EFFECTS OF FLUSHING ON ELECTRO-DISCHARGE MACNINED SURFACE

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We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing.

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I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Electrode discharge machining is the process for shaping hard metal and forming deep by arc erosion in all kind of electro conductive material. The objective of this research is to study effect of flushing parameter of EDM of tungsten carbide on the machining characteristics. The effectiveness of the EDM process with tungsten carbide is evaluated in term of surface roughness, and microstructure of the workpiece also to optimize the machining parameter of machining tungsten carbide using EDM machine. Experiment on tungsten carbide material was carried out using difference pressure flushing machining parameter with copper tungsten electrode. Base on the flushing pressure gauge at machined EDM AQ55L the range pressure flushing on this machine EDM is 0.025 to 0.125 Mpa. In this experiment, the jet flushing pressure is used for flow the dielectric into the gap spark between electrode and workpiece. Better machine performance is obtained generally with the electrode as the cathode and the workpiece as the anode. The optimal flushing pressure is found to be at 0.1 MPa. This is the best flushing rate that will be chose in the parameters because it has small surface roughness. There is little variation on the surface roughness of the workpiece, although at 0.1 Mpa the surface finish tends to be better. At 0.05 MPa to 0.1 Mpa, the grain solid debris begins to decrease on the surface at this pressure. Effects from the higher spark formed a large void and the grains bunchy exist in that area also sticks together in the void.

ABDTRAK

Electrode discharge machining (EDM) adalah satu proses untuk membentuk logam dan permotongan yang dalam pada bahan kerja yang mempunyai kekerasan yang kuat, ia terjadi daripada hakisan arc dalam beraliran elektrod dengan material. Objektif dalam kajian ini ialah untuk mempelajari kesan-kesan terhadap bilasan parameter pada bahan kerja tungsten carbide dengan ciri-ciri pemesinan. Keefektifan daripada proses (EDM) terbahagi kepada kadar kekasaran permukaan bahan dan permukaan bahan kerja selepas pemesinan di lakukan. Dalam kajian bahan kerja tungsten carbide, perbezaan bilasan tekanan pemboleh ubah mesin dengan electrode copper tungsten. Merujuk kepada mesin EDM model AQ55L, tekanan bilasan akan dibuat secara manual pada mesin ini. Kadar keupayaan tekanan yang dilakukan antara 0.025 hingga 0.125 Mpa. Prestasi mesin lebih baik diperolehi kerana biasanya elektrod sebagai katod dan kerja sebagai anod. Tekanan bilasan yang optimum adalah berada pada tekanan 0.1 MPa. Ini merupakan kadar pancuran yang paling baik kerana ia mempunyai kekasaran permukaan yang kecil. Walaupun perubahan pada kekasaran permukaan kerja adalah kecil namun tekanan pada 0.1 MPa mempunyai kemasan permukaan yang labih baik. Pada 0.05 MPa hingga 0.1 Mpa, didapati biji-bijian bermula berkurangan pada permukaan bila tekanan bilasan ditingkatkan. Kesan-kesan daripada bunga api lebih tinggi menyebabkan lubang dan lembah besar terhasil membolehkan bijian terkumpul didalamnya. Pada tekanan bilasan 0.125Mpa, keadaan pemotongan adalah tidak stabil. Ini kerana cecair leburan yang terhasil daripada percikan bunga api pada kawasan yang sama.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Electro-discharge machining, commonly known as EDM, is a machining device that use electrical energy to shape and forming a metal parts. Electro-discharge machining (EDM) is one of the most accurate manufacturing processes in performs the job on hard metal and other materials that are difficult to be done by conventional machine. The application of EDM is limited on machining electrically conductive workpiece material because EDM has the capability of cutting the material regardless of their hardness or toughness.

Electro-discharge machining (EDM) works by eroding the material that appears in the electrical discharge as a conductive path is established between the electrode and the material being machined. So there is no actual contact between the two components and a workpiece that sometimes dipped in a dielectric to develop a potential difference between the workpiece and electrode. This material is responsible for generating spark from tool and the work piece. A shaped tool, electrode, or wire can be used to generate the sparks between the workpiece and electrode. The electrical discharge machining takes place within a bath of dielectric fluid in order to prevent premature sparking. It also conducts electricity between the electrode and the work piece. [10]

Flushing is one of the important factors in operation Electro-discharge machining (EDM). Flushing pressure is produced from both the top and bottom flushing nozzles. The pressurized of fluid help in spark production and in eroded metal particle removal the debris when it is done and also as a cooling the electrode and workpiece. Wong, Y.S. et. al [6].

Electrical discharge machining has the advantages compare to the other machining techniques due to its ability to create complex and intricate parts with a high degree of accuracy. This process is able to machine the hard materials, where the others machining processes would have a difficulties. Another advantage of EDM is its ability to machine parts on an extremely small scale.

1.2 PROBLEM STATEMENT

EDM is commonly used in tool, die and mould making industrial for machining heat treated ceramic material such as tungsten carbide. Electrode discharge machining is the process of electrically removing material by making continuous spark between the electrode and the workpiece in the dielectric

Flushing is one of the important factors in operation Electro-discharge machining (EDM). Flushing pressure is produced from both the top and bottom flushing nozzles. The pressurized of fluid help in spark production and in eroded metal particle removal the debris when it is done and also as a cooling the electrode and workpiece. Wong, Y.S. et. al [6].

Flushing is a useful procedure for removing debris from the discharge zone, however some debris are not clearly removed from the machined surface. Therefore this debris may effects the machined surface and also reduces the material removal rate during machining.

The physical properties of the fluid influence the breakdown voltage and the ignition delay. However, the debris concentration in the fluid will modifies these parameters, decreasing the dielectric strength by many orders of magnitude. Flushing is a useful procedure for removing debris from the discharge zone, however some debris are not clearly removed from the machined surface. Therefore this debris may effects the machined surface and also reduces the material removal rate during machining. Even if it is difficult to avoid concentration gradients and inaccuracy. Lonardo, P. M. [4].

The characteristics that required by a dielectric used in EDM are high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability. Besides these basic requirements, practical criteria need to be considered in the selection of a dielectric including the health and safety, and maintenance. Tool wear and workpiece removal rates are affected by the type of dielectric fluid flushing. Wong, Y.S. et. al [6].

1.3 OBJECTIVE OF THE STUDY

i. To determine the effect of flushing on the machined surfaces of electro-discharge machining such as surface roughness (Ra), and microstructure.
ii. To optimize the machining parameter of machining tungsten carbide using EDM machine.

1.4 SCOPE OF THE STUDY

i. This research to measure the surface roughness (Ra), and microstructure of machined surface.
ii. This project consider the variable of flushing pressure, while other the parameters machine such as polarity, peak current, pulse duration (on-time) and pulse interval (off-time) are constant.
iii. The die sinking EDM Sodick machine model AQ55L will be used to machine tungsten carbide using copper tungsten tool electrode.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION EDM MACHINE

Electrical discharge machining or EDM is a thermal erosion process in which the work piece material is removed through a series of rapidly reoccurring electrical discharge between electrode (cutting tool) and an electrical conductive work piece in a presence of a dielectric fluid.

There is a voltage gap between the electrode and the work piece that form the spark vaporizes minute particles of the work piece material, which is then washed out from the gap by the continuously flushing dielectric fluid. EDM is a diverse process that produces products ranging from tiny electric connectors, medical parts, and automatic stamping dies and aircraft body panels. EDM has replaced much of the machining, grinding steps needed in die making which represents the largest single use of EDM. Die component cut with EDM can often be made in a single piece no matter how complex the internal form. The single piece die are always stronger than those made of segments.

The EDM process also has its limitations. The metal removal rates are low compared to conventional metal cutting processes. Complex materials require lead-time for fabrication and are consumable while cutting and the work piece materials must be conductive. The basic components of the electrical discharge machinery are relatively simple. The electrode is attached to the RAM, which is connected to one pole of the electric power supply. The work piece is connected to the other power supply. The work piece is then positioned so that there is a small piece between work piece and electrode. This gap is flooded with dielectric fluid which acts as insulator until the power is turned out. Once on, the machine delivers thousands of electric pulses per second to the gap and erosion begins. As erosion continues the machine control advances the electrode through the material and is containing a constant gap distance.

As a pulse of DC Electricity reaches the electrode and part an intense electric field develops in the gap, microscopic contaminates suspended in the dielectric fluid are attracted by the field and concentrated in the field's strongest point. These contaminates builds a high conductivity along the gap as the field's voltage increases. These materials in the conductive bridge heat up. Some pieces ionize to form a spark between the electrode and the work piece. At this point the both the temperature and pressure in the channel increase generating a spark. A small amount of the material melts and vaporizes from the material and the work piece at the point of spark contact. A bubble composed of gaseous by products vaporize rapidly expands rapidly outward from the spark generated. Once the pulse ends the spark and the heating action stop collapsing the spark channel. Dielectric fluid then rushes into the gap forcing melted material out from the surfaces. This EDM residue consists of solidified parts of material and gas bubbles.

The EDM cut can have several observable surface layers. The top surface is created when expelled molten material and small amount of electrode material melt forms spheres on part of the surfaces, this layer is easily removed. The next layer is a recast or white layer as EDM has altered the piece metallurgical structure. All work occurs during the on time so pulse duration and the number of cycles per second. The sum of on time and off time is important. Metal removal is proportion to the amount of energy during on time that energy is controlled by the time variables. The peak Amperage or intensity of the spark and the length of the on time. The larger the on time the more the metal erodes.

Off time also affects speed and stability of the EDM cut. Too shorten off time, the ejected material will not flood easily with the dielectric fluid. The next spark may then be not stable. The duty cycle is the percentage of on time relative to the total cycle time. The higher the duty cycle means increased cutting efficiency. Gap distance between work piece material and the electrode also impact the material removal rate. Generally the smaller the gap the better the accuracy and the surface finish are and the metal removal rate is.

There is a direct relationship between the voltage and the gap. The servo system must sense the voltage between the electrode and the work piece. This signal controls the servo system and maintains a constant gap distance between the electrode and the work piece through out the EDM cycles. Most power supplies provide a cut off or fault protection system to stop power flow to the system if a short circuit between the electrode and the work piece occurs. To successful EDM flushing is very essential, where the EDM dielectric system introduces clean dielectric to the EDM cutting zone flushing away the EDM debris and cools the work piece and electrode. Popular dielectric fluids for EDM systems are hydrocarbon and silicon based oil.

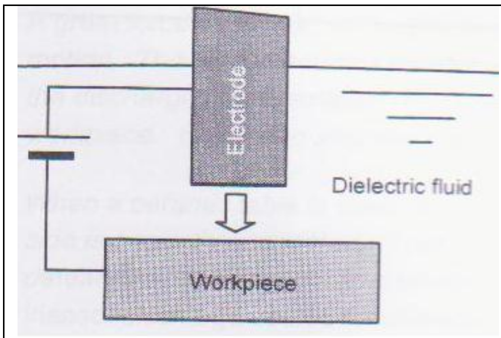
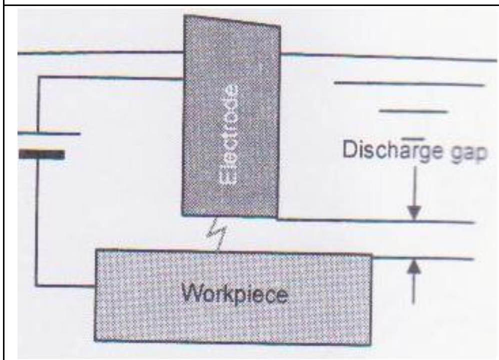
The dielectric fluid is pumped through nozzles through the electrode or through the work piece or some combination of them to continuously flush the work area. Flushing requires careful consideration because of the high forces involved forcing the fluid through small passageways. Many low-pressure holes are preferred to many high-pressure holes. The EDM electrical polarity is usually has a positive charge and the workpiece polarity is negative and depend on the negative and positive workpiece.. Although the metal removal is smaller than if the polarity is reversed. A positive electrode polarity protects the electrode from excessive wear and preserves its dimensional accuracy.

