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Tool technologies for milling of hardmetals and ceramics

Thomas Bergs[a], Volkmar Richter[b], Michael Ottersbach[a], Johannes Pötschke[b*], Carsten Hochmuth[c], Katia Busch[c]

[a] *Fraunhofer Institute for Production Technology IPT, 52074 Aachen, Germany*
[b] *Fraunhofer Institute for Ceramic Technologies and Systems, 01277 Dresden, Germany*
[c] *Fraunhofer Institute for Machine Tools and Forming Technology, 09126 Chemnitz, Germany*

* Corresponding author. Tel.: +49 351 2553-7641; fax: +49 351 2554-278. *E-mail address:* johannes.poetschke@ikts.fraunhofer.de

Abstract

Hardmetals and ceramics are major substrate materials for a wide range of cutting tools and forming dies. Due to their high specific hardness the final part geometry is usually obtained by sintering of preformed green parts, electrical discharge machining, grinding and/or polishing. Machining by milling is not possible due to fast and unpredictable milling tool failures. To enable milling for tungsten carbides and ceramics new tool technologies are developed. The technologies encompass nanoscaled tungsten carbide hardmetals, innovative coating systems, new milling tool designs as well as adapted milling processes. By combining these technologies it becomes possible to mill different grades of hardmetals and ceramics with hardness values over 1200 HV10.

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Keywords: Milling; cutting; ultrafine cemented carbides; nanoscaled cemented carbides; hard machining

1. Introduction

The production of tools and forming dies is an increasingly important market segment for the economy in Germany, Europe and beyond [1]. Especially the flexible and fast production of complex forming tools made from very hard and hard to machine material is a challenge. Forming tools made of hardened steels, which are used for example for deep drawing applications, are manufactured by grinding, electrical discharge machining (EDM), turning or milling. The latter one offers the highest efficiency due to the high flexibility, high material removal rates and a large knowledge on the process of milling. However, so far milling can only be used for materials with a hardness of up to 1000 HV. Milling of harder materials leads to tool failures due to the chipping of the coating or breaking of the cutting edge already after short cutting distances. This is a drawback, since for more and more demanding forming processes very hard materials such as hardmetals or ceramics are used.

So far hardmetals and ceramics are solely machined through grinding or EDM. An exceptional case are cobalt rich hardmetals with a binder content above 30 vol-%, which can be machined with diamond based milling tools. However, the need for hardmetals with a binder content between 10 to 27 vol-% and a hardness between 1150 HV10 and 1700 HV10 is dominant for the tool and die making industry. Actually, the wide use of such materials is limited due to insufficient machinability by milling. [2-5]

Fundamental investigations on turning fine grain sized and coarse grain sized tungsten carbides with a cobalt content of more than 15 vol-% showed the general machinability of tungsten carbides in continuous cutting operations. But the results cannot directly be transferred to milling due to the interrupted cut and the continuously changing engagement conditions of the tool with the workpiece. [6,7]

Previous investigations on finishing of hardmetal coatings demonstrated the feasibility of milling tungsten carbide materials with polycrystalline diamond (PCD) tools in a small parameter range. Tests were performed at the coating material WC-17Co with a hardness of 1100 HV. The abrasive tool wear on the flank face showed a linear behavior (Figure 1). Furthermore, with increasing chip thickness the cutting edge was subject to chipping due to the brittleness of the PCD. This

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wear mechanism entails reduced process reliability. Due to the extensive costs of the milling tools only low efficiency can be reached. Hence, new milling tool concepts are required to realize profitable and reliable machining.

