iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** VIII **Month of publication:** August 2017

DOI: http://doi.org/10.22214/ijraset.2017.8169

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue VIII, August 2017- Available at www.ijraset.com

Finite Element Analysis of Wire Electrode on WEDM Process using ANSYS

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Abstract:- The Wire Electro Discharge Machining (WEDM) process is a violent thermal process where literally thousands of electrical discharges are produced in a fraction of a single second in order to erode a certain volume of metal work piece. The process is mostly and efficiently used in situations where intricate complex shapes need to be machined in very hard materials (such as hardened tool steel, CBN ,Ceramic etc). However, the process generate surfaces that have poor properties such as high tensile residual stresses, high surface roughness, presence of micro-cracks and micro-voids. These properties vary with different levels of the main conventional machining parameters.

The aim of this FEA simulation is to present a transient thermal and structural simulation work that has been a three dimensional finite element model with two new materials to predict the temperature distribution, Total heat flux at different pulses of time as well as stress distribution in WEDM wire electrode. Thermal stress developed after the end of the spark and structural stresses developed due to tension in wire electrode. The effect on significant machining parameter pulse-on-time has been investigated and found that the peak temperature is sharply increases with the parameters. Wire electrical discharge machining process is a mostly used non-conventional material removal processes.

Keywords: ANSYS, WEDM, Thermal transient and structural simulation, Temperature, Heat flux, structural stresses.

I. INTRODUCTION

WEDM was initially developed by manufacturing industry in the since 1960. The development technique is replaced the machined electrode used in electrical discharge machining. In 1974, D.H. Dulebohn introduced the optical line follower system which is automatic control the shapes of the part to be machined by the wire electrical discharge machining process. In 1975, it was popular rapidly, and its capability was better understood by manufacturing industry. When the computer numerical control system was introduced in WEDM process this brought about a most important development of the machining process. Consequently the wide capability of the wire electrical discharge machining process was widely exploited for any through-hole machining owing to the wire, which has to pass through the part to be machined. In micro-wire EDM operation the work piece metal is cut with a special metal wire electrode which has been programmed via CNC to travel along a definite path. Spark discharges and generates between a small wire electrode and a work piece to produce complex two dimensional and three-dimensional shapes according to a NC path. The wire diameter of the electrodes used ranges from 0.02 to 0.30 mm. Material can be removed from the workpiece through the movement of either the workpiece or the wire electrode. The mechanism of metal removal is similar to that in convectional micro EDM. The most prominent feature of a moving wire is that a complicated cut-out can be early machined without using a forming of electrode .Electrical discharge machining (EDM) is an important thermal erosion process which erodes the material from the work piece by a series of Discrete sparks between the electrode and the work piece immersed in a dielectric liquid medium. Electrical energy is used directly to cut the material in final shape, through melting and subsequent vaporization. The molten material is ejected and flushed away through the dielectric medium. Wire electrical discharge machining process is a mostly used non-conventional material removal processes. This is use for manufacturing difficult shape and profile of hard materials.

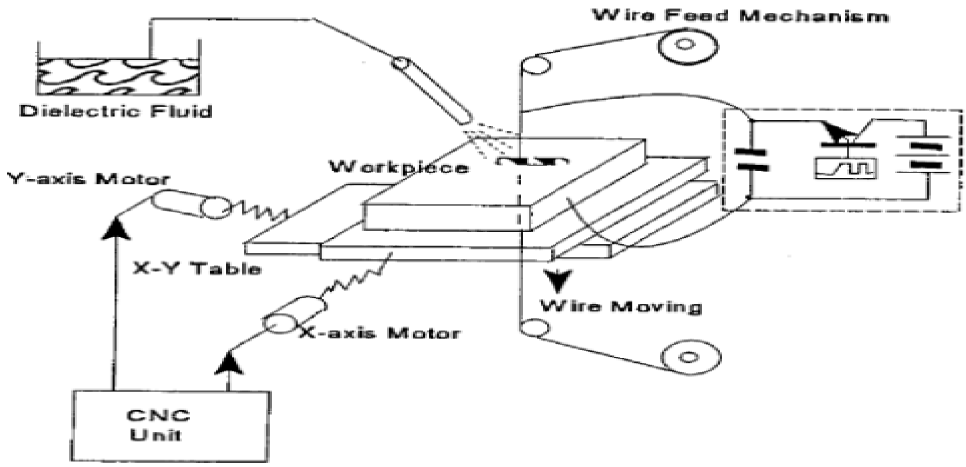

Fig. 1: Schematic Diagram of the Basic Principle of WEDM Process

A. Terms used in WEDM Process:-

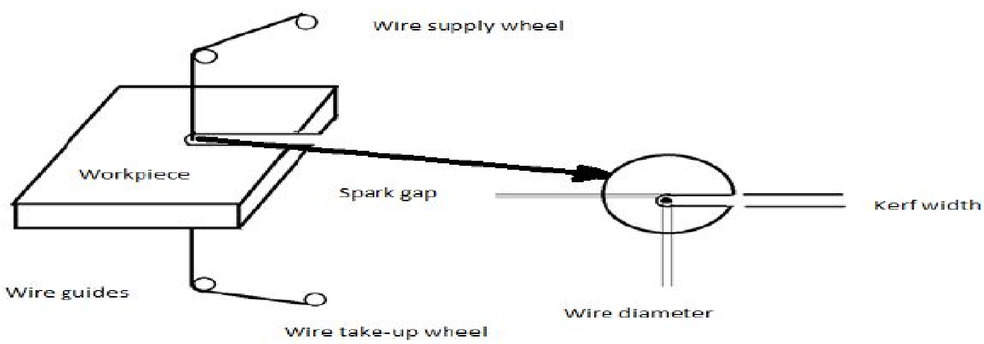

Fig. 2: Sparking phenomena in WEDM process

1) Spark Gap:

Space between electrode and work piece is called spark gap. Here voltage is applied. The electric field created throughout the space between these electrodes.

2) Kerf Width:

It is the sum of the wire diameter and twice of spark gap. The kerf width is generally measure using the Infinite Focus Alicona Machine.

II. LITERATURE REVIEW

A. Fuzhu Han

The tension control of the micro wire electrode is a key technology for the micro wire electro-discharge machining (WEDM). Based on the coupled transient thermal and mechanical analysis, both the three-dimensional temperature and the stress distribution in the micro wire electrode are determined. As a result, the tension of the micro wire electrode during the WEDM process can be optimized in according to the discharge energy, which is sampled and fed back to the tension control system in real time. Then the development of the optimal tension control system is to be characterized by the form of master–slaver structure makes it possible to keep the wire tension optimal in the process of WEDM. The results of the machining experiments show that the optimal wire tension control is effective on the improvement of the machining accuracy with the prevention of breaking of wire electrode for the micro WEDM**.** The three-dimensional temperature distribution of the micro wire has been numerically determined in the study of this paper.

B. Anshuman Kumar

Wire Electrical Discharge machine (EDM) is one of the versatile methods for making micro product of complex geometry. The process parameters play a critical role for the accuracy and precision of the work component. Inconel 718 is a super alloy used for many critical operations. It's a challenging task for ding EDM operation of Inconel-718. It is highly essential to study the process mechanics for effective micro-EDM operation. In the present investigation, numerical simulation of wire EDM has been carried out using ANSYS software in order to determine temperature profile, Material Removal Rate (MRR) for single discharge and converted into the multi-discharge. For multi-discharge machining material removal was calculated by calculating the no. of pulse. Justification of model has been done by comparing the experimental versus numerical result obtained under the same parameter. The predicted results are obtained for single spark and Inconel 718 as a workpiece. Predicted temperature distribution on the workpiece. Make the one by one parameters constant out of three and checking the variation of constant parameter and effect on MRR.

