NC-Form Grinding of Carbon Fibre Reinforced Silicon Carbide Composite

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Abstract. This paper presents an approach for the development and optimization of the NC-form grinding technology for an efficient machining of carbon fibre reinforced silicon carbide composite (C/SiC). The C/SiC properties, the importance and the necessity of the application of a high performance grinding process for the machining of this innovative composite material are introduced first. Then, the methodologies and the experimental investigations of NC-form grinding with the application of several machining parameters and three distinct bond types (vitrified, metal and synthetic resin) of diamond mounted points for the abrasive machining of C/SiC are presented. In order to monitore and analyze the process, grinding forces, surface integrity of ground workpieces and grinding wheel wear are investigated. The results of this paper provide new information regarding the wear behavior of grinding tools and the optimized conditions for grinding of C/SiC.

Introduction

Carbon fibre reinforced silicon carbide composites (C/SiC) contain a ceramic matrix (SiC) reinforced by carbon fibres (C). The first generation of this material was developed for space vehicles and military applications [1,2]. Due to its mechanical and tribological characteristics in addition to its high thermal stability and low specific weight, this material is also of interest for industrial applications. Generally, its fracture behavior is very brittle when compared to metals, but its failure strain can be up to one order of magnitude greater than that of monolithic ceramics. The non-linear stress-strain behavior makes C/SiC an engineering material with quasi-ductile breaking behavior. The combination of the hard ceramic matrix and the strength of the carbon fibre leads to composite properties enabling use as braking discs and pads, clutches, vanes, nozzles and flaps of rocket motors and engines, and leading edges of spacecraft [2].

In order to fulfill the requirements of such applications, it is necessary to consider material properties, final geometry, tolerances, surface quality, machining costs and technology. The machining of C/SiC may be considered a challenge concerning its abrasive characteristic, which implicates high wear of the grinding tool and requires the use of diamond abrasive grains [3]. Therefore, grinding as a finishing process represents a key step of the manufacturing chain and is influenced by the tool and process conditions [4]. The costs for the machining of high performance sintered ceramics could reach up to 80 % of the total costs of the final product [5]. The hard machining of C/SiC must be optimized in order to achieve high performance on machining and a reliable process. This study includes a systematic experimental approach for the investigation of the NC-form grinding of C/SiC. The main objective of this paper is to generate knowledge about the interaction between grinding processes of C/SiC, diamond wheel wear and obtained surface integrity of the machined workpieces.

Experimental Set-Up

Grinding Machine and Measurement System. Experimental tests are carried out using a RXP600DSH UHP 5-axis-grinding machine tool by Röders GmbH, Soltau, Germany. This high-precision machine tool is equipped with an automatic cutting tool changer, an integrated acoustic emission (AE) system, an integrated tactile workpiece measurement system as well as a dressing unit. Due to the linear direct drives of the translational axes, high accelerations can be realized for linear movements. In the experimental investigations a mineral oil based cooling lubricant, DiaMond100, is used. In order to measure the surface roughness of the produced parts the tactile measuring device HOMMEL-ETAMIC nanoscan 855 from Jenoptik AG is applied. A scanning electron microscope (SEM) LEO 1455 VP from Zeiss is used to analyze the protrusion of the diamond grains of the grinding tools and the quality of the workpieces and a dynamometer 9257B from Kistler is used for the acquisition of the signal forces.

Grinding Tool and Workpiece. A metal, a vitrified and a synthetic resin bonded diamond mounted points are applied as cutting tool for the NC-Form grinding experiments. All of these tools have the same specification and concentration of diamond grains. Carbon Fibre Reinforced Silicon Carbide Composite (C/SiC), type CF226/2 P77 (Schunk GmbH, Heuchelheim, Germany), are used for the experiments. This material is reinforced with 60 % volume of continuous fibres and is usually applied in brake systems. The flexural modulus is 55 GPa and Hardness is 118 HRC[6].

Experimental Investigations and Results of NC-Form Grinding

Specific Material Removal Rate Analysis. The specific normal force measured during the experiments is plotted against the specific material removal rate, Q'_w (Fig. 1). For resin and vitrified bond tools at a Q'_w of 8 respectively 13 mm^3/mms the single grain forces achieve such high values, that the strength of the bonding system is exceeded. Due to this overload of the grinding wheel capacity, the normal forces do not increase any further. It can result in a failure on the final geometry of the workpieces and produce high wear rates of the grinding tool. On the other hand, the metal bond tool shows a different behavior and can resist high forces and consequently higher material removal rates compared to the other tools with resin and vitrified bond systems. The first failures of the machined workpieces with metal bond tool could be identified at $Q'_w = 20$ mm^3/mms. In this case, chatter marks on the workpiece surface are detected. The experiments carried out to determine the limits of the tools assumed an important function for the following experiments, as they presented the possible Q'_w to be achieved by every grinding tool.

