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Optimization of Process Parameters of Electric Discharge Machining using Fire Fly Algorithm

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Abstract—*ELECTRIC DISCHARGE MACHINE (EDM) is an unconventional electro thermal machining process used for manufacturing geometrically complex or hard material parts that are extremely difficult-to-machine by conventional machining process. In this study, an attempt has been made to study the process parameters and to optimize them for obtaining best values of surface roughness (SR), material removal rate (MRR) and tool wear rate (TWR). Al6061 is reinforced with 15.45% silicon carbide and this metal matrix composite is used as work material. Experiments are conducted with tool made of copper for selected combination of input variables, such as current (I), Voltage (V) and pulse on time (T). SR, MRR and TWR have been taken as output variables. A linear regression analysis is conducted on the data obtained from the experiments. Multi objective optimization is carried out using fire fly algorithm (FFA) and the results show that the best values of output parameters are obtained for low current value, high voltage value and low pulse on time.*

Keywords*: EDM, Process characteristics, Surface roughness, MRR, TWR and Firefly algorithm*

1. INTRODUCTION TO EDM

The use of Electric Discharge Machining is growing rapidly in tool rooms, die shops and even in general shop floors of modern industries to facilitate complex machining problems in difficult-to-machine materials and provide better surface integrity. Development of wire- EDM and EDM drilling have added new dimension to this technology. EDM, in its three variations, that is die sinking, wire-EDM and EDM drilling, is now the fourth most popular machining process after milling, turning and grinding. The factors that have contributed to its popularity are: absence of any physical contact between the tool and work piece; accurate and distortion-free machining of hardened work pieces; negligible cutting forces; machining of difficult-to-machine materials; generation of complicated internal geometries. A variety of research work has been carried out on different aspects of EDM such as tool material - work piece combination, type of dielectric, pulse train, flushing techniques and hybridization of EDM with other non-conventional techniques such as ultrasonic machining, electro-chemical machining and abrasive machining. In addition to this, detailed literature is available on the surface properties of heat treated steels after spark machining. Electro-spark toughening of cutting tools and steel components has also been explored.

1.1 Important parameter In EDM

The important input process parameters used in process optimization are as follows:

On-time or pulse time: It is the duration of time (μs) for which the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during this on-time.

Off-time or Pause time: It is the duration of time between the sparks. This time allows the molten material to solidify and to be wash out of the arc gap.

Arc Gap: It is the distance between the electrode and the work piece during the process of EDM. It may be called as the spark gap.

Duty Cycle: It is the percentage of on-time relative to total cycle time. This parameter is calculated by dividing the on-time by the total cycle time (on-time plus off-time). The result is multiplied by 100 for the percentage of efficiency or the so called duty cycle.

Intensity: It points out the different levels of power that can be supplied by the generator of the EDM machine.

Voltage (V): It is a potential that can be measure by volt it is also effect to the material removal rate and allowed to per cycle.

Current (I): It is the intensity of current supplied to the tool material.

1.2 Firefly Algorithm

Fireflies, also called lighting bugs in many regions, are one of the most special and nature's wonderful creature. These night-time light emanating insects of the beetle family *Lampyridae* (order *Coleoptera*), live in tropical and temperate regions, and there are around 1900 species in their population. They are capable of producing light due to special photogenic organs located very close to the body surface behind a window of translucent cuticle.

The signals emitted by these bugs serve as elements of courtship rituals, methods of prey attraction, social orientation or as a warning signal to predators (in case of immature firefly forms commonly referred to as glow worms). The light emitting phenomenon of firefly is an interesting area and research is active in the areas of bio-medical and optimization. Researchers in the areas of wireless networks design, dynamic market pricing and mobile robotics, are using and studying, various methods of firefly communication through light bio-cells, and the synchronization of emitting patterns of light by fireflies. The optimization techniques based on this light emitting pattern of fireflies is based on the assumption that the 'glow' of the firefly can be related to the quality of the characteristic in the objective function. A generic algorithm of firefly method is given below:

Generic Firefly Algorithm

Input

$f(z)$, $= [z_i, z_2, \ldots, z_n]^T$ {cost function}

$=[a_k, b_k]$, k=1, … …, n

β_0, γ, $\min u_i$, $\max u_i$ {algorithm's parameters}

Output:

