Numerical Simulation of Optimization of Process Parameters of Micro Wire EDM of Al-SiC Alloys Using COMSOL

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Abstract: Micro Wire EDM process is highly reliable non-conventional process to manufacture highly precise and accurate complex shapes in various types of materials. The accuracy of this process is in micrometres, thus proving it to be superior to other manufacturing processes. Due to the need for achieving desirable properties like high strength, corrosion resistant, high melting temperature, various metal alloys and composites are being used. Of them, Aluminium Silicon Carbide composites (Al-Sic) have proven to be of great interest in field of research. Due to its exceptional properties like high specific strength, high thermal conductivity, low weight and so forth, they are being used in various industrial applications like electronic packaging, automobile, aerospace and defence sectors. So, this paper aims at producing a numerical model of micro machining of various compositions of Al-SiC alloys and study the effects of various parameters on machining such composites. This FEM study is made by using the COMSOL software. A three dimensional model is taken for the analysis of the process. Temperature dependent properties like specific heat capacity, thermal conductivity have been taken into consideration. The heat source is assumed to be a Gaussian distribution on the surface of the model. The distribution of temperature on the surface and effect of various parameters like input current and wire feed rate have been studied on various compositions of Al-SiC composites. These have been compared to the experimental results which have shown a good agreement with the predicted results.

Keywords: Micro Wire EDM, WEDM, Al-SiC alloys, COMSOL

1. Introduction:

Advancements in various fields like automobile sector or aerospace sector and so forth there is always a need for materials that possess a high strength, low weight, a good thermal conductivity, high corrosion resistance etc . Due to this reason, now-a-days the use of Al-SiC metal composites is being increased [1]. It's properties like low density (2.94 g/cm3), high elastic modulus (220 GPa), low coefficient of thermal expansion (8×10–6 K^{-1}) and high thermal conductivity (235 W/(m·K)) is making this material an attractive replacement of Al and Ti alloys in the above industries[2]. But this material is harder than Tungsten Carbide. If a hard material were used to cut the Al-SiC, then due to the friction between them high temperature and pressure is produced on the latter material, an undesired one. Thus, machining of these material composites using conventional techniques is proving to be a great challenge [3]. Due to advancements in material machining technology, various new non-conventional techniques are being developed. Of them Wire EDM (Electro Discharge Machining) is proving to be of great advantage due to various reasons like high-precision, machining accuracy, low cost investment, large design freedom and so forth [4] . This technique has proven to be a great advantage in machining the thermal and electrical conductive materials and metal matrix composites.

2. Wire-EDM Process:

In this manufacturing process, the machining is done by recurring electric sparks. The voltage is applied between the cathode and anode which are separated by dielectric fluid. Due to electric break down of dielectric, a spark is produced at the contact with the metal that generates a plasma channel which attains very high temperature lasting a few micro seconds. This melts metal and subsequently vaporises it. The melted metal is flushed using the dielectric fluid which, mixed with a coolant, cools the work piece. In this micro wire- EDM process the cathode is molybdenum wire and anode is the thermally conductive work piece. This molybdenum wire is spool to avoid the erosion of material from the wire causing it to break, the wire is wound between two spools so that the active part of the wire which is used to machine surface is constantly changing. Hence due to this arrangement the tool wear rate reduces. Here the diameter of wire used is 180 micrometres. This machine is a CNC controlled machine. Thus, due to this reason various 3 dimensional complex shapes can be produces with high accuracy unlike other unconventional techniques.

This paper aims at developing a numerical model and studying the influence of various parameters that effect the machining of the Al-SiC metal matrix composite and arrive at the conclusion. The numerical study is done using COMSOL Multiphysics.

3. Numerical solution:

The numerical model is created using FEM, one of the best methods to avoid costly trial and error techniques. The simulation of the temperature profile is done here.

3.1 Assumptions:

1. The model is developed for single spark.
2. The heat source is assumed to be a Gaussian distribution.
3. Work piece is assumed to be homogeneous and isotropic one.

