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Finite element modelling and machining using WEDM

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Abstract: During the past few decades, due to the demands from the production fields producing really different and compact products, there developed a need to produce materials with proper finish and with proper Material Removal Rate (MRR).So, to know the surface finish(SR) and Material Removal Rate(MRR) of a material. There are some factors effecting these both factors. In this paper we are considering WEDM (Wire Electronic Discharge Machining) as the machining equipment, WEDM is a non-conventional traditional process in which the material is being cut using a electrically charged wire which is fed continusely on to the material and by continues spread of di-electric fluid for flushing out the removed material. In the removal process there are several parameters which have to be understood in getting perfect SR and MRR. There are some fixed parameters like SEN, Material, Wire, Di-electric fluid these are the fixed parameters which can't be changed, and the parameters which can be changed are Feed rate, Pulse-on, Pulse-off and Gap Voltage. In this paper to they performed 9-different experiments using L9 orthogonal array approach, which helps in selecting the optimized values. It's a trail and error process, among those 9 experiments we will get one best optimized way, and we will choose those particular parameters and values chosen as the optimized values for that material. In this paper we are selecting Inconel 718 material as the work piece and molybdenum wire as the feed wire in WEDM .In the study, during machining process time taken each experiment and the weight being reduced after every experiment is being noted down, in the calculation of MRR we need this terms(weight & time), the MRR can be calculated by (Weight of the work piece before machining-Weight of the work piece after machining/Time taken).After calculating MRR and SR manually we are going to compare this values with the mathematical FEA process by using MATlab or ANSYS. In this study we came to know that Duty factor which refers to pulse-on & off time plays an important role in MRR and feed rate plays an important role in SR.

1. Introduction

1.1. Back ground of WEDM

WEDM is a specialized method of machining which uses thermal power to machine parts, which are hard in nature and has complex shape. This is a Non-Traditional machining process which uses spark for material removal process. This WEDM is used for a quick production and to reduce cost. Many experiments are carried out to optimize the process parameters of the WEDM.It can produce a wide – variety of micro parts from metals, alloys, sintered, cemented carbides, ceramics and silicon.

1.2. Over view of WEDM

Wire electrode is a process in which the material erodes and removes the material, an plasma channel is used which has been generated from electric sparks between two conductive materials. The channel of plasma which we use to remove the material is converted to thermal energy at a temperature of 8000^{o} to 12000^{o}C at a direct voltage of 20000 to30000Hz.There is a small gap between work piece and electrode immersed in di-electric fluid. The gap is filled by spark which erodes the material. When the direct current is turned off there is an immediate fall in the temperature and the eroded material will be removed out by the help of dielectric fluid in this gap. With every single there is a crater being formed due to spark, both on the work piece and the electrode which can be reflected in the surface finish of the material. The taper ranges from 15° for 100mm and 30°for 400mm thick.

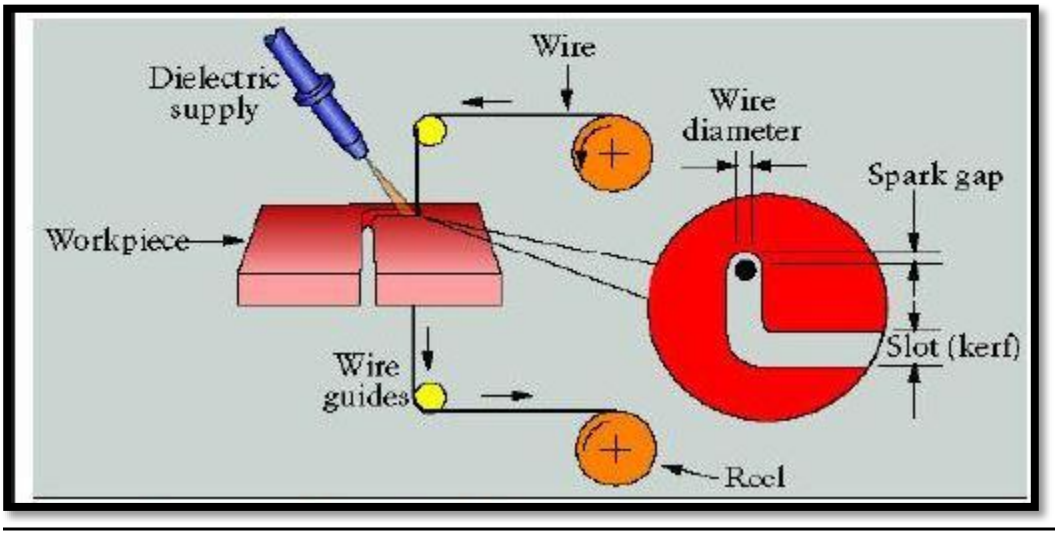

Figure1. Schematic diagram of WEDM.

