STUDY OF THE FACTORS INFLUENCE ON THE OBJECTIVE FUNCTIONS OF WIRE EDM OF AA2124/SiC/25p

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Abstract

AA2124/SiC/25p is a high quality composite material, recently developed, for structural applications in the aircraft industry. It consists of aluminium metal matrix, reinforced with silicon carbide particles in a proportion of 25%. On the one hand this kind of material structure provides a lot of good mechanical properties: high specific stiffness, fatigue strength, and durability. On the other hand, considering the high complexity of shape and the precision conditions imposed on parts made from this material, it is necessary to analyze the available processing techniques. Therefore, the aims of this paper are to study experimentally the processing possibilities of AA2124/SiC/25p composite material by wire electro discharge machining. At first, the paper presents a systemic approach of wire electro discharge processing, and highlights the objective functions of technological interest and the concerned influence factors. Each of these sets of variables is divided into subsets using specific criteria.

The systemic analysis is the basis of a detailed experimental research, having the final aim, the process optimization by wire EDM of AA2124/SiC/25p. We highlight the influence of wire material used for cutting a semi-product having different thickness from Al2124/SiC/25p composite material, on various indicators of technological interest: processing productivity, dimensional precision and cutting shape accuracy. In the same time, were pursued the undesirable possible effects of processing, through the analysis of hardness in the processed areas.

Keywords: metal matrix composite material, silicon carbide reinforcement, wire EDM, material removal rate

1. INTRODUCTION

Nowadays, in transportation markets, particularly in aerospace and automotive industries, high performance is required but weight is critical. Thus, new composite materials have been developed, to replace classic materials and provide better mechanical and physical properties, suited for structural applications. Such a new composite material is AA2124/SiC/25p, consisting of an aluminium metal matrix, reinforced with ultrafine (2-3 micron) silicon carbide (SiC) particles in a proportion of 25% [1]. The controlled phases of the manufacturing process – high energy mixing and hot isostatic compaction – ensure an even distribution of the particles and preserve the purity of the matrix alloy, enhancing mechanical properties of the material: specific stiffness, fatigue strength, hardness, and wear resistance. This combination of properties achieved, recommends AA2124/SiC/25p for a wide range of applications, like aero-engine components, aircraft structure, brakes, wheels, automotive pistons, cylinder liners, valve bodies, control systems.

Obviously, these parts have complex shapes, various dimensions, including micro-sizes, tight tolerances and fine surface finish specifications. Thus, conventional machining reached, in many of these cases, their limits. On the other hand, it is well known that wire electro discharge machining is widely used for manufacturing such parts, made of conductive, difficult-to-machine materials, particularly used in automotive, aerospace and medical industries. So, the objective of this study was to analyze the processing possibilities of AA2124/SiC/25p composite material by wire EDM.
Wire EDM is a dimensional thermo-electrical processing method, consisting of material removal based on erosive effects of electrical discharge pulses, repeatedly primed between workpiece and the wire electrode, separated by a thin film of dielectric liquid (distilled water oil) that is continuously fed to the working zone to flush away the evaporated particles [2]. Wire EDM is difficult to control because of the nature and complexity of the phenomena and processes that are developing among the wire - workpiece interaction. In addition, as the majority of the technological processing systems, wire EDM systems have the following characteristics:

- complexity, depending on many and very different influence factors;
- diffusivity, with significant interactions between the involved factors;
- weakly arrangement, having, at least, a partial stochastic behaviour.

Thereby, for achieving the final goal of optimization or for the analytical and/or empirical identification of the wire electro discharge machining, as a first step, a systemic approach is very useful.

2. SYSTEMIC APPROACH OF THE WIRE EDM PROCESS

Considering EDM process as a technological action system (Fig. 1), this one can be structurally characterized by three main categories of variables [3], [4]:

- independent (input) variables, representing factors which are acting on the system;
- process variables, deciding the process development, which are leading to technological transformations;
- dependent (output) variables, also called objective or response functions, representing technological and technical-economic performance parameters.

2.1 Input variables

The input variables set, which act to initiate technological transformations, can be divided in two subsets (Fig. 1):

- variables related to the technological system’s structure, quasi-inflexible within a specified theme;
- operating variables, which can be adjusted, rapidly, depending on previous variables and on process requirements imposed.

