Development and characterization of Si_3N_4 coated AlCrN ceramic cutting tool

J.V.C. Souza[1,2], M. C.A. Nono[1], O.M.M. Silva[3], G.V. Martins[1], J.P.B. Machado[1], M. Pimenta[4]

[1]INPE - Av. dos Astronautas, 1.758, S. J. Campo s - SP, CEP. 12245-970, Brazil

[2]UNIFOA - Av. Paulo Erlei Alves Abrantes, 1325 - 3 Poços, Volta Redonda - RJ, 27251970, Brazil

[3]CTA-IAE/AMR - Pça. Marechal do Ar Eduardo Gomes, 50, S. J. Campo s - SP, CEP. 12228-904, Brazil

[4]Oerlikon Balzers R. Metálicos Ltda, Rua Balzers, 250, P. Industrial - Jundiaí – SP, CEP 13213-084, Brazil

vitor@las.inpe.br

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Abstract. Nowadays, silicon nitride based cutting tools are used to machine cast iron from the automotive industry and nickel superalloys from the aero industries. Advances in manufacturing technologies (increased cutting speeds, dry machining, etc.) induced the fast commercial growth of physical vapor deposition (PVD) coatings for cutting tools, in order to increase their life time. In this work, a new composition of the Si_3N_4 ceramic cutting tool was developed, characterized and subsequently coated, using a PVD process, with aluminum chromium nitride (AlCrN). The Si_3N_4 substrate properties were analyzed by XRD, AFM, hardness and fracture toughness. The AlCrN coating was analyzed by AFM, grazing incidence X-ray diffraction (GIXRD) and hardness. The results showed that this PVD coating could be formed homogeneously, without cracks and promoted a higher surface hardness to the insert and consequently it can produce a better wear resistance during its application on high speed machining.

Introduction

There is a continuous need for improving the existing cutting tool materials, which is driven by a strong competition on the market and also by more difficult to machine materials. Materials highly resistant to wear, abrasion, erosion and corrosion are of utmost importance in many different industrial fields. Therefore the machining operations of these materials demand a large amount of money annually [1]. Among machining processes, turning still remains the most important operation used to shape metals because in turning, the conditions of operation are most varied. Increasing productivity and reducing manufacturing cost have always been keys to a successful business [2]. In turning, higher values of cutting parameters offer opportunities for increasing productivity but it also involves a greater risk of deterioration in surface quality and tool life [1-3]. The authors have given attetion to important technological challenges in the production of Si_3N_4-based tools able to fulfill such a manufacture goal. Deterioration of surface quality during turning is directly related to the tool wear progression. Researchers have focused their attention on improvements in conventional turning, so that tool life can be enhanced or tool failure can be avoided. Tool failure means a large damage in the tools surface, that it has no ability to remove material from workpiece. This tool damage cannot be avoided but we can find out ways to minimize it [4]. The prime idea in this sense has been the development of new Si_3N_4-based hard tools for applications demanding tribological [5]. In the following, the utilization of new hard coatings has been used in order to increase the lifetime of the Si_3N_4-based insert. In recent years, extensive attempts have been made to cover the ceramics tool with an original and prospective material [6]. In this work, a new composition of the Si_3N_4 ceramic cutting tool was developed, characterized and subsequencially the properties enhanced with a PVD applied aluminum chromium nitride (AlCrN) coating. The motivation behind the present study was the little information in the literature about AlCrN coated Si_3N_4 substrates.

Experimental procedure

The Si_3N_4 ceramic substrate were prepared using 78,50 Si_3N_4– 11.50 AlN– 8.0 Y_2O_3– 2.0 Al_2O_3 (weight %) that was subsequentlly sintered and characterized. The substrates were square-shaped inserts (ISO 1832) that are 12.7 mm wide and 4.76 mm thick with a 0.8 mm corner radius. To remove any possible superficial layer formed during sintering, the sintered samples were rectified and then polished until mirror finishing. After cleaning in ultrasonic bath with acetone and distilled water, the samples were dried in an oven at 100 °C. Before coating, the Si_3N_4 inserts properties were analised by XRD, AFM, hardness and fracture toughness. AlCrN coating was deposited using a commercially process developed by Oerlikon Balzers Inc.. For this purpose, a Balzers Rapid Coating System (RCS) in the cathodic arc ion platting mode was employed [7]. AlCrN coating properties was analised by grazing incidence X ray diffraction (GIXRD – omega = 2°), AFM and Vickers hardness (50 g).

