



Development and Optimization of CrN and CrSiN Coatings for Enhanced Tool Performance in Cryogenic Machining of Ti6Al4V

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Keywords : CrN, CrSiN, HIPIMS, cryogenic machining

Abstract : Cryogenic machining has emerged as a sustainable alternative to conventional cutting fluids, reducing environmental impact while enhancing cooling efficiency at the tool-workpiece interface [1]. This study focuses on the development of protective coatings for cutting tools used in the cryogenic machining of Ti6Al4V titanium alloy. Various coatings are applied to tungsten carbide tools due to their excellent mechanical and tribological properties to improve their machining performance [2,3,4]. Jianliang Lin et al. [5] reported that the CrN coating deposited by modulated pulsed power magnetron sputtering (MPPMS) exhibited a hardness of 26 GPa and a Young's modulus of 330 GPa. The addition of 6.3 at.% silicon in coatings deposited by pulsed DC sputtering further enhanced the mechanical properties, reaching maximum values of 38 GPa for hardness and 395 GPa for Young's modulus. The present study reports the enhancement of mechanical and tribological properties of CrSiN coatings deposited using high power impulse magnetron sputtering (HiPIMS) technique. Several deposition parameters, such as the nitrogen flow rate, target duty cycle, target bias voltage, and the synchronization of the bias pulse (T_{on}) with the target were optimized to enhance film adhesion and density, thereby improving the tool performance.

Microstructural and morphological characterization as well as phase identification were performed using X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive spectroscopy (EDS).

The first part of this work focused on optimizing the properties of CrN coatings. Nanoindentation results revealed a maximum hardness of 33.2 GPa and an elastic modulus of 317 GPa at $T_{on} = 110 \mu s$. Tribological tests, conducted with a rotary tribometer, showed a friction coefficient ranging from 0.51 to 0.53 for all coatings, with a minimum wear volume of $1.24 \times 10^{-5} \text{ mm}^3/\text{Nm}$ obtained for $T_{on} = 210 \mu s$. Moreover, coatings deposited at $T_{on} = 210 \mu s$ and $310 \mu s$ exhibited superior adhesion strength, with critical loads (LC3) of 4.5 N and 4.15 N, respectively with a conical diamond tip. The CrN coating deposited at $T_{on} = 210 \mu s$ showed the best balance between mechanical and tribological properties, confirming the important role of bias pulse synchronization in optimizing the performance of HiPIMS deposited coatings.

In the second stage, the effect of silicon incorporation was investigated. CrSiN coatings with silicon contents ranging from 0 to 10 at.% were deposited using a hybrid HIPIMS/pulsed DC mode. The aim was to evaluate the influence of Si addition on the microstructural evolution and mechanical performance of the coatings, in comparison with the optimized CrN reference.

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