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Thermal Modelling Of Electrical Discharge Machining By Using Fem

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Abstract

A finite element model has been developed to estimate the temperature field and removal rate due to Gaussian distributed heat flux of a spark during EDM. The developed model first calculates the temperature distribution in the work piece material using ANSYS software. The results of the analysis show high temperature gradient zones and the regions of large stresses where, sometimes, they exceed the material yield strength. Results from thermal concern material removal rate be compared with the experimental values. And find out the effect on the creater surface.

1. INTRODUCTION

Electrical Discharge Machining (EDM) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion. In this process an electric spark is used as the cutting tool to cut (erode) the workpiece to produce the finished part to the desired shape. The metal-removal process is performed by applying a pulsating (ON/OFF) electrical charge of high-frequency current through the electrode to the workpiece. This removes (erodes) very tiny pieces of metal from the workpiece at a controlled rate. The material removal is takes place due to localized heating and then vaporization of material during machining. When an electrostatic field of sufficient strength is established then electrons accerate towards the anode. Ultimately a series of narrow columns of ionized dielectric fluid molecules is established, connecting two electrodes causing an avalanche of electrons since the conductivity of the ionized column is very large which is normally seen as a spark. As a result of this spark a compression shock waves is generated and a very high temperature is developed on the electrodes.

Various aspects of EDM process have been studied in detail like types of EDM machines Wire cut/Die-sinking), tooling, control circuits, process performance under chosen conditions, on-line machine control, etc., [1-3]. In the present context, studies on the development of analytical process models of die-sinking EDM process are particularly relevant.

2. LITERATURE REVIEW

Since the early seventies, researches worldwide attempted to thermal model of electrical discharge machining and serach out the thermal stresses in the material AISI 4340. **K.L. Bhondwe** et al. (2002) attempts to develop a thermal model for the calculation of material removal rate (MRR) during EDM.

Vinod Yadav et al. (2002) proposed that the high temperature gradients generated at the gap during EDM result in large localized thermal stresses in a small heat-affected zone leading to micro-cracks, decrease in strength and fatigue life and possibly catastrophic failure. **Philip Allen** et all., (2007) has presented material removal is analyzed using a thermo-numerical model, which simulates a single spark discharge process.

H.K. Kansal et al**,** (2008) proposed the developed model first calculates the temperature distribution in the workpiece material using ANSYS software and then material removal rate (MRR) is estimated from the temperature profiles.**Yeo** et. al (2008) has presented Critical assessment and numerical comparison of electro-thermal models in EDM. He proposed Comparative analyses on the material removal rate (MRR) ratio of the predicted result to experimental data for discharge energy range from 0.33 to 952 mJ showed that DiBitonto's model yielded the closest proximity of 1.2–46.1 MRR ratio. This is followed by Jilani ,Snoey ,Beck and Van Dijck. In this also shows that the disk heat source models can be enhanced by improving approximation of the heat flux and energy fraction. DiBitonto's model shows a better agreement with experimental data as compared to the other models, especially at large discharge energy.

3. THERMAL MODELLING

Due to the random and complex nature of EDM, the following assumptions are made to make the problem mathematically tractable.

ASSUMPTIONS

1. The model is developed for a single spark in view of the fact that machining by EDM is a succession of elementary discharges.
2. The material properties of the workpiece and tool are temperature dependent.
3. Inertia and body force effects are negligible during stress development.
4. The domain is considered as axisymmetric.
5. Work piece and tool materials are homogeneous and isotropic in nature.
6. Heat flux is assumed to be Gaussian distributed [17]. The zone of influence of the spark is assumed to be axi-symmetric in nature.

3.1Governing equation

For the transient, non-linear thermal analysis of EDM process, Fourier heat conduction equation is taken as the governing equation (1),

$$\frac{1}{r}\frac{\partial}{\partial r}\left(k_t r\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial z}\left(k_t\frac{\partial T}{\partial Z}\right)= \rho C\mathrm{p}\frac{\partial T}{\partial t}$$

where r and z are the coordinates of cylindrical work domain; T is temperature; Kt is thermal conductivity; ρ is density and Cp is specific heat capacity of work piece material.

