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# Optimization of Surface Roughness and Kerf Width Parameters in Wire Cut EDM Process through Response Surface Methodology.

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***Abstract**: Machining of Composite materials like Al 7075-SiC metal matrix composites has found its use extensively in Air craft fittings, gears, shafts, missile parts, regulating valve parts, keys and bike frames to enhance high strength, corrosion resistance and thermal resistance characteristics. And also there is a need to improve high material removal rate, better surface finish and good dimensional accuracy. Conventional machining is not able to satisfy these demands. Wire electro discharge machining plays a major role in machining of conductive materials with intricate shapes and complex geometries where a thin metallic wire of 0.1-0.3mm diameter is used as a tool electrode. Al 7075-SiC metal matrix composites are prepared by using Sand casting though manual stirring. The objective is to identify the best parametric combination of Wire EDM to minimize surface roughness and kerf width for Al 7075-10% SiC and Al 7075-15% SiC. For this experimentation Pulse on time(TON), pulse off time(TOFF), peak current(IP) and Spark gap Voltage are the most affecting input parameters to perform experiments on Wire Cut Electro Discharge Machine(ELPULSE 40A). In the present work 34 experimental runs are designed based on the Box-Behnken Design of Response Surface Methodology. ANOVA (Analysis of Variance) is used to get the effect of process parameters on process response. A second order polynomial model has been developed to correlate the process responses and the machining parameters by using Response Surface Method (RSM).*
***Keywords**: Include at least 5 keywords or phrases*

## I. INTRODUCTION

Wire Cut Electro Discharge Machining is an unconventional Electro Thermal machining process which is working based on the principle of repetitive sparking cycles. Due to generation of heat melting and evaporation of both wire and work piece takes place. Gap between wire and work piece is in range of 0.025-0.5mm which is maintained constant by computer controlled positioning system. The gap between wire and work piece is covered with steam of dielectric fluid which is directed to the working zone by the nozzles present at the upper and lower diamond guides. The dielectric can control sparking, cools the process and flushes away the tiny particles very faster. The wire and work piece is mounted on CNC work table. Wire is fed through work piece by a microprocessor to enable machining.

Fig1. Wire cut Electro Discharge Machine

The wire EDM can cut almost all the metals including aluminium, copper, carbide, graphite, steel and titanium. Depending upon the hardness of work piece wire metal changes. With the advent of WEDM process a path provided by CNC is used to machine hard metals through inaccessible locations with the use of electrical sparks exist between tool and work piece. Al most all the areas like aerospace, semiconductor, tool and die making industries are now a days using Wire cut EDM process.

With the increase in demand for high hard, light weight and temperature resistant materials in aerospace, automobile and missile applications quality of a product has became a major concern. And also minimizing of material wastage during machining is important. Wire cut Electro Discharge Machining is the best choice to achieve all these requirements. The present study deals with identification of the best parametric combination of a Wire cut EDM process parameters to achieve minimum surface roughness and kerf width. By using ANOVA the effect of process parameters on process responses has been found.

## II. EXPERIMENTAL DETAILS

### *A. Response Surface Methodology*

Response Surface Methodology is a collection of mathematical and statistical techniques useful for modeling and analysis of a problem in where the responses of interest is influenced by several variables and objective is to optimize this response. An optimal response can be obtained by choosing a proper choice of design and operating conditions on a set of controllable variables. Here output is influenced by the number of input factors. In this method the main goal is, to reduce the expensive analysis cost and optimize the output responses that are influenced by various input parameters. For the visualization of the response, contour and surface plots are used. It gives the relation between the control factors and output responses. Contour plots are used to visualize the shape of response surface.

Suppose ‘x1' and ‘x2’ are the input parameters that are affecting the response ‘y’ can be expressed as follows:

$$y=f(x1,x2)+\mathcal{E} \rightarrow (a)$$

where Ɛ is the noise or error observed in response ‘y’

$$\text{Let } E(y) = f(x1,x2) = \eta \rightarrow (b)$$

The above experiment is the expected response which is known as response surface with levels of ‘x1’ and ‘x2’.

