Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 46 (2016) 416 – 419

www.elsevier.com/locate/procedia

7th HPC 2016 – CIRP Conference on High Performance Cutting

Experimental investigations on the machinability of tungsten carbides in orthogonal cutting with diamond-coated tools

Michael Ottersbach[a]*, Wei Zhao[a,b]

[a]Fraunhofer Institute for Production Technology IPT, Steinbachstrasse 17, 52074 Aachen, Germany
[b]Nanjing University of Aeronautics and Astronautics, 29 Yudao Street, 210016 Nanjing, China

* Corresponding author. Tel.: +49 241 8904 451; fax: +49 241 8904 6451. *E-mail address:* Michael.Ottersbach@ipt.fraunhofer.de

Abstract

A trend in the tool and die making industry is seen towards using highly wear-resistant and extremely hard dies for stamping and forming operations, which are made of tungsten carbides. The limiting factor to manufacture such dies is the poor machinability of these materials. In this paper orthogonal cutting tests on different tungsten carbides with diamond-coated tungsten carbides tools were carried out. It was observed that ductile cutting of tungsten carbides is possible. The influence of different tungsten carbide grades on specific cutting forces with variable process parameters was evaluated in this paper.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair
Prof. Matthias Putz

Keywords: Cutting; Carbides; Diamond coating

1. Introduction

Tungsten carbides are important materials for the production of cutting tools, molds and dies due to their high hardness and excellent resistance against mechanical loadings and wear [1]. Especially in the die and mold making industry, more and more dies are made of tungsten carbides instead of hardened steels or powder metallurgical steels in order to fulfil the market demands of long tool life time. The excellent mechanical properties like a more than two times higher Young`s modulus compared to steel and hardness values of over 2000 HV lead to extremely poor machinability of tungsten carbides. These material properties are the main limitation for the wide use of tungsten carbides. Presently, grinding, polishing, electrical discharge machining (EDM) and electrochemical machining (ECM) are the only mentionable machining technologies. However, these processes are limited in their productivity and geometrical flexibility [1-2]. Therefore cutting processes, especially milling, which are highly flexible and productive in the same way, have a high potential to improve the manufacturing of dies and molds made of tungsten carbides.

Presently it is not possible to apply milling processes to tungsten carbides. The reason is the high thermo-mechanical loading on the tool, which leads to fast and non-predictable failures of the coating and tool substrate when machining tungsten carbides [3-5]. The consequence is that manufacturing of tungsten carbide dies is not economical with the actual milling tool and process technology.

In the past 20 years many researches were working on the topic of machining tungsten carbides with defined cutting edges. LIU et al. [5] studied the micro- and nanoscale ductile cutting of tungsten carbide with CBN cutting tools. They validated that ductile cutting could be achieved when the undeformed chip thickness was below a certain critical value. High precision turning of fine grain sized tungsten carbides was investigated by BERTALAN and by MOELLER for coarse grain sized tungsten carbides [6-7]. The ultrasonic elliptical vibration cutting (UEVC) method was analyzed by SUZUKI et. al., NATH et. al and ZHANG. They found out that by ultrasonic vibrations the cutting process can be improved compared to conventional machining. With this method it was possible to increase the maximum uncut chip thickness for ductile cutting of brittle materials [8-10].

2212-8271
Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair
Prof. Matthias Putz
doi:10.1016/j.procir.2016.04.008

ARIF et al. developed an analytical model to determine the critical uncut chip thickness for finishing a crack-free surface on tungsten carbides by micro milling [11-12]. Furthermore, NAKAMOTO et al. [13] and ZHAN et al. [14] studied the influence of PCD tool wear on the surface roughness of tungsten carbides in micro milling.

First tests in milling with different cooling concepts of thermally sprayed tungsten carbides with tools made of thickfilm CVD-diamond were analyzed by NEUGEBAUER. The tools failed unreproducible and mainly due to brittle chippings on the rake face. [15]

However, the mentioned researches showed that ductile cutting of tungsten carbide is possible, but limited to very small uncut chip thickness of a few micrometers. A transfer to milling operations of dies and molds is therefore limited due to fast tool failures, which are resulting from the poor combination of toughness and hardness of the tools. First tests showed that the combination of tough tungsten carbide substrates with hard CVD-diamond coatings can be a process enabler for milling of tungsten carbides. Actually just rare information and knowledge exist on milling of tungsten carbides.

