are covered by the secondary operations. The most widely used of secondary operations is the machining procedure.

Machining is one of the key scopes under manufacturing processes. Generally, machining is divided into 2 subsections, conventional and non-conventional machining. Examples of conventional machining are sawing, turning, milling and broaching, while for non-conventional are EDM die sinker, EDM wirecut, ECM (Electrochemical Machining) and ABM (Abrasive Jet Machining). For the case of secondary operation, any of these machining processes can be chosen. The choice depends largely on the shape, finishes, tolerances, generally the process capability of the machine itself. Some of the time, there are cases where more than one of the machining processes was chosen. This depends largely on the requirement of the final part. Figure 2.2 shows the general secondary operation for grey cast iron.

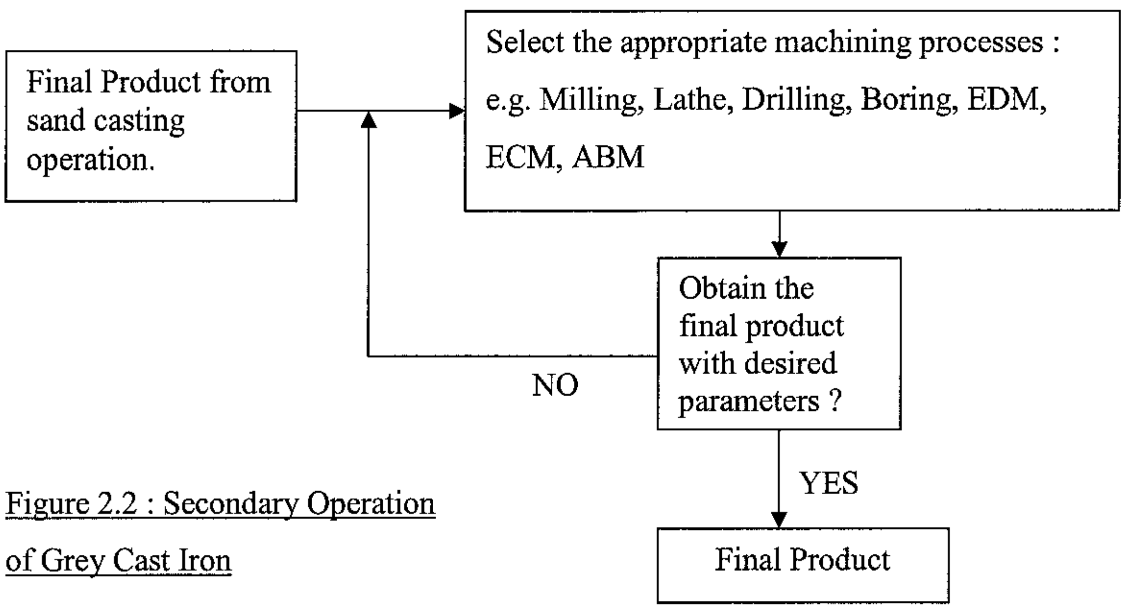

Figure 2.2 : Secondary Operation of Grey Cast Iron

2.1.3. Microstructure Properties of Grey Cast Iron.

As explained previously, the typical composition of the grey cast iron ranges from 2.5 to 4.0% carbon, 1.0 to 3.0% silicon, and 0.4 to 1.0% manganese. The different percentages of these elements in the grey cast iron would influence the microstructure of the iron, and produce different characteristic of the iron.

The usual microstructure of grey iron is a matrix predominantly of pearlite, with graphite flakes dispersed throughout. Foundry practice can be varied so that the nucleation and growth of graphite flakes occurs in a pattern that enhances the desired properties. The amount, size and distribution of graphite are important. Cooling that is too rapid may produce "mottled iron", in which carbon is present in the form of both primary cementite (iron carbide) and graphite. Very slow cooling of irons that contains large percentages of silicon and carbon is likely to produce a matrix predominantly of ferrite, together with coarse graphite flakes. [14]

2.2. Surface Roughness & Surface Finish

Surface roughness and surface finish are two terms included within the scope of surface texture. Surface roughness is a measurable characteristic based on the roughness deviations from the nominal surface that are determined by the material characteristics and the process that formed the surface.[3] Surface finish is a more subjective term denoting smoothness and general quality of a surface. In popular usage, however, surface finish is often used as a synonym for surface roughness.

The most commonly used measure of surface texture is surface roughness. Surface roughness can be defined as the average of the vertical deviations from the nominal surface over a specified surface length.[3] In equation form, this is given as

$$\mathbf{R_a = \frac{y_1 + y_2 + y_3 + \dots y_n}{n}} \quad [1]$$

where :

R_a is the centreline average, the arithmetic average based on the deviation from the mean surfaces.

$y_1, y_2..y_n$ is the vertical deviation from nominal surface.

Figure 2.3 below shows the sketch of a typical surface profile, obtained from a surface profiler. The value of P_t denotes the height from the maximum peak to the deepest trough.

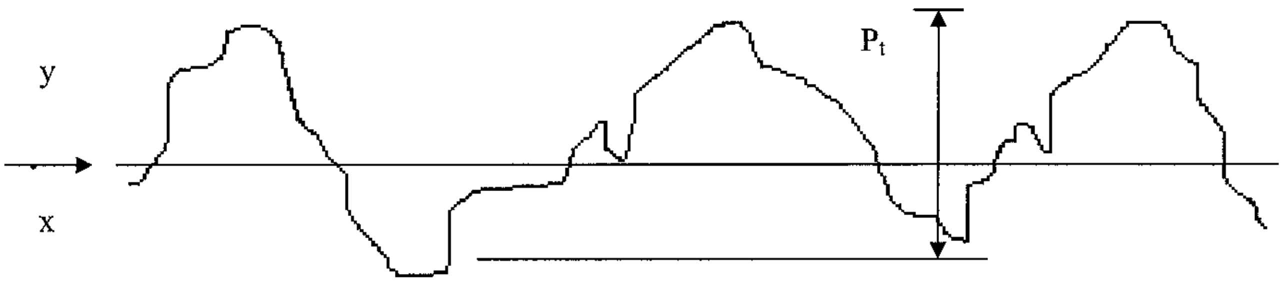

Figure 2.3 Sketch of a surface roughness profile

Although the basic method of calculating the surface roughness is from the use of the equation, the actual measurement would be performed using a stylus, an equipment used for measuring the surface roughness and also to obtain the surface profile. It is important to note that the parameter being measured is the average roughness height, R_a. two surfaces can have the same value of R_a and vary considerable in the details of surface profile.

The significance of surface roughness is evident in the final machining processes, especially in cases where the final product needs to be of within certain values of R_a. In some cases, these could be very rigid, since some components that are machined need to have very specific values of surface roughness. This is where the study of the surface roughness yield from different machining processes would be useful.

Table 2.5 and 2.6 shows the typical surface finish requirements for machine tool components, and aircraft engine component.

Table 2.5 : Typical surface finish requirements for machine tool components.[10]

Components / Parts	Operation	R_a, µm
Cam	Grind	0.40 – 0.80
Holder	Mill	3.2
Bracket	Mill	3.2
Plate	Mill	3.2
Block	Mill	3.2
Junction block	Grind	1.6
Ball screws	Mill / Turned	3.2
Keyways	Mill	3.2
Thread ϕ	Grind	0.8
Ball nut	Mill	3.2

Table 2.6 : Typical surface finish requirements for aircraft engine components.[10]

Part Name	Operation	R_a, µm
Ultrasonic envelope	Turned	1.60
Fan Disk :		
General Surfaces	Turned	1.60 – 3.2
Bolt Holes	Reamed	0.80 – 1.60
Dovetails	Broached	0.80 – 1.60
Corner breaks	Mass Media Finish	0.80
Compressor Casing :		
Flange faces	Turned	1.60
Turbine blade :		
Airfoil	Ground	0.80
Dovetail form	Ground	0.80
General Surfaces	Ground	1.10
Turbine Shaft :		
General Surfaces	Turned	1.60 – 3.20
Bolt Holes	Reamed	0.80
Journals	Ground	0.40

From studying several references pertaining to manufacturing technology, the range of surface roughness for grey cast iron from different machining process is obtained. These values would be invaluable in predicting the range of surface roughness from experimental work. The values for the range of surface roughness are shown in Table 2.7. Note that there might be some discrepancy between the sources, since some books are more tend to take into account more factors that might influence the surface roughness, while others estimated the values according to standard machining condition.

Table 2.7 :Expected Range of Surface Roughness, compiled from different sources

Processes	Roughness, R_a, μm			
	1st [5]	2nd [7]	3rd [2]	4th [3]
Initial – Sand Casting	6.3 – 50	3.2 – 50	6 – 25	2.5 – 25
Conventional :				
Flame cutting	6.3 – 50	10 – 30	8 – 30	10 – 25
Turning, boring	0.05 – 25	0.05 – 25	3.10 – 6.30	0.81 – 6.30
Milling	0.20 – 25	0.20 – 25	1.60 – 6.30	0.40 – 3.20
Band Saw	0.80 – 50	3.20 – 25	6.25 – 25	6.30 – 25.4
Non-Conventional :				
EDM :				
Die Sinker [6]	0.80 – 12.5	0.05 – 12.5	0.80 – 3.10	0.80 – 12.5
Wire Cut [6]	0.80 – 12.5	0.05 – 12.5	0.12 – 2.50	0.20 – 12.5

2.3. General Recommendation for Machining Operation

As explained previously, there are several factors that influence the surface roughness during the machining process, such as the depth of cut, feed rate and also cutting speed. The basic machining procedure is to perform one or more *roughing cuts* at high feed rate and large depth of cuts (and, therefore, high metal removal rates but little consideration of dimensional tolerance and surface roughness), and to follow it with a *finishing cut* at a lower feed and depth cut for a good surface finish[5]. Since the scope of the study is on the surface roughness measurement, the machining process would be conducted using the recommended parameters for both the roughing and finishing cuts. Thus, to maintain the consistency and for ease of operation, a general recommendation for turning and milling operation is used. The recommended parameters for turning and milling processes are as shown in Table 2.8

Table 2.8 General recommendation for turning operation of surface finish – grey cast iron.[5]

Material	Operation	Feedrate (mm / rev)	Cutting Speed (mm / min)	Depth of Cut (mm)	RPM (rev / min)	Expected Range for R_a (μm)
Grey Cast Iron	Roughing (Bar)	0.45	120	1	200	5.0 - 10
Grey Cast Iron	Finishing (Facing)	0.20	200	0.2	200	0.5 – 6.0

For the roughing operation, the feedrate is set at 0.45 mm/rev, the cutting speed at 120 mm/min, and the depth of cut is 1 mm. Basically, during a roughing procedure, where the depth of cut is deep, the cutting speed needs to be set slower. This in turn means a higher feedrate, since at that particular revolution; there are more material being cut. The RPM here is constant; it is the same for both the roughing and finishing operation, since the changing this value would give a different reading for the feedrate.

For the milling operation, the same rule of thumb is observed. For the roughing operation, the feedrate is higher than that of the finishing process, though the cutting speed is lower. Since the cutting speed is lower, it follows that the spindle speed is also lower. For the depth of cut, the ideal depth would be 1 mm for roughing, and 0.25 mm for finishing. However, due to the machine safety measure, which only allows the maximum depth of cut for grey cast iron to be 0.5 mm, the value is set thus. From this, it was expected that the surface roughness value obtained would differ only slightly.

Table 2.9 General Recommendations for Milling Operation of surface finish – grey cast iron.[5]

Material	Operation	Feedrate	Cutting Speed	Depth of cut	Spindle speed	Expected Range for R_a
Grey Cast Iron	Roughing	0.50 mm / rev	120 mm / min	0.5 mm	1178 min^{-1}	1.6 – 6.3 μm
Grey Cast Iron	Finishing	0.20 mm / rev	180 mm / min	0.25 mm	2000 min^{-1}	0.4 – 3.2 μm

Aside from the recommended parameters for the turning and milling operations, there are also recommended parameters for other conventional machining, such as the band saw, hacksaw and the plasma cutter. Since these are more of cutting machines, these recommended parameters are from the manufacturers of the machines themselves. These parameters are shown in table 2.10.

Table 2.10 General Recommendations for other conventional processes – grey cast iron

Process	Saw dimensions (mm)	Cutting Speed (m/min)
Horizontal Band Saw	27 0.9 x 3300	20 (for hard grey cast iron) 40 (for soft grey cast iron)
Hacksaw	27 x 0.8 x 240	Constant speed

Process	Voltage (V)	Air Pressure (bar)	Frequency (Hz)
Plasma Cutter	230	7	50 - 60

For the EDM Die Sinker and Wire Cut, since there are no direct contact between the electrode and the wire with the work piece, there are no cutting forces. As such, the factors that are taken into consideration would be the wire, the gap between the electrode and the work piece, the frequency and the speed of cut.

From Table 2.11, it can be seen that the pulse frequency is tabulated in an increasing order. The range of the current, however, does not follow this fashion. This is due to the fact that a wider range of R_a is possible at low frequency across a wide range of current, however, a smaller range of surface roughness would require a smaller range of current. Also, a smoother surface finish is possible at a higher pulse frequency.

As explained previously, for the EDM Wirecut, the factors taken into consideration for machining process would be the type of wire, the gap between the wire and the work piece and the speed of cut. Table 2.12 gives the recommended parameters for machining grey cast irons using the EDM Wirecut.

