Analysis of Wire Electrode Discharge Machining Process using FEA: A Review

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Abstract— Wire electrical discharge machining is widely used in machining of conductive materials. This work proposes a three dimensional finite element model and new material to predict the temperature distribution at different pulse time as well as stress distribution in wire. 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. 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. In the WEDM, demand is growing for high rate cutting speed and high accuracy machining for improve the productivity of product and also for achieve high excellence quality in machining job.

Key words: ANSYS, Temperature Distribution, Residual Stress

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.

Electrical discharge machining (EDM) is important thermal erosion process which erodes 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 by the dielectric medium. The sparks occur at high frequency which continuously and effectively removes the work prices material by melting and evaporation. To initiate the machine process electrode and work piece are separated by a small gap known as 'spark gap' which results into a pulsed discharge causing the removal of material. The purpose of the dielectric is to provide a deionizing medium between the two electrodes, whose flow helps the removal of re-solidified and optimal conditions for spark generation. The common application of wire electrical discharge machining process is the fabricate the stamp and extrusion tools and dies, fixtures and gauges, prototypes, aircraft and medical parts, and grinding wheel form tools.

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. In WEDM, demand is growing for high rate cutting speed and high accuracy machining for improve the productivity of product and also for achieve high excellence quality in machining job. In wire electrical discharge machining process, wire electrode made of thin copper, brass or tungsten of is used. Generally wire velocity varies from 0.1 to 10 m/min, and feed rate is 2 to 6 mm/min. A direct current is used for generate high frequency pulse to the wire and the work piece. The wire is hold in tensioning device for decreases the chance of producing inaccurate parts. In wire electrical machining process, the work piece and tool is eroded and there is no direct contact between the work piece and the electrode, and this reduces the stress during machining. The symmetric diagram of WEDM is as shown Fig.1.

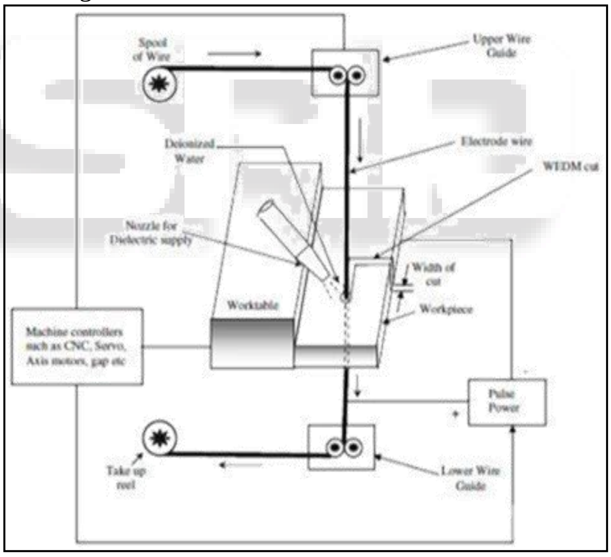

Fig. 1: WEDM Process

A. *Terms used 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.

The method of material removal in wire electrical machining is as like to the conventional electrical discharge machining process concerning the erosion effect on work piece by the spark. In wire electrical discharge machining, material is eroded from the work piece by a cycle of spark occur between work piece and wire which is separate by dielectric liquid, which is continuously fed to the machining zone. But now-a-days, wire electrical discharge machining process is commonly conducted in fully submerge container fill with dielectric liquid. This type of submerge method of wire electrical discharge machining promote temperatures stabilization and efficient flushing in case where the work piece has variation in thickness. The wire electrical discharge machining process generally use of electrical energy generate the plasma channel between the cathode and anode and create thermal energy at a temperature in the range between 8,000 ^{0}C to 12,000 ^{0}C or as higher as 20,000 ^{0}C and create considerable amount of heat and melting of the materials on the surfaces of each pole. When the pulsating direct current power supplying occurs between 20,000 and 30,000 Hz is turned off, the plasma channel breaks down.