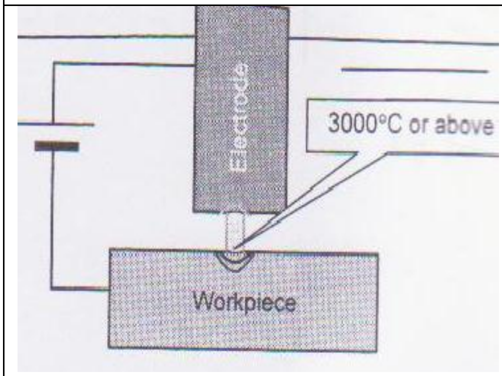
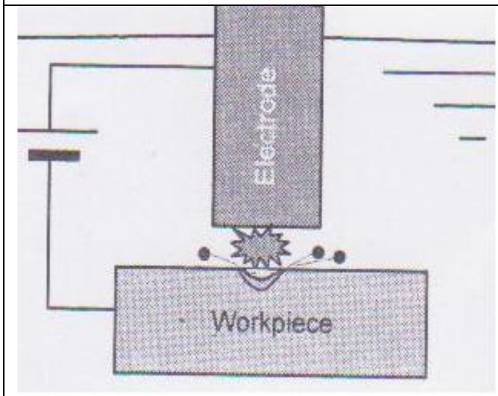
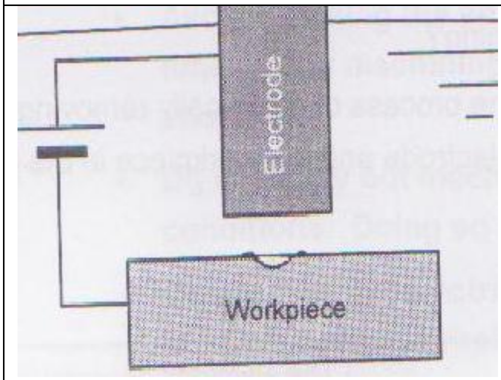
Che Haron et. al [11], Copper and graphite are the most common electrode materials. Whatever the electrode material is used it should combine high strength and high melting point. To help the electrode resist the erosion of the corners where electric field is concentrated. Making the electrode is an important step in ram EDM. The electrodes are shaped on all types of machines. Since the copper material turns to dust, the machine must be equipped with a system of dust control and evacuation.

2.2 APPLICATION ON EDM MACHINE

Electrode discharge machining is the process of electrically removing material by making continuous spark between the electrode and the workpiece in the dielectric. Based on book Nc Power Supply for EDM LN2-LQ Machining Manual, Table 2, show briefly about how the spark produces between workpiece and electrode.

Table 2.1: Show briefly explained about the spark sequence. [14]

<table>
<tr><td>
</td><td>The electrode approaches the workpiece through the medium of dielectric fluid while applying no-load voltage direct current.
• The voltage direct current level is determined by machining condition and parameter.</td></tr>
<tr><td>
</td><td>When there is some space left between the electrode and the workpiece, the electrode further comes closer to the workpiece by mean of servo motion. When the spaces become several or dozen of microns (discharge gap) insulation between the electrode and the workpiece is broken and spark occurs.</td></tr>
</table>

	• The size of discharge gap depends on the intensity of discharge energy.
	An intense energy column of high temperature and voltage is formed at the gap (between the electrode and the workpiece) instantaneously, and is maintained for a certain time. This energy column reaches as high temperature as 3000˚C or above, melting the metallic part of workpiece material with partial ionization.
	When an energy column is formed, the dielectric fluid temperature explosively rises, which causes the fluid to expand and evaporate. Part of melted splashes away and a crater is formed on the workpiece.
	Explosion of dielectric fluid disperses the product. When insulation is recovered at the gap, voltage is applied again to start the next electric discharge process. The above processes are repeated during machining. Once cycle time is approx. several microseconds to several milliseconds, repeating dozens of thousands of times within one second.

2.3 THE MACHINING CHARACTERISTICS OF EDM

Machining characteristic is best defined as the outcome of the machining process. For example surface roughness (Ra) and microstructure of surface structure and many more.

2.3.1 Surface roughness (Ra)

Roughness is defined as closely spaced, irregular deviation on a small scale. It is expressed in term of its height, width, and the distance along the surface. Roughness is a measure of the texture of a surface. It is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small, the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. The surface roughness depends on the current and electrode that used in machine EDM. Serope Kalpakjian [13].

2.3.2 Microstructure

Oxford dictionary define the microstructure is structure of an organism or object as revealed through microscopic examination and also define the microscopic structure of a material in investigated experiment.

Based on Figure 2.1, effects of flushing rate on difference workpiece material. Wong Y.S, et. al [6] found the effects of flushing rate on the types and distribution of recast layers. There is an optimal dielectric flushing rate of about 13ml/s where the crack density and average thickness of the recast layer are at a minimum for all three materials. The trends for the crack density and recast thickness are similar, being higher at flushing rates below and above a basically similar optimal rate. There is also a minimum of type 3 recast at around the same optimal rate. Type 3 recast layers are associated with increased incidents of cracks. Crack density is higher at the corners and sides. The effects of the quenching property and debris removal ability of the dielectric flow conditions on the recast layers.

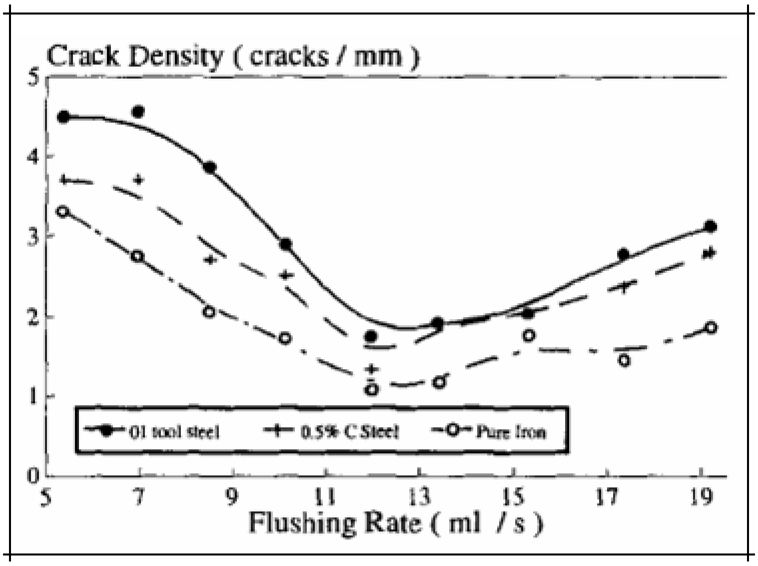


Figure 2.1 Effects of flushing rate on difference workpiece material. [6]

2.4 TYPE OF PARAMETERS IN EDM

Electrode discharge machining parameter can be categorizing into two major groups: electrical and non-electrical parameter. The electrical parameters consist:

i. Electrode material
ii. Average current I (A)
iii. Electrode polarity +/-
iv. working current density, Id (A/cm2)
v. Peak current, Ip(A)
vi. Open gap voltage, Vo (V)
vii. Pulse duration, ti (micro s)
viii. Dielectric
ix. Pause off time, to (micro s)
x. Flushing pressure (Pa)
xi. Average voltage, U (V)
xii. Average current, I (A)
xiii. Jumps speed, (JS)

The non-electrical parameters are servo parameter such as gap and gain. For the EDM machine itself can be spread into four main components which are a machine tool, power supply, computer panel and mechanism. Chen, S.L and Q.C. Hsu. (2003).

Table 2.2: Is show briefly explained about the parameter. [10]

Parameter	**Application**
Electrode material	The tool in the EDM process. It must be made from an electrically conductive material. Its form, or shape, is a mirror image of the finished form or shape desired in the workpiece, with its dimensions adjusted to take into account the amount of over "burn" that occurs.
Electrode polarity (PL)	In EDM, the designation of positive or negative electrical polarity of the electrode. Positive polarity of the electrode (EDM) is considered to be Normal and produces the least amount of electrode wear. The positive or negative polarity depends on the machine.
Peak Current (IP)	The maximum current available from each pulse from the power supply/generator. The peak current is the best defined as the high electrical current that can occur during the discharge. Generally the value of this peak current based on the code, the actual value in unit ampere for this current reading in manual book machine.
Pulse duration (on-time) in time	The duration time of the EDM spark measured in microseconds-μs The longer spark is sustained more is the material removal rate. Except, during roughing all the sparks that leave the tool result in a microscopic removal of particles of the surface. More spark produce much more wear
Pause Duration (off-time) in time	The time between sparks, measured in microseconds. Too short an off-time may result in unstable machining or worse, DC arcing. Longer the off time will cause longer machining time. But this is an integral part of the EDM process must exist. The

	off time also governs the stability of the process. An insufficient off time can lead to erratic cycling and retraction of the advancing servo and result slowing down the operating cycle.
Average current	The average value of all the minimum and maximum peaks of amperage in the spark gap, as read on the ammeter
Open gap voltage	The voltage that can be read across the electrode/workpiece gap before the spark begins to flow. See gap voltage.
Dielectric fluid	In EDM, a liquid medium that fills the gap between the electrode and workpiece and acts as an insulator until a specific gap and voltage are achieved. Used to remove chips and cool the electrode/wire and workpiece. It It then ionizes and becomes an electrical conductor, allowing a current (spark) to flow through it to the workpiece. It also serves to cool the work and to flush away the particles generated by the spark.
Flushing pressure	The pressure supplied by pumps in the dielectric system supply fluid to the spark gap duration (sec).
UP: Jump-up machining time	These parameters specifies the duration of the jump-up motion to be used when removing chips from the gap by moving the axes during machining.
DN: Jump-down machining time	This parameters specifies the duration of electric discharge between the jump-down motion and the next jump-up motion in duration (sec)
JS: Jump Speed	The first and second digits of the parameter specify the axis travel speed for jump-up and jump-down motion. This parameter in (m/min).

2.5 ELECTRODE MATERIAL

EDM electrode materials are the components consist of highly conductive and arc erosion-resistant materials. EDM electrodes are manufactured in many forms such as coated wire, tube shaped, or bar stock, depending on the EDM electrode materials used in machine and suitable to cut the workpiece. Below is a brief explanation about the material.

2.5.1 Brass electrode

Brass is easy to machine and can also be die cast or extruded for use in special applications, also brass is not as wear-resistant as other EDM electrode materials. Brass material is used to form EDM wire and small tubular electrode.

2.5.2 Copper tungsten electrode

Is a common base material because it is highly conductive and strong. Copper tungsten electrode is low cost, good machinability, low wear ratio, good finish but not good for high accuracy.

Chen, S.L. et. al [9] found that the electrode copper-tungsten is better than copper as an electrode material due to homogeneous wear ratio in investigation. Che Haron, [11] found that the wear rate of copper tungsten electrode was lower than that of graphite electrode. This is due to the higher melting point of copper tungsten electrode material 1083˚C and graphite 455˚C, which is less eroding than that of the lower melting point graphite electrode material.

2.5.3 Graphite electrode

Che Haron et. al [11] found that the copper electrode is suitable for roughing process, whilst graphite electrode is suitable for finishing process and Combination of both electrodes will improve machining characteristics and surface finish. Graphite electrode is suitable for finishing process.

Graphite (carbon) electrode is the most common type of EDM electrode because it is easily machined, has high wear resistance, and suitable used for various temperature, and is cost effective.

2.6 TUNGSTEN CARBIDE AS A WORKPIECE

This material is combination of tungsten and carbon. Tungsten carbide and other metal carbides are used for EDM workpiece materials because they have high hardness qualities and are wear resistant. Tungsten carbide is an important tool and die material mostly used because of its high hardness, strength and wear resistance. Specific grades are available with corrosion resistance approaching that of noble metals. Conventional grades have sufficient resistance to corrosion-wear conditions for many applications. Tungsten carbide has very high strength for a material so hard and rigid. Compressive strength is higher than virtually all melted and cast or forged metals and alloys. These materials suitable for make insert mould, punch tool and drill bit.

2.7 EFFECTS OF FLUSHING ON CHARACTERISTIC EDM

From the literature review, the effect of dielectric flushing on the machining characteristics was investigated by Lee [5] using peak current of 24 A, gap voltage of 120 V, pulse duration of 12.8 μs, pulse interval of 100 μs, copper tungsten (CuW) as tool electrode materials with negative polarity, and tungsten carbide as the workpiece material used in the experiment. The effects of flushing pressure on the material removal rate, and surface roughness of the workpiece produced are shown in Figure 2.1 and and Figure 2.2.

2.7.1 Effect of flushing pressure on workpiece surface roughness

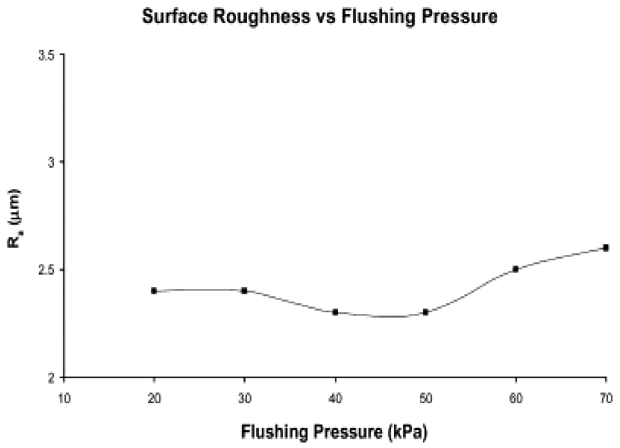


Figure 2.2 Effect of flushing pressure on workpiece surface roughness. [5]

By referring the Figure 2.2, Lee [5] investigated flushing pressure at 40kPa to 50kPa and the surface roughness is smoothing proportionate. When increase flushing pressure the rate of value surface roughness also increase. Factor of flushing pressure is important to remove gaseous and solid debris generated during EDM in the spark gap between material tool and workpiece. Uneven of electrode wear can be affected the accuracy and surface roughness that normally come from improper flushing.

