# The Effect of Using Coolant during Bone Drilling for Surgery Application

by

Goh Ting Sheng

16472

Dissertation submitted in partial fulfilment of

the requirement for the

BACHELOR OF ENGINEERING (Hons)

MECHANICAL ENGINEERING

Jan 2016

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# CERTIFICATION OF APPROVAL

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Approved by,

________________________

Dr Turnad Lenggo Ginta

UNIVERSITI TEKNOLOGI PETRONAS
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Jan 2016

# 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.

______________________________________________

GOH TING SHENG

# Abstract

This final year project focus on the effect of using coolant during bone drilling for surgery application. The study includes the understanding on basic knowledge of bone drilling, method of applying coolant during bone drilling and the methodology in conducting bone drilling experiment. The comprehensive result and discussion concludes parameters that are practicable and acceptable for bone drilling applications. This study is concerned with the effect of applying coolant on the measurement of surface roughness and surface integrity of holes drilled in a cow femur bone. The difference of dry drilling and with coolant on the drilled surfaces was compared in this paper as well. Therefore, the irrigation technique during bone drilling plays an important role for regeneration of bone tissue and fast recovery for fracture bone.

# ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere and upmost appreciation to my supervisor, Dr Turnad Lenggo Ginta, for the patient guidance, encouragement and advice he has provided throughout my time as his Final Year Project (FYP) student. I have been extremely lucky to have a supervisor who continually and convincingly conveyed a spirit of adventure in regards to research and excitement in regards to teaching. A million thanks also to lab technicians, Mr Shaiful Hisham B Samsudin, Mr Zamil Khairuddin, Mr Hafiz Safian, Mr Paris M Said, Nurul Husna Binti Md Muhayadin and Mr Annuar who always provide accessibility for me to carry out my lab work and guide me to collect the sample that I need. I am indebted to them for their help. Lastly, I must express my gratitude to my parents, family members and friends, for their constant love and companionship, through times for hardship and happiness. Their persistence and encouragement, helped through the ups and downs of my final year. For this, I am deeply and truly thankful

**TABLE OF CONTENTS**

## List of figures

## List of tables

# CHAPTER 1

# Introduction

## 1.1 Background of Study

The skeleton system or bone structure of vertebrates is formed by supportive connective tissue that is rich in calcium. Bone fracture caused by an accident, aging or diseases has existed in humans' daily activities. When bone is broken, periosteum, the outer surface of the bone and endosteum, the inner surface of the bone are forming cells and blood vessel which help in bridging the fracture. Bone fracture therapy helps to reallocate the fractured parts to the initial position and immobilizing them during the healing process. Usually, the method to fix the fractured parts for immobilization is accomplished by drilling of bone. The fracture parts can be fixed together by using screws, metal plates and wires.

Bone drilling is most widely used in various fields of surgery operations including orthopedics, neurosurgery, maxillofacial, plastic reconstructive and dentistry. Drilling is associated with the conversion of mechanical work energy into thermal energy. The primary sources of thermal energy are most probably by shear failure and plastic deformation of bone. Furthermore, there are several factors that lead to this temperature rise, including feed-rate ($\mathrm{mm.s^{-1}}$), drill geometry and diameter, rotational speed (rpm), initial drill-bit temperature, axial thrust force (N) and external or internal cooling.

A drastic rise in temperature of soft tissue and adjacent bone above ordinary physiological levels or generation of excessive heat during bone drilling may result in death of the bone tissue called thermal necrosis [1]. Break down of bone due to necrosis around the implantation site may weaken the purchase of surgically placed screws and pins, causing them to loosen post operatively [2]. Besides that, the morphology of the surface of drilled hole affects the bone-screw interface strength as well as the cellular response which is important for healthy bone growth [3]. Therefore, implementation of internal fixation for bone fracture to recover in a short period is beneficial when thermal osteonecrosis no longer exists. Hence, research and study in bone drilling are very important in reducing the chance of thermal osteonecrosis, improving the surface roughness and surface integrity of drilled bone.

## 1.2 Problem Statement

A by-product of the drilling process is the generation of heat energy, which causes a transient increase in temperature of bone tissues and drill-bit itself. The heat is dissipated slowly because of the low thermal conductivity of bone. Many researchers [4, 5, 6, 7, 8] have documented that the most significant method to decreases the temperature induced during bone drilling can be done by coolant irrigation. The temperature limit of undamaged tissue during bone drilling is 44-47℃ for 1 minute of time [1]. Furthermore, the influence of implant surface roughness is an important factor for the success of surgery operation. Internal fixation screws require a stable bone-implant interface for transmission of forces [9]. On the other hand, strong integration between the bone and screw is a disadvantages during the process of screws removal. Hence, it is believed that with the use of coolant during bone drilling can achieve low temperature, better surface roughness and surface integrity for fractured bone to recover.

## 1.3 Objectives

The goal of this project:

1. To investigate the effect of using coolant during bone drilling on the surface integrity and surface roughness of bones.
2. To investigate the comparison between dry drilling and with coolant during bone drilling.

## 1.4 Scope of study

### 1.4.1 Choice of animal bone

Bones are rigid organs composed of an organic protein and inorganic mineral hydroxyapatite. The drilling tests will carry out on bovine femoral bone as it is the most closet animal bone to replicate the characteristic of human bone [10]. The bone can be obtained from a local butcher where it can be boned and stored frozen in order to keep their thermo-mechanical characteristic.

### 1.4.2 Type of coolant for bone drilling experiment

Coolant plays an important role in decreasing the induced temperature during bone drilling. In this experiment, the drilling test on bovine femoral bone will be carried out with the absence of coolant (dry drilling) and constant supply of coolant. External cooling system will be implemented during the drilling test by using cold water and saline solution. The idea of using coolant is to cool the drill hole and drill bit during the drilling test. Moreover, coolant can wash away the chips from bone and thermal effect can be reduced due to the heat convection by chip stream.

### 1.4.3 Surface roughness and surface integrity during bone drilling

The end result of bone drilling test will be focused on effect of using coolant towards bone surface roughness and surface integrity. It is believed that with the present of coolant, a better quality of surface roughness and surface integrity can be achieved compared to the dry drilling test of bone. The drilling parameter is set as constant for this bone drilling test where the feet rate is 1.5mm/s, spindle speed is 800rpm and a 4mm diameter drill bit will be used. Due to the time constraints, the temperature of bone will not be monitored during the drilling test.

## 1.5 Relevancy of study

With the evolution of modern surgery, this study is concerned on the improvement in medical engineering especially in orthopedics. One of the common procedure in operative fracture treatment is bone drilling. Elevated bone temperature that caused by frictional heat during drilling may result in thermal necrosis of bone. Thus, the coolant delivery in this study aim to reduce the heat generation during bone drilling which the resulted outcome is related to measurement and analysis of surface roughness and surface integrity of holes drilled in a cortical bone. It is believed that with the present of coolant will produce a better quality of drilled holes as compared to dry drilling. However, experimental testing was conducted to prove the feasibility of this application.

## 1.6 Feasibility of project

This final year project that issued by mechanical department is feasible to be done in 2 semesters. The duration of the project is eight months which start from September 2015 to May 2016. The project must be completed with the time frame including the gathering of information, purchasing of material, experimentation and result and discussion. The methodology is all based on the availability of the facilities in university. All efforts and precautions are taken to ensure that project can be completed.

# CHAPTER 2

# Literature Review

## 2.1 Introduction

Bone is a supportive connective tissue which rich in calcium material. The natural shapes of the bones enable them to be lightweight and strong while performing other roles involving growth. Bones can be classified into two types, cortical bone and cancellous bone. They represent the outer hard layer and inner spongy layer of a bone (Figure 1). Osteogenic connective tissue forms a hard layer that covered the outer surface of the bone [10]. Similar cell layer with osteogenic properties called endosteum lined at the inner surface of bone. Bone vascular system exists at both the periosteum and endosteum which supply oxygen and nutrients for bone growth and regeneration. The functions of bone can be categorized into physiological and mechanical. Physiologically, bone provides storage for calcium and minerals for the body and produces blood cells in the marrow. Mechanically, bone provides support and protection to the body and its organs. Ligaments and tendons are often attached to bones to acts as a lever system to provide movement and locomotion. Fresh bone can be categorized as poor conductor of heat as thermal conductivity is around 0.38±2.3 J/msK [11].

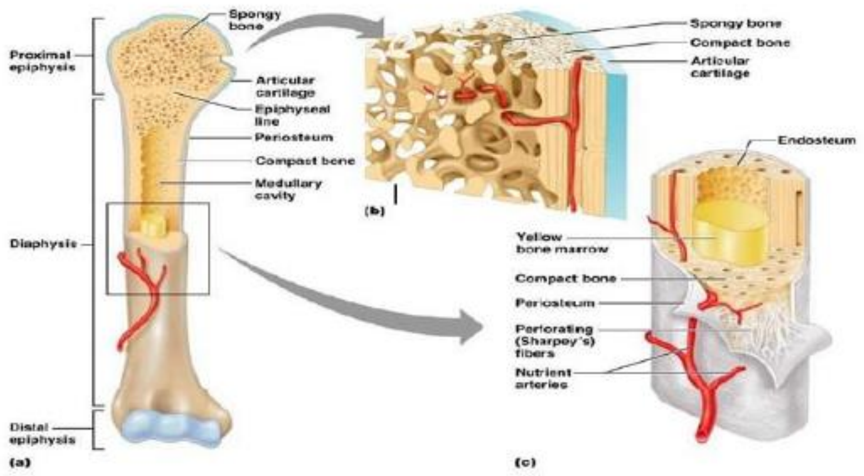



*Figure 2.1: (a) Human cortical bone, (b) Cancellous bone (Inner spongy bone structure), (c) Cortical bone: outer layer of bone structure.*

### 2.2 Bone Drilling

Fractured of bone is a serious matter faced by human from the beginning of human life on this plant. The common way in repairing and reconstructing of such fracture is by bone drilling and fixed the separate or fracture parts together using metal plates wires and screws. The strength of bond between the drilled hole and fixative components is important for healthy bone regeneration. This orthopedic drilling is very much similar to mechanical drilling process which results the reactive forces and increase temperature of surrounding bone material which can cause osteonecrosis in some cases of surgery [12]. Figure 2 shows applications of drilling in the surgery for femoral bone fracture [13].

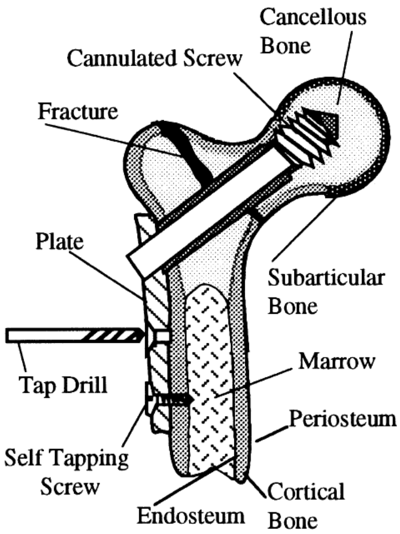



*Figure 2.2: Femoral fracture surgery with drilling at cancellous bone.*

### 2.3 Heat Generation during Drilling

Heat generation during drilling mainly arises from shear deformation from the shear zone. Secondly, friction between the cutting face of the drill bit and chip [14]. The heat generated during bone drilling may be partially carried away by the presence of tissues fluids, blood and chip formed. However, the temperature rise could be significantly high at the cutting edge of a deep cortical hole. The temperature developed in a section is related to the specific heat and thermal conductivity of bone tissue. Various researchers have calculated these parameters for bone (Table 1). Thermal gradient exists when a heat source is applied to a cooler specimen. A drastic increase of heat result in higher thermal gradient which mean the rate of heat transfer is greater.

*Table 2.1: The thermal physical properties of bone [11].*

| Animal species | Specific heat (cal/g °C) | | Thermal conductivity (cal/cm s °C) |
|---|---|---|---|
| | Fresh bone | Dry bone | |
| Man | 0.30 ± 0.01 | 0.30 ± 0.01 | 8.50 × 10 |
| | 0.30 | | 5.45 × 10 |
| Elephant | | 0.28 ± 0.02 | 10.0 × 10 |
| Ox | 0.27 ± 0.01 | 0.28 ± 0.01 | 11.7 × 10 |
| Dog | 0.30 ± 0.01 | 0.26 ± 0.01 | |

## 2.4 Osteonecrosis

The syndrome of reduction of blood flow in bone can be called as osteonecrosis. Osteocytes apoptosis is caused by the accumulation of small cracks in the mineralized matrix of bone. This is due to micro damage during the process of bone drilling [15]. Consequently, depletion of the osteocytes may lead to osteonecrosis, loss of blood supply and increased the risk of structurally weaker bone. Figure 3 shows the presence of empty osteocyte lacunae represent the histological distinctive characteristic of osteonecrosis. Necrotic bone adjacent to a pin tract is indicated by presence of healthy osteocytes are encircled and empty osteocyte lacunae are marked with dots. The line differentiates the border between the present and empty osteocytes [16].

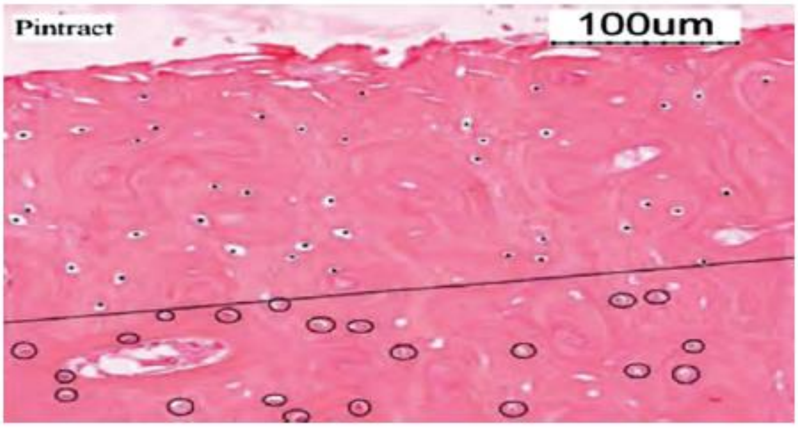



*Figure 2.3: The condition of osteocytes during bone drilling in histological image.*

Besides, Lundskog [10] states cellular necrosis will be induced if bone is exposed beyond 30s at 50℃. Mortiz and Henrique [16] found that epithelial cells will be damaged immediately when exposed to temperature that above 70℃. In the study by Bonfiled and Li, unchangeable condition of bone was discovered when temperature of dog femora reach 56℃ in vivo [17]. It can be concluded that the exposure time and magnitude of temperature elevation had caused thermal damage to bone tissue. Hence, it is important to keep the heat generated below the level during the bone drilling process to ensure proper bone recovery.

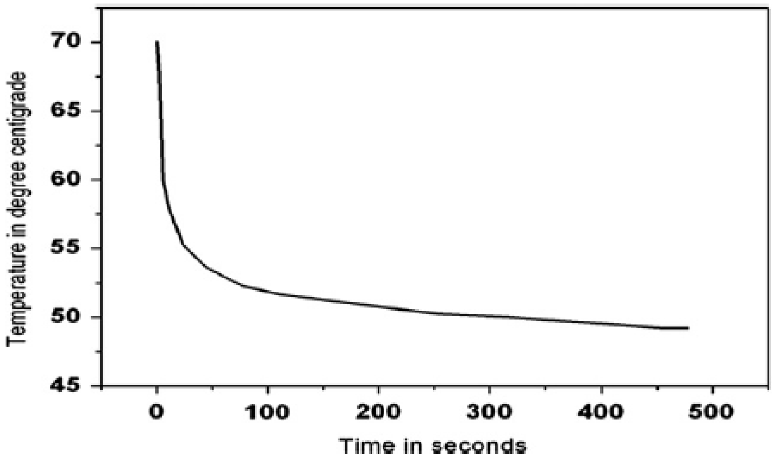



*Figure 2.4: The time- temperature graph indicates thermal necrosis of bone tissue [17].*

**2.5 Influence of coolant**

The use of coolant can minimize temperature elevations during bone drilling. Two methods of cooling system are often implemented for the irrigation of coolant during drilling. They can be categorized as internal cooling systems (closed type and open type) and external cooling system. Internal cooling is operated by supplying coolant through the tubules in the special design drill shaft and reach to the drill tip. On the other hand, external cooling can be carried out by supplying the coolant to the zone of drill tip and contact surface [12].

