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On deposition and characterisation of MoS_x-Ti multilayer coating and performance evaluation in dry turning of aluminium alloy and steel

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Abstract. In recent times, MoS_x or MoS_x-based composite solid lubricant coatings have demonstrated some potential in environment-friendly dry machining. However, most of the previous studies were restricted to drilling and milling operations. In the current research work, MoS_x-Ti coating with TiN underlayer was deposited using pulsed DC closed-field unbalanced magnetron sputtering (CFUBMS) technique. The deposited film was characterised using field emission scanning electron microscopy (FESEM), grazing incidence X-ray diffraction (GIXRD), scratch adhesion test and Vickers microhardness test. The performance test of the coating was carried out in dry turning of ISO AlSiMg aluminium alloy and IS 80C6 high carbon steel with uncoated and MoS_x-Ti (with TiN underlayer) coated cemented carbide inserts. Results indicated that coated tool arrested the tendency of formation of built-up material during machining of aluminium alloy resulting in superior workpiece surface finish compared to that for uncoated tool. During dry turning of high carbon steel, the same coated tool resulted in reduction in axial cutting force in the entire range of cutting velocities (32 to 230 m/min). During machining at higher cutting velocity the same coating provided effective diffusion barrier by restricting crater wear.

Keywords: soild lubricant coating, sputtering, characterisation, turning, alumnium alloy, high carbon steel.

1 Introduction

Recently, dry machining and minimal quantity lubrication (MQL) have assumed immense significance primarily due to modified environmental regulation combined with health and safety concerns related to cutting fluids. Advances in the types of coatings applied to cutting tools have been the major driving force to study the feasibility of dry machining [1]. However, desirable performance can be expected if the coating is wear and abrasion resistant having sufficiently high anti friction or anti sticking properties.

MoS_2 is a well known solid lubricant coating material. However, its low hardness combined with poor resistance to oxidation and humidity has prevented its wide application in machining. Although, co-deposition of MoS_x with various metal dopants like Au, Ti, Cr, W, Zr etc improved structural and mechanical properties of pure MoS_x coating [2-4], the application of such MoS_x-based composite coatings was mainly restricted to drilling and milling operations [3,5-6]. Significant improvement in performance could not be obtained in turning with MoS_x-Ti coated tools due to higher machining temperature encountered [7]. Similarly, during turning of steel cemented carbide tool coated with MoS_x-Zr composite coating exhibited better tool life compared to uncoated insert when working only in the lower range of cutting speed (< 120 m/min) [8]. Therefore, potential of MoS_x-based composite coating in turning of ferrous and non ferrous alloy has not been fully explored. In the current investigation, a double layer coating consisting of MoS_x-Ti multilayer with TiN underlayer (TiN/MoS_x-Ti) has been deposited using pulsed DC closed-field unbalanced magnetron sputtering. The characteristics of the coating were evaluated using scanning electron microscopy (SEM), grazing incidence X-ray diffraction (GIXRD), scratch adhesion test and Vickers microhardness test. Finally, the performance of the coating was studied in the dry turning of aluminium alloy and high carbon steel.

2 Experimental Details

Deposition was carried out on cemented carbide inserts (ISO K10 grade, make: Widia) of two different geometries as shown in Table 1. The cutting tool substrates were thoroughly cleaned ultrasonically by alkaline solution, trichloroethylene and isopropyl alcohol prior to deposition. After ion cleaning of the substrates, a thin (~100 nm) Ti interlayer was deposited to promote improved film-substrate adhesion. This was followed by deposition of an underlayer of TiN, with a thickness of 2-2.5 μm, to improve load bearing capacity of the coating. Functional top layer of MoS_x-Ti coating (over TiN) of around 1.5 μm thick was deposited by simultaneous sputtering from vertically mounted MoS_2 and Ti targets using Ar as sputtering gas. The sputtering was conducted in an in-house dual cathode system operated in pulsed DC closed-field unbalanced magnetron mode. The power supplies for both the targets as well as substrates were operated with a pulse frequency of 35 kHz and duty cycle of 90%. The coating was deposited at a working pressure of 0.3 Pa, substrate temperature of 200 °C and pulsed substrate bias voltage of −50 V.

