Int. Journal of Refractory Metals & Hard Materials 27 (2009) 535–544

Contents lists available at ScienceDirect

Int. Journal of Refractory Metals & Hard Materials

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

Machinability study of pure aluminium and Al–12% Si alloys against uncoated and coated carbide inserts

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ARTICLE INFO

Article history:
Received 27 January 2008
Accepted 17 April 2008

Keywords:
Aluminum
Coated carbide
CVD diamond coated tool
Chemical affinity
Machining

ABSTRACT

An investigation has been undertaken to study the compatibility of cutting materials in dry machining of aluminium and Al–Si alloys. Mono or multilayer coated carbide tools with a top coating of TiC, TiN, TiAlN, Al_2O_3, TiB_2, MoS_2 etc. on WC–Co inserts already made a major breakthrough in dry machining of ferrous materials. But in contrast dry machining of aluminium and Al-alloys is a great challenge. But wide application of aluminium different parts has increased the need to find out the correct cutting tool. Experimental results of turning test, SEM pictures and chip morphology investigation of the cutting tool after machining clearly reveals the inefficiency of TiC, TiN, TiB_2, Al_2O_3, and AlON in dry machining of aluminium. This is because of the formation of very large amount of metal built-up in both rake and flank surface leading to high magnitude of cutting forces and high roughness of the work-piece during machining. The natural diamond and polycrystalline diamond (PCD) can be used as a cutting tool, when the required shape is attached on the edge/tip for machining non-ferrous materials. But both of them are limited for finishing cut because of high cost. So CVD diamond coated tool is a better option to machine these materials. CVD diamond coated tool was free from built-up edge formation leading to clean cut, low magnitude of cutting forces and improved surface finish of the work-piece. However, performances of the diamond tool depend mainly on adhesion of the diamond coating with the carbide substrate.

1. Introduction

High strength to weight ratio of aluminium and aluminium alloys has gained its importance in the rapid growing automobile and aerospace industries. Emerging trend of dry machining i.e. lubricant free environment of materials has given a real challenge in machining aluminium and its alloys. Carbide tools with the hard coatings like TiC, TiN, Al_2O_3 etc. have already proved their supremacy in machining of steels in dry environment even at high cutting velocity. On the other hand, diamond coated carbide tools are ineffective because of its chemical degradation in contact with steel and cobalt. Chemical affinity of aluminium to the different coating materials and its low melting point made this material a critical one for machining.

Coated carbide tools begun its journey as back as late seventies with CVD TiC coating targeting carbon steels and low alloy steels. CVD coatings of TiN, Ti(CN), Al_2O_3 have also been reported to be extremely successful in machining ferrous materials [1]. But still researches are going on to find out the best compactable cutting tool for machining aluminium and its alloys. Many aluminium alloys are reported as susceptible to adhesion with tool and to build up in the chip space [2]. Edge build up is very much common on during machining. It is said that coatings which have proved to be advantageous in many steel machining operation, do not appear to provide nay benefit in the machining of an aluminum alloy [3]. Investigation on dry milling of AlZnMgCu1.5 alloy revealed that uncoated carbide tool produced large build up edge on the rake surface [4]. Coating like TiN, TiAlN and CrN were also not free from that weakness. Dry machining of aluminium casting alloy produced unacceptable built-up edge on uncoated carbide tool and there was an adverse effect on surface quality of the work-piece. It is reported that a coated tool with a MoS_2 top layer can reduce the tendency to build up edge formation [5]. Diamond coated tool has established its supremacy over (Ti, Al)N coated tool machining Al_2O_3 + SiC particle reinforced magnesium alloys [6–9]. This way numerous research investigations have been carried out on compatibility of different coating materials with Al-based work materials. However, findings are inadequate, less informative and sometimes contradictory. The present work is aimed at evaluating the relative performance of different commercially available

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0263-4368/$ - see front matter © 2008 Published by Elsevier Ltd.
doi:10.1016/j.ijrmhm.2008.04.008

carbide tools in terms of chip formation, development of cutting force, nature of build up edge formation on the face and flank of the cutting tools, tool wear, chipping, flaking of the coating and the surface finish of the work-piece.

2. Experimental details

Present study is carried out to investigate the machinability of cast aluminium bar with different coated inserts. Industrially used coated tools have been used for these purposes. The description of tool geometry, tool holder, grades and coating methods are shown in Table 1.

The description of the work-pieces and machining parameters are shown in Table 2. The surface roughness of the cutting tools at the rake surface is shown in Fig. 1. All tools were purchased from the market except the diamond coated insert. The CVD diamond coated insert was being prepared in our own built hot-filament CVD reactor. The micrograin Sandvik WC + 6% Co inserts were pretreated with $HCl + HNO_3 + H_2O$ at 1:1:1 ratio for 15 min. The depositions were carried out at chamber pressure of 20 Torr, CH_4/H_2 ratio 0.5/100, substrate temperature of 720 °C and deposition was carried out for 8 h with a coating thickness of ≈6 μm. The PVD coated TiB_2 tool shows the highest surface finish and diamond coated carbide insert shows highest surface roughness. The specification of the combination turret lathe used during experiment is shown in Table 3. The specification of the dynamometer is shown in Table 4.

