SURFACE ROUGHNESS CHARACTERIZATION ON P20 TOOL STEEL IN WIRE-CUT ELECTRICAL DISCHARGE MACHINING (WEDM) PROCESS

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Manufacturing Engineering

Faculty of Manufacturing Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2013

ABSTRACT

Wire Electrical Discharge Machining (WEDM) is one of the earliest non-traditional machining processes and has a capability in producing high precision parts. An inappropriate WEDM machining parameter will affects the efficiency of WEDM machining process and the quality of the surface roughness parts because of increasing probability on wire breakage. Therefore, this research was conducted to investigate the effect of WEDM machining parameters on surface roughness of tool steel material for injection molding. In this experiment, mold of AISI P20 hardenable steel were produced using WEDM. In material preparation phase, the raw material will undergo milling and deburring processes. The voltage, machined feed rate and wire speed were manipulated to find the best combination of WEDM machining parameters. The results show that the surface roughness values increased with increasing of voltage and it’s create higher energy on machining zones and create deeper and wider crates on machined surface. A smoother surface can be achieved by lowering the machine feed rate speed and wire speed can be ignored since it not affected on the microstructure of machined surface. As the conclusion machining process can work efficiently by controlling the machining parameters at an optimal value to avoid the risk of wire breakage when the machining process is being carried out onto a workpiece.

ABSTRAK

“*Wire Electrical Discharge Machining (WEDM)*” merupakan salah satu dari proses pemesinan moden yang terawal dan mempunyai keupayaan dalam menghasilkan bahan kerja yang berketepatan tinggi. Penetapan parameter pemesinan WEDM yang tidak sesuai akan mempengaruhi kecekapan proses pemesinan WEDM dan kualiti permukaan yang dihasilkan disebabkan oleh kemungkinan peningkatan kerosakan pada wayar pemotong. Sehubungan dengan itu, kajian ini telah dijalankan untuk mengkaji kesan parameter pemesinan WEDM terhadap kekasaran permukaan bahan keluli untuk pengacuan suntikan. Dalam eksperimen ini, acuan keluli AISI P20 telah dibuat menggunakan WEDM. Dalam fasa penyediaan bahan pemesinan, bahan kasar akan melalui proses *milling* dan *deburring*. Parameter voltan, kadar suapan mesin dan kelajuan wayar pemotong dimanipulasi demi untuk mencari kombinasi terbaik pemesinan WEDM. Keputusan menunjukkan nilai kekasaran permukaan meningkat dengan meningkatnya parameter voltan kerana ia mengeluarkan tenaga yang lebih tinggi serta menghasilkan rongga yang lebih dalam dan lebar ke atas permukaan yang telah dimesin. Permukaan yang lebih halus dapat dihasilkan dengan menurunkan kadar suapan mesin manakala kelajuan wayar pemotong boleh diabai memandangkan parameter tersebut tidak mempengaruhi mikrostruktur permukaan yang menjalani proses pemesinan. Kesimpulannya, proses pemesinan dapat dijalankan dengan efisien dengan mengawal parameter pemesinan pada tahap optimum demi untuk mengelakkan risiko kerosakan wayar semasa proses pemesinan dijalankan ke atas bahan kerja.

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µm	Micrometer

LIST OF ABBREVIATIONS

AISI	American Iron and Steel Institute
CLA	Centre Line Average
CNC	Computer Numerical Control
HB/BH	Brinell Hardness
HRC	Hardness Rockwell C-scale
R_a	Surface Roughness
S.I	International system of unit
t.s.i	Tensile Strength
WEDM	Wire Electrical Discharge Machining

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The AISI P20 is hardenable steel used frequently in the manufacturing of polymer injection molds. Some of the typical applications of P20 are plastic injection molding mold, backers, bolster and die holder. P20 is also widely used in the production of plastic mold and die. Due to its requirement Wire Electrical Discharge Machining (WEDM) were choose to produced mold and die.

WEDM been widely used in aerospace, nuclear, automotive industries, surgical components because of it capability of producing high-precision parts. Apart of producing high-precision machining results, increasing demand for quality machined surface made WEDM has been extensively used by many industries such as die-making industry and mold-making industries because the machine also is capable of producing very fine surface finish. This could eliminate secondary process required such as surface finishing. The ability of this CNC machine to move for machine axes to generate taper cut makes WEDM were used to machine profile with precise, complex and irregular shapes in various difficult-to-machine electrically conductive materials.