RSM comprises the following steps

*1)* Prepare a set of trials for sufficient and consistent extent of the output.
*2)* Progress an empirical model of the 2nd order response surface with the suitable sets.
*3)* Identify the efficient set of trial variables that gives a maximum and minimum response values.
*4)* Characterize the direct and the collaborative effects of variables through 2D and 3D graphs.

### *B. Plan of Experiments*

Very vital stage of RSM is to progress a set of trials later difficult detection. Engineering exploration problems are practical in nature and include use of practice.

There are various designs like

*1)* Box Behnken Design
*2)* Full factorial
*3)* Fractional factorial (FFD)
*4)* One factor
*5)* D- optimal
*6)* Latin square
*7)* CCD
*8)* Historical data

### *C. Design of Experiments – Box Behnken Design*

Box Behnken Design is a creative approach to planned experimentation involving relatively smaller number of runs. It involves balance incomplete block design which is important alternative to Central Composite Design. In this design all the design points are equidistant from canter design point. The advantages of Box-Behnken designs includes they are all spherical designs and require factors to be run at only three levels. The designs are also rotatable or nearly rotatable. Some of these designs also provide orthogonal blocking. Thus, if there is a need to separate runs into blocks for the Box-Behnken design, then designs are available that allow blocks to be used in

| Process Parameters | Units | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Pulse on time (A) | Micro sec | 100 | 105 | 110 |
| Pulseoff time(B) | Micro sec | 59 | 60 | 61 |
| Peak Current(C) | Amphere | 180 | 190 | 200 |
| Sparkgap Voltage(D) | Volts | 10 | 15 | 20 |

Table 1 Process parameters and their limits

Such a way that the estimation of the regression parameters for the factor effects are not affected by the blocks. In other words, in these designs the block effects are orthogonal to the other factor effects. Yet another advantage of these designs is that there are no runs where all factors are at either the +1 or -1 levels. This could be advantageous when the corner points represent runs that are expensive or inconvenient because they lie at the end of the range of the factor levels.

| S.No. | Pulse on time(µs) | Pulse off time(µs) | Peak current(Amp) | Spark gap voltage (Volts) |
|---|---|---|---|---|
| 1 | 105 | 61 | 200 | 15 |
| 2 | 105 | 59 | 190 | 10 |
| 3 | 110 | 61 | 190 | 15 |
| 4 | 105 | 59 | 190 | 20 |
| 5 | 105 | 60 | 200 | 20 |
| 6 | 110 | 60 | 190 | 20 |
| 7 | 105 | 60 | 200 | 10 |
| 8 | 110 | 60 | 190 | 10 |
| 9 | 105 | 60 | 180 | 20 |
| 10 | 100 | 61 | 190 | 15 |
| 11 | 105 | 59 | 180 | 15 |
| 12 | 100 | 59 | 190 | 15 |
| 13 | 100 | 60 | 200 | 15 |
| 14 | 105 | 60 | 180 | 10 |
| 15 | 100 | 60 | 190 | 10 |
| 16 | 110 | 60 | 200 | 15 |
| 17 | 105 | 61 | 190 | 20 |
| 18 | 105 | 60 | 190 | 15 |
| 19 | 105 | 60 | 190 | 15 |
| 20 | 100 | 60 | 180 | 15 |
| 21 | 110 | 59 | 190 | 15 |
| 22 | 105 | 60 | 190 | 15 |
| 23 | 105 | 61 | 180 | 15 |
| 24 | 100 | 60 | 190 | 20 |
| 25 | 105 | 61 | 190 | 10 |
| 26 | 110 | 60 | 180 | 15 |
| 27 | 105 | 59 | 200 | 15 |

Table 2: Box-Behnken Design

*D. Selection of Material*

Al 7075- SiC Metal Matrix Composites with varying composition of 10% and 15% Silicon Carbide are used for the melting temperature that is 650$^{O}$C. And then Silicon Carbide particle of size 50 microns is added into the matrix alloy according to the proportion. This combination has to be stirred for some time and then poured into the previously prepared sand mould.