3.2 Boundary condition

A small cylindrical portion of the workpiece around the spark is chosen for analysis. Figs. 1 show the two-dimensional axi-symmetric process continuum and the associated boundary conditions taken for the analysis.

$$-K(T)\frac{\partial T}{\partial Y} = Q(x,t) \quad \text{for conduction, under the plasma channel} \quad (2)$$

$$-K(T)\frac{\partial T}{\partial Y} = h(T - T_0) \quad \text{for convection, exposed to the dielectric} \quad (3)$$

$$\frac{\partial T}{\partial n} = 0 \quad \text{for no heat transfer} \quad (4)$$

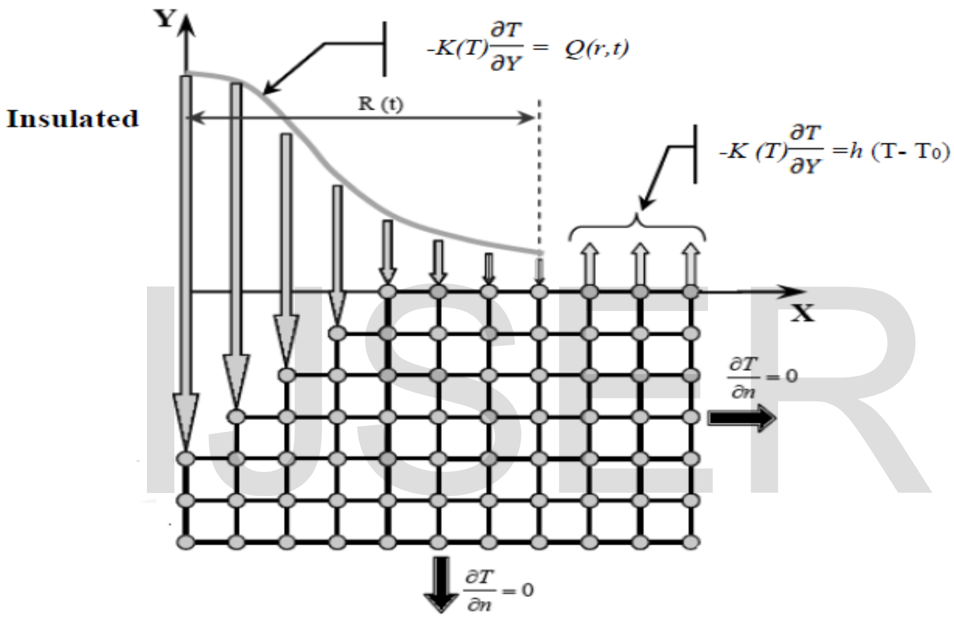


Fig.1 Boundary conditions at the initial moment

3.4 Heat Input

In this present work, the Gaussian distribution of heat flux input [7] has been used to approximate the heat from the plasma. The heat q entering the workpiece due to EDM spark is given by,

$$Q(x,t) = Q_o(t)\exp\left[-4.5\left(\frac{x}{R(t)}\right)^2\right] \quad (5)$$

Using this equation, the maximum heat flux Q_o can be calculated as under Where ,

$$Q_o(t) = \frac{4.45 x V x I x F_C}{\pi x R^2(t)} \quad (6)$$

3.5 Spark radius

Spark radius is an important factor in the thermal modelling of EDM process. In practice, it is extremely difficult to experimentally measure spark radius due to very short pulse duration of the order of few microseconds. Erden [10] has suggested an empirical relationship for the spark radius for selected pairs of electrodes and dielectric. For a rectangular pulse, the spark radius $R(t)$ depends on time t in the following equation

$$R(t) = KQ^{m} t^{n} \quad (7)$$

Here Q is discharge power and m, n and K are empirical constants. These constants are defined in terms of the coefficients L, M and N determined experimentally for different electrode materials:

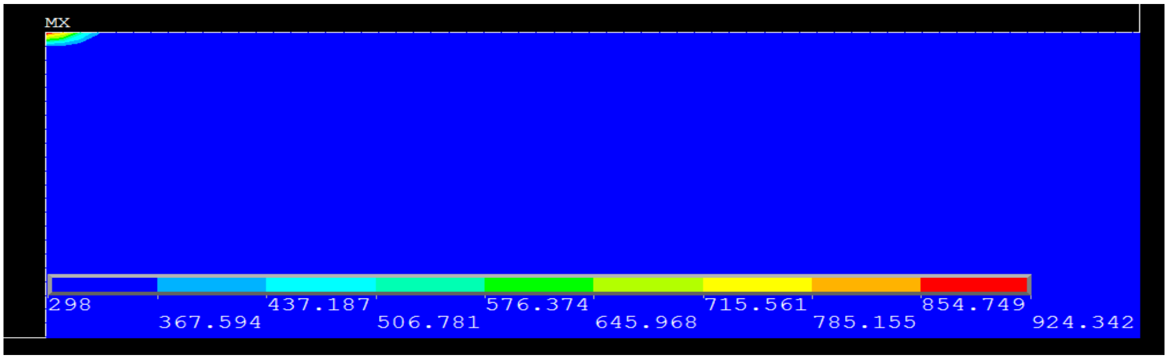
$K = \frac{L}{lM+0.5N}$, m= 0.5N, n = N , (l is discharge length)

So, from the above formulas, we find the values of plasma radius is 120 mirco meter from Literature: Yadav et al. 2002 research paper. The majority of the authors listed above used the fraction (Fc) of power transferred to the workpiece equal to 45%, only Dibitonto et al. [1] took it equal to 18.3%. So finally the power of transferred value is 0.45 be taken.

3.6 Solution methodology

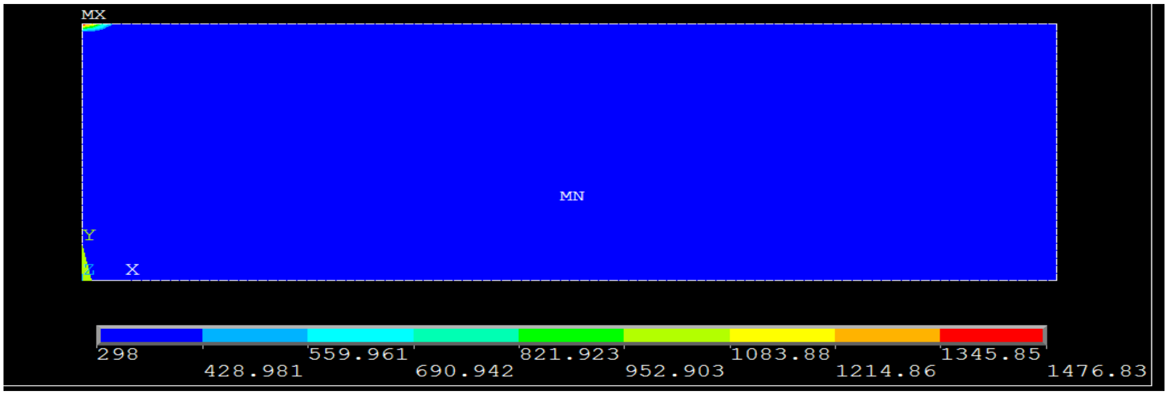
The governing equation (Eq. 1) with boundary conditions was solved by FEM to predict the temperature distribution at the end of each transient heat transfer analysis cycle. ANSYS, a FEM solver was used. A two-dimensional continuum of size ten times the spark radius was considered for the analysis. Four-nodes, axis-symmetric, thermal solid element (PLANE 55) were used for discretization of the continuum. Convergence conditions were tested by increasing the number of elements in the mesh. The transient heat transfer problem was solved by applying the heat flux at the spark location (Eq. (7)) and using the discharge duration as the time step for the analysis.

AISI 4340 tool steel with machining conditions discharge current 40 A, discharge voltage 60 V and discharge time of 0, 20, 30, 50, 100, 200, 400, 500µs. A typical crater cavity `generated' by this analysis.