3.2 Heat Source:

Selection of heat source is an important parameter in the numerical study, various models like Gaussian distribution, uniform disc heat source models exist. Of them Gaussian distribution has proven to be more accurate to the experimental results [5], [6]

3.3 Governing Equations:

The governing differential equation for heat conduction will be

$$\rho C_p \frac{\partial T}{\partial t} = \left[\frac{1}{r}\frac{\partial}{\partial r}\left(Kr\frac{\partial T}{\partial r}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right)\right]$$

Boundary conditions

The following are the boundary conditions taken for the analysis.

1. For the boundary B:

Untill spark radius, R

$$K\frac{\partial T}{\partial z} = Q(r)$$

Beyond spark radius, R:

$$K\frac{\partial T}{\partial z} = h(T - T_0)$$

2. For other boundaries:

$$\frac{\partial T}{\partial n} = 0$$

3.4 Material Properties:

Material properties like thermal conductivity, specific heat capacity, density have been considered as function of temperature to simulate the process in a more realistic fashion.

3.5 Heat Flux:

As, the heat source is assumed to be a Gaussian distribution, the governing equation can be given as,

$$Q(r) = \frac{4.57VIf}{\pi R^2} e^{-4.5(r^2/R^2)}$$

Where,

V is the applied voltage, I is the applied current, R is the radius of spark and f is fraction of heat input to the workspace.

4. Use of COMSOL Multiphysics:

In the COMSOL software, a model is taken. A Gaussian pulse is used to give the heat input to the work piece. Heat transfer module is used. Based on the above mentioned assumptions and boundary conditions, the necessary adjustments are made in the heat transfer module. Transient analysis is used. After the simulation various graphs are plotted.

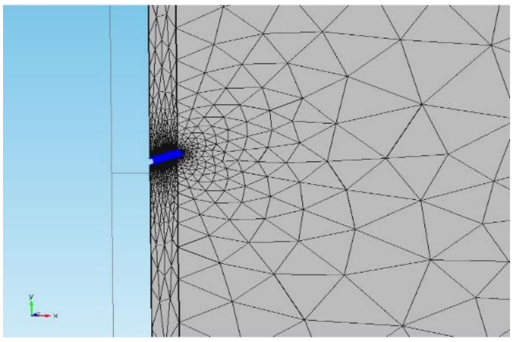


Figure 1: Extremely Fine mesh used in analysis

5. Experimental Setup:

The following parameters were set for performing the experiment:

Pulse ON time: 6µs

Pulse OFF time: 9µs

Maximum wire speed of the machine

Table speed and SIM speed: 150 Hz

A digital balance with sensitivity of 1mg is used to measure the weight of the work piece at regular intervals to calculate the MRR.

6. Results and Discussions:

Thus an experiment was performed on the machining of Al-SiC metal matrix composite using the wire-EDM machine. The effect of variation of couple of parameters is noted viz. current and voltage. Other parameters like the wire feed rate, T_{on} and T_{off} are kept constant. To know the effect of current on machining process, other parameters are kept constant and current is increased gradually. The experimental results are tabulated and computed. Thus, given below show the effect of various parameters.

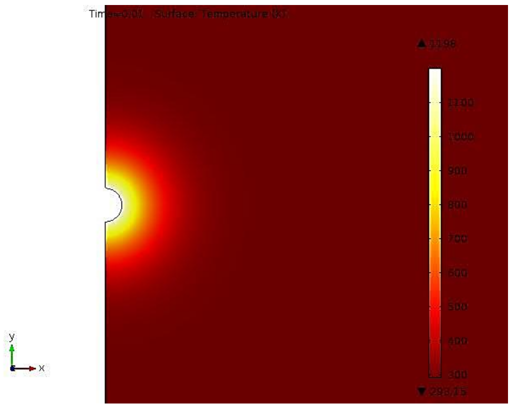


Figure 2: Temperature distribution from analysis

6.1 Effect of current:

From the experimental and theoretical observations, it is very clear that the increase in current will increase the MRR which occurs due to increase in the heat input supplied to the work piece. Through Figure 3,4 it can be observed that the kerf width increases with increase in current. The graph given below depicts the above observation.