Lonardo [4] made an experimental analysis on Chromium (Cr), Molybdenum (Mo), and Vanadium (V) steel die casting by using both copper and graphite electrode. In experimental investigation, flushing produces has significant increase in root mean square (rms) slope (α = 0.99). Interaction between flushing and electrode size appears also significant at same level. Height surface roughness consider strong dependence on the electrode material (α = 0.99). Copper electrode produces lower height. The remaining factors have no significant influence on these parameters.

2.8 FLUSHING PRESSURE

The factor of flushing pressure is important to removal of gaseous and solid debris generated during EDM in the spark gap between material tool and workpiece. Uneven of electrode wear can affect accuracy and surface roughness that normally come from improper flushing. Improper flushing can also reduce removal rates due to unstable machining conditions and arcing around regions with high concentration of debris. Good flushing provides good machining conditions.

From Lee [5], when the flushing pressure is too low, the flushing cannot remove the gaseous and solid debris after each discharge. However, if the dielectric pressure is too high, no proper machining can be done as the ionized channel is continuously wash away and the relative wear ratio will increase. The material removal rate is slightly decreased with higher flushing pressure. Excessive pressure can also accelerate electrode wear and create turbulence in the cavity. The surface roughness does not change too much with flushing pressure.

Jose et. al [2], the flushing of the dielectric during the sparking process has an adverse effect on the EDM performance measures. Wong et. al [6], optimal dielectric flushing rate where cracks and average thickness of the recast layer are at a minimum. Rate of the flushing also effects of the ability flushing to remove the debris between tool and workpiece during process.

Masuzawa [7], stated that a dynamic jet flushing with moving nozzles that sweep along the sparking gap providing an even distribution of debris concentration has been reported recently. Other alternative ways of improving the flushing condition involve making relative motion between tool and workpiece. These include making an electrode planetary movement at the lateral gap allowing dielectrics to flow in from one side and leave at the other side of workpiece.

2.9 DIELECTRIC FLUIDS

During the EDM process the workpiece and the electrode are submerged in the dielectric kerosene, which is an electrical insulator that helps to control the arc discharge. The dielectric kerosene that provides a mean of flushing is pumped through the arc gap. This remove suspended particles of workpiece material and electrode from the work cavity, insulates against premature discharging, and helps to cool the electrode and workpiece. The dielectric fluids perform three important functions:

i. It insulates the gap between the electrode and workpiece preventing a spark from forming until the gap and voltage are correct. When this occurs, the dielectric ionizes and allows the discharge to take place.
ii. It cools the electrode, the workpiece, and solidifies the molten mental particles.
iii. It flushes the metal particles out of the working gap to maintain ideal cutting condition, increase metal removal rate, improve machining condition, and reduce machining time. The dielectric fluid must be filtered and circulated under constant pressure in order to be effective.

2.10 ADVANTAGES AND DISADVANTAGES OF EDM

Every machining process has advantages and disadvantages. In Electrode discharge machining, some of the advantages of EDM include the machining of complex shapes that would otherwise be difficult to produce with conventional cutting tools, machining of extremely hard material to very close tolerances, and machining of very small work pieces where conventional cutting tools may damage the part from excess cutting tool pressure. Some of the disadvantages of EDM include the inability to machine non conductive materials, the slow rate of material removal, and the additional time and cost used for creating electrodes for ram EDM.

CHAPTER 3

METHODOLODY

3.1 INTRODUCTION

In order to achieve the objective of this project, a structure of overall methodology should be well need plan in this chapter and also refer as a execute the experiment. In this project, the arrangement of the procedure should be properly to ensure the objectives achieved.

In this experiment on tungsten carbide material were carried out using different flushing pressure setting with electrode copper tungsten and the other machining parameters such as polarity, peak current, pulse ON and pulse OFF will be consider constant. The type of flushing pressure used during the experiment is jet flushing (refers to Figure 3.9). However, before the exact parameter can be used, tries and error will be done in order to find the best machining parameter for tungsten carbide. The experiment will be run based on the data machining condition obtained from the machine plan (refers to Appendix A). Then, the actual parameter will be used for the whole experiment can be refer in Table 3.3. After that, machining is done, the surface machine will be measured using Mahrsurf XR 20 Pethometer S2 and Scanning Electron of Micrograpy (SEM) on the workpiece tungsten carbide. The conformation test will be discussed in the next chapter. Figure 3.1 is the illustrate of the methodology involve in this study.

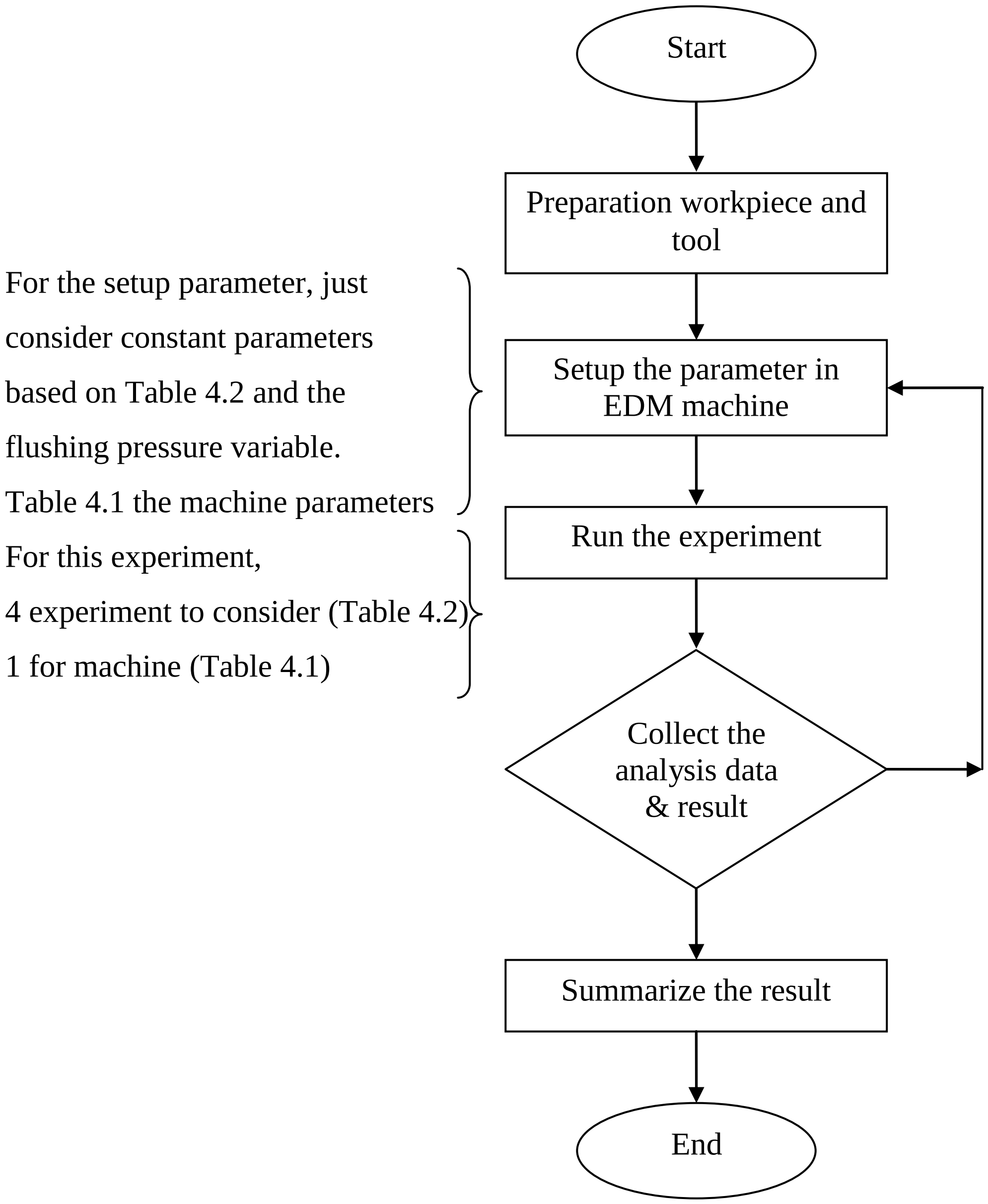


Figure 3.1 Flow chart for the whole process.

3.2 ELECTRODE MATERIAL

Based on the literature review, copper tungsten electrodes is the best electrode choosing and therefore it is chosen to run this experiment. This material is more suitable to machine difficult to machine material like tungsten carbide. The properties of the copper tungsten electrode are show in Table 3.1 and the electrode dimension used is given in Figure 3.2.

Table 3.1: Copper tungsten electrode properties

Physical properties	**Copper Tungsten**
Electrical resistively	5.5 μΩ/cm
Composition	72 % Tungsten, 25 % Copper
Density	15.2 (g/cm^3)
Melting Point	1083 ^{o}C
Hardness	HB 200

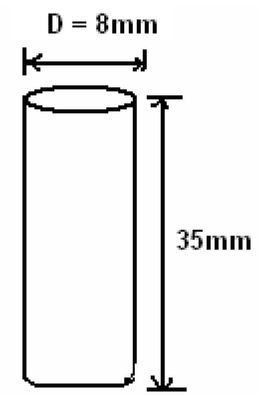


Figure 3.2 The dimension of the electrode used.

There are many advantages in using copper tungsten electrode such as it is highly conductive, low cost, good machinability, low wear ratio, and good finish and good for high accuracy machining.

3.3 WORKPIECE MATERIAL

The workpiece material used in this experiment is tungsten carbide with 15% of cobalt content. The property of the material workpiece is shown in Table 3.2 and in Figure 3.3 is the illustrated of the workpiece dimension.

Table 3.2: Workpiece material properties

Physical properties	**Tungsten Carbide**
Density	15.1 g/cm^3
hardness	HRA 87.0
Melting point	2597 ^oC
Tensile strength	179 kg/mm^2
Strength Toughness	50 kg/mm^2
Compressive	410 kg/mm^2

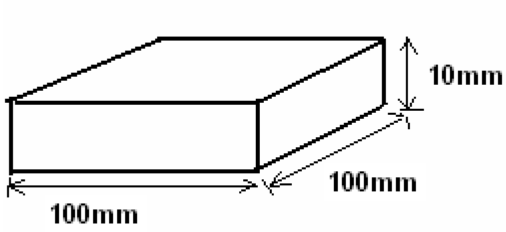


Figure 3.3 The dimension of the workpiece

3.4 SET-UP OF PARAMETERS IN EDM

Based on the literature review done, the investigation of the effect of flushing pressure on the machined surface EDM after undergone machining was still scare. Therefore, in this study the effect of varies flushing pressure with constant other parameters such as polarity, pulse current, pulse-on time, pulse-off time, and gap voltage. Table 3.3 is showed the value of the parameters used throughout this experiment.

Table 3.3: Machining parameters used in the EDM machining.

Parameter	**Condition**
Electrode	Copper Tungsten
Dielectric	Kerosene
Peak current	21.0A
Pulse on time	10µs
Pulse off time	15µs

3.5 EXPERIMENTAL PROCEDURE

In this study, the Electrode discharge machining (EDM) Sodick model AQ551 was used to conduct the experiments refers to the Figure 3.6. Based on the Figure 3.4 is illustrate of the electrode movement on the workpiece surface during the machine run throughout the experiment.

As shown is Figure 3.5, the machining plan (mach plan) based is displayed screen monitor on the EDM after set is done in order to the material. From this machining plan (change all mach plan to machining plan) the data machining will be used as a guideline in order to suitable parameter to cut the material using EDM machine. Table 3.4 is showed the machining data to use in this study.