Table 2.11 General Recommendations for EDM Die Sinker Operation of surface finish – grey cast iron.[6]

Pulse, frequency, kc	Current Amp (Ampere)	Surface roughness (μm)	Crater Size				Removal Rate, mm/hr
			Workpiece		Electrode		
			Depth	Width	Depth	Width	
5	1 – 20	5 – 13	1.9 – 4	5.3	1.2	1.3	43
10	5 – 17	3.8 – 5	1.5 – 1.9	2.4	0.57	0.58	13
20	4 – 12	2.5 – 3.8	1.0 – 1.5	2.0	0.45	0.46	6.5
450	3 – 9	1.3 – 2.0	0.5 – 0.6	0.65	0.18	0.2	2.5
1000	0.5 - 3	0.25 – 0.75	0.1	0.15	0.03	0.04	0.13 – 0.013

Table 2.12 General Recommendations for EDM Wire Cut Operation of surface finish – grey cast iron.[6]

Gap between wire & work piece	Wire Diameter & Type of Wire	Speed of cut
0.025 to 0.05 mm	0.03 – 0.15mm Molybdenum Steel Wire	20 – 60 mm / hr

3.0 METHODOLOGY

The development of the project follows the step-by-step phases of the classic Waterfall Model Methodology. The diagrammatic representation of the model is as follows:

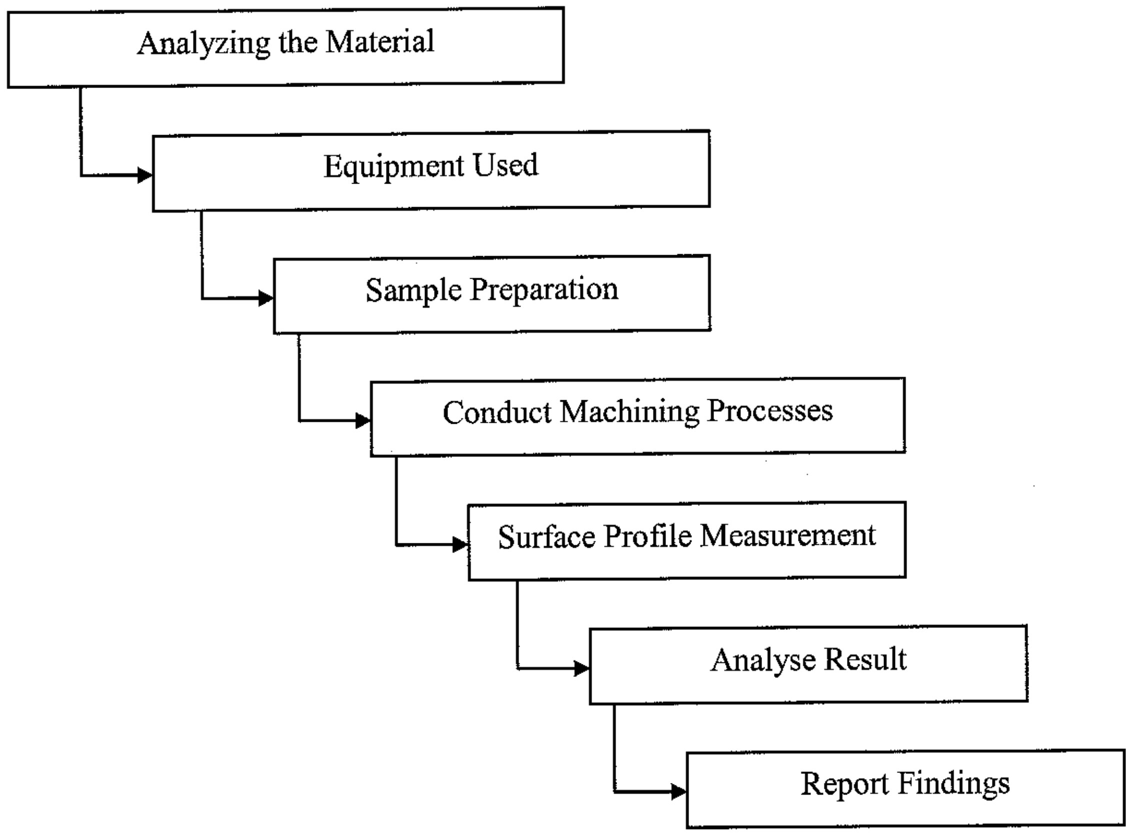

Figure 3.1 : Diagrammatic Representation of Methodology (Waterfall Model Methodology)

The first part of the methodology is to analyse the material. From there can the relevant machining operation be chosen. For conventional machining, the author had chosen the milling and lathe operation. This would cover both the traditional lathe and milling machines, as well as modern machining centres. Also, the author had chosen the band saw, hacksaw and plasma cutter for the conventional machining. This would also include the use of handsaw. As for the non-conventional machining, the EDM Wirecut and Die Sinker were chosen. The specimen of grey cast iron is obtained, in the form of a brake disc. This specimen was divided into several samples for machining.

Next, the samples were machined accordingly using various machining processes, with the parameters as outlined in the literature review. For the machining centres, the specimens were machined with 2 different cuts, the roughing and finishing cuts. For the sample machined with the traditional lathe and mill machines, 3 to 4 different cuts were performed, each with different parameters. Similarly, the samples machined or cut using the hand, band or hack saw have at least 2 type of cuts. For the EDM, the wirecut were used to cut a sample to 2 specimens, while for the die sinker, 5 different machining operations with different parameters were conducted.

From there, the surface roughness test was conducted. Some machined samples were tested once, some twice, depending on the machined area, with each test taking the average from 3 different points from the machined surface. From the surface profile and R_a value obtained, the author is then equipped to discuss the results and draw the relevant conclusion.

3.1. Analysing the Material

The first phase is the analysing of the material. The material needs be analysed to determine its class, whether it has a pearlite, ferrite or martensite configuration. This was conducted with the use of high-powered microscope, since the configurations were easily determined from studying the material under a microscope. Hardness test for the material was also conducted, as a mean to determine the class of the sample.

The method for determining the microstructure of the sample of the grey cast iron involved the following steps. The first step or procedure was polishing the sample to a mirror finish, with polishing grindstone of different quality. This step could be conducted using as many as 9 different grindstones, and as little as 3, depending on the hardness of the material. For the purpose of this study, 4 grindstones of different quality were used. Once the mirror finish was obtained, the surface was then polished. The objective of the polishing procedure was to remove any tiny scratch mark that might appear under the microscope as impurities. Polishing would go through two phases, phase one with the 6 microns polishing solution, and phase two with the 3 microns solution. Upon completion of the polishing procedure, the sample is then cleaned with methanol and etched.

Etching is a process where, with the help of a chemical solution known as an etchant, with the purpose of making clear the microstructure. Only 2 to 3 drops of the etchant was needed on the surface. For grey cast iron, the suitable etchant is 2% nital, which is one of the more commonly used etchant.

After the etching process, the sample was then observed under the microscope, and the microstructure obtained. From the diagram of the result, the microstructure can then be determined to be ferrite, pearlite, or martesite.

From the microstructure analysis, the microstructure was determined to be of pearlite phase with graphite flakes, with pool of carbide eutectics. The illustration of the microstructure is available in the appendix, *(page 40 & 41)*.

Aside from the microstructure analysis, the author had also conducted the hardness test, which is to determine the hardness of the sample. The hardness test was tested for four times per specimen, with a total of 3 specimens from the overall sample. The hardness test was conducted using the Rockwell scale, the HRB. For HRB, the load is 100 kg, and the indenter used is the 1/16" diamond ball indenter. The result of the hardness test is in the results section.

From the hardness test, it had been determined that the grey cast iron sample is of SAE grade 2500, and ASTM Class 25.

3.2. Equipment Used

There are several equipment which were used during the study for this project. As stated previously, for the conventional machining, the chosen method is milling, lathe, band saw, hacksaw, hand saw and plasma cutter, while for non-conventional machining, the chosen method was using the EDM Wirecut and EDM Die Sinker. The list of the equipment is tabulated in Table 3.1 in the next page.

Table 3.1 List of Relevant Equipment Use for Study.

Equipment Used	Phases / Process of Usage
Rockwell Hardness Testing Machine	Hardness Test
Horizontal Band Saw	Sawing
Hack Saw	Sawing
Hand Saw	Sawing
Plasma Cutter	Flame Cutting
Traditional Lathe	Lathe
Traditional Mill	Milling
Mazak Variaxis 630 – 5X	Milling
Mazak Integrex 200 – III	Lathe
Mitsubishi CNC EDM Wire Cut	EDM Wire Cut
Mitsubishi CNC EDM Die Sinker	EDM Die Sinker
MAHR Perthometer PGK 120	Obtaining the Surface Profile

3.3. Sample Preparation

The specimen provided to the author was a pure grey cast iron brake disc. The brake disc was then cut up into several segments, to suit the machining process. Basically the brake disc was divided into 5 parts, one cylindrical segment, while the other 4 were cut into arbitrary shapes. Since the lathe operation would need a cylindrical work piece, the smaller cylinder was prepared for that. For milling, sawing, flame cutting and both the EDM operations, arbitrary shape would not be a problem, since these machines could handle them.

The initial (pre-machined) dimensions of the sample are as listed in Table 3.2a and 3.2b.

Table 3.2a Small Cylinder (for lathe operation)

Inner Diameter (mm)	Outer Diameter (mm)	Height (mm)
58	145	25

Table 3.4 Parameters used for mill operation with CNC Milling Machining Centre.

Material	Operation	Feedrate (mm / rev)	Cutting Speed (mm / min)	Depth of cut (mm)	Spindle speed (min^{-1})	Expected Range for R_a (µm)
Grey Cast Iron	Roughing	0.50	120	0.5	1178	1.6 – 6.3
Grey Cast Iron	Finishing	0.20	180	0.25	2000	0.4 – 3.2

The machining of the sample using the CNC Mazak Variaxis 630 – 5X uses a software known as the Mazatrol. This software is a form of CNC, albeit a much simpler one. Below is the coding used, based on the Mazatrol software.

UNo.	Mat.	Initial Z	ATC Mode	Multi mode	Multi flag	Pitch X	Pitch Y					
0	CST IRN	100	0	OFF	◊	◊	◊					
UNo.	Unit	ADD. WPC	X	Y	th	Z	C	A				
1	WPC – 0		0	0	0	0	0	0				
UNo.	Unit	Depth	SRV – Z	BTM	WAC	FIN Z	FIN R					
2	FACE MIL	2.0	4.5	3	◊	0	◊					
SNo.	TOOL	NOM ϕ	APRCH X	APRCH Y	TYPE	ZFD	DEP Z	WID R	C-SP	FR	M	M
R1	F-MILL	50	-80	-50	YBI	◊	0.5	35	120	0.5	8	1
FIG	PTN	P1X / CX	P1Y / CY	P3X / R	P3Y	CN1	CN2	CN3	CN4			
1	SQR	-90	-20	90	20	R0	R0	R0	R0			
UNo.	UNIT	CONTI										
3	END	0										

For traditional lathe, there were four sets of machining performed, each with different parameters. For the traditional mill, three different cuts with different parameters were done. The parameters used for both the traditional lathe and mill is in Table 3.5 and Table 3.6, respectively.

Table 3.5 Parameters used for lathe operation with traditional lathe machine.

Material	Sample No.	Feedrate (mm / rev)	Depth of Cut (mm)	RPM (rev / min)
Grey Cast Iron	1	0.117	0.5	835
Grey Cast Iron	2	0.117	0.5	525
Grey Cast Iron	3	0.117	0.5	355
Grey Cast Iron	4	0.117	0.5	1320

Table 3.6 Parameters used for mill operation with traditional milling machine.

Material	Sample No.	Depth of cut (mm)	Spindle speed (min^{-1})
Grey Cast Iron	1	1.00	500
Grey Cast Iron	2	1.00	2000
Grey Cast Iron	3	0.10	2000

As for the handsaw and hacksaw, since the parameters are basically constant, thus no parameters need to be specified. The same goes for flame cutting. For band saw, the cutting speed is varied, to see the effect on the surface finish. Table 3.7 and 3.8 shows the parameters used for these operations.

Table 3.7 Parameters used for sawing operation with horizontal band saw machine.

Material	Sample No.	Cutting Speed (m / min)
Grey Cast Iron	1	20
Grey Cast Iron	2	40

Table 3.8 Parameters used for flame cutting operation with plasma cutter.

Process	Voltage (V)	Air Pressure (bar)	Frequency (Hz)
Flame cutting	230	3	50 – 60

For the EDM Wirecut, there is only one type of cut. Since the main objective of the study is to determine the surface finish, the shape of the sample to be machined / cut is a basic straight line. Although the uniqueness of the wirecut machine is in its capability to produce complex shape, that is not tested here, since the scope of the study is the surface roughness yield, rather than process capability of the particular machine.

Below are the data regarding the machining process using the EDM Wirecut machine. The first part is the Numerical Control codes used for machining, while Table 3.9 shows the parameters used for the wirecut operation.

The NC Code used for machining using the EDM Wirecut machine :

```
N0002 M82
N0003 M84
N0004 G90
N0005 G92 X0 Y0
N0006 G01 X-70 Y 0
N0007 M01
N0008 G40 G01 X0 Y0
N0009 G23
```

Table 3.9 Parameters used for wirecut operation with EDM Wirecut.

Machine Name	Wire Diameter (mm)	Wire type	Feedrate (mm / min)
Mitsubishi CNC EDM Wire Cut	0.25	Brass, non-paraffin	1.5 – 5.5

For the die sinker, five different machining operation had been carried out, each with different surface roughness. The uniqueness of the die sinker machine is that the user could input and set the surface roughness that he or she wants into the machine, and the machine would be able to produce that value. However, it should be noted that the surface roughness value obtained is the R_{max} value, rather than the R_a value. Table 3.10 lists the parameters used for EDM Die sinker operation.

Table 3.10 Parameters used for die sinker operation with EDM Die Sinker.

Sample No.	Expected R_{max} (μm)	Electrode used	Depth of cut (mm)	Removal Rate (mm / hr)
1	1 – glossy mirror	Copper, 20 x 20 mm	2	0.3
2	10 – glossy mirror	Copper, 20 x 20 mm	1	0.5
3	20 – glossy mirror	Copper, 20 x 20 mm	1	4.0
4	40 – glossy mirror	Copper, 20 x 20 mm	2	6.5
5	40 – matte finish	Copper, 20 x 20 mm	1	6.5

3.5. Surface Profile Measurement

The next step after the machining process was measuring the surface profile. The surface profiles for the specimen were measured using the MAHR Perthometer PGK120 machine (FormView Ver.2.0 for the software). For the measurement of the surface profile, the traverse length was set to 5.60 mm, which was the recommended traverse length. The profile taken into account was from 0.8 mm to 4.0 mm. Any profile before or after this interval were ignored. This length is also known as the cut-off length, while the traverse length is also known as the common trace length. The value of 0.8 mm is considered to be the standard norm in measuring surface roughness, and the common trace length is usually 5 times the cut-off length, hence 4.0 mm.

For the measuring of the surface profile, three readings were taken per test, with two test conducted for each sample, at different point on the surface. The value used in comparison to the theoretical is R_a, which is the average value of roughness. The surface profiler does not only measures the value of R_a, it also gives the value of R_t, R_{max}, and P_t, on top of the profile of the surface. As explained previously, though a surface could have similar values of R_a, the profile could be very different. Thus it is important to view all these result together, rather than just take the value R_a on its own.

3.6. Analyse Result

After obtaining the surface profile, the result were analysed and studied. Comparison would be done between the expected and the practical ones. As for the EDM machines, since the machine themselves could be set for the required surface finish, the value of surface finish obtained from the experiment were compared with the predicted values.

From the range of surface roughness values that had been obtained, it is then possible to plot a table to show the range of surface roughness based on the machining type. This table is available in the results section.

3.7. Report Findings

The final step in the methodology is to report the findings that have been obtained. From the analysing of the result in the previous steps, the author would need to report on the findings. From the table that had been tabulated, it is then possible for the author to comment on the range obtained. The author would also need to form conclusion on the result obtained.

4.0 RESULT & DISCUSSION

4.1. Result

The result for the values of surface roughness, R_a is shown in Table 4.1

Table 4.1 : Experimental Surface Roughness Obtained from various machining.

Condition / Process	Experimental Surface Roughness, R_a (μm)		
	1^{st} reading	2^{nd} reading	3^{rd} reading
Initial condition (sand casting)	7.00	7.42	8.56
Plasma Cutter	8.42	7.21	6.05
Hand Saw :			
Test 1	5.43	4.05	5.15
Test 2	8.34	5.09	4.19
Hack Saw :			
Test 1	5.05	4.87	5.05
Test 2	5.00	4.84	4.73
Horizontal Band Saw :			
Test 1	4.98	4.76	5.66
Test 2	2.95	4.41	3.62
Test 3	2.87	4.33	4.09
Test 4	1.63	1.72	1.92
Traditional Milling :			
Test 1	2.19	2.14	1.74
Test 2	0.64	1.11	0.82
Test 3	1.72	1.13	1.02
Traditional Lathe :			
Test 1	1.60	1.66	1.70
Test 2	1.81	1.81	1.84
Test 3	2.00	1.97	2.13
Test 4	1.84	1.68	1.65
CNC Milling :			
Roughing	0.35	0.36	0.32
Finishing	0.49	0.23	0.25
CNC Lathe :			
Roughing	2.73	3.09	2.60
Finishing	1.70	1.91	2.25
EDM Wirecut :			
Test 1	3.82	3.28	3.59
Test 2	3.67	3.16	3.56
EDM Die Sinker :	Value in brackets is R_{max}		
Test 1	1.06 (7.49)	0.93 (11.63)	0.93 (7.79)
Test 2	2.93 (21.26)	3.00 (20.58)	2.80 (20.04)
Test 3	5.92 (38.30)	5.47 (36.85)	5.88 (37.86)
Test 4	8.70 (54.47)	8.21 (56.72)	6.97 (41.72)
Test 5	8.26 (55.60)	7.68 (52.42)	9.40 (53.20)

The result for the hardness test is in Table 4.2

Table 4.2 Hardness Test Result - HRB

Sample No	1st reading	2nd reading	3rd reading	4th reading
1	83.3	89.2	92.7	88.4
2	87.0	90.3	87.7	90.4
3	95.4	90.0	86.5	90.4
Average of all readings	89.3			

From the results of surface roughness, the author were able to plot a graph which shows the pattern of the surface finish obtained with respect to the machining procedure, as shown in Table 4.3.