2. Literature survey:

[1]WEDM machining on Aero space materials for improving materials material properties*:*

As we know nickel alloys are strong in nature and can posses good resistance to heat and corrosion ,due to the very compact nature of the alloy, they are used in the manufacture of aerospace parts And WEDM is the no-conventional method used to manufacture the parts. In this paper they have considered three nickel alloys namely inconel, moveland incolony. And by using taguchi method of trail they have took 4 four parameters which will govern the mechanism like pulse on, pulse-off, wire feed rate and current .By changing these parameters they have found MRR and surface roughness for all the selected 3 materials and bought the optimum..[2]Influence of the WEDM process on the fatigue behavior of Inconel 718:In this paper they have selected inconel 718 material as the work piece which is used in aeronautical industries , while machining in EDM , due to the thermal contact of the anode and cathode there will be some changes in the metallurgical properties of the material(inconel 718), which intern will reduce the fatigue life .So, they have bought the significance advances in the development of EDM generators, in this paper they have discussed about the fatigue life of WEDM, surface analysis, metallographic studies, residual stress for inconel 718.[3]Investigation of MRR and SR during WEDM machining of inconel 625 super alloy by cryogenic treated tool electrode*:*In this paper they have considered inconel 625 material as the work material and conducted MRR and SR , by changing the important parameters such as pulse on , pulse off , current and gap voltage .By using taguchi L18 method, experiments are being carried out .They have compared the results by changing the wire used in WEDM they have used two wires one is the zinc wire and the other one is the cryogenic treated zinc wire.[4]Finite element modeling and simulation of Inconel 718 using WEDM:

In this paper they have selected iconel 718, a nickel based alloy and machined in WEDM,taking copper wire as the feed wire, they have modeled an equivalent model in ANSYS, it's a 3D model, they have composed single spark thermal model WEDM with Gaussian distribution of heat, and spark radius for one-single spark were been obtained in ANSYS. And are compared with the heat and spark radius values with original machining values and they found both comes comparatively same but with little difference.

[5]Review on modeling and optimization of electrically discharge machining process using modern techniques:
In this paper, they mentioned that it is very important to produce with high precession and a large number of products. So, the input parameters plays an important role in MRR and SR of a material. In this paper they have took a common material and machined in different machines like WEDM, EDM and micro machining and they found out the key parameters which effects the machining properties , they are pulse –on and duty factor.[6]The quantitative results of size effect in piezo-electric self-adaptive micro-EDM:In this paper, they have selected brass wire as electrode and HSLA as work piece, and machined in WEDM, to know the process parameters which effects the machining, the mathematical model has been developed with help of RSM and further processed with GA to get optimized machining. The error between experimental and predicted is about (+/-)10%.

3. Materials and Methods

3.1 Inconel 718

First of all, Inconel 718 is a nickel based allow it has high strength and very tough material, we have many grades in Inconel. Out of all the grades Inconel 718 has good mechanical compositions and due its tough and hard nature it is mostly used in Aero space, Navy and making sharp medical equipments like blades and knives its properties and composition is list in Table1 and Table 2.

Table 1. Shows thermal and mechanical properties.

Thermal conductivity(w/wk)	11.4
Specific heat,cp(j/kgk)	435
Density,(kg/m^3)	8190
Melting temperature,(k)	1609
Young’s modules,E,GPa	205
Poison’s ratio	0.29

Table 2. Material composition

Element	Ni+Co	Cr	Fe	Nb+ta
Component %	50-55	17-21		4.75-5.5
Element	Mo	Ti	Al	
Component%	2.2-3.3	0.65-1.15	0.2-0.8	

3.2 Inconel 718 material

Figure 2. Inconel 718 material

3.3 Molybdenum wire

Molybdenum wire has high strength with tensile strength ranging from275000Psi. It has melting temperature around 2625^{o}C and vaporizing temperature around 5560^{o}C. Respectively it is a poor electrode material. Due to its high temperatures, the crater formed on the EDM will be less compared with brass-wire, which avoids flushing. It has a very good wall thickness and it in turns reduces wire breakage. Note: molybdenum wire is an application specific due to its high cost

3.4 Methodology

Step-1: process parameters and their ranges were determined by the trail tests. The parameters are identified for the test such as current, pulse-on, feed rate.
Step-2:To select an appropriate orthogonal array for the experiments, on the basis of parameter selection and its levels. Here we have three parameters and three levels are selected.
Step-3 : nine experimental runs were conducted as per the L9 orthogonal array, the test runs were carried out random to avoid systematic error creeping into the experimental procedure.

3.5 L9 Orthogonal array

Input parameters:
Factor A=duty factor
Duty factor(d)=(pulse on time/(pulse on time+pulse off time)
Factor B=wire feed rate(M/min)
Factor C=gap voltage(V)

Table 3. Input parameters

Factor	Name	Low	High
A	Duty factor	0.81081	0.9434
B	Gap voltage	15	20
C	Feed rate	65	100

Table 4. Fixed parameters

SR.NO	Fixed parameters	Set values
1	Work material	Inconel 718
2	Tool wire material(0.18)mm	Molybdenum
3	Peak current	4
4	SEN	10
5	Dielectric fluid	di-ionzed water

Table 5. L9 Orthogonal array

DF	GV	Feed
0.81081	15	65
0.81081	17.5	85
0.81081	20	100
0.8771	15	85
0.8771	17.5	100
0.8771	20	65
0.9434	15	100
0.9434	17.5	65
0.9434	20	85

4. Testing

The material removal rate is calculated by using (Weight of work piece before machining – Weight of work piece after machining)/(Time).
MRR unit: (Gram/minute)
Sample MRR calculation:

