Thermo Physical Modeling of Powder Mixed EDM using ANSYS10.0

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Abstract— An Axi symmetric 2D model for powder blended electric discharge machining (PMEDM) has been worked out utilizing FEM. It considers the few critical perspectives for example, temperature , shape and size of heat source (Gaussian heat distribution), work piece and dielectric liquid, rate dispersion of heat among tool, material ejection efficiency, pulse on/off time and so forth. Finite element simulation of powder blended EDM process for H13 Hot Die steel material is worked out utilizing applicable limiting conditions along with different assumptions. The cavity shape was produced utilizing simulated temperature profiles to estimated volume removed in single crater formation and to anticipate the thermal behaviours and material removal mechanism in PMEDM. Death of element technique (DOE) is utilized to produce material removal effect.

Key words: EDM, ANSYS10.0

I. Introduction

In 1770, a scientist Priestley detected the erosive impact of electrical discharges on metals. Throughout analysis (to remove the erosive effects on electrical contacts) the soviet scientists, Lazarenko and Lazarenko (1940), decided to take advantage of the damaging impact of electrical discharge and developed a controlled methodology of metal machining. In 1943, they declared the development of the primary Spark Erosion machine. The spark generator utilized in 1943, referred to as the Lazarenko circuit, has been utilized over a many years in powder EDM machines also an improved version is being employed in several current applications.

A. Working Principle of EDM Process:

The fundamental principle in EDM is that the conversion of electricity into thermal energy through a series of distinct electrical discharges occurring between the electrode and work piece immersed within the dielectric fluid. The insulating impact of the dielectric is vital in avoiding electrolysis of the electrodes throughout the EDM method. Spark is initiated at the point of smallest inter-electrode gap by a high voltage, overcoming the dielectric breakdown strength of the little gap. At this stage, erosion of each electrode takes place. After every discharge, the capacitor is recharged from the DC supply through a resistor and therefore the spark that follows is transferred to next narrowest gap. The accumulative impact of a succession of sparks over complete work piece surface ends up in its erosion to a form that is roughly complementary to it of the tool.

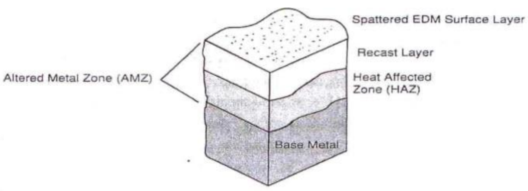

Fig. 1: Layers of EDM surface

The dielectric fluid serves to concentrate the discharge energy into a channel of terribly little cross-sectional space. Also it cools the two electrodes and flushes away the product of machining from the gap, the electrical resistance of the dielectric influences discharge energy and time of spark initiation. Because the work piece is spark-eroded, tool should advance through the material towards it. A servo system is used to make sure that the electrodes moves at a correct rate to take care of the correct spark gap, and to retract the conductor, if short-circuiting happens. Spark energy is the product of peak current and pulse-on time and since these variables are readily adjusted; machining conditions will designated for specific effects required. Though the method is incredibly advanced, once the electrode is separated from the work piece, potential within the circuit voltage is typically regarding 100V, because the material begins to ionize, current starts flowing and therefore the potential drops to level of thirty five volts. Most of the conductor wear happens during the ionization time.

Although EDM machining technology is wide employed in mechanical manufacuring, its low efficiency and poor surface quality are the key drawback limiting its development. So it's of nice importance to enhance the machining efficiency and surface quality of EDM technology. The EDM method are often compared with the traditional cutting method, except that during this case, a suitably formed tool conductor, with precision controlled feed movement is utilized in situ of the short length electrical impulses. EDM has found applications within the machining of hard metals or alloys which may not be machined simply by standard strategies.