| Material | Weight of Al 7075(gm) | Weight of SiC(gm) | Rockwell Hardness |
|---|---|---|---|
| Al 7075- 10%SiC | 1800 | 200 | 120.67 |
| Al 7075- 15%SiC | 1700 | 300 | 183.33 |

Table3. Hardness of Aluminium Metal Matrix Composites

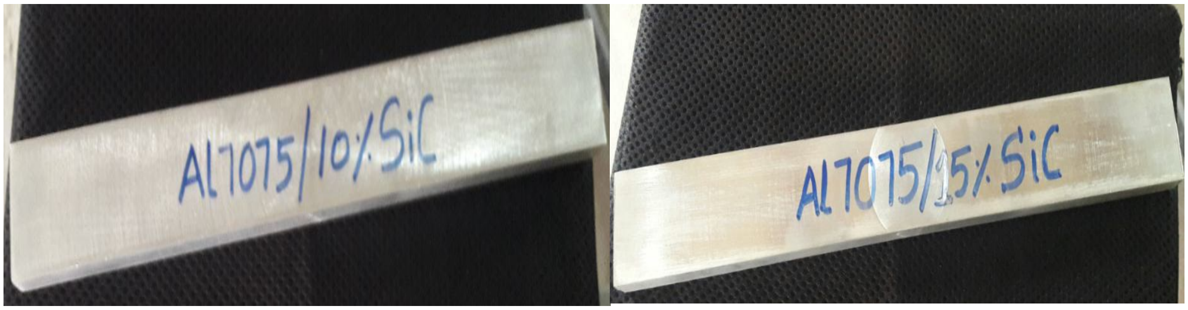


Fig 2. Al 7075-SiC(10% and15%) after casting

## III.RESULTS AND DISCUSSIONS

The experiments are performed based on the order of Box-Behnken Design and responses characteristics like Surface Roughness and Kerf Width have been observed by using Talysurf and Tool makers microscope are tabulated below

*A. Response Table for Surface Roughness and Kerf Width*

| S.No | Ton (μ sec ) | T off (μ sec ) | Ip (Amp) | SV (V) | Al 7075-10% SiC | | Al 7075- 15% SiC | |
|---|---|---|---|---|---|---|---|---|
| | | | | | KERF(mm) | SR(microns) | KERF(mm) | SR(microns) |
| 1 | 105 | 61 | 200 | 15 | 0.374 | 3.874 | 0.353 | 3.708 |
| 2 | 105 | 59 | 190 | 10 | 0.372 | 4.085 | 0.34 | 3.271 |
| 3 | 110 | 61 | 190 | 15 | 0.375 | 5.335 | 0.397 | 4.211 |
| 4 | 105 | 59 | 190 | 20 | 0.447 | 3.78 | 0.366 | 3.368 |
| 5 | 105 | 60 | 200 | 20 | 0.416 | 3.711 | 0.396 | 3.607 |
| 6 | 110 | 60 | 190 | 20 | 0.373 | 4.863 | 0.333 | 6.041 |
| 7 | 105 | 60 | 200 | 10 | 0.347 | 3.693 | 0.329 | 3.736 |
| 8 | 110 | 60 | 190 | 10 | 0.392 | 4.367 | 0.385 | 4.902 |
| 9 | 105 | 60 | 180 | 20 | 0.449 | 4.377 | 0.336 | 4.459 |
| 10 | 100 | 61 | 190 | 15 | 0.362 | 3.17 | 0.313 | 3.466 |
| 11 | 105 | 59 | 180 | 15 | 0.381 | 4.04 | 0.336 | 4.042 |
| 12 | 100 | 59 | 190 | 15 | 0.384 | 3.121 | 0.306 | 2.909 |
| 13 | 100 | 60 | 200 | 15 | 0.38 | 3.057 | 0.341 | 2.292 |
| 14 | 105 | 60 | 180 | 10 | 0.436 | 3.305 | 0.378 | 4.407 |
| 15 | 100 | 60 | 190 | 10 | 0.396 | 3.016 | 0.392 | 3.177 |
| 16 | 110 | 60 | 200 | 15 | 0.297 | 2.759 | 0.388 | 3.181 |
| 17 | 105 | 61 | 190 | 20 | 0.372 | 3.546 | 0.391 | 4.118 |
| 18 | 105 | 60 | 190 | 15 | 0.326 | 4.802 | 0.362 | 4.063 |
| 19 | 105 | 60 | 190 | 15 | 0.382 | 4.413 | 0.329 | 3.964 |
| 20 | 100 | 60 | 180 | 15 | 0.397 | 3.306 | 0.335 | 3.087 |
| 21 | 110 | 59 | 190 | 15 | 0.378 | 4.139 | 0.315 | 4.467 |
| 22 | 105 | 60 | 190 | 15 | 0.409 | 4.121 | 0.339 | 5.046 |
| 23 | 105 | 61 | 180 | 15 | 0.391 | 3.954 | 0.369 | 3.675 |
| 24 | 100 | 60 | 190 | 20 | 0.412 | 3.256 | 0.394 | 2.921 |
| 25 | 105 | 61 | 190 | 10 | 0.369 | 4.462 | 0.371 | 3.863 |
| 26 | 110 | 60 | 180 | 15 | 0.443 | 4.37 | 0.388 | 4.98 |
| 27 | 105 | 59 | 200 | 15 | 0.389 | 4.412 | 0.362 | 4.34 |