The principle of spark erosion is simple. The work piece and tool are placed such a way that these don't touch each other. These are separate through a gap which is filling with dielectric fluid. The cutting mechanism therefore takes place in a container. The work piece and tool are connected to a direct current source. There is a switch in one lead. When this is closed, an electrical potential is applied between the work piece and tool. At initially no current flows since the dielectric between the work piece and tool is an insulator. If gap is decreases then a spark jumps across it when it reaches a certain very small size. In this process, current is converted into heat and form plasma channel. Surface of the materials is very powerfully heated in the area of the discharge channel. If the flow of current is sporadic the discharge channel collapses very quickly. Therefore the molten metal on the surface of the material evaporated explosively and takes liquid material with it down to a certain depth. A small crater is formed. If one discharge is followed by another, new craters are formed next to the previous ones and the work piece surface is constantly eroded.

3) 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	G Pa	97
Bulk Modulus	G Pa	140
Poisson's Ratio		.31
Melting Temperature	^{o}C	1083
Shear Modulus	G Pa	37
Solidus	^{o}C	885

Table 1: Properties of brass wire

Thermal Conductivity, K(W/mK)	11.4
Specific Heat, C(J/kg K)	435
Density, ρ (Kg/m^3)	8190
Melting Temperature (K)	1609
Young's Modulus, E (GPa)	205
Poisson's Ratio	0.29

Table 2: Thermal properties and mechanical properties of INCONEL 718

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

Table 3: Chemical composition of INCONEL 718

II. LITERATURE REVIEW

A. Fuzhu Han [1]

The tension control of the micro wire electrode is a key technology for the micro wire electro-discharge machining (WEDM). Based on the coupled thermo-mechanical analysis, both the three-dimensional temperature and the stress distribution in the micro wire are determined. As a result, 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.

B. Di Shichun [2]

In micro-wire electrical discharge machining (micro-WEDM), the machined kerf width varies with different machining parameters, which greatly influences the machining precision. In order to study the kerf variations 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. Under this model, a 30.8mm width slot is achieved on a stainless steel work piece with+30mm wire-tool.

C. K. Hada [3]

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). With this method, the dependences of the impedances on the electromagnetic properties of the electrodes were investigated. The impedances measured 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 material properties of the electrodes, serving a tool to optimize the machining conditions.

D. S. Saha [4]

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. At any instant of time, the spatial heat distribution profile of the wire can be mapped on the transient analysis of any point on the wire traversing through all the heat zones from the top spool to the bottom end. 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. The model successfully predicts the thermal distribution profile accurately for various wire materials, for increased wire velocity and for reduction in heat transfer coefficient. This simple model is a precursor of development for 3-D finite element models that can describe the cross-sectional wire erosion as the work piece cutting progresses. The modelling may lead to the development of a smart electro-discharge machining system with a sensor and feedback control to increase the cutting speed and minimize breakage.

E. Y.S. Liao [5]

The relationship between machining parameters and machining characteristics of different materials in WEDM is difficult to obtain because a large number of experiments must be conducted repeatedly. A new concept attempting to solve this problem is presented in this paper. The specific discharge energy (SDE) defining as the real energy required removing a unit volume of material is proposed. The SDE is constant for a specific material. Experimental results reveal that the relative relationship of SDE between different materials is invariant as long as all materials are machined under the same machining conditions. It is also found that the materials having close value of SDE demonstrate very similar machining characteristics such as machining speed, discharge frequency, groove width and finish of the machined surface under the same machining conditions. This result can be applied for the determination of the settings of machining parameters of different materials.

F. Anshuman Kumar [6]

Wire Electrical Discharge machine (EDM) is a versatile method for making micro product of complex geometry. The process parameters play a critical role for the accuracy and precision of the component. Inconel 718 is a super alloy used for many critical operations. It is 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.

G. Masanori Kunieda [7]

This paper describes the development of a new dry wire electrical discharge machining (dry-WEDM) method, which is conducted in a gas atmosphere without using dielectric liquid to improve the accuracy of finish cutting. In dry-WEDM, the vibration of the wire electrode is minute due to the negligibly small process reaction force. In addition, as the gap distance is narrower than that in conventional WEDM using dielectric liquid, and there is no corrosion of the work piece, high accuracy in finish cutting can be realized in dry-WEDM. However, some drawbacks of dry-WEDM include lower material removal rate compared to conventional WEDM and streaks are more likely to be generated over the finished surface. Increasing the wire winding speed and decreasing the actual depth of cut is effective to resolve these drawbacks.