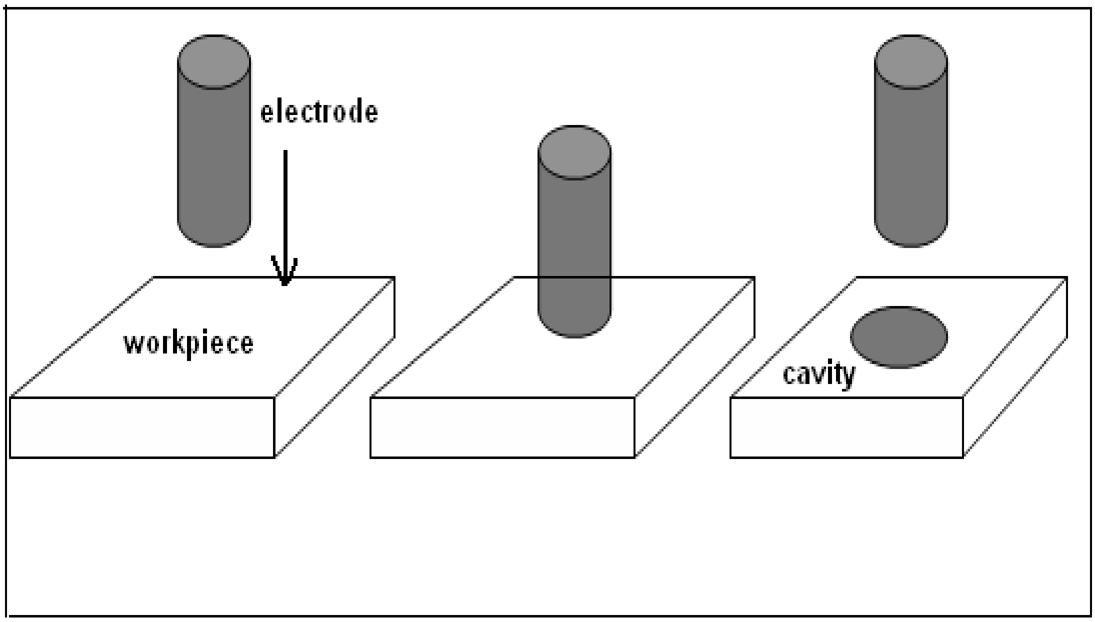


Figure 3.4 The electrode movement to the workpiece

3.5.1 Initial setup experiment procedure

1) After prepare the material to conduct the experiment (workpiece and electrode) is done.
2) "ON" the main switch at EDM machine and power supply.
3) Setup the condition EDM machine, based on the Figure 3.5 is show the display machining plan at the panel display machine to set and keep in the data. Table 3.4 is show the data parameters used to conduct the experiment.

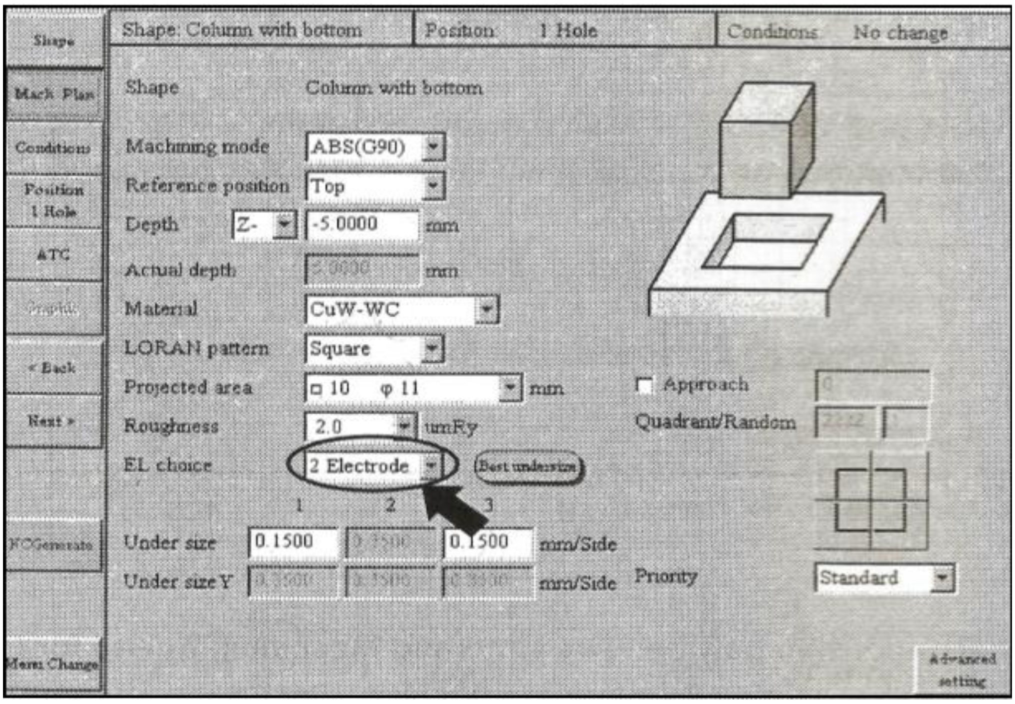


Figure 3.5 Mach plan to generate the machining parameters.

Table 3.4: Data machining program based on the EDM machine.

Item	Setting Data	Explanation
Shape	Standard	Based on the shape to produce.
Depth	Z- : -0.5mm	Machining to Z = -0.5
Material	CuW – WC	Electrode: Copper Tungsten Workpiece: Tungsten Carbide
LORAN pattern	OFF	OFF
Projected area	10mm sq, Ø 8mm	The area where the electrode is projected on the workpiece is approximately $100mm^2$. (This projected area select based on the machine data)
Roughness	2µmRy	This value for surface select in the machine
EL choice	1 electrode	Based on the electrode what will used
Undersize	NA	This undersize automatic calculate by machine after keep in the value projected area

4) After that generate the NC data. Click save and OK
5) After finish generate the NC data, clamp the workpiece on the table machine. Off and On magnetic used to clamp the material.
6) Prepare type of flushing to attach on the material and workpiece, the flushing must suitable used in this experiment. The volume flushing pressure can measure based on the flushing gauge machine. For this experiment, the jet or side flushing used to conduct the experiment. Figure 3.9 is show the type of flushing and dimension we used.
7) Change the electrode. Press the [manual] button at monitor and press [El Cha.] electrode change to select where position tool used in this experiment
8) Positioning to setting electrode and workpiece (The codeless function is used for positioning. The coordinates in the current coordinate system are reset zero)
    8.1 Move the electrode to the desired position
    8.2 Press the [manual] button, the [codeless] button, and the [appr. Face] button.
    8.3 Specify the desired axis and direction, and press the [Enter] switch. End face positioning is performed. When and face positioning has been complete, the electrode retreats from the workpiece by the distance specified for “ST to return”.
    8.4 Perform and face position again to confirm that there is no variation in the position. Be sure to select “OFF” for “Coordinate 0 (zero) set”
9) Finish setting the position electrode and material, push [edit] button to load the program NC.
10) Finally, push the [Run] button to run the experiment. Be careful, check again to confirm that the setting program in the

3.5.2 Surface roughness (Ra)

Surface roughness (Ra), is commonly defined as the arithmetic average roughness. While the (Ra) parameter is easy and efficient, there are other parameters that can be more specific and useful depending on the application requirements. It is the parameters that enable us to define surface roughness. Figure 3.7 is showed the Mahrsurf XR 20 Pethometer S2 machine, since it measuring used for the surface roughness. Mostly, fine surface finish used in the give the good quality of hardness and microstructure on of a workpiece. Table 3.5 showed the setting level of flushing pressure in this experiment.

Table 3.5: The effect of flushing pressure on the machined surface

Pressure flushing (Mpa)	Run 1	Run 2	Run 3	Surface Roughness, (Ra)
0.025				
0.05				
0.1				
0.125				

3.5.3 Microstructure

Microstructure is the structure of an organism or objects that revealed through microscopic examination and also defines as microscopic structure of a material. Table 3.6 showed three level of flushing pressure used in EDM machining of tungsten carbide.

Table 3.6: Table setting level flushing pressure at Microstructure

Run	1	2	3	4
Flushing pressure (Kpa)	25	50	100	125

3.6 EQUIPMENT AND INSTRUMENTS

The equipments involved in this study is listed in the figures below:

Figure 3.6 The die sinking EDM Sodick machine model AQ55L

Figure 3.7 Mahrsurf XR 20 pethometer S2 for measuring surface roughness

The Scanning Electron Microscope (SEM) is a microscope that uses electrons rather than light to form an image. There are many advantages when using the SEM instead of light microscope. The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. The SEM also produces images high resolution, which means any surface, can be examined and observed at a very high magnification. In order to use SEM machine, all the specimen must be ensure that it is a conductive material other wise, SEM can be performed. The combination of higher magnification, larger depth of focus, and greater resolution. Makes the SEM is one of the most important instruments in studies of microstructure of a workpiece after undergoing machining operation.

Figure 3.8: Scanning Electron Microscope model ZETXS EVO 50

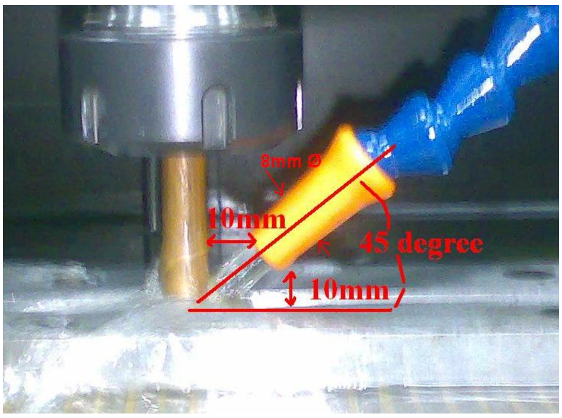


Figure 3.9 The diagram of jet Flushing Pressure

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This thesis is done in order to study to know about the optimum parameter of flushing pressure to be used for EDM Die Sinking in machining tungsten carbide. The investigation on machining characteristic of EDM have been done by running the machine based on varies level of flushing pressure with constant other parameters machine as shown in the Table 4.1, Table 4.2, and Table 4.3.

This chapter will covers on the experimental result and the data analysis obtained. First, analyzed the surface roughness result which measured by Mahrsurf XR 20 Penthometer S2 machining. After that. SEM is used in order to examine the surface defects on the machined of the workpiece. Finally, the data collection then will be compared with the reference by previous research to find the defects and confirmation in investigation.

Table 4.1: Machine condition data parameters

code	PL (polarity)	ON (on-time, μsec)	OFF (off-time, μsec)	IP (peak current, Amp)
C007	- ve	0008	0016	031.0 (124A)
C006	- ve	0008	0016	031.0 (124A)
C005	- ve	0006	0012	015.0 (60A)
C004	- ve	0005	0010	007.0 (28A)
C003	- ve	1004	0010	003.0 (12A)
C002	- ve	1002	0006	000.0
C913	- ve	1002	0006	000.0

Table 4.2: Constant setting data parameters

code	PL (polarity)	ON (on-time, μsec)	OFF (off-time, μsec)	IP (peak current, Amp)
C007	- ve	0010	0015	007.0 (28A)
C006	- ve	0010	0015	007.0 (28A)
C005	- ve	0010	0015	007.0 (28A)
C004	- ve	0010	0015	007.0 (28A)
C003	- ve	0010	0015	007.0 (28A)
C002	- ve	0010	0015	007.0 (28A)
C913	- ve	1010	0015	007.0 (28A)

Table 4.3: Value of flushing setting parameters

Run	1	2	3	4
Flushing (Kpa)	25	50	100	125

4.2 EXPERIMENTAL RESULT

After all the experiment perfectly done based on data parameters, the result will be collected. Then, the data for each structure surface roughness will be analyzed. Table 4.4 shows the data that had been collected. Figure 4.4 shows the graph of the data collection from the analysis. All the result analysis for surface roughness and microstructure is also attached in the Appendix A.

4.2.1 Surface roughness result.

Table 4.4: Surface roughness result

Run Flushing pressure	1 (Ra)	2 (Ra)	3 (Ra)	Average (Ra)
0.025 MPa	2.354	2.459	2.433	2.415
0.05 MPa	2.038	2.245	2.225	2.169
0.1 MPa	1.773	1.863	1.801	1.812
0.125 MPa	1.929	1.959	1.944	1.944

Table 4.4 shows the result for the average of surface roughness based on the three running measurement for each flushing pressure. After getting the value of average for each flushing pressure, the graph was plotted to find the effect of flushing pressure on the workpiece material. The experiment of the parameters can refer at Figure 4.1.

