OPTIMIZATION OF WEDM PROCESS DURING MACHINING OF REINFORCED ALUMINIUM METAL MATRIX

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Abstract: Machining of metal matrix composites (MMCs) has been considerably difficult due to the extremely abrasive nature of the reinforcements that causes rapid tool wear and high machining costs. This paper explains the influence of WEDM machining parameters such as Pulse ON Time, Pulse OFF Time, Wire Feed Rate and current on the responses such as Hardness and Surface Roughness (SR) for Wire Electric Discharge Machining (WEDM) of SiC/Al 6061 Metal Matrix Composite. Taguchi design of experiments is used for experimental design such as L9 orthogonal array. Experiments are carried out based L9 array and responses viz SR, MRR and Hardness. This work is mainly focused on microstructure analysis in terms of machining parameters using scanning electron microscope.

Key Words: Metal Matrix composites, WEDM, Optimization, Grey relational analysis.

1. Introduction

The metal matrix composites contain a relatively wide range of materials defined by the metal matrix, reinforcement type, and reinforcement geometry. By far, the largest usage is in Aluminium metal matrix composites [1]. MMCs have
better properties like hardness, durability, strength, high modulus, low ductility, light-weight, wear resistance etc as compared to its pure forms of the constituting materials [2]. The applications of MMCs in automotive, aerospace and defence industries can be attributed to its improved thermo-mechanical properties and high strength to weight ratio [3]. Mechanical properties of PAMCs are inferior compared to whisker/short fibre/continuous fibre reinforced AMCs but far superior compared to unreinforced aluminium alloys. These composites are isotropic in nature and can be subjected to a variety of secondary forming operations. Several studies [4] have been conducted on the machinability of the MMCs using traditional conventional methods.

2. WEDM Machining

The Electric Discharge Machining (EDM) process converts the electrical energy generated in a channel between a cathode and an anode to thermal energy which creates sufficient high temperature (10000 °C to 20000 °C) for the erosion of work piece material [5]. This distinct feature of thermo-electric conversion of EDM makes it suitable for manufacturing of complex parts used in numerous industries [6]. In EDM process, the desired shape of the object is obtained by electrical discharges i.e., sparks. In Wire electrical discharge machining (WEDM), also known as wire-cut EDM a thin single strand of metal wire, usually brass, is fed through the work piece, submerged in a tank of dielectric fluid. Wire-cut EDM is typically used to cut plates as thick as 300mm and to make punches, tools, and dies from hard metals that are difficult to machine with other methods. The wire is constantly fed from a spool and is held between upper and lower guides. The guides usually CNC-controlled move in the xy plane.

3. Effect of Process Parameters

The objective of WEDM process is to obtain an accurate and an efficient operation of machining without reducing the machining performance. This can be achieved by studying the inter-relationships between various parameters affecting the process and finding the optimal set of machining parameters from a range of experimental values [8]. The maximization of Material Removal Rate (MRR) and minimization of SR is one of the key objectives for which many parametric optimization studies have been carried out [7]. For multi response optimization, mathematical models were developed using non-linear regression
method. Results show that factors like discharge current (A), pulse duration (B), dielectric flow rate (F) play a significant role in cutting operations.

4. Methodology

The step wise procedure of Grey relational analysis integrated with taguchi method has given in subsequent sections.

5. Taguchi Grey Relational Analysis

The step by step procedure is given below.

Step 1 Normalization of S/N ratio.

It is the first step in the grey relational analysis; anormalization of the S/N ratio is performed to prepareraw data for the analysis where the original sequence i transferred to a comparable sequence. The material removal rate is a higher-the better performance characteristic, since the maximization of the quality characteristic of interest is sought and expressed as:

$$ S/N Ratio = -\log_{10}(1/n) \sum_{i=1}^{n} \frac{1}{y_{ij}^2} $$  \hspace{1cm} (1)

Where $n$ Number of replications and $y_{ij}$ Observed response value. Where $i = 1, 2...n$; $j = 1, 2...k$. The surface roughness was the lower the better performance characteristic and the loss function for the same can be expressed as:

$$ S/N Ratio = -\log_{10}(1/n) \sum_{i=1}^{n} y_{ij}^2 $$  \hspace{1cm} (2)

Step 2: Calculation of grey relational coefficient (GRC)