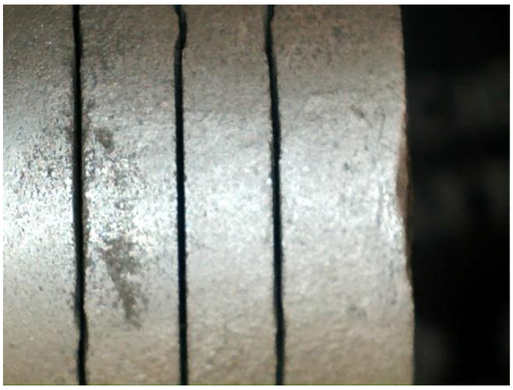


Figure 3: Effect of current on machining Al-5% Vol SiC at 75V; decreasing from left to right (3, 2, 1 A respectively)

6.2 Effect of voltage:

The same pattern as observed with the current is observed here. As voltage increases, due to increase in heat input the MMR increases as depicted in the graph below.

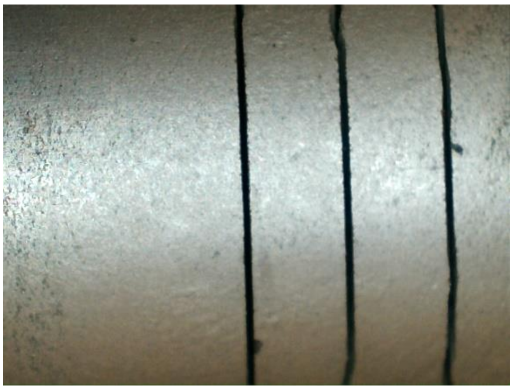
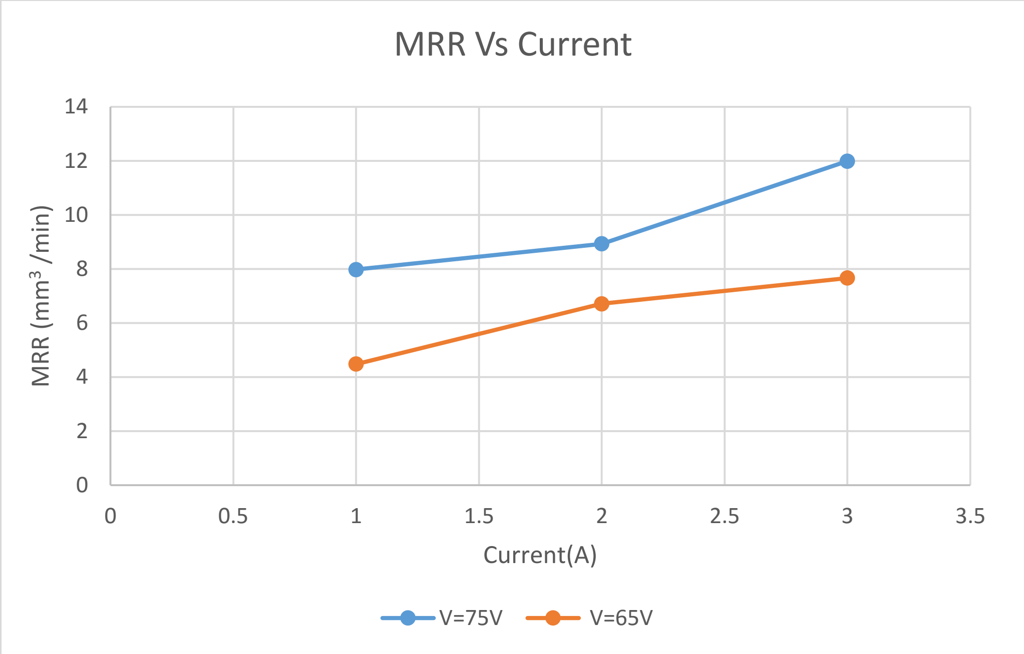


Figure 4: Effect of current on machining Al-5%Vol SiC at 65V; decreasing from left to right (3, 2, 1 A respectively)



7. Conclusion:

The simulation results indicate that the minimum temperature required to melt the composite should be at least 200K more than the melting point for effective machining. Among the parameters affecting the process, voltage and current are considered keeping the remaining parameters constant. From the graphs it is evident that the increase in current at a particular voltage has an increased kerf width and material removal rate. Increase in voltage increases the material removal rate but causes a rough machining. Thus high current and low voltage produces good machining of the composite in lesser time. From the experiment it is clear that Al- SiC composites can be efficiently machined using Micro Wire-EDM process rather than die cast forging techniques to create desired shapes.

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