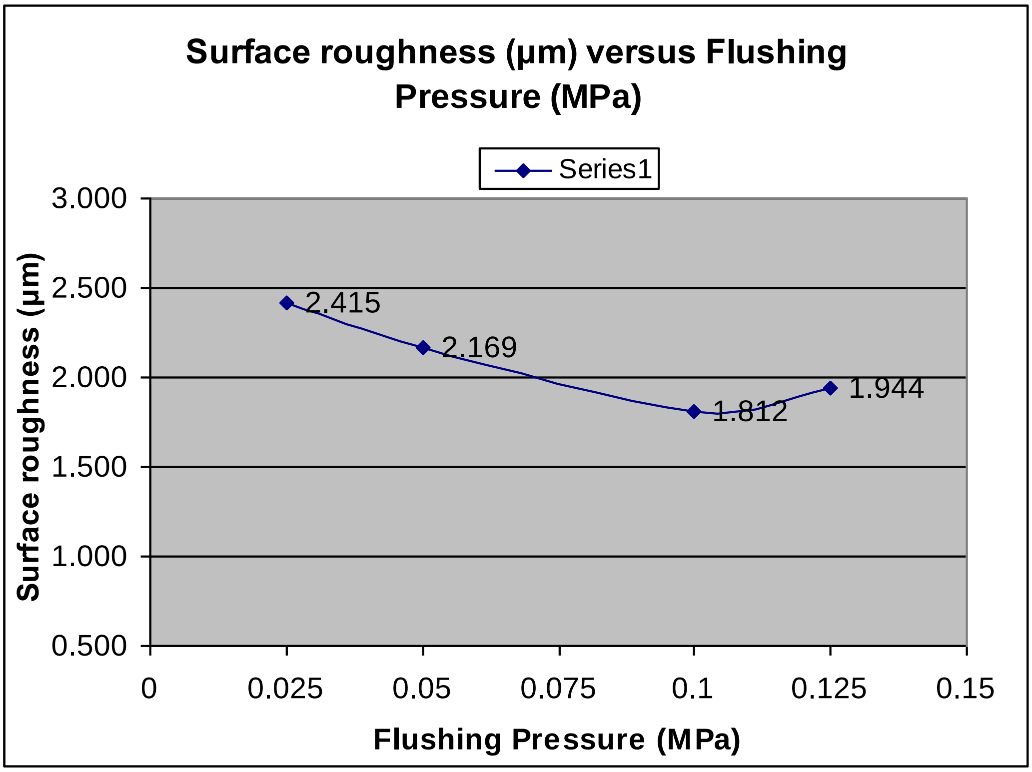


Figure 4.1 Effects of flushing pressure on workpiece surface roughness

4.2.2 Effects of flushing pressure

The effect of dielectric flushing pressure on the machining characteristics was investigated based on Table 4.2 with peak current of 28A, a pulse on-time of 10 µsec, a pulse off-time of 15 µsec, copper tungsten (CuW) as tool electrode material with negative polarity, and tungsten carbide as the workpiece material. The effects of flushing pressure on the surface finish of the workpiece produced shown in Table 4.4. Figure 4.1 shows the graph of the effects of flushing pressure versus surface roughness.

Based on the Figure 4.1, the optimal flushing pressure is found to be at 0.1 MPa. This is the best flushing rate that will be chose in the parameters because it has small surface roughness. There is little variation on the surface roughness of the workpiece, although at 0.1 Mpa the surface finish tends to be better. It is found that at 0.025 MPa to 0.05 MPa, the surface roughness is high.

One of the most important factors in successful EDM Die Sinking is flushing pressure flow rate and the angle of the jet flushing that used in this experiment, which is the removal of the metal particles generated in the spark gap between electrode and the material. It involves the distribution of flushing pressure flow through the spark gap to removes the gaseous, grains and solid debris generated during cutting process and maintain the dielectric condition parameters. Improper flushing also can cause the grains of the solid debris to stick on the surface and reduce removal rate due to unstable machining condition.

When the flow of the flushing pressure is too slow between electrode and workpiece surface, the flushing cannot removes the solid debris after discharge. However, if the flushing pressure is too high, no proper machining can be done as the ionized channel is continuously wash away.

4.2.3 Microstructure Based on Data Machine Generate

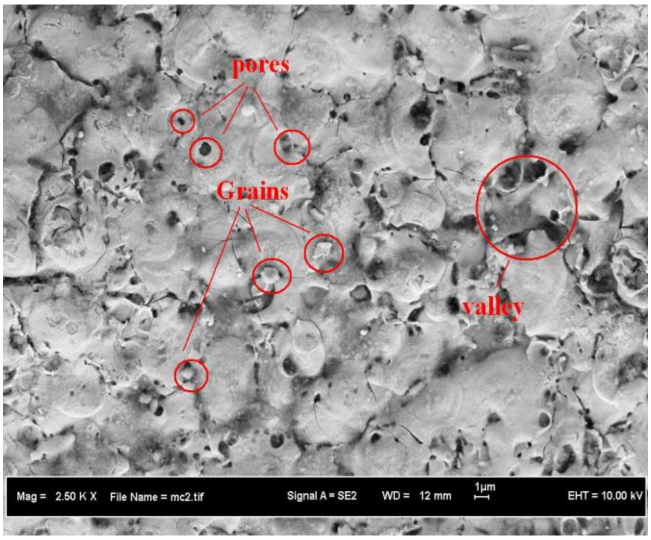


Figure 4.2 Microstructure Data Machine Generate (actual)

Based on the Figure 4.2, the investigations made by using the data generate from the machine refer to Table 4.1. The flushing pressure is 0.05 MPa. There are a few grains still stick on the surface workpiece which could not be eliminated by the flushing pressure. Besides that, there are also some pores forms and valley that happened from the cutting process. This factor will make the surface and the valley in some of surface structure out of phase. The other figure microstructure is also attached in the Appendix B.

4.2.4 Microstructure at Flushing Pressure 0.025 MPa

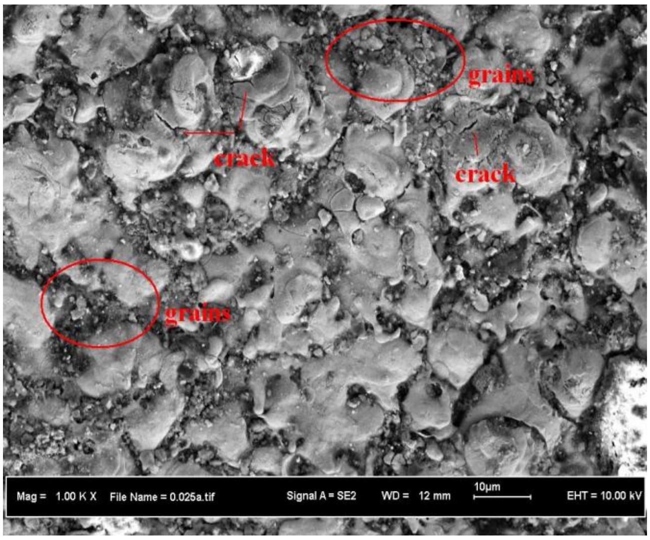


Figure 4.3 Microstructure at flushing 0.025 Mpa

Based on the Figure 4.3, the constant parameters refer on the Table 4.2 are used and the flushing pressure is at 0.025 MPa. This solid debris produces the surface structures like sandy, stone and gross at the overall surface material. Other than that, there were also pores large hole and a large void also forms occurs on the workpiece. This is because the spark is unsuitable and the flushing pressure is too low. This caused the structure material uneven, valley and gross. The other figure microstructure is also attached in the Appendix B.

4.2.5 Microstructure at Flushing Pressure 0.05 Mpa

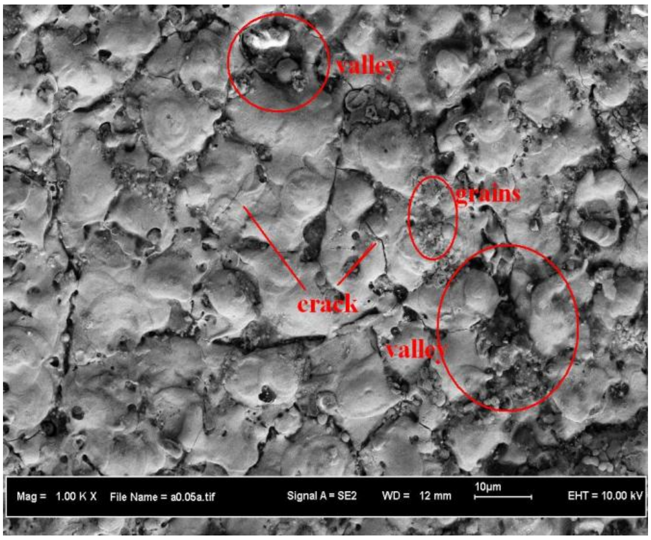


Figure 4.4 Microstructure at flushing 0.05 Mpa

Based on the Figure 4.4, it is found that the grain solid debris begins to decrease on the surface. Some grain solid debris accumulates at a region when imposed flushing pressure at 0.05 MPa. Effects from the higher spark formed a large valley. A grain bunchy exists in that area also and sticks together in the valley. Besides that, there also erosion happened in the areas around the long valley, effects from improper flushing during cutting process. This will make the surface cracking happens. This pressure also causes surface structure gross in the area with groove in. Some of surface area become out of phase and smooth. Based on Table 4.4, it shows the result of measurement surface roughness by using Mahrsurf XR 20 penthometer S2. The other figure microstructure is also attached in the Appendix B.

4.2.6 Microstructure at Flushing Pressure 0.1 Mpa

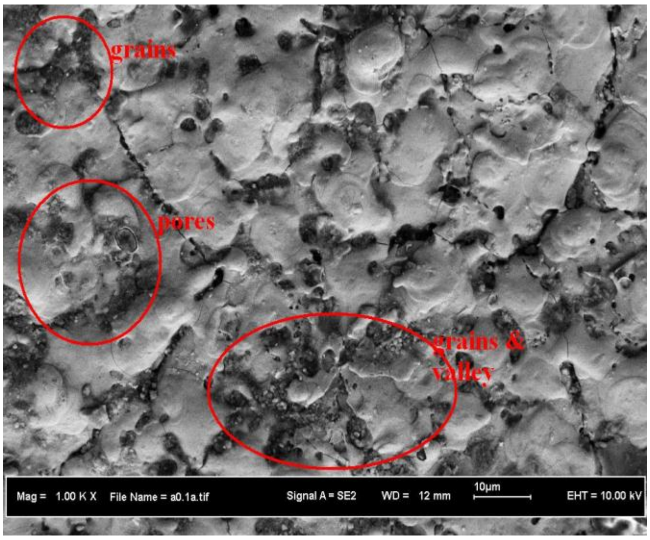


Figure 4.5 Microstructure at flushing 0.1 Mpa

Based on the Figure 4.5, it found that at flushing pressure 0.1 Mpa, half of the surface shows that the debris is decreasing. This means at this flushing pressure is the suitable pressure to removes debris from the surface. There is also a form of micro void or pores effects from the peak current which is not suitable. The big void trapped the debris. Refer to Appendix B shows the value and profile surface.

4.2.7 Microstructure at Flushing Pressure 0.125 Mpa

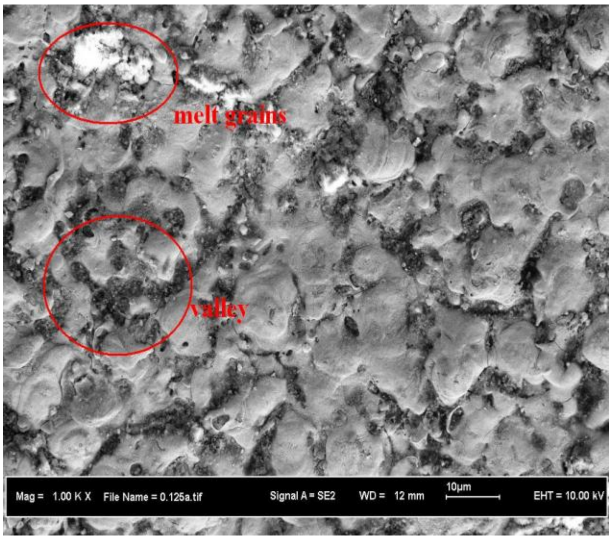


Figure 4.6 Microstructure at flushing 0.125 Mpa

Based on the Figure 4.6, it found that The flushing pressure is high. Therefore, the machining condition is not stable. This will melt the debris from the effects of several areas. The void still appears from the current that is not suitable in this cutting process. The surface is rough after the analysis had been done. Refer to Appendix B shows the value and profile surface.

4.3 DISCUSSION

After the research was carried out completely at the tungsten carbide workpiece, it was found that the value of 0.1 Mpa suited the parameter and it showed that the surface roughness condition that is flat and smooth. Referring to Figure 4.1, the effects of flushing pressure on workpiece surface roughness proved that the material's surface is really flat and smooth. In SEM research, it showed that solid debris were reduced from sticking to the surface. Void that was formed was due to the fact of the peak current which does not suit the finishing cut.

