Thermal treatment effect on structural and mechanical properties of Cr–C coatings

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ABSTRACT

In the present study, the effect of thermal treatment on the mechanical and structural properties of chromium carbide coatings with different thicknesses is evaluated. The coatings were deposited by cathodic magnetron sputtering on XC100 steel substrates. Samples were annealed in vacuum, at different temperatures ranging from 700 to 1000°C for 1 h, resulting in the formation of chromium carbides. X-ray diffraction (XRD), microanalysis X/energy-dispersive X-ray spectrometer (EDS), X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy analysis were used to characterise the samples. Mechanical properties were evaluated by nano-indentation tests and the residual stress was calculated with the Stoney formula. The XRD analysis suggests the formation of the Cr_7C_3, $Cr_{23}C_6$ carbides at 900°C. For thin films, they transformed totally to ternary $(Cr, Fe)_7C_3$ carbides and their partial transformation has been observed in the case of thick films at 1000°C, without the formation of Cr_3C_2. The EDS and XPS showed the diffusion mechanism between the chromium film and the steel substrate for the Cr, Fe, C, O elements during the annealing treatment. The increase of chromium film thickness from 0.5 to 2.64 µm, contributed to the significant enhancement of mechanical properties such as hardness (H) (from 12 to 26.3 GPa) and Young's Modulus (E) (from 250 to 330 GPa), respectively.

KEYWORDS

Chromium carbide; hardness; Young's modulus; annealing treatment; diffusion

1. Introduction

During the last decade, transition metal carbides and nitrides with good mechanical properties have started to make their mark in surface engineering.[1] They have attracted much attention due to their excellent mechanical and physical properties such as high hardness (about half that of diamond), high melting temperature, high chemical and thermal stability, good wear and corrosion resistance.[2] The hard chromium carbide coatings produced by physical vapour deposition,[3] chemical vapour deposition[4] or by means of electrodeposition techniques[5,6] with a few microns thickness, have enhanced the mechanical resistance of various parts. For example, Zhou *et al.*[7] discovered that chromium and ternary chromium carbide films are effective in protecting steel and various alloys from chemical attack.

At present, it's considered the best choice, in various industrial applications. Recent results from Castillejo *et al.*[8] and Aissani *et al.*[9] showed that chromium-based coatings, because of their high wear resistance and hardness, can be used for steel protection for sliding bearing applications etc. In general, chromate conversion coatings produced on various metals by chemical or electrochemical treatment with mixtures of chromium hexavalent compounds and certain other compounds are soft and gelatinous when freshly formed, but become harder once dried or aged.[10] The effect of thermal treatments on the mechanical properties of interference films electrochemically deposited on stainless steel has been investigated by Poletika *et al.*[11]

However, the possibility of using the steel substrate itself as a source of carbon, in order to create very coherent hard chromium carbide coatings by means of a diffusion and transformation process has not been investigated comprehensively. Hence the main focus of the present study is to evaluate the above feasibility and also to investigate the influence of annealing treatment and the film thickness on the chemical composition, structure, surface morphology and mechanical properties of the Cr/XC100 samples.

2. Experimental details

Chromium (Cr) thin films were deposited in a high vacuum system with a base pressure of $2{\times}10^{-5}$ Pa by radio frequency (R.F) magnetron sputtering (NORDIKO type 3500. 13.56 MHz) in a pure Argon atmosphere on Si (100) wafers (10×10 mm^2, 380 µm thick) and polished XC100 steel discs (15 mm diameter and 3 mm thick). A Cr (99.95 at.-%) target with a diameter of 10.16 cm and mounted in an off-axis configuration with a substrate-to-target distance of 8 cm and 45° from normal was used to deposit the Cr films. The typical composition of XC100 steel is: (0.95–1.05) wt-% C, (0.5–0.8) wt-% Mn, 0.05 wt-% S, 0.25 wt-% Si, 0.035 wt-% (P and S), with Fe as the balance. The substrates were ground, polished and ultrasonically cleaned for 5 min (each successively in trichloroethylene, methanol and acetone) to an average roughness (Ra) of 30 ± 0.01 nm (measured by an atomic force microscope). Before deposition, the substrates were bombarded with Ar^+ ions for 5 min at −700 V and at 1 Pa to clean them of any contaminants and oxide films. During deposition, the substrate temperature was estimated to be around 150–200°C. The Cr