C. Di Shichun

In micro-wire electrical discharge machining (micro-WEDM), the machined kerf width is varying with different machining parameters, which greatly influences the machining precision. In order to study the variation in kerf in micro-WEDM, the mathematical model of wire lateral vibration in machining process is established and its analytical solution is obtained in this paper. The model is practically verified on a self-developed micro-WEDM machine.

D. K. Hada

It is difficult to find the optimum machining conditions in wire electrical discharge machining (wire-EDM), because discharge current is influenced by the impedances of the wire and work piece electrodes which may vary depending on the diameter of the wire, height of the work piece and materials of wire and work piece even if the pulse conditions are the same. Hence, this study aims to develop a simulator to analyze the distribution of the current density, and magnetic flux density in and around the wire to obtain the impedances of the wire and work piece electrodes using the electromagnetic field analysis by finite element method (FEM).

E. S. Saha

This research develops a simple finite element model and a new approach to predict the thermal distribution in the wire fairly accurately. The model can be used to optimize the different parameters of the system to prevent wire breakage. Based on this principle, the finite element model and optimization algorithm are used to determine that the heat generated is the critical variable responsible for wire breakage.

III. TRANSIENT THERMAL AND STRUCTURAL ANALYSIS

In the wire EDM, a series of rapid electric spark occur in the gap between WEDM wire (Electrode) and the work piece. Addition of particles into the dielectric fluid makes this process more complex and random. The following assumptions are made without sacrificing the basic features of the wire EDM model to make the problem mathematically feasible.

A. Assumptions:

1) The model is developed for a single spark.
2) The work domain considered as axisymmetric.
3) The material of the wire is homogeneous, isotropic and has constant properties.
4) The composition of the material of workpiece is assumed to be homogeneous and isotropic.
5) The thermal properties of work piece material are considered as a function of temperature. It is assumed that due to thermal expansion, density and element shape are not affected.
6) Temperature analysis is considered to be of transient type.
7) The heat transferred to the electrodes occurs by conduction.
8) The temperature variation across the diameter of the wire is neglected.
9) The workpiece is free from any type of stress before process.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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B. Governing Equation:

In this study, a finite element model is used to numerically analyse the thermal response of the WEDM wire electrode under the load of electro discharge. Considering that the wire diameter is only 0.1 mm, the ratio of the length to the diameter of the wire inside the workpiece will be larger than 30 even if the height of the workpiece is as thin as 3 mm.This is the equation for calculation of transient temperature distribution within workpiece. The differential governing equation of thermal diffusion differential equation in a model is governed by the following**:**

$$\frac{\partial}{\partial r}\left(k_w \frac{\partial T}{\partial r}\right) + \frac{1}{r^2}\frac{\partial}{\partial \theta}\left(k_w \frac{\partial T}{\partial \theta}\right) + \frac{\partial}{\partial z}\left(k_w \frac{\partial T}{\partial z}\right) + q''' = \rho c \frac{\partial T}{\partial t} \qquad \text{.............. (1)}$$

Where r and θ are the radial and angle coordinates of point P, respectively, z is the axial coordinate of point P, ρ and C, respectively, the density and the specific heat of the wire material, and T is the temperature of the micro element in the wire.

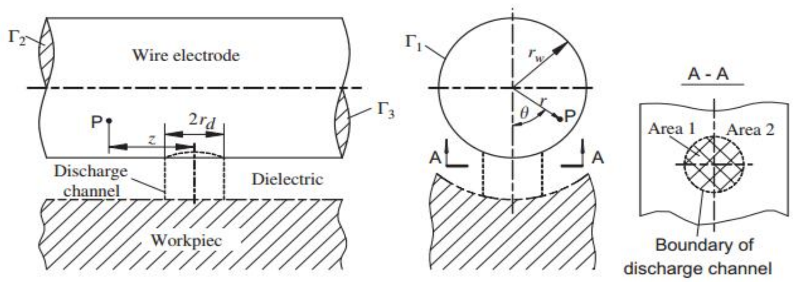

Fig. 3: Three-dimensional thermal analysis model for WEDM

C. Boundary Condition

The boundary between area 1 and area 2 can be mathematically determined by the following equations:-

Here; $r = r_w$ .... (2)

$(r_w \sin\theta)^2 + z^2 = r_d^2$ .... (3)

Where r_d is defined as the radius of the discharge channel, r_w is the wire radius. From fig. 3 in inside area 2, the thermal equilibrium can be described as the following equations:

If $r = r_w$ and $(r_w \sin\theta)^2 + z^2 > r_d^2$ .... (4)

Then; $k_w \frac{\partial T}{\partial r} = h(T - T_0)$ ....(5)

Where, h is the heat transfer coefficient, T_0 is the initial temperature of wire electrode and T Temperature.

D. Material Properties

In wire EDM process, huge thermal energy is generated, so material properties are required for analysis this process. In this paper two materials are taken:-

1) Brass Wire: The chemical composition of brass is 62% Cu and 38% Zn.

Table No. 1: Properties of brass wire

Properties	Unit	Value
Density	Kg/m^{-3}	8490
Thermal conductivity	W/m-K	115
Specific heat	J / kg-K	380
Modulus Of Elasticity	G Pa	97
Bulk modulus	G Pa	140
Poison's ratio		0.31

Melting temperature	^{0}C	1083
Shear modulus	G Pa	37
Solid	^{0}C	885

Inconel 718 Wire

Table No. 2: Chemical composition of Inconel 718

Inconel 718							
Element	Ni+Co	Cr	Fr	Nb+Ta	Mo	Ti	Al
Content (%)	50-55	17-21	Bal	4.45-5.5	2.8-3.3	0.65-1.15	0.2-0.8

No. 3: Thermal Properties and Mechanical Properties of Inconel 718

Properties	**Unit**	**Value**
Density	Kg/m^{-3}	8190
Thermal conductivity	W/m-K	11.4
Specific heat	J / kg-K	435
Modulus of elasticity	GPa	205
Poison's ratio		0.29
Melting temperature	^{0}C	1609

The specification of WEDM wire electrode is taken from paper Fuzhu Han [1] and Anshuman Kumar [2]. Which is listed as following:-

Table No. 4: Parameters of Electrode Used For Transient Thermal and Structural Analysis in WEDM Process

Parameters	**Units**	**Value**
Radius of wire	Mm	0.1
Length of wire	Mm	100
Initial temperature	^{0}K	298
Co-efficient of heat transfer of dielectric fluid	(W/m^{2}K)	10,000
Maximum Tension in wire	N	13.7295

IV. HEAT FLUX DUE TO THE WIRE ELECTRODE IN SINGLE SPARK

In this paper, a Gaussian heat distribution is assumed. If it is assumed that total power of power of each pulse is to be used only single spark can be written as follows:-

$$Q_w\,(r) = \frac{4.45\,H_i\,VI}{\pi R^2}\; e^{\left\{-4.5\left(\frac{r}{R}\right)\right\}} \qquad \text{................. (6)}$$

Where q(r) is the heat flux at the radius of r, k is the heat concentration coefficient (k= 4.5, Kunieda et al. case), R (t) is the radius of arc plasma at the moment of t, P is the energy distribution coefficient (P = 0.38, Kunieda et al.), V is the voltage between anode and cathode during discharge occur, I is the peak current and r is the distance from the centre of arc plasma.

A. Spark Radius

Spark radius is an important parameter in the thermal modelling of WEDM process. In practice, it is very difficult to measure experimentally, because spark radius very short pulse duration of in microseconds.

$$\text{Spark Radius (R)} = \{(2.04\, e^{-3})\, I^{0.43}\, T_o^{0.44}\} \qquad \text{.............. (7)}$$

V. ANSYS MODEL CONFIRMATION

In this section we have firstly make a model of WEDM process for brass wire with parameter setting as given in Table 4 in CatiaV5 and select a sectional area where we will proceed our analysis . The main objective to select a particular sectional area to check the temperature distribution and heat flux generated inside the wire to check failure criterion of the wire electrode.

