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Thermal Analysis of Wire Electrical Discharge Machining

Shashi Kant[1] Dr. Vandana Somkuwar[2]
[1]Research Student [2]Associate Professor
[1,2]Department of Mechanical Engineering
[1,2]NITTTR Bhopal India

Abstract— New developments in the machining of materials have become a hard task for Electrical Wire Discharge Machining process used for machining an alternative material in future. Wire electrical discharge machining (WEDM) is widely used in machining of conductive materials when precision is considered as a prime importance. This is an electro-thermal non-traditional machining process, where electrical energy is used to create the electrical spark and material removal takes place due to thermal erosion of work piece due to spark discharge. This work proposes a three dimensional finite element model using ANSYS software and new approach to predict the temperature distribution at different pulse time as well as stress distribution in wire. A transient thermal analysis assuming a Gaussian distribution heat source with temperature-dependent material properties are being used to investigate the temperature distribution and stress distribution. Thermal stress developed after the end of the spark and residual stress developed after subsequent cooling is measured. The effect on significant machining parameter pulse-on-time and optimum diameter of wire tool for performance are going to be investigated.

Key words: WEDM, Wire Size, Wire Material, Work Piece Material, Cutting Parameters

I. INTRODUCTION

Electrical discharge machining (EDM) is a non-conventional machining process which is widely used for material removal and to produce products like dies, moulds in metal making industries. It is also known as Spark-over initiated discharge machining, Spark erosion machining or simply Spark machining. It is probably the most versatile of all electrical machining method. This method has been developed in the late 1940s and has been one of the fastest growing methods in developed area during 1980s and 1990s.

This machining method is commonly used for very hard metals that would be impossible to machine with conventional machine. It has been widely used, especially for cutting complicated contours shape and profile of hard materials, which would have been tough to produce with conventional machining methods. However, one critical limitation is that EDM only works with electrically conductive materials. Metal that can be machined by using EDM are nickel, copper based alloy.

WEDM was initially developed by manufacturing industry in late 60’s. In 1974, D.H. Dulebohn introduced the optical line follower system which automatically controls the shapes of the part to be machined by the wire electrical discharge machining process. In 1975, it was popular among the industries 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 phase in 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. The common application of wire electrical discharge machining process is to fabricate the stamp and extrusion tools and dies, fixtures and gauges, prototypes, aircraft and medical parts, and grinding wheel form tools.

A. How FEA does work?

The finite element method is a numerical technique which is commercially used for the finding of an approximate solution of partial differential equation as well as integral equation. In some solving partial differential equations the first problem is to create an equation that approximate the equation which is to be studied. It means that during calculations the error should not accumulate, thereby causing the output as to be meaningless.

Introduction of ANSYS - ANSYS is a finite element analysis (FEA) software package. It uses a pre-processor software engine to create geometry. Then it uses a solution routine to apply loads to the meshed geometry. Finally it outputs desired results in post-processing. FEA is used throughout almost all engineering design including mechanical systems and civil engineering structures.

The goal of meshing in ANSYS Workbench is to provide robust, easy to use meshing tools that will simplify the mesh generation process. These tools have the benefit of being highly automated along with having a moderate to high degree of user control.

B. Advantages of FEA

- Visualization increases
- Design cycle time reduces
- No. of prototypes reduces
- Testing reduces
- Optimum design

The process of performing ANSYS can be broken down into three main steps.

- Pre-processing
- Solver
- Post-processing

1) Pre-processing

- CAD modeling: CAD model is created by using sketching and modeling tools for the creation of the required part/ geometry, which is to be performed in FEA.
- Meshing: one of the critical operations in FEA is meshing. In this the geometry is divided into pieces of large number. These pieces are called mesh. The accuracy of analysis mainly depends on this. By decreasing the size of mesh, the FEA speed decreases but the accuracy increases to a great extent.
- Defining boundary condition: We have to feed the boundary conditions like direction of deformation, load application etc.

2) Solve

In this step we tell the FEA package to solve the problem for the defined material properties, boundary conditions and mesh size.

3) Post processing

In this step the interpretation and viewing of result is performed. The results can be viewed in various formats: graph, contour profile, 3d view, value, animation etc.

II. LITERATURE REVIEW

Various related literature such as transactions, proceeding of various national and international conferences and other journals which available on Google scholar were reviewed.

N.B.V. Prasad (2015) here an attempt was made to evaluate the best wire both in size and material at rated wire speed and tension. Experimentation was carried out on various work materials using different wire materials, Copper alloy, Molybdenum and Tungsten and sizes ranging from 0.03mmto 0.30mm.The effect of wire material composition were also determined on various cutting parameters and criterion.