The machining performances of the tools were carried out in dry turning of Al and Al–12% Si alloy in a combination turret lathe. The tool was held in a standard Sandvik tool holder mounted on a 3-D piezoelectric dynamometer (KISTLER 9257B Switzerland) for measurement of axial (F_X) and tangential forces (F_Z). The signals were amplified by charge amplifiers (KISTLER 5501, Switzerland) with the help of data acquisition card, PCL 818AG-DAS and software Dasylab 4.0(Germany). They were also used for recording both static and dynamic characteristics of the cutting force components during machining.

Relative performances of different cutting tools were assessed by looking at the nature and geometry of the chips produced, magnitude of cutting forces, built-up edge formation of the work material on the face and flank of the tool. Damage of the tool edges by wear, edge chipping, flaking of the coating etc. was also measured. SEM pictures were taken at the tool tip after machining followed by cleaning with NaOH to remove adhered material. The experimental set-up is shown in Fig. 2. Fig. 3 shows the microstructure of Al–12% Si alloy and silicon particles are being distributed uniformly, so that constancy will be made during experiments.

Cutting forces F_X and F_Z were recorded by dynamometer. Each individual tip of the insert was taken freshly for machining purpose. Three time intervals of 5 s, 30 s and 2.5 min were taken to see the change in forces, tool wear and aluminum adherence to the inserts.

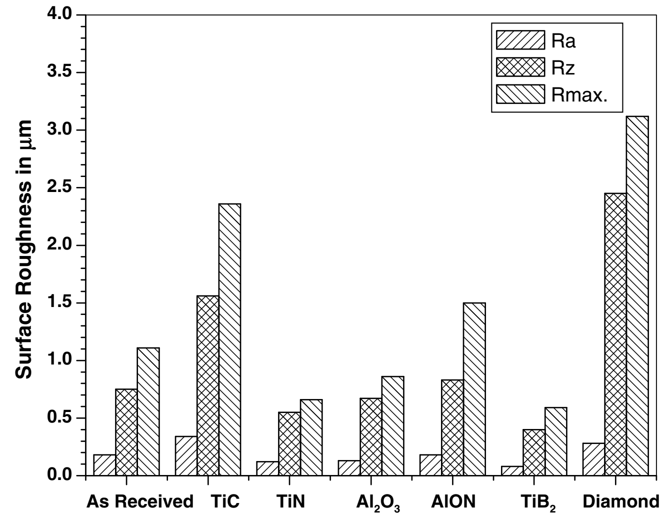

Fig. 1. Surface roughness of all the carbide inserts used before machining.

Table 1
Description of tool geometry, tool holder and coating methods

Cutting tool insert	SPGN 120308		
Tool geometry	0°, 6°, 5°, 15°, 75°, 0.8 mm (ISO)		
Tool holder	Sandvik CSBPL 2525 16M (ISO) with top clamp chip breaker		
Sl. no.	Types of coating	Coating materials	Grade
Tool 1	As received		K 10
Tool 2	CVD	TiC coated carbide insert	K 10
Tool 3	CVD	TiN coated carbide insert	K 10
Tool 4	CVD	Al_2O_3 coated carbide insert	K 10
Tool 5	N_2 ion implanted on Al_2O_3	AlON	K 10
Tool 6	PVD	TiB_2 coated carbide insert	K 10
Tool 7	HFCVD (Developed in our own reactor, coating thickness ≈ 6 μm)	Diamond	K 10

Table 2
Description of the work-pieces and machining parameters

Work-piece material	Cast aluminum bar and cast Al–12% Si alloys
Dimension	ϕ160 × 780 mm
Cutting speed	400 m/min
Feed	0.1 mm/rev
Depth of cut	0.5 mm
Environment	Dry

Table 3
Specification of the combination turret lathe

Ward model no. 7, England, Type: KZ5622, No. 50289H2
Power of the driving motor, 7.5 HP; Maximum speed, 1000 rpm; Bed length, 800 mm (max.),
Maximum run out on the head stock and tail stock are 50 μm and 90 μm

Table 4
Specification of dynamometer

Specification of the Kistler dynamometer
Transducer sensitivity: For F_X = 7.75 and for F_Z = 3.71, Socket no. 5407A
Dasylab configuration, 2000 Hz

3. Results and discussion

Discontinuous chips of almost regular size and shape were produced from the beginning of machining with uncoated cemented carbide tool. Formation of such elements are in good agreement with the fact that machining of ductile material like aluminium in dry turning process involving high friction results formation of built-up edge and consequently secondary shearing and intermittent fracture of chips.