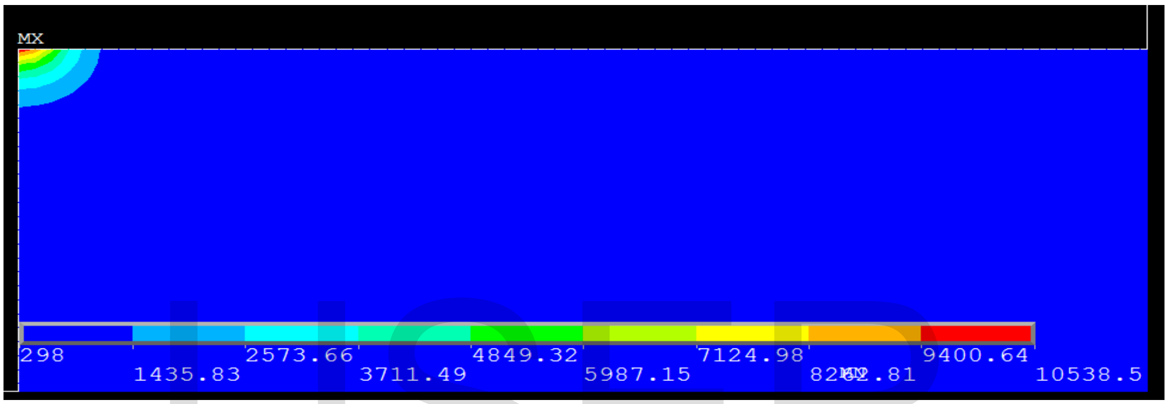


Temperature distribution obtained at the end of spark after 0 µs

Similarly, at the discharge time 20, 30, 50, 100, 200, 400 and 500 µs , the temperature distribution will be find out same as above.