Avinash Shilpi et al (2015) this work proposes three dimensional finite element model using ANSYS software to predict the temperature distribution at different pulse time as well as stress distribution in wire. A transient thermal analysis assuming a Gaussian distribution heat source has been used with temperature-dependent material properties to investigate the temperature distribution and stress distribution. Thermal stress developed after the end of the spark and residual stress developed after subsequent cooling. The effect on significant machining parameter pulse-on-time has been investigated and found that the peak temperature sharply increases with the parameter.

Mohan Kumar Pradhan (2014) in this case, an attempt has been made to model the EDM process with the help of Finite Element Method (FEM) using ANSYS 12.0 software. Here the effects of most significant machining parameters on the workpiece such as current, voltage and pulse duration have been analyzed. The effect of these parameters causes development of residual stresses beneath the crater. The analysis shows the temperature distribution at the end of pulse duration, development of residual stresses after the completion of cooling and the changing nature of compressive stresses to the tensile stresses in various stages of machining process.

Sharanya Nair et al (2014) most widely used composite materials is metal matrix composite. The ever increasing demand for lightweight, strong, and inexpensive materials has led to the increased use of this material. Conventional machining of these materials causes tool wear due to the presence of abrasive reinforcing particles and thus reduced tool life. Hence the increased use of nonconventional machining methods continues to grow at an accelerated rate in industries. Wire electrical discharge machining (WEDM) are quite successful for machining of MMCs. WEDM seems to be a better choice as it is to easy control and can machine intricate and complex shapes.

P. Sivaprakasam et al (2014) investigates the influence of three different input parameters such as voltage, capacitance and feed rate of micro-wire electrical discharge machining (micro-WEDM) performances of material removal rate (MRR), Kerf width (KW) and surface roughness (SR) using response surface methodology with central composite design (CCD). The experiments are carried out on titanium alloy (Tie6Ale4V). The machining characteristics are influenced by the electrical and non-electrical parameters in micro-WEDM process. Analysis of variance (ANOVA) was performed to find out the important influence of each factor. The model developed here can use a genetic algorithm (GA) to determine the optimal machining conditions using multi-objective optimization technique. The optimal machining performance of material removal rate, Kerf width and surface roughness are 0.01802 mm/min, 101.5mm and 0.789mm, respectively, using this optimal machining conditions viz. voltage 100 V, capacitance 10nF and feed rate15mm/s.

Mehul G. Mehta et al (2014) due to high temperature developed by the electric spark during electrical discharge machining, high residual stress are developed on the surface of the electrical discharge machining parts. These thermal stresses leads to micro-cracks decrease in fatigue life, strength and possibly catastrophic failure. The results of the analysis show high temperature gradient zones and regions of large stresses where, sometimes, they exceed the material yield strength. A transient thermal analysis assuming a Gaussian distribution heat source with temperature dependent material properties can be used to investigate the temperature distribution. In this paper basic review can be seen based on different parameters and various methods applied by others to estimate the temperature distribution and thermal stress analysis.

Keshav Prasad Patel et al (2014) investigate the performance of micro WEDM machining the AL material. WEDM is mainly used in machining of conducting materials when accuracy and precision is the main criterion. Simple 2D axis symmetric model for wire electrical discharge machining has been developed using the finite element method (FEM). The authenticity of FEM model has been checked by comparing the present model with previous thermal model of INCONEL718 material. The observation has been effected by various characteristics namely material removal rate (MRR) and residual stress. Results have been compared with theoretical results and experiment one. Design was based on L9 orthogonal array based on Taguchi approach.

Neeraj Sharma et al (2013) here investigation has been done to study the effect of parameters on cutting speed and dimensional deviation for WEDM using HSLA as workpiece. The main factor for cutting speed and dimensional deviation is pulse on time, while two factor interactions plays an important role in this analysis. Response surface technology has been used process parameter for cutting speed and dimensional deviation. Central composite rotatable design was used here to conduct the experiments. The analysis of variance was further used for the investigation of significant factors.

Manpreet Singh et al (2013) in this paper study has been done on the recent work development in the field of wire electrical discharge machining. The properties of the work material and parameters that affects the performance of the machine has been analysed here.