Initial weight: 0.975kg
After machining weight: 0.970kg and the weight of cut specimen: 0.005
So initial weight – final weight = 0.975-(0.970+0.0131665) = 0.0081665 kg
Time taken to machine: 10 minute
MRR =(0.8335/10) = 0.00081665 kg/min

Surface Roughness

Experiment 1

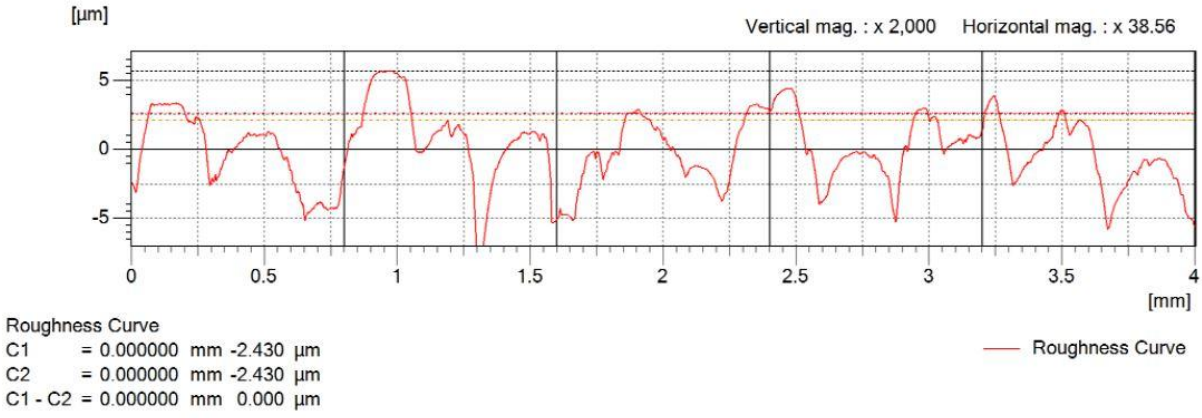

Figure 3. SR for experiment 1

Ra=2.0971 µm;
Rq=2.6182 µm; Rz=10.5125 µm;

Experiment 2

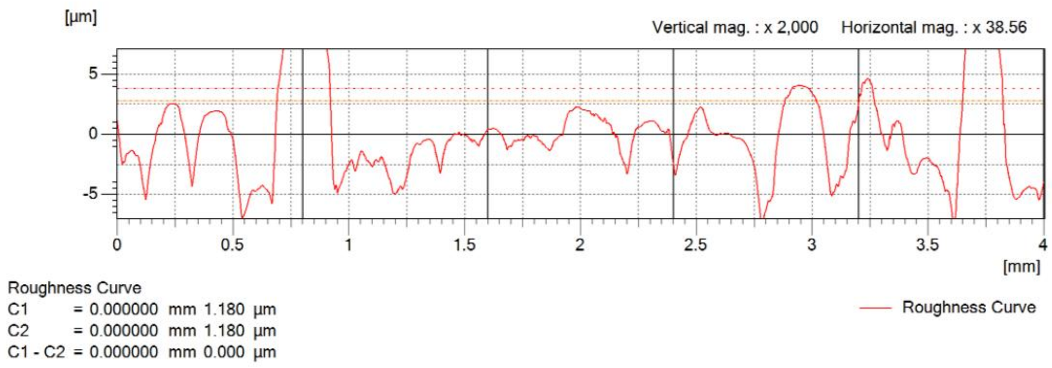

Figure 4. SR for experiment 2

Ra=2.7940 µm;
Rq=3.5778 µm;
Rz=13.7957 µm;

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Experiment 3

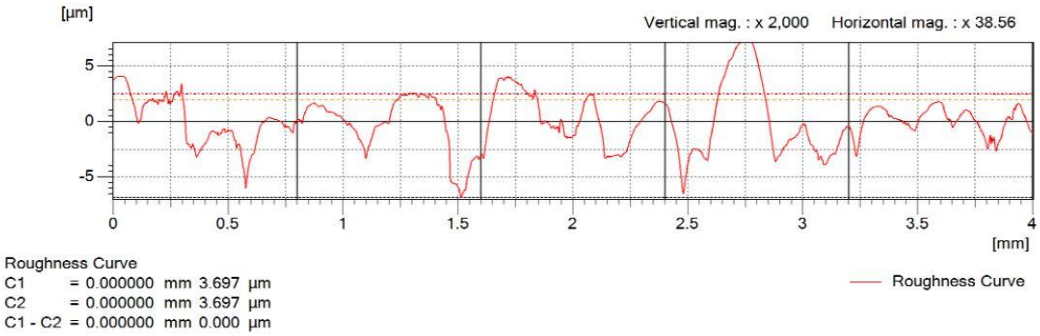

Figure 5. SR for Experiment 3

Ra=1.9146 µm;
Rq=2.3480 µm; Rz=9.1924 µm;