Table 1. Details of workpiece, cutting tools and machining condition

Workpiece material	AlSiMg alloy	IS 80C6 steel
Chemical composition (wt%)	Si-0.658, Fe-0.140, Cu-0.005, Mg-0.549, Mn-0.032, Ti-0.018 with rest Al.	C-0.786, Si-0.043, Mn-0.563, P-0.025, S-0.053, Cr-0.056 with rest Fe.
Insert designation	SPUN 12 03 08	SNMA 12 04 08
Tool geometry (ORS)	0°, 6°, 6°, 6°, 15°, 75°, 0.8 (mm)	−6°, −6°, 6°, 6°, 15°, 75°, 0.8 (mm)
Cutting velocity (m/min)	150, 200, 250, 300	32, 77, 130, 230
Feed (mm/rev)	0.14	0.20
Depth of cut (mm)	1	2
Machining duration (s)	10	10

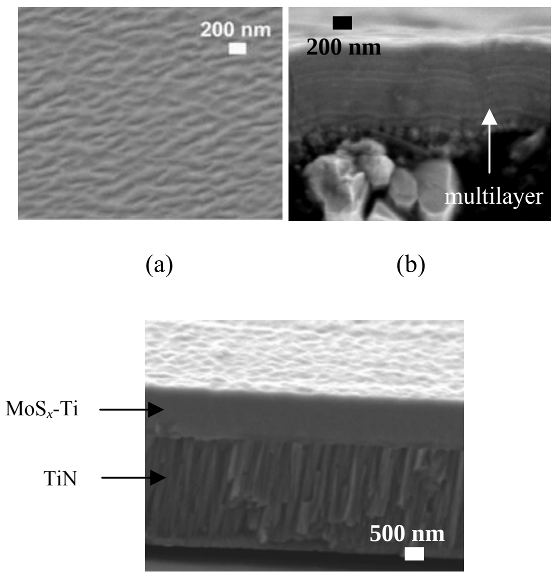
After deposition, the microstructure and phases of the coating were studied using scanning electron microscopy (SEM) and X-ray diffraction (XRD). Coating-substrate adhesion was evaluated using scratch test and composite microhardness of the coating was determined by Vickers microhardness test with a load of 0.5 N.

The performance of the coating was then evaluated in dry machining of AlSiMg aluminium alloy and IS 80C6 (AISI 1080) high carbon steel. The purpose of this study was to investigate the response of MoS_x-Ti coating (with TiN underlayer) against both ferrous and non-ferrous alloys in dry turning operation. The composition of workpiece materials, details of cutting tools and machining conditions are provided in Table 1. Uncoated carbide inserts were also used for comparison of performance. It is evident from Table 1 that cutting velocity was varied from 150 to 300 m/min during machining of aluminium alloy and that from 32 to 230 m/min during machining steel. After each cut, the inserts were examined using both optical microscopy, SEM and energy dispersive spectroscopy (EDS) by X-ray. Roughness of the machined surface was studied using a surface profilometer after machining of aluminium alloy. Axial cutting force (P_x) was measured using a piezoelectric type dynamometer during machining of steel with both uncoated and coated inserts. However, in the current investigation, the tests could not be repeated due to non-availability of sufficient number of coated inserts.

3 Results and Discussion

3.1 Characterisation of the coating

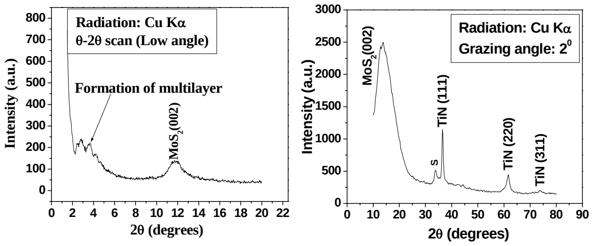
Figure 1 shows SEM micrographs depicting surface morphology and fractograph of MoS_x-Ti coating with or without TiN underlayer. The surface morphology was found to be smooth. SEM image of fractograph revealed formation of multilayer of MoS_x and Ti as evident from Fig. 1(b). Formation of multilayer structure might be attributed to the configuration of the system and slow rotaion (3 rpm) of the substrates during depsotion. Previous studies have indicated formation of MoS_x-metal multilayer structure arrests columnar growth of MoS_x leading to good mechanical properties of coating [2]. Figure 1(c) reveals microstructure of MoS_x-Ti coating with TiN underlayer.



(c)

Fig 1. SEM micrographs of showing (a) surface morphology, (b) fractograph of MoS_x-Ti coating and (c) fractographs of MoS_x-Ti with TiN underlayer

Figure 2 shows low angle XRD spectrum for MoS_x-Ti coating. Presence of multiple peaks at very low angles



(a) (b)

Fig 2. (a) Low angle XRD and (b) GIXRD spectra of MoS_x-Ti coating with TiN underlayer

also indiactes the formation of multilayer structure. However, GIXRD spetrcum for MoS_x-Ti coating with TiN underlayer shown in Fig. 2 (b), highlights basally oriented MoS_x (111) phase. Different phases of TiN have also been detected because of TiN underlayer. Scratch test indicated critical load in excess of 80 N and composite Vickers microhardness of the coating was found to be around 20 GPa.