Table 4.3 : Range of Surface Roughness Obtained from various machining processes.

Process	µm	9.0	8.5	8.0	7.5	7.0	6.5	6.0	5.5	5.0	4.5	4.0	3.5	3.0	2.5	2.0	1.5	1.0	0.5	0.1
Initial (sand casting)			•			• •														
Plasma Cutter				•		•		•												
Hand Saw				•						••••		•								
Hack Saw										••	•••									
Horizontal Band Saw								•			••	•••	•		••		•••			
Traditional : - Milling																••	••	•••	••	
- Lathe																••	••••••••••			
Machining Centre - Milling																				••••••
- Lathe														•	••	•	••			
EDM - Die Sinker		•	•	••	•		•		••	•				•	••			•	••	
- Wirecut													••••	••						

4.2. Discussion :

From the table that had been plotted out, it is evident that there is a wide range of surface roughness available for all different machining procedures. The machining process that would yield the worst or roughest surface finish is the plasma cutter, which is to be expected, since the material is cut with flame. This is then followed by the handsaw. Since the motion during using the handsaw was not constant (and it is highly improbable that it could be so), the roughness value is high. The use of the hack saw and band saw has similar range of surface roughness, though the band saw could in fact yield smoother finishes, due to the one directional movement of the saw, as opposed to the two directional movement of the hack saw.

For the traditional lathe and milling operation, the surface roughness value obtained was relatively smoother. In fact, the values obtained for these machining is better than that of using non-conventional machining, such as the wirecut. The use of the machining centre, on the other hand, had yield quite smooth finishes, especially the CNC Milling machine. This is to be expected, since the CNC Milling Machine is so designed more for the purpose of high speed cutting, rather than high volume cutting. Thus, it follows that at high speed, the depth of cut and feedrate is lower, and this would yield a smoother finish.

The die sinker is unique in the sense that the user or operator could input the required surface finish (in terms of R_{max}) to the machine, and the machine would theoretically yield that value of roughness. This explains the wide range of roughness value for the EDM. However, it can be seen that the experimental value (of R_{max}) is higher than the expected values from the machine. For the case of wirecut, the surface roughness of the machined work piece is usually not the top priority during the machining. Since the main use of the wirecut machine is to cut complex shapes (for moulding, casting or punching purposes), the roughness value that were obtained is concentrated in a small range.

5.0 CONCLUSION & RECOMMENDATION

From the results that had been obtained, it can be concluded that there are a range of values of surface roughness that is attainable through different machining processes. Some machining processes could yield a large range of surfaces, such as the EDM die sinker, and the traditional lathe and mill. Others are more rigid, producing the surface roughness within a certain set of range. A good example would be the wirecut, since, as stated previously, the wirecut is more for cutting complex shape, rather than for obtaining specific surface roughness. Another example is the plasma cutter, where it is nearly impossible to get a surface roughness of 5 μm or less. Thus, it would seem that there are a whole range of surface roughness values that is attainable by varying the machining parameters.

The significance of this study is that it provides readers and users with a basic idea on the process capability of different machining processes of grey cast iron, with respect to the surface finish. This is especially useful in cases where the range of surface finish has to be within certain range, as illustrated in the literature review. (*page 17*).

As a recommendation, the author would suggest that this study be continued with other machining parameters. By varying the machining parameters, it is predicted that different values of surface roughness would be obtained. This would in turn provide valuable information for machining and manufacturing processes.

6.0 REFERENCES

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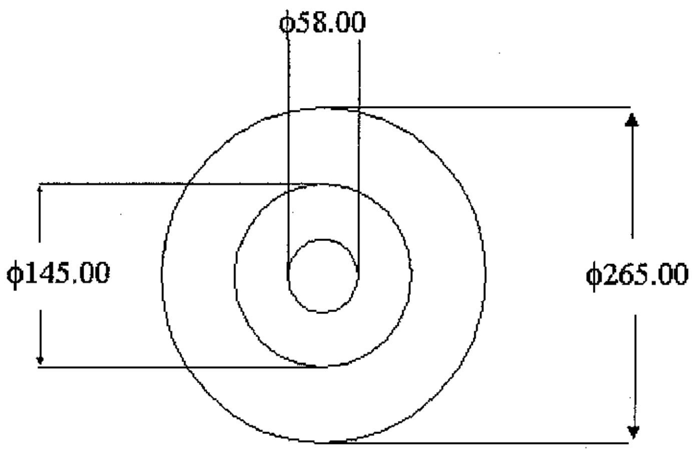
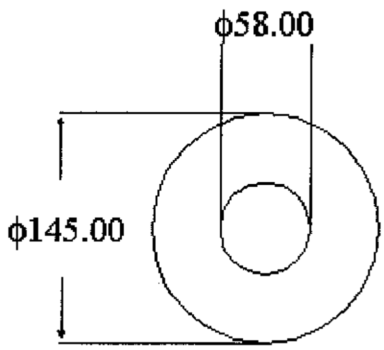
7.0 APPENDICES



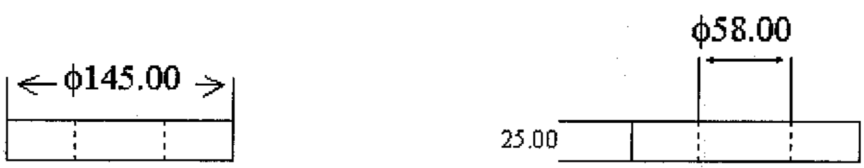
*note : all dimensions in mm

Initial Specimen of Grey Cast Iron (Brake Disc)

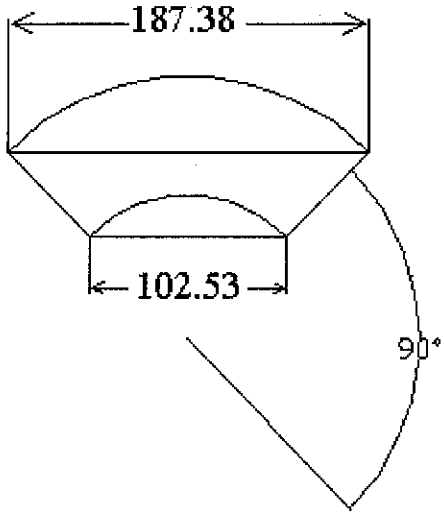


*note : all dimensions in mm

Specimen of Grey Cast Iron for Lathe Operation (Brake Disc)



*note : all dimensions in mm



Milling, Sawing & EDM Specimen of Grey Cast Iron (Brake Disc)

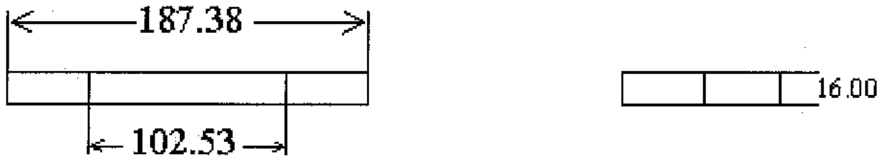
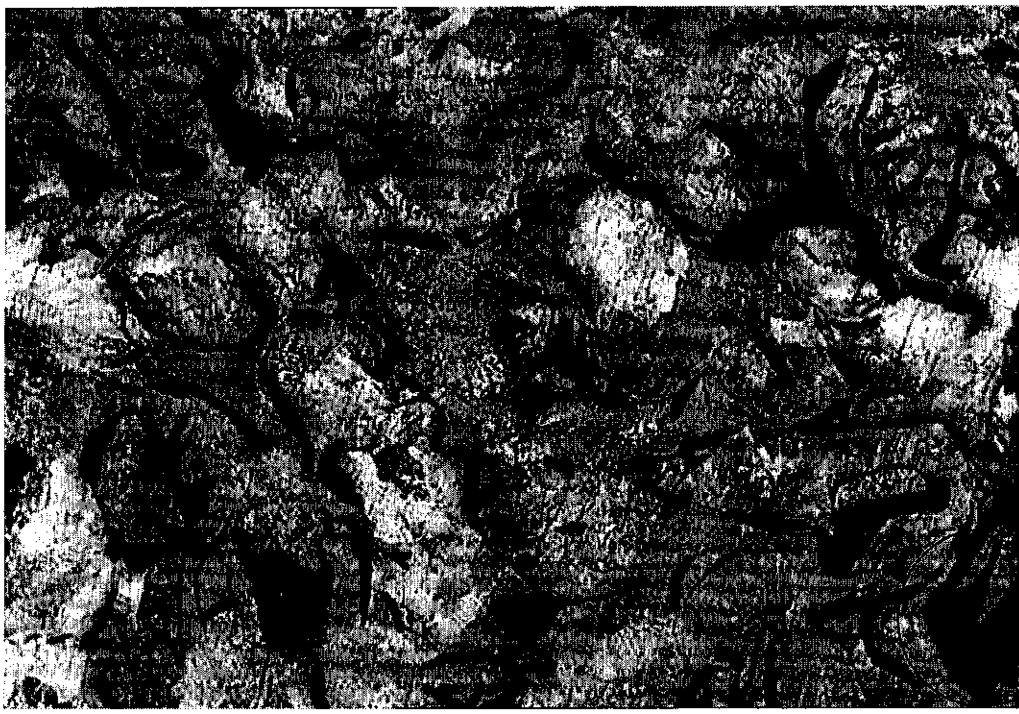


Illustration of the microstructure of grey cast iron specimen



Graphite Flakes

Image 1 : at 10 x magnification

Image 2 : at 20 x magnification

Pool of carbide eutectics

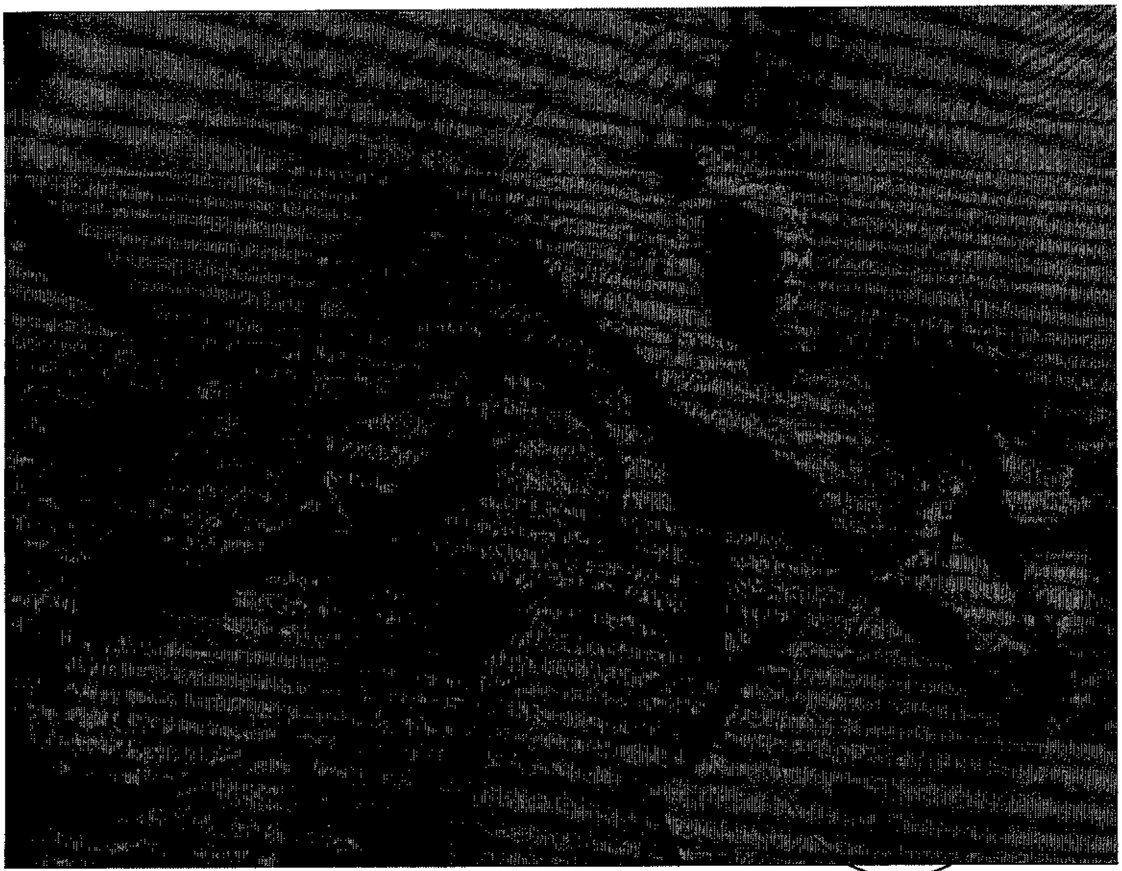


Image 3 : at 50 x magnification

Pearlite

GANTT CHART FOR FIRST SEMESTER

No	Details / Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**Selection of Project**	■														
	Propose title	■														
	Topic assigned to student		■													
2	**Prelimanary research work**			■	■											
	Introduction															
	Objective															
	Project planning															
3	**Submission of Prelimanary report**				■											
4																
5	**Submission of weekly reports**					■	■	■	■	■	■	■	■	■		
6	**Project work (01)**															
	Familiarization with machining technique				■	■	■									
	Material Analysis						■	■								
7	**Submission of progress report**															
8	**Project work (02)**									■						
	Machining Procedure - CNC Lathe								■							
	Machining Procedure - CNC Milling								■							
9	**Project work (03)**															
	Surface Finish Calculation										■	■				
10	**Submission of interim report draft**												■			
11	**Oral presentation**													■		
12	**Submission of interim report**														■	
13	**Study week & Final exam**														░	░