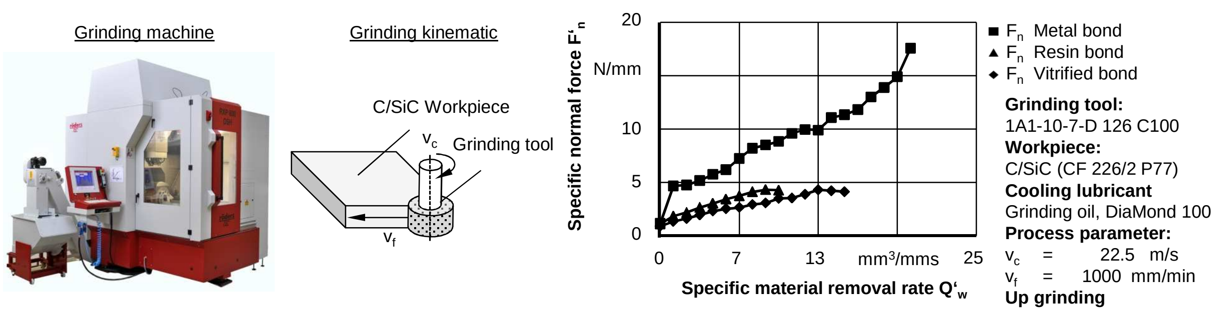

Figure 1 – Machine, applied kinematic and the results of the experiments with the limits of Q'_w

In order to compare the three different types of bonds two specific material removal rates, Q'_w of 4 and 6 mm^3/mms are applied in the tests. For each grinding test the interval of the measurements are divided into eight steps of specific material removal (V'_w): 100, 250, 500, 750, 1000, 1500, 2000 and 2500 mm^3/mm. At each step the work piece roughness and the grinding wheel wear are measured. Fig. 2 shows the achieved results at the chosen specific material removal rates. It is possible to distinguish a significant difference between the normal and tangential grinding forces for all the tools. Q'_w of 6 mm^3/mms seems to be an adequate parameter especially for the vitrified and the resin bonded tools. This parameter produces a stable process what implies a uniform grain and bond wear. The tools are working in the self-sharpening stage, which is a positive effect to achieve a stable process. However, these tools present high wear. The metal bond can resist higher forces and shows the lowest radial wear.

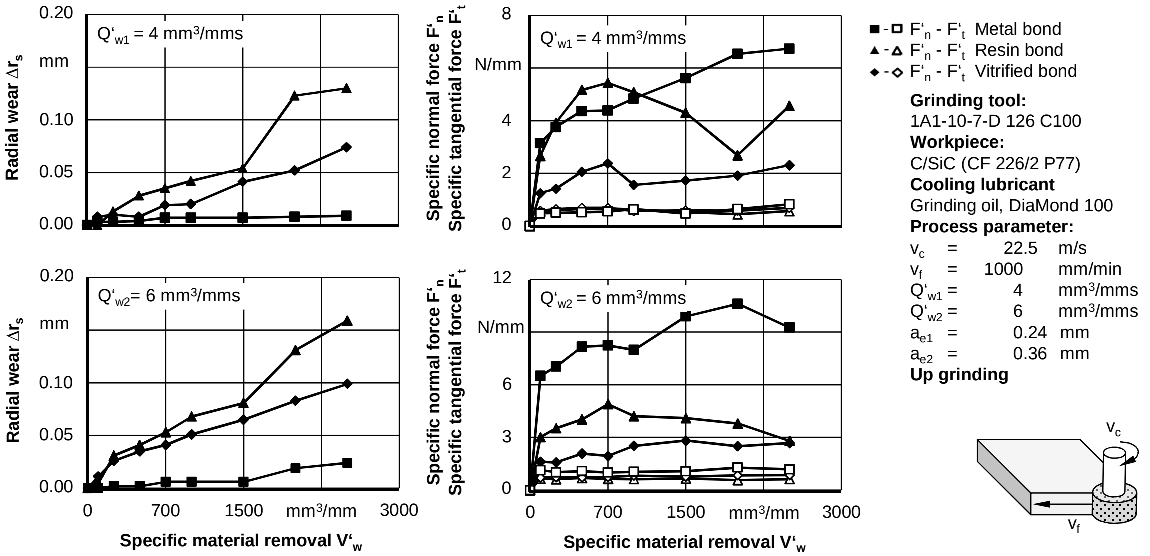

Figure 2 – Radial wear of the grinding tools and grinding forces at Q'_w of 4 and 6 mm^3/mms

Surface Roughness Analysis. Fig. 3 shows that the obtained suface roughness is very similar for vitrified and resin tools. The specimens ground with metal bond shows lower Ra (arithmetic average of the absolute values of the roughness profile) and Rk (core roughness depth) values compared to the specimens machined with the resin and vitrified bond tools. The metal bond tool may presents flattening as a prevailing wear mechanism. The flattening of the diamond grains at the metal bond tool can increase the produced surface quality of the work pieces after a certain volume of machined material.

