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Development of monolithic ceramic milling tools for machining graphite

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Abstract

Due to the international competition, continuous increases in productivity, product quality and reduction of production costs are required. Especially, the development of milling tools made of innovative cutting materials and application-specific tool geometries are in focus to overcome these challenges. Besides copper, graphite is the most important electrode material for electrical discharge machining (EDM). The machining of graphite leads to high tool wear due to a strong abrasive effect. Short tool life has a considerable influence on the economic efficiency of manufacturing processes. Currently, for the machining of graphite cost intensive diamond coated carbide tools are applied. In order to reduce machining costs, innovative cutting materials and dedicated manufacturing processes have to be applied. First results show a great potential of ceramics as tool material for machining graphite. The aim of this investigation is the characterisation and identification of novel ceramic cutting materials and the evaluation of an innovative tool micro-geometry especially designed for machining graphite. Therefore, the cutting material properties such as hardness, fracture toughness and wear resistance of four ceramic materials were investigated. Various hardness tests and particle blasting tests were carried out. Based on this investigations to manufacture the ceramic milling tools, a specific and innovative tool micro-geometry with defined angles was used. Thereby, a suitable cutting ceramic was identified, which represents a promising approach for an optimised machining of graphite.

Keywords: Ceramic, micro-milling, graphite, grinding

1. Introduction

Tool and mould making is one of the most important sectors in the manufacturing industry. The manufacturing of cost-effective and wear-resistant tools is needed to increase the efficiency of production processes and product quality.

Graphite and copper are the most important electrode materials for die-sinking EDM. Graphite is mainly used as an electrode material for die-sinking EDM in tool and mould making, in reactor technology for radiation and heat generation and in the aerospace industry [1, 2].

Currently, the machining of graphite is limited due to the crystal structure. During the machining of this material, no chip formation occurs, much more graphite particles are broken out of the micro-structure, which results in graphite dust. The described material behaviour leads to high wear and rapid tool failure [3]. According to the state of the art, cost-intensive carbide tools with abrasion-resistant diamond coatings are currently used for industrial applications. In order to overcome current challenges in precision machining of graphite, cutting tools made of oxide ceramics are a promising approach.

2. Experimental setup

2.1. Cutting material selection

For the investigations, three different aluminium-reinforced zirconium dioxide ceramics from the company Bce Special Ceramics GmbH, Mannheim, Germany, and the zirconium dioxide-reinforced aluminium oxide ceramic from the company OxiMaTec GmbH, Hochdorf, Germany, were analysed. Table 1 shows the chemical composition of the ceramics.

Table 1 Main chemical composition of the used ceramics

Ceramic	Chemical composition	Amount [%]
Aluminium oxide ceramic AZ25PPr	Aluminium oxide Zirconium dioxide	75.0 25.0
Zirconium oxide ceramic Z 513	Zirconium & Hafnium oxide Magnesium oxide remaining ingredients	96.0 3.5 0.5
Zirconium oxide ceramic Z 700 E	Zirconium & Hafnium oxide Yttrium oxide remaining ingredients	94.5 5.2 0.3
Zirconium oxide ceramic Z 700 3E	Zirconium & Hafnium oxide Yttriumoxid Aluminiumoxide remaining ingredients	92.0 5.2 2.5 0.3

2.2. Testing methods and devices

For the investigation of the material properties, the hardness H, the fracture toughness K_{Ic} and the wear against abrasion and surface attrition were examined.

The measurement of the hardness H was realised with the testing device Miniload 2 of the company Ernst Leitz Wetzlar GmbH, Wetzlar, Germany. The macro-hardness measurement device Dia Testor 2 of the company Wilson Wolpert instruments, Aachen, Germany, was used to investigate the fracture toughness K_{Ic}.

The wear behaviour of the used ceramics could be analysed according to POLTE ET AL. [4] with particle blasting tests using the air blast machine FSA-1 of the company SABLUX TECHNIK AG, Bachenbülach, Switzerland. For the measurement of the mass losses m_l, the precision scale PLS 1200 of the company KERN & SOHN GMBH, Ettenheim, Germany, was used.

3. Experimental investigations

In order to analyse the properties of the ceramics, a Vickers hardness test was performed to identify the hardness of the ceramics. The test force to carry out the experimental investigations was $F_t = 9.81$ N. Based on the experimental results, it could be demonstrated that the aluminium oxide ceramic has the highest Vickers hardness with a value of H_v = 2,189 HV, while the Vickers hardness of the three zirconium oxide ceramics was determined in the range of 1,200 HV $\leq H_v \leq$ 1,500 HV. The micro-structure of the ceramic type AZ25PPr has a specific micro-structure, which result in optimised hardness properties. The micro-structure consists of special elongated grain structures of lanthanum and aluminium oxide, which improve the material properties.