Table4. Surface Roughness and Kerf Width for Al 7075-10% SiC and Al 7075-15% SiC

### B. *Analysis of Variance and Regression Equations*

| Source | Sum of Squares | df | Mean Square | F-Value | p-value Prob> F | Remarks |
|---|---|---|---|---|---|---|
| Model | 0.11 | 14 | 7.962E-003 | 19.67 | < 0.0001 | significant |
| A-A | 8.090E-004 | 1 | 8.090E-004 | 2.00 | 0.1736 | |
| B-B | 1.164E-003 | 1 | 1.164E-003 | 2.88 | 0.1062 | |
| C-C | 9.366E-003 | 1 | 9.366E-003 | 23.14 | 0.0001 | significant |
| D-D | 2.421E-003 | 1 | 2.421E-003 | 5.98 | 0.0244 | significant |
| AB | 1.228E-004 | 1 | 1.228E-004 | 0.30 | 0.5882 | |
| AC | 5.978E-003 | 1 | 5.978E-003 | 14.77 | 0.0011 | Significant |
| AD | 3.760E-004 | 1 | 3.760E-004 | 0.93 | 0.3473 | |
| BC | 2.006E-004 | 1 | 2.006E-004 | 0.50 | 0.4899 | |
| BD | 1.453E-003 | 1 | 1.453E-003 | 3.59 | 0.0734 | Significant |
| CD | 1.089E-003 | 1 | 1.089E-003 | 2.69 | 0.1174 | |
| $A^2$ | 0.015 | 1 | 0.015 | 36.71 | < 0.0001 | Significant |
| $B^2$ | 0.017 | 1 | 0.017 | 40.81 | < 0.0001 | Significant |
| $C^2$ | 0.026 | 1 | 0.026 | 64.74 | < 0.0001 | Significant |
| $D^2$ | 0.039 | 1 | 0.039 | 96.34 | < 0.0001 | Significant |
| Cor Total | 0.12 | 26 | | | | |
| R-Squared 0.9292 | | | | | | |

Table5. ANOVA Table for Kerf Width on machining of Al 7075-10%SiC

### C. *Regression Equation for Kerf Width*

143.12942-0.21847*Ton-4.12600*Toff-0.084458*Ip+0.13222*SV+9.50000E-004*Ton*Toff-6.45000E-004*Ton*Ip-3.50000E-004*Ton*SV-6.25000E-004*Toff*Ip-3.60000E-003*Toff*SV+2.80000E-004*Ip*SV+ 1.37167 E-003*Ton$^2$+0.034917*Toff$^2$ +4.81667E-004* Ip$^2$+2.33167E-003*SV$^2$.

