



Design and fabrication of gradient cermet composite cutting tool, and its cutting performance



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ARTICLE INFO

Article history:

Received 11 September 2017

Received in revised form

21 October 2017

Accepted 23 October 2017

Available online 25 October 2017

Keywords:

Tool design

Functionally gradient

Tool material

Cermet

Cutting inserts

Cutting performance

ABSTRACT

According to performance demands of tool materials for high speed machining difficult to cut materials, gradient cermet composite tool materials were designed and fabricated based on hot pressing sintering after dry pressing. The gradient cermet composite tool materials were composed of surface layer, subsurface layer and substrate and exhibited gradient microstructure and mechanical properties. The surface layer had a high hardness, subsurface layer had a high bonding strength and substrate had a high flexural strength. Three gradient composite cutting inserts were fabricated with the gradient structure on different tool faces. To evaluate the cutting performance of gradient cermet composite cutting inserts, effects of cutting speeds on the tool life and surface roughness were investigated during continuously dry turning 17-4 PH stainless steel. The developed gradient cermet composite cutting inserts showed longer tool life and better machining quality than conventional Ti(C,N) cermet inserts under the same cutting conditions. Cutting speeds played a significant effect on both tool life and failure mode of cutting inserts. The favorable cutting performance of gradient cermet composite cutting inserts was attributed to high surface hardness, good wear resistance of surface layer and reasonable gradient structure.

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1. Introduction

Cermet composites have been used as cutting tool materials with suitable properties between cemented carbide tools and ceramic tools. Ti(C,N)-based or TiB₂-based cermet composites have high hardness, high melting point, good wear-resistance and poor affinity with Fe elements [1,2]. Therefore, they have been used in the machining of various alloys and cast irons [3–5]. A reactively hot pressed TiB₂-SiC ceramic tool has been used to machine Invar 36 alloy and showed a high reliability [3]. A developed Al₂O₃/Ti(C,N) ceramic tool by Xu et al. [6] exhibited better wear resistance and higher fracture resistance when machining hardened 45 steel. Zhao et al. [7] pointed that the flexural strength of TiB₂-TiC-SiC composite materials at 800 °C was higher than that at room temperature and the composite materials still maintained a relatively high flexural strength value at 1000 °C, therefore they were suitable for tool materials. A Ti(C₇N₃)/WC/TaC cermet cutting tool has been

used to turn stainless steel with a cutting speed of 300–400 m/min [8]. Pengnan et al. [9] demonstrated that the boundary wear and the serrated chip formation of cermet tools were closely related with the mechanical fatigue crack formation during milling 3Cr13Cu (44 HRC) stainless steel. Ti(C,N) cermets were made into micro milling and used to mill aluminum alloy 2024 [10]. However, high metal content in cermet composites will give rise to a lower surface hardness and the tool materials will be softened easily under high cutting temperature. Except that, tool breakage (such as chipping and peeling) has been observed on cermet tools due to their lower fracture toughness. Functionally gradient structure is an ideal cutting tool structure for high speed machining difficult-to-cut materials, such as coated cutting tools. However, the coating of cutting tools is peeled off readily during machining of difficult-to-cut materials due to work hardening and high cutting temperature. And the thickness of coating is only a few of micrometers far less than crater wear depth.

Stainless steel possess good corrosion resistance and a relative high strength due to the addition of chromium and nickel elements [11,12]. Therefore, various stainless steel such as 316 L, 321, 440 stainless steel are widely used in a wide range of engineering fields

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Table 1
Composition of gradient cermet composite cutting tool materials.

Symbols	Ti(C ₇ ,N ₃)	TiB ₂ -TiC (7:3)	VC	Mo	Ni	Remarks
TD		86	4	4	6	Surface layer
	84			4	12	Substrate

such as surgical implant material, automobile, aerospace, oil and gas industries [13]. However, poor machinability of stainless steel inhibits their application further [14,15]. In machining of stainless steel, severe work hardening, high cutting force and temperature, adhesive wear will occur due to low thermal conductivity and high chemical affinity. Thus, failure modes of cutting tools such as flank wear, crater wear and tool breakage will happen and tool life will be shortened.

In this work, gradient cermet composite tool materials with a flexural strength of 1520 MPa, a surface hardness of 27.2 GPa and a fracture toughness of 7.0 MPa m^{1/2} were prepared by hot-pressed sintering at 1500 °C for 40 min under 32 MPa after dry pressing. The mechanical properties and microstructure of gradient cermet cutting tool materials were investigated. Three gradient composite cutting inserts were designed and fabricated. The cutting performances including tool life, surface roughness, failure modes and chips morphologies were studied during continuously dry turning 17-4 PH stainless steel. Meanwhile, for comparison, a commercially available Ti(C,N) cermet cutting tools was used.