Surface roughness is a machining characteristic that plays a very critical role in determining the quality of engineering components. Some benefits of having good quality surface are improved fatigue strength, corrosion and wear resistance of the workpiece

(Spedding and Wand, 1997). Selection of the optimal values for different process parameters of WEDM process is observed to be of immense importance to enhance the machining performance measured.

1.2 PROJECT BACKGROUND

Plastic injection molding is a versatile process capable of producing complex shape with good dimensional accuracy and one of the most used manufacturing technologies for mass produced goods. However, to get a better mold surface roughness requires a wide availability of knowledge of design and processing as well as equipment in many variations. Mold surface roughness affects the physical performance of the part where every customer judge works by the surface quality. It is more easily, and much reducing money and time consuming if we perform steps to get a good mold surface than to touch up every part after it is finished.

Present development and application of WEDM is able to produce fine surface finish for the injection molding mold. The main problem is different material use different machining parameters in order to archive good surface finish. Machined surface produced by WEDM process consist of many crates where will result in low quality of surface roughness. This may happen if unsuitable machining parameters were used. To overcome this problem, many researchers working toward to investigate the best machining parameters can be used for every type of material.

This study purpose is to investigate the effect of WEDM machining parameters on surface roughness of tool steel material (P20) for injection molding.

1.3 PROBLEM STATEMENT

AISI P20 is among the best material used for injection mold making. Mold that is made using WEDM process require knowledge on the optimum machining parameters. Machined surface with good quality can only be obtained through best combination of machining parameters. Voltages, wire speed, wire feed and wire tensions are some of the machining parameters that affecting the roughness of machined surface. Main problem in operating WEDM is wire breakage (Amorim and Weingaertner, 2005). Inappropriate machine parameters used may lead to wire breakage. Besides lowering surface machined quality, wire breakage can cause increasing work time and cost of tool. This can give effect to various manufacturing field especially in industries where demand of products are always high. The purpose of this research is to investigate what are the parameters suitable to use for cutting P20 tool steel material in order to get smoother machined surface while avoiding wire breakage from occur.

1.4 OBJECTIVE

The objective of this project is:

i. To investigate the effect of WEDM machining parameters on surface roughness of P20 tool steel material for injection molding.

1.5 SCOPE OF PROJECT

Material that will be used in this experiment is P20 hardenable steel material that used in injection molding making. The cutting tool that is used is copper wire with diameter 0.2mm. Machining input variables that considered in this experiment are wire speed, voltage and machine feed rate while surface roughness of the machined material will be the output parameter. The cutting operation is performed by Wire-cut Electrical Discharge Machining (WEDM) machine (SODICK VZ300L). The output parameter, which is the surface roughness of the machined material, is analyzed by using perthometer ZEISS brand (SURFCOM 130/480A).

1.6 SIGNIFICANT OF STUDY

The study of surface roughness characteristic on P20 in wire-electrical discharge machining process can bring benefits to mold industries. Even a high skill technician also may have difficulty to set optimum parameters that will be used in the WEDM process. Result obtained from this study might be useful in determining the optimum machining parameters especially in mold industries that are using P20 as mold for producing plastic product with good surface finish. This may lead to reduced cost and time usage since the secondary finishing process for the product produced is not required.

People may use this research for academic purpose. The whole process involved in this study can be used again as a reference for future research in WEDM as well as P20. So there will be more research that will be conducted in future to improve the quality of product produced by mold made from AISI P20.

Any details or information used in this study can be used for all wire electrical discharge machines that have similar control mechanisms to the SODICK VZ300L WEDM.

CHAPTER 2

LITERATURE REVIEW

2.1 PRINCIPLE OF WIRE ELECTRICAL DISCHARGE MACHINING

The Spark Theory on a wire EDM is basically the same as that of the vertical EDM process. In wire EDM, the conductive materials are machined with a series of electrical discharges (sparks) that are produced between an accurately positioned moving wire (the electrode) and the work piece. High frequency pulses of alternating or direct current is discharged from the wire to the workpiece with a very small spark gap through an insulated dielectric fluid (Huang et al., 2003).

Mechanism of WEDM is illustrated in Figure 2.1. CNC wire cut EDM machine puts impulse voltage between electrode wire and workpiece through impulse source, controlled by servo system, to get a certain gap, and realize impulse discharging in the working liquid between electrode wire and workpiece. Numerous tiny holes appear due to erosion of impulse discharging, and therefore get the needed shape of workpiece (Kalpakjian and Schmid, 2009).