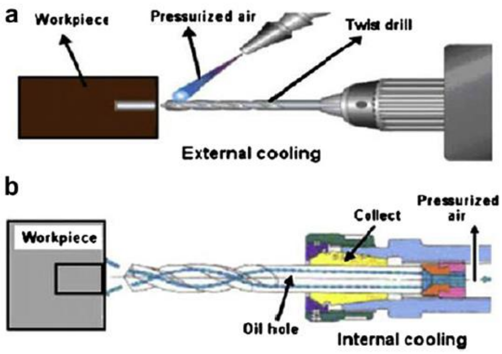



*Figure 2.5: a) External cooling and b) internal cooling approaches [24].*

For closed-type internal cooling system, there is no contact between coolant and the bone takes place. The cooling process is done completely by the mechanism of conduction of heat. Coolant flows through continues system of tubules at the drill shaft up to the tip of the drill bit and recycle back into heat exchanger. Meanwhile, open-type internal cooling system is designed to take away the heat by conduction. The coolant channel through the tubules in the drill shaft and flow out at the exit of the drill tip. Study by Kirschner and Meyer discovered that open-type of internal cooling in dental surgery combined the effect of cooling and rinsing on bone which result in lower temperature as compared to external cooling and without cooling [18]. Furthermore, in the vitro study by Lavelle and Wedgwood, internal irrigation at low rotational speed of 350rpm with force of 19N reduces the temperature more effectively as compared to external irrigation [5].

Coolant provides lubrication and irrigation in reducing heat generation that cause by friction during drilling. Short chips were being produced by bone in dry situation. In orthopedic operation, bone produced watery chip that get clogged easily. The elevation of temperature during drilling is due to the friction between cutting tool chips. Therefore, irrigation of coolant provides effective removal of chips and debris that avoid clogging of flutes during bone drilling. External cooling provides the chances in eliminating and preventing clogged of drill bit flutes. Matthews and Hirsch claimed that bone temperature can be obtained below the critical level with higher irrigation rate for external cooling. Water irrigation is being carried out during the drilling process. The water act as coolant at room temperature with different of flow rate from 300 to 1000ml/min. Irrigation rate of 500ml/min showed significant effect in lowering the bone temperature below 50℃ which is close to the marginal level of 47℃ [19].

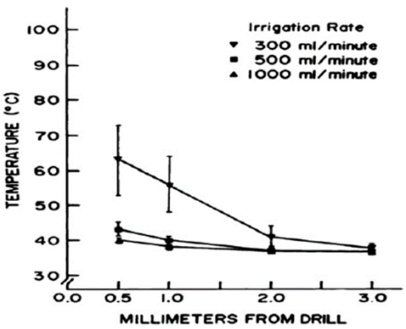



*Figure 2.6: Range of irrigation rate that recorded at drill zone [19].*

Haider compared the effects of internal and external cooling during the histographical studies on sheep [6]. The result showed that external irrigation is beneficial on the surface only. Internal irrigation showed the effectiveness as the depth increases. On the other hand, Benington found that the external and internal cooling obtain the similar thermal changes at implant zone [7]. Thus, external irrigation is beneficial compared to the expensive internal irrigation. In the experiments that conducted by Kalidindi, a significant rise in temperature is observed during the dry drilling and found that reduction of heat generation during drilling can be achieved by external cooling method [8]. Furthermore, in a vitro studies on bovine mandible by Sener, the outcome showed that high profile of heat generation is being discovered on the surface of drilling cavity as compared to the bottom surfaces. External irrigation by saline solution at 10℃ and 25℃ showed that lower coolant temperature had successfully reduced the elevation of temperature during bone drilling. Hence, external irrigation meets the cooling requirement during bone drilling [20]. Besides that, Al-Dabag and Sultan obtained similar outcome by using coolant at 25℃ and 5℃. In the recent studies by Augustin, he performed various drilling experiments on porcine femora and discovered that water coolant at 26℃ can reduce bone temperature during drilling [11]. Besides, Augustin also found that thermal osteonecrosis can be avoided with the implementation of internal type irrigation system as bone temperatures is below the critical level [5].

### 2.6 Surface roughness and surface integrity of bone

Surface roughness and surface integrity of bone is referred to the texture of a bone surface after the drilling test. Morphology of the drilled surface is important for the fixative components such as screws, pins and hooks on the influence strength of the bonds between them. Bone loss due to the thermal necrosis will result inappropriate fixation component as the bone tissues unable to produce appropriate complement of autocrine and paracrine. Internal fixation screws require a stable bone-implant interface for transmission of force [9]. Therefore, surface roughness of drilled holes plays an important role for adequate stimulation of osteogenesis. Appropriate surface ensures the bone tissues at the implant surface to interact between cells and in distal tissue, resulting in the successful incorporation of the implant into the surrounding bony tissue. On the other hand, strong integration between the bone and screw is a disadvantage when considering removal of screws. Alberktsson and Wennerberg classified surface roughness of implants as shown in Table 2.2.

*Table 2.2: Surface roughness categories of implants [21, 22]*

| Category | Surface roughness range ($R_a$) | Bone implant connection |
|---|---|---|
| Smooth surfaces | <0.5 μm | Temporary |
| Minimally rough surfaces | 0.5 to 1.0 μm | Temporary |
| Moderately Roughened surfaces | 1.0 to 2.0 μm | Permanent |
| Rough surfaces | >2.0 μm | Permanent |

Analysis of surface integrity micro-cracks resulted will justify the use of coolant during bone drilling. According to O'Brien, micro-cracks of less than 100 μm in length stopped growing when they encountered a cement line [23]. However, micro-cracks in the range 150μm to 300 μm continued to grow after encountering a cement line surrounding an osteon. Only micro cracks greater than 300 μm were obverted to cause failure when subjected to stress fracture. Surface microstructure is the main determining factor in removal of screw. Bony integration is minimized by using the surfaces with minimal microstructure reducing the forces required to remove screws [24].

# CHAPTER 3

## Research Methodology

The section will outline the project flow on how the study will be conducted. The experiments will be carried out accordingly and the procedure are outlined based on the best practices in conducting bone drilling studies in UTP.

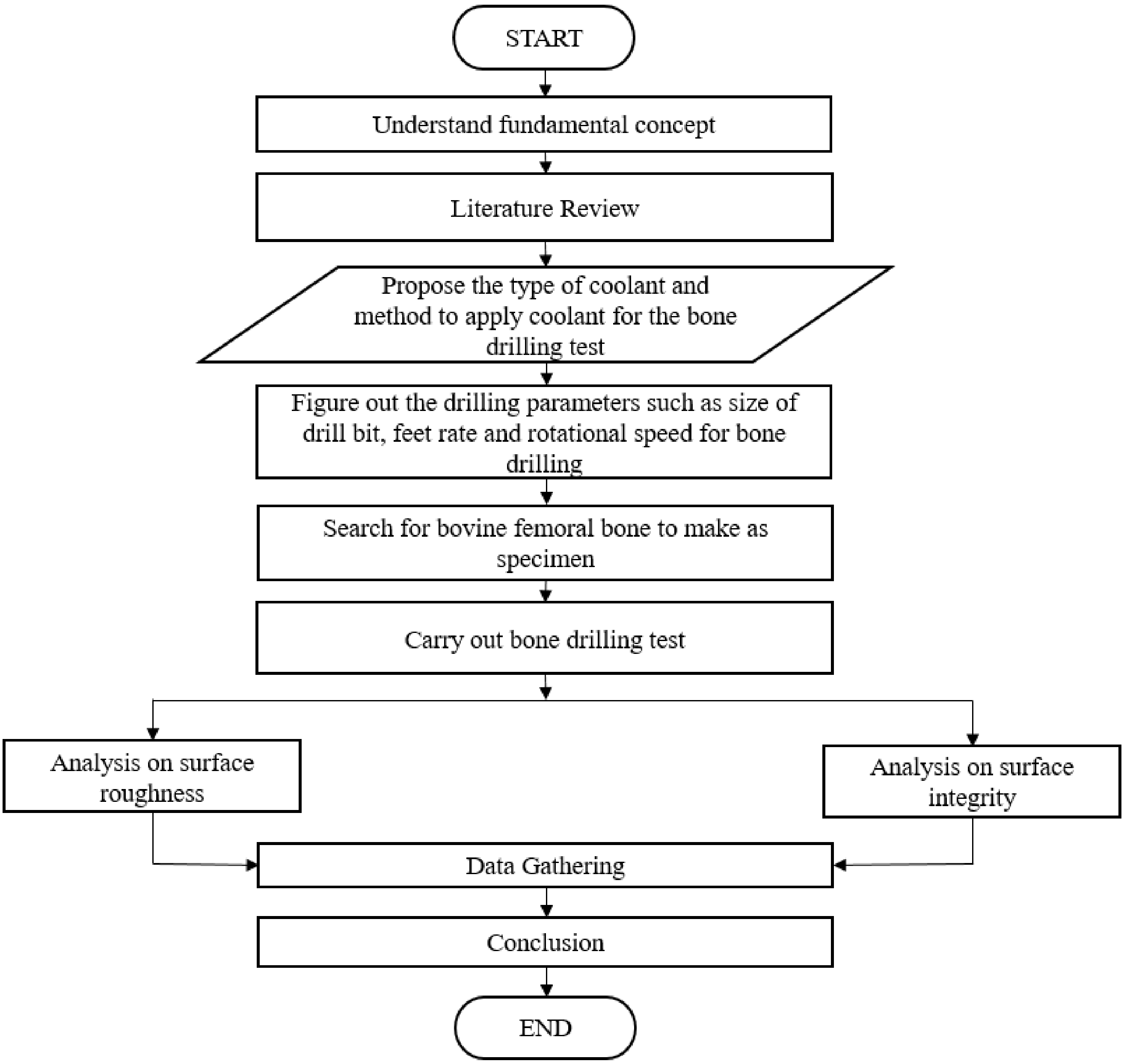



*Figure 3.1: Flow chart of the project*

### 3.1 Drilling parameter throughout the study

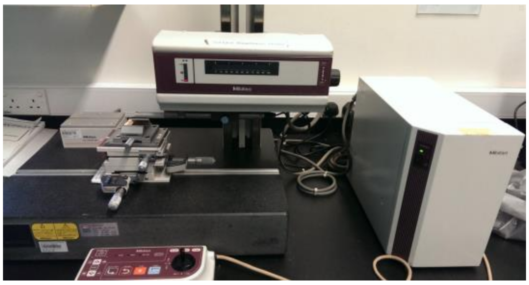
*Table 3.1: Parameter set throughout the study*

| **Drilling parameter** | **Specification** |
|---|---|
| Feet rate | 1.5mm/s |
| Spindle speed | 800rpm |
| Drill bit | 4mm diameter hardened steel |
| Bone | Bovine femoral bone |
| Coolant | Distilled water and saline (salt) solution |

### 3.2 Facilities and equipment throughout the study

*Table 3.2: Type of facilities / equipment to carry out the experiment*

| Facilities/ Equipment | Function |
|---|---|
| i. Computer Numerical Control Milling Machine (Block 16)   | Bone Drilling test. Good precision in drilling. Distilled water and saline solution as the coolant and supply manually. |
| ii. 4mm NACHI HSS drill bit  | To drill hole on bovine femur bone. |

| | |
|---|---|
| iii. Isomet 5000 Linear Precision Cutter with series 5LC Diamond Blade (Block 17)<br><br> | Cutting specimen into smaller section to enable analysis of surface integrity ad surface roughness. |
| iv. DELTA Abrasimet Cutter (Block 17)<br><br> | Cutting specimen into half to enable analysis of surface integrity and surface roughness. |
| v. Surface Roughness Profilometer (Block 17)<br> | Inspect the surface roughness of the drilled hole in micron-meter (µm). |

| | | |
|---|---|---|
| vi. | Field Emission Scanning Electron Microscopy (FESEM, Block P)   | Capture the surface microstructure on the cross section of drilled hole on bone. |
| vii. | Bottle with nozzle opening   | To supply coolant during drilling test. Flow rate at 400ml/min. Press the bottle and channel the coolant directly to the drill bit/ drill area. |
| viii. | Weighing machine  | To weight 9 grams of solid sodium chloride. |

## 3.3 Experimental procedure of preparing specimen and saline solution

*Table 3.3: Stages for handling of bone throughout the study*

| Stages | Description |
|---|---|
| Before experiment | • Purchase fresh cow femoral bones.<br>• The bone is left unwashed, meatless and frozen. |
| During experiment | • Saw the bones into small pieces of specimen before drilling.<br>• 3 pieces of bones is prepared for the drilling test:<br>1. Dry drilling<br>2. Drill with distilled water<br>3. Drill with saline coolant<br>• Clamp the specimen in good condition to avoid any damage on the bone structure. |
| After experiment | • Let specimen to partially dry before sectioning the small pieces of specimen along its long axis. |

*Figure 3.2: Fresh cow femoral bone with plastic wrap and stored frozen.*

3.3.1 Cutting of bone into smaller pieces

1. The fresh cow femoral bone is left unwashed and meatless.
2. Let the frozen bone rest at room temperature before sawing them into smaller section.
3. Mark the bone into smaller section at dimension of 10cm long each.
4. Clamp the bone into suitable position at the table clamp without damage its structure.
5. Using hand saw to section the bone according to the guiding line.
6. Repeat the steps 1 to 5 until 3 bone specimens are collected.
7. Label the specimens accordingly to ease data gathering during the experiments.
8. Stored the specimens into refrigerator to avoid it from decomposing.

*Figure 3.3: Fresh cow femoral bone.*

*Figure 3.4: 3 bone specimens with 10 cm long each.*

3.3.2 Preparation of saline solution

1. Get the solid sodium chloride (NaCl) with the molecular of weight of 58.5 grams per mole.
2. Weight 9 grams of solid sodium chloride by using the weighing machine.
3. Place the 9 grams of solid sodium chloride into a 1000ml beaker.
4. Fill the beaker with 1000ml of distilled water and stir with a spoon in order to let the sodium chloride to dissolve.
5. Pour the saline solution into bottles and store at room temperature.


*Figure 3.5: NaCl with molecular weight of 58.5g/mol*

### 3.3.3 Bone drilling

1. Let the frozen specimens rest at room temperature before starting the bone drilling experiment.
2. Set the drilling parameters for CNC XLMILL machine at feet rate of 1.5mm/s and rotational speed of 800rpm.
3. Clamp the specimen in a good position at the drilling platform.
4. Start drilling hole on the bone specimen. 3 holes are drilled on the specimen with 25mm center-to-center point of gap.
5. Clean the drill bit after finish drilling a bone specimen.
6. Repeat step 1 to 5 for bone drilling on the following specimens and coolant is applied manually to the drilling region.

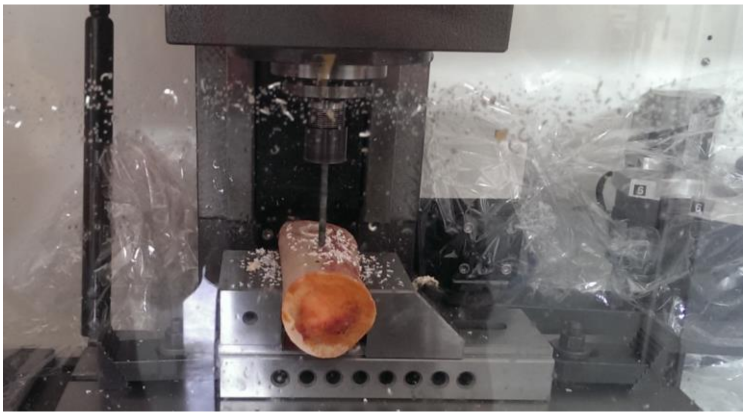


*Figure 3.6: Bone drilling process*


*Figure 3.7: Apply coolant manually during the bone drilling process*

3.3.4 Spindle specimen into smaller section

1. Measure and draw a guiding line on the drilled specimen.
2. Clamp the small piece of drilled specimen on the platform without damaging the structure of the drilled specimen.
3. Set the blade aligned to the guiding line and start the DELTA abrasive cutter machine to section the drilled specimen into desired size of 40mm (L) X 20mm (W).
4. Label the specimen accordingly for the ease of data gathering.
5. Repeat step 1 to 4 for the following specimens.