The Electric Discharge machining (EDM) has been widely used as a material removal method to provide components molds and dies form many decades. Only recently the surface modification strategies by EDM are studied. Like different machining strategies, EDM machining is additionally divided into 2 phases: Rough machining and finish machining. The finish machining section needs high surface quality, whereas rough machining section needs high machining efficiency with a particular quality**.**

B. Problem Identification:

It is seen that although a lot of work is already done in the sector of electrical Discharge Machining associated with Material Removal Rate and Tool Wear Rate. However result of PMEDM on the various parameters like Material Removal Rate has not been studied however. In past, work has been done exploitation varied powders like nickel, Silicon, Titanium etc., however nobody has tried however Graphite powder, thus its attention-grabbing to check the result of graphite mixed dielectric upon the material Removal Rate. Finite element simulation of powder mixed EDM process for H13 Hot Die steel material is worked out using relevant boundary conditions along with other assumptions. The crater shape was developed using simulated temperature profiles to approximate volume removed in single crater formation. An Axi symmetric 2D model of powder mixed EDM has been worked out using FEM. Also model takes into account the several important aspects such as temperature ,shape and size of heat source (Gaussian heat distribution), work piece and dielectric fluid, percentage distribution of heat among tool , material ejection efficiency, pulse on/off time etc. to predict the thermal behaviour and material removal mechanism in PMEDM . Death of element technique is used to produce material removal effect.

Electro discharge machining (EDM), one among the foremost common non-conventional machining processes, is electro-thermal method within which work piece is typically submerged with in a liquid dielectric medium and formed through the action of a succession of high frequency distinct electrical discharges (sparks) made by a DC generator. Each spark regionally erodes (melts and vaporizes) little quantity of the material surface, the general result being a of complementary shap of tool geometry over the machined surface. Besides tool and die production, within the recent years, EDM has found several applications within the fields of automobile, aerospace, surgical instruments and military industry. The key drawback to use EDM is its low machining rate and poor surface finish for large scale production. Several advances have emerged with in EDM to beat these difficulties. One among those advancements is powder mixed EDM (PMEDM).

The use of semiconductive solid particles in EDM as dielectric is named as PMEDM. It's a recent innovation of EDM for enhancing its capabilities. to reinforce the machined surface properties by means that of fine powders of conducting material, Graphite, aluminium,silicon are mixed with dielectric fluid . Reduces Surface Roughness (SR), Tool Wear Rate (TWR). Also increases overcut size and Material Removal Rate (MRR). All electrically conductive materials can be machined irrespective of its hardness, toughness, strength and microstructure.

Literature review reports that extensive experimental as well as analytical studies are carried on modeling of EDM process for the improvement of accuracy and productivity. Worldwide Researchers have attempted to model various types of electric discharge phenomena and the mechanism of anode and cathode erosion in the EDM process. Numerous researchers developed a process model of EDM mechanism by design of experiments (DOE) tools. Also several researchers attempted to develop process models of EDM through analyzing the spark phenomenon and material removal mechanism in EDM.

S.N. Joshi, S.S.Pande etal [1]. Carried Numerical analysis of the single spark operation of EDM process.There research work was based on thermo-physical analysis of single spark operation of EDM process by considering the 2D Axi_Symmetric process continuum. The analysis is made more realistic by adopting assumptions such as Gaussian distribution of heat flux, latent heat of melting, Spark radius equation based on discharge current and discharge duration etc, to predict the shape of crater cavity formed and the material removal rate (MRR).

Process model was also developed by S.N. Joshi; S.S. Pande [3] is further used for optimization of electric discharge machining (EDM) process. To achieve optimal process conditions an intelligent process modelling approach for EDM is adopted in this work.

Numerical method for predicting heat affected zone in EDM process for AISI H13 tool steel is reported by M.R. Shabgard, M. Seyedzavvar [2]. They also reported the influence of EDM input parameters on the state of thermal distribution in heat affected zone of H13 tool steel by ABAQUS/CAE software.

Researcher H.K. Kansala, Sehijpal Singh, and Pradeep Kumar [4] worked out on numerical simulation of powder mixed EDM. This simulation is based on the various important parameters such as temperature sensitive material properties, shape and size of heat source(Gaussian heatdistribution),Percentage distribution of heat among tool-work piece and dielectric fluid, material ejection efficiency, pulse on/off time, and phase change (enthalpy) etc. to estimate the temperature distribution.