Experiment 4

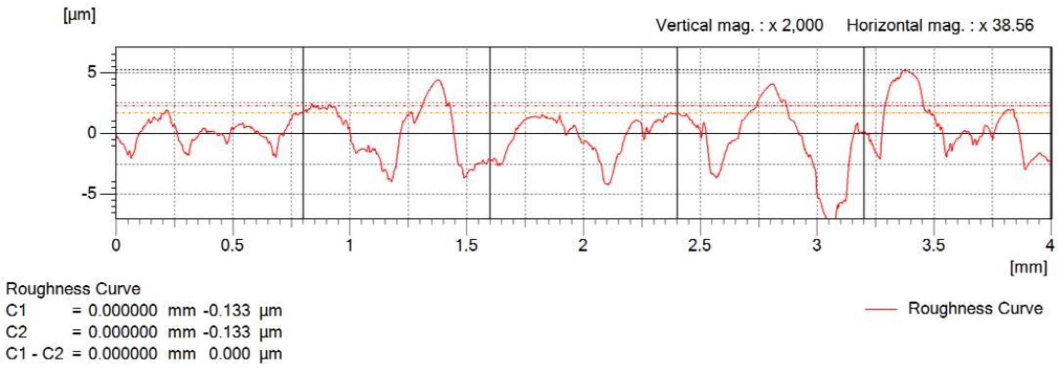

Figure 6. SR for Experiment 4

Ra=1.7125 µm;
Rq=2.1152 µm;
Rz=7.9766 µm;

Experiment 5

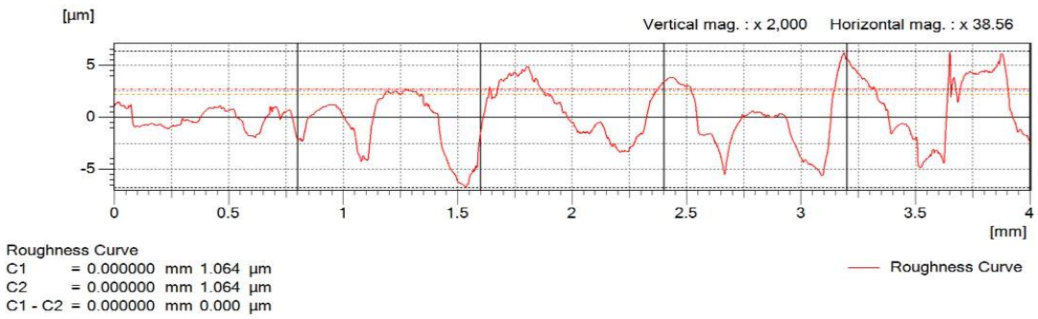

Figure 7. SR for Experiment 5

Ra=2.1743 µm;
Rq=2.5730 µm;

Rz=8.8652 µm;

Experiment 6

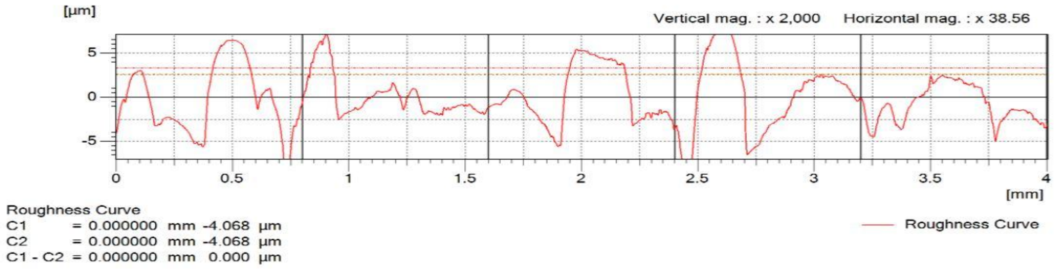

Figure 8. SR for Experiment 6

Ra=2.6471 µm;
Rq=3.1924 µm;
Rz=11.8795 µm;