At flushing pressure of 0.025 Mpa, it was found that the material's surface was covered with solid debris. Formation of large voids at the surface enables the solid debris to be collected inside it. This was due to the fact that low flushing pressure cannot play it's role perfectly in the cutting process as a flushing agent. Surface roughness test showed the surface of the material at low flushing pressure yields surfaces that were rough and un smooth.

When the flow of the flushing pressure is too slow between electrode and workpiece surface, the flushing cannot removes the solid debris after discharge. However, if the flushing pressure is too high, no proper machining can be done as the ionized channel is continuously wash away.

For jet or side flushing of an array of shallow cavities have important must be considerations are distribution of the nozzle, flow rate, angles at which nozzle are directed at the gap between electrode and workpiece.

4.4 COMPARISONS RESULT

From Lee [5], when the flushing pressure is too low, the flushing cannot remove the gaseous and solid debris after each discharge. However, if the dielectric pressure is too high, no proper machining can be done as the ionized channel is continuously wash away and the relative wear ratio will increase. Excessive pressure can also accelerate electrode wear and create turbulence in the cavity. The surface roughness does not change too much with flushing pressure.

In the comparisons made previously, the statement that was made by Lee [5], shows that the research conducted was very correct. Flushing does play a very important role in producing surfaces that are flat, also it is good for productivity.

Comparisons were also made on the machining plan where the parameter for surface roughness was set to 2µm. After the research was made, it was found that the value for surface roughness was far more different from the machining plan. This shows that constant parameter gives the effect on the workpiece in this research. Low flushing pressure increases the value for surface roughness due to the debris that was not expelled from the workpiece.

4.5 FACTOR THAT AFFECTS TO MACHINE SURFACE

Many factors can be affecting on the machine surface. The good surface can be the best give the best result from aspect productivity. These are the factor should consider:

1. Polarity (PL), the suitable polarity can give the good result and condition for the machine stable. The polarity depending on the machining condition and the material combination of the workpiece and the electrode. The wrong polarity may effect on the surface such as crack, void and electrodes wear.

2. On Time (Pulse on Time), the time for electric discharge during cutting process. Long electric discharge effects on surface finish and produce great discharge energy. Short for electric discharge is fine on surface finish and narrow discharge gap. On time closely related with closely related with peak current.

3. Peak Current (IP), this parameter specifies the peak current for electric discharge machining. If the great IP allow fast machining speed but the surface finish is rough. Small peak current take long time cutting process because slow machining speed. It also produces small discharge energy and discharge gap between electrode and workpiece. The peak current can cause electrode wear. Among of parameter closely related with peak current is on time and polarity.

4. Flushing pressure is important because eroded particles must be removes from the gap for the efficient cutting. It also brings fresh dielectric oil into the gap and cools the electrode and workpiece. The deeper the cavity, the greater the difficulty for proper flushing.

5. Jump Speed (JS), this parameter that consider the rate of jump speed during cutting. Rate of the jump also influence the spark gap between electrode and workpiece.

6. Material and electrode that were used must suitable in EDM machine. For the hardness material, used the electrode which has high hardness properties and density. The combination of electrode also suitable to use for the hard material and to produce good surface finish. Selecting the wrong electrode for cutting can effect the workpiece such as electrode easy to wear, cutting machine speed is slow and effect on the surface finish.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

An extensive experiment study has been conducted to investigate the effects of the machining parameters on machining characteristics in EDM of tungsten carbide. The machining parameters which is consider is flushing pressure and other parameters such as polarity , peak current, pulse-ON, pulse-OFF. The machining characteristics are surface roughness and micro structure.

The effect of the flushing pressure on this material has been presented.

1. There is an optimal flushing pressure at 0.1 MPa where there is a little variation on the surface roughness of the workpiece, although at 0.1 Mpa the surface finish tends to be better and has small surface roughness.

2. The microstructure at flushing pressure of 0.1 MPa is a good surface structure. The grains which stick on the surface of the workpiece is decrease compare to low pressure. Therefore, this pressure is suitable for this experiment.

3. The trends for surface roughness are increase at low flushing pressure. The low pressure gives the deep impact to the surface. There are many grains are left and spread out and stick on the workpiece surface. The flushing also cannot remove the gaseous and solid debris after discharge.

4. When increase the flushing pressure, the trend for surface roughness also increase. At the higher flushing pressure no proper can be done. The Molten debris happens on surface because this pressure.

5. The flushing pressure rate flow as important significant parameters for good surface finish. As more dielectric passes through the workpiece and tool get good cooling effect and give good finish.

6. Improper flushing pressure can also reduce removal debris due to unstable machining conditions and arcing around regions with high concentration of debris. Good flushing pressure provides good machining condition. The used flushing pressure in maintain a state of die-ionization in the gap at the end of a long pulse duration is well recognized.

7. Other factor can be effect on the surface roughness is pulse ON and peak current. When the higher value peak current the cutting process is faster but, will be formed void large.

5.2 RECOMMENDATION

1) Used another type of flushing pressure such as pressure flushing, combined pressure and suction flushing to find the effects of surface machine or electrode wear.

2) Making an experiment based on the jump speed (JS). JS is the first and second digits of the parameter specify the axis travel speed for jump-up and jump-down motion. These parameters must consider produce the rate movement up and down during cutting process.

3) The value constant parameters must be select carefully and suitable to used in EDM machine. If not suitable, it can be effects to the surface material and electrode. For the future try to use the data from machine generate after keep in the data machining program. The data generate from the machine is very suitable to used.

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APPENDIX A

THE MACHINE PARAMETER CHARACTERISTICS

1) The condition parameter generate by machine

```
();machine condition
(2008/09/02 V11.5A SHAMSUL2 Column with bottom);
(        PL  ON   OFF   IP    SV  S  UP  DN  JS  LNS  STEP     V  HP  PP C  ALV  OC   LF   JM LS LNM);
C007   =  - 0008 0016 031.0 070 20 008 015 036 0000 0.0000  22 000 10 5 0015 0000 0005 01 00 303;
C006   =  - 0008 0016 031.0 070 20 010 025 036 0000 0.0000  22 000 10 5 0015 0000 0005 01 00 000;
C005   =  - 0006 0012 015.0 080 20 010 025 020 0000 0.0000  22 000 10 5 0015 0000 0005 01 00 000;
C004   =  - 0005 0010 007.0 080 22 010 025 010 0000 0.0000  22 000 10 5 0015 0000 0005 01 01 000;
C003   =  - 1004 0010 003.0 080 32 010 025 005 0000 0.0000  22 000 10 3 0010 0000 0005 01 02 000;
C002   =  - 1002 0006 000.0 110 52 020 035 001 0000 0.0000  22 012 10 1 0010 0000 0005 01 02 000;
C913   =  - 1002 0006 000.0 120 73 020 045 101 0000 0.0000  22 001 10 0 0010 0000 0005 01 03 300;
```

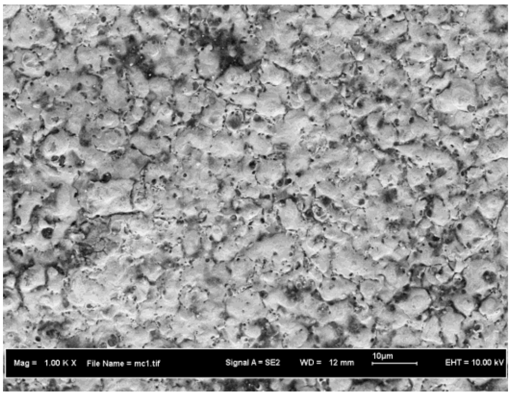
2) The condition at constant parameter

```
();Parameters at constant
(2008/09/03 V11.5A Column with bottom);
(        PL  ON   OFF   IP    SV  S  UP  DN  JS  LNS  STEP     V  HP  PP C  ALV  OC   LF   JM LS LNM);
C007   =  - 0010 0015 007.0 070 20 005 015 010 0000 0.0000  22 000 10 5 0015 0000 0005 01 00 303;
C006   =  - 0010 0015 007.0 070 20 005 025 010 0000 0.1680  22 000 10 5 0015 0000 0005 01 00 303;
C005   =  - 0010 0015 007.0 080 20 005 025 010 0000 0.2120  22 000 10 5 0015 0000 0005 01 00 303;
C004   =  - 0010 0015 007.0 080 22 008 025 010 0000 0.2460  22 000 10 5 0015 0000 0005 01 01 303;
C003   =  - 0010 0015 007.0 080 32 008 025 005 0000 0.2680  22 000 10 3 0010 0000 0005 01 02 303;
C002   =  - 0010 0015 007.0 110 52 010 035 001 0000 0.2830  22 012 10 1 0010 0000 0005 01 02 303;
C913   =  - 0010 0015 007.0 120 73 010 045 101 0000 0.2879  22 001 10 0 0010 0000 0005 01 03 303;
```

