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Tool wear characteristics of binderless CBN tools used in high-speed milling of titanium alloys

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Abstract

Titanium alloys are difficult-to-cut materials, and the performance of conventional tools is poor when used to machine them. In this paper, a new tool material, which is binderless cubic boron nitride (BCBN), is used for high-speed milling of a widely used titanium alloy Ti–6Al–4V. The performance and the wear mechanism of the tool have been investigated when slot milling this alloy. This type of tool manifests longer tool life at high cutting speeds. Analyses based on the SEM and EDX suggest that adhesion of workpiece, attrition and diffusion–dissolution are the main wear mechanisms of the BCBN tool when used in high-speed milling of Ti–6Al–4V.

Keywords: Titanium alloy; Tool wear; High-speed milling; Tool life

1. Introduction

Titanium alloys have been widely used in the aerospace, biomedical, automotive and petroleum industries because of their good strength-to-weight ratio and superior corrosion resistance. However, it is very difficult to machine them due to their poor machinability. In 1955, Siekmann [1] pointed out that “machining of titanium and its alloys would always be a problem, no matter what techniques are employed to transform this metal into chips”. The poor machinability of titanium and its alloys have led many large companies (for example Rolls-Royce and General Electrics) to invest much in developing techniques to minimize machining cost [2].

Among all titanium alloys, Ti–6Al–4V is most widely used; so it has been chosen as the workpiece material in this study. When machining Ti–6Al–4V, conventional tools wear rapidly because the poor thermal conductivity of titanium alloys results in higher temperature closer to the cutting edge during machining and there exists strong adhesion between the tool and workpiece material [3]. In addition, titanium alloys are generally difficult to machine at cutting speed of over 30 m/min with high-speed steel (HSS) tools, and over 60 m/min with cemented tungsten carbide (WC) tools, resulting in very low productivity [4]. Since the performance of conventional tools is poor when machining Ti–6Al–4V, and with the evolution of a number of new cutting tool materials, advanced tool materials, such as cubic boron nitride (CBN) and polycrystalline diamond, are being considered to achieve high-speed milling. Some of the ultra-hard materials, such as polycrystalline diamond and CBN have been used in machining of titanium alloys [3,5–8]. Both polycrystalline diamond and CBN are currently very expensive; in addition, they are highly reactive with titanium alloys, and consequently are not suitable for machining titanium alloys. Zareena [9] had carried out an extensive study that shows that the binderless CBN (BCBN) inserts have a remarkably longer tool life than conventional CBN inserts under all cutting conditions (up to 400 m/min); however, the wear mechanism of BCBN tool is still unknown. In this project, BCBN inserts are selected to in-

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vestigate its wear characteristics when high-speed milling Ti–6Al–4V.

2. Experiment

2.1. Workpiece materials

The workpiece material used in the experiment is an alpha-beta Ti–6Al–4V titanium alloy with nominal composition (wt.%) shown in Table 1. Its properties are shown in Table 2.

2.2. Cutting tool materials

The binderless cubic boron nitride sintered product contains neither a binder nor a sintering agent or catalyst. The raw material of hexagonal boron nitride (hBN) is completely converted to a cubic phase at a high temperature and under an extremely high pressure, and the converted particles of CBN are bonded together keeping the particle size extremely fine. The mechanical properties of BCBN and CBN are shown in Table 3 [10]. The properties of cemented carbide and ceramic materials [11] were also cited for highlighting the hardness of BCBN material as shown in Table 3. Table 3 shows that cemented carbide (6% of Co) has higher transverse rupture strength (TRS) value, but its hardness value is lower. On the contrary, BCBN has the higher hardness and lower TRS values. Normally, increasing the hardness of a material reduces its TRS. Although the TRS value of the BCBN material is slightly less than that of CBN containing binder material at room temperature, it has much higher hardness and thermal conductivity than CBN. While at 1000 °C, the BCBN material has higher hardness and larger TRS values than the corresponding CBN tool material.

The BCBN tools are thought to exhibit excellent mechanical properties and superior thermal stability because the sintered body contains no secondary phases and consists of extremely fine CBN particles [12]. Therefore, this type of tool shows great promise to become a new cutting tool material for high-speed milling of difficult-to-cut materials. The main advantageous features of the binderless CBN sintered product are as follows [13]:

- It has high thermal conductivity as well as outstanding resistance to heat and thermal shock because it is a sintered product made of single-phase CBN. Thus, it minimizes the possibility of thermal cracks and chipping occurring at the edge.
- It is suitable for interrupted cutting, having superior mechanical characteristics, such as hardness and strength, because it is made of fine particles not larger than 0.5 μm that are solidly bonded to one another without a binder or a sintering agent/catalyst in the grain boundaries.
- It can be cut and brazed to create desired shapes for turning and milling, as well as the manufacturing of special brazing tools.

Table 1
Composition of Ti–6Al–4V

Content	Composition (wt.%)
C	0.05
Fe	0.09
N	0.01
O	–
Al	6.15
V	4.40
H	0.005
Ti	Balance

Table 2
Mechanical properties of Ti–6Al–4V

Workpiece material	Ti–6Al–4V
Tensile strength (MPa)	993
Yield strength (MPa)	830
Elongation (%)	14
Modulus of elasticity(GPa)	114
Hardness (HRC)	36

Table 3
Properties of CBN, BCBN, cemented carbide and ceramic tool materials

Properties	BCBN	CBN	Ceramic carbide (6% CO)	Ceramic Si_3N_4 (hot-press)
CBN contents (vol%)	>99.9	85–90	–	–
CBN grain size (micron)	<0.5	1–3	–	–
Other constituents	–(comp. hBN)	Binder (Co, etc.)	–	–
Process	Direct conv.	CBN + binder	–	–
Hardness (GPa)				
Room temperature	50–55	35–40	15.69	21.58
1000 °C	20	12	–	–
TRS* (GPa)				
Room temperature	1.35	1.40	2.20	0.793
1000 °C	1.60	0.55	–	–
Thermal conductivity (W/mK)	360–400	100–130	95	29
Thermal stability	1620	1270	–	–