Experiment 7

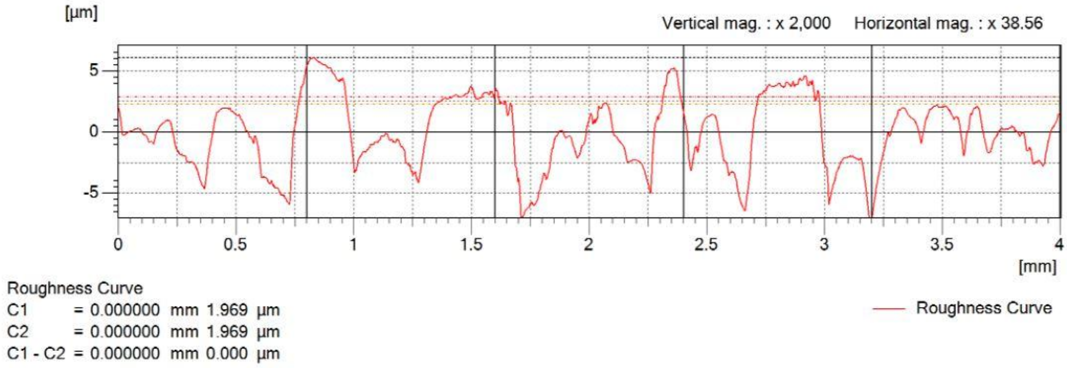

Figure 9. SR for Experiment 7

Ra=2.3188 µm;
Rq=2.7927 µm;
Rz=11.1097 µm

Experiment 8

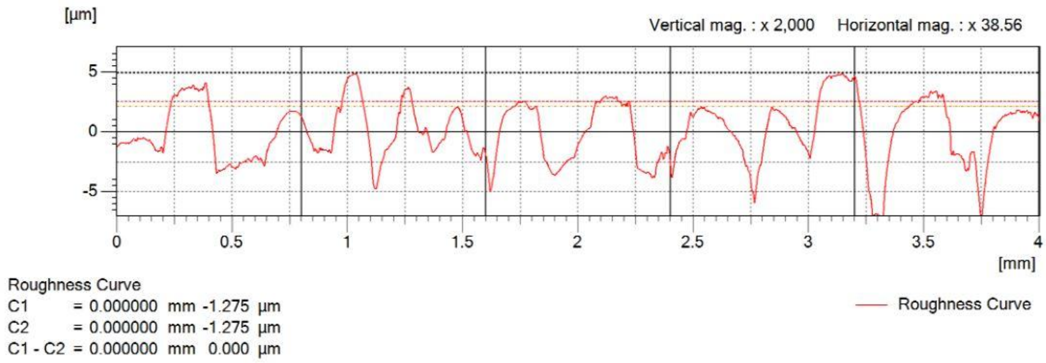

Figure 10. SR for Experiment 8

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Ra=2.1450 µm;
Rq=2.5353 µm;
Rz=9.6064 µm;

Experiment 9

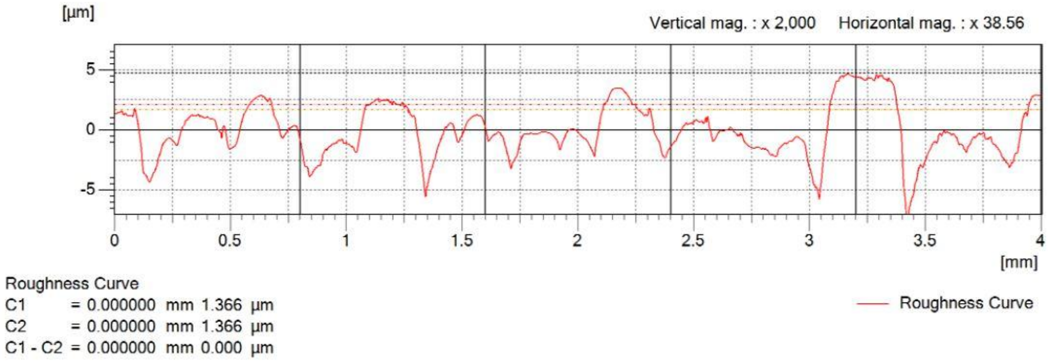

Figure 11. SR for Experiment 9

Ra=1.6758 µm;
Rq=2.1023 µm;
Rz=8.9878 µm;

5. Result

Table 6 . Results

Pulse-on	Pulse-off	Gap voltage	Feed	Time taken	Weight
50	11	15	65	10:03	0.970
50	11	18	85	10:56	0.966
50	11	20	100	11:28	0.960
60	9	20	85	10:10	0.957
60	9	15	100	9:34	0.952
60	9	18	65	9:50	0.947
70	4	15	100	7:29	0.943
70	4	18	65	7:16	0.938
70	4	20	85	7:30	0.933

Work piece after machining:

Figure 12. After machining

6. Simulation

6.1. Spark Radius

We can find out the radius of the spark for a single spark,by the formulae, shown below:

$Rs=(2.04 \times 10^{-3}).I.\ t_{on}{}^{0.44} = 4.743105292 \times 10^{-5}$ m (1)

Where,

I=20A

t_{on} =50µm

Ews=0.8

V_b =15v

6.2. Heat Flux

Heat flux or the heat which is being produced at the time of production of spark can be calculated by the formulae:

$q_{ws} = (4.55 * Ews * V_b * I) \exp(4.5(r/Rs)^2) = 30901334139.14180$ W/m^2 (2)

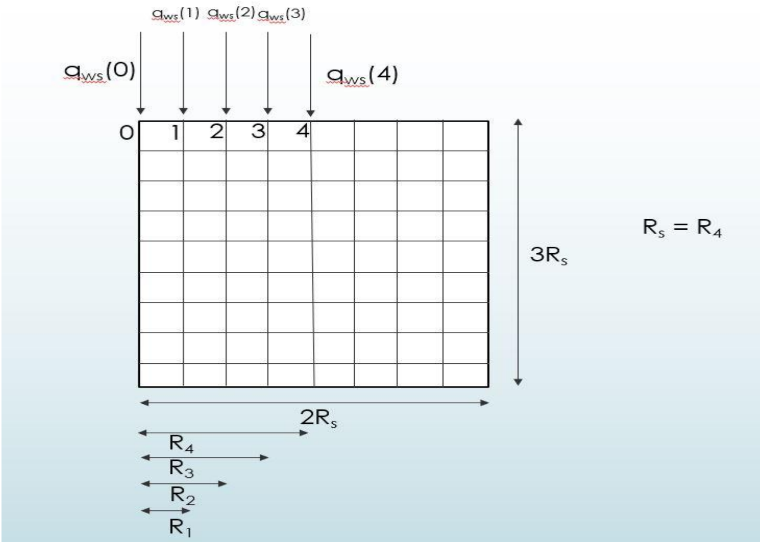

Figure 13. Simulation model of the work piece.

The spark radius value is being divided into portions, this helps in plotting clearly the spark and detail the intensity of heat at every portion exactly.