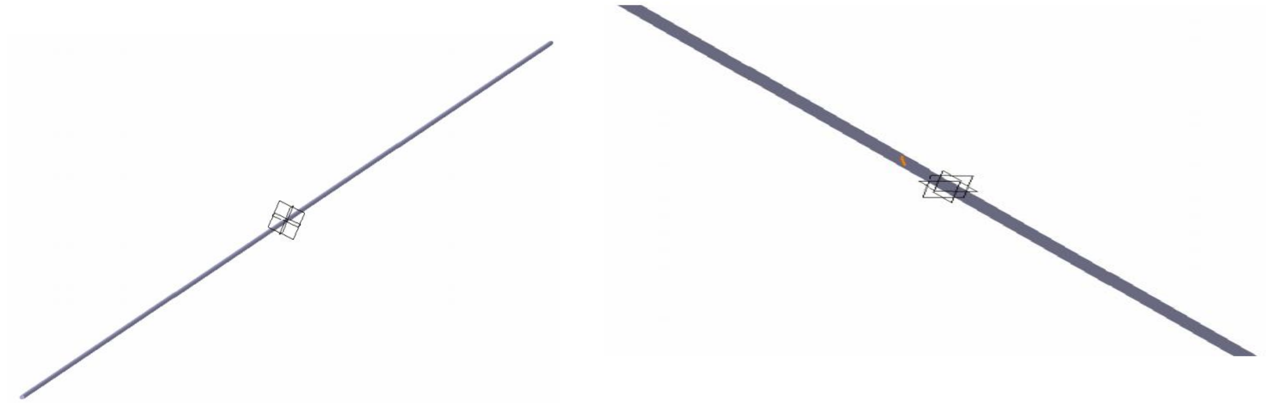

Fig. 4: WEDM wire electrode in Catia V5

VI. RESULT AND DISCUSSION

As there are two equations for spark radius and heat flux is given above in equation no. 7 and 6 respectively. It is taken by Fuzhu Han [1] and Anshuman Kumar [2]. It is difficult to solve the non-linear equation with simple calculation. So, we use MATLAB.

Table No. 5: Heat flux dissipation chart on 25 volt and 27 amp

S. No.	**Voltage (Volt)**	**current (Amp)**	**Time (µs)**	**Energy Distribution Constant**	**Spark Radius (mm)**	**Heat Flux (W/mm^2)**
1	25	27	0.12	0.38	0.37763	2545.03853
2	25	27	0.24	0.38	0.53066	1289.82789
3	25	27	0.36	0.38	0.61235	968.82995
4	25	27	0.58	0.38	0.75530	636.89145
5	25	27	1.20	0.38	1.04009	335.95617
6	25	27	1.82	0.38	1.24929	232.87706
7	25	27	1.92	0.38	1.27904	222.17097
8	25	27	2.0	0.38	1.30225	214.33252

Table No. 6: Heat Flux dissipation chart on 50 volt and 11 amp

S. No.	**Voltage (Volt)**	**Current (Amp)**	**Time (µs)**	**Energy Distribution Constant**	**Spark Radius (mm)**	**Heat Flux (W/mm^2)**
1	50	11	0.12	0.38	0.25667	4480.63216
2	50	11	0.24	0.38	0.36068	2272.82602
3	50	11	0.36	0.38	0.41621	1707.58172
4	50	11	0.58	0.38	0.51339	1122.79960

5	50	11	1.20	0.38	0.70694	592.39672
6	50	11	1.82	0.38	0.84914	410.66591
7	50	11	1.92	0.38	0.86935	391.78929
8	50	11	2.0	0.38	0.88511	377.9686

VII. TRANSIENT THERMAL ANALYSIS

Unlike one-dimensional analysis, this three-dimensional analysis not only gives a detailed temperature a heat flux distribution of wire electrode, but also records the history of the wire temperature and heat flux change. Eight typical fragments of the history are intercepted , which shows the temperature distribution and heat flux generated inside wire electrode, when the time is at t= 0.12, 0.26,0.36,0.58,1.20,1.82,1.92 and 2.0 µs during a single discharge.

A. Transient Thermal Analysis of WEDM Wire Electrode on 25 Volt and 27 Amp

In this section we find the transient temperature distribution and heat flux on WEDM Brass wire and Inconel wire. First step is to add the material which is given in table 1 and 3 for the Brass and Inconel 718.

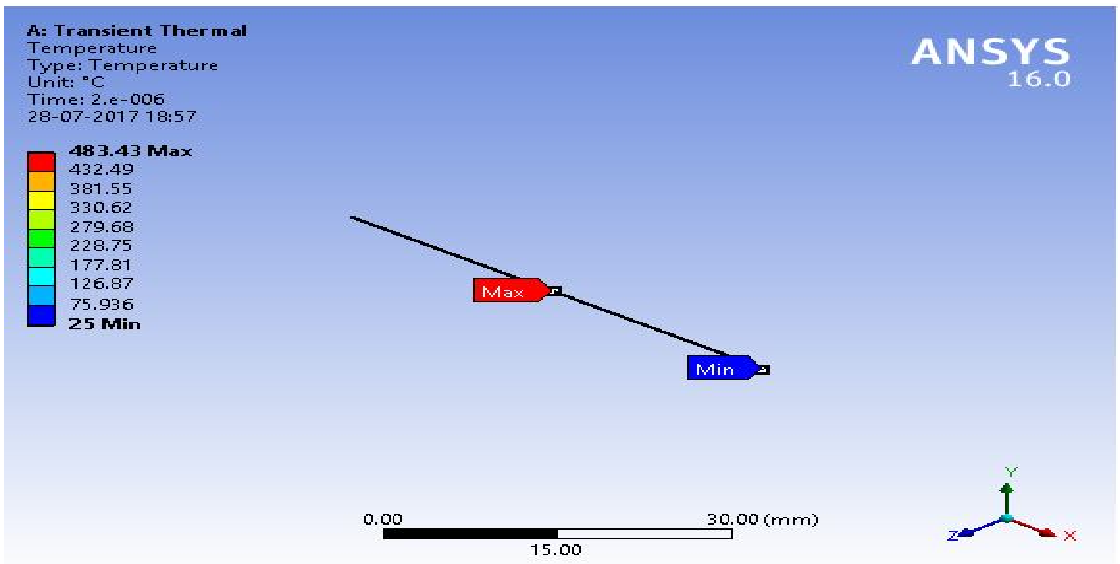

Fig. 5: Transient temperature distribution on Brass wire electrode.

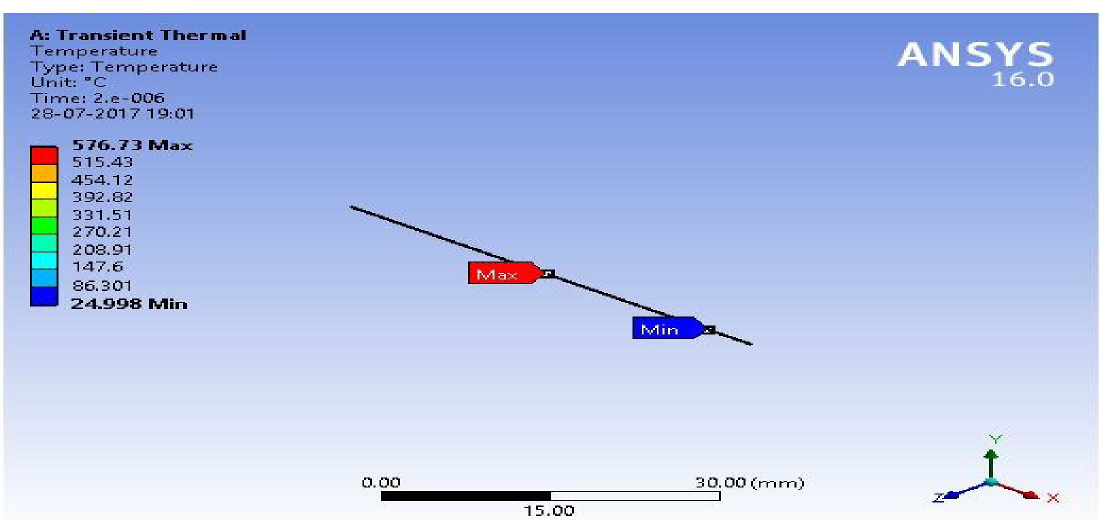

Fig. 6: Transient temperature distribution on Inconel 718 wire electrode.