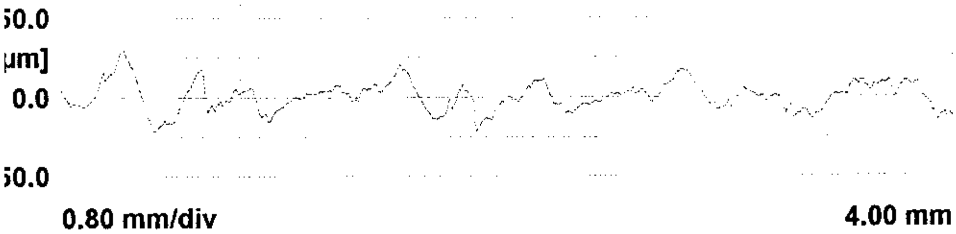
GANTT CHART FOR SECOND SEMESTER

No	Details / Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**Updating Literature Review**															
	Literature Review Update															
2	**Project work (04)**															
	Machining Procedure - EDM Wirecut															
	Surface Finish Calculation															
3	**Submission of Progress Report 2**															
4	**Submission of weekly reports**															
5	**Project work (05)**															
	Machining Procedure - EDM Die Sinker															
	Surface Finish Calculation															
6	**Submission of Progress Report 3**															
7	**Project work (06)**															
	Machining Procedure - Traditional Mill & Lathe															
	Machining Procedure - Sawing & Flame Cutting															
8	**Project work (07)**															
	Surface Finish Calculation															
9	**Submission of Final Report Draft**															
10	**Oral presentation**															
11	**Submission of Final Report**															
12	**Study week & Final exam**															

versiti Technology Petronas chanical Engineering Lab. ıdar Sri Iskandar 50 Tronoh,Perak.	**Perthometer Concept**	
ect: Gray Cast Iron nber: Initial Unmachined	Remark: Test 2 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 12:20

asurement No. 1

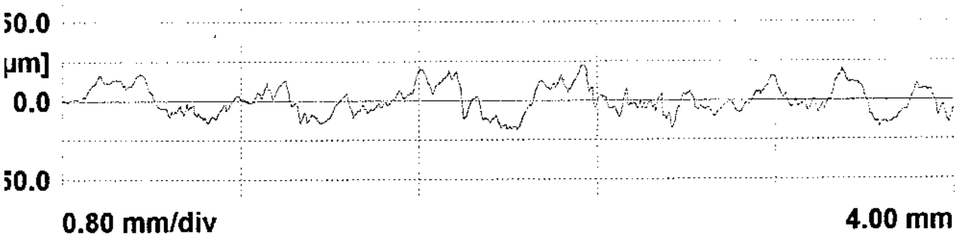
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	7.00	µm
Rmax	51.38	µm
Rz	34.56	µm
Pt	81.79	µm

asurement No. 2

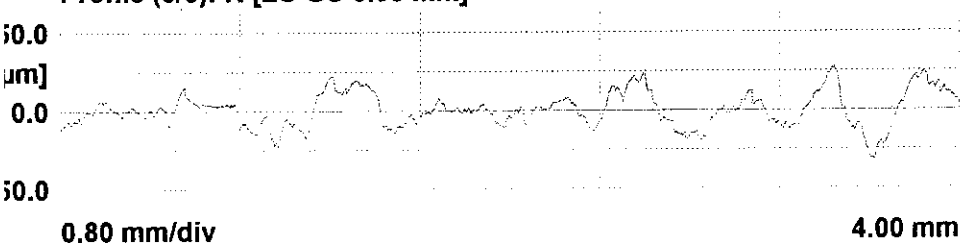
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	7.42	µm
Rmax	41.00	µm
Rz	35.05	µm
Pt	126.20	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



	3	
Ra	8.56	µm
Rmax	59.66	µm
Rz	39.29	µm
Pt	92.94	µm

versiti Technology Petronas :chanical Engineering Lab. ıdar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ect: Grey Cast Iron nber: Plasma Cutter	Remark: Test 1 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 12:13

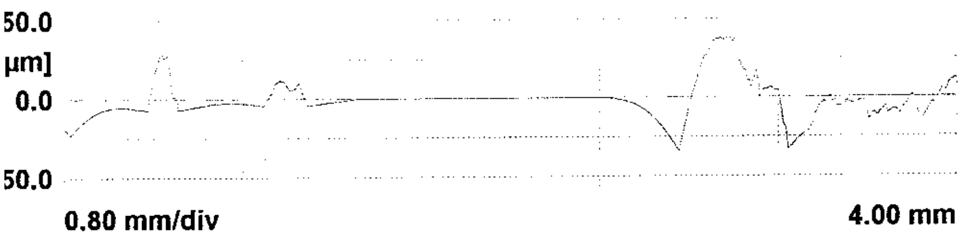
asurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

	1	
Ra	8.42	µm
Rmax	65.68	µm
Rz	46.46	µm
Pt	269.38	µm

asurement No. 2

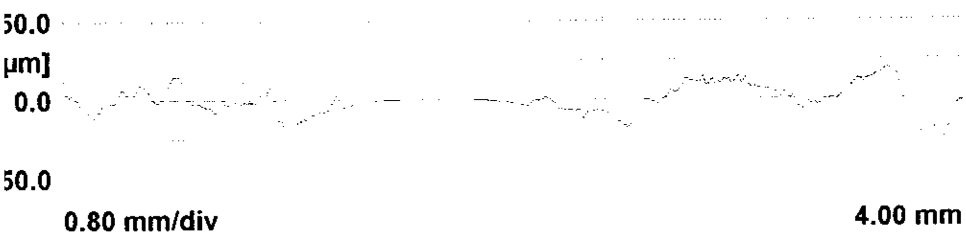
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	7.21	µm
Rmax	73.03	µm
Rz	37.21	µm
Pt	225.13	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

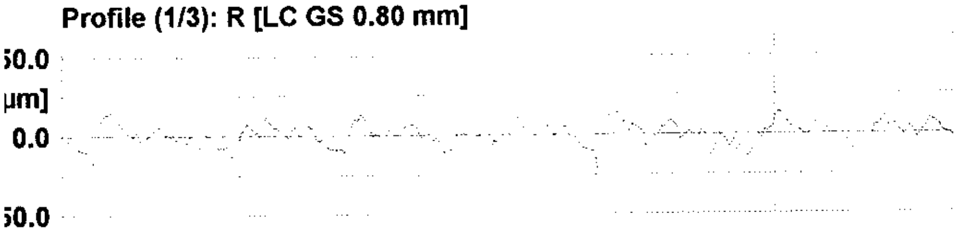


	3	
Ra	6.05	µm
Rmax	44.87	µm
Rz	28.70	µm
Pt	386.34	µm

versiti Technology Petronas :hanical Engineering Lab. ıdar Sri Iskandar 50 Tronoh,Perak.	**Perthometer Concept**	
ect: Grey Cast Iron nber: Hack Saw	Remark: Test 1 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:55

asurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

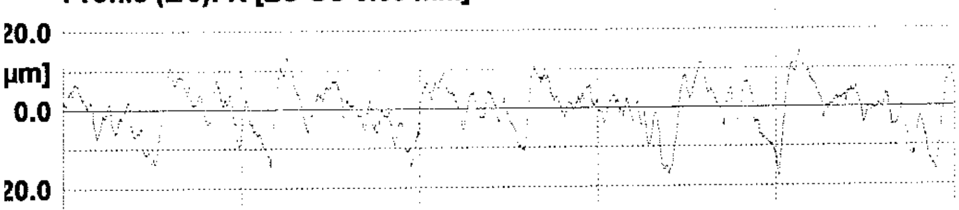


0.80 mm/div **4.00 mm**

	1	
Ra	5.05	µm
Rmax	36.96	µm
Rz	31.91	µm
Pt	41.96	µm

asurement No. 2

Profile (2/3): R [LC GS 0.80 mm]

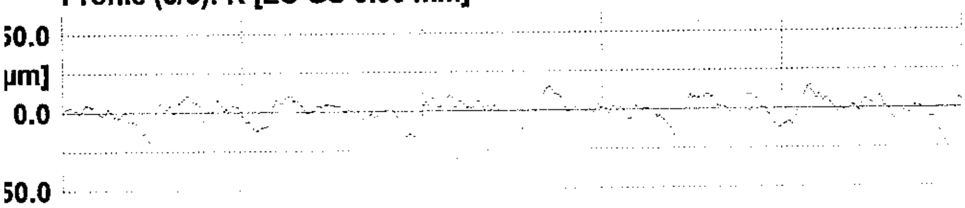


0.80 mm/div **4.00 mm**

	2	
Ra	4.87	µm
Rmax	32.26	µm
Rz	27.17	µm
Pt	44.94	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



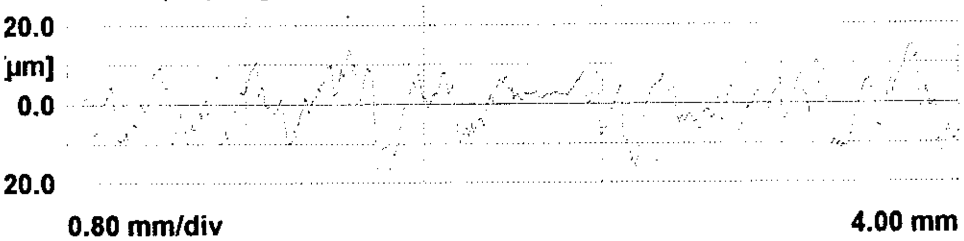
0.80 mm/div **4.00 mm**

	3	
Ra	5.05	µm
Rmax	36.70	µm
Rz	31.18	µm
Pt	50.04	µm

versiti Technology Petronas chanical Engineering Lab. ıdar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron nber: Hack Saw	Remark: Test 2 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 12:01

asurement No. 1

Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	5.00	µm
Rmax	30.69	µm
Rz	24.10	µm
Pt	46.41	µm

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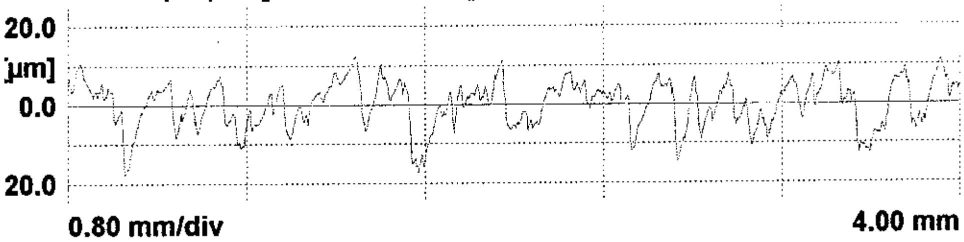
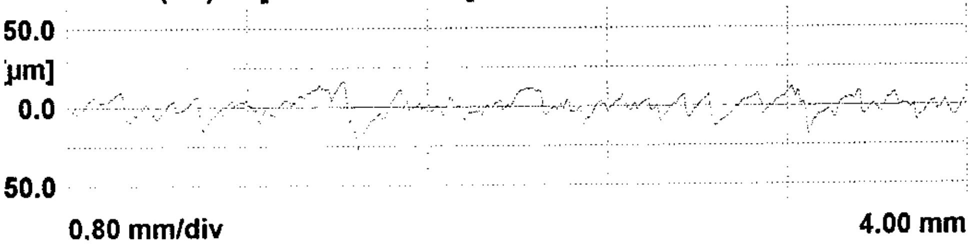
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	4.84	µm
Rmax	29.74	µm
Rz	25.84	µm
Pt	47.54	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

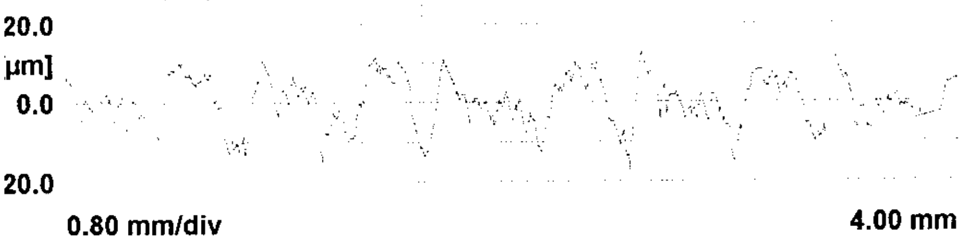


	3	
Ra	4.73	µm
Rmax	43.62	µm
Rz	28.84	µm
Pt	50.08	µm

versiti Technology Petronas chanical Engineering Lab. ıdar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
;ect: Grey Cast Iron nber: Horizontal Band Saw	Remark: Test 1 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:25

asurement No. 1

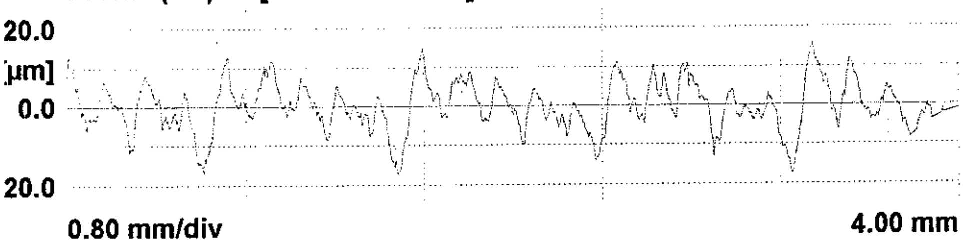
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	4.98	µm
Rmax	30.26	µm
Rz	25.36	µm
Pt	56.95	µm

asurement No. 2

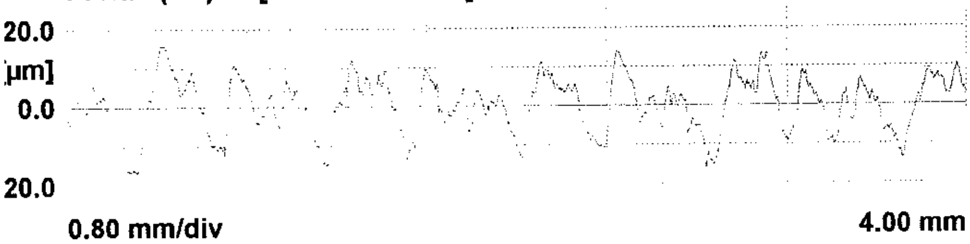
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	4.76	µm
Rmax	33.14	µm
Rz	29.34	µm
Pt	58.08	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



	3	
Ra	5.66	µm
Rmax	32.74	µm
Rz	27.72	µm
Pt	51.03	µm

versiti Technology Petronas chanical Engineering Lab. ıdar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron nber: Horizontal Band Saw	Remark: Test 2 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:32

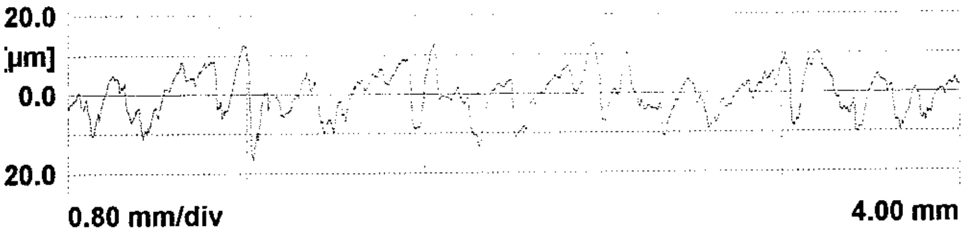
asurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

	1	
Ra	2.95	µm
Rmax	17.09	µm
Rz	15.02	µm
Pt	29.58	µm

asurement No. 2

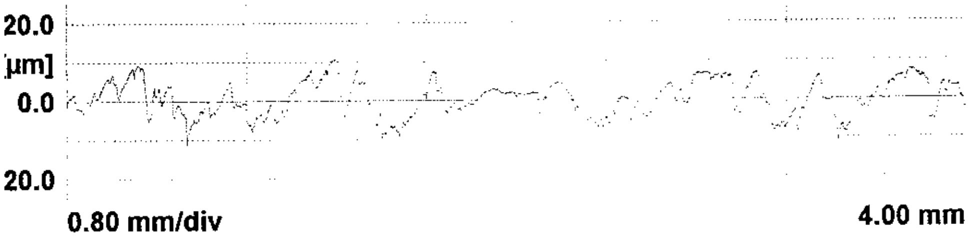
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	4.41	µm
Rmax	28.00	µm
Rz	24.06	µm
Pt	35.24	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

