

Micro crack formation in hardmetal milling tools



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A B S T R A C T

Hardmetal milling tools are frequently used for machining of hard materials, e.g. titanium alloys. Such tools are often reground after the end of their lifetime. This is intended to increase the resource and the economical efficiency of the required but expensive hardmetal blanks. However, end users often notice a decreased lifetime when using reground tools. Subsurface damages that are not removed during regrinding probably cause this effect. This paper investigates the formation of cracks in hardmetal milling tools and consequently suggests grinding strategies that consider the removal of all present micro cracks. The results show a correlation between the required amount of material removal and the size of the optically measurable breakouts at the cutting edge.

1. Introduction

Titanium alloys are used in many different fields of applications, e.g. the aerospace industry. Their comparatively low density, high hardness, corrosion resistance, and high temperature properties allow their utilization in very hot environments, where Aluminum alloys are not suitable [1]. However, the occurring removal rates of up to 95% of the titanium alloy workpieces as well as the high tool load during the corresponding milling process demand the utilization of hardmetal tools [2]. The main properties of the hardmetals, i.e. high hardness and toughness, cause a market share of up to 50% of all produced milling tools [3,4]. However, the comparatively low lifetimes of 30 to 60 min and the high costs for the hardmetal blanks make regrinding operations for an economical recycling process of those tools essential (see Fig. 1).

The main challenge for the recycling process is the precise evaluation of the present defects of a worn milling tool. The maximum depth of the biggest defect of each individual tool has to be identified in order to determine the necessary allowance during the subsequent regrinding operation. Currently, the responsible worker for this job detects the damage depth only using magnifying glasses or without any help of measuring equipment. Therefore, the process is very tedious and a detection of microscopic damages, e.g. micro cracks, cannot be performed. However, the remaining micro cracks in the reground milling tool can result in a significant reduction of the tools lifetime in the consecutive milling process. Furthermore, wrong estimations of the worker may lead to allowances that are too high and thus reduce the resource efficiency since more material than necessary is removed. In consequence, the amount of possible regrinding operations is reduced and the economability of the tool and its related milling operation

decreases.

2. Experimental setup

This paper investigates the wear behavior of hardmetal milling tools in order to estimate economically and environmentally friendly grinding allowances that ensure constant tool lifetimes. The investigated end mills have a diameter of about 23 mm. As material, the specification Extramet EMT 210 is used. Each milling tool has been used differently and therefore experienced divergent process loads. This leads to a high variation of different forms and sizes of tool wear in the investigated sample.

Different measuring devices have been investigated during preliminary research work in order to identify viable methods to quantitatively measure the tool wear of hardmetal end mills. For the detection and evaluation of external defects, e.g. breakouts, optical measurement devices based on stripe light projection or focus variation have been identified as the best choice. Both methods can determine the depth of breakouts with a resolution of under 5 µm in a timely manner [5]. Consequently, a Keyence VR 3000 Stripe light projection microscope has been used for the determination of external defects. However, this device only determines the defect depth orthogonal to the cutting edge. Therefore, it does not give any information about the defect size at the flank and rake face that might be of larger extend. Thus, cross sections of the milling tools were produced and investigated using a Keyence VHX 600 digital microscope. The resulting pictures have been evaluated in regards of the defect size at the rake and flank face. Furthermore, a topcon SM 510 W scanning electron microscope was utilized for the creation of high resolution pictures of the end mills cross section. X-

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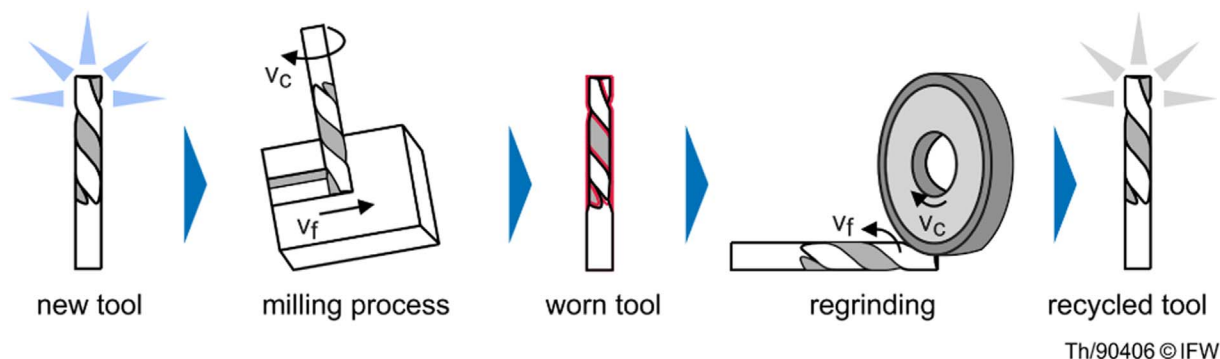


Fig. 1. Life cycle of milling tools.

ray examinations were considered for the detection of internal defects of the hardmetal. However, the high atomic number of the tungsten leads to a high density of the hardmetal, which makes x-ray investigations unsuitable.