H. Oana Dodun [8]

The wire electrical discharge machining is based on the developing electrical discharges between a travelling wire tool electrode and a plate work piece, in order to detach parts characterized by machined ruler surfaces. The practical experience and the study of the specialty literature highlighted the possibilities to improve the material removal rate by acting on the wire tool electrode. Two versions of devices able to periodically change the wire travelling motion speed are discussed and proposed; the devices could be included in the circuit of guiding the wire electrode on the wire electrical discharge machine.

I. Zejian Xu [9]

Thermo mechanical behaviour of tungsten-based composite 93 W–4.9Ni–2.1Fe is investigated systematically over strain rates ranging from 0.001 to 3000 s^{-1}, and temperatures ranging from 173 to 873 K. Different micro mechanisms are found in the evolution of microstructures between quasi-static and dynamic tests. The deformation of the tungsten particles is sensitive not only to strain rates, but also to plastic strain levels; the interaction between the grains is found to be the determining factor that cracks the grains, regardless of strain rates. Based on experimental results, two phenomenological and five physically based constitutive models are established through a procedure of regression analysis and constrained optimization. Descriptive and predictive capabilities of these models are examined and compared. The performance of the models in characterization of work-hardening, temperature, and strain rate effects of the material is also investigated separately.

J. Allen et al. [10]

This paper indicated the build-up of tensile residual stresses near the crater boundary in all directions. The effect of machining parameters like pulse current and pulse duration on the residual stresses by Using ANSYS software.

K. Mahapatra et al. [11]

This paper WEDM process parameters to achieve better MRR, surface finish, and cutting width simultaneously. After calculating the metal removal rate through experimentation, they applied the Taguchi method to optimize the parameters and output.

L. Hargrove et al. [12]

This paper describes the development an experiment to find the optimum machine parameters that will maintain a balance between cutting speed and minimum surface damage. The analysis of three different surface layers formed due to WEDM – recast layer, white layer, and heat affected zone – was done. The optimum cutting parameters were first calculated using FEM simulation and then experimentally verified.

M. Sanchez et al. [13]

This paper describes the development a new approach to the prediction of angular error in wire-EDM taper-cutting is presented. A systematic analysis of the influence of process parameters on angular error is carried out using Design of Experiments (DoE) techniques. A quadratic equation for the prediction of angular error that takes into account electrical parameters and part geometry is derived. Validation results reveal a dominant influence of the mechanical behaviour of then wire, rather than that of EDM regime. Following this assertion an original finite element model (FEM) to describe the mechanical behaviour of soft wires, typically used in taper-cutting operations, has been developed taking into account non-linear phenomena such as contact mechanics, plastic behaviour, stress-stiffening and large displacements. Both the results of DoE techniques and FEM simulation have been validated through experimental tests in industrial conditions.

N. Liao and Yu [14]

This paper describes the development the relationship between machining parameters and machining characteristics of different materials in WEDM. It is difficult to obtain because a large number of experiments must be conducted repeatedly. A new concept attempting to solve this problem is presented in this paper. The specific discharge energy (SDE) defining as the real energy required to removing a unit volume of material is proposed. The SDE is constant for a specific material. Experimental results reveal that the relative relationship of SDE between different materials is invariant as long as all materials are machined under the same machining conditions. It is also found that the materials having close value of SDE demonstrate very similar machining characteristics such as machining speed, discharge frequency, groove width and finish of the machined surface under the same machining conditions. The result obtained can be applied for the determination of the settings of machining parameters of different materials.

O. Albert and Su [15]

This paper describes the development the tapering process of WEDM, which can generate curved surfaces on work piece, is a very unique ability of this machining process. This report is dedicated to the removal analysis of tapering WEDM and to the improvement of contouring accuracy in application to conjugate surfaces. An inclined discharge angle (IDA) analysis was 16 proposed to study the removal mechanism with a novel point of view. Based upon the analysis, a theoretical removal model was proposed. Furthermore, it might be reasonable that the machining load and contouring error could be inferred from the removal burden. Therefore, an improvement strategy including control of discharged power and wire tension was proposed to adapt to the variation of machining load. Effects of the proposed method were verified through experiments. It is evident that the tapering accuracy was improved significantly, and it is feasible to the generation of precise conjugate surface.