Electrode wire is connecting to cathode of impulse power source, and workpiece is connecting to anode of impulse power source. When workpiece is approaching electrode wire in the insulating liquid and gap between them getting small to a certain value, insulating liquid was broken through; very shortly, discharging channel forms, and electrical discharging happens. Figure 2.2 illustrate the mechanism of WEDM. During cutting process huge high temperature instantaneously release, up to more than 10000 degree centigrade, the eroded workpiece is cooling down swiftly in working liquid and flushed away (Gokler and Ozanozgu, 2000). Study regarding to relationship of WEDM machine parameters was performed by Hang et al. (2006) found that temperature produced during cutting and sparks generates give huge effect to surface roughness condition.

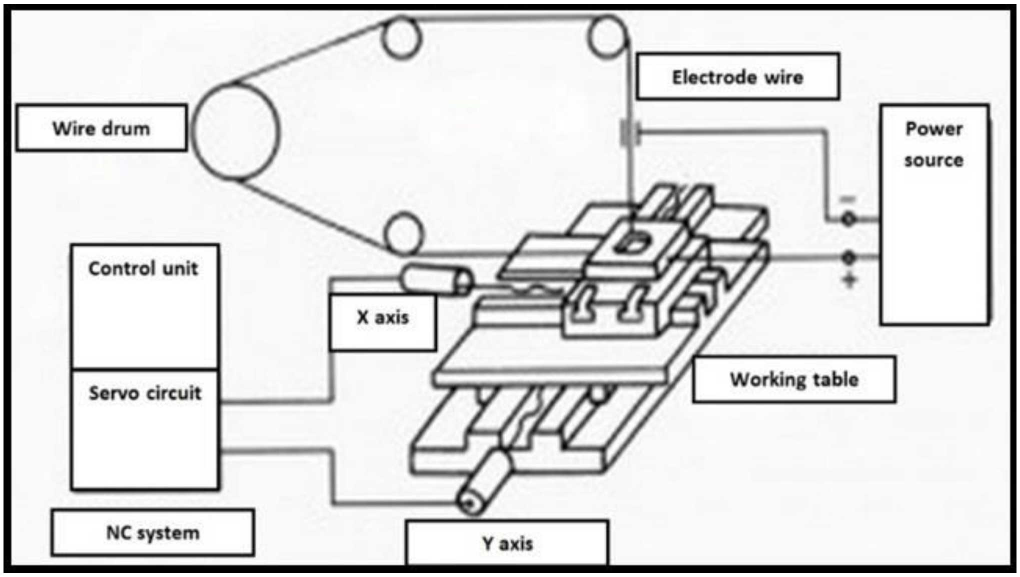


Figure 2.1: Mechanism of WEDM

Source: Kalpakjian and Schmid (2009)

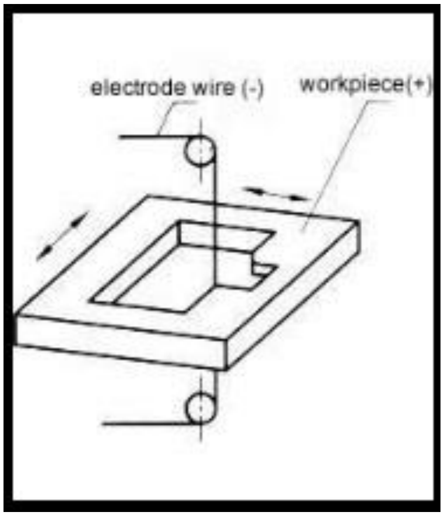


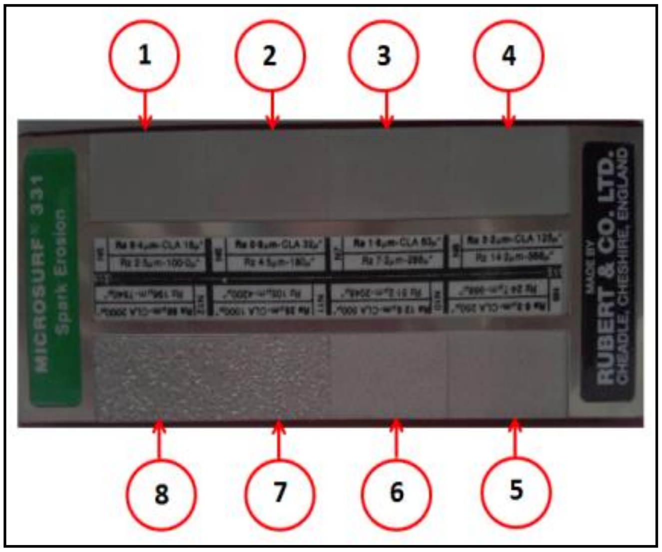
Figure 2.2: Cutting mechanism of electrode wire and workpiece

