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Advances in tool grinding and development of end mills for machining of fibre reinforced plastics

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Abstract

The extensive use of lightweight construction materials in the aerospace industry poses a great challenge for tool manufacturers. Materials like carbon fibre reinforced plastics (CFRP) are difficult to machine and therefore put high demands on cutting tools in terms of the cutting material as well as the macro- and microscopic design. In this paper two approaches for the improvement of CFRP milling processes are presented. One approach involves the optimization of the flute grinding process for cemented carbide milling tools by the use of innovative grinding wheel specifications and their influence on cutting-relevant tool features. The other approach deals with the development of ceramic end mills for CFRP machining. Investigations about the influence of different process- and tool-related parameters on the work result and process parameters are presented.

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Keywords: tool grinding; ceramic; cemented carbide; CFRP; milling

1. Introduction

The ongoing awareness for sustainability issues in the industrial sector is resulting in optimization and advancements of existing technological systems in multiple fields to more resource preserving solutions. A usual approach, especially for dynamic systems, is to seek for a lower component weight. Besides constructive measures, further weight savings can usually be reached by the use of innovative materials, which have comparable or even better mechanical properties than conventional materials and at the same time have a lower density. A good example for the substitution of established materials could be observed in the aerospace industry for the last decades and is still ongoing [1]. Huge parts of modern airplanes consist of innovative lightweight materials like carbon reinforced plastics (CFRP) and aluminum alloys. Recently, the automotive industry has also put great efforts in the substitution of car body parts from steel to CFRP in order to compensate the battery induced weight gain of hybrid or fully electric power trains [2]. Thus, but also because of the increasing use of CFRPs in the wind energy, sports and molding compound sector, a rising demand for fibre reinforced plastics (FRP) is expected in the next years [3].

Since the part quality is insufficient in most cases after the primary shaping manufacturing processes of FRPs, the machining of inner and outer contours is often necessary in order to meet the high dimensional and surface qualities especially for the aerospace industry [4,5]. The superior properties of CFRPs put high demands on machining processes like milling and drilling as their two phase composite structure consisting of fibre and matrix material with diverse attributes goes along with an inhomogeneous and anisotropic configuration. High-tensile, brittle carbon fibres, which are embedded in a temperature sensitive synthetic matrix with high failure strain result in predominant abrasive wear during the machining process [6,7].

The superior properties of CFRPs on the other side pose a great challenge for tool manufacturers. As the characteristics of CFRP materials can vary widely due to different compositions of e.g. fibre types, diameters, lengths and

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orientations as well as the synthetic matrix specification, they show also a diverse behavior during machining. Therefore it is often necessary to develop application related cutting tools in order to meet the different requirements that come along with variable workpiece properties. Hence, during machining of CFRPs versatile machining errors like delamination, fraying, fibre fracture, burr formation and burn can be observed. Currently polycrystalline diamond (PCD) and diamond coated cemented carbide tools are widely used [8,9].

There are some specific requirements regarding the tool design and the cutting material that should be met by all used tools. In terms of the tool design, it was investigated, that sharp cutting edges with a low cutting edge radius and chipping are necessary in order to realize a cutting of the fibres and prevent machining errors [10,11]. Another important tool feature with influence on the cutting process is the surface quality of the rake face. It was observed, that the surface quality can influence the adhesion tendency and the coating process significantly [12,13]. Regarding the cutting material a certain resistance against abrasive wear is essential to ensure an economical application of cutting tools. In recent research activities at the Institute for Machine Tools and Factory Management (IWF) different approaches were pursued in order to improve the machining behavior of CFRP cutting tools. In the following, two of them will be described in detail.

As the tool grinding process has a verifiable influence on the machining behavior of cutting tools [14] several investigations on the optimization of the flute grinding process of end mills were conducted. Therefore grinding tests with innovative grinding wheel specifications were carried out and the work result was evaluated in terms of cutting tool relevant parameters. Furthermore results from the development and use of ceramic end mills for CFRP machining are shown. Investigations about the influence of different process- and tool-related parameters on the milling work result and process parameters are presented.

2. Optimization of the flute grinding process

Tool grinding as the essential manufacturing process in the generation of the cutting edge geometry of end mills plays an important role because it influences the machining behavior of the milling tool notably. It involves all grinding operations for the generation of shapes and functional surfaces on a cutting tool. For one-piece end mills it can be applied that despite the great variety of tool geometries basically three grinding operations are necessary: flute, peripheral and face grinding. Within these operations the flute grinding process (Fig. 1) itself has a major function because in comparison it possesses a high material removal V_w that goes along with a high main time and also has the dominating influence on the cutting edge generation [14,15]. Due to economical reasons flute grinding processes are generally performed in creep feed grinding mode.

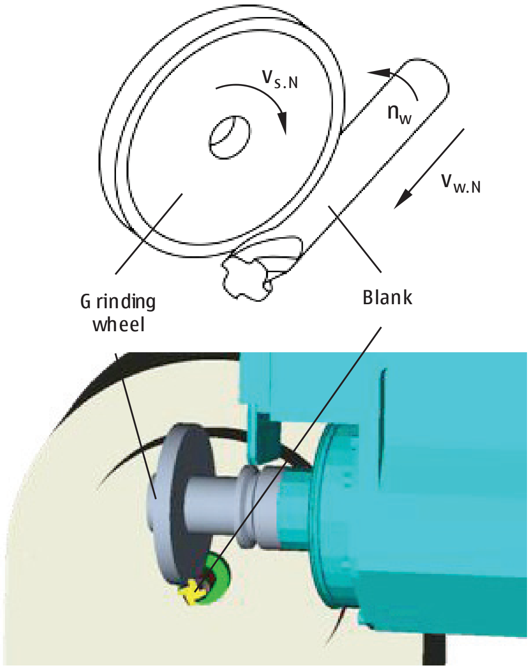

Fig. 1. Kinematics of a flute grinding process [14].

Cemented carbide is extensively used in the cutting tool industry and requires the application of superabrasive grinding wheels because of its brittle hard material properties. In many cases resin bonded grinding wheels are used, although the material removal rate Q'_w is limited, good surface and cutting edge qualities can be achieved [14,16]. In the last years new hybrid bond specifications were developed, which show a high potential for productivity and quality enhancements during flute grinding. Thus, grinding tests were performed with different grinding wheel specifications in terms of the bond and are analyzed regarding grinding forces, surface quality in the flute and cutting edge quality.

2.1. Experimental setup

The grinding tests were carried out on a 5-axis tool grinding machine WU 305micro by Alfred H. Schütte GmbH, Cologne. Equipped with 3 translational and 2 rotational linear drives, the grinding forces were evaluated by the analysis of the electric current from the machine control. The surface quality of the flute was analyzed with the tactile stylus instrument nanoscan 855 from Hommel Etamic GmbH, Schwenningen.

For each grinding test three flutes were ground in a round cemented carbide blank in order to neglect grinding-in effects. To determine the work result easily the helix angle was set to $\lambda = 0°$ with a lead angle of $\lambda_v = 2.5°$. After the third flute a material removal of $V_w = 1700\ mm^3$ was reached and the work result and process relevant parameters were analyzed. Important properties of the used grinding wheels and cemented carbide blanks are shown in Table 1 and Table 2.