S.H. Yeo, W. Kurnia, and P.C. Tan [7] carried out Critical assessment and numerical comparison of various electro-thermal models in EDM. Five EDM models from Snoeys, Van Dijck, Beck, Jilani, and DiBitonto are analyzed in respect of the temperature distribution, crater geometry, and material removal at cathode. This work carried out comparative analyses on the material removal rate (MRR) ratio of the predicted result to experimental data.

J. Marafona, J.A.G. Chousal [8] worked on development of a thermal–electrical model for sparks generated by electrical discharge in a fluid (liquid) media. Discharge channel used between the electrodes is of cylindrical shape. The discharge channel being an electrical conductor will dissipate heat, which can be explained by the Joule heating effect.

Review of the research work done by S.N. Joshi, S.S. Pande only on die-sinking EDM and effect of powder mixed di-electric fluid remains unexamined. Whereas H.K. Kansala research reported numerical simulation of powder EDM but parametric studies were not carried out. Thus, there is a need to develop a thermo-physical model of PM-EDM and its use for powder mixed-EDM parametric study.

II. SIMULATION METHODOLOGY

In PMEDM, a series of fast, repetitive and arbitrarily distributed distinct electrical sparks occur within the space between work and tool electrodes for a cycle of few μ seconds. Addition of powder particles into the dielectric fluid makes this method complicated and random. The mixing of powder in dielectric medium with in EDM makes the discharge method a complicated and random with a series of discharges spread all over the surface,the subsequent assumptions are made without sacrificing the fundamental features of the EDM model to model the process mathematically possible.

A. *Assumption Made For The Analysis:*

- The modeling and its analysis represent results for only single spark. Thermal properties of the work piece are temperature dependent. The expansion of the body because of thermal heating is negligible, therefore the elements within the mesh remains unaffected.

- The result of latent heat of fusion and vaporization on simulation study has been neglected.
- Latent heat as well as density of the work piece material is considered temperature independent.
- Thermal analysis is transient also heat source has Gaussian distribution of heat flux incident on the work piece surface.
- Portion of heat energy that goes into the work piece specimen (Kw) remains constant throughout pulse.
- Flushing efficency is nearly 100 percent with continuous stirring action.
- Transfer of heat energy to the electrode is by conduction and Convection is applied on the topmost surface of the work piece specimen which is submerging with powder mixed dielectric.
- Material for work piece assumed to be homogeneous and is free from any internal residual stresses before machining.
- The result of impulse force wasn't considered during modeling.

B. Governing Equation:

Fourier heat conduction equation is used as governing equation for transient and Non Linear thermal Analysis in EDM.The governing differential equation for heat conduction in an axisymmetric solid surface is given by

$$\rho c_p \frac{\partial T}{\partial t} = \left[\frac{1}{r}\frac{\partial}{\partial r}\left(Kr\frac{\partial T}{\partial t}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right)\right] \quad \text{....eq.1}$$

Where CP is the specific heat,K is the thermal conductivity of the work material,T is the temperature,t is the time , ρ is the density of material r and z are corresponding coordinate axes . Dielectric medium is used to submerge the work piece, thus (T_a) is assumed to be ambient temperature to start with the process.

The upper surface of work piece is in direct contact with the dielectric fluid. Boundary condition ie. Heat flux (q) is applied on this surface.

C. Thermal Model, Heat Distribution and Heat Input in the Work-Piece:

The discharge phenomenon in EDM can be modeled as the heating of the work electrode by the incident plasma channel. Fig.2 shows the idealized case where workpiece is being heated by a Gaussian type of heat source. The mode of heat transfer in solid is conduction.

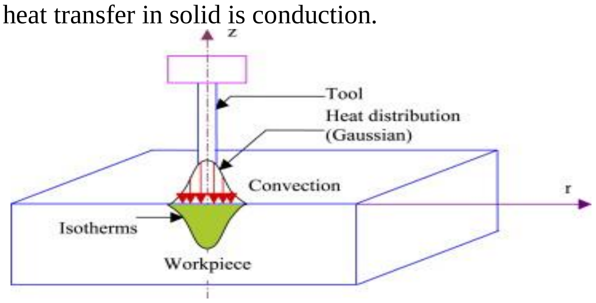

Fig. 2: Gaussian distribution in PM-EDM

Discharge behaviour within the spark region was modelled assuming Gaussian distribution. Heating of the workpiece was considered to be due to such heat source inside the spark which is conducted to the workpiece and dissipated to the environment (powder mixed dielectric) by convection outside the spark region on workpiece top surface. Though many studies involving analysis of EDM process have used a uniform disc heat source inside the spark plasma, Gaussian heat distribution is still more realistic for EDM process as concluded by many researchers.