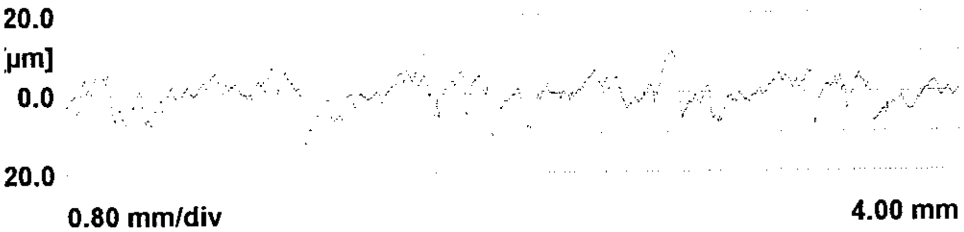


	3	
Ra	3.62	µm
Rmax	20.66	µm
Rz	17.82	µm
Pt	34.77	µm

versiti Technology Petronas chanical Engineering Lab. ıdar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron nber: Horizontal Band Saw	Remark: Test 3 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:38

asurement No. 1

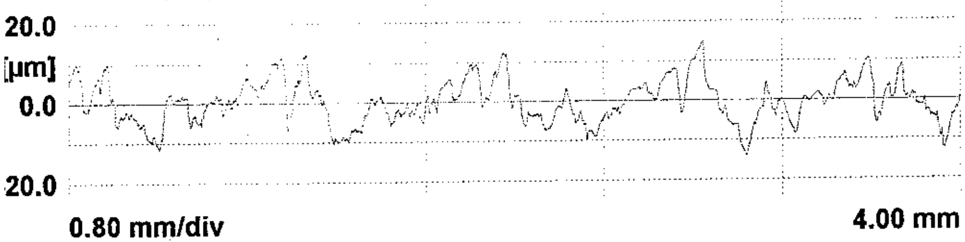
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	2.87	µm
Rmax	19.30	µm
Rz	16.94	µm
Pt	28.66	µm

asurement No. 2

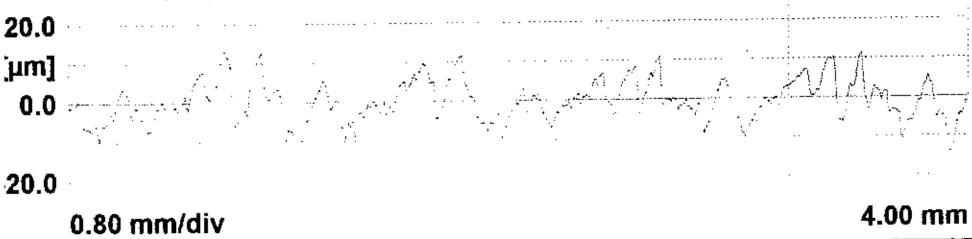
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	4.33	µm
Rmax	29.09	µm
Rz	23.72	µm
Pt	38.88	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



	3	
Ra	4.09	µm
Rmax	25.65	µm
Rz	22.73	µm
Pt	40.03	µm

iversiti Technology Petronas chanical Engineering Lab. ıdar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron nber: Horizontal Band Saw	Remark: Test 4 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 12:04

·asurement No. 1

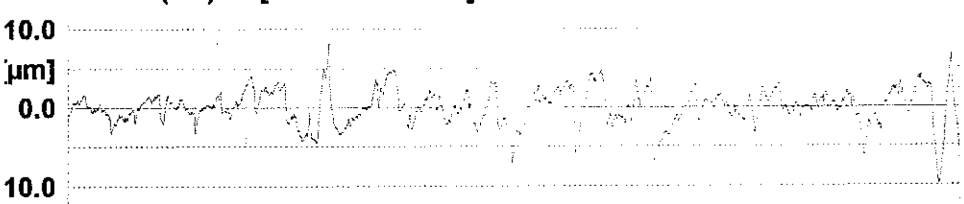
Profile (1/3): R [LC GS 0.80 mm]

0.80 mm/div **4.00 mm**

	1	
Ra	1.63	µm
Rmax	12.71	µm
Rz	10.47	µm
Pt	22.57	µm

asurement No. 2

Profile (2/3): R [LC GS 0.80 mm]

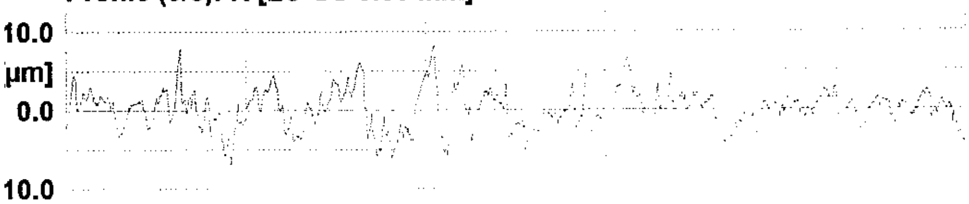


0.80 mm/div **4.00 mm**

	2	
Ra	1.72	µm
Rmax	16.62	µm
Rz	11.69	µm
Pt	20.59	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



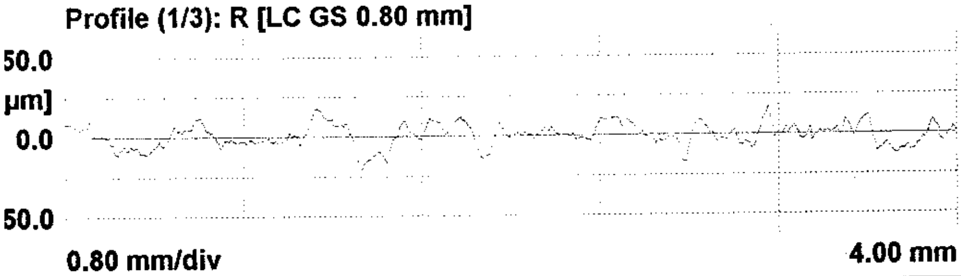
0.80 mm/div **4.00 mm**

	3	
Ra	1.92	µm
Rmax	14.91	µm
Rz	12.25	µm
Pt	46.07	µm

versiti Technology Petronas chanical Engineering Lab. ıdar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ect: Grey Cast Iron nber: Hand Saw	Remark: Test 1 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:47

asurement No. 1

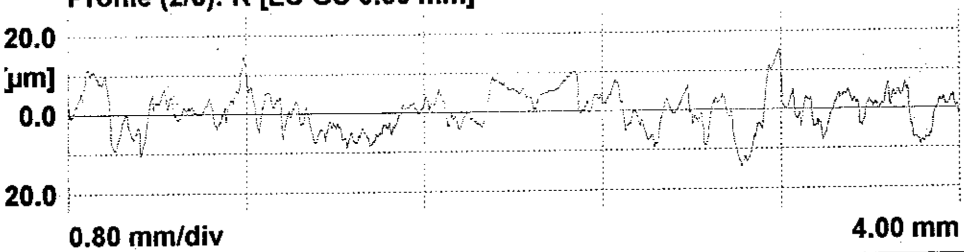
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	5.43	µm
Rmax	39.24	µm
Rz	29.77	µm
Pt	202.26	µm

asurement No. 2

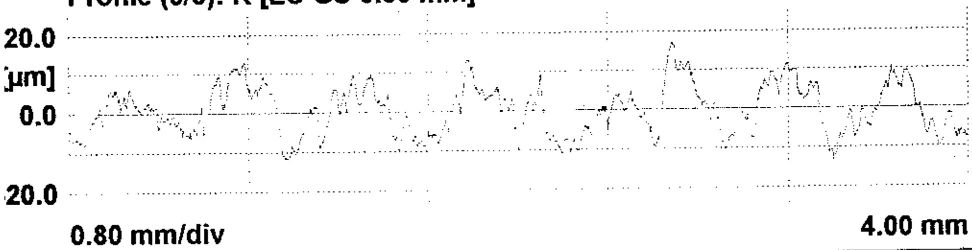
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	4.05	µm
Rmax	30.13	µm
Rz	22.00	µm
Pt	231.63	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

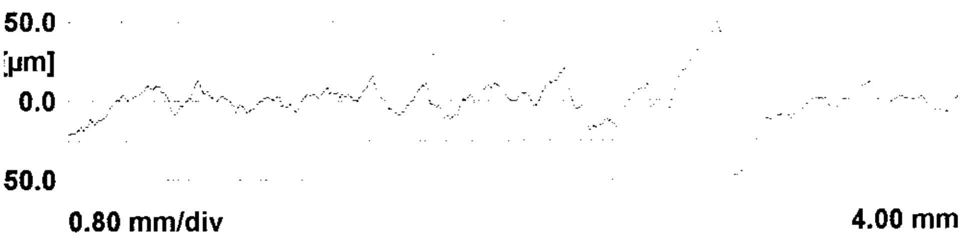


	3	
Ra	5.15	µm
Rmax	27.64	µm
Rz	23.78	µm
Pt	68.00	µm

iversiti Technology Petronas chanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Hand Saw	Remark: Test 2 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:51

asurement No. 1

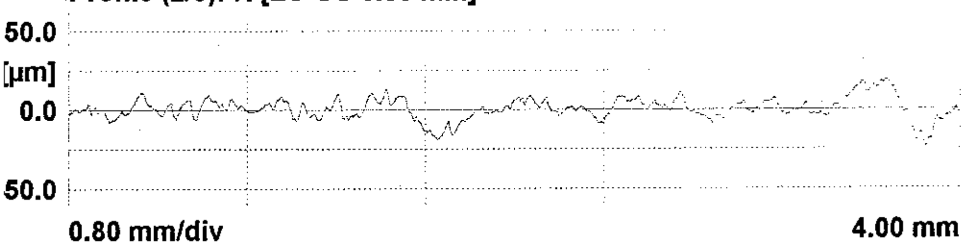
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	8.38	µm
Rmax	97.34	µm
Rz	43.99	µm
Pt	202.00	µm

asurement No. 2

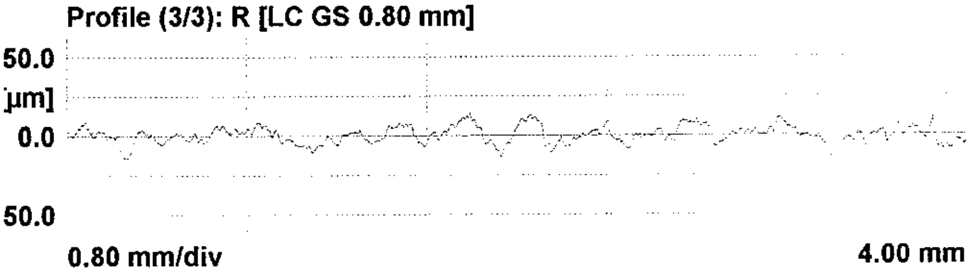
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	5.09	µm
Rmax	43.02	µm
Rz	27.39	µm
Pt	124.90	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



	3	
Ra	4.19	µm
Rmax	31.96	µm
Rz	24.33	µm
Pt	123.86	µm

iversiti Technology Petronas chanical Engineering Lab. ndar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Lathe Conventional	Remark: RPM 835 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 10:50

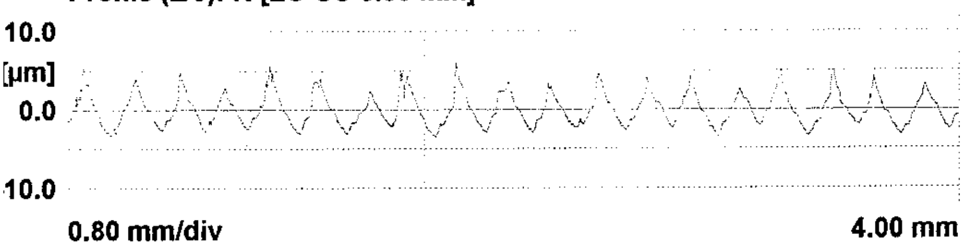
asurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

	1	
Ra	1.60	µm
Rmax	9.71	µm
Rz	8.74	µm
Pt	12.57	µm

asurement No. 2

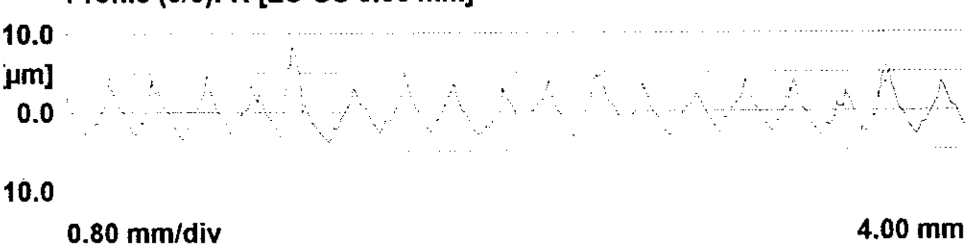
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	1.66	µm
Rmax	9.77	µm
Rz	8.90	µm
Pt	13.07	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

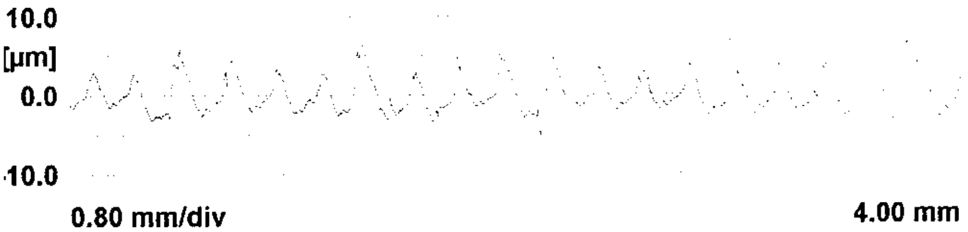


	3	
Ra	1.70	µm
Rmax	12.28	µm
Rz	8.91	µm
Pt	14.21	µm

iversiti Technology Petronas chanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Lathe Conventional	Remark: RPM 535 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 10:55

easurement No. 1

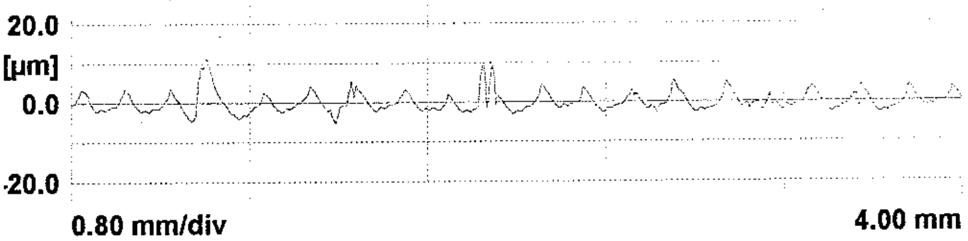
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	1.81	µm
Rmax	10.03	µm
Rz	9.63	µm
Pt	19.56	µm

easurement No. 2

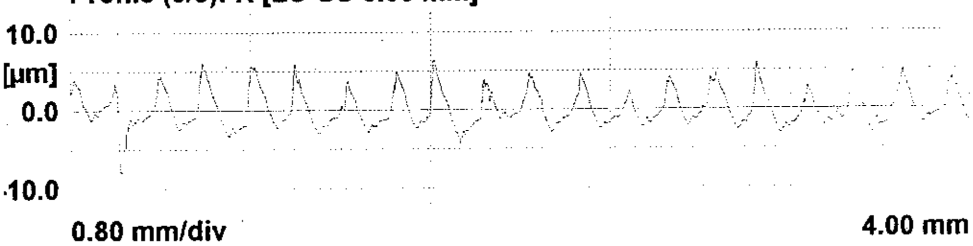
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	1.81	µm
Rmax	15.82	µm
Rz	11.01	µm
Pt	21.81	µm

easurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

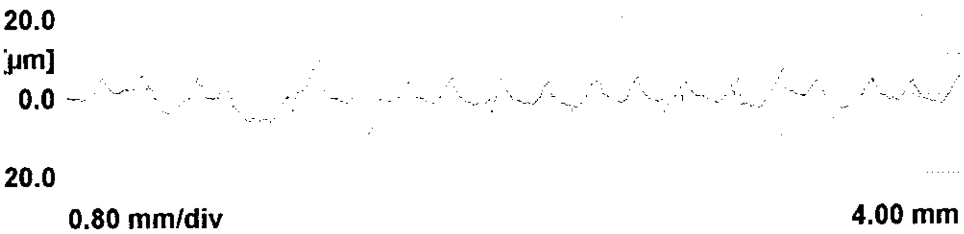


	3	
Ra	1.84	µm
Rmax	14.09	µm
Rz	10.24	µm
Pt	17.96	µm

iversiti Technology Petronas chanical Engineering Lab. ndar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Lathe Conventional	Remark: RPM 355 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 10:59

asurement No. 1

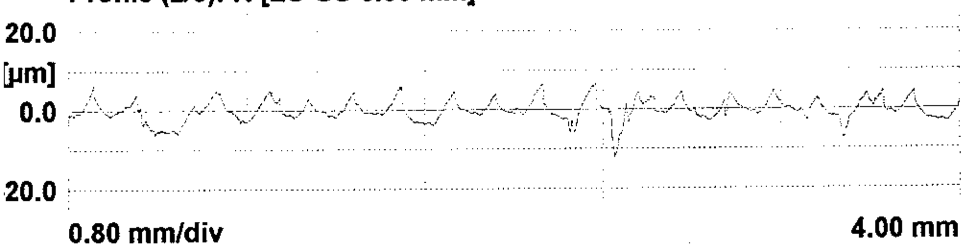
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	2.00	µm
Rmax	19.93	µm
Rz	13.08	µm
Pt	42.06	µm

asurement No. 2

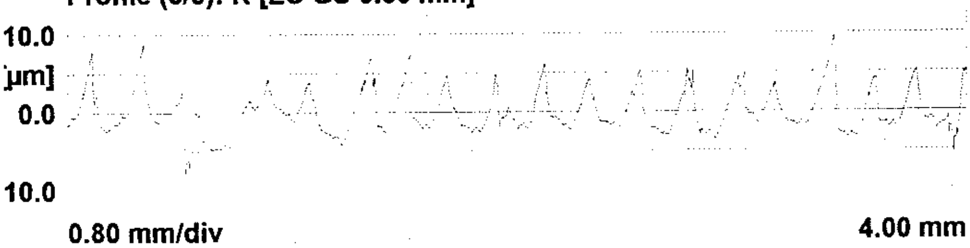
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	1.97	µm
Rmax	17.04	µm
Rz	12.81	µm
Pt	42.17	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

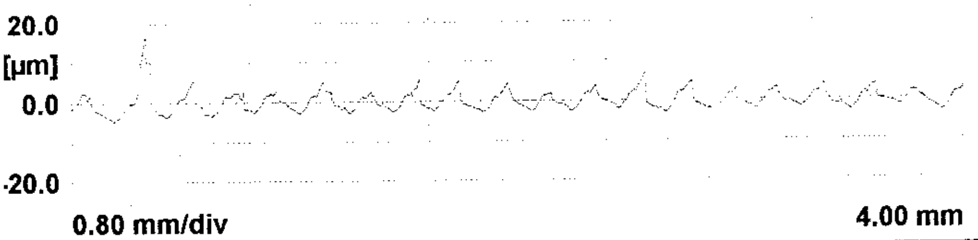


	3	
Ra	2.13	µm
Rmax	16.55	µm
Rz	12.21	µm
Pt	41.17	µm

iversiti Technology Petronas chanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Lathe Conventional	Remark: RPM 1320 Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:02

:asurement No. 1

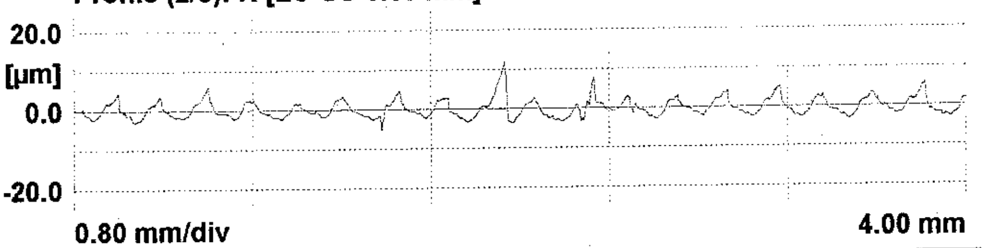
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	1.84	µm
Rmax	21.17	µm
Rz	10.93	µm
Pt	23.38	µm

:asurement No. 2

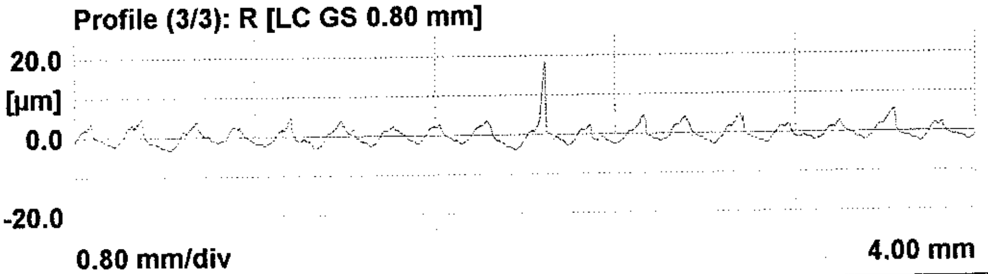
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	1.68	µm
Rmax	15.34	µm
Rz	10.29	µm
Pt	19.31	µm

:asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



	3	
Ra	1.65	µm
Rmax	22.06	µm
Rz	10.78	µm
Pt	23.00	µm

iversiti Technology Petronas chanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Mill Conventional	Remark: RPM 500 D.O.C. 1 mm Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:13

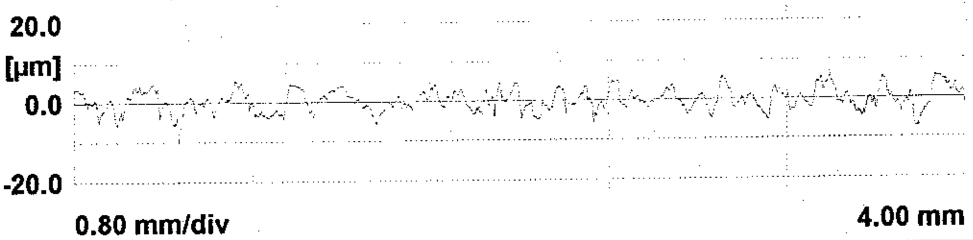
easurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

	1	
Ra	2.19	µm
Rmax	18.66	µm
Rz	12.75	µm
Pt	20.71	µm

easurement No. 2

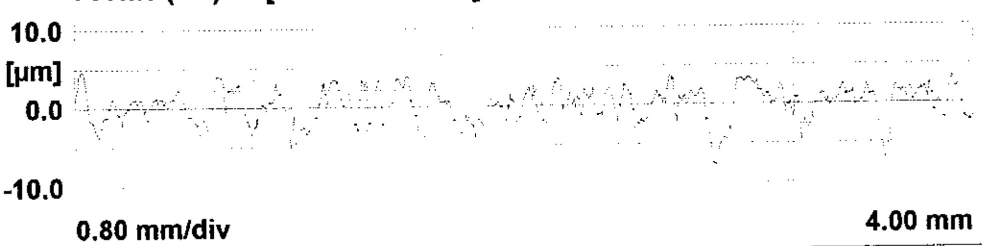
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	2.14	µm
Rmax	15.79	µm
Rz	12.46	µm
Pt	18.98	µm

easurement No. 3

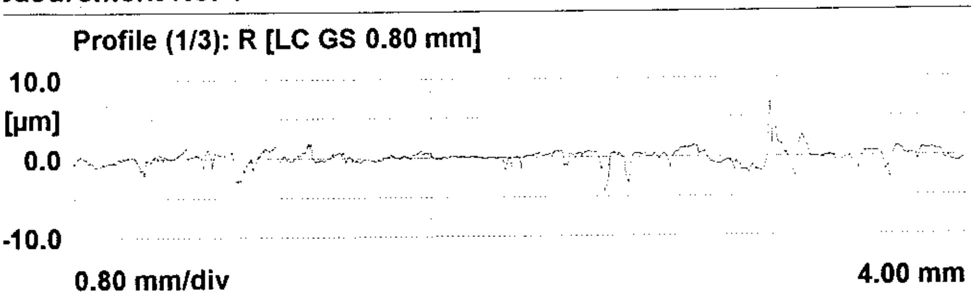
Profile (3/3): R [LC GS 0.80 mm]



	3	
Ra	1.74	µm
Rmax	11.52	µm
Rz	9.48	µm
Pt	15.56	µm

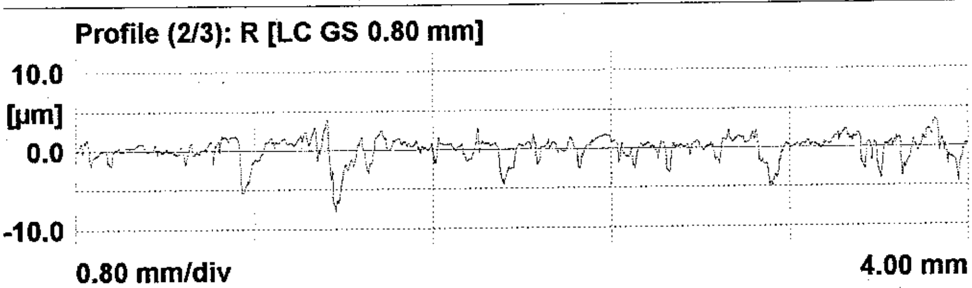
iversiti Technology Petronas chanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Mill Conventional	Remark: RPM 2000 D.O.C. 1 mm Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:16

easurement No. 1



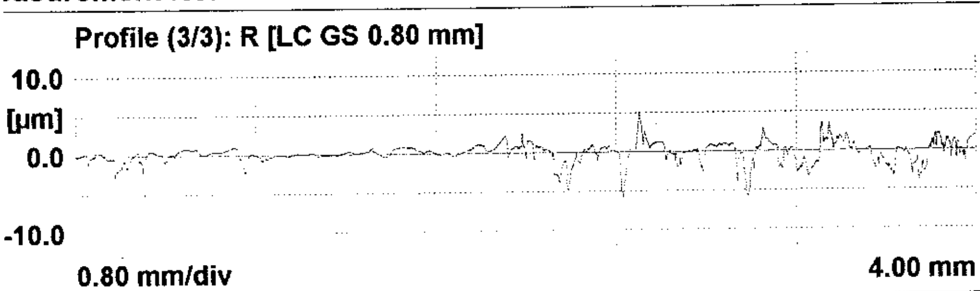
	1	
Ra	0.64	µm
Rmax	10.44	µm
Rz	5.81	µm
Pt	12.64	µm

easurement No. 2



	2	
Ra	1.11	µm
Rmax	11.78	µm
Rz	8.32	µm
Pt	15.36	µm

easurement No. 3

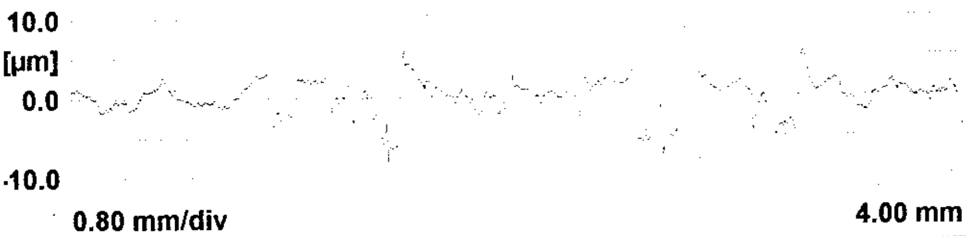


	3	
Ra	0.82	µm
Rmax	10.86	µm
Rz	6.26	µm
Pt	25.64	µm

iversiti Technology Petronas chanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Mill Conventional	Remark: RPM 2000 D.O.C. 0.1 mm Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 21.04.2004, 11:20

easurement No. 1

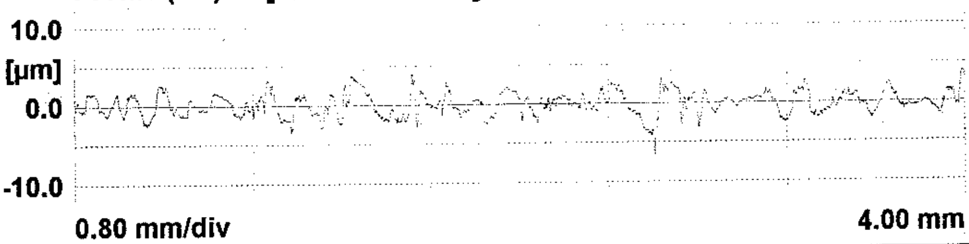
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	1.72	µm
Rmax	16.50	µm
Rz	10.17	µm
Pt	19.04	µm

easurement No. 2

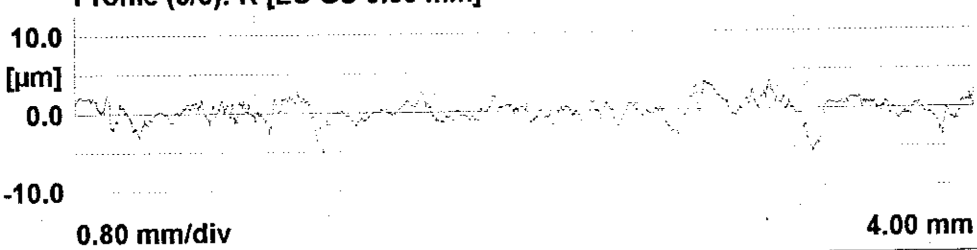
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	1.13	µm
Rmax	9.83	µm
Rz	6.88	µm
Pt	11.30	µm

easurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

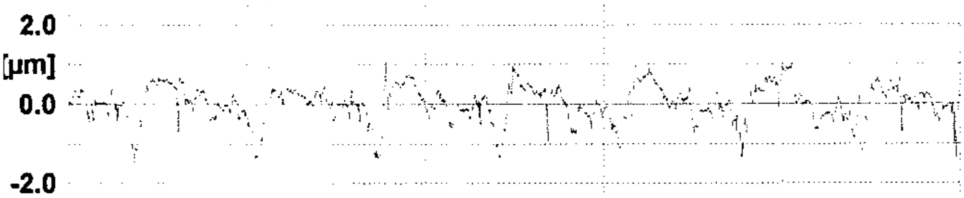


	3	
Ra	1.02	µm
Rmax	7.88	µm
Rz	6.42	µm
Pt	14.05	µm

iversiti Technology Petronas ıchanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Test No 2	Remark: Milling (Roughing) Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 26.02.2004, 12:37

ıasurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

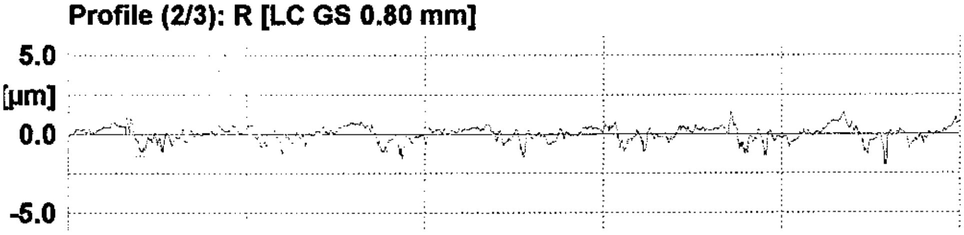


0.80 mm/div **4.00 mm**

	1	
Ra	0.35	µm
Rmax	2.56	µm
Rz	2.39	µm
Pt	3.82	µm

ıasurement No. 2

Profile (2/3): R [LC GS 0.80 mm]