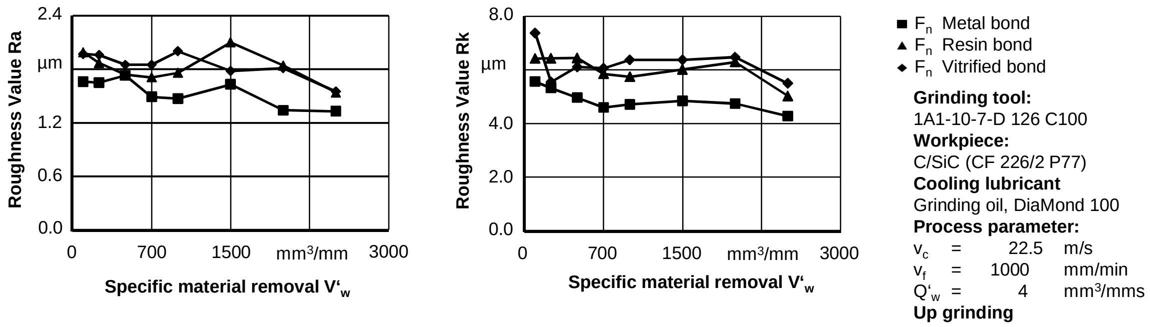

Figure 3 – Roughness values of the ground workpieces by Q'_w of 4 mm^3/mms

SEM Analysis. The SEM pictures of the workpiece and the grinding tool after grinding are presented in the Fig. 4. The picture on the left shows the workpiece surface with visible SiC matrix and C fibres. The other three pictures show the disposal of the diamond grains and the structure of the bond systems for each respective grinding tool. It can be observed that the metal bond tool presents a high protrusion of the diamond grains. This characteristic points to be beneficial for the grinding process of C/SiC. This high grain protrusion is necessary for the cutting process to evacuate the removed C/SiC volume and to permit the cooling lubricant reaching the grinding area.

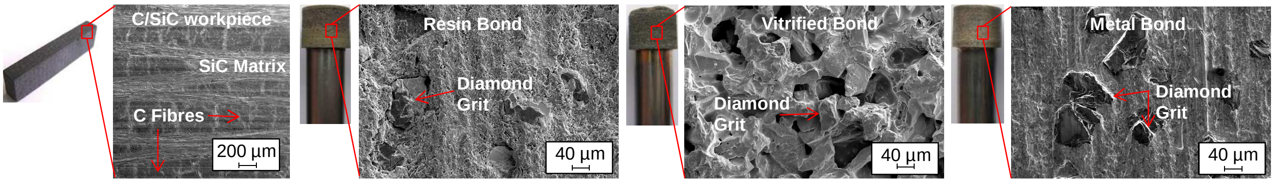

Figure 4 – SEM images after machining of V'_w = 2500 mm^3/mm with Q'_w = 4 mm^3/mms

Bending Tests. To investigate the influence of the machining processes on the fracture strength of the ground workpieces, four-point bending tests are carried out. The tested specimens are machined to a thickness of 4 mm with the metal bond tool and the parameters Q'_w of 0.3, 2.0, 6.0 and 15 mm^3/mms, respectively. The fracture strength values obtained with Q'_w of 0.3 mm^3/mms are considerate reference values for no damaged C/SiC specimens. Fig. 5 shows the average fracture strength for different material removal rates. There is nearly no deterioration of the mechanical properties of the machined samples if high specific material removal rates are used.

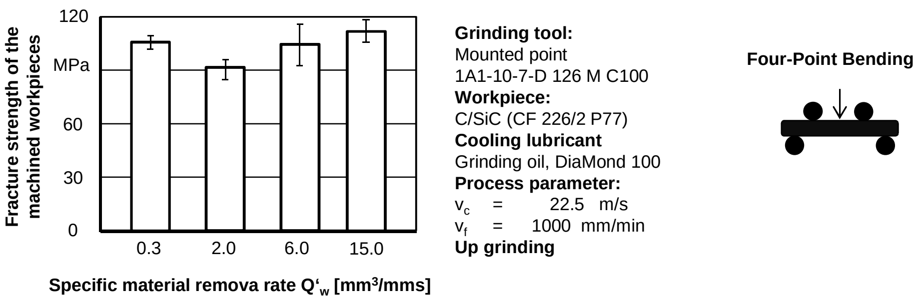

Figure 5 – Fracture strength for different machining parameters

Summary

The aim of the present work is to provide new information regarding the performance of diamond grinding tools and the optimal process conditions for the machining of C/SiC. Resin and vitrified grinding tools showed a stable process but high grinding wheel wear rates during the machining of C/SiC. Metal bond tools with a high protrusion of the diamond grains are appropriate for the NC-form grinding of C/SiC. The metal tools produced the best workpiece surface qualities and presented the lowest wear of the grinding wheel. Even at high material removal rates no critical damage on the ground specimens is detected during the realized bending tests. Through the use of optimized process parameters, favorable grinding wheel wear mechanisms can be achieved and consequently workpieces with high surface integrity can be produced.

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