Source: Kalpakjian and Schmid (2009)

2.2 SURFACE ROUGHNESS

Surface roughness is one of machining characteristic that plays a very important role in determining the quality of engineering products. In mold making industries, requirement for having good surface machined is to avoid any secondary process such as finishing thus give reduction in cost. Good surface produced can be indicate by its own surface roughness value measured on its surface. Rao and Sarcar (2008) in their study on Evaluation of Optimal Parameters for Machining Brass with Wire Cut EDM discover that the higher the surface roughness value measured, the rougher the surface machined condition. This relationship was earlier found by Altpeter and Perez (2003). Both studies were prove by using surface indicator shown in Figure 2.3. Surface gets rougher from indicator 1 represent the smoother surface machined while indicator 8 is the rougher surface machined. In Table 2.1 shows smoother surface have the lowest surface roughness value range. Note that the term CLA means exactly the same thing as R_a. the different is

CLA used metric unit while R_a is in S.I unit. In WEDM, rougher surface was formed by crates. Crates were produced when a tiny volume of material is vaporized as a result from spark during cutting process. The deeper and wider cavities left on machined surface the larger the crates thus producing product with low surface quality (Bobbili et al., 2013). The crates deep and width depend mostly on machine parameters used during cutting (Mohammadi et al., 2008) thus choosing the optimum combination of WEDM parameters is crucial in producing good surface of product. This work is intended to carry on in order to find the optimum WEDM parameters suitable to use during cutting especially for AISI P20.



Smoother **Rougher**

1	2	3	4	5	6	7	8

Figure 2.3: Surface roughness indicator for surface machined

Source: www.rubert.co.uk

Table 2.1: Surface roughness range for surface roughness indicator

Indicator no.	**Surface roughness range**
1	Ra 0.4 µm – CLA 6 µ”
2	Ra 0.8 µm – CLA 32 µ”
3	Ra 1.6 µm – CLA 63 µ”
4	Ra 3.2 µm – CLA 125 µ”
5	Ra 6.3 µm – CLA 250 µ”
6	Ra 12.5 µm – CLA 500 µ”
7	Ra 25 µm – CLA 1000 µ”
8	Ra 50 µm – CLA 2000 µ”

Source: www.rubert.co.uk

2.3 RELATIONSHIP BETWEEN MACHINING PARAMETERS AND SURFACE ROUGHNESS

Surface roughness of surface machined most affected by machine parameters. The selection of various process parameters during WEDM process plays crucial role in achieving optimal machining parameters (Shandilya et al., 2012)

There were two experiment conducted by Alias et al. (20012) to investigate relationship of machine feed rate (mm/min) and surface roughness (Ra). Although both experiment used Titanium Ti-6Al-4V as specimen, result yield were different. Figure 2.4 show surface machined of Titanium Ti-6Al-4V smoother by applying higher machine feed rate while Figure 2.5 shows surface roughness of Titanium Ti-6Al-4V increase with increasing machine feed rate.