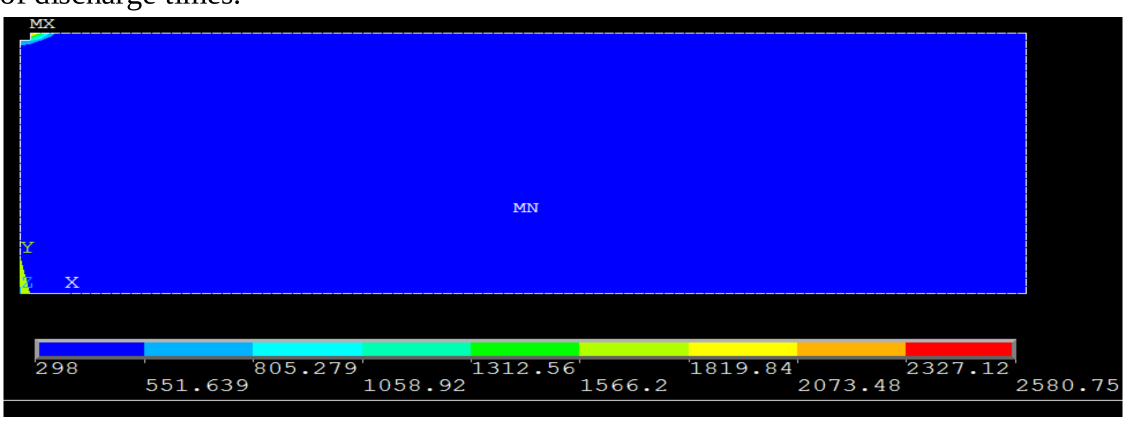


Temperature distribution obtained at the end of spark after 10 µs

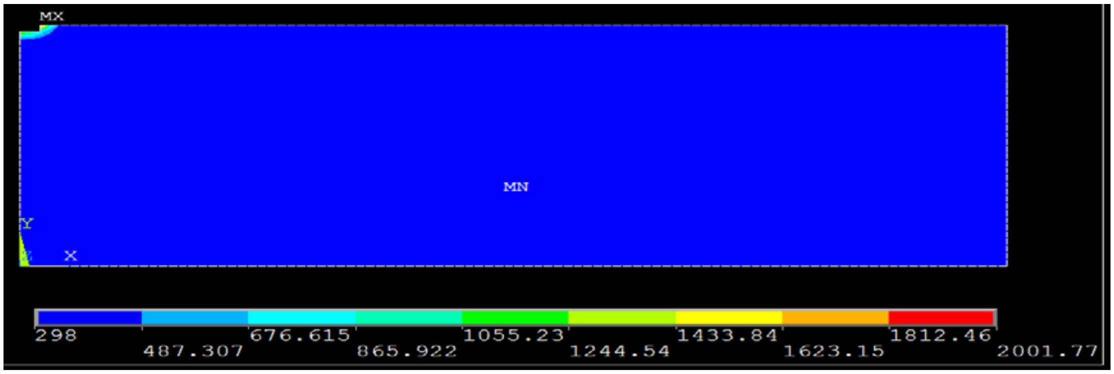


Temperature distribution obtained at the end of spark after 500 µs

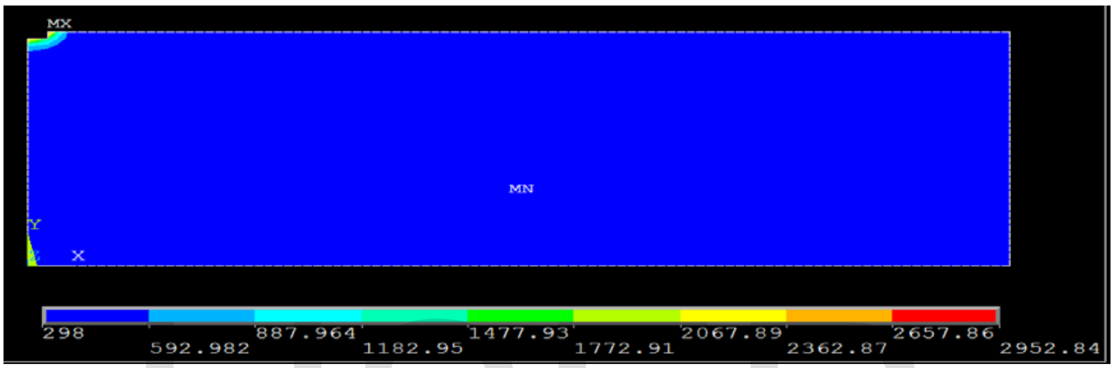
All elements of the workpiece with a temperature value above 1427K were “killed” by the ANSYS software. The elements showing temperature more than melting point were selected and eliminated from the complete mesh of the work domain for further analysis. As the temperature contours shows the different contours as different times. As the time increases the red color zone i.e crater is also increased where as at 0 µs the maximum temperature reached is 924.3K and at last 500 µs the maximum temperature is 10538.5K.The below figures are showing the material removal rate at various values of discharge times.



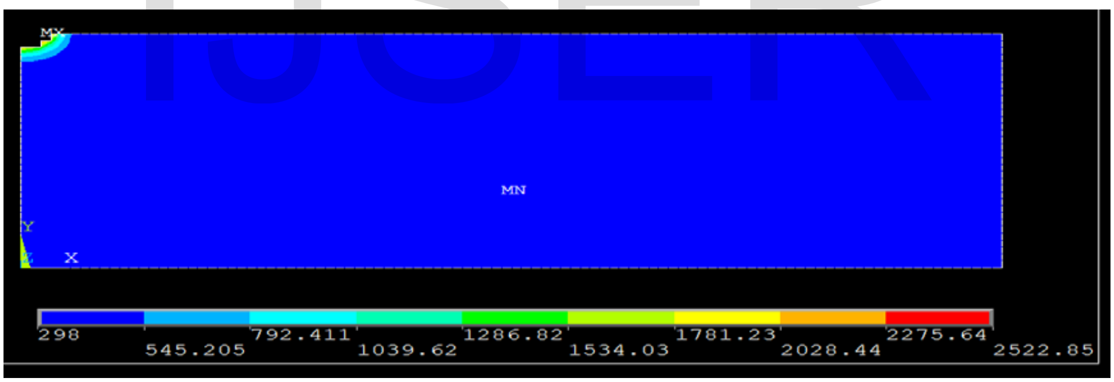
Material removal rate after 30µs.