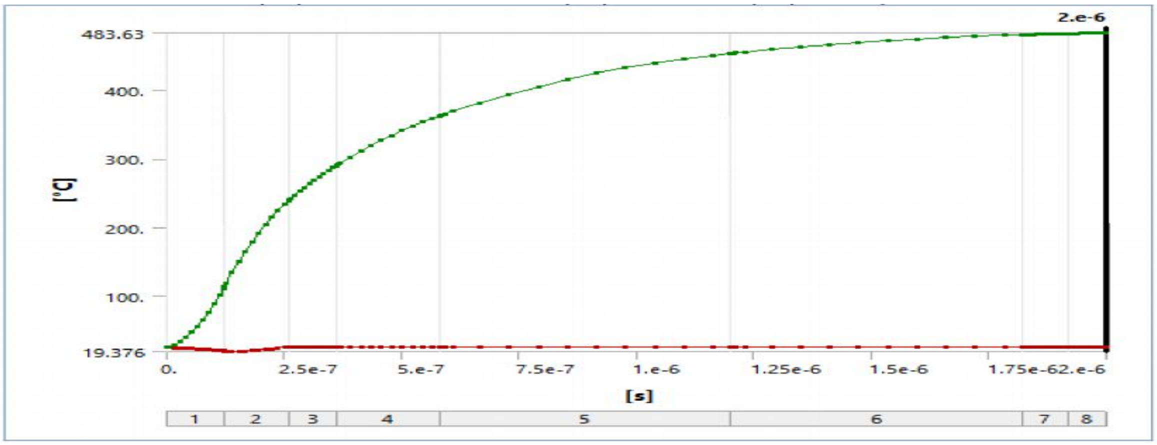

Fig. 7: Graphical representation of maximum and minimum transient temperature distribution on Brass wire electrode.

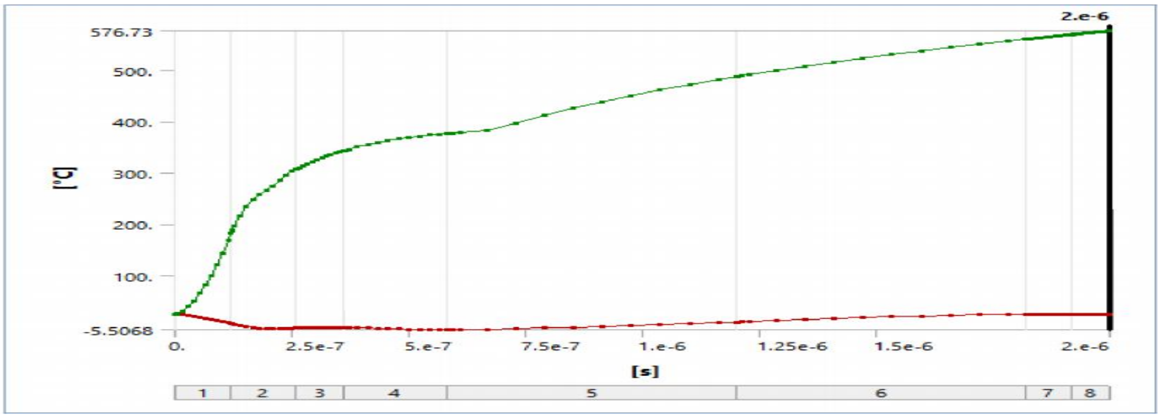

Fig. 8: Graphical representation of maximum and minimum transient temperature distribution on Inconel 718 wire electrode.

Here the transient temperature distribution of both wire is shown in fig 7 and fig 8. The maximum temperature developed inside the both wire electrode, as we observed that the initial stage temperature variation is higher as compared to latter stage and the maximum temperature generated Inconel 718 is higher as compared to Brass wire electrode.

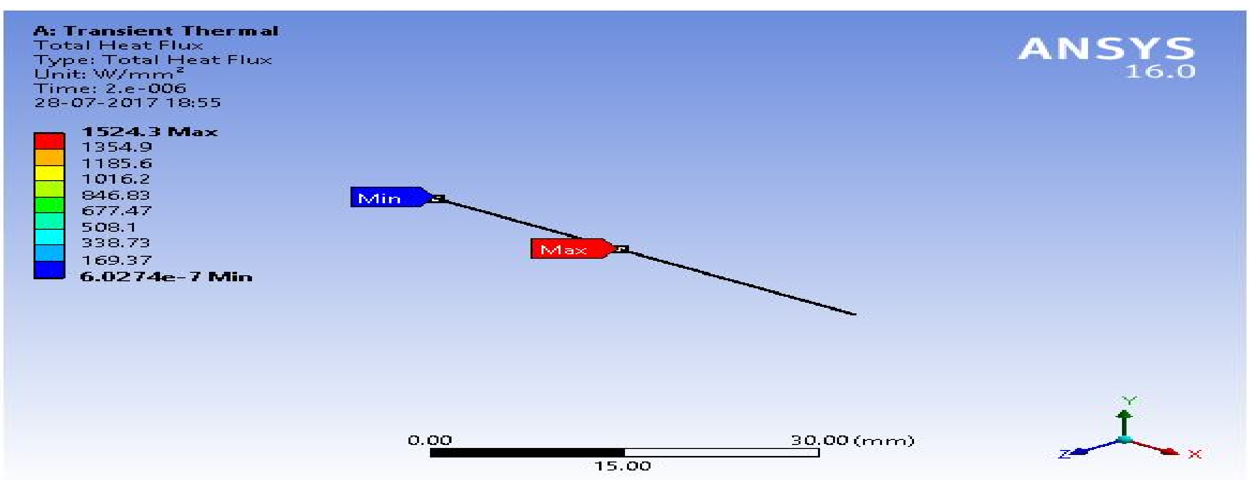

Fig. 9: Transient heat flux distribution on Brass wire electrode.

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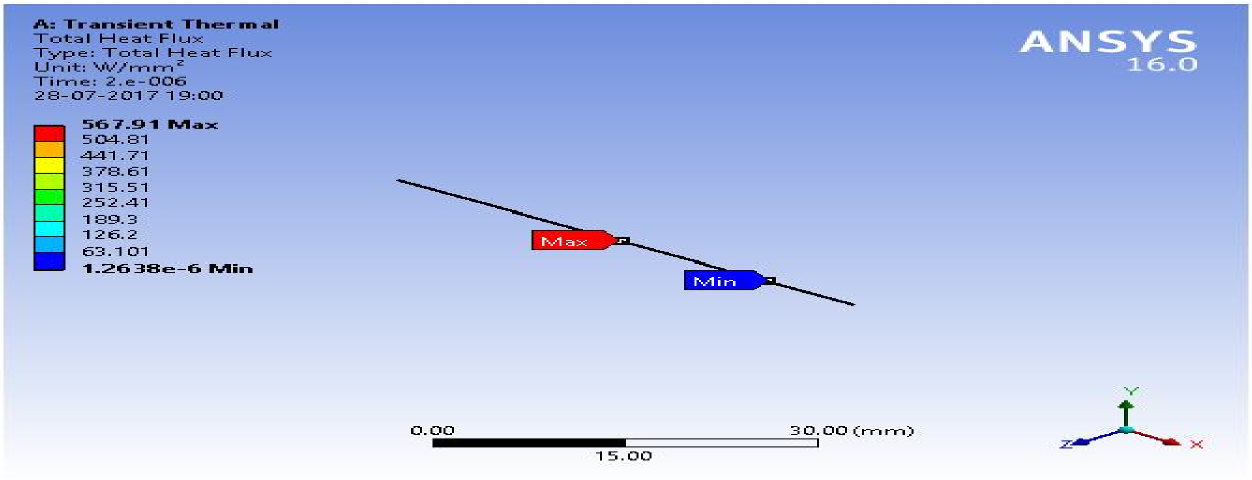

Fig. 10: Transient heat flux distribution on Inconel 718 wire electrode.