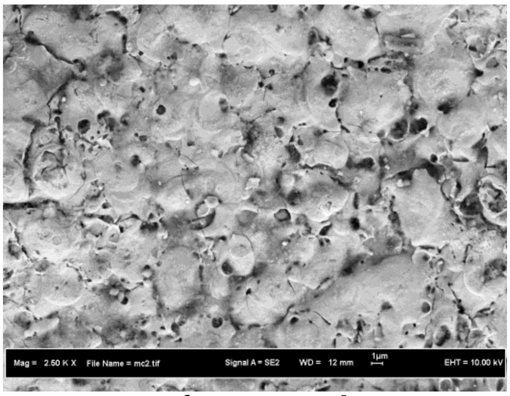
APPENDIX B

FIGURE SURFACE MICROSTRUCTURE

i) Machine condition parameter

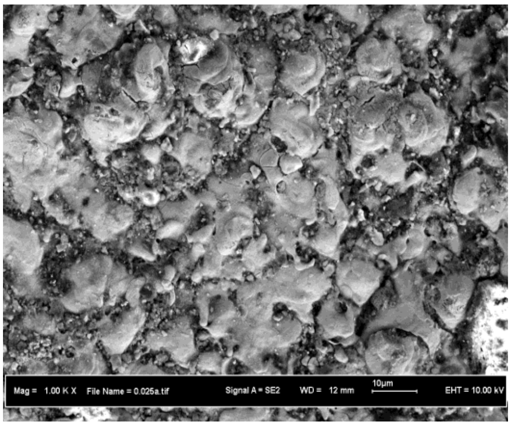


magnification 1.00k

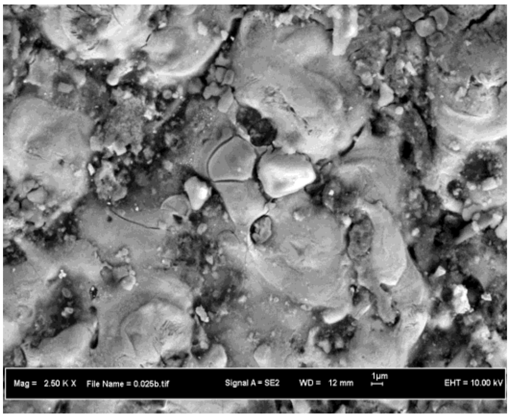


magnification 2.50k

ii) Setting flushing pressure 0.025 Mpa

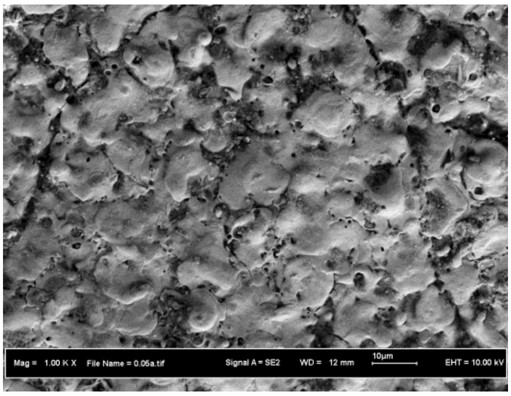


magnification 1.00k

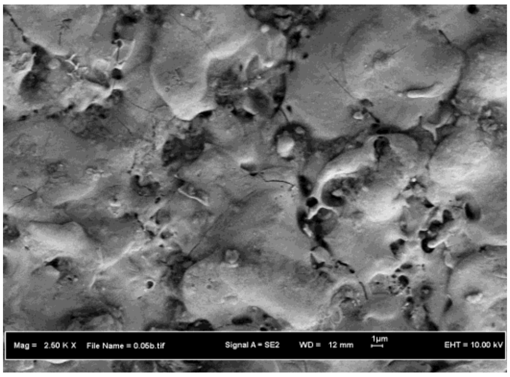


magnification 2.50k

ii) Setting flushing pressure 0.05 Mpa

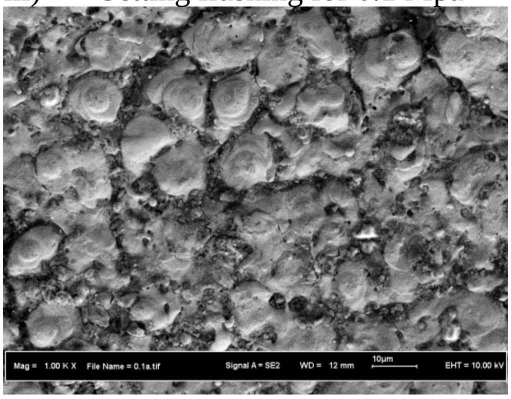


magnification 1.00k

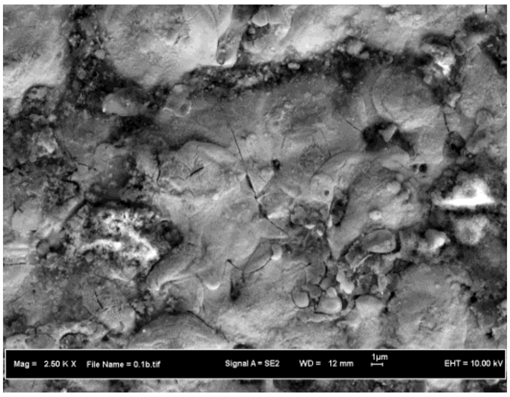


magnification 2.50k

iii) Setting flushing for 0.1 Mpa

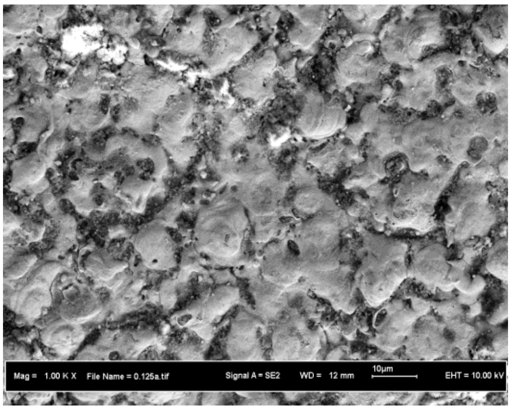


magnification 1.00k

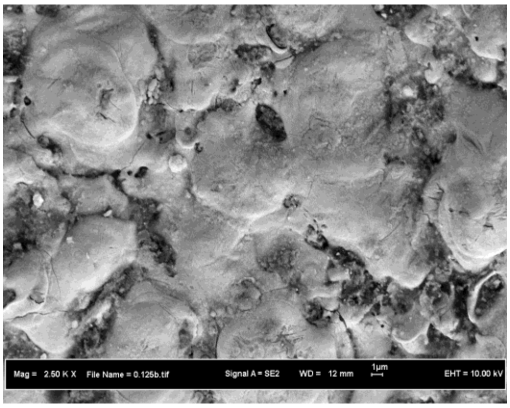


magnification 2.50k

iv) Setting flushing pressure 0.125 Mpa



magnification 1.00k

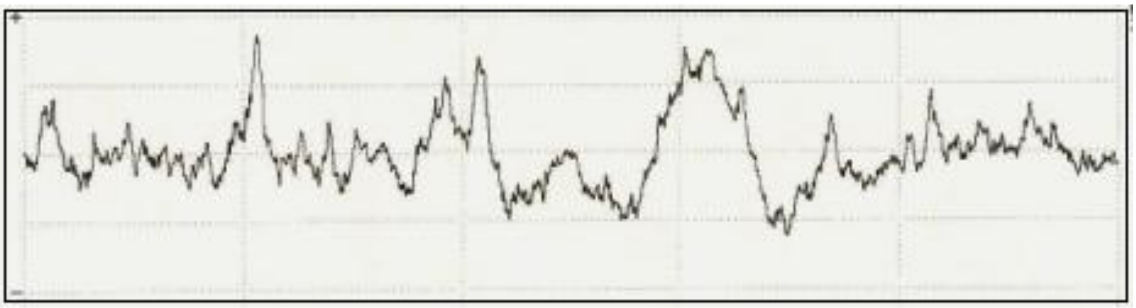


magnification 2.50k

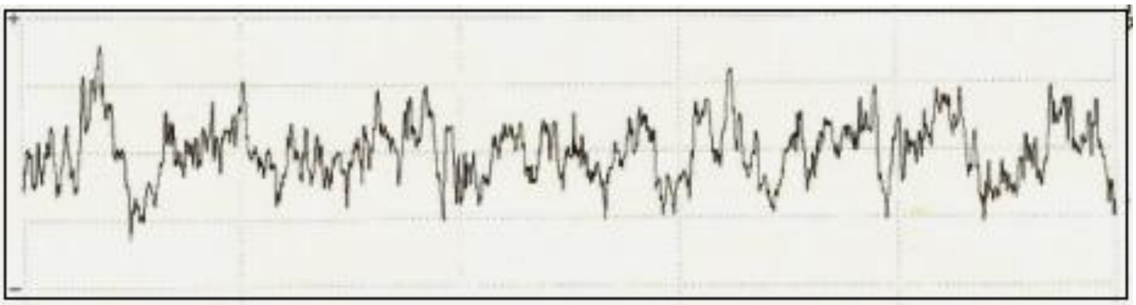
APPENDIX C

SURFACE ROUGHNESS PROFILE

1) Surface profile for machine condition data before constant parameter.



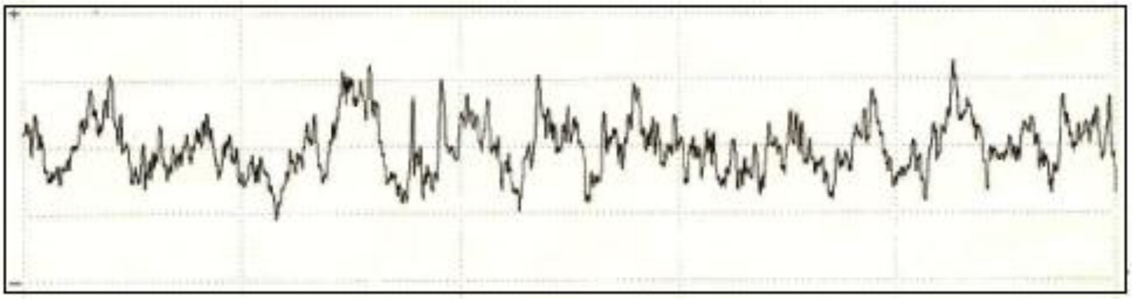
Run Order 1 – (Ra 1.917 µm)



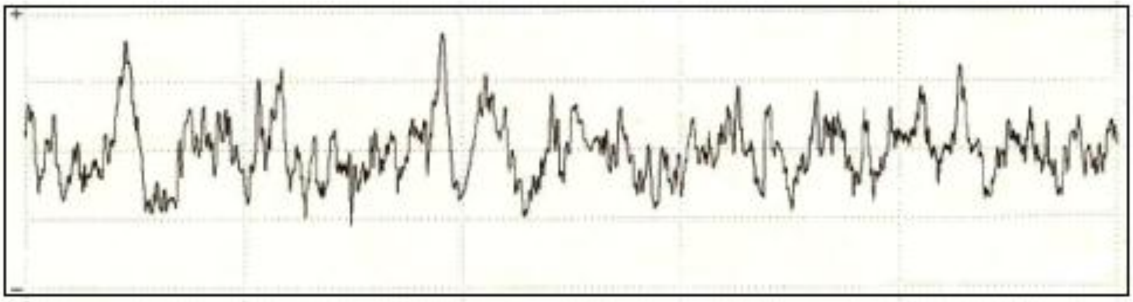
Run Order 2 – (Ra 1.797 µm)

Run Order 3 – (Ra 1.379 µm)

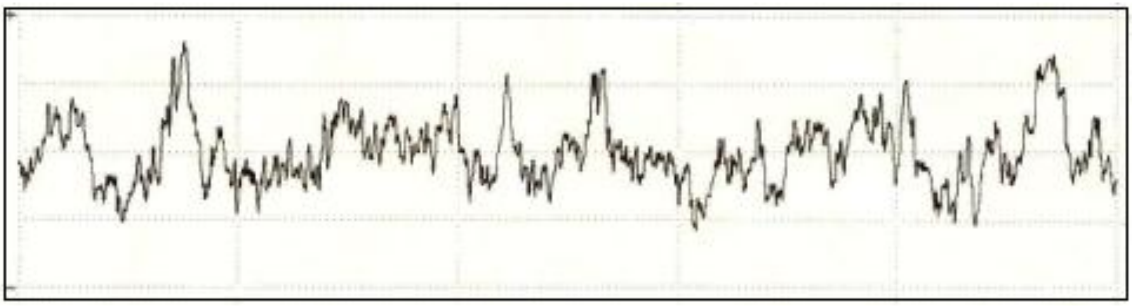
2) Surface profile at flushing pressure 0.025MPa



Run Order 1 – (Ra 2.354 μm)

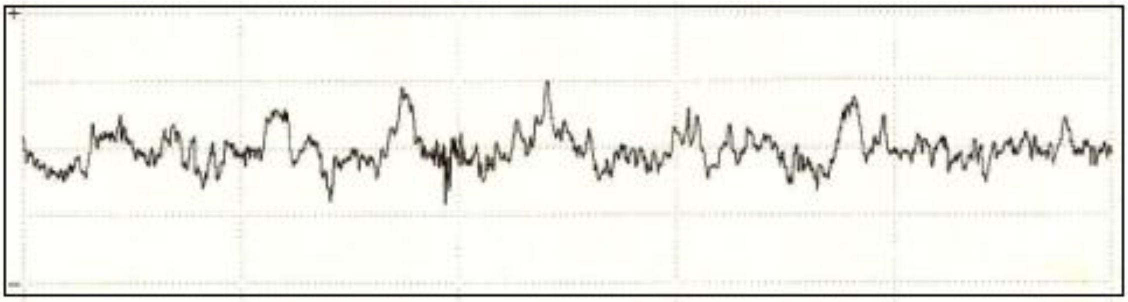


Run Order 2 – (Ra 2.459 μm)

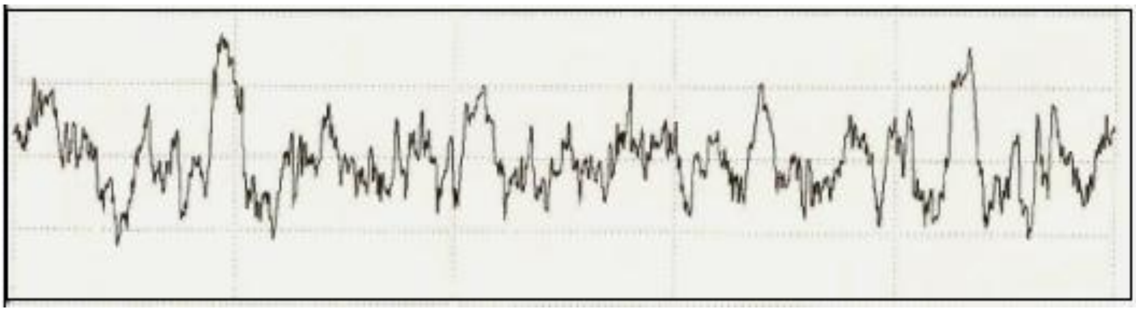


Run Order 3 – (Ra 2.433 μm)

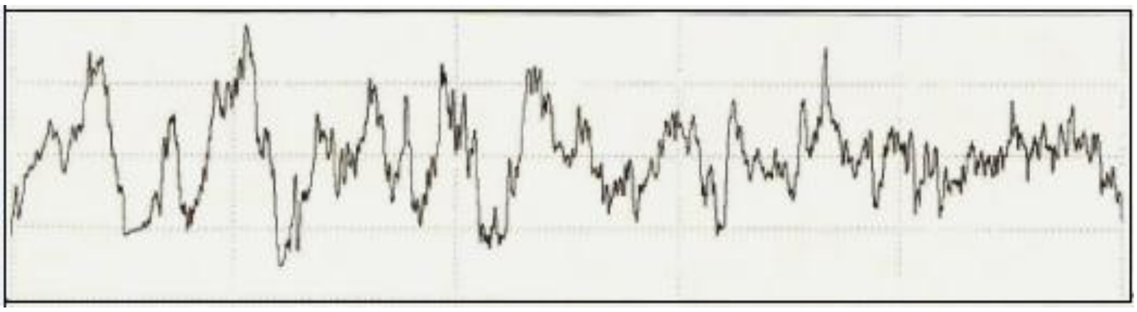
3) Surface profile at flushing pressure 0.05MPa



Run Order 1 – (Ra 2.354 μm)