6.3. Boundary condition

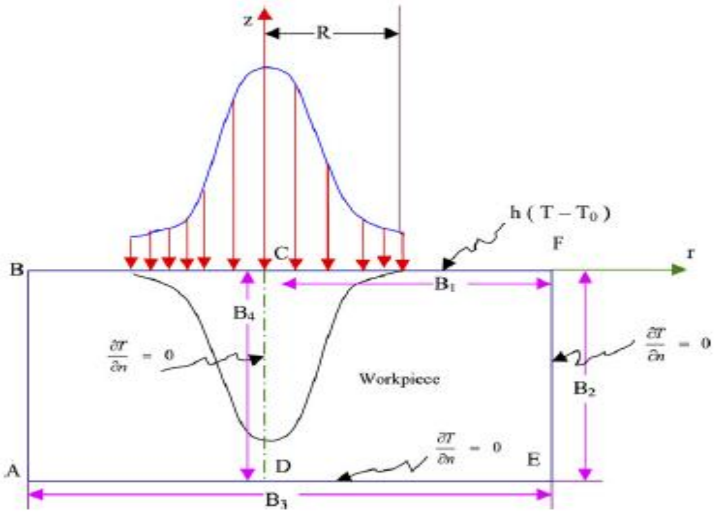

Figure 14. boundary conditions and the development of spark.

The area at which the spark is being applied has conduction and the outer parts will be treated with convection, where the di-electric fluid flows.

6.4 Ansys input:

Table 7 . Inputs parameters

Element Type	*Quad 8 Node 77*
Thermal conductivity	*11.4 W/mK*
Specific heat	*435 J/kgK*
Density	*8190 kg/m^3*
Melting point of material	*1609K*
Element Behaviour	*Axi-Symmetric*
Discharge Voltage	*15V*
ton	*50 µs*
Current	*20A*
Energy partition(Ews)	*0.8*

6.5 Meshing

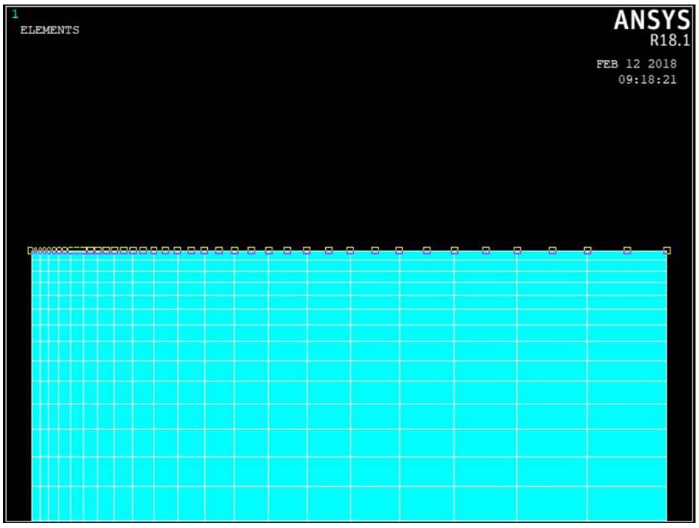

Figure 15. Meshing

Here, the meshing of the work piece is done in such a manner that it has closely spacing at the place where it encounters the spark and has largely spacing at the portions out of the spark where we can see convection. It can be achieved by "Flip bias to adjust the bias" in meshing option. Inputs parameters are given in table (7)

6.6 Result

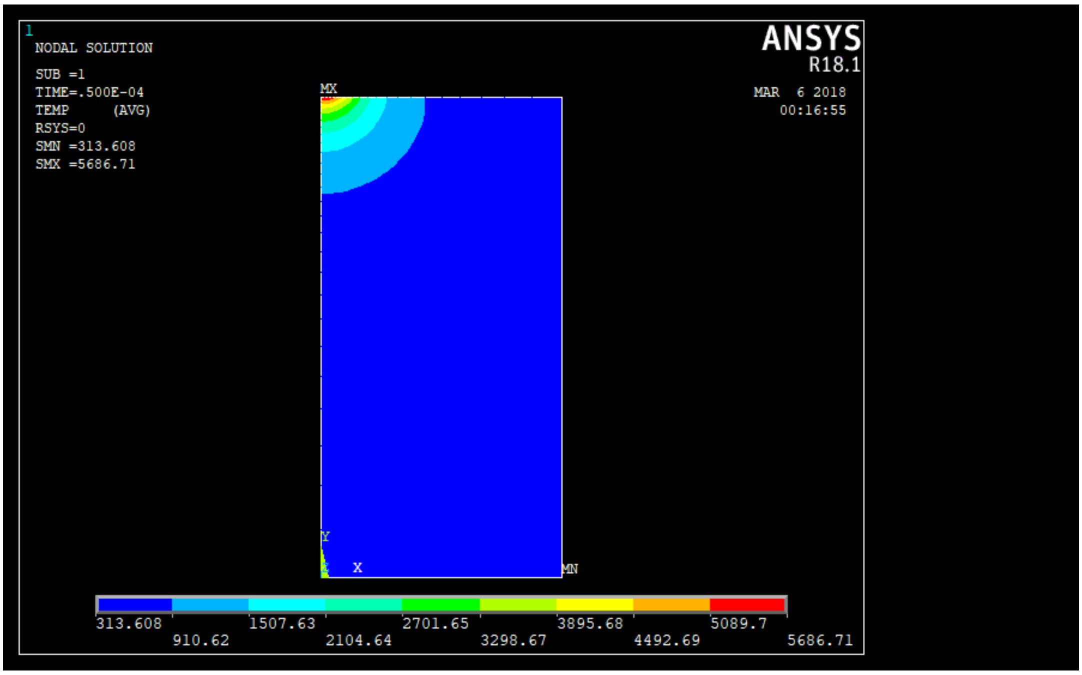

Figure 16. Transient temperature distribution.