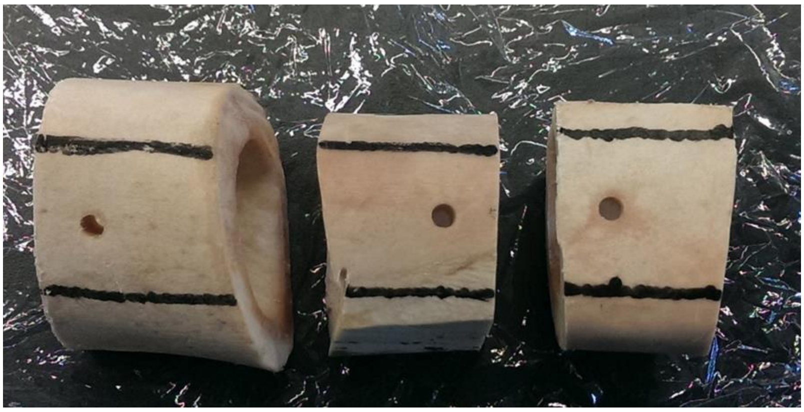


*Figure 3.8: Use handsaw to cut the specimen into smaller pieces with one hole on each and draw a guiding line on the drilled specimen*

*Figure 3.9: Clamp the drilled specimen aligned to the blade.*

### 3.3.5 Spindle specimen into half

1. Draw a guiding line that divides the specimen into two symmetrically.
2. Set the origin of the blade position by switching on the “TARE” button.
3. Clamp the specimen tightly and without damaging the structure of drilled specimen.
4. Set the diamond blade of Isomet 5000 linear precision cutter aligned to the guiding line which is also the middle of the drilled hole.
5. Set the parameters for the machine at feed rate of 1.2m/s and rotational speed of 1800rpm.
6. Switch ON the cycling button to run the machine along with the irrigation on the cutting zone.
7. Switch OFF the cycling button when the specimen been completely cut into half.
8. Label the specimens accordingly for ease of data gathering.
9. Repeat step 1 to 8 for the following specimens.

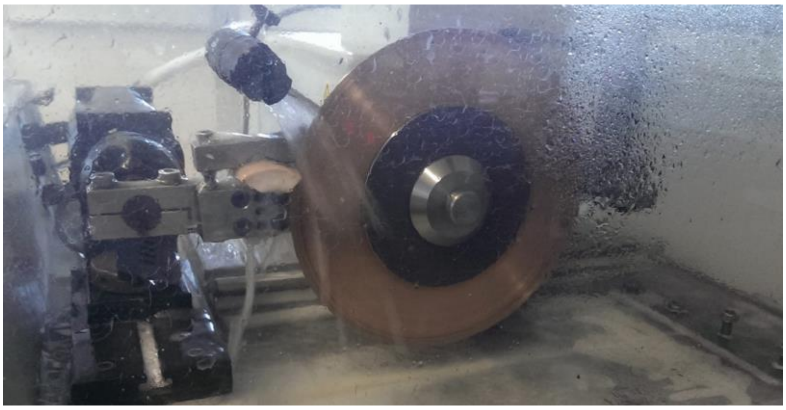


*Figure 3.10: Cut the drilled specimen into half to ease the analyzed of surface roughness and surface integrity.*

### 3.4 Experimental procedure of surface roughness analysis

1. Switch on the surface roughness tester SV3000 machine and the computer.
2. Run the profilometer software SURFPAK SV-Version 12.01.
3. Select the Ra parameter in term of x-axis.
4. Clamp the sample at the platform.
5. Adjust the stylus to the cross section of drilled hole.
6. Run the analysis by pressing "RUN" button on the machine.
7. Three sampling data are collected on each specimen.
8. Save the data and reset for the following specimens.
9. Label the specimens accordingly to ease the data gathering.
10. Repeat step 1 to 9 for the following specimens.

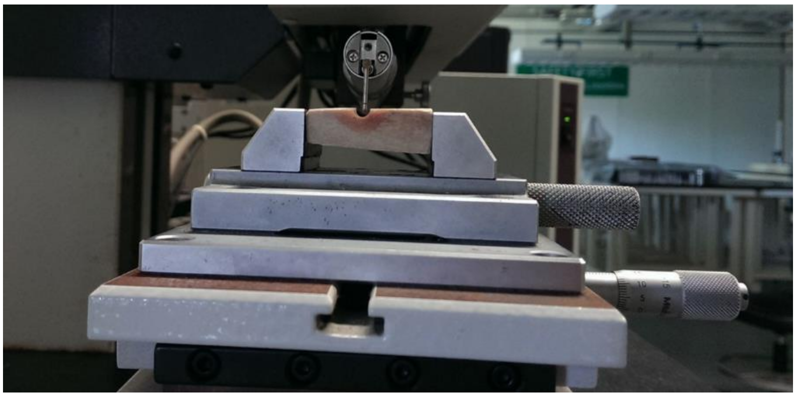


*Figure 3.11: Experimental setup of specimen on the surface roughness tester SV3000 machine.*

*Figure 3.12: The stylus of surface roughness tester SV3000 machine has to be placed on top the drilled region.*

## 3.5 Experimental procedure of surface integrity analysis

1. Coating of gold on the specimens to improve the imaging signal during Field Emission Scanning Electron Microscope (FESEM) analysis.
2. Run the scoping software.
3. Place the specimens into the scanning platform of FESEM.
4. Key in the parameters and select zooming level at 50x, 100x and 500x.
5. Adjust the focus lenses for better and clear view on the specimen.
6. Save the data and proceed with the following specimen.

*Figure 3.13: The specimens were coated with a thin layer of gold to improve the imaging signal.*

## 3.6 Project Timeline (Gantt chart)

*Table 3.4: FYP 1 Project Timeline*

| Details | Week | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| **Title selection** | ■ | ■ | | | | | | | | | | | | |
| **Understand the requirement of project and set the objectives** | | | ■ | ■ | | | | | | | | | | |
| **Identify the scope of study: The effect of coolant on bone drilling in term of surface roughness and surface integrity** | | | | | ■ | | | | | | | | | |
| **Prepare Literature Review by research on current studies and paper** | | | | | ■ | ■ | | | | | | | | |
| ***Milestone: Relating the relevant references with project: properties of bone, heat generation during bone drilling, method and influent of cooling system during bone drilling*** | | | | | | ■ | ■ ● | | | | | | | |
| **Research on Methodology of the project: Drilling parameter and facilities throughout the study** | | | | | | | ■ | ■ | | | | | | |
| **Research on method to apply coolant during bone drilling** | | | | | | | | | ■ | ■ | | | | |
| **Survey and search for cow femoral bone to make as specimen** | | | | | | | | | | ■ | ■ | | | |
| **Figure out the method to prepare saline solution and record temperature during drilling test** | | | | | | | | | | | ■ | | | |
| ***Milestone: Figure out all the drilling parameters*** | | | | | | | | | | | ● | | | |
| **Lab booking for bone drilling experiment (Bridgeport machine)** | | | | | | | | | | | ■ | | | |
| **Prepare and saw bone into smaller section (10cm long)** | | | | | | | | | | | ■ | | | |
| **Bone drilling by Bridgeport machine** | | | | | | | | | | | | ■ | | |
| ***Milestone: Data gathering and data analysis*** | | | | | | | | | | | | | ■ | ■ ● |

Legend: ● Key Milestone

*Table 3.5: FYP 2 Project Timeline*

| Details | Week | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| **Lab booking for bone drilling (Bridgeport machine)** | ■ | | | | | | | | | | | | | |
| **Lab Booking for FESEM: microstructure inspection on drilled surface** | ■ | | | | | | | | | | | | | |
| ***Milestone: Lab Booking*** | | ● | | | | | | | | | | | | |
| **Cutting specimen into smaller section (10 cm long)** | | ■ | | | | | | | | | | | | |
| **Prepare saline coolant** | | | ■ | | | | | | | | | | | |
| ***Milestone: Preparation before drilling*** | | | | ● | | | | | | | | | | |
| **Bone drilling** | | | | | ■ | | | | | | | | | |
| **Cutting specimen into half and send for analysis on surface roughness and surface integrity of drilled surface** | | | | | ■ | ■ | | | | | | | | |
| **Data gathering and analysis** | | | | | | | ■ | | | | | | | |
| **Result and discussion for the bone drilling project** | | | | | | | | ■ | ■ | | | | | |
| ***Milestone: Gathering of all data of bone drilling project*** | | | | | | | | ■ | ● | | | | | |
| **Compilation of bone drilling project** | | | | | | | | | | ■ | ■ | ■ | ■ | ■ |
| ***Milestone: Complete the bone drilling project*** | | | | | | | | | | | | | | ● |

Legend: ● Key Milestone

# CHAPTER 4

# Result and Discussion

## 4.1 Surface roughness

### 4.1.1 The effect of dry drilling on surface roughness of the drilled bone

Dry drilling process had been conducted in this project. The first specimen was used for dry drilling process. The bone drilling process was carried out by the CNC XLMILL machine. 3 targeted drill spots were marked on the specimen with 25mm of point to point gap by marker pen to ease the process of drilling. The specimen was clamped in a good condition on the workpiece platform. During the drilling process, the drill bit drilled through the specimen in a one-way manner for all the 3 holes.

*Figure 4.1: The condition of the first specimen after dry drilling process.*

The specimen was then take for further sectioning and cutting to carry out the surface roughness analysis. During the surface roughness analysis, each cross section of the drilled hole was being analyze up to 3 times in order to get the average surface roughness result. Appendix I indicates the results of average surface roughness of first specimen. The effect of dry drilling on surface roughness of the drilled bone were recorded by the surface roughness tester SV3000 machine and tabulated in Table 4.1. Based on the result obtained, the range of surface roughness for dry drilling condition is between 2.056µm to 2.301µm. This result can be categorized under rough surfaces which mean the parameter is recommended for permanent bone-implant connection [21,22].

*Table 4.1: Data gathering for specimen with dry drilling process.*

| **Drilling condition** | **Dry drilling** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Spindle speed, rpm** | 800 | | | | | | | | |
| **Feed rate, mm/s** | 1.5 | | | | | | | | |
| **Drill bit size, mm** | 4 | | | | | | | | |
| **Position of hole on specimen** | 1 | | | 2 | | | 3 | | |
| **Surface roughness Ra, µm** | Read. 1 | Read.2 | Read.3 | Read. 1 | Read.2 | Read.3 | Read. 1 | Read.2 | Read.3 |
| | 2.058 | 2.054 | 2.056 | 2.149 | 2.150 | 2.147 | 2.304 | 2.300 | 2.300 |
| **Average surface roughness Ra, µm** | 2.056 | | | 2.149 | | | 2.301 | | |
| **Surface roughness category [21,22]** | Rough surfaces | | | Rough surfaces | | | Rough surfaces | | |

4.1.2 The effect of applying coolant during drilling on surface roughness of the drilled bone.

External irrigation had been applied to the second and third specimen during the drilling process. The type of coolant used was distilled water and saline solution. Each coolant at room temperature had been applied to the respective specimen. The bone drilling process was carried out by the CNC XLMILL machine. 3 targeted drill spots were marked on the specimen with 25mm of point to point gap by marker pen to ease the process of drilling. The specimen was clamped in a good condition on the workpiece platform. During the drilling process, the drill bit drilled through the specimen in a one-way manner for all the 3 holes. Coolant was stored in a bottle with nozzle opening and applied manually from the top side of the machine. External irrigation took place where a small hose was channeled to the contact surface of drill bit and specimen.

*Figure 4.2: Experimental setup of coolant supply during the bone drilling process.*

The specimen was then take for further sectioning and cutting to carry out the surface roughness analysis. During the surface roughness analysis, each cross section of the drilled hole was being analyze up to 3 times in order to get the average surface roughness result. Appendix II and Appendix III indicates the results of average surface roughness of second and third specimen. The effect of applying coolant during bone drilling on surface roughness of the drilled bone has been recorded by the surface roughness tester SV3000 machine and tabulated in Table 4.2 and Table 4.3. Based on the result obtained, the range of surface roughness for bone drilling with the irrigation of distilled water is between 0.847μm to 1.739μm. Meanwhile, the range of surface roughness for bone drilling with the irrigation of saline solution is between 0.895μm to 1.237μm. Both result can be categorized within minimally and moderately rough surfaces which mean the parameter is suitable for temporary and permanent bone-implant connection [21,22].

*Table 4.2: Data gathering for specimen that irrigated by distilled water during bone drilling process.*

| **Drilling condition** | **Drilled along with the irrigation of distilled water** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Spindle speed, rpm** | 800 | | | | | | | | |
| **Feed rate, mm/s** | 1.5 | | | | | | | | |
| **Drill bit size, mm** | 4 | | | | | | | | |
| **Position of hole on specimen** | 1 | | | 2 | | | 3 | | |
| **Surface roughness Ra, µm** | Read. 1 | Read.2 | Read.3 | Read. 1 | Read.2 | Read.3 | Read. 1 | Read.2 | Read.3 |
| | 0.847 | 0.847 | 0.846 | 1.270 | 1.269 | 1.268 | 1.737 | 1.741 | 1.740 |
| **Average surface roughness Ra, µm** | 0.847 | | | 1.269 | | | 1.739 | | |
| **Surface roughness category [21,22]** | Minimally rough surfaces | | | Moderately rough surfaces | | | Moderately rough surfaces | | |

*Table 4.3: Data gathering for specimen that irrigated by saline solution during bone drilling process.*

| **Drilling condition** | **Drilled along with the irrigation of saline solution** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Spindle speed, rpm** | 800 | | | | | | | | |
| **Feed rate, mm/s** | 1.5 | | | | | | | | |
| **Drill bit size, mm** | 4 | | | | | | | | |
| **Position of hole on specimen** | 1 | | | 2 | | | 3 | | |
| **Surface roughness Ra, µm** | Read. 1 | Read.2 | Read.3 | Read. 1 | Read.2 | Read.3 | Read. 1 | Read.2 | Read.3 |
| | 0.893 | 0.895 | 0.896 | 1.039 | 1.036 | 1.035 | 1.238 | 1.236 | 1.236 |
| **Average surface roughness Ra, µm** | 0.895 | | | 1.037 | | | 1.237 | | |
| **Surface roughness category [21,22]** | Minimally rough surfaces | | | Moderately rough surfaces | | | Moderately rough surfaces | | |

4.1.3 Comparison between dry drilling and with coolant during bone drilling on surface roughness of drilled bone.

*Table 4.4: Comparison of surface roughness for different drilling condition.*

| **Drilling condition** | **Dry drilling** | | | **Drilled with the present of distilled water** | | | **Drilled with the present of saline solution** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Avg Surface Roughness of drilled hole Ra, µm** | Hole 1 | Hole 2 | Hole 3 | Hole 1 | Hole 2 | Hole 3 | Hole 1 | Hole 2 | Hole 3 |
| | 2.056 | 2.149 | 2.301 | 0.847 | 1.269 | 1.739 | 0.895 | 1.037 | 1.237 |
| **Avg Surface Roughness of all drilled holes on each specimen Ra, µm** | 2.169 | | | 1.285 | | | 1.056 | | |
| **Category** | Rough surfaces | | | Moderately rough surfaces | | | Moderately rough surfaces | | |

By referring to Table4.4, the average surface roughness of all drilled holes on the specimen that undergo dry drilling process gives that highest value of reading at 2.169µm. The result obtained can be categorized as rough surfaces and suitable for permanent bone-implant connection. The second specimen was drilled with the irrigation of distilled water during drilling process. It has the lower value of average surface roughness of all drilled holes on the specimen at 1.285µm. The result obtained can be categorized as moderately rough surfaces and suitable for permanent bone-implant connection. The last specimen shows the lowest value of average surface roughness of all drilled holes on the specimen at 1.056µm. The result obtained is within the margin of minimally rough surfaces and moderately rough surfaces. The specimen that irrigated with saline solution during drilling process is recommended for temporary and permanent bone-implant connection as well.

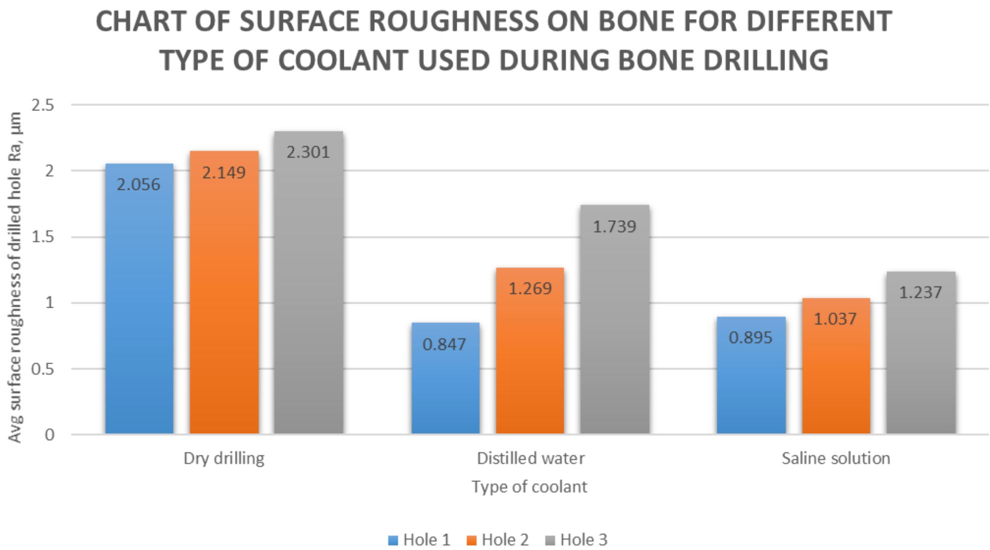



*Figure 4.3: Chart of average surface roughness on specimen for different type of coolant used during drilling.*

## 4.2 Surface integrity

4.2.1 The effect of dry drilling on surface integrity of the drilled bone.

Field Emission Scanning Electron Microscope (FESEM) had been used to inspect the length of micro crack for specimen that used in dry drilling process. Various magnifications had been made to capture the surface images. The range of micro cracks on the first specimen is between 15.860µm to 27.030µm.