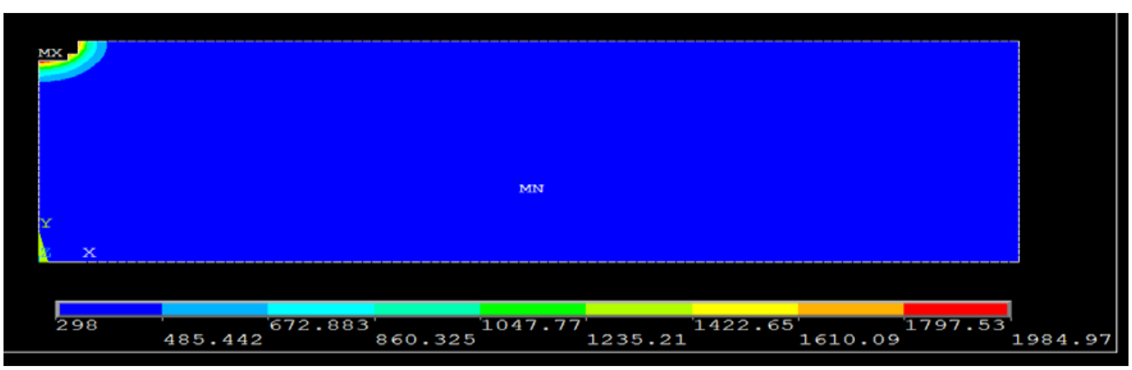
Material removal rate after 50µs



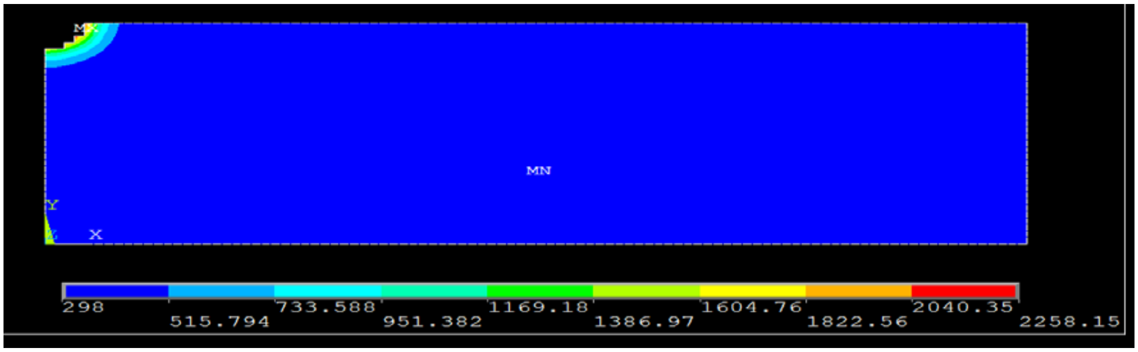
Material removal rate after 100µs



Material removal rate after 200µs



Material removal after 400µs



Material removal after 500µs

By using the formula crater volume, we find the different values of MRR at various time. The formula is

Crater Volume, $V = \frac{\pi}{6} h (3r^2 + h^2)$

Where, r is the radius of craters and h is the depth of the craters.

Result and discussion

After the experiment of material AISI 4340 in electrical discharge machining to obtain the removed material we obtained the difference in the material removal rate. The following table shows the material properties

Density (g/cm³)	Melting point (°C)	Yeild strength (MPa)	Elastic modulus (Gpa)	Possion's Ratio	Brinell Hardness
7.85	1427	470	196	0.3	217

The below table shows the experimental and FEM data of material removal rate with different discharge time at constant voltage and current.

