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New observations on tool wear mechanism in dry machining Inconel718 ☆

Zhaopeng Hao [a,*], Dong Gao [a,1], Yihang Fan [b], Rongdi Han [a]

[a] School of Mechanics Engineering, Harbin Institute of Technology, Harbin 150001, China
[b] School of Mechanical & Power Engineering, Harbin University of Science and Technology, Harbin 150080, China

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ABSTRACT

Tool wear is a problem in machining nickel-based alloy Inconel718, and it is thus of great importance to understand tool wear. Tool wear mechanism in dry machining Inconel718 with coated cemented carbide tools was analyzed in this paper. CCD and scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectrometer (EDS) were used to study tool wear mechanism. The results show that the main reason which causes cutting tool wear was that the tool materials fall off from the tool substrate in the form of wear debris. In addition,, element diffusion between tool and workpiece and oxidation reaction all accelerate the formation and the peeling of the wear debris. According to analysis of tool wear mechanism, tool flank wear model was established. The optimal temperature in machining Inconel718 with PVD-coated (TiAlN) tool was obtained through the established model. Excellent experimental agreement was achieved in optimal temperature calculated by the established model.

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1. Introduction

Inconel718 is widely used in aerospace engine parts, gas turbine wheel, and vanes, owing to its unique properties such as high oxidation resistance, corrosion resistance even at very high temperatures, and retaining a high mechanical strength under these conditions as well. But due to peculiar characteristics such as lower thermal conductivity, work hardening, presence of abrasive carbide particles, hardness, and affinity for tool material, the cutting tools wear very rapidly [1]. Inconel718 is classified as "difficult-to-cut materials" and more attention is paid to tool wear mechanism in machining Inconel718.

Liao and Shiue [2] came to a conclusion that in turning of Inconel718 with carbide tools, the tool wear during high speed turning condition (v_c=35 m/min) was caused by diffusion of elements (Ni or Fe) in workpiece into tool's binder (Co) by a grain boundary diffusion mechanism. Kitagawa and Kubo [3] dealt with the high-speed machining of lncooe1718 using ceramic tools from a thermal point of view. They claimed that for lnconel718, severe wear of ceramic tools, particularly highly developed boundary notch wear, was correlated with variation of the chip formation mechanism from continuous to discontinuous, which was accompanied by large side flow of the chip and plastic burrs of the workpiece. This indicated that tool wear was developed by an abrasive process rather than by a thermally activated mechanism. Song and Zhao [4] claimed that the main tool wear feature was coating peeling when machining Inconel718 using coated carbide tools. Devillez et al. [5] analyzed tool wear in dry machining Inconel718 with coated carbide tools. They observed that work material adhered to the cutting edge at the early stage of cutting, and then to form a built-up-edge (BUE), and a built-up-layer (BUL) on tool faces. Depending on cutting conditions and on used tool, the BUE and BUL were not always stable and sometimes fragments of adhering work material were removed, and they can drag out tool particles leading to a crater on rake face. Thakur et al. [6] studied the influence of cutting parameters on the machinability characteristics of Inconel718. They claimed that increase in cutting speed and feed rate caused a greater increase in cutting temperature at the cutting edge of the tools. The higher temperature caused the tools to lose their strength and then plastic deformation occurred. The main type of wear was abrasion, micro-chipping, and also some plastic deformation under dry cutting condition. The BUE formation was unseen for the selected machining parameters (v_c=40−60 m/min).

Some researchers study the tool wear using the method of FEM. Lorentzon and Jarvstrat [7] developed a finite element tool wear model based on an empirical tool wear model in a commercial finite element (FE) code to predict tool wear. Different friction and wear models have been analyzed, as well as their impact on the predicted wear profile assessed. Excellent experimental agreement was achieved in wear simulation of cemented carbide tool in machining Inconel718.

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* Corresponding author. Tel.: +86 159 4599 4371; fax: +86 0451 86413810.
E-mail addresses: haozhaopeng@126.com (Z.P. Hao), gaodong@hit.edu.cn (D. Gao).
[1] Tel.: +86 0451 86413810.

