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Evaluation on wear behavior of Cr–Ag–N and Cr–W–N PVD nanocomposite coatings using two different types of tribometer

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Abstract

Practice has proven that CrN performs better than TiN under some specific tribological applications. Nevertheless, the relatively soft nature of CrN still remains a problem. This paper reports experimental results on increases in hardness of sputtered PVD CrN coatings by means of additions of varying content of Ag or W. The resulting Cr–Ag–N and Cr–W–N coatings, grown on JIS SKH51 steel substrates, were characterized using SEM, EDS, WDS, XRD, micro-indentation hardness testing and scratch adhesion tests. Moreover, wear behavior was studied on two types of tribometer, employing different contact regimes — a 'cylinder-on-disk' line-contact reciprocating-sliding regime and a 'ball-on-disk' point-contact rotating-sliding regime.

The experimental results can be summarized as follows: The hardness of Cr–W–N coatings increased with increasing W content; reversely, that of Cr–Ag–N coatings decreased with increasing Ag content. The additions of Ag and W resulted in a formation of secondary phases, elemental Ag and WN, respectively, uniformly embedded in the CrN coatings. With the two different types of tribometer, the observed trends for wear behavior, wear and friction coefficient, were nearly identical, indicating that both Ag and W additions to CrN coatings were beneficial. However, the Cr–W–N coatings were significantly more wear resistant than the Cr–Ag–N coatings. With the addition of W at 6.8 at.%, the largest wear improvement of 73%–85% was achieved.

Keywords: Cr–Ag–N; Cr–W–N; WN; Ag; Hardness; Wear

1. Introduction

For over two decades, transition metal based PVD and CVD ceramic coatings have been one of the solutions for surface protection. Among them, titanium nitride (TiN) coating is still the most popular material used in industrial applications. However, much evidence has shown that chromium nitride (CrN) coating performs better under some specific environments.

Navinšek et al. [1] found that CrN coatings improved forming performance of plough crowns and forming knives. Nouveau et al. [2] demonstrated that in cutting wood CrN coated carbide inserts performed well. Navinšek and Panjan [3] studied CrN coatings by means of long-term performance tests, and found a higher quality surface finish of products and high reliability of CrN coated tools in production. They applied CrN coatings on die casting moulds (AISI H11 tool steel) and cold forming tools (AISI D2 and D3 tool steel) for mass production of many kinds of Al alloy components, and achieved improvements in tool life by somewhere from 100% to 500%, as compared with uncoated tools. In a later study of Panjan et al. [4] on performance of extrusion dies (AISI H13 tool steel) in extruding aluminum alloys, it was found that CrN coated dies showed large improvements as compared with traditional gas nitrided dies for the die lives and throughput in the extrusion process. In machining applications, Kondo et al. [5] studied the cutting performance of uncoated, CrN- and TiAlN-coated carbide endmills for machining copper, and concluded that CrN-coated endmills were superior to uncoated and TiAlN-coated ones. In addition, it has been practically confirmed that

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CrN coatings can prolong tool-life in machining non-ferrous metals, *e.g.* Monel and Inconel [6].

When compared with TiN, CrN showed much better wear performance in such applications, due to its lower friction coefficient and higher toughness [7]. However, the comparatively low hardness of CrN ($HK_{0.05}$ 2756 vs. 2065), based on our previous research results [8–10], still remained a problem, in which both coatings were prepared using an identical PVD technique.

Recently, researchers have tried to further increase the hardness of metal-based ceramic coatings, as well as to achieve new physical properties, by means of an addition of a third party metal element. The resulting coatings can be divided into two groups: (1) MeN/hard phase, and (2) MeN/soft phase; where Me = Cr, Ti, W, V, Zr, etc.; hard phase = a-Si_3N_4 [11,12], a-TiB_2 [13], etc., or transitional metal nitride, carbide, boride, etc.; soft phase = Cu [14], Ni [15], Y [16] Ni [17,18], etc. These new coatings show many interesting properties, such as: (1) varying hardness achieved by combinations of a main first phase MeN and a second phase at different ratios, and (2) especially superhardness (>40 GPa) obtained, some up to 55 GPa (for example Zr–Cu–N, Cu 1–2 at.% [19]).