*Figure 4.4: Microstructure of drilled surface for dry drilling process.*

4.2.2 The effect of applying coolant during drilling on surface integrity of the drilled bone.

Based on the FESEM analysis, the range of micro crack for drilling specimen with the irrigation of distilled water fall within 8.514µm to

10.720µm. On the other hand, the result obtained for specimen that using saline solution as the coolant is between 5.435µm to 8.264µm.

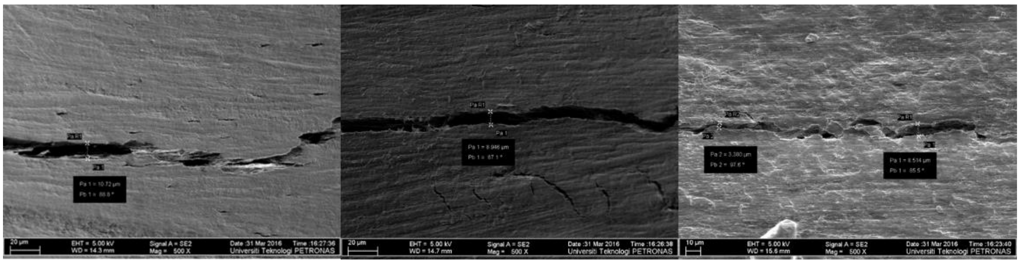


*Figure 4.5: Microstructure of drilled surface for irrigation of distilled water during drilling process.*

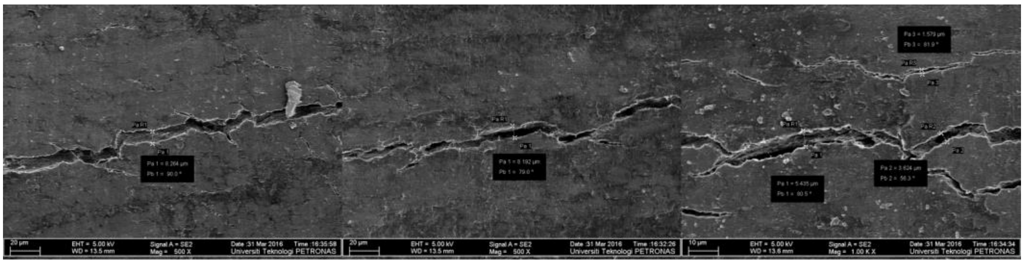


*Figure 4.6: Microstructure of drilled surface for irrigation of saline solution during drilling process.*

### 4.2.3 Comparison between dry drilling and with coolant during bone drilling on surface integrity of drilled bone.

*Table 4.5: Comparison of micro crack for different drilling condition.*

| **Drilling condition** | **Dry drilling** | | | **Drilled with the present of distilled water** | | | **Drilled with the present of Saline solution** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Micro crack, µm** | Read. 1 | Read. 2 | Read. 3 | Read. 1 | Read. 2 | Read. 3 | Read. 1 | Read. 2 | Read. 3 |
| | 27.03 | 17.42 | 15.86 | 10.72 | 8.946 | 8.514 | 8.264 | 8.192 | 5.435 |
| **Avg micro crack on selected specimen, µm** | 20.103 | | | 9.393 | | | 7.297 | | |

Based on the data tabulated in Table 4.5, the mean length of micro crack during dry drilling is the highest among all the drilled specimen. Specimens drilled with the irrigation of coolant obtained micro crack not more than 10µm. It is a good quality of drilled because the bone tissue can recover and heal within a short period. The micro cracks of all the specimens are less than 100µm in length. Hence it will stop growing when they encountered a cement line. Only micro cracks greater than 300 µm will cause failure in the specimen because cracks at this length is able to penetrate through osteon [23].

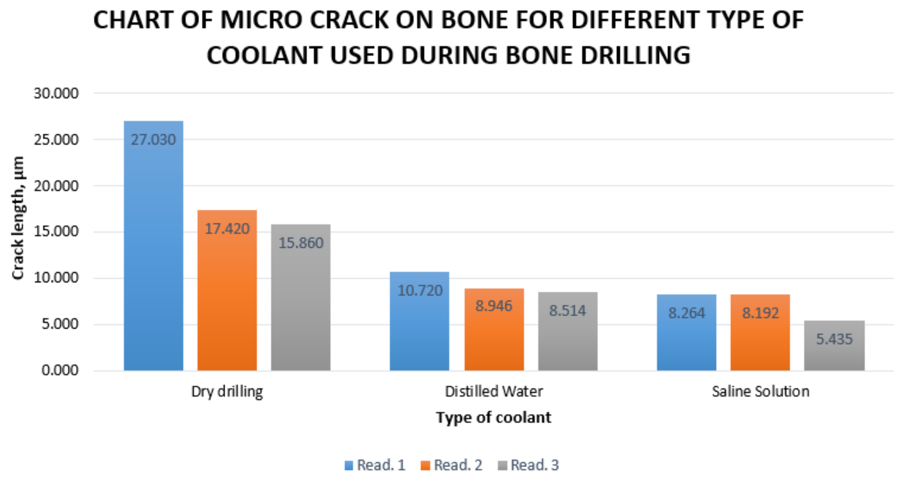



*Figure 4.7: Chart of micro cracks on specimen for different type of coolant used during drilling.*

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

The level of surface roughness and surface integrity of holes drilled in the cow femur bone were measured. Drill bit of 4mm diameter had been used for drilling the cow femur bones. The experiment was carried out with and without coolant during the drilling process. The same drilling parameters such as feed rate at 1.5mm/s and rotational speed at 800rpm were used throughout the experiment.

The parameter for surface roughness is average roughness (Ra). The results obtained is suitable for permanent bone-implant connection. The rough surfaces will provide better anchorage of bone tissue to the implants and fixing screws. However lower surface roughness was found on the hole drilled with the irrigation of coolant. This attributed to the improved chip removal to avoid clogging at the drilling region. This type of lower surface roughness is recommended for temporary bone-implant connection when considering removal of screws.

Surface integrity of holes drilled in dry drilling and with coolant were captured by the FESEM image. Specimen that used for dry drilling result in bigger micro crack on the drilled surface. Whereas, the microstructure of drilled surfaces with the irrigation of coolant result in smaller crack. This shows a remarkable effect of applying coolant during drilling for the character of the surfaces and the cellular response which is essential for healthy bone growth.

Future recommendation can be focus on the effect of coolant on the heat generation during bone drilling. Continuous improvement in bone drilling could be produced to enhanced the effectiveness of using this irrigation technique as one of the medical solution in healing fracture bone and related applications.

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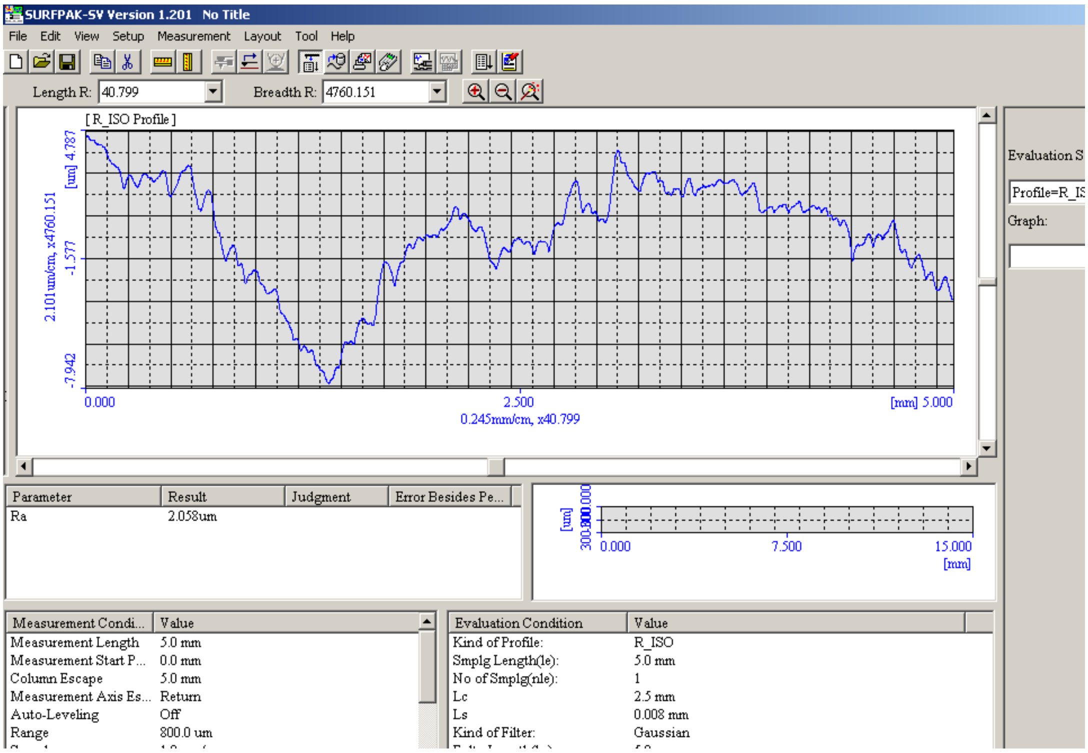
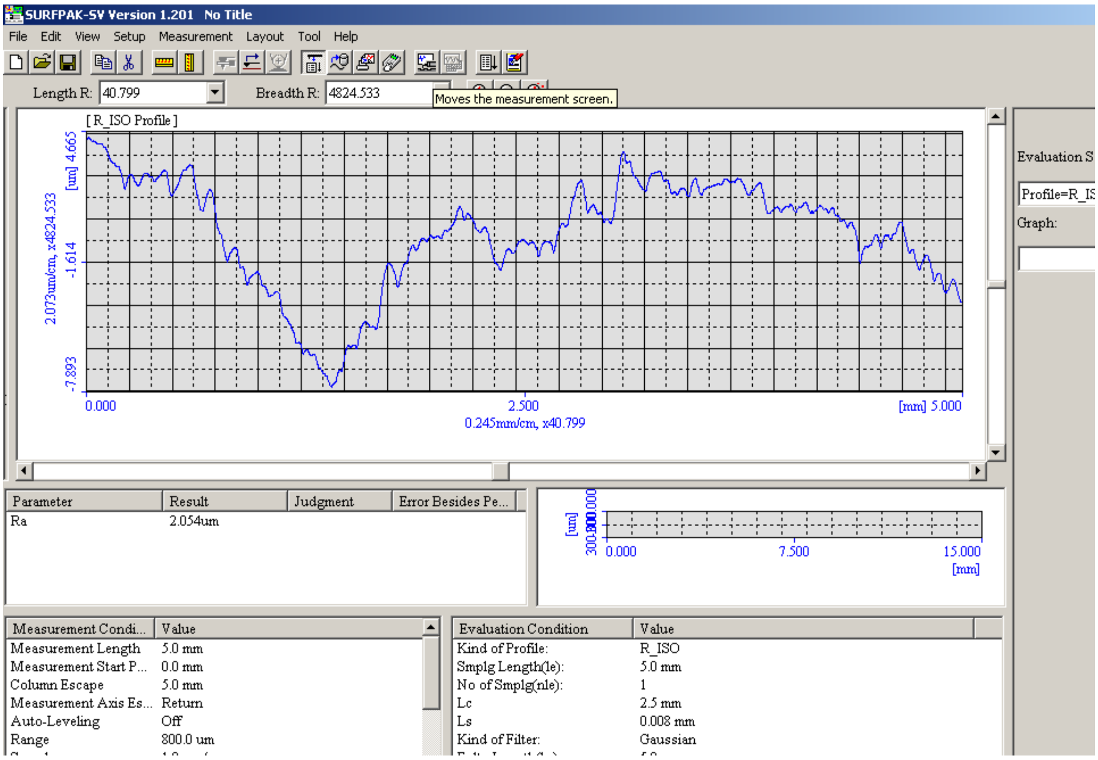
Appendices

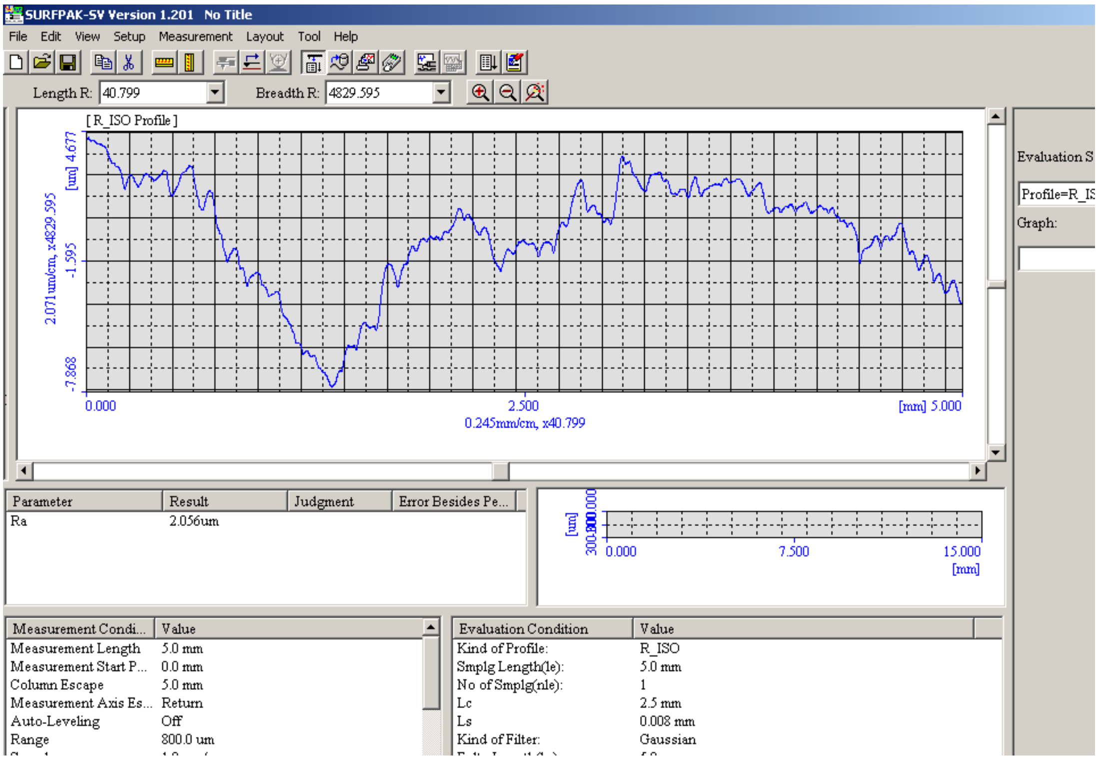
# APPENDIX I



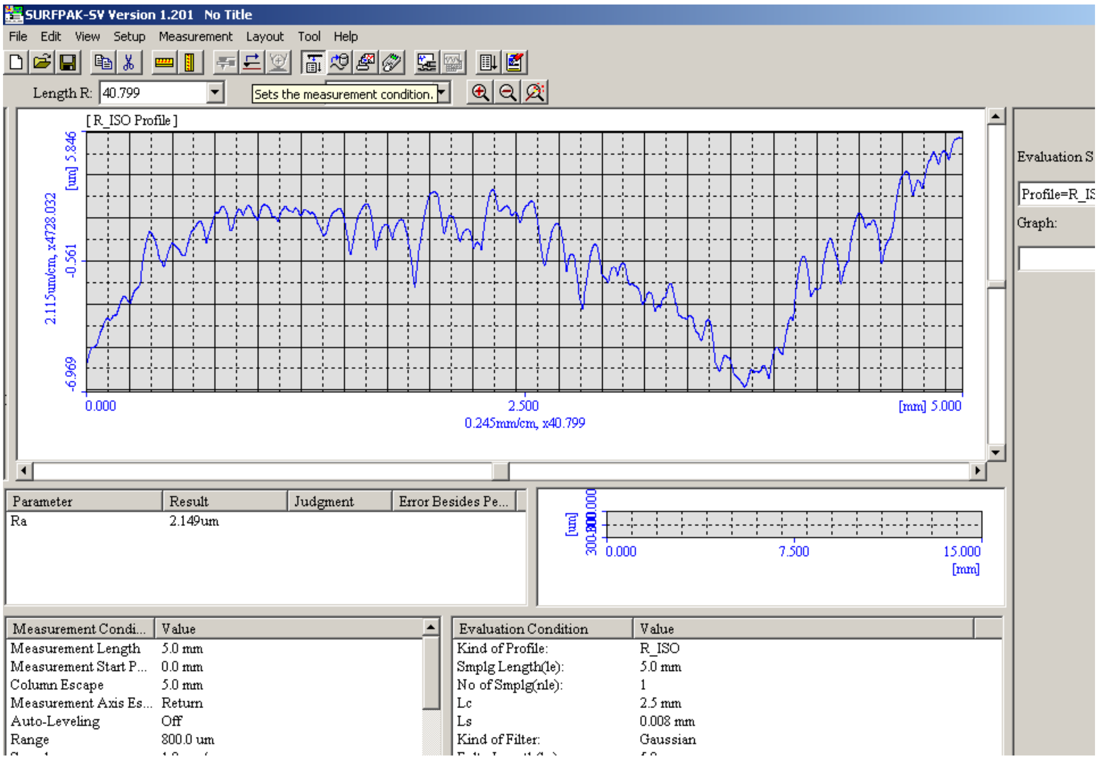

APPENDIX I-a Result of surface roughness for hole 1 on first specimen. (Dry drilling)