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Nomenclature

v_c	cutting speed
f	feed rate
a_p	cutting depth
h	thickness of wear debris
h_0	flank wear width
dh_0	elemental flank wear width
t	cutting time
dt	elemental cutting time
T	tool life
σ_f	fraction intension of the tool
dl	cutting length
G	shear modulus (the ratio of shearing stress and shearing strain)
b	Burgers vector
ν	Poisson's ratio
p	normal load
γ_0	rake angle of the cutting tool
α_0	relief angle of the cutting tool
θ	cutting temperature
κ_r	cutting edge angle
K, C, A, C_0	empirical constants

Besides the wear mechanism, the measurement of tool wear is also important for the tool wear research. Jurkovic et al. [8] proposed a new approach in tool wear measuring technique using CCD vision system. The system consists of a light source to illuminate the tool, CCD camera, and laser diod with linear projector, grabber for capturing the picture, and a PC. The technique can determine the profile deepness with the help of projected laser raster lines on a tool surface.

This paper presents a study on tool wear mechanism through the observation and analysis of the tool wear surface and establishes a tool flank wear model. The optimal temperature for one pair of tool-workpiece in machining Inconel718 with PVD-coated (TiAlN) tool was obtained through the established model. This can provide an efficient and quick way for reasonable choice of cutting parameters in machining Inconel718.

2. Experimental procedure

The workpiece used in this study was an Inconel718 bar of diameter of 100 mm. Mechanical properties of Inconel718 is shown in Table 1.

Turning was conducted on a lathe (CA6140) with a frequency converter by dry machining using two types of tools. The tool material and geometry parameters are presented in Table 2. CCD observation system and SEM were used to measure and observe tool wear. Energy dispersive X-ray spectrometer (EDS) was used to study tool wear mechanism.

Natural thermocouples were used to measure the cutting temperature (the average temperature). The cutting force measurement system composed of Kistler 9257A three-dynamometer, 5007 charge amplifier, and data acquisition card were used to record the cutting force signals in three directions.

In machining Inconel718, the cutting speed v_c is the main reason that affected the tool life [5]. The experiments were conducted with different cutting speeds. The feed rate and cutting depth were constant (a_p=1 mm, f=0.1 mm/rev).

3. Results and discussion

3.1. Tool wear morphology

At the cutting speed v_c=20 m/min, the tool wear morphology is shown in Fig. 1. There are lots of adhesion materials at cutting edge (built-up-edge, as shown in Fig. 1(a)). With cutting process going on, the adhesion material was taken away by chip. It resulted in chipping on the one hand, (as shown in Fig. 1(b)). On the other hand it led to cracks in tool subsurface, which subsequently fell off in the form of wear debris.

In high-speed cutting Inconel718, cracks occurred between lamellar wear debris and tool substrates (as shown in Fig. 2(a)), subsequently workpiece material filled in the cracks with cutting process going on. Grooves were also found in tool rake face after lamellar wear debris falling off. The increasing cutting speed made the density of wear debris become larger, as shown in Fig. 2(b) and (c).

3.2. Tool chipping

In the process of cutting Inconel718, the friction and squeezing at tool–chip and tool–workpiece interface led to high temperature and cutting pressure and thereby destroyed oxidation layer and adsorption film. The workpiece material adhered to tool surface, which resulted in BUE and unstable adhesion material. With cutting process going on, BUE and unstable adhesion material fell off. At the same time, the massive tool material was taken away, and then tool chipping occurred.

Table 1
Mechanical properties of Inconel718.

Material	Density, ρ (kg/m^3)	Yield strength, σ (0.2) (MPa)	Tensile strength σ_b (MPa)	Elongation δ_5 (%)	Shrinkage, ψ (%)	Toughness, a_k (J/cm^2)
Inconel718	8280	1260	1430	24	40	40

Table 2
Tool information.

Tool type	Tool material	Tool geometry		
		Rake angle, γ_0(deg.)	Relief angle, α_0(deg.)	Cutting edge angle, κ_γ(deg.)
SNMG120408- AC520U	PVD-TiAlN	9	7	45

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