3.2 Performance evaluation in machining

Figure 3 demonstrates optical micrographs of uncoated and coated inserts after dry machining of aluminium alloy with different cutting velocities. The figure clearly indiactes severe formation of built-up layer (BUL) on tool rake surface which is a common problem encountered during machining of aluminium or its alloys. However, MoS_x-Ti multilayer coating with TiN underlayer significantly arrested material adhesion on tool surface as evident from Fig. 3. This was further confirmed from SEM and EDS analyses. The superior anti-sticking property of MoS_x might have played a major role in arresting build-up of work material on rake surface of the insert. Figure 4 shows the variation of surface roughness (R_a) with cutting velocity for both uncoated and coated inserts. Though the variation of surface roughness with cutting velocity was not significant, the surface roughness has been significantly reduced with MoS_x-Ti coated insert (with TiN underlayer).

Figure 5 reveals variation of axial cutting force (P_x) with cutting velocity during dry machining of high carbon steel with uncoated and coated carbide inserts. It is evident that coated tool provided a reduction of cutting force (9 to 17%) in the operational range of cutting velocity. Excellent anti friction properties of solid lubricant MoS_x phase could be primarily responsible for this. The conditions of tool rake surface have been depicted in Fig. 6. It may be observed that uncoated insert suffered from major crater wear as cutting velocity was increased up to 230 m/min. This might be attributed to the poor resistance to diffusion of uncoated carbide insert. However, resistance to crater could be significantly improved with MoS_x-Ti coating with TiN underlayer, which can be clearly seen from Fig. 6. It may

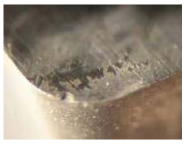
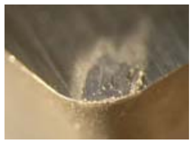
Cutting velocity (m/min)	Cutting tool	
	Uncoated	Coated
150		
200		
250		
300		

Fig 3. Optical micrographs of uncoated and coated turning inserts after machining of aluminium alloy with different cutting velocities

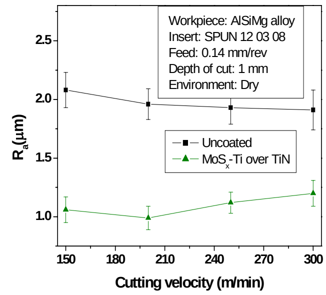


Fig 4. Variation of workpeice surface roughness (R_a) with cutting velocity during dry turning of aluminium alloy with uncoated and coated inserts

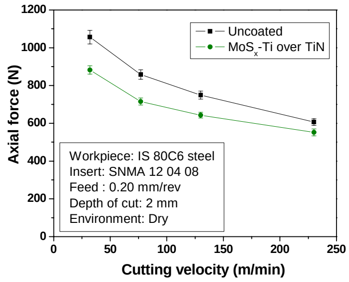


Fig 5. Variation of axial cutting force (P_x) with cutting velocity during dry turning of steel with uncoated and coated inserts

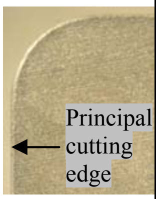
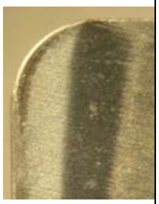
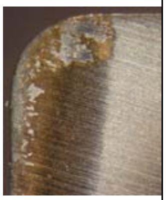
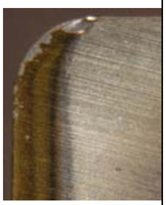
Cutting velocity (m/min)	Cutting tool	
	Uncoated	Coated
32		
77		
130		
230		

Fig 6. Optical microscopic images showing rake surfaces of uncoated and coated turning inserts after machining of steel with different cutting velocities

be observed that though removal of coating took place particularly at low cutting velocity, most of the coating was intact while machining at higher cutting velocity. This was further confirmed using EDS analysis. The superior characteristics of this double layer coating system compared to its uncoated counter part might be ascribed to good solid lubricant properties of MoS_x, while Ti maintained structural integrity and good adhesion characteristics of MoS_x. TiN provided improved load bearing capability of the coating.

4 Conclusion

In the current study, MoS_x-Ti coating with TiN underlayer was deposited using dual cathode pulsed DC CFUBMS technique followed by characterisation and performance evaluation of the coating in dry turning of aluminium alloy and high carbon steel. The following conclusions may be drawn from the current investigation:

- The structure of MoS_x-Ti coating has been found to be multilayer.
- The coating exhibited reasonably good adhesion with the cutting tool substrate and composite microhardness.
- During dry turning of aluminium alloy the coating helped to restrict the formation of BUL resulting in superior workpiece surface finish compared to that with uncoated insert.
- During dry turning of high carbon steel, the same tool resulted in reduction in axial cutting force in the range of 9 to 17% and provided much better resistance to crater wear compared to that with its uncoated counter part particularly at higher cutting velocity (230 m/min).

Therefore, the double layer coating system has exhibited some promise in dry turning of steel and aluminium alloy. However, further investigation should be undertaken to study its performance in comparison with various conventional hard coatings during machining of ferrous and non-ferrous alloys.

5 References

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