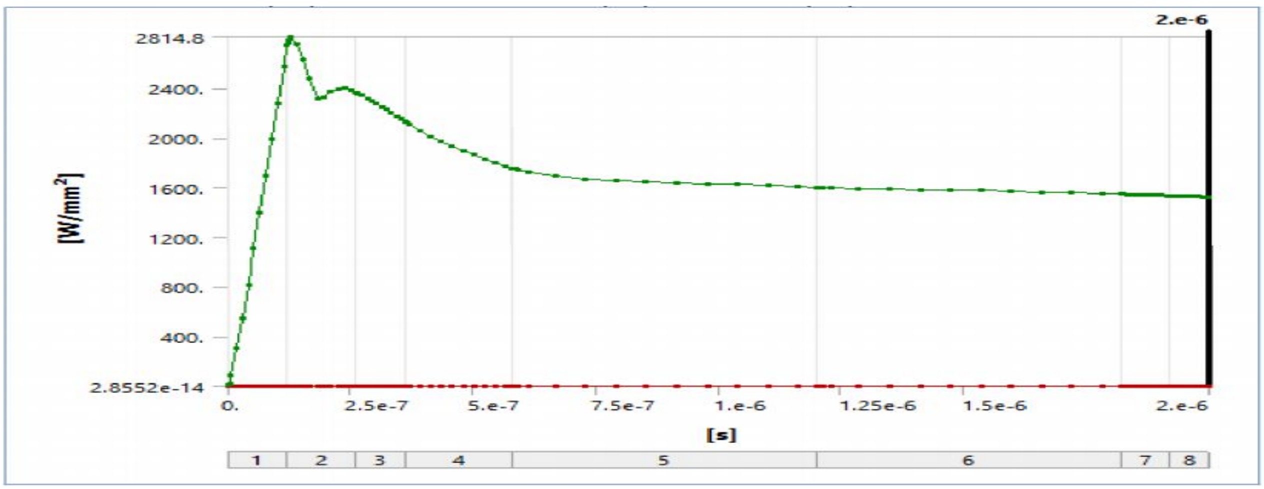

Fig. 11: Graphical representation of maximum and minimum transient heat flux distribution on Brass wire electrode.

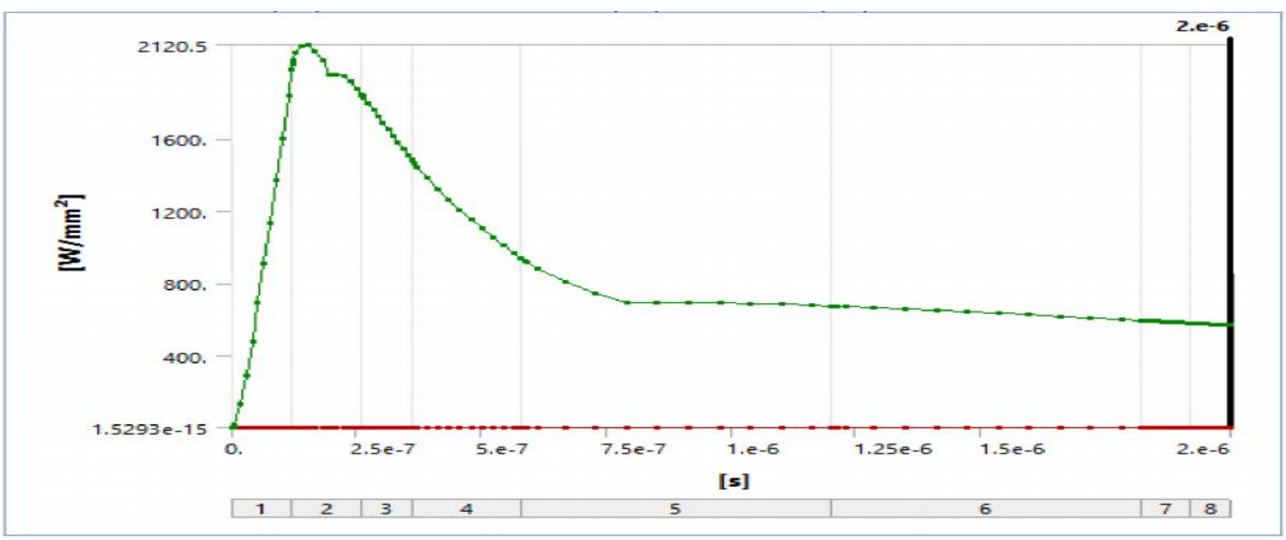

Fig. 12: Graphical representation of maximum and minimum transient heat flux distribution on Inconel 718 wire electrode.

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Here the graphical representation of maximum and minimum transient heat flux distribution is shown in fig 11 and fig 12. Here we can observe that the maximum heat flux generated inside the Inconel 718 is higher as compared to the Brass wire electrode.

B. Transient Thermal Analysis of WEDM Wire Electrode on 50 Volt and 11 Amp

In this section we find the transient temperature distribution and heat flux on WEDM Brass wire and Inconel wire with the same boundary condition as taken for 25 volt and 27 amp. Then we got the various results which are discussed as below:-

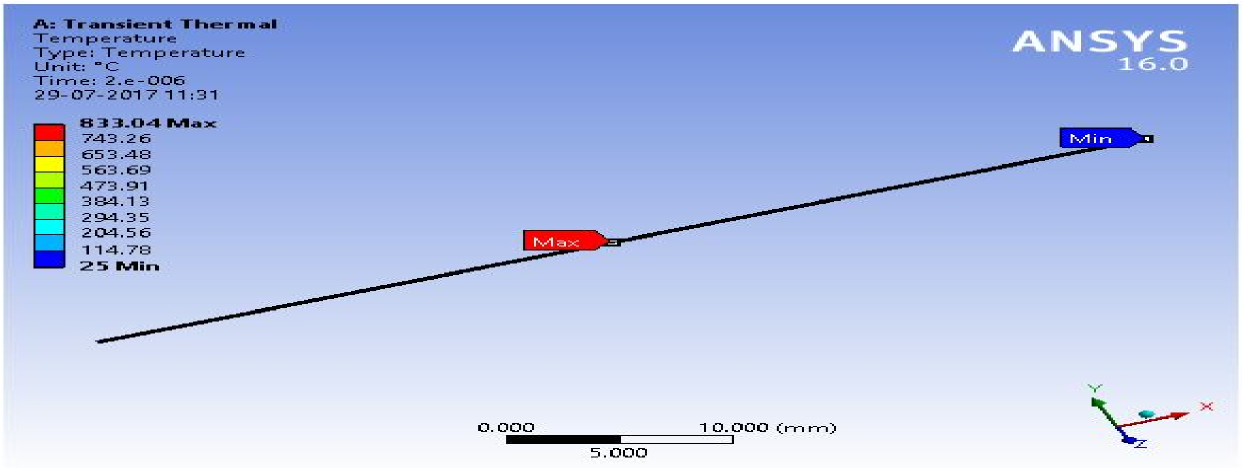

Fig. 13: Transient temperature distribution on Brass wire electrode.

