ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 17 (2017) 467–474

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

New observations on wear mechanism of self-reinforced SiAlON ceramic tool in milling of Inconel 718

*ZhaoPeng Hao, YiHang Fan, JieQiong Lin *, FangFang Ji, Xiaoyong Liu*

School of Mechatronic Engineering, ChangChun University of Technology, ChangChun 130012, China

ARTICLE INFO

Article history:
Received 4 August 2016
Accepted 25 December 2016
Available online 18 January 2017

Keywords:
Inconel718
Self-reinforced SiAlON ceramic tool
Wear mechanism
Optimal cutting temperature range

ABSTRACT

Self-reinforced SiAlON ceramic tool materials, due to its unique properties such as high wear resistance, high hardness and low affinity with metal, is widely used in machining nickel-based alloy. The self-reinforced SiAlON ceramic tool was used in the experimental process of high speed milling nickel-based alloy Inconel718. The results obtained through observing the tool wear morphology and further analysis showed that when cutting speed v_c = 50–200 m/min, abrasive wear and lamellar spalling was the main cause of tool wear. When cutting speed v_c = 350, 500 m/min, the bond strength between β-SiAlON whisker and SiAlON matrix reduced, and then the tool material fell off, which led to the formation of hole and groove. When the hole and groove mark connected, the crack nucleation formed. The crack propagation resulted in fracture eventually. At last, according to the tool wear mechanism, tool wear model was established and the optimal cutting temperature range, which can lead to minimum tool wear in milling Inconel718 using self-reinforced SiAlON ceramic tool, was obtained.

1. Introduction

Nickel-based alloy Inconel718 has excellent properties at high temperature. However, it is classified as difficult-to-machine materials owing to the serious tool wear in cutting process. In order to reduce tool wear, different kinds of cooling lubricant are used widely. However, the increasing attention to the environmental and health impacts of industry activities by governmental regulation and by the growing awareness in society is forcing manufacturers to reduce the use of lubricants [1,2]. Dry cutting and other new auxiliary cutting technology have attracted the attention of academia and business circles. A lot of researches about cutting deformation, tool wear, auxiliary cutting, and new coolant have been carried out [3–7].

The ceramic tool is the better choice of cutting Inconel718 under high cutting temperature because of its high red hardness. Tian et al. [8] studied the effects of cutting speed on cutting forces and tool wear when high-speed face milling Inconel718 with Sialon ceramic tools with the milling tests (Both down-milling and up-milling). The results showed that the cutting forces, tool wear morphologies, and the tool failure

* *Corresponding author.*
E-mail address: lin_ccut@163.com (J. Lin).
http://dx.doi.org/10.1016/j.acme.2016.12.011
1644-9665/

Nomenclature

v_c	milling speed
f_z	feed engagement per tooth
a_p	milling depth
a_e	milling width
k	the slope of the curve
α_o	tool relief angle
γ_o	tool rake angle
Fc	the main cutting force
θ	cutting temperature
W	wear value
P	load
D	average diameter of abrasive grains
K_{IC}	fracture toughness of materials
H	hardness of materials
C, M	constants. They have relation with the mechanical properties of materials $\Delta K = K_{max} - K_{min} = \Delta\sigma\sqrt{\pi a}$
ΔK	amplitude of stress intensity factor, which is the driving force of fatigue crack propagation
$\Delta\sigma$	stress difference
a	crack size
K_{max}	maximum stress intensity factor
K_{min}	minimum stress intensity factor
da	increment of cyclic number of alternating stress
dN	increment of corresponding crack length
a_c	critical crack size
a_0	initial crack size
σ	workpiece yield strength
$\sigma_{bonding}$	bond strength of ceramic tool

mechanisms changed with the cutting speeds (600–3000 m/min). Zhuang et al. [9] studied wear mechanism of alumina-based ceramic cutting tools during dry turning of Inconel718. They made an attempt by employing the hardened layer beneath the workpiece surface to explain the occurrence of notch wear. Based on tool wear mechanism analysis, a predictive model of notch wear depth considering the influence of work hardened layer is developed. Suzuki et al. [10] studied tool failure mechanism in high-speed milling of Inconel 718 by use of ceramic tools. They found that the cutting edge was worn rapidly and a round shape was formed at the initial stage of machining. When the radius of the round cutting edge becomes considerably large, the ploughing process is dominant in ceramic milling. Stress field analysis revealed that the large tensile stress instantaneously generates around the stagnation point. The right selection of process parameters is very important in milling process of Inconel 718 using ceramic tool. Euan et al. [11] presented some models of static and dynamic cutting forces and vibrations for indexable milling tools with round ceramic inserts. These models can be used to determine the cutting parameters for optimum quality and maximum productivity.

Besides dry cutting, other new cutting methods were also studied by many researchers. Altin et al. [12] carried out a series of tool life experiments using silicon nitrite based and whisker reinforced ceramic tools which have two different geometries and three different ISO qualities with 10% water additive cutting fluid. The experiment results showed that crater and flank wears were usually dominant wear types in ceramic square type (SNGN) inserts while flank and notch wear were dominant in round type (RNGN) inserts. Minimum flank wear was seen with SNGN tools at low cutting speeds while it is seen with RNGN tools at high cutting speeds. Leopardi et al. [13] used Laser Assisted Milling (LAM) in cutting Inconel718 to improve the machinability. They investigate the effects of laser and milling parameters in the hybrid process. The response variables were measured as tool wear, tool deflection, active machining force Fa and passive force Fp. The results showed that machining forces, tool deflection and also tool wear could be reduced by laser heating, especially using enhanced cutting data. Obikawa and Yamaguchi [14] studied the notch and flank wear specific to a SiC whisker reinforced alumina tool in air jet assisted (AJA) turning of nickel-base superalloy Inconel718 at high cutting speeds. The air jet applied to the tool tip in addition to coolant dramatically reduces the depth-of-cut notch wear. The width of flank wear determined the life of a ceramic tool in AJA machining of Inconel718.

According to the literatures above, valuable research results about the wear of ceramic tool material in machining Inconel718 have been obtained. The present paper aims at revealing wear mechanism of ceramic tool further based on studying the properties change of ceramic tool and workpiece material under different milling conditions, and then modeling tool wear to find the optimal cutting temperature range which can lead to minimum tool wear in milling Inconel718 using self-reinforced SiAlON ceramic tool.

2. Experiment conditions and experiment process

2.1. *Workpiece and cutting tool*

The workpiece used in this study was an Inconel718 bar (Solid solution + Aging) of diameter of 100 mm and length of 500 mm. Chemical composition and mechanical properties of Inconel718 are shown in Tables 1 and 2.

Indexable face milling cutters were used in experiments. The milling insert is round, which is provided by Sandvik (CC6060 grade in tool catalog). Its material is self-reinforced SiAlON ceramic (77%Si_3N_4 + 13%$A1_2O_3$). The Physical and mechanical properties of CC6060 is shown in Table 3. The flank angle γ_o is −7 °C. The rake angle α_o is 7 °C. Plasma etching was performed on the polished insert specimens, and then the micrograph of milling insert was obtained by SEM, as shown in Fig. 1(a).

The XRD spectrum of milling insert was obtained through XRD analysis, as shown in Fig. 1(b). According to Fig. 1(b), the main phase components of the tool are β-Sialon (Si5AlON7) and α-Sialon (Y0.54Si9.57Al2.43O0.81N15.19). The β-Sialon is rod-like whiskers, which is a reinforced phase in the tool material [15].