Int. Journal of Refractory Metals and Hard Materials 48 (2015) 24–30

Contents lists available at ScienceDirect

Int. Journal of Refractory Metals and Hard Materials

journal homepage: www.elsevier.com/locate/IJRMHM

High wear performance of the dual-layer graded composite diamond coated cutting tools

Ravikumar Dumpala [a,b,c], Maneesh Chandran [b], S. Madhavan [a], B. Ramamoorthy [a], M.S. Ramachandra Rao [b,*]

[a] Manufacturing Engineering Section, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600036, India
[b] Nano Functional Materials Technology Centre, Department of Physics, Indian Institute of Technology Madras, Chennai 600036, India
[c] GMR Institute of Technology, GMR Nagar, Rajam 532127, Andhra Pradesh, India

ARTICLE INFO

Article history:
Received 2 May 2014
Accepted 23 July 2014
Available online 1 August 2014

Keywords:
CVD diamond
Wear resistance
Nanocrystallinity
Graded coatings
High speed machining
Metal matrix composites

ABSTRACT

In the present experimental study, wear performance of the diamond coated cutting tools with various coating architectures was studied by turning Al_m–30%SiC_p metal matrix composite material. Chemical vapor deposited (CVD) diamond can be classified into nanocrystalline diamond (NCD) and microcrystalline diamond (MCD) that are known for their distinct characteristics. Diamond coatings with three different coating architectures were deposited for the machining study; (i) mono-layer MCD coating (MCD/WC–Co), (ii) dual-layer composite diamond coating (NCD/MCD/WC–Co) and (iii) dual-layer graded composite diamond coating (NCD/transition-layer/MCD/WC–Co). Wear performance of the diamond coated (3 architectures), uncoated and commercial TiN coated tools was evaluated and compared by conducting high speed machining tests. Superior wear performance of the diamond coated tools was clearly evident from the tool wear measurements. The poor tool life ($t <$ 1 min) of the uncoated and TiN coated tools was attributed to the abrasive action of the hard SiC reinforcement particles. Dual-layer graded composite diamond coated ($t = 14.7$ min) and mono-layer MCD coated ($t = 13.5$ min) tools showed superior machining performance in comparison to that of the dual-layer composite diamond coated tool ($t = 9.8$ min). Dual-layer graded composite diamond coatings deposited with the concept of transition-layer are the prospective tool coatings for high performance machining applications due to their top-layer nanocrystallinity and enhanced interfacial integrity.

Introduction

Al–SiC metal matrix composites (MMC) and carbon fiber reinforced plastics (CFRP) are widely used engineering materials in the aerospace and automobile industries due to their high strength to weight ratio. These materials are considered as difficult-to-machine because of the hard and abrasive reinforced particles or fibers [1,2]. The most commonly used tools and tool coatings fail to perform due to the aggressive machining conditions [3,4]. The stringent machining applications demand high performance super hard coatings with a designed coating-substrate system for better performance and durability [5,6].

In general, the coating-substrate system can be divided into three different entities such as coating, interface and substrate. The functional and basic requirements of these three entities for mechanical and tribological applications are considered as follows; (i) coating: surface coating is expected to have high wear resistance, low friction coefficient, good surface finish, high oxidation resistance, high fracture toughness, high thermal conductivity and enough thickness for load-bearing applications, (ii) interface: good adhesion and shear strength represent a good interface quality and (iii) substrate: high elastic modulus, high temperature strength and high thermal conductivity are the most important properties that a substrate should possess [7]. For high performance applications, all the design considerations and requirements of the coatings may not be possible to realize with a single layer coating architecture. Design and utilization of different layers of the coatings are important particularly for high performance machining applications [8].

CVD diamond coatings are known for their unique characteristics such as high hardness (>40 GPa) and low friction coefficient (<0.1). The mechanical characteristics such as wear resistance, friction coefficient and interfacial adhesion integrity of the diamond coatings are greatly influenced by the surface pre-treatment and grain size of the coated layers [9]. Hence the microstructure and coating-substrate architecture of the CVD diamond coatings need to be tailored to achieve the basic functional requirements such as high wear resistance, low friction coefficient and good interfacial adhesion integrity [10].

Nanocrystalline diamond (NCD, grain size < 100 nm) coatings are known for their tribological properties due to the smooth surface

* Corresponding author. Tel.: +91 44 2257 4872; fax: +91 44 2257 4852.
E-mail address: msrrao@iitm.ac.in (M.S.R. Rao).

http://dx.doi.org/10.1016/j.ijrmhm.2014.07.023

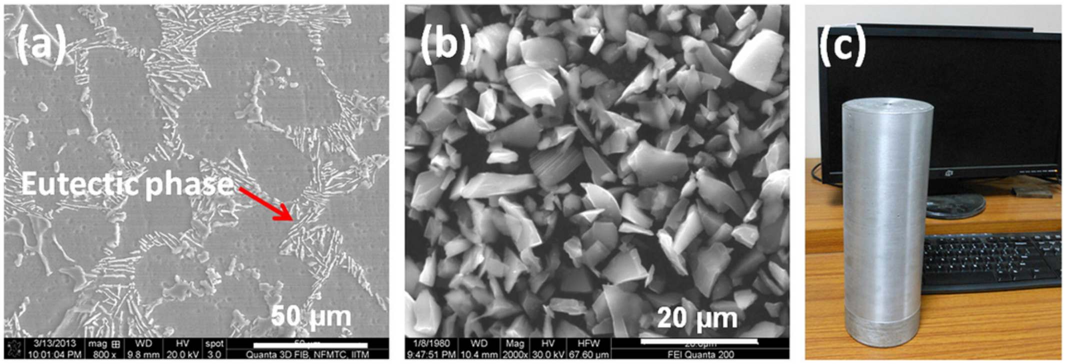

Fig. 1. (a) Microstructure of the etched Al_m (Al–12%Si alloy), (b) HRSEM image of the raw SiC particles and (c) photograph of the casted Al_m–30%SiC_p ingot.

features, reduced grain size and the presence of non-diamond carbon phases at the grain boundaries. On the other hand, microcrystalline diamond (MCD, grain size > 500 nm) coatings exhibit high hardness and good adhesion characteristics [9]. However, NCD and MCD coatings have their own merits which can be exploited by developing the multi-layer coating architectures [11].