| Source | Sum of Squares | df | Mean Square | F-Value | p-value Prob> F | Remarks |
|---|---|---|---|---|---|---|
| Model | 13.16 | 14 | 0.94 | 6.19 | 0.0002 | Significant |
| A-A | 2.01 | 1 | 2.01 | 13.21 | 0.0018 | Significant |
| B-B | 0.13 | 1 | 0.13 | 0.84 | 0.3714 | |
| C-C | 0.28 | 1 | 0.28 | 1.87 | 0.1875 | Significant |
| D-D | 0.031 | 1 | 0.031 | 0.20 | 0.6592 | |
| AB | 0.18 | 1 | 0.18 | 1.20 | 0.2875 | |
| AC | 0.46 | 1 | 0.46 | 3.05 | 0.0967 | |
| AD | 0.016 | 1 | 0.016 | 0.11 | 0.7462 | |
| BC | 0.051 | 1 | 0.051 | 0.34 | 0.5688 | |
| BD | 0.093 | 1 | 0.093 | 0.61 | 0.4428 | |
| CD | 0.28 | 1 | 0.28 | 1.83 | 0.1922 | |
| $A^2$ | 5.37 | 1 | 5.37 | 35.34 | < 0.0001 | Significant |
| $B^2$ | 1.48 | 1 | 1.48 | 9.77 | 0.0056 | Significant |
| $C^2$ | 2.52 | 1 | 2.52 | 16.58 | 0.0007 | Significant |
| $D^2$ | 1.06 | 1 | 1.06 | 6.97 | 0.0161 | Significant |
| Cor Total | 16.05 | 26 | | | | |
| R-Squared 0.8201 | | | | | | |

Table 6. ANOVA Table for Surface Roughness on machining of Al 7075-10%SiC

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1) *Regression Equation for Surface Roughness*: 2719.20818+10.89089*Ton+59.51850*Toff+3.62392*Ip+3.01951*SV-0.042650*Ton*Toff-6.81000E-003*Ton*Ip+2.56000E-003*Ton*SV-0.011300*Toff*Ip-0.030550*Toff*SV-5.27000E-003*Ip*SV-0.033308*Ton$^2$-0.43782*Toff$^2$-5.70317E-003*Ip$^2$-0.014798* SV$^2$

| Source | Sum of Squares | df | Mean Square | F-Value | p-value Prob> F | Remarks |
|---|---|---|---|---|---|---|
| Model | 0.034 | 14 | 2.413E-003 | 5.56 | 0.0004 | Significant |
| A-A | 1.302E-003 | 1 | 1.302E-003 | 3.00 | 0.0995 | Significant |
| B-B | 2.380E-003 | 1 | 2.380E-003 | 5.48 | 0.0303 | |
| C-C | 6.075E-005 | 1 | 6.075E-005 | 0.14 | 0.7125 | |
| D-D | 3.675E-005 | 1 | 3.675E-005 | 0.085 | 0.7742 | |
| AB | 1.406E-003 | 1 | 1.406E-003 | 3.24 | 0.0878 | Significant |
| AC | 9.000E-006 | 1 | 9.000E-006 | 0.021 | 0.8870 | |
| AD | 7.290E-004 | 1 | 7.290E-004 | 1.68 | 0.2105 | |
| BC | 4.410E-004 | 1 | 4.410E-004 | 1.02 | 0.3262 | |
| BD | 9.000E-006 | 1 | 9.000E-006 | 0.021 | 0.8870 | |
| CD | 2.970E-003 | 1 | 2.970E-003 | 6.84 | 0.0170 | Significant |
| $A^2$ | 5.018E-003 | 1 | 5.018E-003 | 11.56 | 0.0030 | Significant |
| $B^2$ | 2.226E-003 | 1 | 2.226E-003 | 5.13 | 0.0354 | Significant |
| $C^2$ | 6.270E-003 | 1 | 6.270E-003 | 14.44 | 0.0012 | Significant |
| $D^2$ | 0.013 | 1 | 0.013 | 29.92 | < 0.0001 | Significant |
| Cor Total | 0.042 | 26 | | | | |
| R-Squared 0.8038 | | | | | | |