Voltage	current	Discharge time	Experimental MRR	By FEM MRR
50V	40V	30 µs	2.0487×10^{-15} µm^3	1.884×10^{-15} µm^3
50V	40V	50 µs	3.0001×10^{-15} µm^3	3.6756×10^{-15} µm^3
50V	40V	100 µs	5.222×10^{-15} µm^3	4.3825×10^{-15} µm^3
50V	40V	200 µs	5.509×10^{-15} µm^3	5.953×10^{-15} µm^3
50V	40V	400 µs	6.0×10^{-15} µm^3	6.0436×10^{-15} µm^3
50V	40V	500 µs	6.923×10^{-15} µm^3	7.23822×10^{-15} µm^3

The material removal is obtained by succession of plasma. In each of this plasma channel, the heating suffered by the material affected and the geometry of the corresponding crater is calculated. The first stage comprises the heating of the material affected by the discharge and ends when the pulse on time is reached and the formed plasma channel extinguishes. The variation graph of the experimental and FEM result are found to be similar. Fig 1.1 illustrates the material removal rate variation graph. As we found that with increases the time at constant temperature and voltage, the material removal rate be also increases. Someway its follows the linear relationship with time. The melting temperature of the workpiece is 1427K. As well as the temperature reaches more than this melting temperature the material begins to evaporates. And in this way it begins evaporate at 30μs. The below graph illustrates this condition.

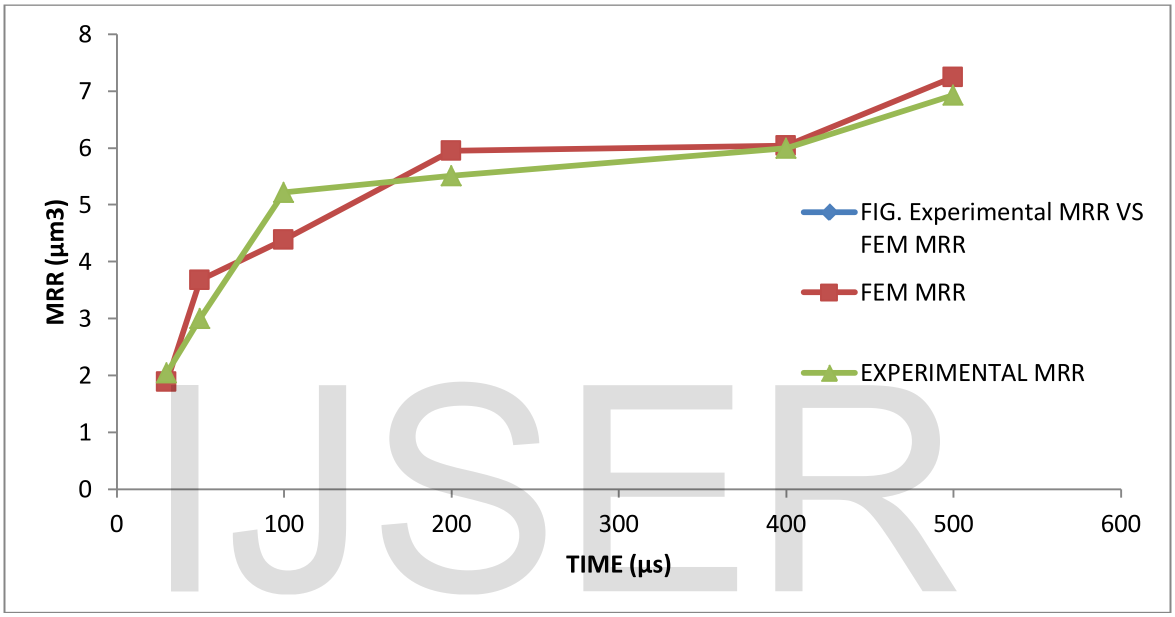


FIG.2 Comparison graph between MRR vs time of experimental and FEM MRR.

CONCLUSION

Result from the experimental and FEM material removal rate have been presented during electric discharge process. The material removal rate has dependency to the temperature which also depends on the electrical conductivity of the material. The crucial importance of the experimental results depends on the accuracy of electrical conductivity and gives the better correlations with FEM observations.

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