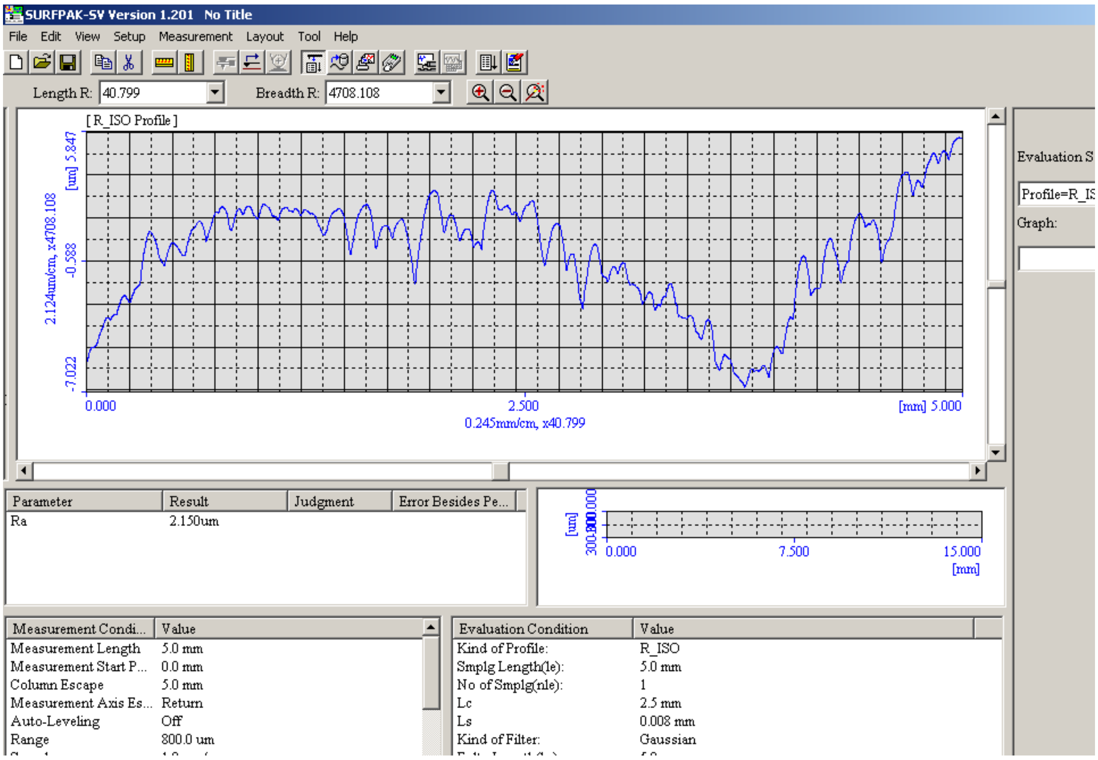

APPENDIX I-b Result of surface roughness for hole 1 on first specimen. (Dry drilling)



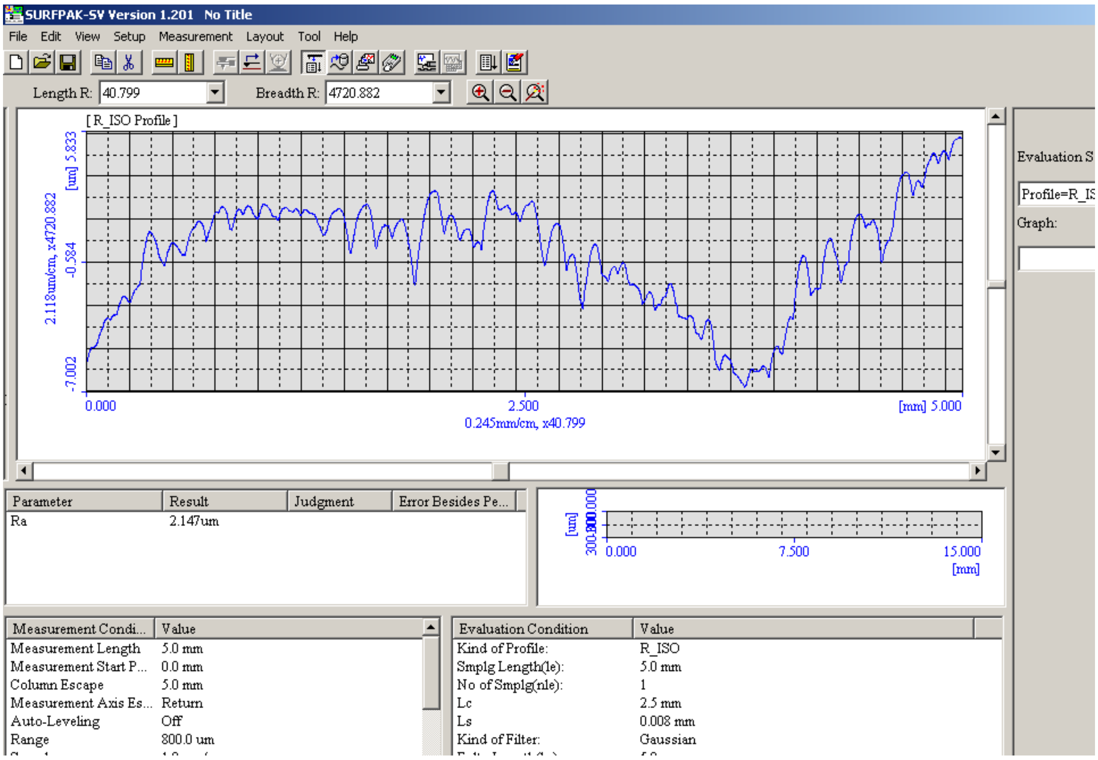
APPENDIX I-c Result of surface roughness for hole 1 on first specimen. (Dry drilling)



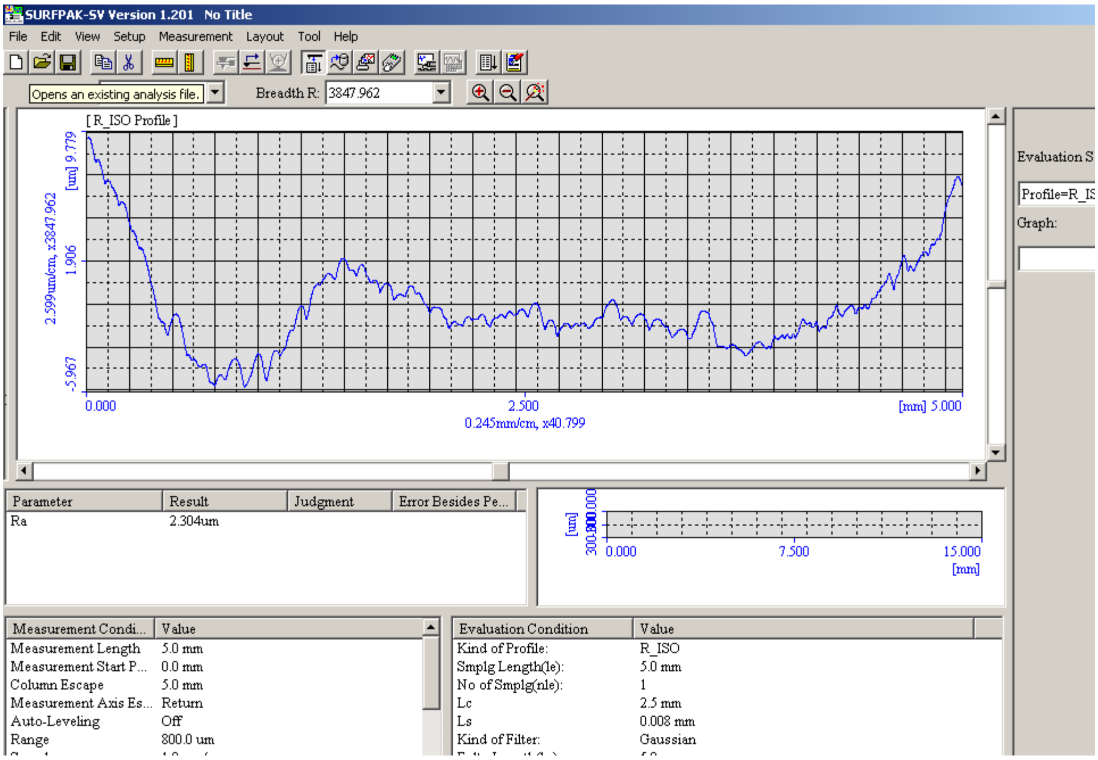
APPENDIX I-d Result of surface roughness for hole 2 on first specimen. (Dry drilling)



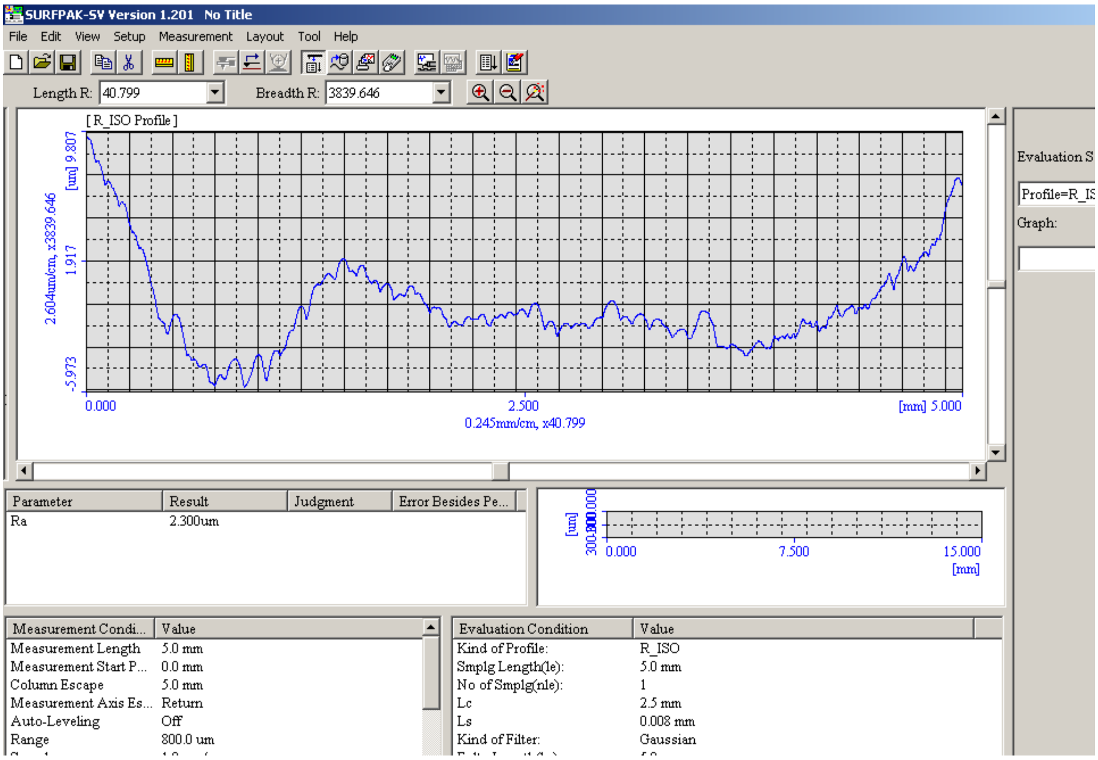
APPENDIX I-e Result of surface roughness for hole 2 on first specimen. (Dry drilling)



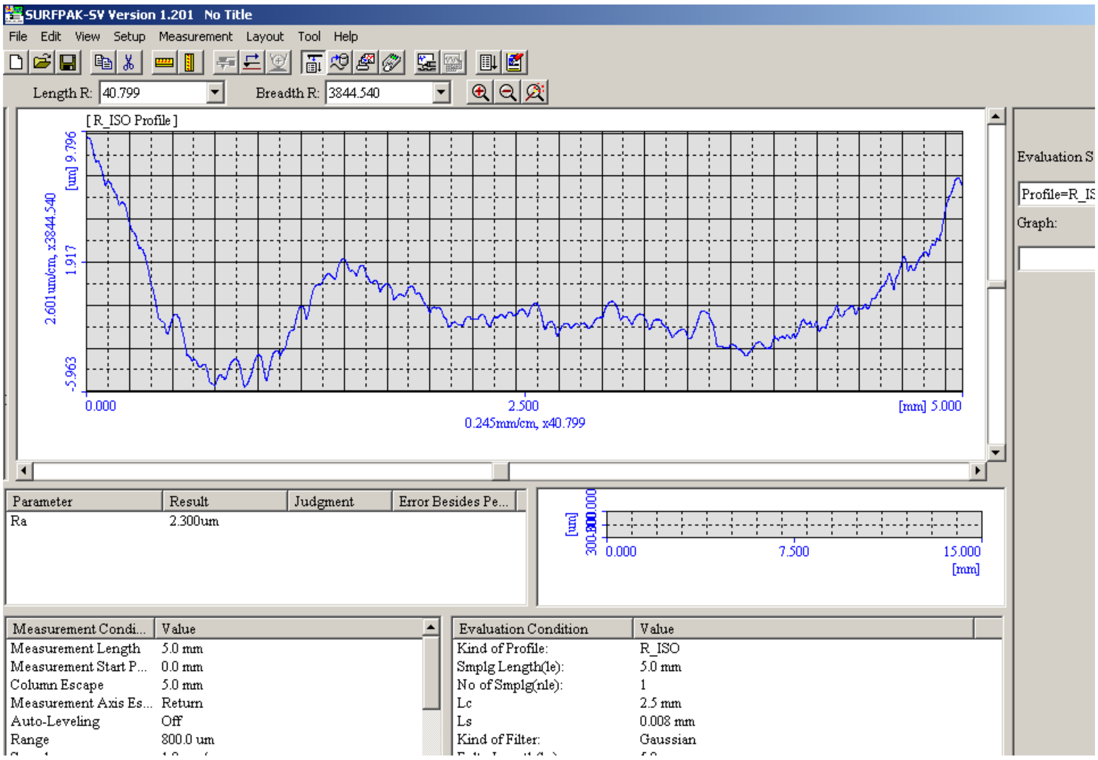
APPENDIX I-f Result of surface roughness for hole 2 on first specimen. (Dry drilling)




APPENDIX I-g Result of surface roughness for hole 3 on first specimen. (Dry drilling)