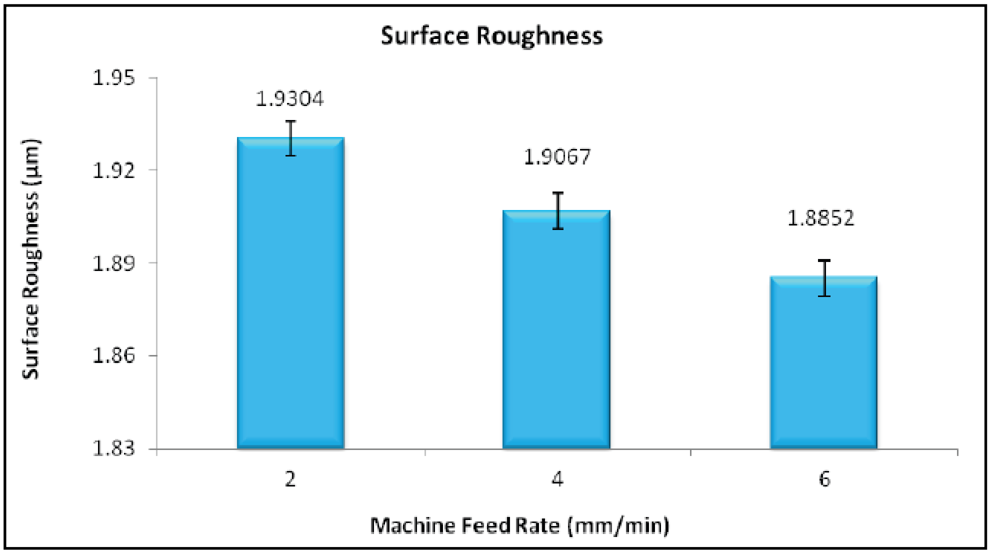


Figure 2.4: Result on surface roughness rate at different machine feed rate

Source: Alias et al. (2012a)

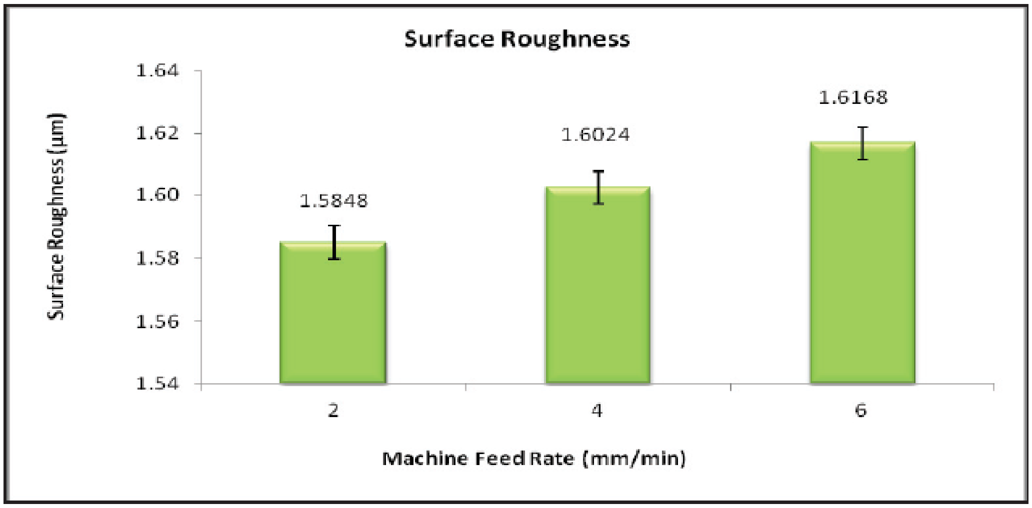


Figure 2.5: Result on surface roughness at different machine feed rate

Source: Alias et al. (2012b)

Both studies show different result although they are using the same material and parameters. These different results may bring confusing to set optimum parameters in order to get good surface finish. Thus in my research relationship between wire feed rate and surface roughness will be examined by using WEDM SODICK VZ300L.

Research conducted by Khan et al. (2006) proved quality of surface machine of any material can be improved by setting low value of current and voltage during machining. In Figure 2.6 shows carbide machine surface get rougher when high current was applied. Stainless steel show same effect when it was machined using high voltage value. In this study experiment will be conduct in the same way which WEDM cutting process will be performed with different range value of voltage while maintaining the value of current but by using P20 as a material specimen. This may yield optimum parameter that can be use on P20.