$x_{i^{min}}$ {Obtained minimum location}

begin

for i=1 **to** m **do**

x_i← Generate Initial Solution ()

end

repeat

$i^{min} \leftarrow \arg min_i$ f(x_i)

$x_{i^{min}} \leftarrow \arg min_{x^i}$ f(x_i)

for i=1 **to** m **do**

for j=1 **to** m **do**

if f(x_j) < f(x_i)

then {move firefly i towards j}

r_j ← Calculate Distance (x_i ,x_j)

$\beta \leftarrow \beta_0 e^{-\gamma r x_j}$ {obtain attractiveness}

u_i← Generate Random Vector (min u_i, max u_i)

for k=1 **to** n **do**

$x_{i,k} \leftarrow (1-\beta)x_{i,k} + \beta\, x_{j,k} + u_{i,k}$

end

end

end

end

$u_{i^{min}}$ ← Generate Random Vector ($\min u_i$,$\max u_i$)

for k=1 **to** n **do**

$x_{i^{min}x_k} \leftarrow x_{i^{min}x_k} + u_{i^{min}_k}$

{best firefly should move randomly}

end

until *stop condition true*

end

In addition to introduction, review of literature is done in section-2, experimental procedure is explained in section-3, results and analysis is given in section-4 and finally conclusions drawn from this work are given in section-5.

2. REVIEW OF LITERATURE

Che Chung et al. [1] studied machining on Al_2O_3/6061 Al using process parameters, such as, peak current, volume %, rotational speed and flushing pressure. They considered material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR). They found that MRR with rotating hollow tube electrode is found higher than that of with solid electrode. Although the tool wear rate is higher for hollow tube electrode, the peak current and volume fraction significantly affect the MRR, TWR and SR. In contrast, the rotating speed and flushing pressure of the electrode have minor effects on the same performance measures. Samra Arooj et al., [2] used Al6061 T6 as tool material and conducted experiments with copper as electrode. They took current as input variable and MRR as output variable. It is seen that the MRR, AGD and the inter-globule distance seem to increase with an increase in the machining current values. The white layer thickness seems to increase initially with increasing current, however, for very high cur- rent the white layer thickness reduces again. Singh et al., [3] also used Al/ Al_2O_3 as work material and copper as tool material. They used pulse current, aspect ratio, tool electrode life time, pulse on time, gap voltage and duty cycle as input variables and MRR as output variable. From their studies, it was found that the pulse current has the strongest effect among the other process parameters used to study the multi-performance characteristics. The order of importance of the process parameters to the multi-performance characteristics is pulse current, aspect ratio, tool electrode lift time, pulse ON time, gap voltage and duty cycle. Experimental results have shown clearly that the material removal rate, tool wear rate and surface roughness in the EDM. Vikas Pare [4] et al. studied characteristics of Al6061 reinforced with silicon carbide and they studied its machinability characteristics using CNC high speed machining. Ramulu and Taya [5] used 15 vol.% Al and 25 vol.% SiC whisker/2124 aluminum matrix as work material and copper and brass electrodes. The input parameters used were volume percentage of SiC and output is measured in terms of material removal rate, machining time and surface roughness. They found that the MRR in 15% by volume SiC results in least value. Machining time was also found to be less. Hung et al. [6] used reinforced aluminum matrix with SiC_p as work material and studied MRR and surface finish by considering power and current as input variables. It was found that the presence of SiC particles results in reduced MRR. MRR and depth of recast layer is mainly controlled by input power and the current alone dominates the surface finish of machined surface. De Silva and Rankine [7] used AlSiC as work material and observed in their studies that sparking, the matrix surrounding the reinforcement particles was melted, thus easing out the reinforcement particles from the matrix, resulting in improved machining.

3. EXPERIMENTAL PROCEDURES

Experiments are conducted on die sinking smart electric discharge machine made of electronic with specifications 300x200x250, movable table type design, definable erosion axis, high speed jump, 1500 mm/min and built in GURU. The experimental procedure is taken up by conducting the following steps:-

Step-1: Preparation of desired combination of material. Al6061is selected for study and it is reinforced with SiC in order to increase the hardness. This material finds application in aerospace industry due to its ductility, hardness and machinability. The metal matrix composite is made using stir casting method.