The motivation of this paper is to conduct systematical analyses in orthogonal cutting tests on different tungsten carbide grades with diamond coated tungsten carbide tools. The aim is to get fundamental knowledge about the machinability of the hard to machine materials tungsten carbides when varying the process and material parameters. In this first investigation the chip formation and the specific cutting forces are evaluated. With the generated knowledge it will be possible to optimize milling tool's geometry and to design economical high performance milling processes for tungsten carbides. It will be possible to significantly improve the actual process chain for manufacturing dies and molds of tungsten carbides by the substitution of EDM and grinding by milling.

2. Experimental setup

The orthogonal cutting tests were carried out on a specially developed test bench. By this it is possible to obtain fundamental knowledge about the machinability of difficult-to-cut materials like tungsten carbides (see Fig. 1). The test bench is driven by hydrostatic linear direct drives and equipped with a Kistler force measurement unit, a high velocity video camera and a thermal video camera [16].

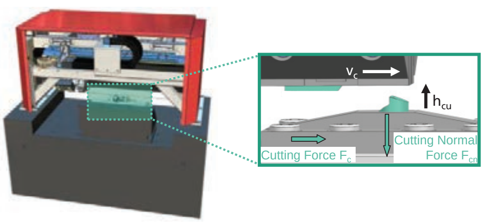

Fig. 1: Setup of test bench

The analyzed tools are made of submicron grain sized tungsten carbide (average grainsize 0.4 µm) coated with a multilayer CVD diamond. To ensure reproducibility of the tests the geometry of the cutting edge of the tools is measured with an Alicona Infinite Focus 4G measurement system (see Table 1).

Table 1. Properties of cutting tools and coating material

Properties	Rake angle (°)	Clearance angle (°)	Cutting edge radius (µm)	Coating thickness (µm)	Coating hardness (HV0.05)
	0	15	19±2	20	10,000

In total two different tungsten carbide grades were machined. The focus in this analysis was to investigate the influence of the variation of the cobalt content on the machinability. Thus fine grain sized tungsten carbides were chosen with a cobalt content varying from 17.5 to 11.8 weight percent. To define the average grain size, cross sections of both materials were taken and afterwards analyzed by a linear structure analysis (see Fig. 2). The average measured grain size of the tungsten carbides was 0.7 µm in both cases. The composition and the resulting physical properties can be found in Table 2 and Table 3.

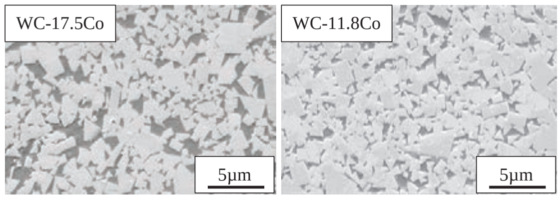

Fig. 2. Cross sections of the investigated tungsten carbides

Table 2. Composition of the workpiece materials

Composition / **Grade**	WC (wt.-%)	Co (wt.-%)	Other (wt.-%)	Average measured grain size (µm)
WC-17.5Co	80.3	17.5	2.2	0.7
WC-11.8Co	87.0	11.8	1.2	0.7

Table 3. Physical properties of the workpiece materials

Properties / **Grade**	Hardness	Transverse rupture strength	Fracture toughness	Density	Young's modulus
	HV10	MPa	$MPa \cdot m^{0,5}$	g/cm^3	GPa
WC-17.5Co	1150	3300	15	13.56	480
WC-11.8Co	1400	3000	12	14.15	551

For the experiments the process parameters cutting velocity v_c and uncut chip thickness h_{cu} are varied. The cutting velocities are set to the values 70 and 140 m/min and the uncut chip thickness was varied step by step to values between 1 and 30 µm. The width of cut b, which is given by the thickness of the specimen, is 1.22 mm. The cutting length is 20 mm. To increase the precision of the test bench, the actual uncut chip thickness is measured by a tactile measurement sensor, which measures the height of the specimen before and after each test. By subtracting both profiles the exact thickness of the removed material is calculated.