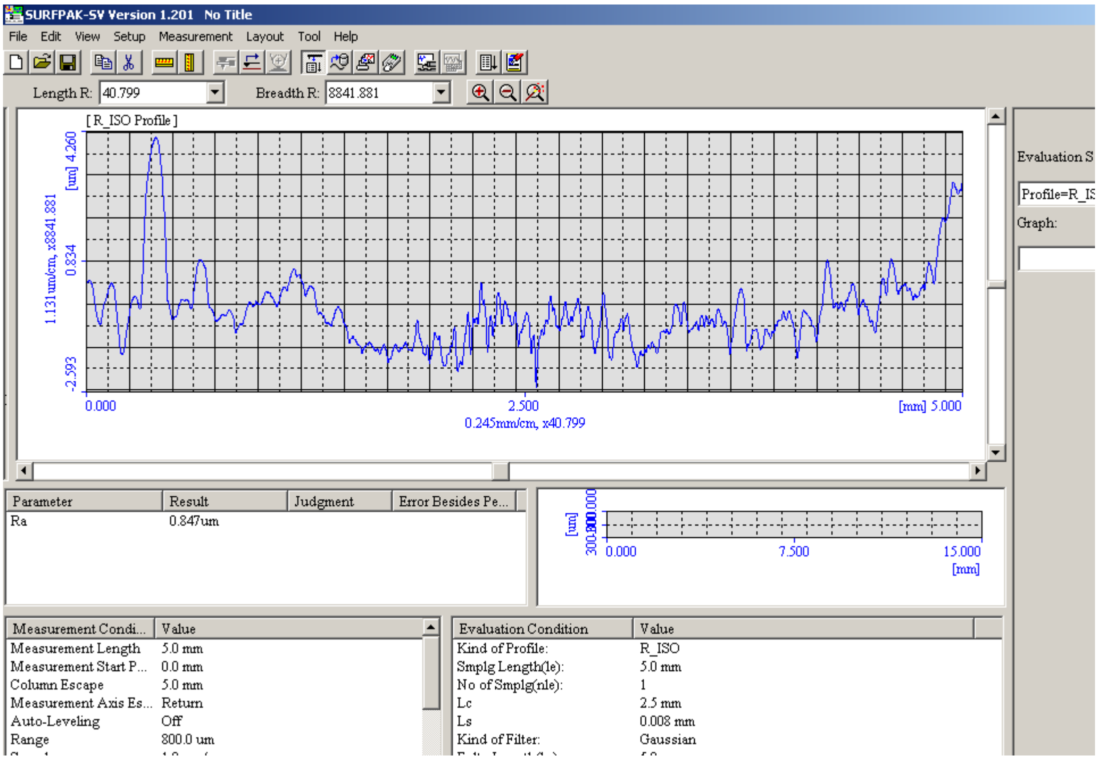



APPENDIX I-h Result of surface roughness for hole 3 on first specimen. (Dry drilling)

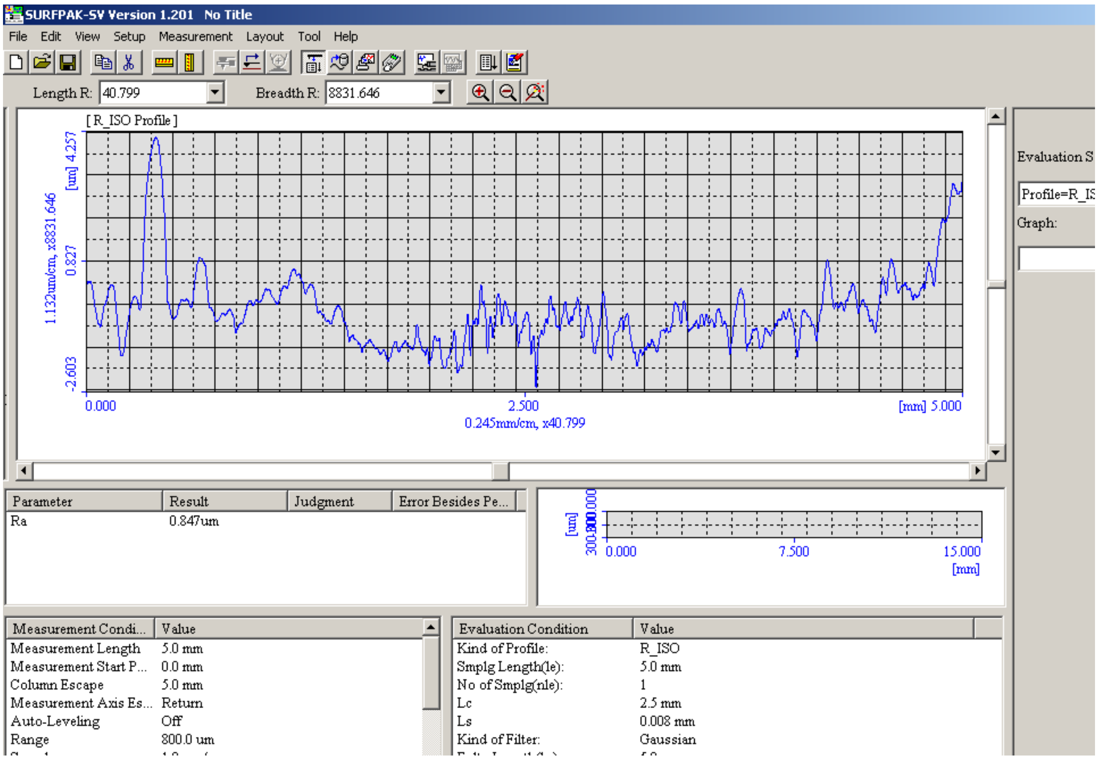



APPENDIX I-i Result of surface roughness for hole 3 on first specimen. (Dry drilling)

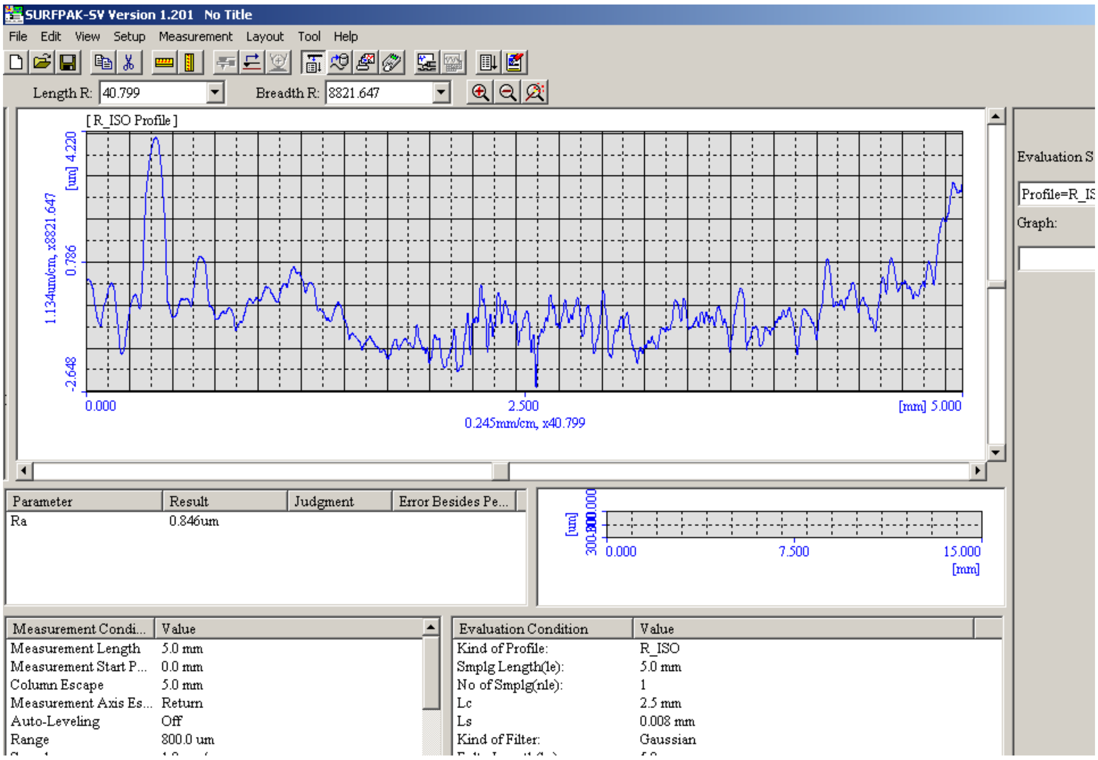
APPENDIX II



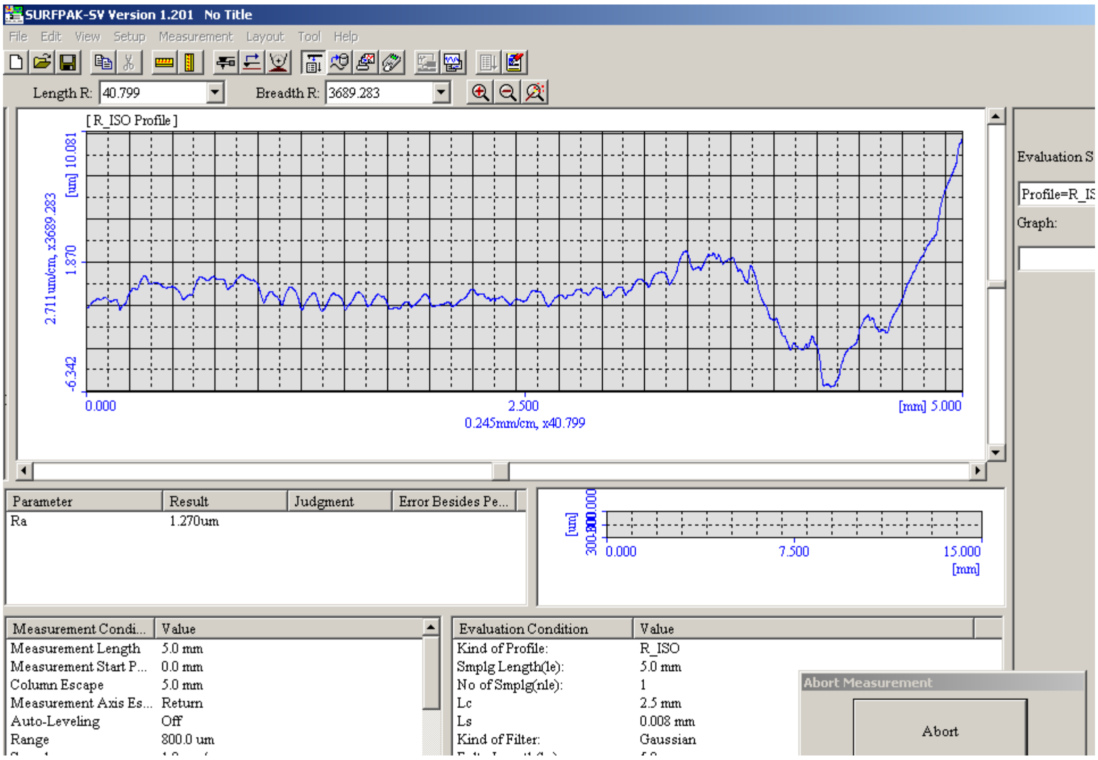

APPENDIX II-a Result of surface roughness for hole 1 on second specimen. (Drilled with the irrigation of distilled water)



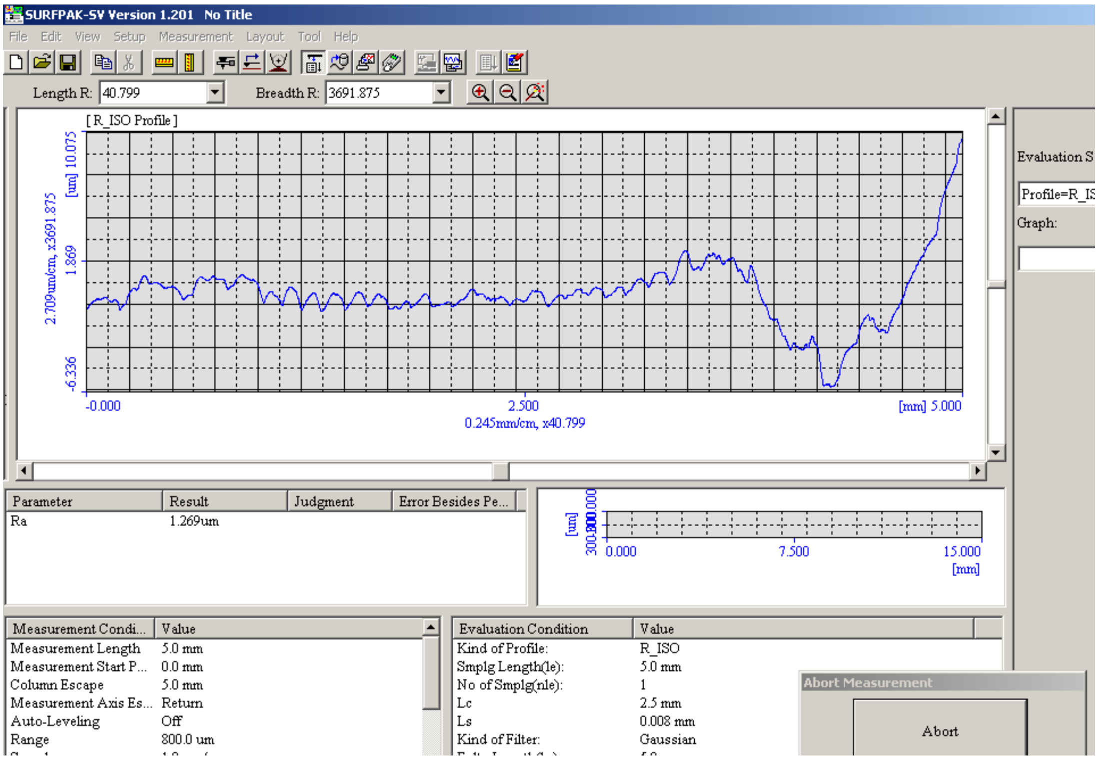

APPENDIX II-b Result of surface roughness for hole 1 on second specimen. (Drilled with the irrigation of distilled water)



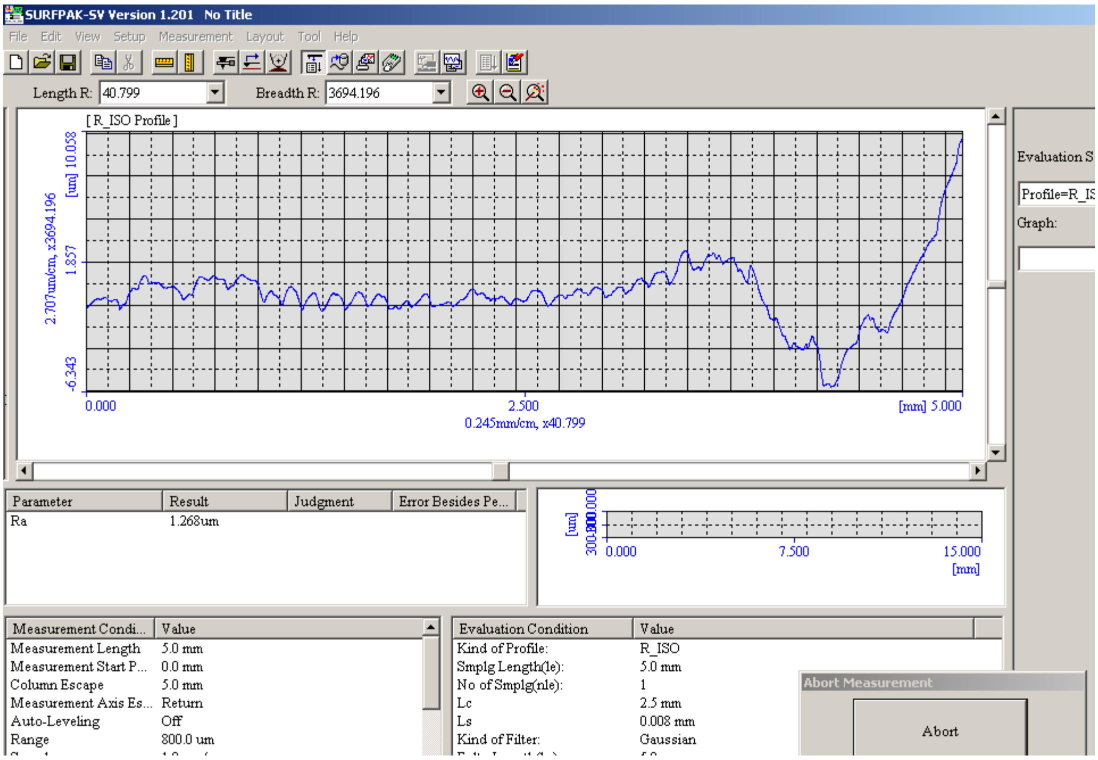

APPENDIX II-c Result of surface roughness for hole 1 on second specimen. (Drilled with the irrigation of distilled water)