D. Heat Distribution:

For analytical tractability, many authors have used uniform disc heat source. Moreover, the assumption of Gaussian distribution is well accepted for modeling the heat input in EDM. Therefore Gaussian heat distribution has been considered in the present work

III. BOUNDARY CONDITIONS

The boundary conditions are given as follows:

1) Taking boundary condition (B1):Upto Spark radius, R:

$$K\frac{\partial T}{\partial Z} = QW(r) \qquad \text{....eq 2}$$

2) Taking boundary condition beyond spark radius, R:

$$K\frac{\partial T}{\partial z} = h(T - T0) \qquad \text{....eq 3}$$

3) Taking boundary (B2, B3, B4)

$$\frac{\partial T}{\partial n} = 0 \qquad \text{...eq 4}$$

Where, h is heat transfer coefficient between the work surface and powder mixed dielectric fluid, QW(r) is the heat flux owing to the spark produced; T_0 is the initial temperature which is equal to room temperature.

A. Heat flux:

Most specialists have considered the hemispherical heat source for thermal modelling in EDM. However this estimate is neither sensible nor solid. It has been accounted in [12] that the isothermal curves got for EDM thermal model can be precisely approximated by Gaussian appropriation. Yadava et al. have reported a heatflux.

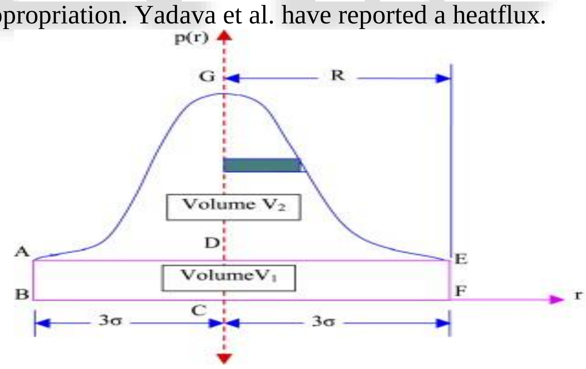

Fig. 3: Gaussian distribution. [12]

Equation used for flux generation on ansys model is:

$$Q_w(r) = \frac{4.57 K_n V_b I R_w}{\pi R^2} e^{-4.5\left(\frac{r}{R}\right)^2} \quad \text{......eq.5}$$

Data For Modeling of PMEDM for H13 Hot Die Steel Material	
MATERIAL PROPERTY	H-13 STEEL
Density(kg/m^3)	7861
Conductivity(W/mk)	29
Modulus of elasticity(N/mm^2)	207x10^3
Specific Heat(J/gk)	473x10^{-3}

Table 1: Data for Modelling of Pmedm for H13 Hot Die Steel Material

Numerical model and the analysis of the PMEDM process was completed using FEM software ANSYS (ANSYS/Multi-physics) utilizing transient thermal Analysis

(Transient Thermal, h method) module. Model was created with a domain of 0.5 ×0.5×0.25 mm with H13 material

IV. MODELING PROCEDURE USING ANSYS 10.0

PMEDM involves complicated interaction of various physical phenomena and is a complicated thermal process. Work piece temperature and stress distributions can be simulated by FEM. To develop the FEM based model of PMEDM, a strong software package is needed which takes in account about all complicated aspects of the method.

ANSYS is one such intense tool that might be utilized in FEM investigation of the different models [11]. Any troublesome geometry can be investigated in ANSYS. It incorporates a few limited component investigation capacities, ranging from linear, static examination to a complex, nonlinear, transient element investigation inside of the fields such as structural mechanics, thermal and electro Magnetics systems. In the present work the modelling and simulation of results for PMEDM are performed in ANSYS Software [11]. The work geometry has been made in ANSYS by taking into consideration the various limiting conditions. Meshing of the work piece is done by mapped Meshing procedure. It consists of either quadrilaterals or triangular shape components.

