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Microstructural characteristics of Alloy 718 and Waspaloy and their influence on flank wear during turning

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ABSTRACT

The present study deals with the influence of the microstructures of two wrought superalloys on the flank wear of uncoated cemented tungsten carbide tools in turning. Tool life tests have been performed in order to compare the flank wear development during machining of Alloy 718 and Waspaloy. Additionally, microstructural aspects, such as hardness, grain size as well as types and quantities of hard, abrasive phases have been determined and compared for both machined superalloy workpieces.

The results show that Alloy 718 is associated with faster flank wear progression as compared with Waspaloy. The difference in wear is not likely to be the result of higher thermal and mechanical loads on the tool during machining Alloy 718. Characterization of obtained flank wear topographies after removal of adhered workpiece material revealed that abrasive wear is the dominant wear mechanism during machining both superalloys with the investigated cutting parameters. Varying extents of abrasive tool wear during cutting of the two alloys are therefore the likely reason for the different wear rates. In connection to that, significantly larger quantities of hard phases, specifically primary MC-type carbides and TiN-inclusions were found in the Alloy 718 workpiece which can explain the faster flank wear progression during machining this alloy.

1. Introduction

The deterioration of metal cutting tools during machining operations has a direct influence on the obtained properties and hence performance of machined components. It is therefore necessary to replace tools before a critical level of wear is reached to avoid damage of the produced component. Understanding and prediction of tool wear is especially relevant when cutting difficult-to-machine materials like Ni-based superalloys [1]. Such alloys are commonly used for safety critical components in the combustor section of modern aircraft engines [2].

Flank wear –often the tool life determining wear form– when machining superalloys has shown to be significantly affected by workpiece characteristics [3,4]. For example, Olovsjö et al. [3] have compared the flank wear progression of uncoated cemented tungsten carbide tools (WC-Co) when machining two different superalloys, Waspaloy and Alloy 718. They reported significantly higher flank wear rates when machining Alloy 718 as compared with Waspaloy. The same trend was shown by Polvorosa et al. [4] both after employing conventional and high-pressure cooling during turning.

Generally, flank wear is considered to take place by a combination of several mechanisms like abrasion, adhesion and diffusion, in some cases along with plastic deformation of the tool material [5].

Even though reports regarding the main active wear mechanisms during machining of superalloys are rather inconclusive [5], most studies report abrasive wear to be active [6,7]. This is often attributed to the presence of large fractions of different types of hard, abrasive phases present in superalloys.

Despite the contribution of hard workpiece precipitates on the flank wear of metal cutting tools, little attention was paid to this aspect by Olovsjö et al. [3] and Polvorosa et al. [4]. In both studies no quantitative information about any of the phases present was given. Such information could however provide additional insights into the possible reasons for the different wear rates obtained when machining Alloy 718 and Waspaloy.

The present study deals with comparing the flank wear characteristics when turning Alloy 718 and Waspaloy. Tool life tests were conducted with uncoated WC-Co tools and followed by in-depth analysis by means of scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX). Results are presented regarding (1) the workpiece microstructures with emphasis on the types and relative amounts of primary carbides and non-metallic inclusions and (2) the wear topographies obtained after machining the respective alloys. The

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Table 1
Chemical composition (wt%) of the two superalloys with Ni as balance.

	Cr	Co	Fe	C	Mo	Al	Ti	Nb	B	Mn	Si
Alloy 718	18.4	0.3	17.5	0.04	3.0	0.6	0.9	5.5	0.001	0.09	0.05
Waspaloy	19.4	13.2	1.2	0.03	4.1	1.3	3.1	–	0.005	0.03	0.05

Table 2
Investigated cutting parameters.

Workpiece	Cutting speed, v_c [m/min]	Feed rate, f [mm/rev]	Depth of cut, a_p [mm]
Alloy 718	45	0.05	1
Waspaloy	45	0.05	1
Alloy 718	45	0.1	1
Waspaloy	45	0.1	1

Table 3
Mechanical and microstructural properties of the workpieces. Given are also the standard deviations of the measured values.

Workpiece	Average hardness [GPa]	Average hardness [HV]	Average grain size [µm]
Alloy 718	4.22 ± 0.05	430 ± 5	27 ± 2
Waspaloy	3.75 ± 0.04	382 ± 4	65 ± 4

observed microstructural differences between the two superalloy workpieces are then discussed with respect to their contribution to the flank wear behavior.