Whilst the structure’s variables include both quantitative and qualitative factors, operating variables are expressed only by physical quantities, which establish dependence mathematical relationships with the processing and output variables values. The most important influence factors are the electrical parameters, through which pulse energy can be controlled. But, the objective functions values are determined by the combination of influence factors, each having impacts with different magnitude. For example, material removal rate and surface finish particularly depend on applied peak current and wire materials [2]. Nevertheless, the role of the other input variables can’t be neglected. For instance, to keep the distance between the wire and the workpiece – called discharging gap – appropriate, the characteristics of the servo control is very important. Otherwise, wire breaking can occur.

2.2 Objective functions

The finality of the processing is evaluated considering both technological and technical-economic objective functions (Fig. 1).
The technological objectives characterize the effects induced in the workpiece by technological transformations (accuracy of the processed workpiece, surface quality, heat affected layer properties), as well as the technological process (material removal rate). Also, besides the desired transformations, some unwanted effects occur (wire and liquid wear). The technical-economic objectives are related to the production processes (investment, manufacturing and maintenance cost).

Depending on the goal of the machining process – roughing or finishing – these objective functions have a different importance. However, it is possible to define some global performance indicators, which can assess the efficiency of the EDM process, taking into account both the effects – material removal rate $Q_c$, surface
roughness $Ra$, confidence interval of the mean technological gap $\varepsilon$ – and energy consumptions – mean current $I_m$:

$$PI_1 = \frac{Q_c}{R_a}$$

$$PI_2 = \frac{Q_c}{R_a \cdot \varepsilon}$$

$$PI_3 = \frac{Q_c}{R_a \cdot \varepsilon \cdot I_m}$$

3. DESIGN OF EXPERIMENTS

For establishing the influence of thickness of the material laminate and of the wire material on the material removal rate of the EDM Al2124/SiC/25p composite material, a bi-factorial ANOVA was considered to be an appropriate assessment method.

The study was carried out on 3 values for the material thickness, meaning that $x_1 = h$ factor, has $l_1 = 3$ levels:
- $h = 15$ mm;
- $h = 54$ mm;
- $h = 63$ mm.

These samples were machined by wire EDM cutting, using the same straight pattern, each of 200 mm length, with 2 types of brass wire, uncoated and coated. So, the second factor selected, $x_2$, was a qualitative one, the nature of wire material and had $l_2 = 4$ levels.

The objective function chosen was the material removal rate, $y = Q_c$ [mm$^3$/min], as a representative evaluation of the process performance, especially for roughing applications. For every factor combination, $n=4$ replicas were performed, with no randomization. The material removal rate was determined by measuring the total processing time $t_c$ and weighting the samples before and after machining.

$$Q_c = \frac{\Delta m}{\rho \cdot t_c} = \frac{V_c}{t_c},$$

where:
- $\Delta m$ – mass variation;
- $\rho = 2.88$ g/cm$^2$ – material density;
- $V_c$ – eroded volume.

For performing the experiment, the input variables of the Wire EDM Centre SODICK AQ300L were selected. The variables values, corresponding to roughing operations, were maintained constant during all runs. The experimental results are centralized in Tab. 1. The roughness of the processed surface was measured, using an MITUTOYO SJ-201P apparatus, the cut width deviations were evaluated with an HIROX digital microscope (see Fig. 2) and also, the Vickers micro hardness (HV0.1) along the cut was measured.

It was measured at all samples the roughness $Ra$ and its values were in the range of 1.93-1.98 µm. We have been expected these results, because Wire EDM process is known for his sensitivity and precise cutting. Also, very small cut width deviations were obtained. The micro hardness

Fig. 2 The evaluation of cut width deviations
measured was between 131 – 147 HV0.1 for all 3 values of material thickness (15 mm, 54 mm, 63 mm). Because the micro hardness of all samples was similar irrespective of thicknesses, we can say that is due to the distribution of silicon carbide particle, and not because of thermal influence of the process. Based on this we can say that Wire EDM process did not thermal affect the material irrespective of thickness.