Results and discussion

The green compacts of Si_3N_4 inserts showed 60.5 % of the theoretical density, whereas the sintered specimens presented 99. 12 % of the theoretical density. The Vickers hardness was of 18.10 GPa and fracture toughness was 5.68 MPa $m^{1/2}$. The measured hardness values are lower than that of the pure α-SiAlON ceramics, ranging from 20 to 22 GPa, but higher than that of β-Si_3N_4, ranging from 15 to 17 GPa. Fig. 1a shows the square and round shaped cutting inserts of Si_3N_4 obtained after sintering. Fig. 1b shows the AlCrN coated insert.

The machineability of materials can be improved due to the application of a coating in the cutting tool. Hard coatings, deposited by physical vapour deposition on inserts, have been used for a long time in order to increase their life time. The hardness of the AlCrN coating was 30.16 GPa (1.66 times higher than the uncoated insert).

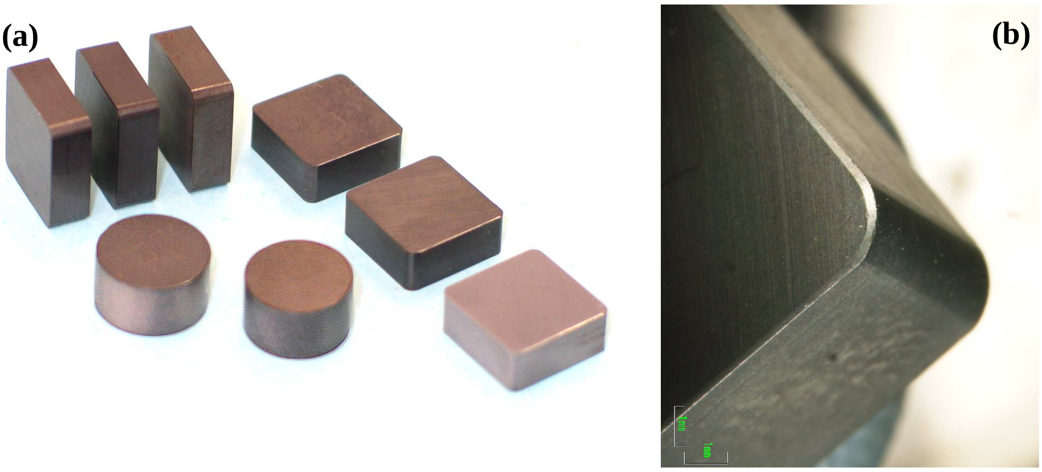

Fig. 1. (a) Square and round shaped Si_3N_4 cutting inserts. (b) AlCrN coated insert.

Fig. 1. shows the XRD pattern for uncoated Si_3N_4 cutting tool. These peaks are charateristcs of the β-Si_3N_4 phase. Fig. 2 presents the GIXRD pattern of AlCrN coated cutting tool with cubic structure, and their major peaks are located close to the corresponding cubic AlN peaks. The AlCrN has (200), (111) and (222) preferential orientation.

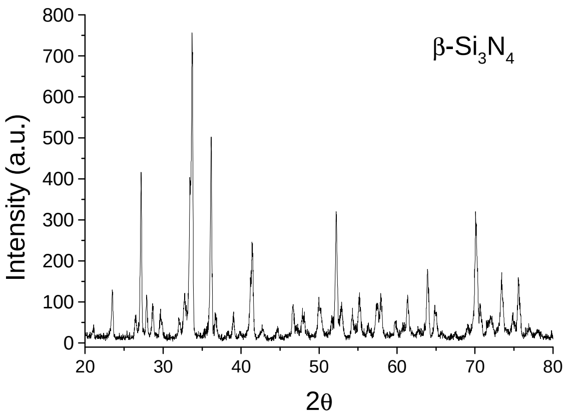

Fig.1. XRD pattern of uncoated Si_3N_4 cutting tool.

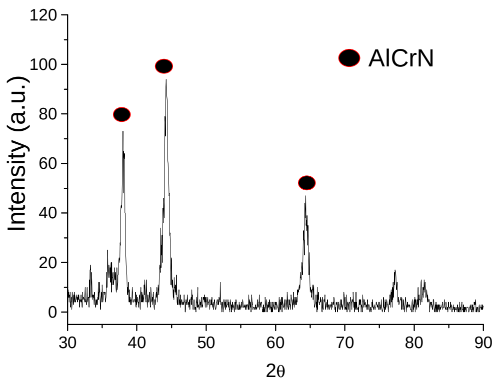

Fig.2. XRD pattern of AlCrN coated Si_3N_4 cutting tool

The development of a cutting tool surface with microscale and nanoscale textures to improve frictional behavior is mainly dependent of material type. Fig. 3(a) shows the topography of the uncoated Si_3N_4 cutting tool and it can be observed clearly the scratches (elongated shape) produced during grinding (grinding wheel). The arithmetic average roughness (Ra) was 245 nm. A groove 1.8 µm wide and 0.8 µm deep was fabricated on the over cutting tools surface. Fig. 3 (b) shows a topography image of the AlCrN coated Si_3N_4 cutting tool and it was observed that it was formed a new homogeneous texture (without cracks) for the cutting tool with round shaped AlCrN grains that present an average grain size of 1 µm. This new surface is much smoother (Ra = 93.9 nm) compared to the uncoated.