By the inputs which we have taken while machining experimentally, are being used as inputs in simulation though ANSYS and we can successfully predict the solution.

Getting x and y co-ordinates and temperature values for each node

Get the co-ordinates of every node on the simulated model, and achieve the exact co-ordinates by using MATlab software.

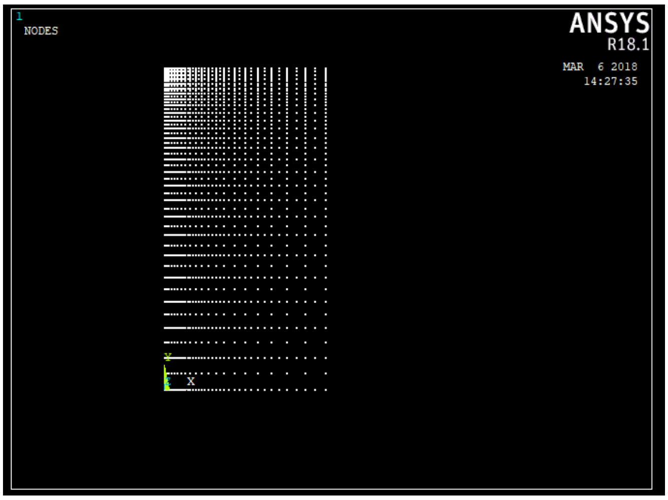

Figure 17. Complete picture of nodes.

In the same way after the solution done, get the heat values for every node in the simulation. List the X ,Y and heat values in a excel sheet.

	A	B	C	D
1	x	y	temp	
2	0	0	298	
3	0.00014	0	298	
4	8.77E-07	0	298	
5	1.75E-06	0	298	
6	2.74E-06	0	298	
7	3.73E-06	0	298	
8	4.85E-06	0	298	
9	5.97E-06	0	298	
10	7.23E-06	0	298	
11	8.49E-06	0	298	
12	9.91E-06	0	298	
13	1.13E-05	0	298	
14	1.29E-05	0	298	
15	1.45E-05	0	298	
16	1.64E-05	0	298	
17	1.82E-05	0	298	
18	2.02E-05	0	298	
19	2.23E-05	0	298	
20	2.46E-05	0	298	
21	2.69E-05	0	298	
22	2.95E-05	0	298	
23	3.21E-05	0	298	
24	3.51E-05	0	298	
25	3.80E-05	0	298	

Sheet1 Sheet2 Sheet3

Figure 18. Excel sheet representing the X ,Y and temperature values

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6.7 Usage of surfer software

After getting the excel sheet with required values export it to surfer software and obtain the grid representation by selecting the melting temperature of the material. The red color line represents the melting point of the material. Now, the nodes which are present on the surface of the melting point curve are taken and the co-ordinates of the nodes are being noted.

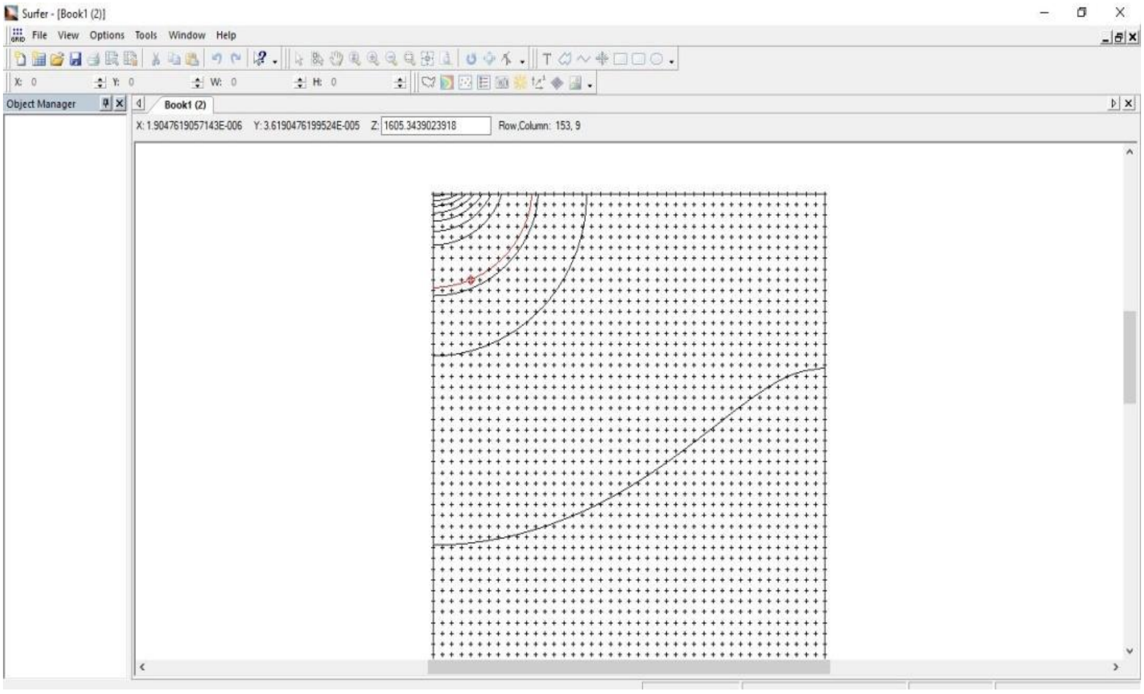

Figure 19. Simulation model in surfer.