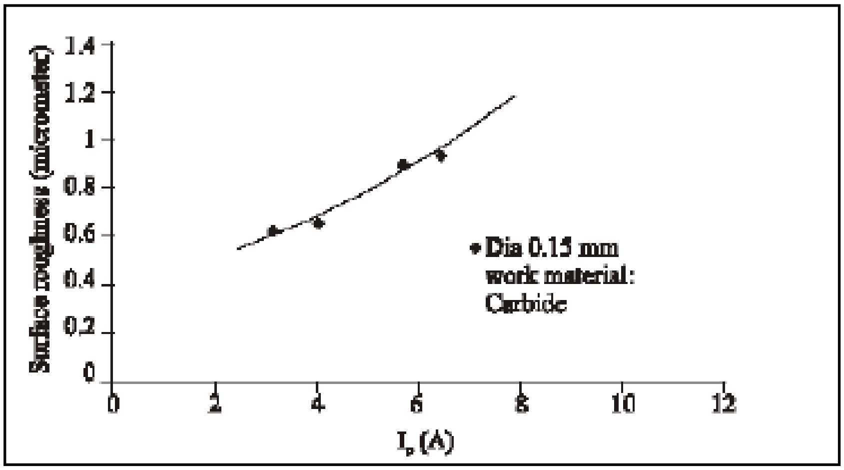


Figure 2.6: Relationship of surface roughness and current

Source: Khan et al. (2006)

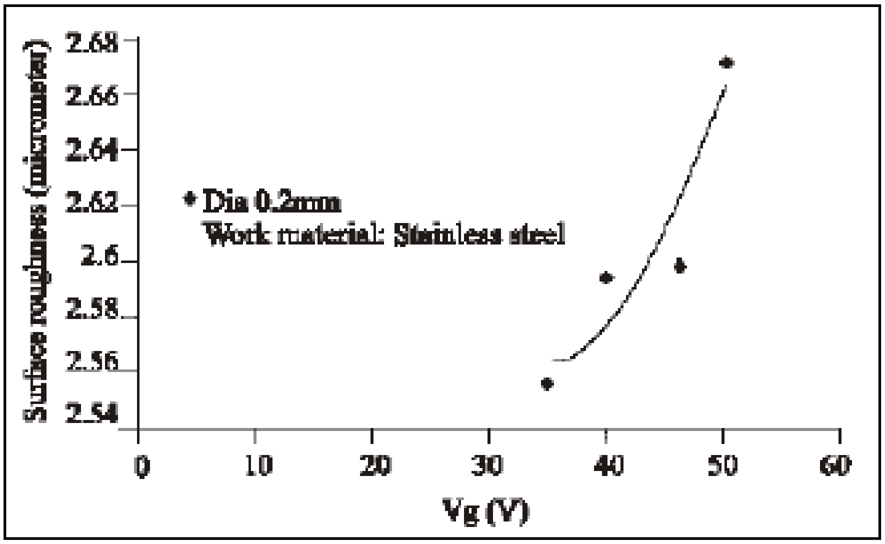
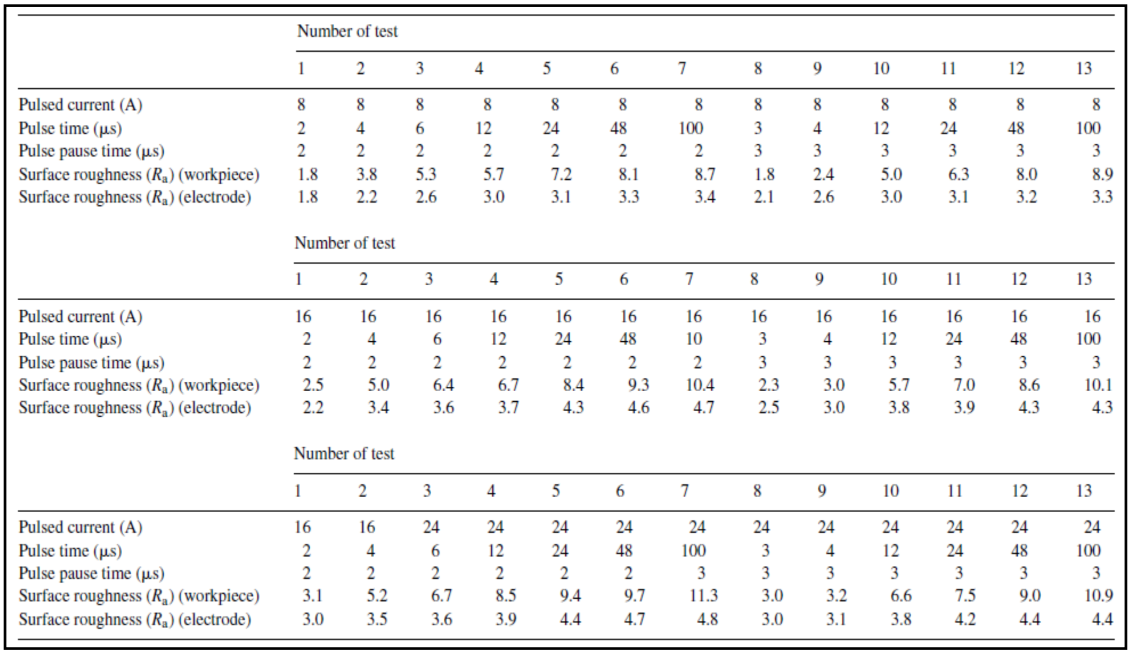