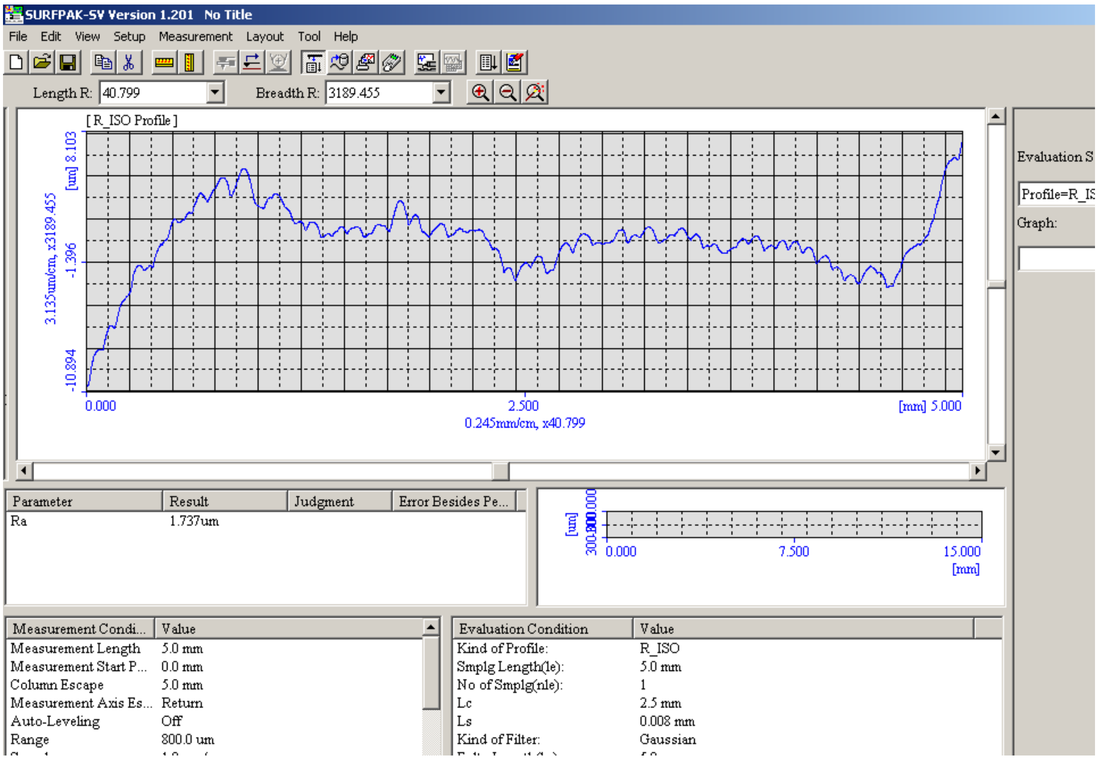

APPENDIX II-d Result of surface roughness for hole 2 on second specimen. (Drilled with the irrigation of distilled water)



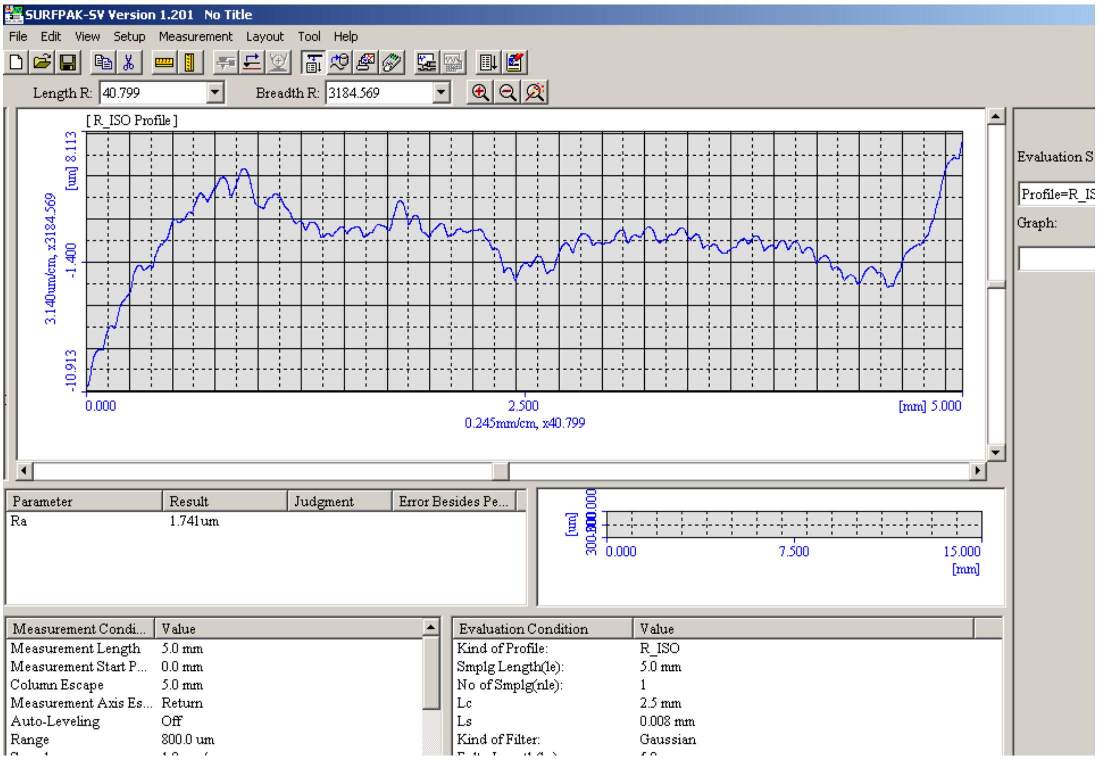

APPENDIX II-e Result of surface roughness for hole 2 on second specimen. (Drilled with the irrigation of distilled water)



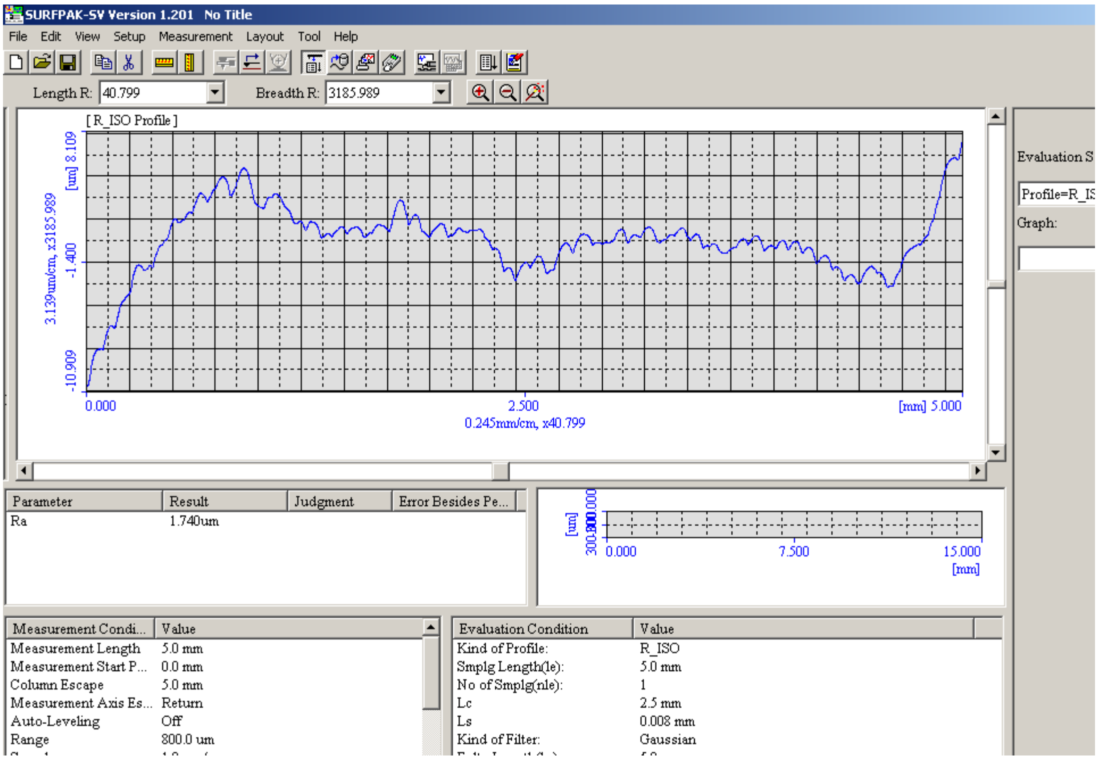

APPENDIX II-f Result of surface roughness for hole 2 on second specimen. (Drilled with the irrigation of distilled water)




APPENDIX II-g Result of surface roughness for hole 3 on second specimen. (Drilled with the irrigation of distilled water)

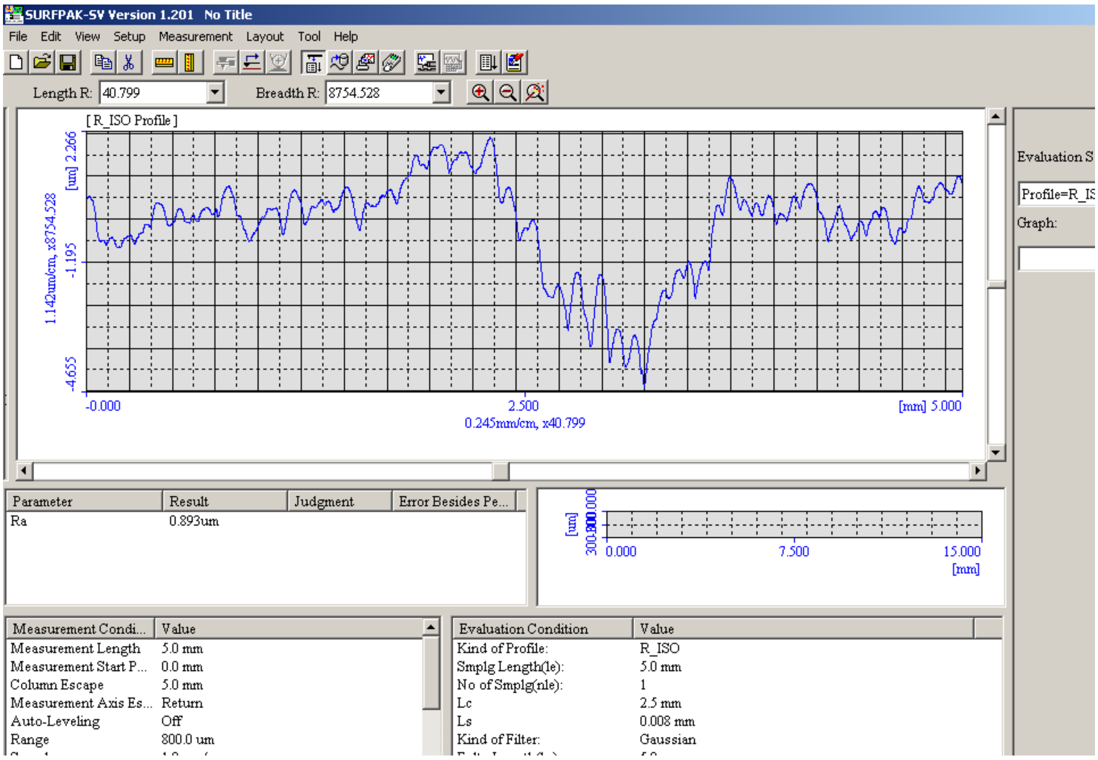



APPENDIX II-h Result of surface roughness for hole 3 on second specimen. (Drilled with the irrigation of distilled water)

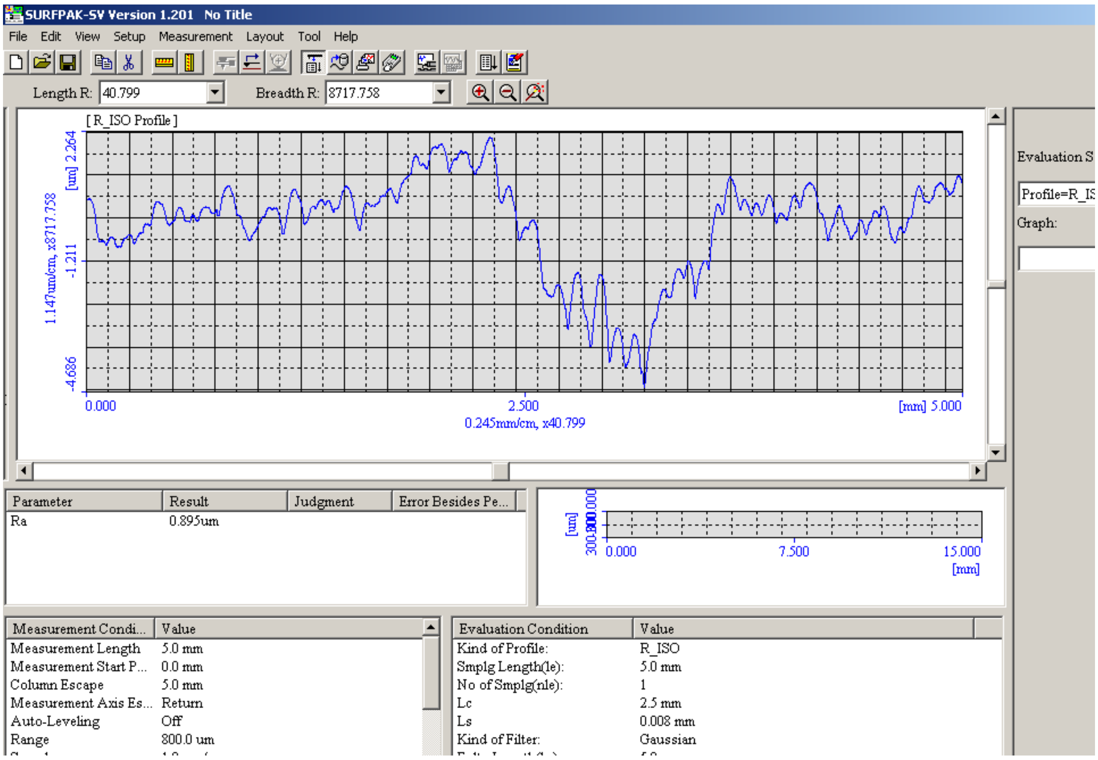



APPENDIX II-i Result of surface roughness for hole 3 on second specimen. (Drilled with the irrigation of distilled water)

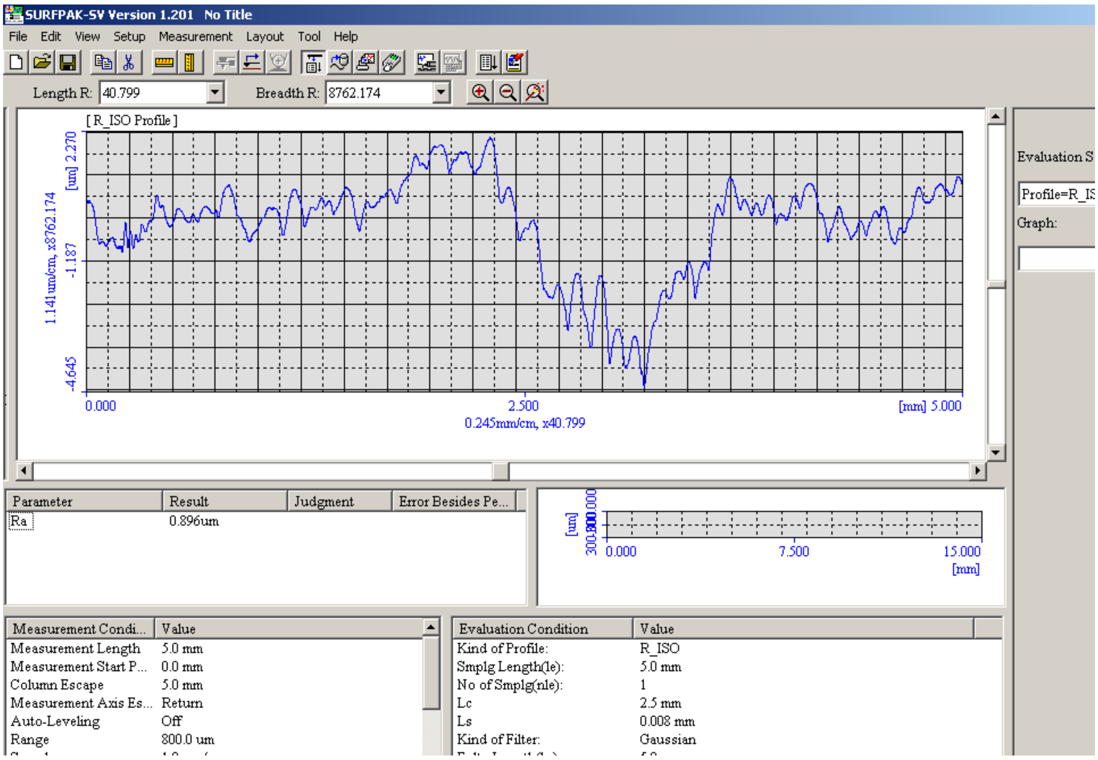
APPENDIX III



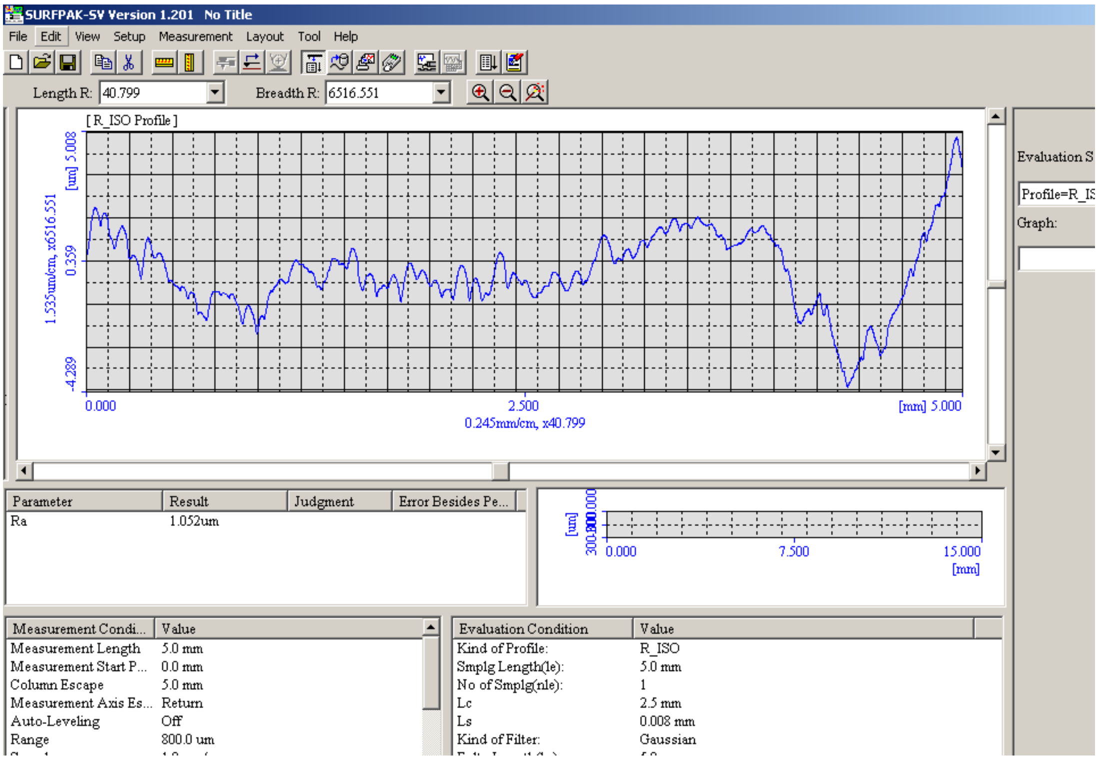

APPENDIX III-a Result of surface roughness for hole 1 on third specimen. (Drilled with the irrigation of saline solution)