Several studies have been reported on dual- and multi-layer composite diamond coatings by depositing a combination of NCD and MCD layers with different coating architectures [12–19]. Dual-layer composite diamond coating (NCD/MCD/WC–Co) is the commonly used architecture to realize thick diamond coatings with top-layer nanocrystallinity for mechanical applications [20]. The integrity of the dual- or multi-layer composite diamond coatings was found to be compromised due to the sharp interface between the constitute NCD and MCD layers. In our earlier studies, dual-layer graded composite diamond coatings with the architecture of NCD/transition-layer/MCD/WC–Co were developed to enhance the interfacial integrity by eliminating the sharp interface between the NCD and MCD layers [10,21].

In the present study, wear performance of these dual-layer graded composite diamond coated cutting tools was studied by machining Al_m–30%SiC_p MMC material. Flank wear and nose wear on the cutting tools were measured to estimate and compare the tool life.

Experimental details

Five variants of the coated and uncoated cutting tools (geometry: SPUN 120308) were used for the tool wear studies. Three diamond coating variants, (i) mono-layer MCD coating (MCD/WC-Co), (ii) dual-layer composite diamond coating (NCD/MCD/WC-Co) and (iii) dual-layer graded composite diamond coating (NCD/transition-layer/MCD/WC–Co) are deposited with the coating thickness of ~10 μm. MCD monolayer coating was deposited for 12 h. Dual-layer composite diamond coating was deposited for 14 h with the coating architecture of NCD-8 h/MCD-6 h/WC–Co. Dual-layer graded composite diamond coating (dual-layer composite diamond coating with graded diamond transition-layer between NCD and MCD layers) was deposited for 14 h with the coating architecture, NCD-6 h/transition-layer-2 h/MCD-6 h/WC–Co. Gradient diamond transition-layer of ~1 μm thickness (transition from MCD grains to NCD grains) has been obtained by changing the process parameters linearly from MCD to NCD within the duration of 2 h. Complete experimental details including the substrate pretreatment and deposition process were discussed elsewhere [10,21]. Commercially available uncoated and TiN coated inserts were the other two variants used for the performance comparison.

Al_m–30%SiC_p MMC material is the work material for machining experiments and the ingot of size Ø100 × 300 mm was fabricated using sand mold casting method and the fabrication process is as follows. The matrix material (Al_m), Al–12%Si alloy ingot was cut into small pieces and melted using an electric arc furnace and the temperature of the molten metal was maintained at around 725 °C. Degassing process was carried out by adding hexachloroethane tablets to the molten metal, which removed nitrogen, carbon-dioxide and other gases absorbed by the melt in the furnace. The molten base alloy was stirred for about 5 min at ~450 rpm. The silicon carbide particles (30% by volume) of the size ranging from 8 to 10 μm were heated to a temperature of 650 °C and added to the molten base metal with simultaneous stirring under argon atmosphere. During stirring, a mixture of magnesium and aluminium powder was also added to the molten metal mixture to enhance the wettability. The stirring process was continued for 15 min and then the molten mixture was poured into the sand mold. Fig. 1(a) shows the HRSEM image of the microstructure of the etched Al–12%Si matrix material, Fig. 1(b) shows the HRSEM image of the raw SiC particles and Fig. 1(c) shows the photograph of the casted Al_m–30%SiC_p ingot.

Surface topography and cross-sectional characteristics of the diamond coatings were studied using a high resolution scanning electron microscope (HRSEM, Quanta 3D, FEI). Cross-sections of the diamond coatings were prepared using a low speed diamond saw cutter (ALLIED

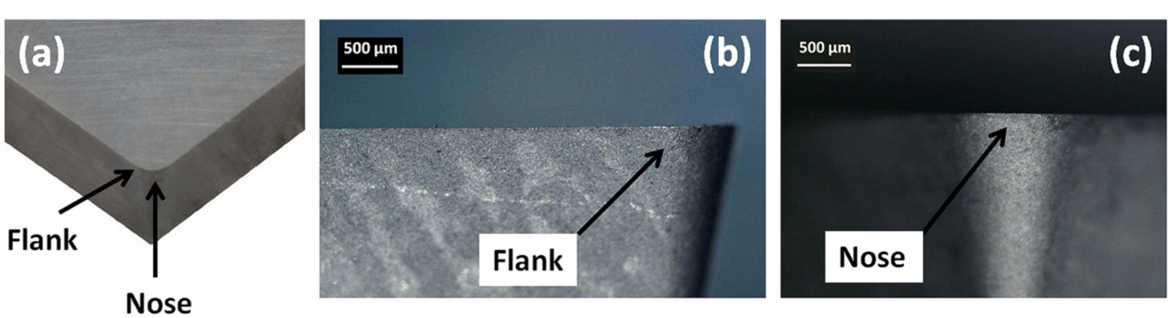

Fig. 2. Views of the tool cutting edge. (a) Isometric view, (b) flank face and (c) nose.