Figure 2.7: Relationship of surface roughness and voltage

Source: Khan et al. (2006)

Study was performed on P20 based on parameters on Table 2.2. Parameter used in this research are pulse current (A), pulse time (μs) pulse pause time (μs). In general based on Figure 2.8 and Figure 2.9 good surface finish can be archived by applying low current and pulse time with high pulse pause time (Kiyak & Cakir, 2007).

Table 2.2: Parameters of examination



	Number of test												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Pulsed current (A)	8	8	8	8	8	8	8	8	8	8	8	8	8
Pulse time (µs)	2	4	6	12	24	48	100	3	4	12	24	48	100
Pulse pause time (µs)	2	2	2	2	2	2	2	3	3	3	3	3	3
Surface roughness (R_a) (workpiece)	1.8	3.8	5.3	5.7	7.2	8.1	8.7	1.8	2.4	5.0	6.3	8.0	8.9
Surface roughness (R_a) (electrode)	1.8	2.2	2.6	3.0	3.1	3.3	3.4	2.1	2.6	3.0	3.1	3.2	3.3

	Number of test												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Pulsed current (A)	16	16	16	16	16	16	16	16	16	16	16	16	16
Pulse time (µs)	2	4	6	12	24	48	10	3	4	12	24	48	100
Pulse pause time (µs)	2	2	2	2	2	2	2	3	3	3	3	3	3
Surface roughness (R_a) (workpiece)	2.5	5.0	6.4	6.7	8.4	9.3	10.4	2.3	3.0	5.7	7.0	8.6	10.1
Surface roughness (R_a) (electrode)	2.2	3.4	3.6	3.7	4.3	4.6	4.7	2.5	3.0	3.8	3.9	4.3	4.3

	Number of test												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Pulsed current (A)	16	16	24	24	24	24	24	24	24	24	24	24	24
Pulse time (µs)	2	4	6	12	24	48	100	3	4	12	24	48	100
Pulse pause time (µs)	2	2	2	2	2	2	3	3	3	3	3	3	3
Surface roughness (R_a) (workpiece)	3.1	5.2	6.7	8.5	9.4	9.7	11.3	3.0	3.2	6.6	7.5	9.0	10.9
Surface roughness (R_a) (electrode)	3.0	3.5	3.6	3.9	4.4	4.7	4.8	3.0	3.1	3.8	4.2	4.4	4.4

Source: Kiyak & Cakir (2007)

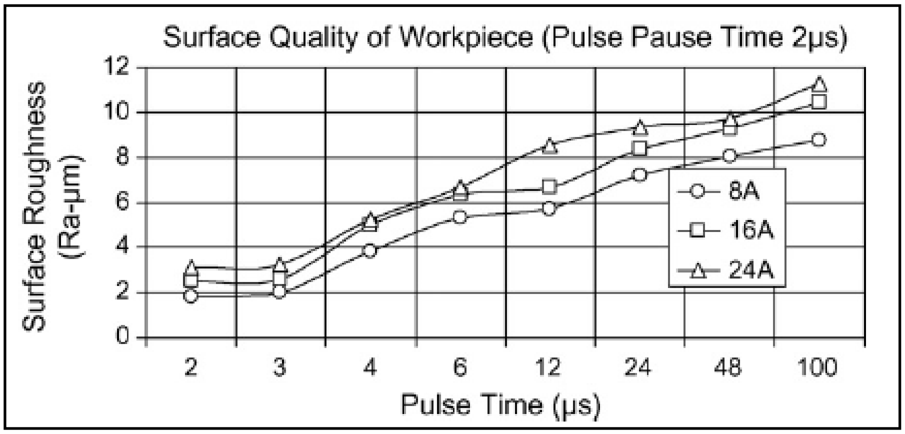


Figure 2.8: Effects of pulse time and pulsed current on surface roughness of workpiece (2 µs pulse pause time)

Source: Kiyak & Cakir (2007)