Table7. ANOVA Table for Kerf Width on machining of Al 7075-15%SiC

2) *Regression Equation for Kerf Width:* 93.59971-0.42297* Ton-2.21067* Toff-0.049942* Ip-0.077650* SV+3.75000E-003* Ton * Toff-3.00000E-005* Ton* Ip-5.40000E-004* Ton * SV-1.05000E-003* Toff * Ip-3.00000E-004* Toff * SV+5.45000E-004* Ip * SV+1.01833E-003* Ton$^2$ +0.016958* Toff$^2$+2.84583E-004* Ip$^2$+1.63833E-003* SV$^{2.}$

| Source | Sum of Squares | df | Mean Square | F-Value | p-value Prob> F | Remarks |
|---|---|---|---|---|---|---|
| Model | 25.14 | 14 | 1.80 | 7.69 | < 0.0001 | Significant |
| A-A | 12.71 | 1 | 12.71 | 54.44 | < 0.0001 | Significant |
| B-B | 0.036 | 1 | 0.036 | 0.15 | 0.7003 | |
| C-C | 0.17 | 1 | 0.17 | 0.71 | 0.4103 | |
| D-D | 0.52 | 1 | 0.52 | 2.22 | 0.1526 | |
| AB | 0.17 | 1 | 0.17 | 0.71 | 0.4100 | |
| AC | 1.892E-003 | 1 | 1.892E-003 | 8.107E-003 | 0.9292 | |
| AD | 1.03 | 1 | 1.03 | 4.40 | 0.0496 | Significant |
| BC | 3.025E-003 | 1 | 3.025E-003 | 0.013 | 0.9106 | |
| BD | 0.18 | 1 | 0.18 | 0.77 | 0.3922 | |
| CD | 0.19 | 1 | 0.19 | 0.81 | 0.3781 | |
| $A^2$ | 1.91 | 1 | 1.91 | 8.20 | 0.0100 | |
| $B^2$ | 1.00 | 1 | 1.00 | 4.30 | 0.0519 | Significant |
| $C^2$ | 4.04 | 1 | 4.04 | 17.29 | 0.0005 | Significant |
| $D^2$ | 4.08 | 1 | 4.08 | 17.47 | 0.0005 | Significant |
| Cor Total | 29.58 | 26 | | | | |
| R-Squared 0.8501 | | | | | | |

Table 8. ANOVA Table for Surface Roughness on machining of Al 7075-15%SiC

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3) *Regression Equation for Surface Roughness:* 1541.50563-1.91423*Ton-39.00900*Toff-2.57093*Ip-4.66618*SV-0.040700*Ton*Toff+4.35000E-004*Ton*SV+ 0.020260*Ton*SV-2.75000E-003*Toff*Ip+0.042300*Toff*SV-4.36000E-003*Ip*SV+0.019883*$Ton^2$+0.3602*$Toff^2$+7.22083E-003 *$Ip^2$+0.029028*$SV^2$