3. Investigation of worn milling tools

The results show that the defect length on rake and flank face increase with increasing defects at the cutting edge (see Fig. 2). The data scatters strongly and thus does not show a direct correlation of the defects at the cutting edge and the defects on the flanks. Contrary, for optical defects of above 300 μm , defects on the rake face tend to be greater than the corresponding defects on the flank face. This effect is probably caused by the higher process load of the rake face during the previous milling operation.

Further, scanning electron microscope (SEM) pictures of the cross section of worn milling tools were investigated. As a result multiple micro cracks could be detected near the macroscopic defects. Consequently, the sample of 30 worn milling tools has been evaluated in consideration of micro cracks and their size. It has been shown that all identified micro cracks have a width of below 500 nm. Therefore, they cannot be detected by dye penetrant inspection or the investigated optical systems other than the SEM. The resolution of dye penetration inspection methods is too low and can only be used reliably for cracks wider than 1,5 μm . Therefore, it is not suitable for the identification of micro cracks in hardmetal tools. Contrary, common optical methods can reach the required resolutions when using a fitting wavelength and numerical aperture of the utilized lenses. However, the disadvantage of those optical approaches is the required measurement and processing

time of up to several days for the creation of a single picture. Furthermore, a detection of micro cracks on those pictures must be done manually since the cracks are hard to distinguish from grain boundaries and the diameter of the crack exit is below 1 μm . In that sense the manual detection can lead to identification errors. The crack exits also do not give any information about the depth of identified cracks. Consequently, surface pictures would not lead to any conclusions regarding the necessary allowance during the subsequent grinding operation.

The measurement by SEM is the only viable option for the evaluation of micro cracks, but requires the destruction of the investigated tools. Therefore it is not transferable to the industrial application. However, the method can be used to investigate the statistical relationship between the optically measurable defect depth and the depth of the present micro cracks. The developed model can consequently be considered during the determination of an individual allowance for worn milling tools.

Three different states of micro cracks have been detected: Macroscopic cracks (see Fig. 3) have a width of several micrometer and occur close to macroscopic defects of the cutting edge. Those cracks are the main reason for the local spalling of the cutting edge.

The second state is micro cracks that occur due to the high strain at the edges of macroscopic cracks (see Fig. 3) and damage the tool into a higher depth. These cracks crop up between the tungsten carbide grains and weaken the stability of the milling tool. They have a length of up to 400 μm and may lead to tool failure if they are not properly removed during the regrinding process. Broken tools may damage the workpiece and thus can lead to high follow-up costs. Furthermore, remaining cracks increase the variation of the lifetime of reground tools. Thus, the

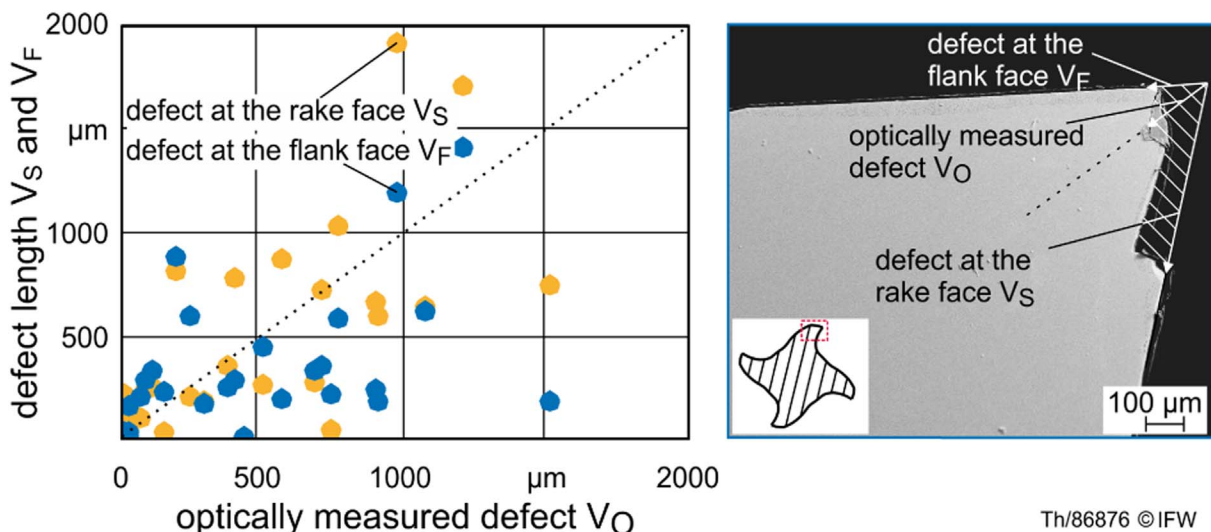


Fig. 2. Size of the defects on the rake and flank face in dependency of the defect size at the cutting edge.

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