To determine the fracture toughness K_{Ic}, the Palmquist method was used. Within the investigation, a flat surface is needed because surface defects have a strong influence on the crack formation. The results of the experimental investigations showed slight advantages of zirconium oxide ceramics with a fracture toughness of $K_{Ic} \geq 7.6$ compared to the aluminium oxide ceramic with a fracture toughness of $K_{Ic} = 7.5$. However, the aluminium oxide ceramic showed a significantly higher fracture toughness K_{Ic} than conventionally used aluminium ceramics. This property is also achieved by the special micro-structure.

Furthermore, the resistance of the ceramic milling tools against abrasion and surface attrition was investigated and explained in the following describtion. The abrasion describes the mass loss m_l of a material with a low hardness H by the penetration of a material with a higher hardness H. Surface disruption is the effect of temporally and locally changing stresses in a tribological system.

Figure 1 show the mass loss m_l over the blasting time t_b for the resistance of the ceramics against abrasion.

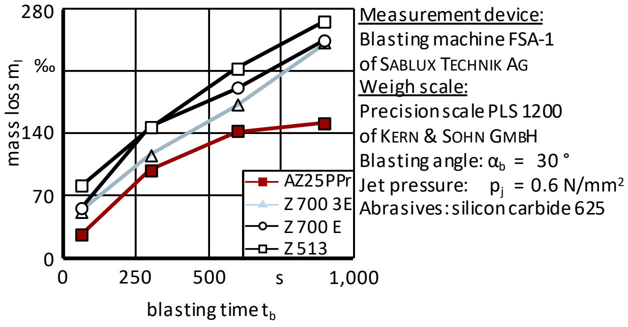

Figure 1 Resistance against abrasion

The mass loss m_l of all investigated ceramics increases as a function of the blasting time t_b and shows a linear curve for all graphs. The lowest mass loss m_l and the highest wear resistance against abrasion was achieved with the aluminium oxide ceramic type AZ25PPr with a value of m_l = 151 ‰. Figure 2 shows the results for the investigations of the resistance against surface attrition.

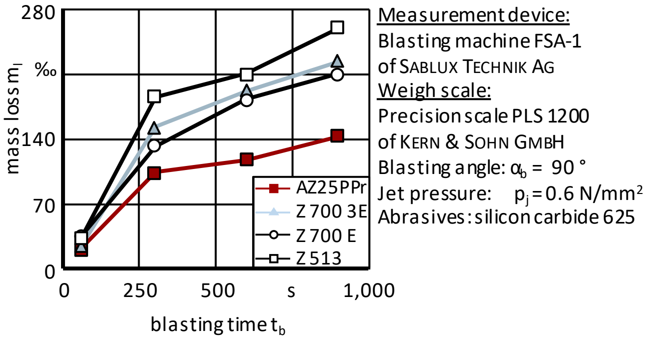

Figure 2 Resistance against surface attrition

The mass loss m_l of all ceramics increases strongly up to a blasting time of $t_b = 300$ s and all graphs show a linear behaviour. The highest wear resistance could be proved for the aluminium oxide ceramic type AZ25PPr with a mass loss of m_l = 122 ‰ after a blasting time of $t_b = 900$ s. The results show that the improved properties of the aluminium oxide ceramic type AZ25PPr enables an optimised machining of graphite.

4. Innovative geometry of the used ceramic tools

The tool geometry has defined angles for optimised machining of graphite and a parabolic radius r transition to the cutting part. This enables optimised process conditions and a low tool wear. The developed ceramic milling tool is shown in figure 3. For the grinding process, the grooves-, the circumference-, the recess- and the face grinding were used. Furthermore, optimised process results could be identified by increasing the cutting speed v_c.

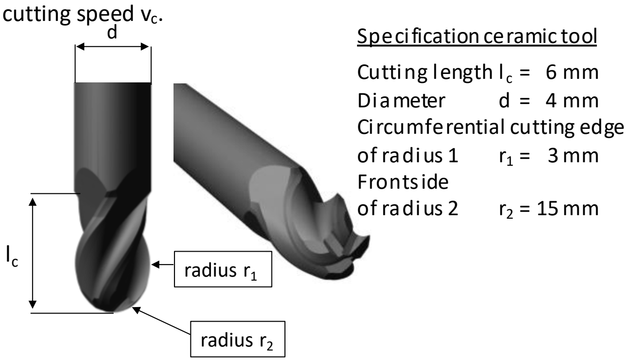

Figure 3 Innovative ceramic milling tool with specific micro-geometry

5. Conclusion

The aim of the investigation was the identification of a suitable ceramic for the optimised machining of graphite. The best conditions could be identified for the aluminium oxide ceramic type AZ25PPr due to the material properties. Further investigations will adress the experimental applicability of the ceramic milling tools, optimisation approaches should be aimed and simulations will be carried out. This work is supported by the funding program Zentrales Innovationsprogramm Mittelstand (ZIM) by the FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY (BMWI).

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