P. Cheng et al. [16]

This paper describes a special device is developed to measure the average temperature increment of the wire after a period of short circuit discharges, and the thermal load imposed on the wire is also tracked and recorded in advance. Then, based on the thermal model of the wire, the convective coefficient can be calculated accurately. Some tuning experiments are carried out inside and outside a previously cut profile to examine the influence of the kerf on the convective coefficient. As soon as the wire cuts into the work piece, the convective coefficient will decrease more than 30%. With this method, the effect of the coolant flushing pressure on the convective coefficient is also estimated. If the pressure is raised from 0.1 to 0.8 Mpa, the convective coefficient will increase more than 20%, and thus ameliorate the cooling condition of the WEDM process.

III. CONCLUSION

From the above literature survey we find that there are many researchers done analysis on wire electrode discharge machining process, but it is found that analysis of Brass and Inconel electrode is big challenge by non-conventional wire electrode discharge machining process. Thermal stress was developed after the end of the spark and also residual stress was developed after subsequent cooling. A transient thermal analysis has been used to predict the temperature distribution and stress distribution on electrode of wire electrode discharge machining process. Certain parameters such as discharge current and discharge duration, the latent heat, heat flux transferred to the tool electrode have made this study nearer to real process conditions. So a 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 both electrodes to obtain an optimized and economical result of wire electrode discharge machining process.

REFERENCES

[1] Hana, F., Chenga, G., Fenga, Z. and Isagoc, S. Thermo-mechanical analysis and optimal tension control of micro wire electrode, International Journal of Machine Tools & Manufacture. International Journal of Machine Tools & Manufacture, vol. 48, pp. 922–931
[2] Shichun, Di. Xuyang, C.,Dongbo, Zhenlong, W.and ChiLiu, Analysis of kerf width in micro-WEDM. International Journal of Machine Tools & Manufacture vol. 49 pp. 788.
[3] Hada, K. and Kunieda, M. Analysis of wire impedance in wire-EDM considering Electromagnetic fields generated around wire electrode. Procedia CIRP vol.6 245 – 250.
[4] Saha, S., Pachon, M., Ghoshal, A.and Schulz d, M.J. Finite element modeling and optimization to prevent wire breakage in electro-discharge machining Mechanics. Research Communications, vol. 31,pp. 451–463
[5] Aliasa, A. Abdullaha, B. and Mohd., Influence of machine feed rate in WEDM of titaniumti-6Al-4V with constant current (6A) using brass wire. Procedia Engineering, vol. 41 pp.1806 – 1811.
[6] A Kumar, D K Bagal and K P Maity. Numerical Modeling of Wire Electrical Discharge Machining of Super alloy Inconel 718, Journal of Materials

Processing Technolog.Procedia Engineering VOL 150 PP 1512 – 1523
[7] Kunieda, K. and Furudate, C. High Precision Finish Cutting by Dry WEDM Journal of Materials Processing Technology, vol. 149 pp. 77–82
[8] Dodun, O., Slătineanu and Lorelei, G. Improving the WEDM process acting on the tool electrode. Procedia Technology, vol.12 pp. 427 – 432
[9] Zejian Xu, Fenglei Huang, Thermo mechanical behavior and constitutive modeling of tungsten-based composite over wide temperature and strain rate ranges. International Journal of Plasticity 40 (2013) 163–184
[10] Philip Allen, Xiaolin Chen; Process simulation of micro electrodischarge machining of molybdenum11S.S. Mahapatra, Amar Patnaik; Optimization of WEDM process using Taguchi method. Jmpt 186,
[11] The Finite Element Method and Applications in Engineering Using ANSYS Erdogan Madenci and Ibrahim Guven)
[12] Liao Y.S. and Yub, Y.P. The energy aspect of material property in WEDM and its application .Journal of Materials Processing Technology vol. 149 pp.77–82.
[13] Tani, T., Fukazawa, Y., Mohri , N. Saito, N., Okadaa, M. Machining phenomena in WEDM of insulating ceramics, Journal of Materials Processing Technology vol. 149 pp. 124–128.
[14] Aliasa, A., Abdullaha , B. and Mohd, A Influence of machine feed rate in WEDM of titaniumti-6Al-4V with constant current (6A) using brass wire, Procedia Engineering, vol. 41 pp.1806 – 1811.
[15] Dodun, O., Slătineanu and Lorelei, G. Improving the WEDM process acting on the tool electrode. Procedia Technology, vol.12 pp. 427 – 432.
[16] Cheng, G., Zhijing, H.and Feng (2007) Experimental determination of convective heat transfer coefficient in WEDM, International Journal of Machine Tools & Manufacture, vol.