Y-S. Liao et al (2013) here the value of TIC of a known workpiece height is taken to estimate the workpiece height during the WEDM process. The actual workpiece height is obtained by multiplying the estimated value by the correction factor of the related workpiece height. Experimental results obtain shows that the system works satisfactorily. The estimation error of workpiece height is within 1mm while the response time is within one second in general. In the practical application of machining a workpiece with dynamic variations in thickness, a model relating optimum servo voltage and workpiece height that leads to maximum machining speed is established in advance. The servo voltage is adjusted according to the requirement of the height. It is found that the process can be maintained very stable at maximum machining speed without wire breaking.

Kimura et al (2013) here study has been done for the slicing of the silicon carbide ingot using high efficient and precise slicing method. The new development in multi-wire electrical discharge slicing method would decrease the Kerf width and the cracks generated on machined surface. In this case a higher wire tension is required in order to reduce wire vibration and to perform a smaller Kerf width. Thin wire electrode with round section does not have sufficient cross sectional area under the high wire tension condition. Therefore, a wire electrode with track shaped section was proposed and applied to the wire EDM slicing method for the silicon carbide ingot. The running control of wire electrode with track-shaped section was done experimentally and investigated. The side support method with fixture plates could decrease the Kerf width by brass coated steel wire electrode with track-shaped section. The parallel drawing type of the traverser and the short distance setting points of side support fixture plates could perform the smaller vibration of wire electrode with track-shaped section and the decrease of Kerf width.

J.R. Mevada (2013) a comparative experimental investigation on process parameters has been carried out in reusable type wire electrical discharge machining on high nickel chromium based Inconel 600 material, using three different wires namely, molybdenum, plain brass and zinc coated brass wires. Investigation here is carried out to find out the best optimal level for higher material removal rate at lower surface roughness for Inconel 600 material and to check best suitable wire among the three wires. The experiments were conducted under varying pulse on time, pulse off time and peak current. A full factorial design of experiment with L_{27}array was used to determine the setting of machining parameters. Based on array total 81 experiment has been conducted for three wires. The level of importance and percentage contribution of each parameter for MMR and surface roughness are determined by using analysis of variance (ANOVA). Grey relational analysis method is used to obtain optimum machining parameter. The variation of the material removal rate and surface roughness is mathematically modelled by using regression analysis method. The optimal search for machining parameters for objective of maximum material removal rate with lower surface roughness is performed by comparing the optimal level obtained by grey relational analysis with the established mathematical model.

Hada and Kunieda et al (2013) investigation has been done to obtain the optimum machining conditions in wire electrical discharge machining (wire-EDM). Discharge current was influenced by the impedances of the wire and workpiece electrodes which get affected by the diameter of the wire, height of the workpiece and materials of wire and workpiece even if the pulse conditions are the same. Hence, they developed 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 workpiece electrodes using the electromagnetic field analysis by finite element method (FEM). The impedances were by measured by using an LCR meter coincided with the analysis results. Thus it was confirmed that this analysis is useful to obtain the discharge current waveform which may change depending on the dimensions and properties of the material of the electrodes, serving a tool to optimize the machining conditions.

Rajeev Kumar et al (2012) here the work proposes on newer aspects of wire EDM in the field of analysis and optimisation. The mathematical models have been developed while machining AISID2 tool steel to predict material removal rate (MRR) and surface finish at different machining conditions. A neural network model and simulated annealing algorithm have been formulated in order to predict and optimize the cutting velocity and surface roughness of the WEDM process in machining of SUS 304 stainless steel materials. The cutting speed surface roughness of EDM process has been modelled through the RSM methodology and ANN.

J.R. Mevada (2012) this research proposes experimental investigation to find out the wire wear rate at different machining parameter such as peak current, pulse on time, pulse off time, based on full factorial design of experiment. Molybdenum wire of diameter 0.18 mm and EN-8 material were used as tool and work piece material for the experiment respectively, ANOVA analysis were done to find out the effect of peak current, pulse on time, pulse off time on wire wear and found that the increasing in peak current slowly increase the wire wear but increasing in pulse on time increase the wire wear rapidly and pulse off time not much affects the wire wear.

Jatinder Kapoor et al (2010) this research paper focuses on evolution of EDM wire from copper to brass and from brass to various other coated wire, which has helped to conduct wire EDM machining, the method of choice for high-speed production applications, as well as applications requiring improved contour accuracy and improved surface finishes. Some of the characteristics of high performance wire electrodes have been presented, which helps in significantly increasing the wire electrical discharge machining productivity.

Fuzhu Han et al (2008) the tension of the micro wire electrode during the WEDM process can be optimized in accordance with the discharge energy, which is sampled and fed back to the tension control system in real time. Then the development of an optimal tension control system 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 wire breakage for the micro WEDM.

