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Model System Studies of Wear Mechanisms of Hard Metal Tools when Cutting CFRP

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Abstract

Within the publicly-funded ZAFH research project SPANTEC light, the Competence Center for Tribology in Mannheim, Germany, examines the wear mechanisms of hard metal tools when cutting carbon-fiber-reinforced plastic in drilling and milling processes. The research project includes a test series with a tribological model test.

The development of a new tribological simulation model system, a modified pin-on-disc system respectively called as edge-on-disc system, for cutting CFRP with hard metal composites is systematically analyzed and presented in this work. With this model system, a new method for tool wear analysis of the tool materials against CFRP is described.

As result, there are further findings on the wear mechanism of the hard metal tungsten carbide in cobalt matrix (WC-Co) compared with carbon-fiber-reinforced plastic (CFRP). Research parameters for the tribological system in this paper are the WC-Co materials, with their WC-grain size and cobalt content, and the carbon fiber orientation.

This study introduces a first approach to determine WC-Co wear compared with a CFRP-specimen, unlike most hard metal wear tests. Furthermore it is shown, that properties of the drilling and milling processes can be adapted by altering the model systems rotating speed and normal force. The results originality is also provided by using a variety of WC grain size classes (sub-µm to approximately 7-9 µm grain size) and cobalt contents far above usual CFRP-machining properties to show the wear process between carbon fibers and WC-Co in detail.

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Keywords: Wear; tribology; hardmetal; pin-on-disc; machining; CFRP

1. Introduction

When cutting CFRP, tools suffer high stress loads, the intensity of which clearly depends on the structure of the CFRP workpiece. These loads cause strong abrasive tool wear on uncoated hard metal tools. As the cutting edges of the worn tools become increasingly rounded, they load increasing mechanical stress on the cutting zones and cause damage to the workpiece. The damage caused is delamination of the top coat near the surface and of the surface-near coating layers, fiber protrusion or matrix degeneration. The quantification and the method of quantification of the delamination damage by the tool wear-states are shown by Lissek [9].

A limit to the quantified CFRP work piece damage can be set and a correlating tool life for a drill or miller can be estimated. Tool life predictions for CFRP drilling were done by Iliescu [7]. The Method described is depending on the tool geometry and leads to good results in tool life predictions for known geometries. A geometry independent tool life prediction therefore is not described. But common loading conditions, like thrust force estimations through wear prediction can be adapted to basic edge geometry.

When modeling the tribological system at the cutting contact, the optimization parameter for qualitatively good cutting results is an optimally sharpened cutting edge which suffers minimal wear while also being resistant to load changes without fracturing.

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Models systems with coatings sometimes need to be viewed critically as qualitatively good coating requires a small cutting edge radius. It is also possible to use cutting edge geometries which are intended to remain sharp through the wear process [2].

One key objective in the analysis of a tribological system is the determination of the type of wear. In steel machining applications, the tools suffer chipping and metal adhesion, as shown by Chinachanikar [4]. Also built-up edges and mild abrasion are common, shown in the tool life determination of Krolczyk [5]. Hard coated tools also suffer chipping in CFRP machining due to high dynamic loads when cutting the fibers [7]. The wear mechanisms mostly depend on the tool's material and surface structure and, of course, the counter body. In the hard-metal-/ CFRP- system as shown and described later on, the wear mechanism tends to be purely abrasive to both, the cobalt and WC-phase.

The objective of this work is to provide a more detailed description of the complex system of primary stress loads and the incurred wear mechanisms on the tools. This insight into the wear mechanisms of the commonly used WC-Co hard metals provides ideas for improvement and optimization of the hard metal composition.

This paper is divided into three chapters: a description and analysis of the tribosystem, a description of the wear mechanisms and the results. The chapter on the results outlines, interprets and quantifies the most significant influencing factors of the system.

2. Wear mechanisms and wear testing for CFRP-machining applications

For the state of the art of wear testing for CFRP-machining applications, the application itself, e.g. drilling or milling of CFRP-pieces is used to derive the wear, mechanisms and the propagation of tool wear and workpiece damage.

Approaches for single elements of the tribological system are done in various works. For example, the WC-Co wear depending on different WC-grain sizes and Co contents is described in [8]. The mating counterbody used in the system is a hard body of silicone-carbide. The system itself is described in the ASTM G65.

By now, a CFRP-counterbody for wear testing is by doing drilling and milling tests with complex tool shapes. This demands higher efforts than model testing. Furthermore it is especially important for the screening of fine-tuned system compositions in statistically relevant quantities. For the geometric dependencies of the tool shapes, the application-like testing often leads to special shapes of the cutting tool.

As a first combined approach for the development of a CFRP-machining model system is therefore described in the following parts.

Nomenclature

CFRP	carbon-fibre-reinforced plastic
WC	tungsten carbide
Co	cobalt / cobalt volume fraction [%]
HM	hard metal
MD	multidirectional (laminate)
UD	unidirectional (laminate)
WC-α	tungsten carbide grain size [µm]
p	pressure as surface load [MPa] or line load [N/mm]
v	velocity / speed
s	sliding distance
G	geometry (as a state variable)
p_m	intermediate pressure as stress load on cutting edge [MPa]
W	wear (once used as a state variable)
W	wear rate as volume loss [mm³] per pressure load [N mm^{-2}] and sliding distance [mm]; Short Unit: [mm^4 N^{-1}]

3. System Analysis

Following the common systematic approach of Czichos [10, 11] and Habig [11], the system is divided into two structural elements – the HM tool as base body and the CFRP workpiece as counterbody. The system is an open system as the set feed and speed of the tool results in a continuous and nearly constant amount of material wear on the CFRP workpiece. The abrasive effect of the CFRP surface is constantly renewed in the cutting process. Atmospheric influences on the tribosystem are normally a negligible factor in real systems as long as the chips do not remain in the friction point because real systems normally rarely use liquid cooling lubricants and have cycle times that do not allow temperature-induced increase in the oxidation of the hard metal used.