Step-2: Conduction of Experiments. Experiments are conducted on above material by taking it as work material and copper as tool material. Input parameters chosen are current (I), voltage (V) and pulse on time (T). They are varied over a range shown in Table-1.

Table 1: Ranges of input variables

Process parameter	Minimum value	Maximum Value
Current (I)	3	5
Voltage (V)	40	60
Pulse on Time (T)	200	800

Step-3: Selection of output variables and measurement: Material removal rate, tool wear rate and surface roughness are chosen as output variables and they are measured by using the following relations:

$$MRR = \frac{(w_{jb} - w_{ja})}{t}$$

Where, w_{jb} is weight of work material before machining and w_{ja} is weight of work material after machining.

$$TWR = \frac{(w_{eb} - w_{ea})}{t}$$

Where, w_{eb} is weight of electrode before machining and w_{ea} is weight of electrode after machining. The surface roughness is measured using Taylor Hobson surface roughness tester for each of the twelve values of data. The twelve values of data obtained are tabulated.

Step-4: Statistical analysis of data is performed by taking each of the output variable as dependent variable and input variables as independent variables. Linear regression equations are developed using MINITAB 17 software and significant effect of independent variable on dependent variables are studied.

Step-5: The equations are used as objective functions in Fire Fly algorithm which is developed in MATLAB 2010 and optimum values of surface roughness, material removal rate and tool wear rate are found. The set of input variables for which the output variables are maximum are noted down.

Step-6: The results are analyzed by changing the importance given to each of the output variables and the outcome is reported.

4. RESULTS AND DISCUSSION

The methodology explained above is followed and the results obtained are as follows:

From Step-1, AlSiC metal matrix composite is prepared with 15.45% silicon carbide and the microstructure is observed using electron microscope. The microstructure is found to be stable. From Step-2, data is collected for selected variation of input variables and combination of twelve values is tabulated. The output values are measured in the next step. MRR increases with increase in current indicating high current is desirable for obtaining removal of more material for the given machining time. Surface roughness however decreases with high current and tool wear rate increases. Using the data obtained, statistical analysis is done using MINITAB version 17 software package. Linear regression equations are established between the output variables and input process variables. All the variables are found to be significant and the 'p' value is less than 0.01. The F value obtained is greater than 30 in all the cases indicating significant relationship between the selected variables. The equations obtained are as follows:

$$MRR=0.45650 + 0.01142*I - 0.000425*V + 0.000035*T \quad - (1)$$

$$TWR=0.04 + 0.001333*I - 0.000033*V + 0.000008*T \quad - (2)$$

$$SR=6.50 + 0.311*I + 0.0031*V + 0.001575*T \quad - (3)$$

These relationships are taken as objective functions and values of parameters are fed into firefly algorithm. The firefly algorithm used the number of flies (n) as 40, number of iterations (N) as 500, alpha value of 0.5, beta value of 0.2 and gamma value of 1. Increase of number of fireflies beyond 40 does not have any significant effect on the optimum result. Number of iterations has been arbitrarily fixed at 500. Surface roughness is taken as objective function and other two have been taken as constraints by fixing a target value for both of them. The program of the algorithm which is written in MATLAB 2010 yields a best solution is given below in Table-2.

Table 2: The optimum values of variables

I	V	T	MRR	TWR	SR
3	40	200	0.44884	0.040826	7.5275

Total number of evaluations is 20000 and time for obtaining optimum result=5 secs.

The above solution can be used for setting the machine in order to get the desired values of selected output values.

5. CONCLUSIONS

A metal matrix composite made of Al6061 reinforced with SiC is used for machining in this research paper as it has very wide application in aerospace industry. This paper contributes to introduction of new materials and setting the electric discharge machine at optimum conditions. Firefly algorithm is one of the best developed optimization methods which can be used for multi objective optimization. The material removal rate and the tool wear rate are fixed at desired values as is preferred in real life machining environment and surface roughness is optimized. Researchers in future may try for non-linear relationships between input variables and output variables and optimize them for better results. The methodology described in this paper can also be used for newly developed metal matrix composites.

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