III. METHODOLOGY

To Platform of above problem of thermal analysis of wire electrical discharge machining following step are going to be used.

A. Steps Followed

- Identification of problem
- Literature survey
- Modelling of wire electrode using ANSYS
- Process of Thermal Modelling of wire electrode using ANSYS software
- Measuring residual stress and temperature distribution caused by Wire EDM
- Coupled thermal-structural finite element simulation
- Report preparation

IV. IMPLEMENTATION

In the wire EDM, a series of rapid electric spark occur in the gap between tool (wire) and workpiece. 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. Thermal Model of Wire EDM

The working principal of WEDM is as same EDM process, when the distance between the two electrodes (wire and the workpiece) is reduced the intensity of electric field in the volume between the electrodes (wire and the workpiece), become greater than the strength of the dielectric, which breaks, allowing current to flow between the two electrodes. For this reason the spark will generated.

B. Governing Equation

This is the equation for calculation of transient temperature distribution with in workpiece. The differential governing equation of thermal diffusion differential equation in a model is governed by the following.

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

Where r and θ are the radial and angle coordinates respectively, z is the axial coordinate, ρ and **c** are the density and the specific heat of the wire material, KW thermal conductivity of the wire material and T is the temperature of the micro element in the wire.

C. Brass Wire

The chemical composition of brass is 62% Cu and 38% Zn.

Properties	Unit	Value
density	Kg/m^3	8490
Thermal conductivity	W/m-K	115
Specific heat	J/kg-K	380
Modulus of elasticity	GPa	97
Bulk modulus	GPa	140
Poisons ratio		.31
Melting temperature	°C	1083
Shear modulus	GPa	37
solidus	°C	885

Table 1: Properties of brass wire

D. Molybdenum Wire

Properties	Unit	Value
density	Kg/m^3	10280
Thermal conductivity	W/m-K	139
Modulus of elasticity	GPa	329
Coefficient of linear thermal expansion	K^{-1}	$4.8*10^{-6}$
Poisons ratio		.31
Melting temperature	°C	2523
Shear modulus	GPa	126

Table 2: Properties molybdenum wire

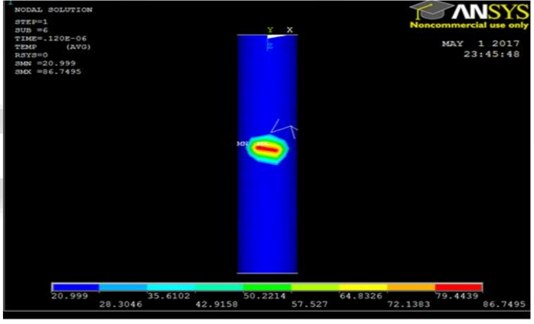
V. RESULT AND DISCUSSION

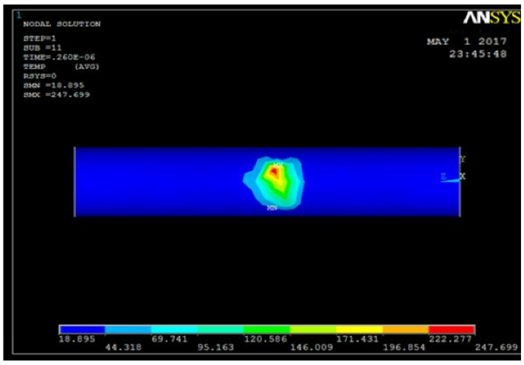
A. Thermal modelling of wire EDM for single spark in brass wire

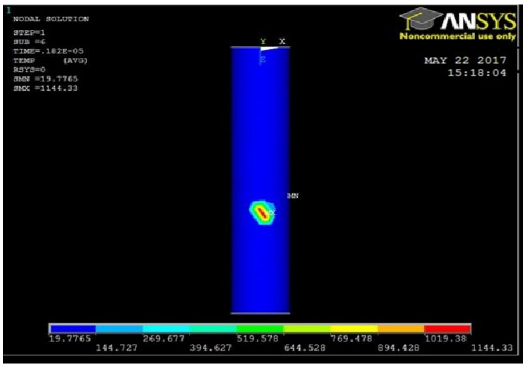
Main parameters of the thermal analysis (analysis parameters)

Parameter	Unit	Value
Peak current of electro- discharge	A	27
Voltage of electro discharge,	V	25
Duration of single pulse	μs	0.12, 0.26, 0.36, 0.58, 1.2, 1.82
Wire radius	mm	0.05
Convective coefficient	W/m^2 °C	3040
Temperature of the dielectric	°C	21
Coefficient of linear thermal expansion	K^{-1}	1.9×10^-5
Poisson's ratio		0.31