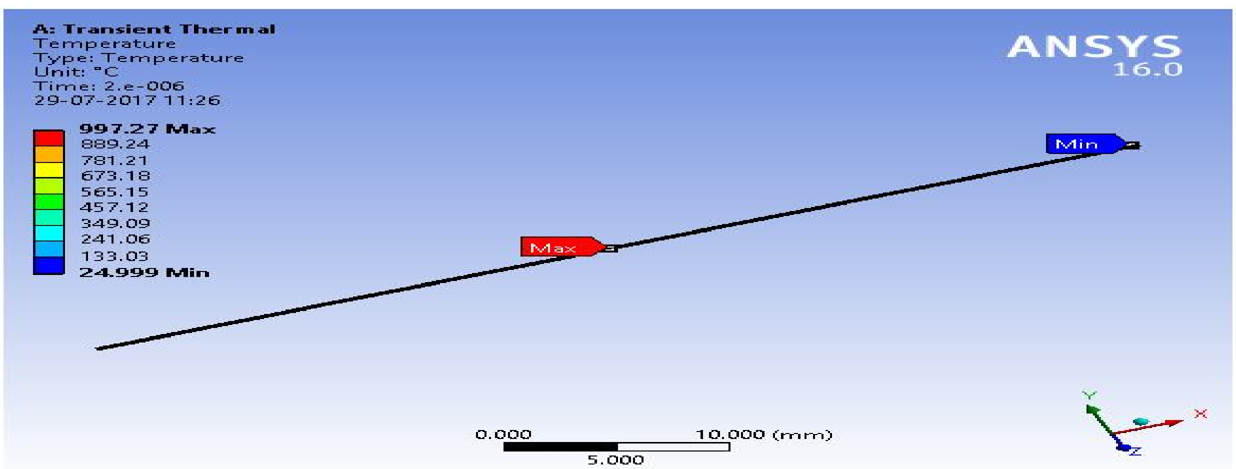

Fig. 14: Transient temperature distribution on Inconel 718 wire electrode.

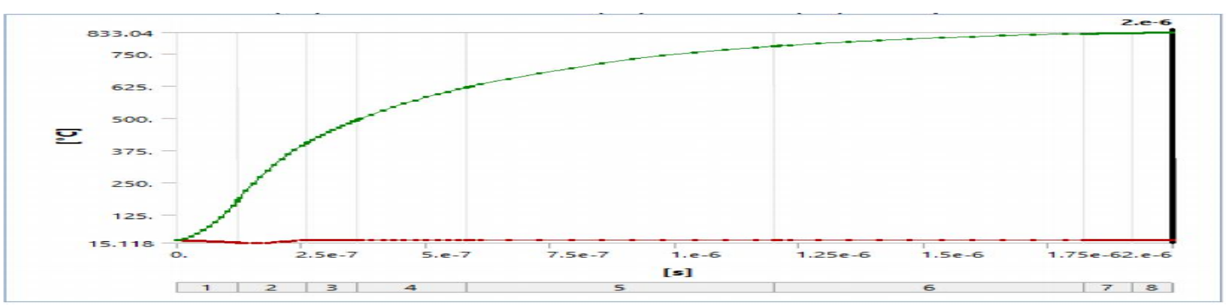

Fig. 15: Graphical representation of maximum and minimum transient temperature distribution on Brass wire electrode.

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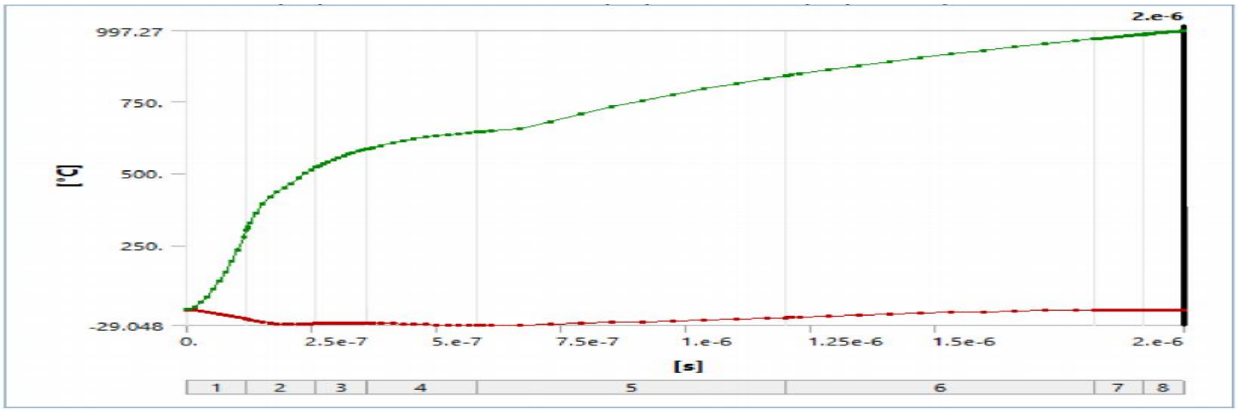

Fig. 16: Graphical representation of maximum and minimum transient temperature distribution on inconel 718 wire electrode.

Here the transient temperature distribution of both wire is shown in fig 15 and fig 16. The maximum temperature developed inside the both wire electrode, as we observed that the initial stage temperature variation is higher as compared to latter stage and the maximum temperature generated Inconel 718 is higher as compared to Brass wire electrode.
Now the heat flux result is obtained as follow:-

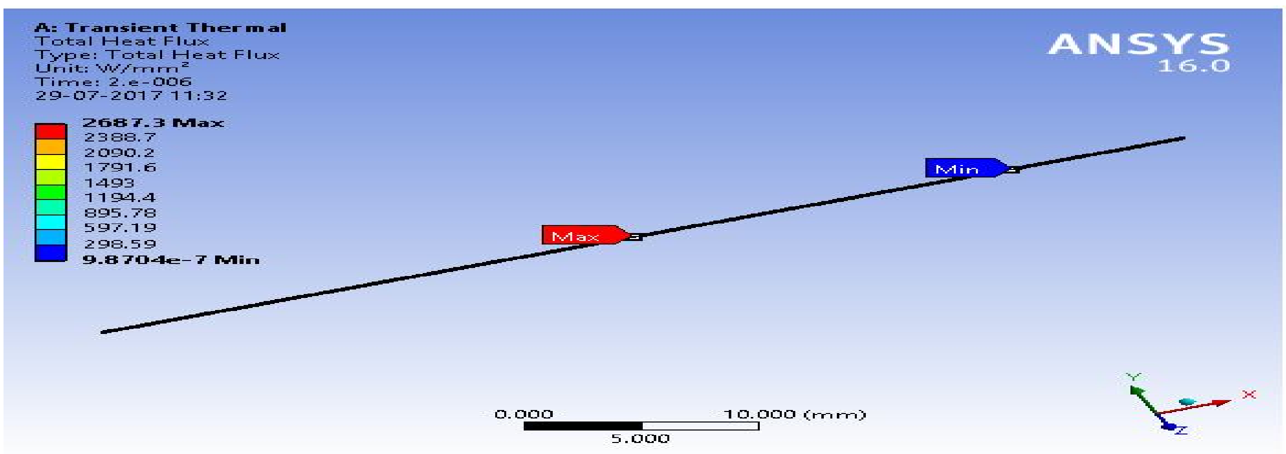

Fig. 17: Transient heat flux distribution on Brass wire electrode.