The accompanying steps depict the methodology utilized for Modelling PMEDM with in ANSYS:

1) Step 1: Objective: the objective of this investigation is to decide temperature distribution in the work piece prepared by PMEDM.
2) Step 2: Units: All measurements are in mm unit.
3) Step 3: Software used: ANSYS10/Multiphysics
4) Step 4: Analysis technique: Thermal, h strategy
5) Step 5: Form of investigation: Transient
6) Step 6: Problem aspect: The geometry of the problem is formulated in ANSYS. 3D work pieces geometry is shaped. However, the domain is axisymmetric about Z coordinate axis thus the final result is formulated in 2-dimensional diagram. The size of the piece of work piece domain is 0.5 mm × 0.2 mm. The 2-dimensional model is shown in Figs. 5.
7) Step 7: Selection of element: Two-dimensional, four Noded Quadrilateral element (Thermal solid plane-55) with 20 µm size.

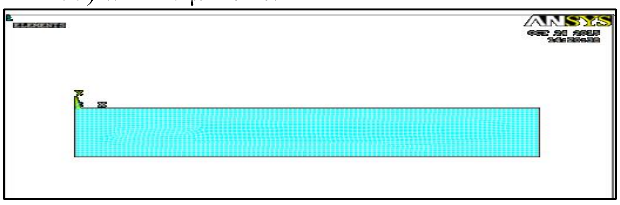

Fig. 4: 2D model of Ansys developed for PMEDM

A. *Determination of material removal rate (MRR) from FEM:*

The temperature profile obtained from FEM analysis is used to calculate the amount of material removed from the surface of the workpiece that is exposed to the heat flux.

A failure criterion is applied which correlates the temperature with the possibility of failure, to predict which part of the material is failing due to the heat flux. On the workpiece surface.

According to the failure criterion a region in the temperature profile is identified, where the temperature is greater than the melting temperature of the workpiece material (1623K). The material from that zone where temperature exceeds the melting temperature of the workpiece is assumed to be eroded due to spark.

V. THE STEPS FOR MODELLING ARE DETAILED BELOW:

A. *Preprocessing:*

1) Open Mechanical APDL (ANSYS).
2) Go to File > Change Title and give a new title for the example.
3) We shall be dealing with a rectangular block of length 0.5mm, width 0.2mm, and thickness 1 mm.
Also the spark radius is taken as 5 µm. Since we shall be doing a 2D modeling, the thickness of the material will not be taken into consideration.
To create the rectangle, we go to Preprocessor > Modeling >Create > Areas > Rectangle.
4) Define the type of element (Thermal Solid, Quad 4node 55 –PLANE55) from Preprocessor > Element Type > Add/Edit/Delete Click on Options and switch to the Axi-symmetric view.

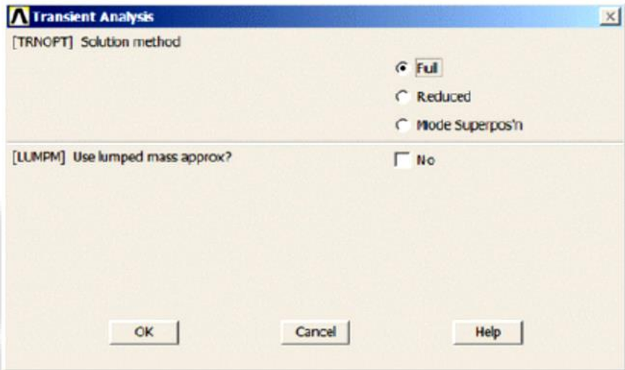

Fig. 5: Transient Analysis

5) Enter the element material properties (thermal conductivity, specific heat, and density) in Preprocessor > Material Props >Thermal
6) For FEM modeling we need to create a mesh. Here we have chosen an element edge length of 1 µm. To define the mesh size, go to Preprocessor > Meshing > Size Controls > Manual Size > Areas> All Areas…. The mesh can then be framed from
Preprocessor > Meshing > Mesh > Areas > Free > "Pick All".