Table 3: Parameters used for thermal analysis in WEDM process







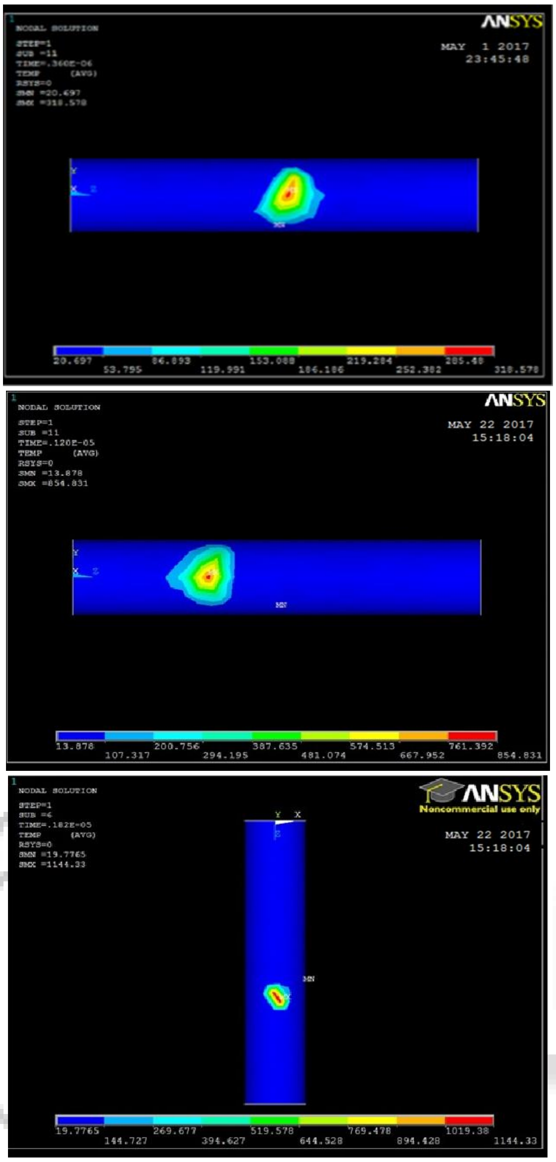


Fig. 1: Results

Temperature distributions at the end of the pulse time are shown in Figs. 5.1to 5.6 to know the effects on WEDM. The temperature distribution during single discharge is calculated with the energy input constant parameter I_p= 27A, voltage = 25V with varying pulse time. At pulse time = 0.12μs, corresponding temperature is 86.75°C. At pulse time = 0.26μs, corresponding temperature is 247.7°C. At pulse time = 0.36μs, corresponding temperature is 318.6°C. At pulse time = 0.58μs, corresponding temperature is 578.335°C. At pulse time = 01.2μs, corresponding temperature is 854.8°C. At pulse time = 1.82μs, corresponding temperature is 1144°C. Further increasing the pulse temperature is not possible because at temperature 1083°C brass wire melt.

The different stress distributions in WEDM process, enumerated at the end of heating cycle are presented. Here, Gaussian heat flux distribution is used for the calculation of distribution. Later on, by varying the parameter thermal stresses are presented. Fig 5.8 to 5.21 shows the thermal stress in different pulse on time. Thermal stresses are developed after the end of the spark and residual stress are developed after subsequent cooling. The nature of the maximum stress is compressive, and it is because during the pulse duration, the heat flux supplied to the tool electrode is for a very short duration (in μs). The maximum compressive stress is 563MPa for t_{on}=0.12μs in X-component and maximum residual stress is 778MPa. The maximum compressive stress is 425Mpa for t_{on}=1.82μs in Z-component and maximum residual stress is 533MPatemperature

VI. CONCLUSION

In this dissertation, a robust three dimensional finite element model has been developed using ANSYS software to predict the temperature distribution at different pulse time as well as stress distribution in the wire of WEDM. From the analysis it is seen that while increasing the pulse time, temperature increases. On further increasing the pulse time beyond 1.82μs is not possible as wire melts. The result which has come through this analysis is approximately same as that of Han et al. From the results it seems that optimal working condition for this process is between 0.12 to 0.58μs as maximum compressive stress it can bear is between this duration.

VII. SCOPE FOR FUTURE WORK

On the basis of the work reported in this thesis, the following areas can be identified for further study:

- Thermal analysis can also be done for different materials
- Helps up us to know the behaviour of electrode by changing the parameter
- Optimal working condition can be found out through this process

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