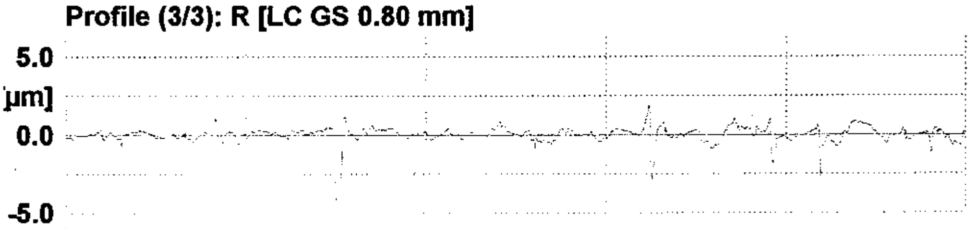


0.80 mm/div **4.00 mm**

	2	
Ra	0.36	µm
Rmax	3.42	µm
Rz	2.55	µm
Pt	4.75	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



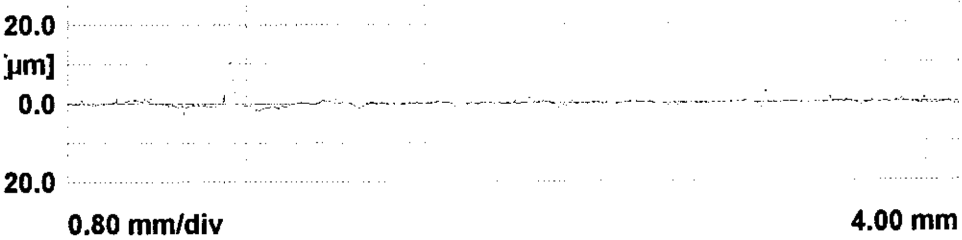
0.80 mm/div **4.00 mm**

	3	
Ra	0.32	µm
Rmax	5.37	µm
Rz	3.44	µm
Pt	6.78	µm

iversiti Technology Petronas chanical Engineering Lab. ıdar Sri Iskandar '50 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: Test No 2	Remark: Milling (Finishing) Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 26.02.2004, 13:07

asurement No. 1

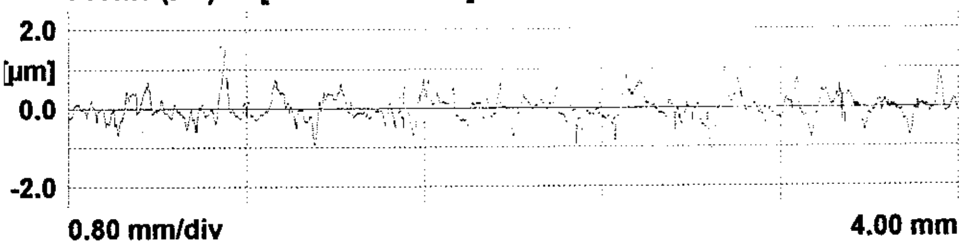
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	0.49	µm
Rmax	13.48	µm
Rz	5.49	µm
Pt	13.97	µm

asurement No. 2

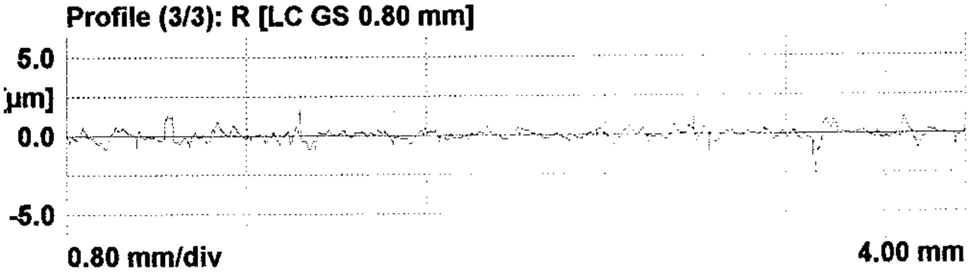
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	0.23	µm
Rmax	2.59	µm
Rz	2.02	µm
Pt	2.89	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

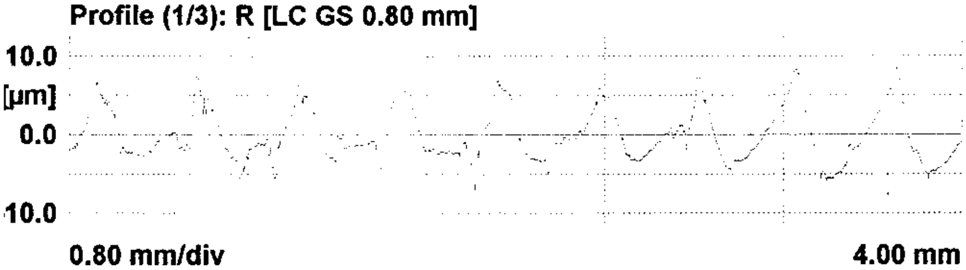


	3	
Ra	0.25	µm
Rmax	4.00	µm
Rz	2.51	µm
Pt	4.67	µm

iversiti Technology Petronas ichanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: GREY CAST IRON mber: test no 2	Remark: Lathe Operation, Roughing Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 25.02.2004, 17:01

ıasurement No. 1

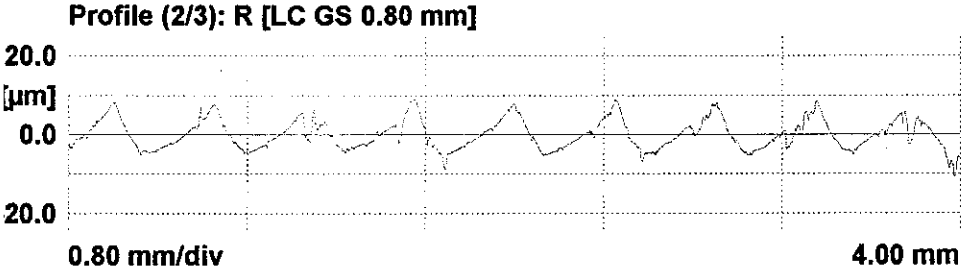
Profile (1/3): R [LC GS 0.80 mm]



1		
Ra	2.73	µm
Rmax	14.35	µm
Rz	13.10	µm
Pt	34.71	µm

ıasurement No. 2

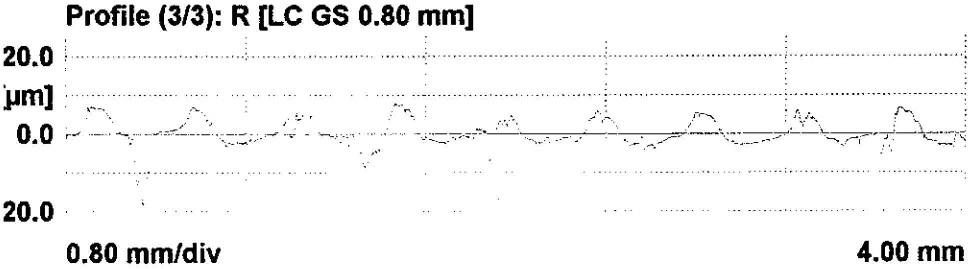
Profile (2/3): R [LC GS 0.80 mm]



2		
Ra	3.09	µm
Rmax	19.35	µm
Rz	15.85	µm
Pt	23.28	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



3		
Ra	2.60	µm
Rmax	25.56	µm
Rz	15.36	µm
Pt	28.57	µm

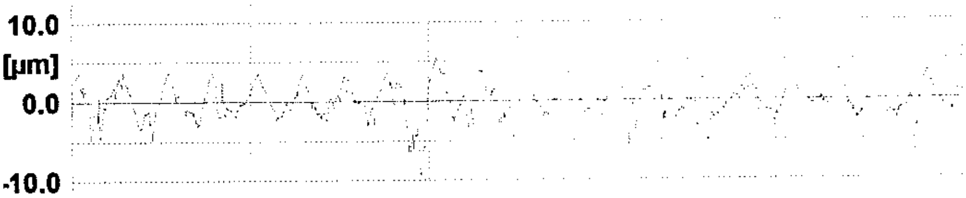
iversiti Technology Petronas
ːchanical Engineering Lab.
ndar Sri Iskandar
750 Tronoh,Perak.

Perthometer Concept

ject: GREY CAST IRON	Remark: Lathe Operation, Finishing	Inspector:	Meor
mber: test no 1	Pick-up: MFW-250 #2799 23,S-CAL	Date, time:	25.02.2004, 16:53

ːasurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

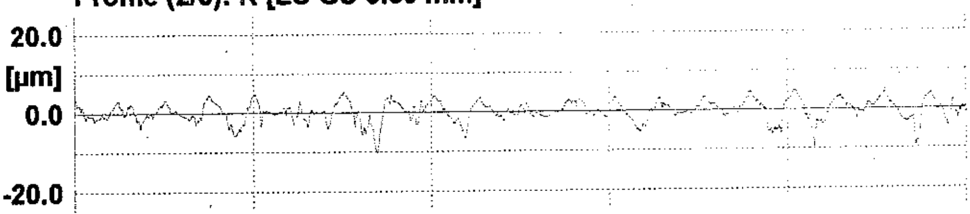


0.80 mm/div **4.00 mm**

	1	
Ra	1.70	µm
Rmax	13.06	µm
Rz	10.83	µm
Pt	22.40	µm

ːasurement No. 2

Profile (2/3): R [LC GS 0.80 mm]

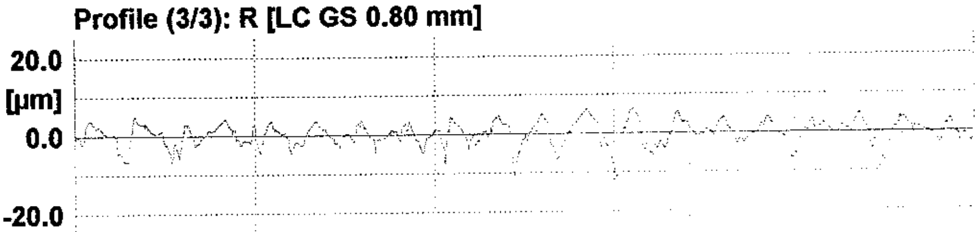


0.80 mm/div **4.00 mm**

	2	
Ra	1.91	µm
Rmax	15.58	µm
Rz	12.47	µm
Pt	19.18	µm

ːasurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



0.80 mm/div **4.00 mm**

	3	
Ra	2.25	µm
Rmax	17.70	µm
Rz	14.00	µm
Pt	18.50	µm

iversiti Technology Petronas :chanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: WireCut 3rd Sample	Remark: Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 31.03.2004, 11:38

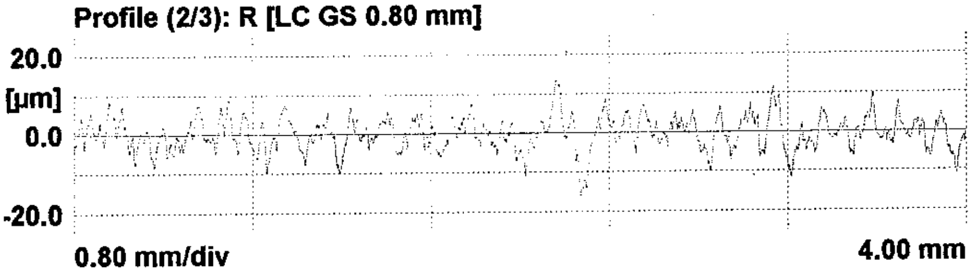
easurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

	1	
Ra	3.82	µm
Rmax	25.58	µm
Rz	22.06	µm
Pt	30.63	µm

easurement No. 2

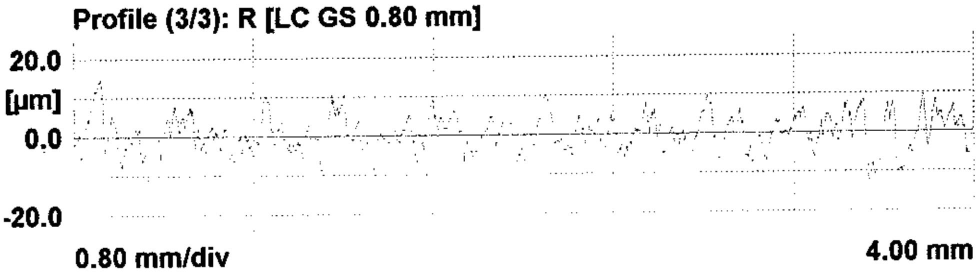
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	3.28	µm
Rmax	29.62	µm
Rz	21.48	µm
Pt	42.07	µm

easurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

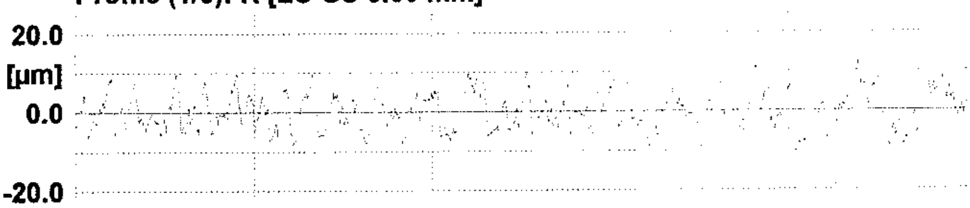


	3	
Ra	3.59	µm
Rmax	25.86	µm
Rz	20.71	µm
Pt	29.21	µm

iversiti Technology Petronas echanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron umber: WireCut 4th Sample	Remark: Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 31.03.2004, 11:41

easurement No. 1

Profile (1/3): R [LC GS 0.80 mm]

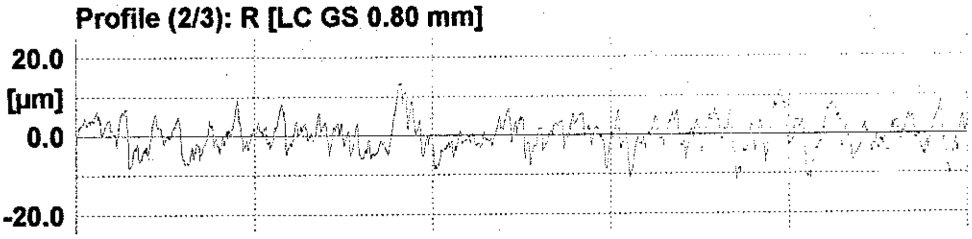


0.80 mm/div **4.00 mm**

	1	
Ra	3.67	µm
Rmax	24.13	µm
Rz	19.50	µm
Pt	31.19	µm

easurement No. 2

Profile (2/3): R [LC GS 0.80 mm]