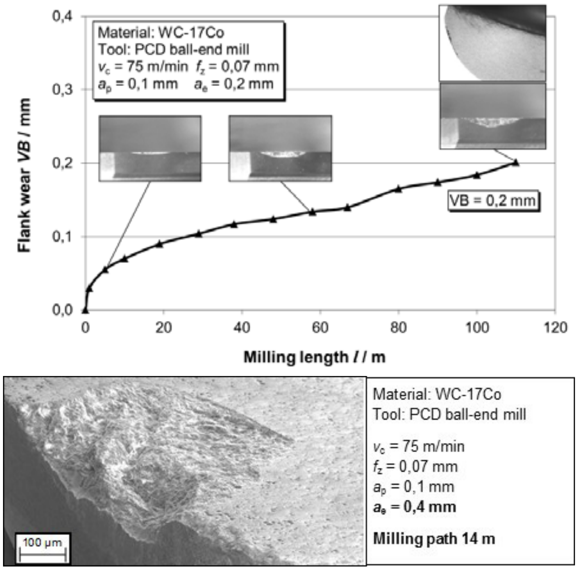

Figure 1. Tool wear in milling of a hardmetal coating with PCD tool

First potentials of the application of coated carbide-end-mills in finishing hardmetal could be shown in a fundamental study. However, chipping of the coating on the tool rake face followed by a spontaneous failure of the coating on the flank face result in low process reliability concerning tool life and surface quality of the workpiece (Figure 2).

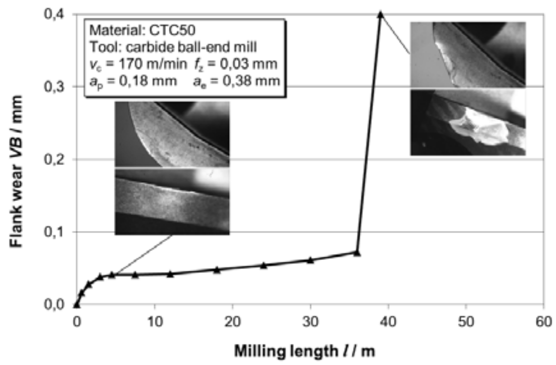

Figure 2. Tool wear in milling of hardmetal with coated carbide tool

Further researches were done in the field of micromilling with PCD and CBN tools. They showed that ductile cutting of tungsten carbides is also possible [8,9]. An analytical model was set up to define the region of ductile-brittle material removal processes. The tools just showed short tool lifetime and failed mainly through chippings and breakages of the cutting edges. [10,11] Additionally, ARIF investigated the chip formation mechanism when cutting hardmetals [12].

Currently some milling tool and machine tool manufacturers showed the possibility of cutting tungsten carbides in trial and error tests. At this point no fundamental process knowledge is existing [13-16].

Hence, the following requirements for the development of carbide milling tools for hardmetal materials can be derived from the first investigation results:

- High wear resistance and predictable wear behavior
- High coating adhesion on the substrate
- Sufficient toughness of the substrate
- Optimized cutting edge geometry

Furthermore, milling processes have to be systematically adapted and improved to machine tungsten carbides.

2. Concept of research

In this paper a new innovative concept will be presented, which will cover the complete process chain to develop innovative milling technologies. To set up newly hard milling technologies for hardmetals, a concept, which unites several research disciplines, is set up. Based on a fundamental understanding of process correlations and dependencies, the improvements will be further developed and finally transferred to industrial applications. The project »HakeMill« is splitting the research work for milling of hardmetals into three development modules “Milling tools”, “Process Technology” and “Forming tools” (see Figure 3). The development tasks in each module are connected to each other and continuously linked with the work in the other modules. In the end the results of the three modules are combined again, which allows a qualification and an evaluation of the technology concept.

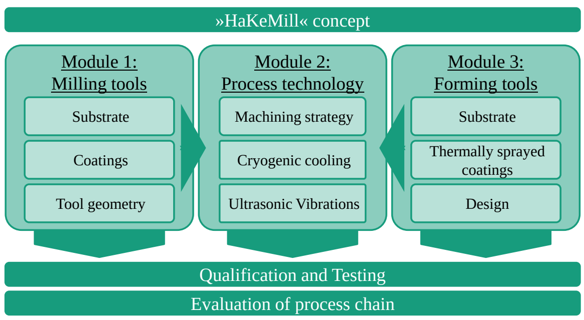

Figure 3. Modular research concept for milling of tungsten carbides

In Module 1 the milling tool technology is developed. It is focussed on the three development fields substrate, coatings and tool geometry. These three fields have to be combined to develop milling tools, which can resist the high thermo-mechanical loadings from milling hardmetals. Therefore high fracture toughness and compressive resistance as well as high hardness of the tools are needed. Furthermore the substrate material should show high temperature hardness to tolerate temperatures up to 1000°C which occur in the cutting zone. To avoid damage to the substrate it is necessary that most of the energy in the cutting zone is absorbed in the chip. The development of new nanocrystalline cemented carbide