2. Design and fabrication of gradient composite cutting tools

2.1. Design of gradient cermet composite cutting tools

Ti(C,N)-based cermet was selected as the substrate material due to its high flexural strength while TiB₂-TiC cermet composite was selected as the surface layer material due to its high hardness, chemical stability at high temperature and good wear resistance as well as good compatibility with Ti(C,N) substrate [16,17]. Ni and Mo were used as the metal binder phase and addition phase, respectively. Particularly, the addition of VC in the surface layer composite was in favor of the decrease in densification temperature of TiB₂-TiC surface layer. Material components of gradient cermet cutting tool materials were shown in Table 1. Fig. 1 showed the formation process of gradient cermet composite cutting tool materials. Before sintering, the composite was composed of TiB₂-TiC surface layer and Ti(C,N) substrate. However a subsurface layer was formed by an element diffusion driving force during sintering. Ti(C,N) would be decomposed at high temperature due to the existence of some carbides [18]. N elements diffused outward from substrate to

surface layer under chemical potential gradient of N, while Ti elements diffused in an opposite direction due to a strong thermodynamical coupling between the N and Ti elements. Under the diffusion driven force, the Ni binder were aggregated in the subsurface zone and a gradient structure with three layers was formed. Fig. 2 showed the SEM micrographs of polished cross profile of gradient cermet composite tool materials. The thickness of surface layer was 200–250 μm, while that of subsurface layer was 20–30 μm. The Microstructure of composites was fine and compact. According to our previous studies [19,20], the surface layer had a high hardness, subsurface layer had a high fracture toughness and bonding strength and the whole had a high flexural strength. Meanwhile, the gradient cermet composite tool materials showed a better wear resistance than conventional Ti(C,N) cermet tool materials [21]. The distribution of mechanical properties was appropriate for usage of cutting tool.

According to tool failure modes during high speed machining of difficult-to-cut materials, crater wear was formed on the rake face while abrasive wear and groove wear was observed on flank face [5,22]. TDA with a gradient structure only on the rake face, TDB with a gradient structure only on the flank face and TDC with a gradient structure on all face were designed as shown in Fig. 3. The surface layer thickness of gradient cermet composite cutting tool was 230 μm larger than the crater wear depth. To obtain high strength of cutting edge, tool nose radius varied from 0.6 to 0.8 mm.

2.2. Fabrication and cutting experiments of gradient cermet composite cutting tools

Preparation process of gradient composite cutting tools was shown in Fig. 4. The gradient cermet cutting tool materials were prepared by vacuum hot-pressed sintering at 1500 °C for 40 min under 32 MPa after dry pressing. And then, the cutting tools were cutting into 13 mm × 13 mm × 5 mm using wire cut electric discharge machine (Model Huafang H350, China). The edge preparation of gradient cermet cutting inserts was made by micro-blasting technology after grinding and chamfering. At last, the cutting inserts were polished to improve the surface finish.

The dry cutting tests were carried out on a CNC lathe (PUMA200MA, Korea) by gradient cermet cutting tools on 17-4 PH martensitic stainless steel. The nose radius and rounded cutting edge radius of cutting inserts were 0.8 mm and 60 μm, respectively. The effective geometries of inserts after rigid clamping in the tool post were as follow: rake angle $\gamma_0 = -6^\circ$, clearance angle $\alpha_0 = 6^\circ$, inclination angle $\lambda_s = -5^\circ$ and side cutting edge angle $K_r = 45^\circ$. The compositions and mechanical properties of workpiece materials were as shown in Table 2. Meanwhile, the workpieces were solution

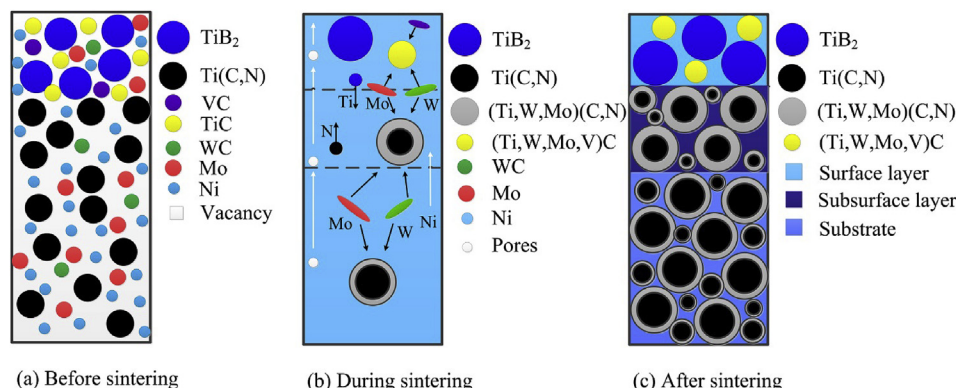


Fig. 1. Formation process models of gradient cermet composite cutting tool materials.

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