B. *Solution:*

1) To define the analysis type, go to Solution > Analysis Type > New Analysis > Transient.
2) Turn on the Newton-Raphson solver by typing NROPT, FULL in the command line. This is necessary as the material can be removed from the model only when the N-R solver has been used.
3) To set the solution controls, go to Solution > Analysis Type >Solution Controls. Set the Tone time (2 µs) and Toff time (100 µs). Set the desired number of sub steps and iterations (20 and 100).
4) To set the initial temperature (298 K) go to Solution > Define Loads > Apply > Initial Condition > Define > Pick All.
5) Now we have to apply the heat flux equation, which is :Q(r) = (4.45*P*V*I)/ (3.14*R^2)*exp (-4.5*(r/R)^2)

Here, P is the percentage heat input,V is the voltage, I is the current, and R is the spark radius.

6) To solve the system, we go to Solution > Solve > Current LS.

C. Post Processing:

1) To read the results, go to General Postproc > Read Results > Last Sets.
2) The data that was gathered during analysis must now be input to a table, which can then be used by ANSYS to remove metal from the work piece. To create the element table, go to General Postprocessor > Element Table > Define Tale > Add. Enter a new table name, and select DOF solution > temperature TEMP.

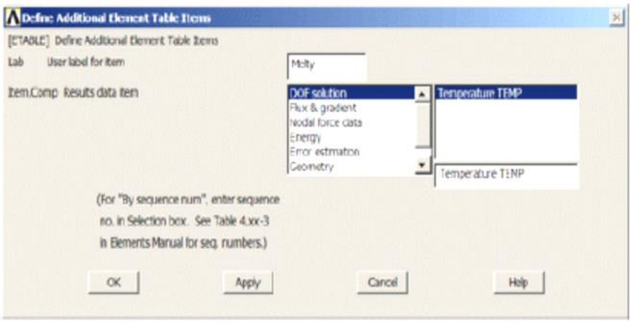

Fig. 6: Screenshot

3) To start killing (removing) the element, go to Utility Menu > Select > Entities > Select Elements > By Results >From Full >OK. Use the previously created table from the list and enter the melting temperature (1623 K) in the appropriate field.
4) Restart the analysis from Solution > Analysis Type > Restart > OK, and use the ekill, all command to remove the molten material.
5) To view the results, Elements > Live Elem's > Unselect > Select All > From Full. Then General Postproc > Plot Results > Contour Plot > Nodal Solution > DOF Solution > Temperature TEMP.

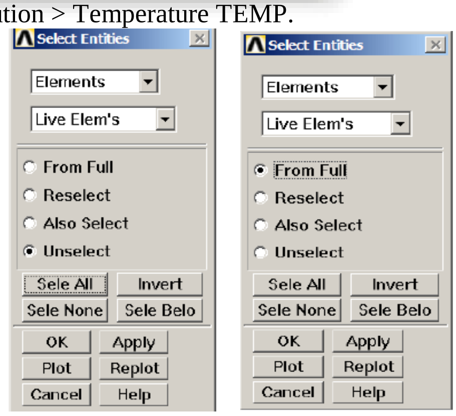

Fig. 6: Screenshot

VI. PROCESS VARIABLES USED

FE simulation with ANSYS was completed for different process parameter settings to study the temperature profile after PMEDM. From the temperature profiles, the amount of volume removed during a single crater was calculated and was also validated experimentally. The cooling rate and stresses induced due to the heating of the work-piece by spark was also evaluated for some select cases. The process Parameters varied during this simulation work were current, pulse on time, pulse off time and K_w. Other parameters such as K_f, discharge voltage and spark radius were kept constant.

