

THE EFFECT OF WEDM CUTTING PARAMETER ON INCONEL 718 SUBSURFACE MICROHARDNESS

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ABSTRACT: This paper reports on the effect of wire electrical discharge machine (WEDM) cutting parameter on the subsurface hardness of Inconel 718. The response surface methodology (RSM) using Box-Behnken design was used to conduct the experiment and analyze the relationship between control variables and responses. A total of 8 runs was carried out during the experiment. The Historical Data of Response Surface Methodology (RSM) was used as a tool of design of experiment (DOE). The selected WEDM parameters were Voltage (40-42V), feed rate (6-8V) and current (0.5-1.5 mm/min). The subsurface hardness was measured at the distance of 50 μm , 100 μm , 300 μm , 500 μm beneath the cutting surface. Observation of the results shows that the subsurface hardness is higher at the distance of 50 μm than 500 μm . The hardness was gradually decreased toward bulk hardness of HV0.1 270. Analysis of variance (ANOVA) was used to identify the significant effect of the factors on the response. Based on the analysis, feed rate and current were found to be the most significant factors in hardness change. Mathematical models were developed for hardness prediction with an average error of 2.7%. The minimum hardness change of HV0.1 30 was obtained by the combination of feed rate = 1.29 mm/min, servo voltage = 40.33 V, current = 7.94 A.

KEYWORDS: *Wire Electrical Discharge Machine, Response Surface Methodology, Historical Data, Inconel 718, Subsurface Microhardness*

1.0 INTRODUCTION

WEDM is one of the non-contact cutting process. The process gaining popular in mold making, aerospace, automotive, industry due to high precision ($\pm 5 \mu\text{m}$) and better surface finish ($0.2 \mu\text{m}$). The material removed by mean of a controlled rapid and repetitive electrical spark discharge between the tool and work piece that caused electrical erosion of conductive materials. The process creates a small gap of $0.01 - 0.5 \mu\text{m}$ [1]. The spark temperature of WEDM can reach $12,000^\circ\text{C}$ far than sufficient to melt and evaporate of Inconel 718 creating fomation of recast layer [2]. The changes of the microstructure from asrternite to martensite creating undesirable hard but brittle white layer [3].

Inconel 718 is a popular material in aerospace engine due to chemical and mechanical resistance. The requirement for aerospace component is very crucial to avoid problem occurrence during operation. The characteristics of surface integrity post machining include normal residual stress, no cracks, no discoloration, no foreign material, no white layer, no redeposit layer, no recrystallized zone, no recast layer, no porosity. The surface roughness should be less than $0.8 \mu\text{m}$ in order to obtain this characteristics [4].

The effect of cutting parameter on subsurface hardness in WEDM is studied less extensively by researchers, although there are some important features that contribute to surface integrity. The parameter that always reported was peek current, duty factor and pulse-on time. [5] reported that the material removal rate (MRR) increases as the pulse on time and current increases. However, the MRR decreased as the voltage and pulse off increased. This paper presents the influence of cutting parameter on microhardness of Inconel 718 subsurface.

2.0 METHODOLOGY

The material employed in the WEDM experiment was Inconel 718 grade AMS5662 with the nominal hardness of HV 270. Before the experiment, a block of Inconel 718 was squared by the face mill to a good surface finish. The dimension of the block was cut into $160 \times 25 \times 160 \text{ mm}$ rectangular blocks (Figure 1). The chemical compositions were 53% Ni,

18.30% Cr, 18.7% Fe, 5.05% Nb, 3.05% Mo, 1.05% Ti, 0.23% Mn and C balance (% wt.). All tests were done by using Mitsubishi WEDM RA90 Series. The brass wire of 0.25 mm diameter was used in this test due to low cost and high material removal rate for finishing process. Distilled water was used as lubricant and dielectric fluid.



Figure 1: Dimension of Inconel 718



Figure 2: WEDM model MITSUBISHI RA 90

The specimens were cut into a straight line with the following cutting parameter; Servo voltage (SV) 40-42V, peak current 6-8A, feed rate 0.5 – 1.5 mm/min. The wire speed and pulse off time were maintained at 8 m/min and 1 μ sec respectively throughout the experiments. After machining, the specimens were cross sectioned cut with precision cutter. The cross section of the sample was ground and polished with 400, 600, 800 and 1200 grit of Silicon Carbide sanding disc. The microhardness machine used in this study was Mitutoyo HM 200. The hardness of mirror finished sample was measured seven times at different subsurface depth (50 μ m, 300 μ m, 500 μ m). The hardness reading is commonly fluctuates by 50% [6]. To establish minimum deviation of average value, the measured hardness exceed than 20% of average considers as outlier and will be eliminated from the data set. The load of microhardness and dual time were 0.1 kgf and 15 second respectively. The minimum distance between indentations was

2.5 times of diagonal indenter, d to avoid the effect of work-hardened regions by previous indenter and the new indenter edge [7].

