Die-sinking EDM of a SiC-boride-composite

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Abstract
Silicon carbide-based composites are highly demanded for industrial applications, like heat exchangers in corrosive environments. In consequence of the mechanical properties like high hardness H and brittleness, cutting processes are still challenging. An opportunity for processing difficult-to-cut materials with sufficient electrical conductivity σ is electrical discharge machining (EDM). In order to develop suitable machining technologies, known parameters for common material combinations can serve as a starting point. Hence, standard technologies from the database of a commercial die-sinking EDM machine tool were applied for machining a silicon carbide-boride-composite. The material removal rate QAV and the arithmetical mean deviation Ra for finishing and roughing operations are observed. The formation of cracks and the extend of the typical deposition layer are studied. Scanning electron microscopy is used to analyse the surface topography and the formation of cracks. Challenges of processing ceramics with EDM arise from typical material removal mechanisms like spalling, which can lead to a poor surface quality [5]. Furthermore, high temperatures at the surface of the workpiece can lead to the formation of a deposition layer and micro-cracks, which compromises the mechanical and thermal stability [6]. To optimise machining efficiency and to avoid those effects, machining technologies need to be developed for ceramic composites. Finding parameter combinations can be time consuming due to the high complexity of the process and the lack of starting parameters. However, since EDM is a well-established machining process, technologies for common material combinations and machining regimes have been generated in the past. One approach to solve the aforementioned problems is to adopt those settings for processing silicon-carbide composites and serve as starting point for experimental strategies for parameter optimizations. Thus, this study aims to investigate the machinability of a silicon carbide-composite with S-EDM in hydrocarbon oil, when industrial available parameter technologies, designed for different material combinations, are applied.

Keywords: silicon carbide composite, die-sinking EDM, parameter technologies

1. Introduction
There is an increasing demand for silicon carbide based composites for applications in the aerospace, automotive and energy sector. The reason for that are the high resistance of this material in high temperature and high corrosion environments [1]. Because of high hardness H and brittleness, processing these materials with conventional manufacturing methods is time consuming and therefore expensive [2, 3]. In order to overcome these limitations, die-sinking electrical discharge machining (S-EDM) can be applied to those ceramic composites with sufficient electrical conductivity σ, because no mechanical forces F occur and the fabrication of complex shapes is possible [2, 3, 4]. Challenges of processing ceramics with EDM arise from typical material removal mechanisms like spalling, which can lead to a poor surface quality [5]. Furthermore, high temperatures T at the surface of the workpiece can lead to the formation of a deposition layer and micro-cracks, which compromises the mechanical and thermal stability [6]. To optimise machining efficiency and to avoid those effects, machining technologies need to be developed for ceramic composites. Finding parameter combinations can be time consuming due to the high complexity of the process and the lack of starting parameters. However, since EDM is a well-established machining process, technologies for common material combinations and machining regimes have been generated in the past. One approach to solve the aforementioned problems is to adopt those settings for processing silicon-carbide composites and serve as starting point for experimental strategies for parameter optimizations. Thus, this study aims to investigate the machinability of a silicon carbide-composite with S-EDM in hydrocarbon oil, when industrial available parameter technologies, designed for different material combinations, are applied.

2. Experimental setup
The experiments for this study were conducted on the commercial die-sinking EDM machine tool Genius 1000, ZIMMER & KREIM GMBH & Co. KG, Brensbach, Germany, using the oil-based dielectric fluid Ioloplus IME-MH distributed by OELHELD GMBH, Stuttgart, Germany. All workpieces were made out of a silicon carbide-boride-composite (SiC/B) developed by FCT INGENIEURKERAMIK GmbH, Frankenblick, Germany. Cavities with a depth t = 0.5 mm were produced in triplicate during all experiments. Electrolyte copper rods served as tool electrodes for this experiments. Machining technologies, designed for machining steel with copper electrodes and stored at the internal database of the EDM machine tool, were studied. This included parameter for finishing (F), semi-roughing (SR) and roughing operations (R). The ignition voltage U, discharged current I, pulse duration ton and pulse-off time toff of these technologies are displayed at table 1. Moving from technology F to R corresponds to an increase in the discharge energy W.

Table 1. Applied machining technologies

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<td>F</td>
<td>270</td>
<td>1.5</td>
<td>5</td>
<td>10</td>
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<tr>
<td>SR</td>
<td>270</td>
<td>6.7</td>
<td>40</td>
<td>24</td>
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<tr>
<td>R</td>
<td>270</td>
<td>9.5</td>
<td>50</td>
<td>30</td>
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In order to evaluate the feasibility of these commercial available parameters for machining the SiC/B, the material removal rate QAV and the arithmetical mean deviation Ra of the cavities were evaluated. Additionally, thermal induced cracks and the deposition layer at the workpiece surface were observed with scanning electron microscopy (SEM).
3. Results of the experiments

The results for material removal rate $Q_W$ and arithmetical mean deviation $Ra$ of the experiments are depicted in figure 1. The material removal rate $Q_W$ varies between the values $0.01 \text{ mm}^3/\text{min} \leq Q_W \leq 0.07 \text{ mm}^3/\text{min}$, as is shown in figure 1 a). Hence, the material removal rate $Q_W$ is increasing when higher discharge energies $W$ are applied. In contrast, the arithmetical mean deviation $Ra$ is nearly the same for finishing and roughing operations, shown in figure 1 b). This property is only varying between $1.50 \mu m \leq Ra \leq 1.68 \mu m$. This can be explained, if spalling is considered as the main material removal mechanism and the size of the removed particles is related to the grain size $d_0$ of the material used in this experiment. Figure 2 shows a SEM-image of a cross-sectioned cavity machined with the parameters belonging to the roughing technology with a magnification factor of 100. Although the highest degree of heat inflicted surface damage can be expected in case of this technology, no cracks due to thermal shock appear in the bulk material. Moreover, no deposition layer can be observed on the surface of the workpiece. In addition, fragmentary particles, broken from the surface, can be seen in figure 2. These particles can be interpreted as debris from the EDM-process, which were not removed by the flushing. This would be an indication for the suspected material removal mechanism of spalling.

![Tool electrode: Electrolyte copper rod Workpieces: SiC/B-composite Process parameters: Technologies F, SR and R EDM-System: Z+K Genius 1000 Error bars: Standard derivation $s$ Cavity depth: $t = 0.5 \text{ mm}$](image)

Figure 1. Comparison of a) material removal rate $Q_W$ and b) arithmetical mean deviation $Ra$ for cavities with depth $t = 0.5 \text{ mm}$ on SiC/B for machining technologies F, SR and R

![debris particles](image)

Figure 2. Surface integrity of cross-sectioned cavity produced by applying roughing technology

4. Summary

The findings of this investigation show that commercially available machining technologies can be applied for the manufacturing of silicon carbide-boride-composites. No surface damage due to high temperatures $T$ could be found and the arithmetical mean deviation $Ra$ is not dependent of the machining regime. The second finding can be related to the specific material removal mechanism of spalling. Higher material removal rates $Q_W$ were achieved through increasing the discharge energy $W$. Further research is needed to confirm these observations and enhance machining efficiency.

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References