### B. 3D Surface Plots for Process Responses Vs Process Variables

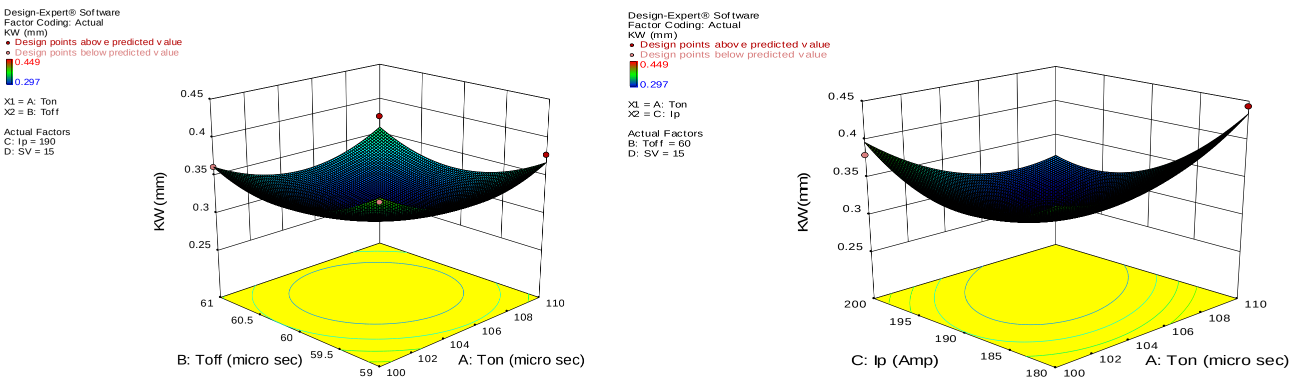


Fig3. Surface graph for interaction effect on Kerf Width for Al 7075-10% SiC

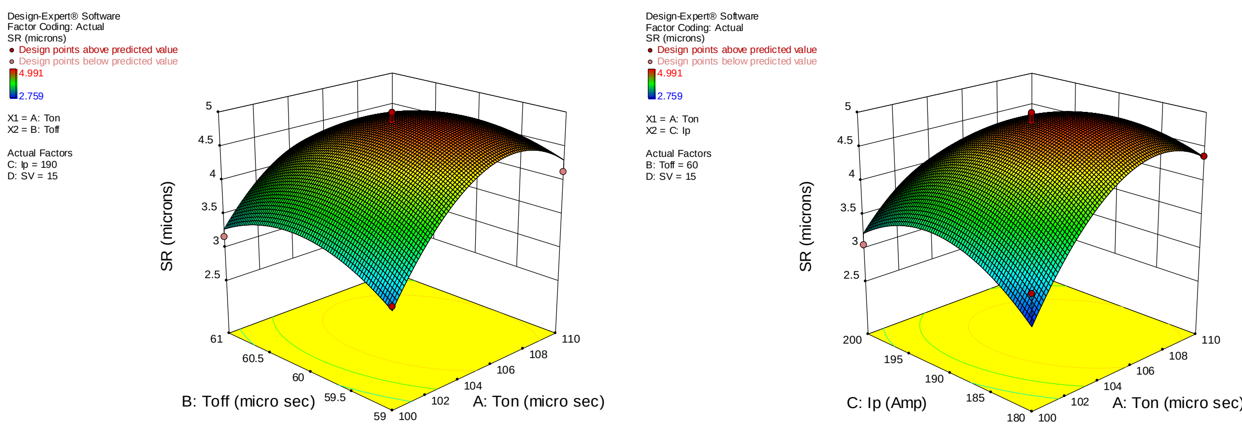


Fig4. Surface graph for interaction effect on Surface Roughness for Al 7075-10% SiC