3.0 RESULTS

Figure 3 shows the image of a cross section Inconel 718 after WEDM process. The SEM image shows the minimum thickness range of 3 – 10 μm recast layer with no micro-crack detection. Some literatures consider recast layer also as unetchable white layer [8]. However, 1 μm of thin white layer was detected underneath the recast layer, which was identifiable in both of the parent and recast layer materials.

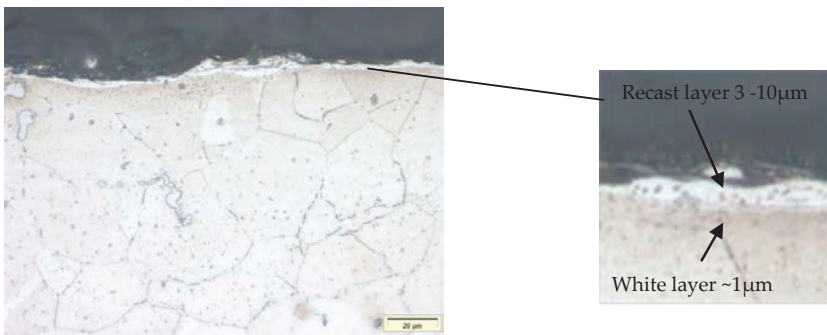


Figure 3: SEM image of a recast layer and white layer after WEDM

Figure 4 shows the hardness profile at different cutting parameters. Generally, the higher hardness value was obtained near the machined surface. This is caused by the remaining carbon rich recast layer and the quenching process by dielectric. The other factor is a residual stress caused by thermal input so that this region is named as altered sub-surface material zone [6]. The trend of significant parameter is hard to be distinguished. Thus, ANOVA was used to aid in determining the most contributing factor which will be discussed later. It was notified that the cutting process of WEDM causes increase of specimens microhardness. The hardest profile was identified close to the machined surface and gradually decreased further from the surface toward bulk nominal hardness of HV 270. Unlike traditional contact cutting process (milling and turning) which normally the machined affected zone (MAZ) was between 200 – 500 μm and some 50 μm [9,10]. MAZ for WEDM was detected beyond 500 μm . Only the combination parameter of feed rate 1.0 mm/min, Servo voltage 40V, current 7A and feed rate 1.0 mm/min, servo voltage 42V, current 8A can minimize MAZ gap below 500 μm .

Analysis of variance for microhardness was performed to identify the influence of cutting parameter on microhardness. Table 1 is the ANOVA table for microhardness test. Based on the result at 95% confidence level, the distance of subsurface measurement, current and feed rate had a significant effect on microhardness with p-value less than 5%. The cutting voltage found to be marginally significant. Subsurface distance is the most contributing factor due to highest F-value (188.71) than current (32.91), feed rate (20.29) and voltage (0.07).

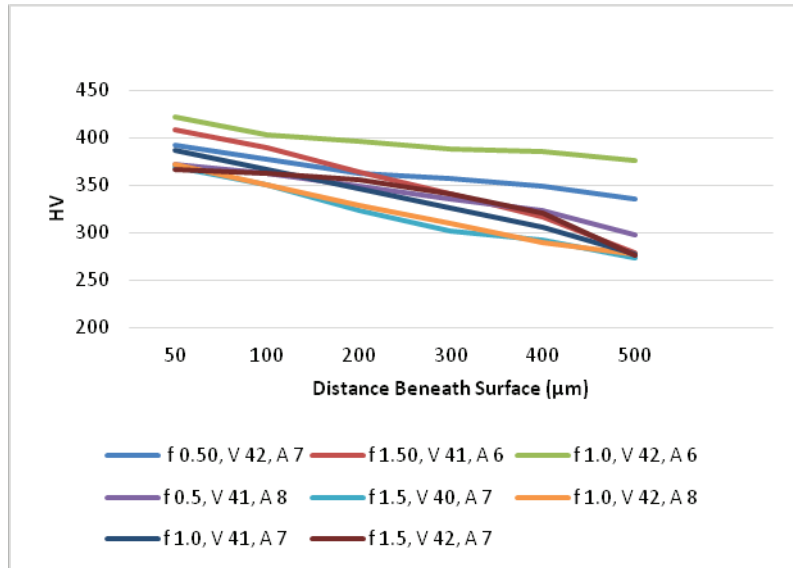


Figure 4: Hardness profile at different cutting parameters

Figure 5 shows the effect of cutting parameters within a predetermined range on microhardness. It was found that the microhardness decreases as the feed rate increases. Conversely, higher in servo voltage setting will increase microhardness. The effect of current is the most significant with the steep slope of the graph. Increases in current drastically reduces microhardness. This result is similarly found by [1]. They claimed the high current caused the hard carbide particle of the base material was flushed out during cutting process to reduce microhardness.