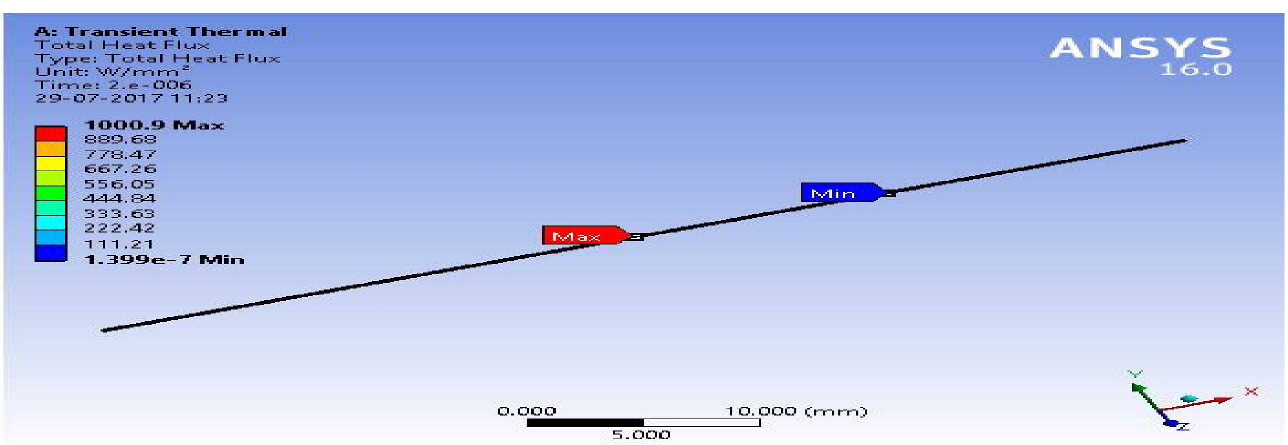

Fig. 18: Transient heat flux distribution on Inconel 718 wire electrode.

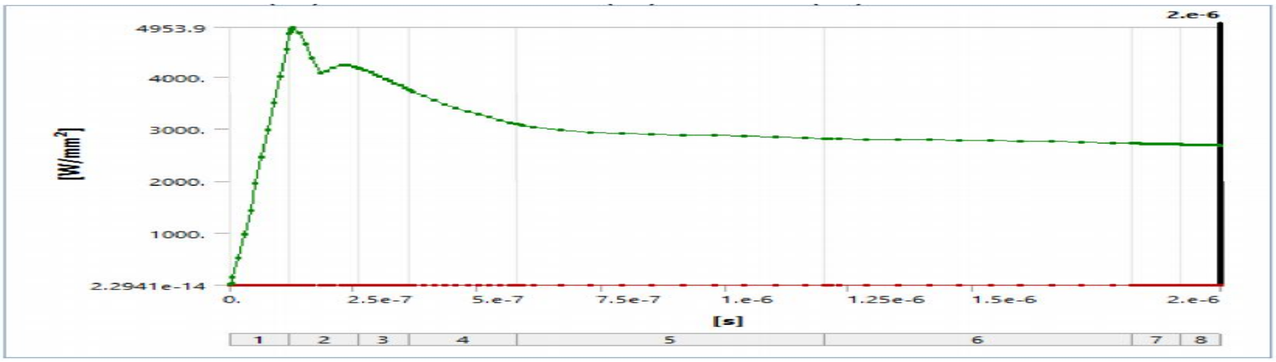

Fig. 19: Graphical representation of maximum and minimum transient heat flux distribution on Brass wire electrode.

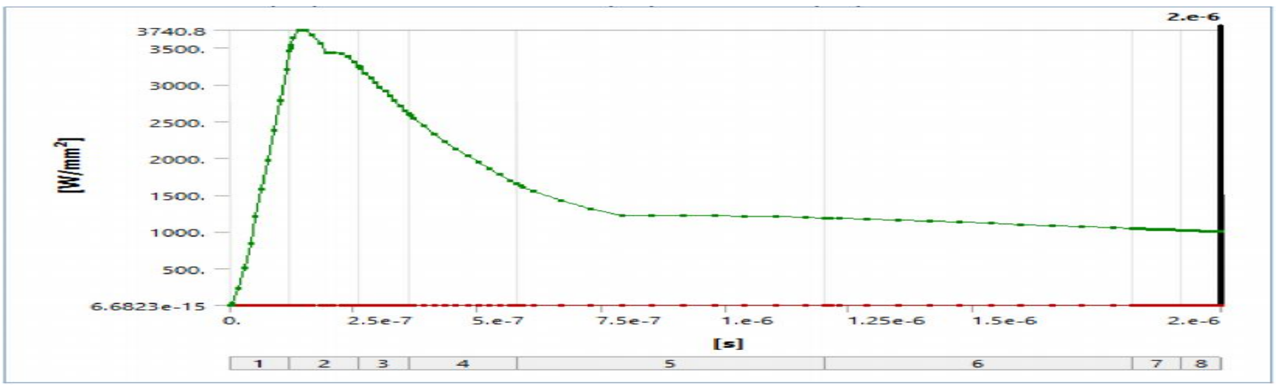

Fig. 20: Graphical representation of maximum and minimum transient heat flux distribution on Inconel 718 wire electrode.

Here the graphical representation of maximum and minimum transient heat flux distribution is shown in fig 19 and fig 20. Here we can observe that the maximum heat flux generated inside the Inconel 718 is higher as compared to the Brass wire electrode.

VIII. TRANSIENT STRUCTURAL ANALYSIS

The WEDM wire electrode is wounded on two wheel due to this the tension is created on the wire due to the application of tension in wire there is deformation and the stresses is developed in the wire. In this section we deals with the transient structural analysis of both brass and INCONEL 718 WEDM wire electrode. The wire is moving with the velocity 5.2 mm/min. The maximum value of tension and the boundary condition is given in the table 4.

Now we get the following result:-

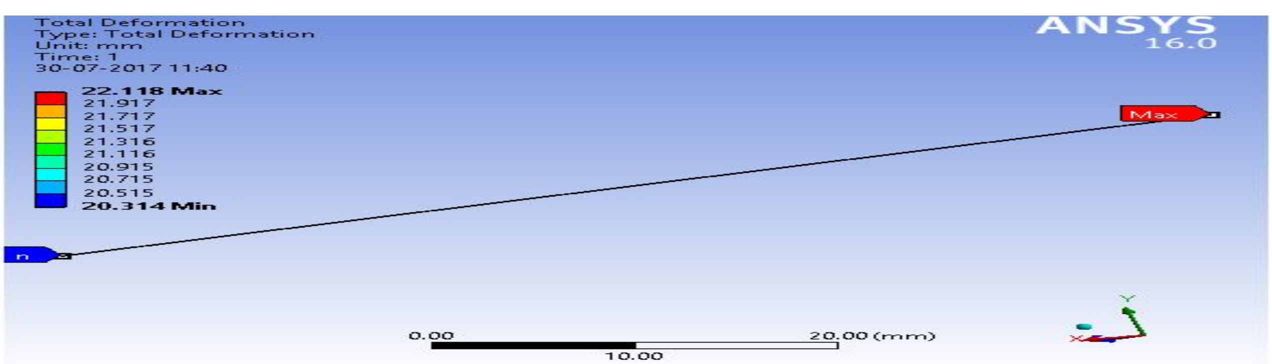

Fig. 21: Total Deformation of Brass wire electrode.

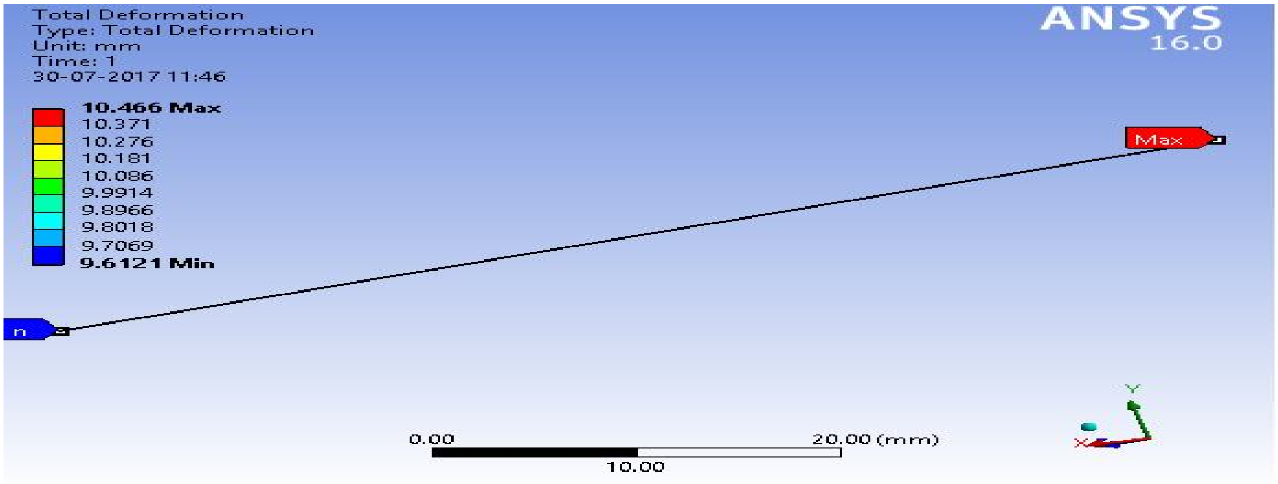

Fig. 22: Total Deformation of Inconel 718 electrode.