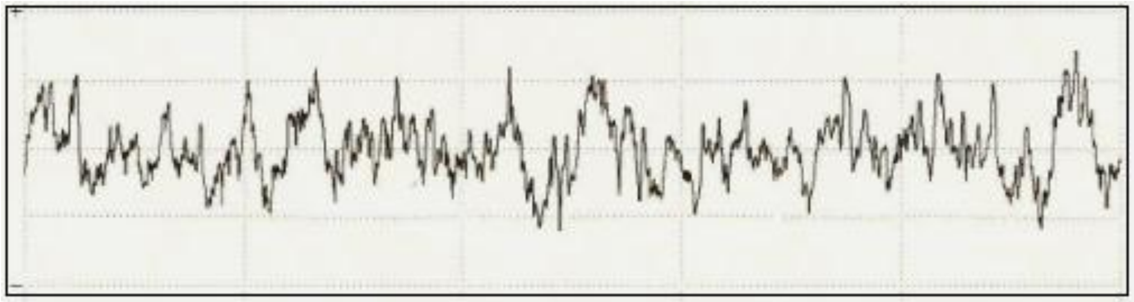


Run Order 2 – (Ra 2.455 μm)

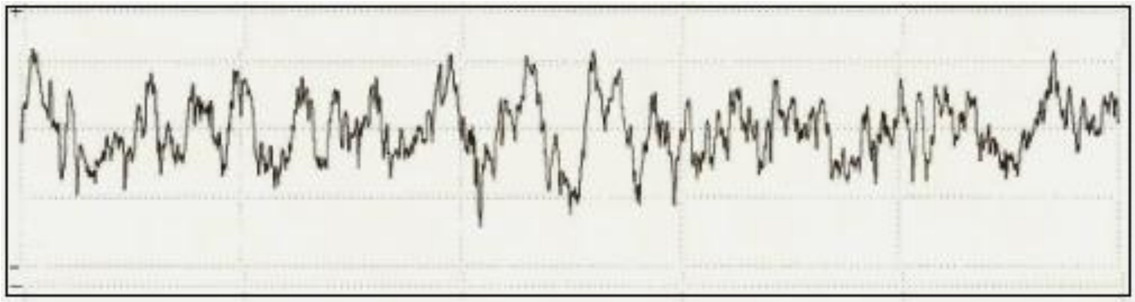


Run Order 3 – (Ra 2.225 μm)

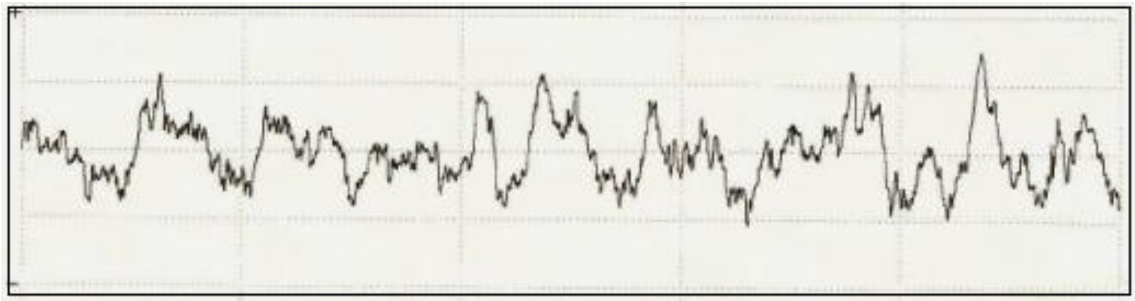
4) Surface profile at flushing pressure 0.1MPa



Run Order 3 – (Ra 1.773 μm)

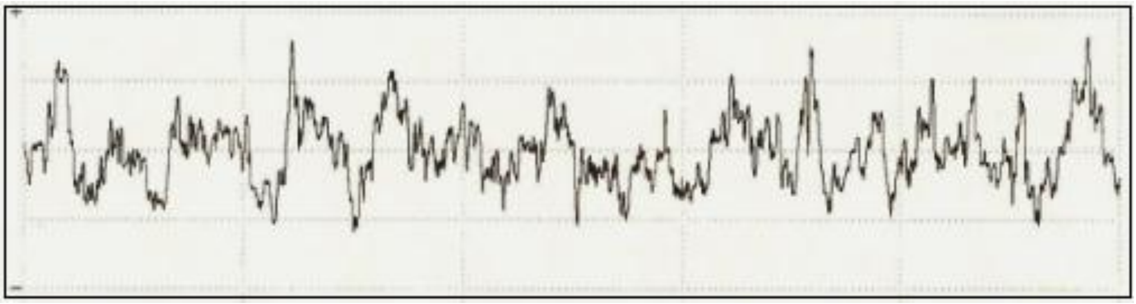


Run Order 3 – (Ra 1.863 μm)

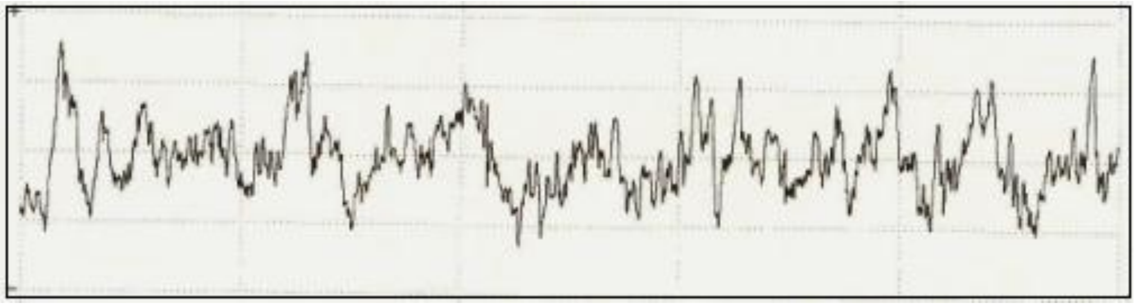


Run Order 3 – (Ra 1.801 μm)

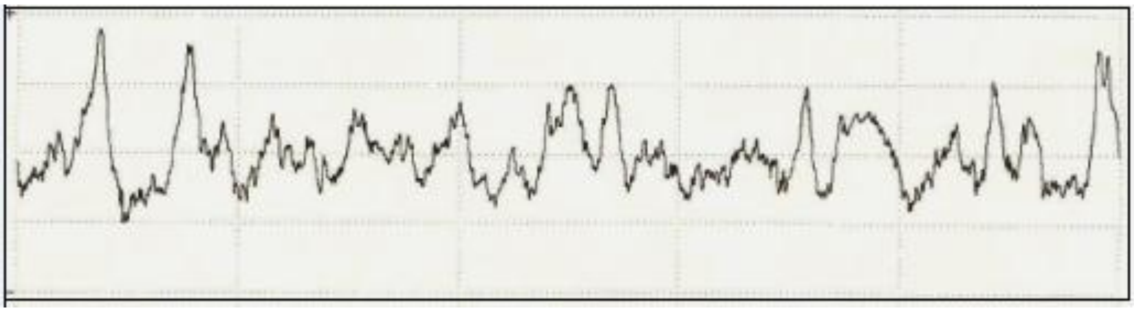
5) Surface profile at flushing pressure 0.125MPa



Run Order 3 – (Ra 1.929 μm)



Run Order 3 – (Ra 1.959 μm)



Run Order 3 – (Ra 1.944 μm)

APPENDIX D

GANTT CHART FOR PSM 1

Project Activities	Progress	W1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15
Determine the objective& scope project	Target															
	Actual															
Literature review to get more information	Target															
	Actual															
Methodology of the project	Target															
	Actual															
Write the progress report	Target															
	Actual															
Submit report for Correction	Target															
	Actual															
Submit final report and presentation	Target															
	Actual															

GANTT CHART FOR

PSM 2

Project Activities	Progress	W1	W 2	W 3	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15
Preparation of experimental tool and workpiece	Target															
	Actual															
Experiment process (collect data, result analysis)	Target															
	Actual															
Write the progress report	Target															
	Actual															
Submit report for correction	Target															
	Actual															
Submit final report and presentation	Target															
	Actual															

APPENDIX E

FLOW CHART

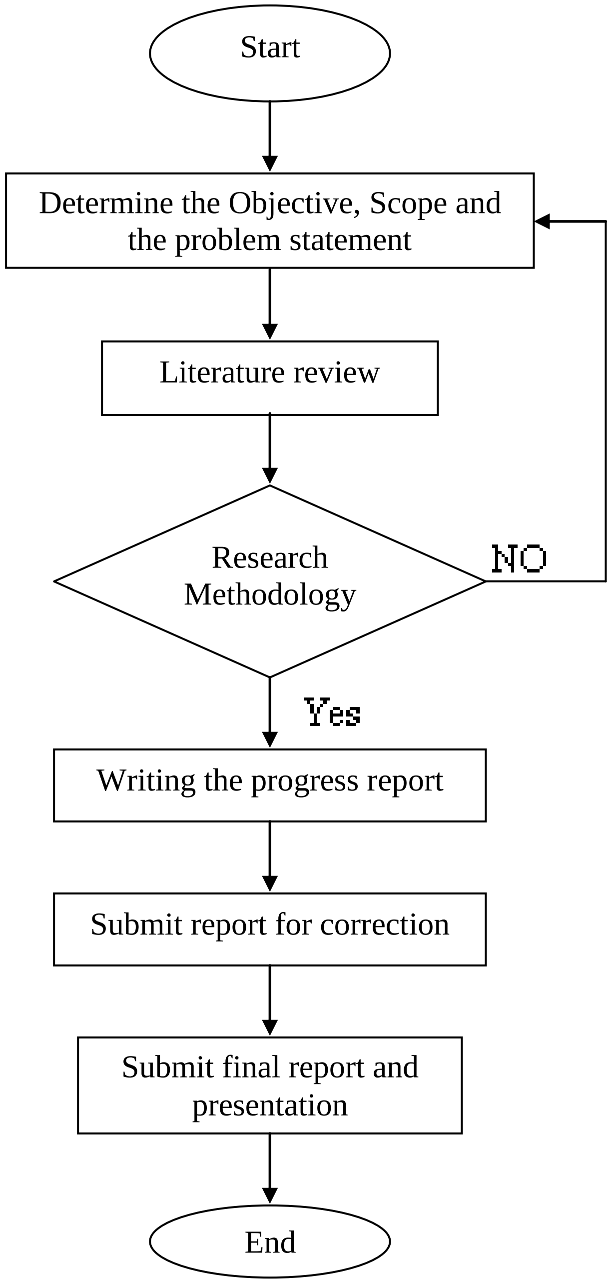


Figure 1: Flow chart for PSM 1

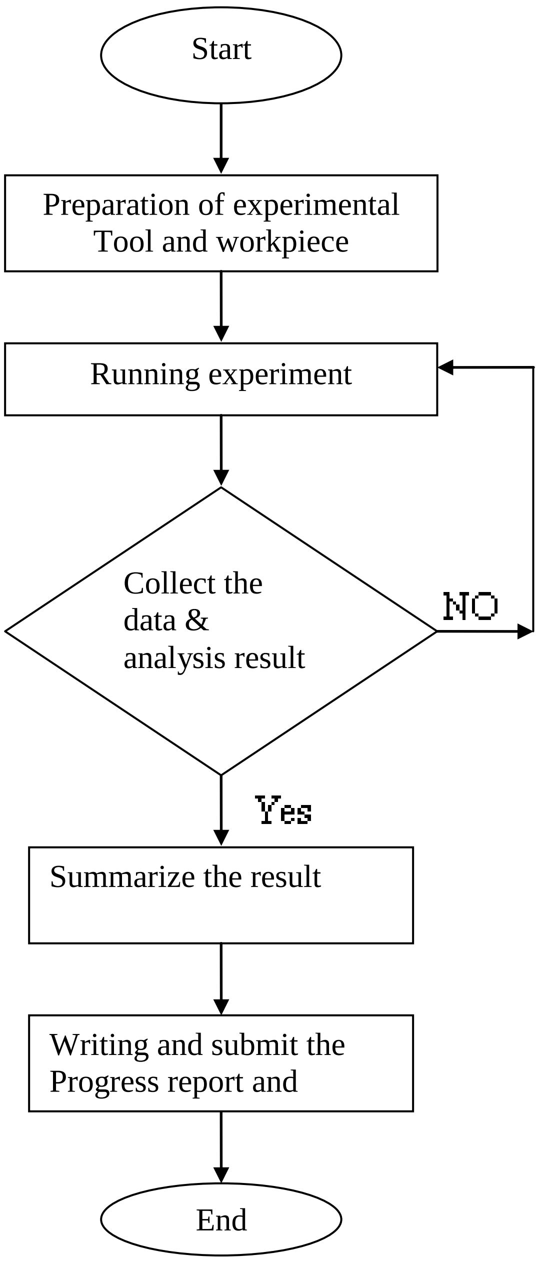


Figure 2: Flow chart for PSM 2