6.8 Usage of CATIA software:

Export the co-ordinates of the nodes lying on the surface of the melting point arc and join the points which forms an arc, and rotate the arc which intern gives the area of material removed and the volume.

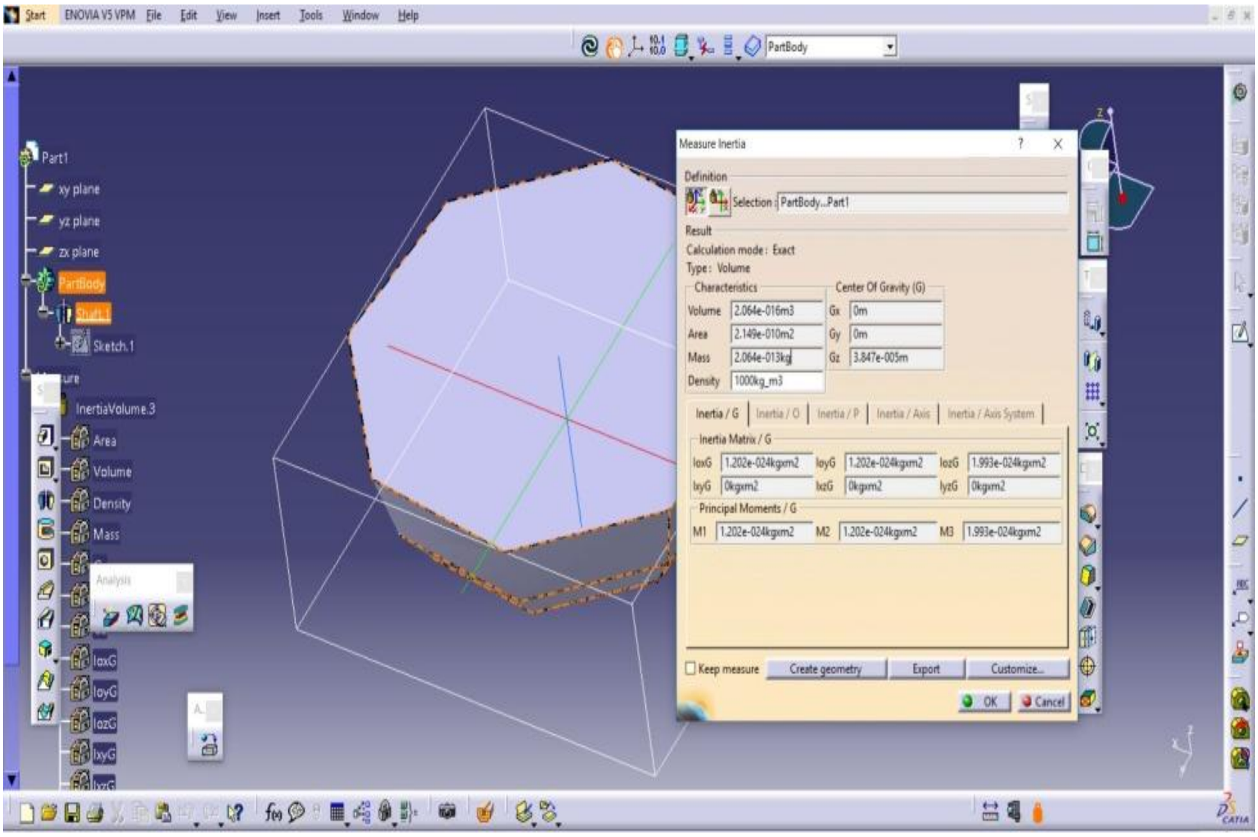

Figure 20. Material which is being removed.

Experimental Volume: 8.166 * 10^{-10} m^3/min
Simulation Volume : 2.064 * 10^{-15} m^3/min
Error % : 9.9%
Experimental value < Simulation value ,
this is because, in experimental analysis, the removal of material cannot be done very exactly, some material gets evaporated and some of the material will be melted and settled at the bottom of the work piece. Due to this nature we will always see E.V<S.V.

7. Conclusion
The machining part of our proposed project was completed and we need to compare the results which we obtained during machining to the results which we are going to obtain from FEA MATlab by modeling our own code. As of now, we came to know that the duty factor has much impact on the MRR, surface roughness, as the duty factor increases there is an increase in the MRR and surface roughness. This happens because duty factor is the parameter which will control the pulse-on time and pulse-off time, and these two parameters are responsible for the production of the spark .So, we can clearly say that increase in duty factor increases the MRR and surface roughness.

8. References
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