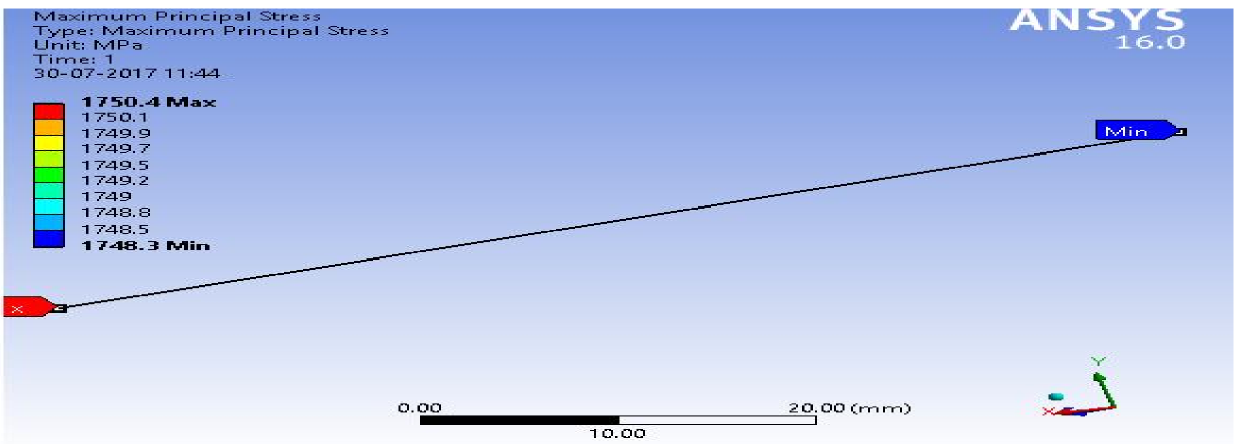

Fig. 23: Maximum Principle Stress on Brass and Inconel 718 wire electrode.

IX. CONCLUSION

If we were discuss the maximum temperature and maximum heat flux generated inside the WEDM wire electrode then we observed the following table:

Table No. 7: The maximum value of temperature and heat flux of Brass and Inconel wire

Material WEDM wire electrode	**Maximum value on 25 volt and 27 amp**				**Maximum value on 50 volt and 11 amp**			
	Temperature (^{0}C)	**On fig. no.**	**Heat Flux (W/mm^2)**	**On fig. no.**	**Temperature (^{0}C)**	**On fig. no.**	**Heat Flux (W/mm^2)**	**On fig. no.**
Brass	483.63	7	2814.8	11	833.04	15	4953.9	19
Inconel 718	576.73	8	2120.5	12	997.27	16	3740.8	20

From the above table we can conclude the maximum temperature generated by the Inconel 718 wire electrode is more than the Brass wire electrode , The maximum heat generated inside the Brass wire is more than as compared to Inconel 718 electrode ,The deformation in the Brass wire is more than Inconel 718 as discussed in fig no. 21 and 22.Then finally we can state that Inconel 718 is better composite material for WEDM wire electrode because of higher maximum temperature generation minimum heat generated inside wire and minimum deformation. When there is minimum heat generated inside the wire then the chances to reach the recrystallization and melting is less.

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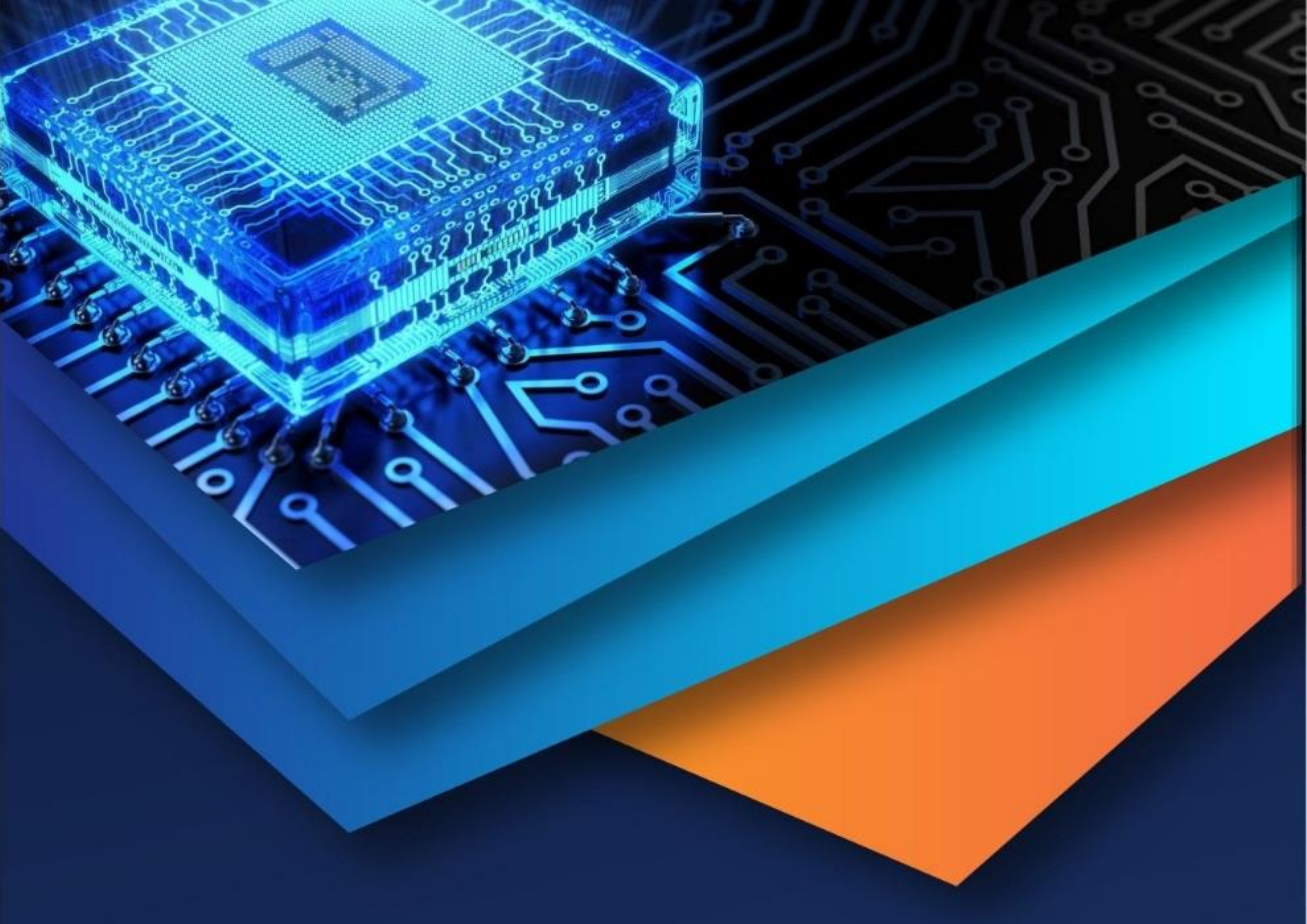

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