Sr.no	Parameters	Values
1	Discharge voltage ,v	35 V
2	Spark radius,R	100μm
3	Work piece polarity	Anode
4	Frequency constant ,Kf	2.4
5	Powder	Graphite
6	Reference temp to °C	27
7	Current,I	2,4,6,8,A,

Table 2: Process parameters

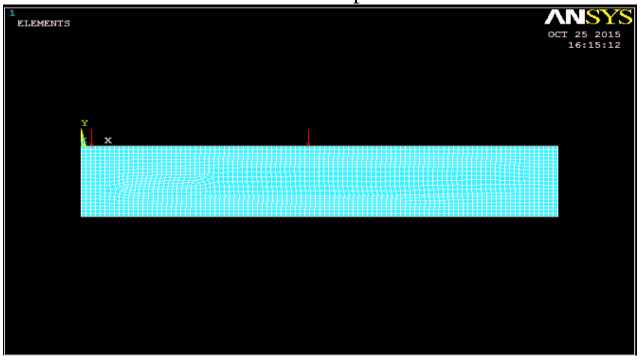

Fig. 7: Loaded view of sample

A. Technique Adopted Death of Element:

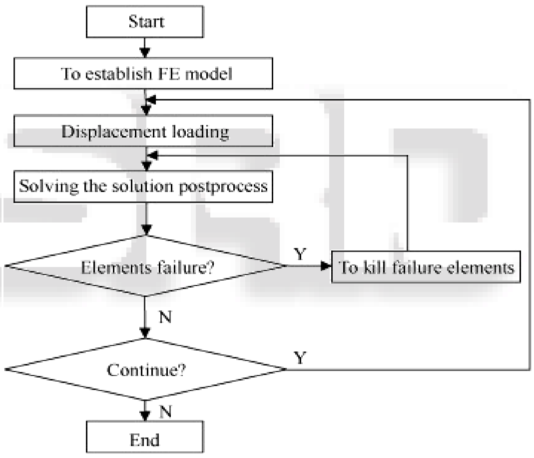

Fig. 8: Flowchart of solution technique involving birt-death element.

VII. RESULT & DISCUSSIONS

FE simulations were completed varying the process parameters like I, Kw, Ton and to obtain the temperature distribution. The nodal temperatures as well the nodal coordinates were exported and sorted to observe the temperature variation along radial direction on the top surface of the work-piece (at z = 0) as well along the depth direction (at the centre of crater, i.e., r = 0).

These were utilized to study the effect of process parameters. Using these results of temperature distribution, volume removed by single crater under the same process conditions can calculated and was subsequently validated for some select conditions.

A. Volume Removed:

In the present study, after obtaining the simulated temperature profiles, the region above the melting temperature of the work-piece material was identified assuming100% flushing efficiency. This region was isolated from the model to define the crater volume. The nodal coordinates of the left out material were measured to calculate the crater diameter and depth. The corresponding crater volume was calculated assuming that the crater is a part of a sphere.

$vc = (\pi/6)\times(3r^2 + h^2)$,where vc is the crater volume, r is the crater radius and h is the crater depth.

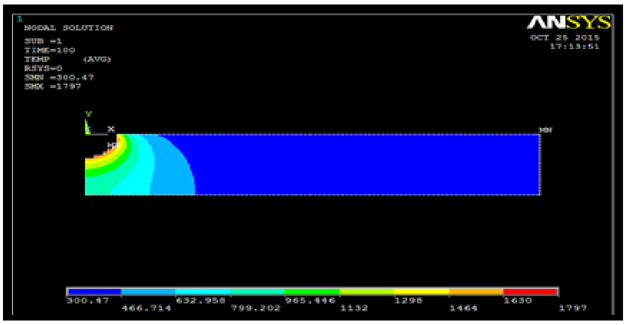

Fig. 9: Temp profile for 2amp current & 0.15kw

Current(amp)	kw	Volume removed x 10^{-4}(mm^3)
2	0.15	0.45
	0.2	0.72
	0.25	1.3
4	0.15	1.89
	0.2	3.0
	0.25	3.2
6	0.15	2.95
	0.2	4.1
	0.25	6.1

Table 3: showing the MRR for single crater.

VIII. Conclusions and Scope for Future

FEM simulation software ANSYS 10.0 is used to simulate the PMEDM for H13 Hot Die steel work-piece material by varied process parameters to come up with the temperature variation.

The volume of material removed in single crater was predicted from the temperature profiles produced due to heating of work piece by spark. The simulated knowledge of temperature distribution of the work piece can be used as input for performing the structural modeling so can also be used to predict the stresses generated because of thermal loading and cooling rate.

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