GRC for all the sequences expresses the relationship between the ideal (best) and actual normalized S/N ratio. If the two sequences agree at all points, then their grey relational coefficient is 1.\( \gamma(x_0(k), x_i(k)) \) Can be expressed by Eq. (3)

$$ \gamma(x_0(k), x_i(k)) = \frac{\Delta min + \xi \Delta max}{\Delta 0i(k) + \xi \Delta max} $$  \hspace{1cm} (3)

Step 3 Determination of grey relational grade (GRG)

The overall evaluation of the multiple performance characteristics is based on
the grey relational grade. The grey relational grade [4] is an average sum of the
grey relational coefficients which is defined as follows:

\[ \gamma(x_0, x_i) = \left(\frac{1}{m}\right) \sum_{i=1}^{m} \gamma(x_0(k), x_i(k)) \]  
(4)

If the two sequences agree at all points, then their grey relational coefficient is
1 everywhere, and therefore, their grey relational grade is equal to 1. Step 4
Determination of optimum parameters
The grey relational grade calculated for each sequence is taken as a response
for the further analysis. The larger the better quality characteristic was used
for analysing the GRG, since a larger value indicates the better performance of
the process. The quality characteristics used is given by Eq. 1.

6. Experimental Details

Experiments were conducted by varying the process parameters such as Pulse
ON Time (T ON), Pulse OFF Time (T OFF), Wire Feed Rate (WF) and Cur-
rent on an EZEECUT NXG CNC WEDM machine. Brass Wire is conside-
red for machining of the Aluminium Metal Matrix Composite. L9 orthogonal ar-
ray is used to conduct 9 experiments. Surface Roughness (SR) and Material
Removal Rate (MRR) are the performance measures considered and the micro
structure analysis in terms of machining parameters using energy-dispersive X-
ray, scanning electron microscope is carried out.
The work piece used in this experiment is Al 6061 along with 2% Sic and 5%
reinforcement. The details of work piece material are given in table 1.

The process parameters for experimentation are presented in Table 2. Ma-
terial removal rate and surface roughness are considered as response character-
istics for optimization.

The MRR is calculated as

\[ MRR = \frac{(2Wg + D) \times t \times L}{T} \left( mm^3/min \right) \]

Where MRR is material removal rate and Wg is Spark gap between wire
and work piece (mm), D is Diameter of wire (mm), t is thickness or height of

Table 1: Combination of Metal matrix composites used for experimentation

<table>
<thead>
<tr>
<th>SI. No</th>
<th>Body Material</th>
<th>Reinforced Material</th>
<th>S.R.F.M % reinforcement</th>
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<tbody>
<tr>
<td>1</td>
<td>Al6061</td>
<td>SiC</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
<tr>
<td>Process parameter</td>
<td>Unit</td>
<td>Level-1</td>
<td>Level-2</td>
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<td>-------------------</td>
<td>------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>Pulse On Time</td>
<td>µs</td>
<td>32</td>
<td>65</td>
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<tr>
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<td>µs</td>
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<td>5</td>
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<tr>
<td>Wire Feed</td>
<td>mm/min</td>
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<td>50</td>
</tr>
<tr>
<td>Current</td>
<td>Amp</td>
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<td>3</td>
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Table 3: Experimental Results and S/N ratios of experimental results

<table>
<thead>
<tr>
<th>EN.</th>
<th>TN</th>
<th>TF</th>
<th>WF</th>
<th>C</th>
<th>MRR</th>
<th>SR</th>
<th>SNMRR</th>
<th>SNSR</th>
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<tr>
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<td>1</td>
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<td>2</td>
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<td>3</td>
<td>3</td>
<td>111.69</td>
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<td>40.9533</td>
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<tr>
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<td>2</td>
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</tbody>
</table>

where EN-Exp. No., TN-Ton, TF-Toff, WF-Wire Feed, C-Current, SNMRR - S/N ratio of MRR, SNSR - S/N ratio of SR.

the work piece (mm), L is Distance travelled by the tool (mm), and T is Time taken to cut one profile (min). The 9 experiments were conducted according to the Taguchi L9 orthogonal array and results are presented in Table 3.

7. Single objective optimization

Single response optimization is carried out to investigate the effects of machining parameters on MRR and SR. The objective of optimization is to maximize the MRR and minimize the SR. From Fig.2 the response graphs for MRR and SR can be shown.

From the graph it is shown that machining on composite with Sic, cutting speeds are high. From this it can be concluded that for higher machining rates Sic is advisable reinforced material for development of composites if the object is only higher machining rates.