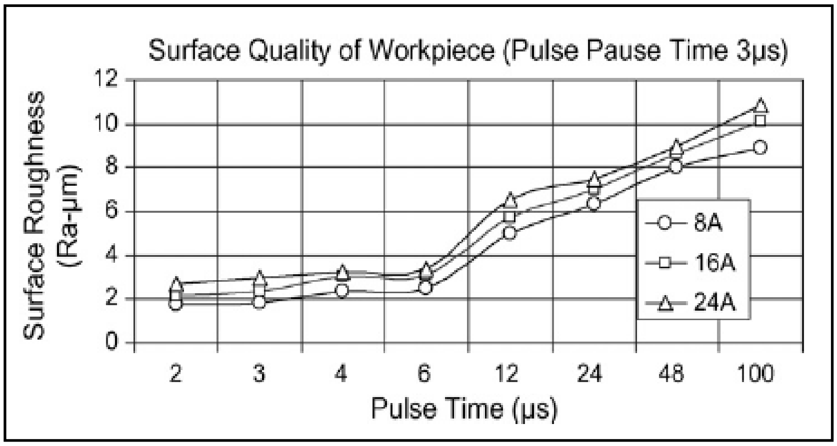
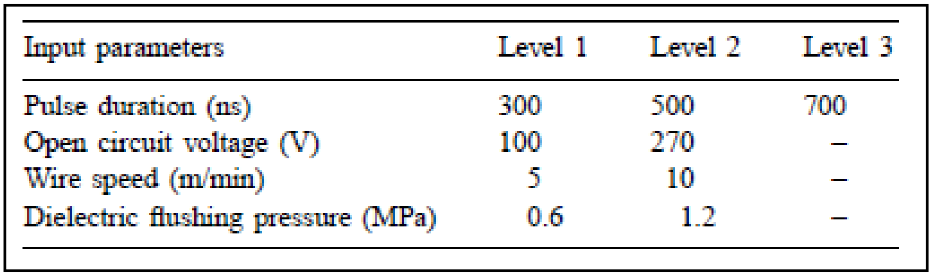


Figure 2.9: Effects of pulse time and pulsed current on surface roughness of workpiece (3 µs pulse pause time)

Source: Kiyak & Cakir (2007)

In experiment conducted on AISI D5 tool steel based on parameters stated in Table 2.3 wire speed seems to have less influence in surface roughness effect (Hascalyk & Caydas, 2004) The effect of wire speed may yield different result in experiment as parameters used are voltage, wire feed and wire tension which is different from this study.

Table 2.3: Parameters of the setting



Input parameters	Level 1	Level 2	Level 3
Pulse duration (ns)	300	500	700
Open circuit voltage (V)	100	270	–
Wire speed (m/min)	5	10	–
Dielectric flushing pressure (MPa)	0.6	1.2	–

Source: Hascalyk & Caydas (2004)

2.4 AISI P20

Increasing demands to the tools in plastic moulding ask for the specific development of tool steels having certain service properties for different ranges of application. Tools for the processing of plastics are mainly stressed with regard to pressure and wear. According to the type of plastics, there may in addition exist a stressing by corrosion (Uslu, 2007). The various types of plastics and different processing methods set requirements on the tool steel, as for instance; economical machinability, smallest change in size upon heat treatment, good polish ability, great compressive strength, high wear resistance and sufficient corrosion-resistance. AISI P20 becomes the best steel that can fulfill these requirement bases on its characteristics (Abou-El-Hossein et al., 2007). Properties and characteristic of AISI P20 used in this experiment shows in Tables 2.4 to Table 2.6.

Table 2.4: Hot Forming for AISI P20

Soft annealing °C	Cooling	Hardness, HB
710-740	furnace	max. 235

Source: www.assab-malaysia.com

Table 2.5: Hardness and tensile strength after quenching

Tempering, °C	100	200	300	400	500	600	700
HRC	51	50	48	46	42	36	28
N/mm^2	1730	1670	1570	1480	1330	1140	920

Source: www.assab-malaysia.com

Table 2.6: Properties and composition of AISI P20

	Chemical composition						
	C	Cr	Mn	Mo	Ni	S	Si
	0.37	2	1.4	0.2	1	Max. 0.01	
Hardness	290 - 341 HB						
Elasticity module	205 Gpa						
Thermal conductivity	29 W/m K						

Source: www.assab-malaysia.com