2. Experimental

2.1. Workpiece heat treatments and tool life tests

The workpiece materials used in this study were Alloy 718 and Waspaloy. Alloy 718 is a Ni-Fe based superalloy and Waspaloy a Ni based superalloy. The chemical compositions of both alloys is given in Table 1. The workpieces consisted of discs with diameter of 126 mm and 128 mm and thickness of 38 mm and 27 mm for Alloy 718 and Waspaloy, respectively. The discs were heat treated to achieve fully age-hardened microstructures prior to the machining tests. The heat treatments were conducted in accordance to AMS 5662 (Alloy 718) and AMS 5707 (Waspaloy) standards [8,9].

The heat treatment of Alloy 718 consisted of solutionizing at 954 °C (2 h holding time) followed by water quenching and subsequent two-step ageing at 718 °C (8 h) and 621 °C (10 h). For the Waspaloy workpiece, solutionizing was carried out at 1010 °C (4 h) followed by a stabilization heat treatment at 843 °C (4 h). Ageing was then done at 760 °C for 16 h.

Face turning tests were conducted on an EMCO 365 CNC lathe equipped with a Kistler 9275A three component dynamometer. Throughout the tests, cutting fluid (6–7% emulsion) was supplied to the tool rake faces. The experimental setup can be seen in Fig. 1a. Commercially available uncoated cemented tungsten carbide inserts (Sandvik Coromant, TCMW 16 T3 04 grade H13A) were used. The tool grade consists of WC and Co with an average WC grain size of 0.8 µm and 10 vol% Co-binder [10]. In combination with the applied tool holder (Sandvik Coromant, C3-STGCR-22040-16) this led to 0° rake angle, 7° clearance angle and 91° entrance angle. To minimize the effect of geometrical variations of the cutting edges of the used inserts, edge radii measurements were performed. Only inserts with similar edge radii were used during the tests.

The used machining parameters are summarized in Table 2. For each superalloy workpiece, the same two sets of cutting parameters were employed to be able to compare the tool wear behavior associated with the respective workpiece. Each test was conducted in intervals. After each interval the machine was stopped and a stereo optical microscope (Zeiss Discovery V20) was used to measure the width of flank wear land (VB). In that way the tool wear progression with increasing cutting time was monitored. The tests were stopped either when the maximum width of flank wear land exceeded 250 µm or when a total of eight intervals were machined. Each test was performed at least two times in order to ensure repeatability of the obtained results.

Average cutting forces were determined when cutting with still unworn tools, i.e. during cutting in the beginning of the first machining interval of each test. In that way it was possible to compare the cutting forces associated with machining the two workpiece materials without the influence of different flank wear rates.

2.2. Characterization methods

For characterization of the workpiece microstructures and the obtained flank wear characteristics, light optical microscopy (Leitz DMRX) and scanning electron microscopy (SEM) were applied. Both a FEI/Philips XL-30 SEM and a Zeiss Leo 1550 Gemini field emission SEM were used. The latter one was equipped with a detector for energy dispersive X-ray spectroscopy (EDX, Oxford X-Max silicon drift detector).

2.2.1. Workpiece analysis

The hardness and grain size of each of the workpieces was measured at several locations. For this purpose, a total of four samples were extracted from each of the centers of the two workpieces prior to the turning tests (see Fig. 1a and b). Standard polishing techniques were employed as well as etching by use of Kallings number 2 etchant.

As-polished samples were used for hardness testing (Vickers, 10 kg load). For each sample an average of five hardness indents was obtained.

Average grain sizes of the two workpieces were determined by obtaining the respective mean lineal intercept lengths [11]. For each

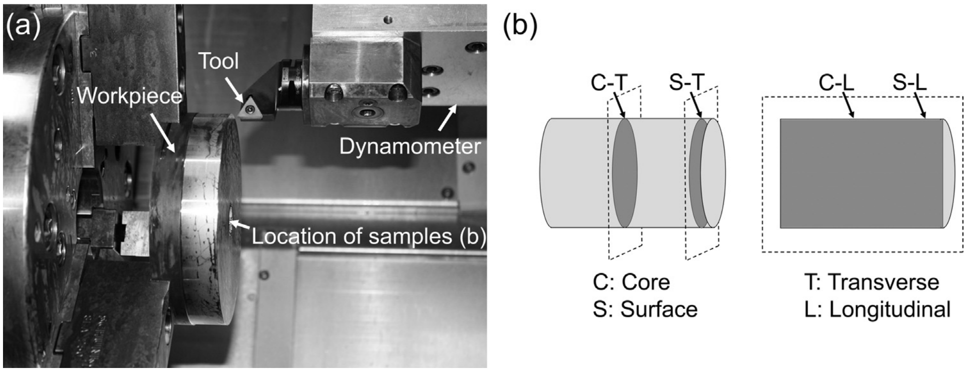

Fig. 1. Experimental setup of face turning tests with location of extracted sample for metallographic investigation indicated (a). Approximate locations of microstructural characterization on the extracted samples (b).

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