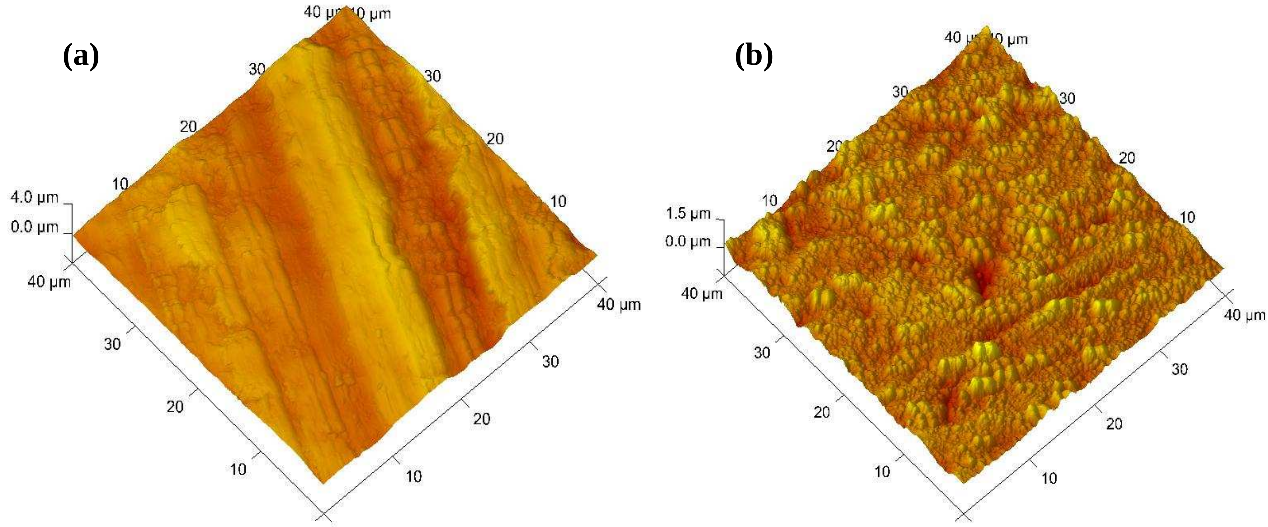

Fig. 3. AFM topography images of the: (a) uncoated Si_3N_4 cutting tool. (b) AlCrN coated Si_3N_4 cutting tool.

Conclusions

The results showed that Si_3N_4 inserts presented good mechanical properties. With the development of a new experimental methodology it was possible to coat the inserts with AlCrN, which leaded to a higher surface hardness. This is a new way to minimize wear and extend life of Si_3N_4 cutting tools that are generally applied under severe machining conditions. The coated cutting tools can promote dry machining with consequent reduced infrastructure, lower costs and a cleaner environment, compared to today's practice of wet machining.

Acknowledgements

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References

[1] S. Kurama, M. Herrmann and H. Mandal, The effect of processing conditions, amount of additives and composition on the microstructures and mechanical properties of α-SiAlON ceramics, J Eur Ceram Soc 22 (1) (2002), pp. 109–119.

[2] I.M. Hutchings and Tribology, Friction and Wear of Engineering Materials, Edward Arnold, London (1992).

[3] S. Dolinsek, B. Sustarsic and J. Kopac, Wear mechanisms of cutting tools in high-speed cutting processes, *Wear* (2001), pp. 349–356.

[4] H.G. Prengel, W.R. Pfouts and A.T. Santhanam, State of the art in hard coatings for carbide cutting tools, *Surf. Coat. Technol.* 102 (1998), pp. 183–190.

[5] SOUZA, J.V.C. ; NONO, M.C.A. ; Ribeiro, M.V. ; Machado, J.P.B. ; SILVA, O.M.M. . Materials and Design, v. 30, p. 2715-2720, 2009.

[6] SOUZA, J.V.C.; SILVA, C.R.M.; CORAT, E.; MENDONÇA, W. G.; BELMONTE, M.; LANNA, M. A.. CVD Diamond Coated Si3N4 Tools. Acta Microscópica, v. 12, n. Suplement, p. 171-172, 2003.

[7] G.S. Fox-Rabinovich, B.D. Beake, J.L. Endrino, S.C. Veldhuis, R. Parkinson, L.S.
Shuster, M.S. Migranov, Surf. Coat. Technol. 200 (2006) 5738.