Table 1: ANOVA table for regression of coefficients

Source	Sum of Square	DF	Mean Square	F Value	Prob > F	Remarks
Model	44068	4	11017	64.30	< 0.0001	Significant
Feed rate, f	3477	1	3477	20.29	0.0003	Significant
Voltage, V	630	1	630	3.68	0.0711	Marginally significant
Current, A	5640	1	5640	32.91	< 0.0001	Significant
Subsurface distance, d	32333	1	32333	188.71	< 0.0001	Significant
Residual	3084	18	171			
Cor Total	47152	22				

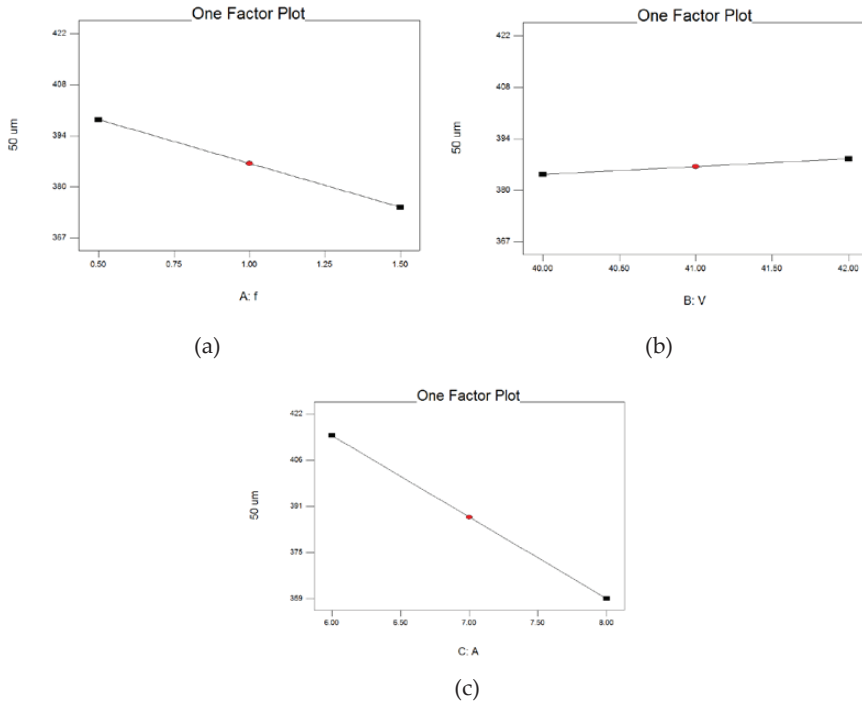


Figure 5: Correlation between variable cutting input against hardness; (a) feed rate (b) servo voltage (c) current

In this work, a mathematical model was developed using a historical data of Response Surface Methodology (RSM). Based on the experimental data. The linear in the normal operating ranges is inadequately modeled by the first-order function. This first order model can be denoted by the following equation:

$$\widehat{HV}_d = 291.36 + 37.38 f + 7.96 V + 26.21 A + 0.21 d \pm e \tag{1}$$

In Figure 6, all of the 23 out of 24 data samples are randomly scattered between predicted and actual microhardness. The group of points

scattered along the straight line indicates better prediction model. The accuracy of the model was tested by comparing the computed values and actual values where the average error found to be 3%.

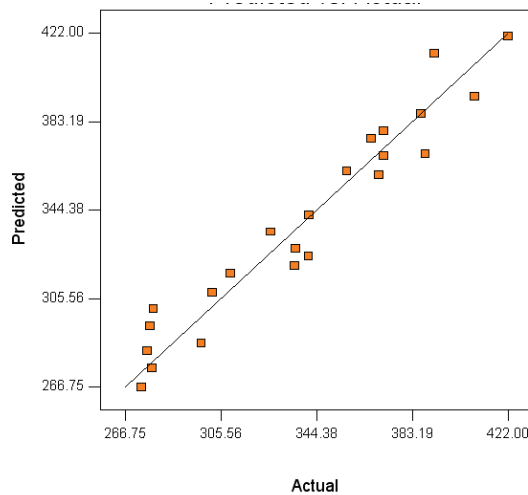


Figure 6: Prediction vs actual value of subsurface microhardness

4.0 CONCLUSION

A series of experiments using historical data of RSM were conducted to investigate the effect of cutting parameter during WEDM of Inconel 718 on the subsurface hardness. The conclusion of the experiment can be summarized as follows:

1. Hardness of nickel-based alloy surface slowly reduces at beneath surface. It shows in the HAZ area has higher hardness and slightly reduce for a distance of $500\mu\text{m}$. Then, the hardness will maintain at bulk hardness which is HV 270. The machining process of WEDM produces heat at the specimens cutting surface and generate the work hardening.
2. The microhardness prediction model was developed to predict the effect of cutting process by WEDM on subsurface hardness. The average deviation between predicted and measured microhardness value at various subsurface depth was approximately 3%.
3. The optimal WEDM cutting parameter as to achieve minimum microhardness change are feed rate, $f = 1.29$

mm/s, servo voltage, $V = 40.33V$, current, $A = 7.94A$. With this parameter, the minimum subsurface hardness change of HV 64 can be obtained.

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