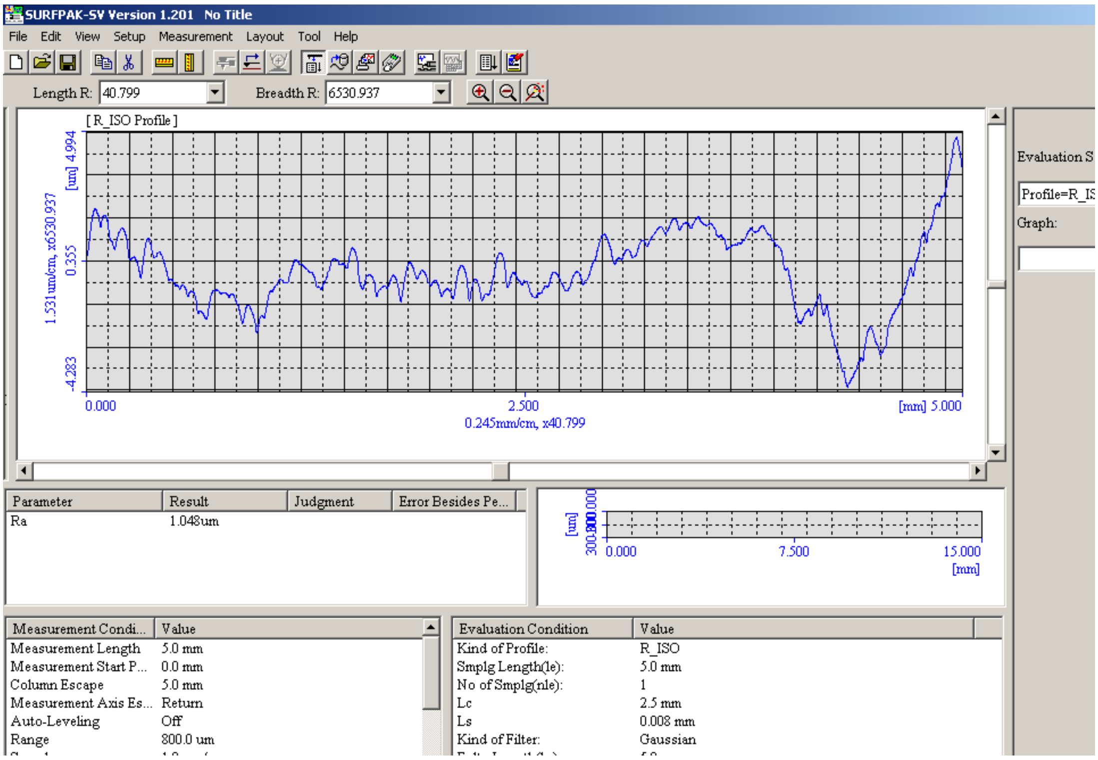

APPENDIX III-b Result of surface roughness for hole 1 on third specimen. (Drilled with the irrigation of saline solution)



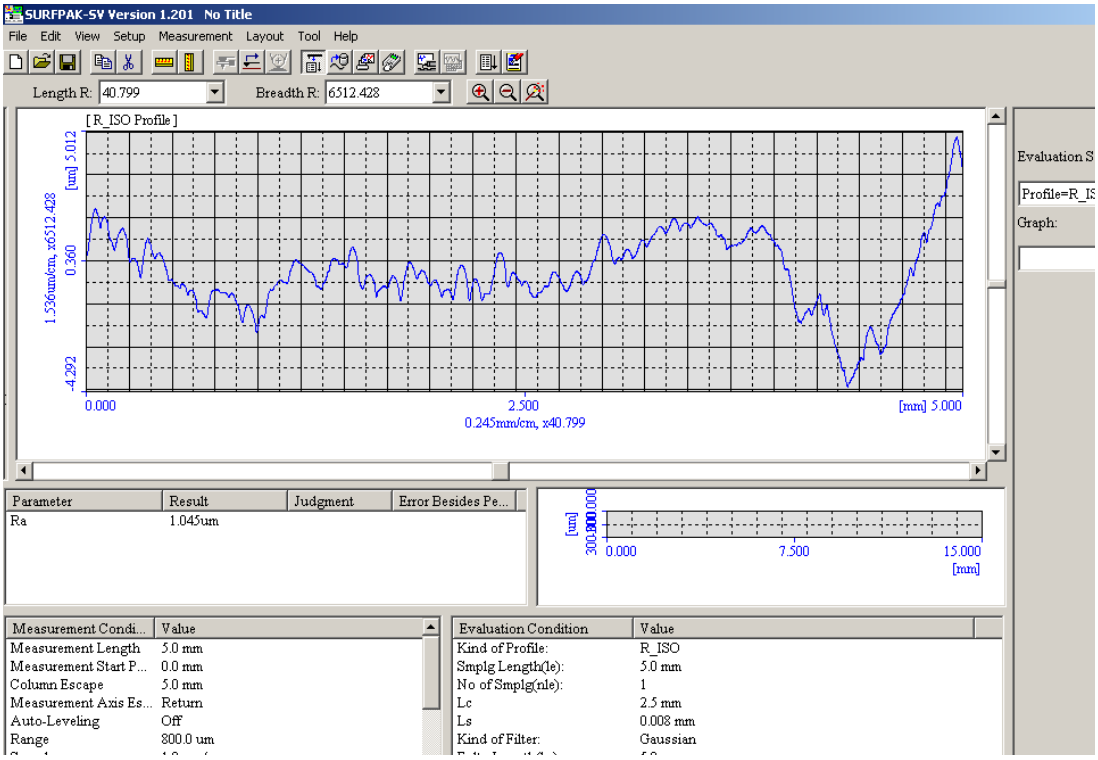

APPENDIX III-c Result of surface roughness for hole 1 on third specimen. (Drilled with the irrigation of saline solution)



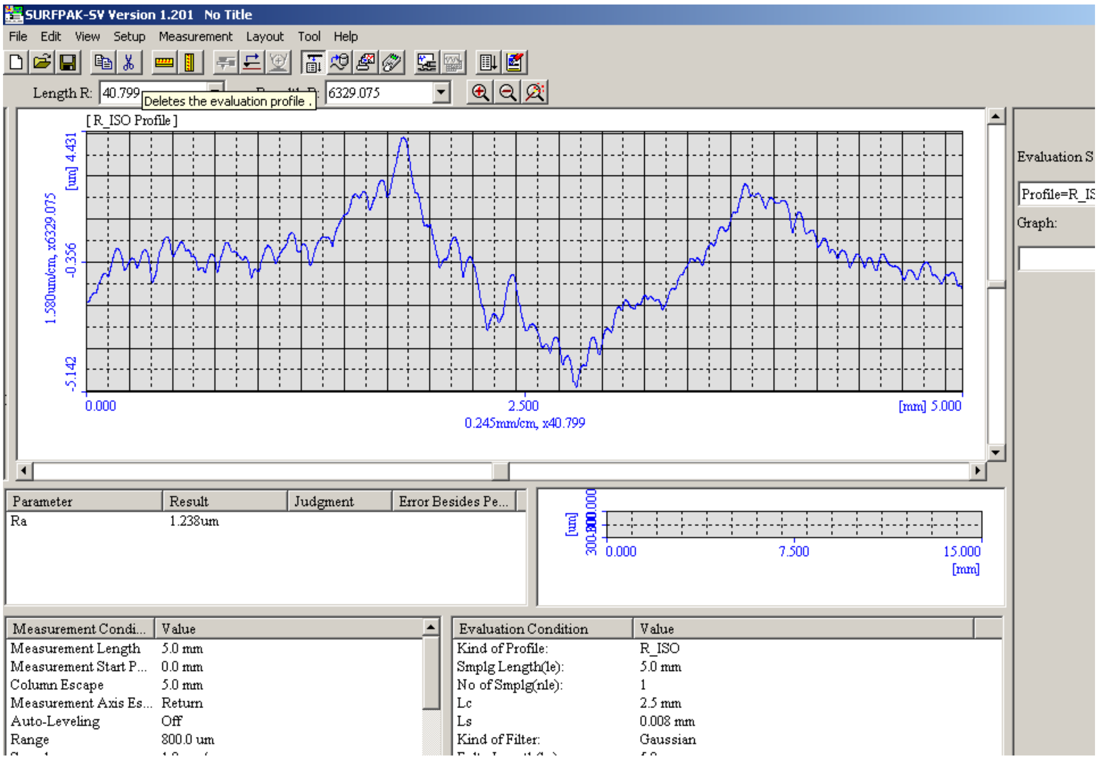

APPENDIX III-d Result of surface roughness for hole 2 on third specimen. (Drilled with the irrigation of saline solution)



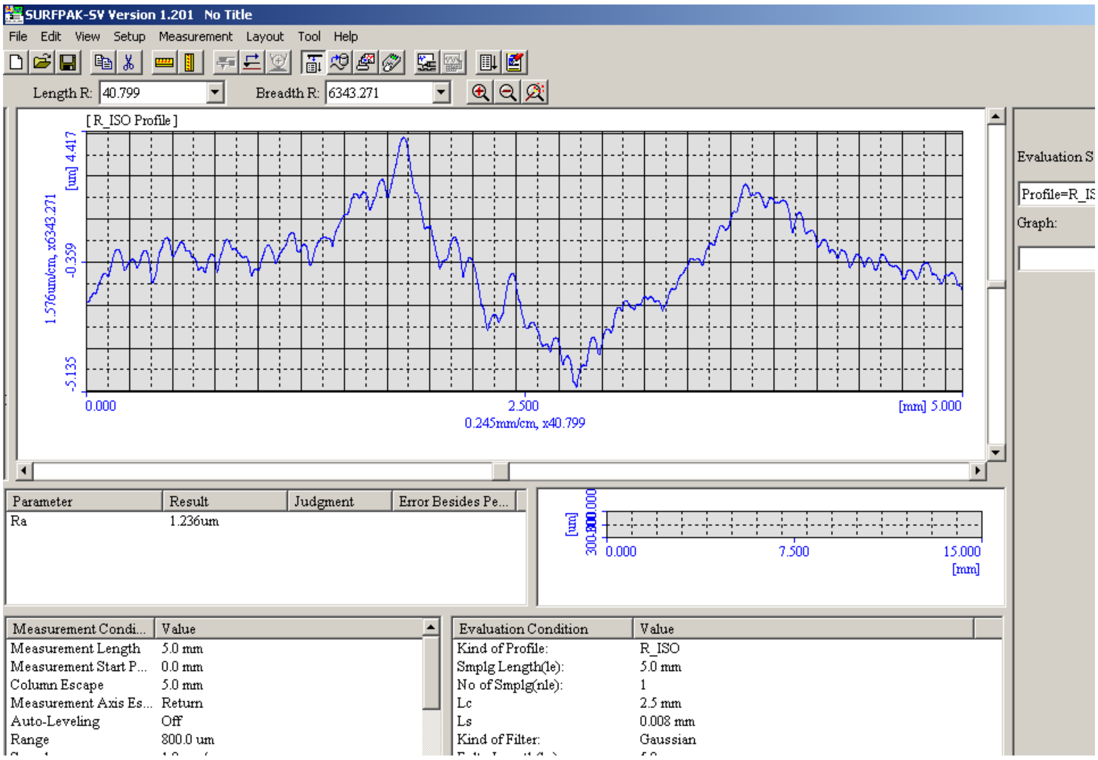
APPENDIX III-e Result of surface roughness for hole 2 on third specimen. (Drilled with the irrigation of saline solution)



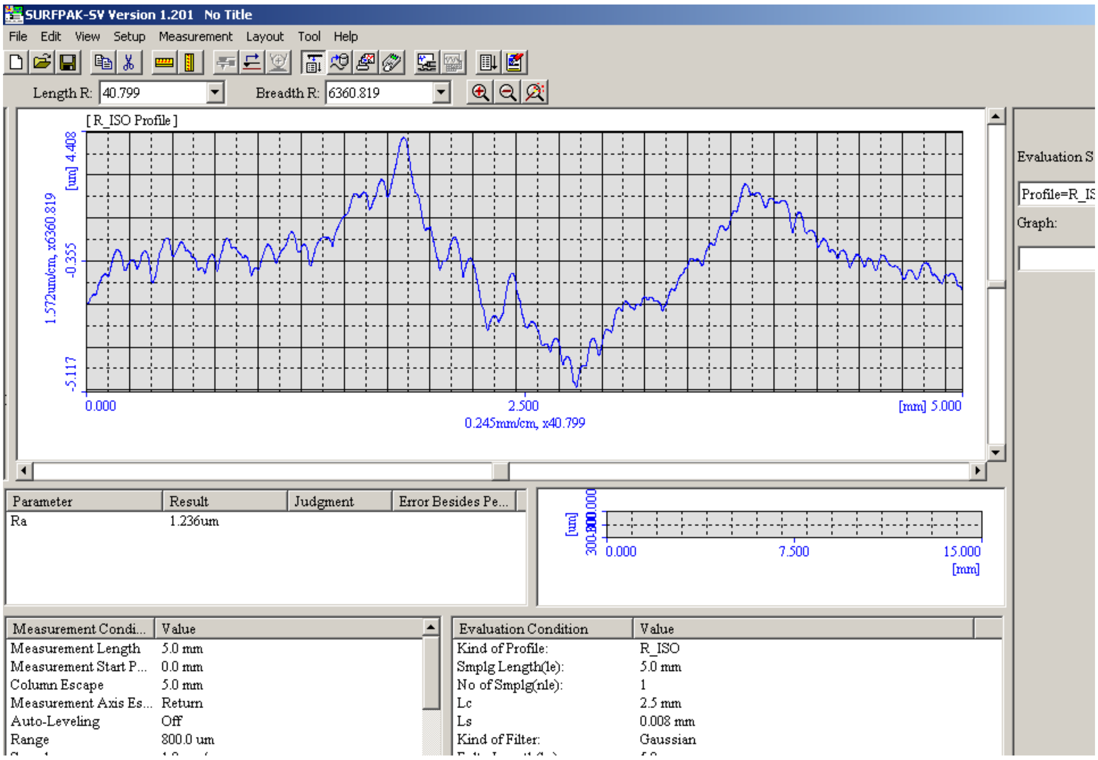
APPENDIX III-f Result of surface roughness for hole 2 on third specimen. (Drilled with the irrigation of saline solution)



APPENDIX III-g Result of surface roughness for hole 3 on third specimen. (Drilled with the irrigation of saline solution)



APPENDIX III-h Result of surface roughness for hole 3 on third specimen. (Drilled with the irrigation of saline solution)




APPENDIX III-i Result of surface roughness for hole 3 on third specimen. (Drilled with the irrigation of saline solution)

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