**Tab. 1 Experimental results**

<table>
<thead>
<tr>
<th>Run</th>
<th>Thickness (x_1)</th>
<th>Wire material (x_2)</th>
<th>Material Removal Rate (y=Q_c) [(\text{mm}^3/\text{min})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>brass</td>
<td>17.01</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>brass</td>
<td>17.78</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>brass</td>
<td>16.35</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>brass</td>
<td>18.04</td>
</tr>
<tr>
<td>5</td>
<td>54</td>
<td>brass</td>
<td>17.29</td>
</tr>
<tr>
<td>6</td>
<td>54</td>
<td>brass</td>
<td>17.42</td>
</tr>
<tr>
<td>7</td>
<td>54</td>
<td>brass</td>
<td>16.83</td>
</tr>
<tr>
<td>8</td>
<td>54</td>
<td>brass</td>
<td>17.21</td>
</tr>
<tr>
<td>9</td>
<td>63</td>
<td>brass</td>
<td>17.24</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
<td>brass</td>
<td>17.51</td>
</tr>
<tr>
<td>11</td>
<td>63</td>
<td>brass</td>
<td>17.02</td>
</tr>
<tr>
<td>12</td>
<td>63</td>
<td>brass</td>
<td>16.92</td>
</tr>
</tbody>
</table>

**4. RESULTS AND INTERPRETATIONS**

The results of the bi-factorial analysis of variance for the objective function – Material Removal Rate [\(\text{mm}^3/\text{min}\)] are presented in Table 2. The aim of the analyse is to determine which factors have a statistically significant effect on material removal rate [\(\text{mm}^3/\text{min}\)], using Fisher tests. For this purpose, the ANOVA method decomposes the variability of material removal rate [\(\text{mm}^3/\text{min}\)] into contributions due to various factors. All F-ratios are based on the residual mean square error. Since Type III sums of squares have been chosen, the contribution of each factor is measured having removed the effects of all other factors. The results of the test show that thickness of the material didn’t have statistically significant influence on the material removal rate at the 95.0% confidence level, because the corresponding P-value is greater 0.05. Since P-value is less than 0.05, the second factor – wire material – had a statistically significant effect on material removal rate at the 95.0% confidence level. In Table 3 the mean material removal rate for each level of the factors was computed. The last two columns show 95.0% confidence intervals for each of the means. These means and intervals are plotted in Fig. 3, which highlights the ANOVA conclusions.

**Tab. 2 Analysis of Variance for Material Removal Rate [\(\text{mm}^3/\text{min}\)]**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>Df</th>
<th>Mean Square</th>
<th>F-Ratio</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIN EFFECTS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.Thickness h [(\text{mm})]</td>
<td>7.61773</td>
<td>2</td>
<td>3.80887</td>
<td>3.46</td>
<td>0.0514</td>
</tr>
<tr>
<td>B.Wire material</td>
<td>204.809</td>
<td>1</td>
<td>204.809</td>
<td>185.87</td>
<td>0.0000</td>
</tr>
<tr>
<td>RESIDUAL</td>
<td>22.0375</td>
<td>20</td>
<td>1.10188</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL (CORRECTED)</td>
<td>234.464</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tab. 3 Least Squares Means for Material Removal Rate \([\text{mm}^3/\text{min}]\) with 95.0\% Confidence Intervals

<table>
<thead>
<tr>
<th>Level</th>
<th>Count</th>
<th>Mean</th>
<th>Stnd Error</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRAND MEAN</td>
<td>24</td>
<td>20.1396</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness (h) [\text{mm}]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>8</td>
<td>20.6763</td>
<td>0.371126</td>
<td>19.9021</td>
<td>21.4504</td>
</tr>
<tr>
<td>54</td>
<td>8</td>
<td>20.3813</td>
<td>0.371126</td>
<td>19.6071</td>
<td>21.1554</td>
</tr>
<tr>
<td>63</td>
<td>8</td>
<td>19.3613</td>
<td>0.371126</td>
<td>18.5871</td>
<td>20.1354</td>
</tr>
<tr>
<td>Wire material</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>brass</td>
<td>12</td>
<td>17.2183</td>
<td>0.303023</td>
<td>16.5862</td>
<td>17.8504</td>
</tr>
<tr>
<td>coated</td>
<td>12</td>
<td>23.0608</td>
<td>0.303023</td>
<td>22.4287</td>
<td>23.6929</td>
</tr>
</tbody>
</table>

Fig. 3 Means and 95.0\% LSD Intervals Plot

5. CONCLUSIONS

The performed experiments showed that the thickness of the laminate doesn’t have a significant influence on the material removal rate of wire EDM of AA2124/SiC/25P, at the 95.0\% confidence level. Contrarily, the use of a coated wire led to a significant growth of the removal rate, at the same confidence level. Future optimization experiments should analyze the influence of the electrical parameters on the objective functions.

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LITERATURE