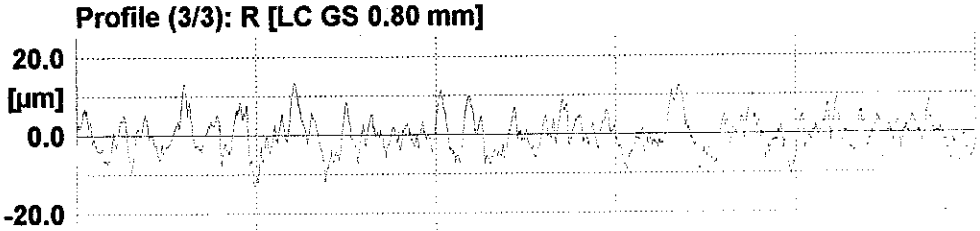


0.80 mm/div **4.00 mm**

	2	
Ra	3.16	µm
Rmax	23.09	µm
Rz	19.14	µm
Pt	26.92	µm

easurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



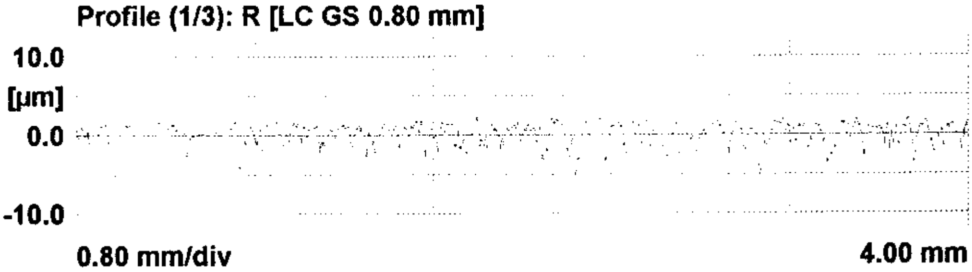
0.80 mm/div **4.00 mm**

	3	
Ra	3.56	µm
Rmax	26.30	µm
Rz	22.27	µm
Pt	32.29	µm

iiversiti Technology Petronas echanical Engineering Lab. ındar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ɔject: Grey Cast Iron ımber: EDM Die Sinker 1	Remark: EDM Die Sinker 1st Sample Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 07.04.2004, 12:05

easurement No. 1

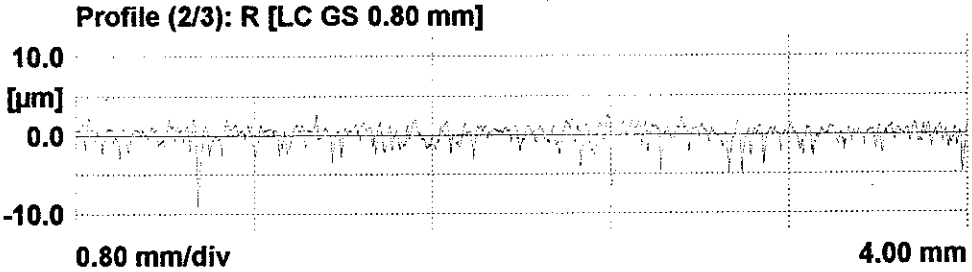
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	1.06	µm
Rmax	7.49	µm
Rz	7.02	µm
Pt	11.05	µm

easurement No. 2

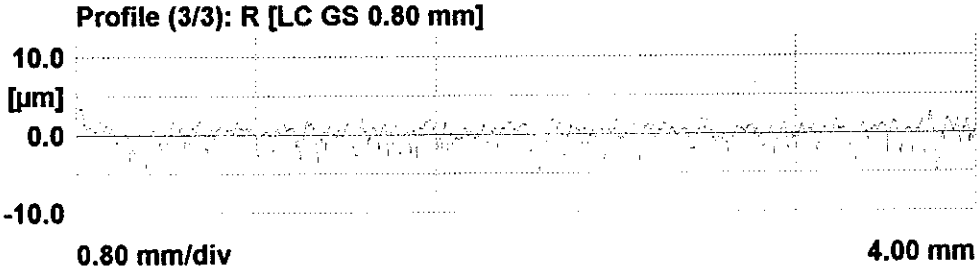
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	0.93	µm
Rmax	11.63	µm
Rz	7.94	µm
Pt	16.11	µm

easurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

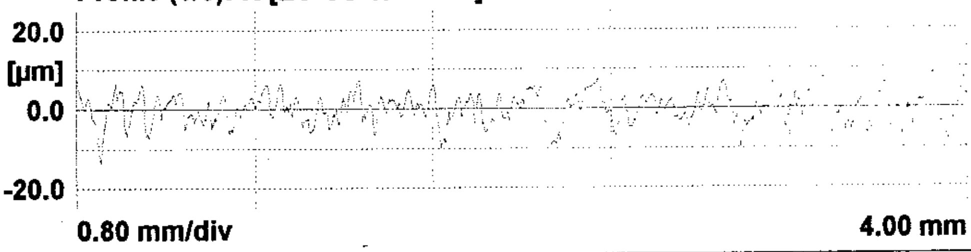


	3	
Ra	0.93	µm
Rmax	7.79	µm
Rz	6.64	µm
Pt	9.23	µm

iiversiti Technology Petronas echanical Engineering Lab. ındar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ɔject: Grey Cast Iron ımber: EDM 2	Remark: EDM Die Sinker 2nd Sample Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 07.04.2004, 12:21

ɘasurement No. 1

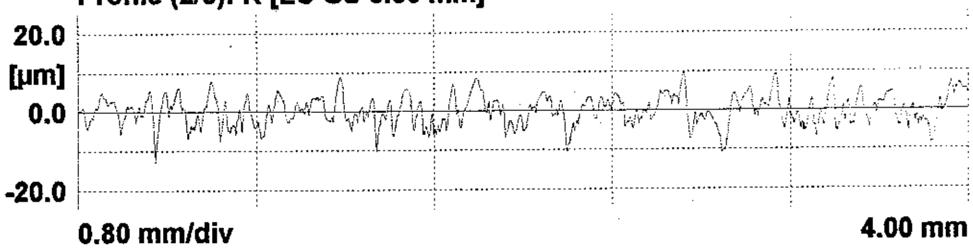
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	2.93	µm
Rmax	21.26	µm
Rz	17.33	µm
Pt	24.76	µm

ɘasurement No. 2

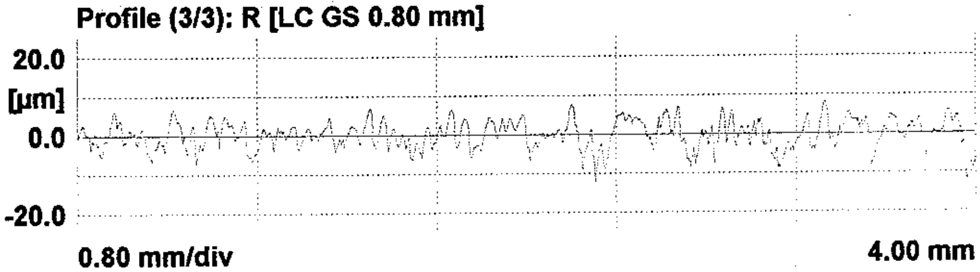
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	3.00	µm
Rmax	20.58	µm
Rz	19.29	µm
Pt	23.92	µm

ɘasurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



	3	
Ra	2.80	µm
Rmax	20.04	µm
Rz	16.63	µm
Pt	25.29	µm

iiversiti Technology Petronas echanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
)ject: Grey Cast Iron ımber: EDM 3	Remark: EDM Die Sinker 3rd Sample Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 07.04.2004, 12:26

easurement No. 1

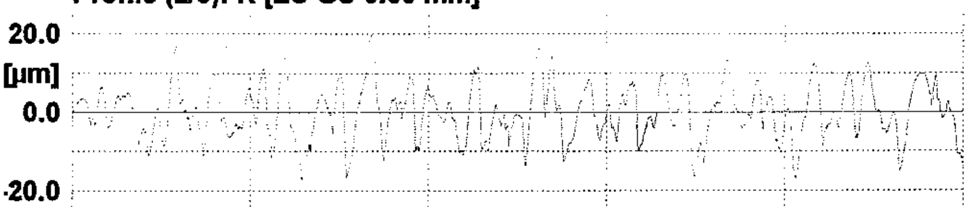
Profile (1/3): R [LC GS 0.80 mm]

0.80 mm/div **4.00 mm**

	1	
Ra	5.92	µm
Rmax	38.30	µm
Rz	34.35	µm
Pt	47.65	µm

easurement No. 2

Profile (2/3): R [LC GS 0.80 mm]

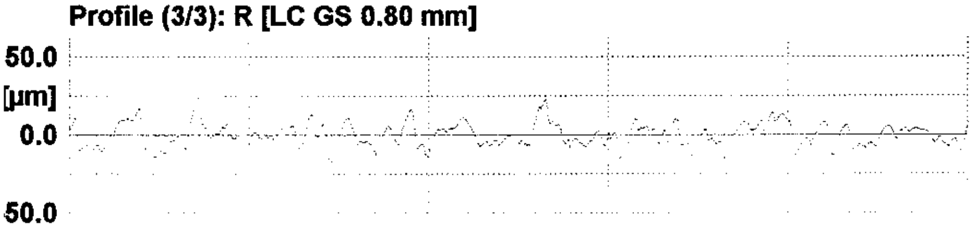


0.80 mm/div **4.00 mm**

	2	
Ra	5.47	µm
Rmax	36.85	µm
Rz	31.00	µm
Pt	43.34	µm

asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



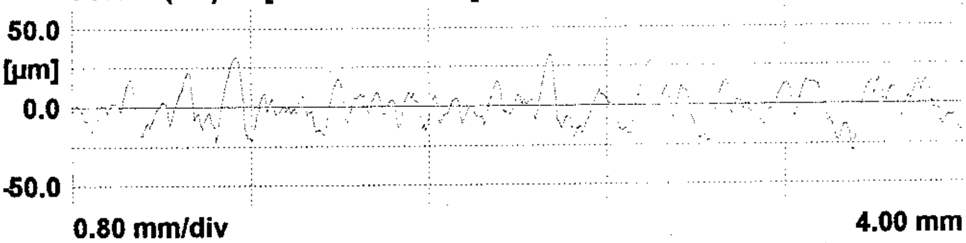
0.80 mm/div **4.00 mm**

	3	
Ra	5.88	µm
Rmax	37.86	µm
Rz	32.24	µm
Pt	47.14	µm

iversiti Technology Petronas :chanical Engineering Lab. ndar Sri Iskandar 750 Tronoh,Perak.	**Perthometer Concept**	
ject: Grey Cast Iron mber: EDM Die Sinker 4	Remark: EDM Die Sinker 4th Sample Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 07.04.2004, 12:32

:asurement No. 1

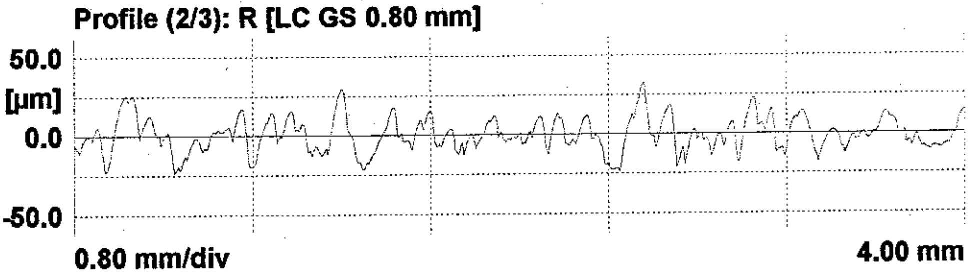
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	8.70	µm
Rmax	54.47	µm
Rz	48.61	µm
Pt	68.44	µm

:asurement No. 2

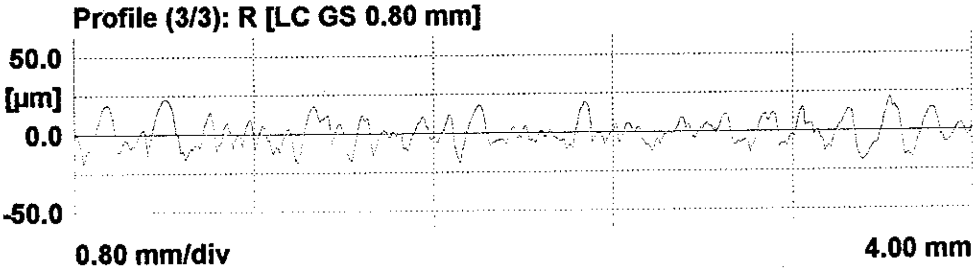
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	8.21	µm
Rmax	56.72	µm
Rz	44.61	µm
Pt	66.33	µm

:asurement No. 3

Profile (3/3): R [LC GS 0.80 mm]

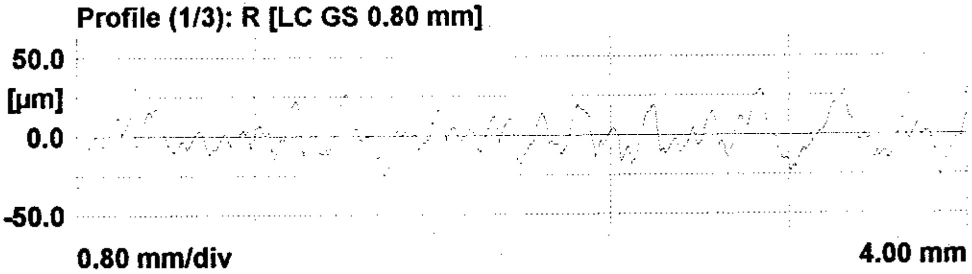


	3	
Ra	6.97	µm
Rmax	41.72	µm
Rz	36.39	µm
Pt	59.63	µm

niversiti Technology Petronas echanical Engineering Lab. andar Sri Iskandar 1750 Tronoh,Perak.	**Perthometer Concept**	
bject: Grey Cast Iron umber: EDM Die Sinker 5	Remark: EDM Die Sinker 5th Sample Pick-up: MFW-250 #2799 23,S-CAL	Inspector: Meor Date, time: 07.04.2004, 12:36

easurement No. 1

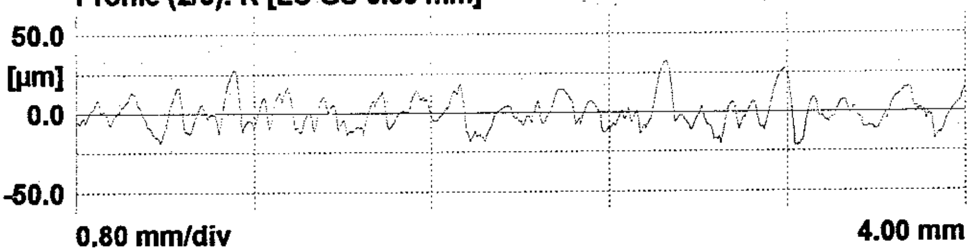
Profile (1/3): R [LC GS 0.80 mm]



	1	
Ra	8.26	µm
Rmax	55.60	µm
Rz	48.41	µm
Pt	87.15	µm

easurement No. 2

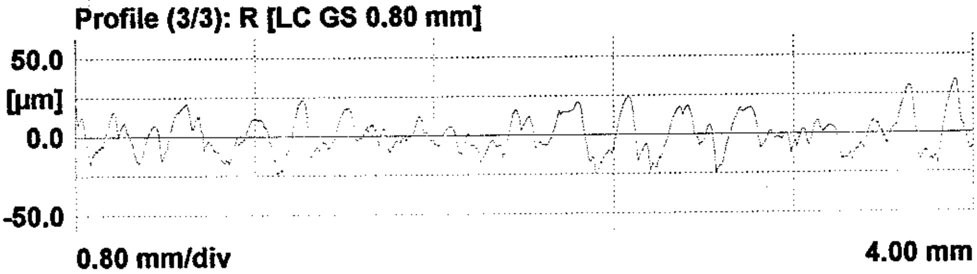
Profile (2/3): R [LC GS 0.80 mm]



	2	
Ra	7.68	µm
Rmax	52.42	µm
Rz	42.28	µm
Pt	67.04	µm

easurement No. 3

Profile (3/3): R [LC GS 0.80 mm]



	3	
Ra	9.40	µm
Rmax	53.20	µm
Rz	46.67	µm
Pt	66.65	µm