Investigating the electrical discharge machining (EDM) parameter effects on Al-Mg$_2$Si metal matrix composite (MMC) for high material removal rate (MRR) and less EWR—RSM approach

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Abstract Al-Mg$_2$Si composite is a new group of metal matrix composites (MMCs). Electrical discharge machining (EDM) is a nonconventional machining process for machining electrically conductive materials regardless of hardness, strength and temperature resistance, complex shapes, fine surface finish/textures and accurate dimensions. A copper electrode and oil-based dielectric fluid mixed with aluminum powder were used. The polarity of electrode was positive. Response surface methodology (RSM) was used to analyze EDM of this composite material. This research illustrates the effect of input variables (voltage, current, pulse ON time, and duty factor) on material removal rate (MRR), electrode wear ratio (EWR), and microstructure changes. The results show that voltage, current, two-level interaction of voltage and current, two-level interaction of current and pulse ON time, and the second-order effect of voltage are the most significant factors on MRR. Pulses ON time and second-order effect of pulse ON time are the most significant factors affecting EWR. Microstructure analysis of EDM on Al-Mg$_2$Si samples revealed that voltage, current, and pulse ON time have a significant effect on the profile and microstructure of machined surfaced.

Keywords Metal matrix composite (MMC) · Electrical discharge machining (EDM) · Response surface methodology (RSM) · Material removal rate (MRR) · Electrode wear ratio (EWR) · Microstructure

1 Introduction

Electrical discharge machining (EDM) is a nonconventional machining process that precisely controls sparks falling between the electrode and electrical conductive workpiece causing the removal of material [1–4]. The EDM process is useful for machining electrically conductive materials with various hardness, strength and temperature resistance, complex shapes, fine surface finish/textures, and accurate dimensions [1–3, 5–7]. Adding aluminum powder in the dielectric leads to increased material removal rate (MRR) and improved surface roughness (SR) during EDM [1, 8]. The chain formation of powder particles in the dielectric helps to bridge the gap between electrode and workpiece which causes the early explosion. Therefore, faster sparking within discharge occurs and faster erosion from the workpiece surface takes place [9]. Al-Mg$_2$Si composite is a new group of metal matrix composites (MMCs) that could be a better substitute for Al-SiC and Al-Si composites in the aerospace and automotive industries [10, 11] due to their excellent castability, low density, and good wear resistance and mechanical properties [11, 12]. In addition, Al-Mg$_2$Si composite exhibits potential to be used in the fabrication of automobile brake disks, pistons, piston rings, linear cylinders, and connecting rods because Mg$_2$Si has a high melting point [13].

Recently, several research works related to the various aspects of EDM on MMCs have been done. It is noted that the Lexicographic Goal Programming (LGP) technique has been selected for optimizing MRR, SR, and recast layers during EDM of Al-6061 composite [6]. Seo et al. [14] chose a copper electrode for the EDM process of 15–35 vol% SiC$_p$/Al composites. Sidhu et al. [15] explored the effect of PMEDM input variables on the surface modification of three kinds of MMCs (65 vol% SiC/ A36.2, 10 vol% SiC-5 vol% quartz/Al, and 30 vol% SiC/A359) using the Taguchi method. Gopalakannan and Senthilvelan investigated about the EDM parameter effect on metal matrix
nanocomposite (MMNC) of Al-7075 reinforced with 0.5 wt% SiC nanoparticles by applying response surface methodology (RSM) \cite{16}. The effect of input variables during EDM on matrix Al-7075 nanocomposite reinforced with 0.5 wt% B4C nanoparticles by RSM was studied \cite{17}. Kumar et al. \cite{18} noted that RSM is a method of evaluating EDM parameters on Al-based hybrid MMC (Al-6063/SiC/Al2O3/g). Singh and Yeh \cite{19} evaluated EDM parameters on 6061 Al/Al2O3p/20p aluminum matrix composites (AMCs) for multiple responses using the Taguchi method. Senthilkumar and Omprakash stated that Al-MMCs with 5 and 2.5 \% TiC reinforcement using a copper electrode and L18 orthogonal array are suitable conditions for determining the effect of EDM parameters. Velmurugan \cite{20} reported that a central composite rotatable design is one means of evaluating input variables during EDM of Al-6061 hybrid MMCs with 10 \% SiC and 4 \% graphite particles. EDM of hybrid Al-5\%SiC-5 \% B4C and Al-5\%SiC-5\%Glass MMCs with a copper electrode and L9 orthogonal array has been investigated \cite{21}. As mentioned previously, several researchers have evaluated EDM performance using the RSM and Taguchi methods. Agarwal et al. \cite{22} compared the results of optimizing power consumption after analysis with face-centered central composite design (RSM) and \textit{L27} orthogonal array (Taguchi method) during the turning process. The results indicate that RSM evaluates the effect of parameters on response and optimizes them better than the Taguchi method.

After conventional MMCs, Al-Mg2Si is a novel material. There is no research addressing the effects of EDM parameters (voltage, current, pulse ON time, and duty factor) on Al-Mg2Si in situ composite. High MRR and low electrode wear ratio (EWR) are important in the roughing step of the EDM process. Therefore, developing a mathematical model and simultaneously evaluating the suitable machining parameters for MRR and EWR using the RSM method during the EDM process of Al-Mg2Si in situ composite are some of the goals of the current research. Another aim is to observe the effects of EDM parameters on the microstructure and surface of machined surfaces.

### 2 Experimental details

#### 2.1 Fabrication of workpiece

Commercial Al-11.7Si-2Cu alloy, pure aluminium, and pure magnesium were used to fabricate an Al-20Mg2Si ingot with chemical composition given in Table 1. The composite ingot was first cut into smaller pieces, cleaned, dried, and melted in a 2-kg-capacity SiC crucible using an induction furnace. After around 5 min of allowing homogenization, the melt was stirred, skimmed, and then poured at a temperature of 750±5 °C into a mild steel mould to fabricate the workpiece with 100×30×200 mm dimensions.

#### 2.2 Experimental conditions and procedure

In this research, the experiments were performed on an AG40L Sodick electrical discharge machine (Fig. 1). A copper electrode with a 5.5-mm diameter was selected. The depth of holes on Al-Mg2Si in situ composite was 6 mm. The polarity of the electrode was positive, and oil-based dielectric fluid mixed with aluminum powder (PGM WHIT 3) was also used. Voltage, current, pulse

<table>
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<th>Symbol</th>
<th>Parameters</th>
<th>Unit</th>
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<td>A</td>
<td>Voltage ((V))</td>
<td>V</td>
<td>50 80 110</td>
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<tr>
<td>B</td>
<td>Current ((I_p))</td>
<td>A</td>
<td>3 9 15</td>
</tr>
<tr>
<td>C</td>
<td>Pulse ON time (\text{on})</td>
<td>(\mu s)</td>
<td>10 105 200</td>
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<tr>
<td>D</td>
<td>Duty factor(^a) ((D_f))</td>
<td>%</td>
<td>0.25 0.55 0.85</td>
</tr>
</tbody>
</table>

\(^a\text{Duty factor} = \frac{\text{Pulse ON time}}{\text{Pulse ON time} + \text{Pulse OFF time}} \times 100(\%)\)