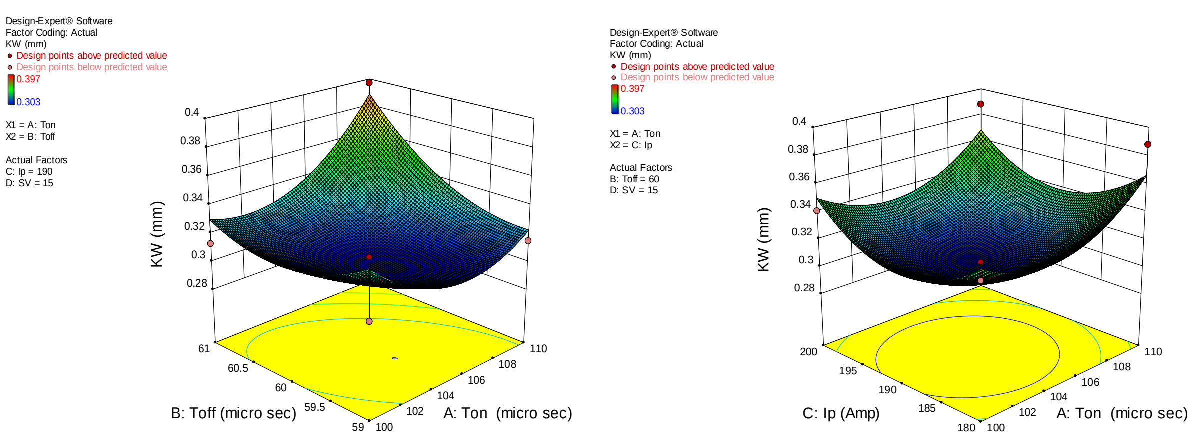


Fig5. Surface graph for interaction effect on Kerf Width for Al 7075-15% SiC

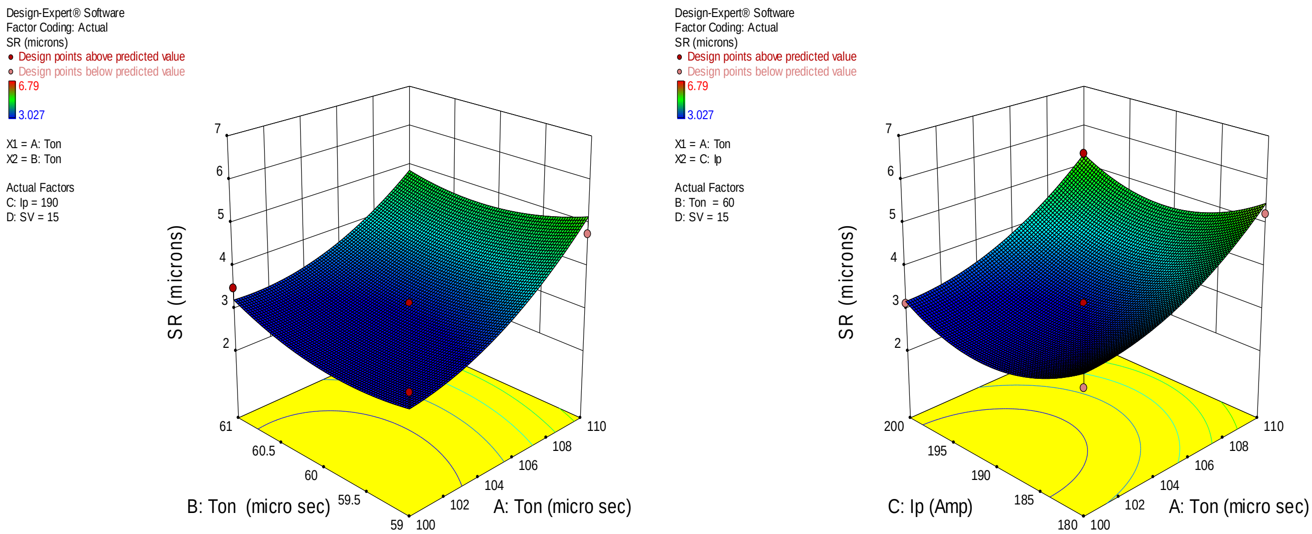


Fig6. Surface graph for interaction effect on Surface Roughness for Al 7075-15% SiC

## IV. CONCLUSION

The important conclusions with the machining of Al 7075 -10% SiC and Al 7075 -15% SiC on Wire cut EDM using Response Surface Methodology includes as follows:

The optimal set of process parameters are identified for achieving minimum Surface Roughness and minimum Kerf width for each material.

Second order polynomial equation have been generated for both Surface Roughness and Kerf width.

ANOVA results to identify the effect of process parameters on process responses and percentage contribution of each parameter on process response

### *A. 7075-10% SiC*

1) The optimal parameter setting for achieving minimum Kerf Width is obtained at 110µ sec of pulse on time and 60µ sec of pulse off time 200 Amp of peak current and 15Volts of Spark gap voltage i.e 0.297 mm.
2) The optimal parameter setting for achieving minimum Surface Roughness is obtained at 110µ sec of pulse on time and 60 µ sec of pulse off time 200 Amp of peak current and 15Volts of Spark gap voltage i.e 2.759 microns.

### *Al 7075-15% SiC*

3) The optimal parameter setting for achieving minimum Kerf Width is obtained at 100 µ sec of pulse on time and 59 µ sec of pulse off time 190 Amp of peak current and 15Volts of Spark gap voltage i.e 0.306mm
4) The optimal parameter setting for achieving minimum Surface Roughness is obtained at 100 µ sec of pulse on time and 60 µ sec of pulse off time 200 Amp of peak current and 15 Volts of Spark gap voltage i.e 2.292 microns.

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