The addition of Mo [20] and Ti [21] to CrN coatings was investigated, but no positive results were gained with regard to increased hardness. Purushotham et al. [22] incorporated 3 at.% and higher Zr content into CrN coatings by using a metal vapor vacuum arc implantation method, and investigated the tribological behavior and hardness. They found that the tribological properties were not enhanced and the Zr implanted zones were softened. Nevertheless, Hones et al. [21,23] found that the hardness of CrN coatings showed a steep increase with only a small addition of W: The addition of 10 at.% W could enhance the hardness by 85%. Up to date, no data report the addition effect of Ag to CrN coating.

This paper presents results of experimental investigations on CrN coatings with varying content of Ag or W addition, mainly aiming at enhancing the overall hardness of CrN coatings, and then exploring their potential use in wear applications. In addition, characterizations of the synthesized coatings were conducted.

Table 2
Important coating process settings for CrN series of films

1. Pre-treatment	Degreasing, rinsing in distilled water, drying using high pressure N_2 jet
2. Pump down	Base pressure $<7\times10^{-5}$ mbar
3. Substrate conditioning	Time = 10 min. Ar flow rate = 25 sccm ($P_{Ar}\sim2\times10^{-3}$ mbar), bias voltage $U_B=-350$ V, D_{S-T}[a] = 150 mm, ω[b] = 5 rpm
4. Cr interlayer (~0.1 μm)	Time = 10 min. Ar flow rate = 25 sccm, 4 × Cr targets, Cr target current = 3 A (~3.0 W cm^{-2}), $U_B=-110$ V, $D_{S-T}=150$ mm, ω = 5 rpm target dimension = 437.3 mm × 178.2 mm × 10.2 mm
5. Top CrN coatings	1. CrN: 4 × Cr targets *Cr–Ag–N coatings:* 2. Ag02: (3 × Cr or 1 × Ag) targets, Ag target current = 0.2 A (~0.2 W cm^{-2}) 3. Ag04: (3 × Cr or 1 × Ag) targets, Ag target current = 0.4 A (~0.4 W cm^{-2}) 4. Ag05: (3 × Cr or 1 × Ag) targets, Ag target current = 0.5 A (~0.5 W cm^{-2}) 5. Ag08: (3 × Cr or 1 × Ag) targets, Ag target current = 0.8 A (~0.8 W cm^{-2}) 6. Ag10: (3 × Cr or 1 × Ag) targets, Ag target current = 1.0 A (~1.0 W cm^{-2}) 7. Ag15: (3 × Cr or 1 × Ag) targets, Ag target current = 1.5 A (~1.5 W cm^{-2}) 8. Ag20: (3 × Cr or 1 × Ag) targets, Ag target current = 2.0 A (~2.0 W cm^{-2}) *Cr–W coatings:* 9. W05: (3 × Cr or 1 × W) targets, W target current = 0.5 A (~0.5 W cm^{-2}) 10. W10: (3 × Cr or 1 × W) targets, W target current = 1.0 A (~1.0 W cm^{-2}) 11. W15: (3 × Cr or 1 × W) targets, W target current = 1.5 A (~1.5 W cm^{-2}), 12. W20: (3 × Cr or 1 × W) targets, W target current = 2.0 A (~2.0 W cm^{-2}) 13. W30: (3×Cr or 1 × W) targets, W target current = 3.0 A (~3.0 W cm^{-2}) *General conditions:* Cr targets current = 3 A (~3.0 W cm^{-2}), Time = 50 min. Ar or N_2 flow rate = 25 or 15 sccm ($P_{Total}\sim1\times10^{-3}$ mbar), $U_B=-35$ V, $D_{S-T}=150$ mm, $\omega=5$ rpm
6. Cooling down and venting	Time = 30 min

[a] Distance between substrate and target.
[b] Substrate holder rotating speed.

2. Experimental procedure

Three types of materials, JIS SKH51, S45C and SUJ2 steels, were used, whose chemical compositions are listed in Table 1. SKH51 and S45C bar steels were machined to specific specimen shapes and dimensions, heat-treated to hardnesses of H_RC 55 and H_RC 28, respectively, and then mechanically polished to a surface roughness of Ra < 0.1 μm. SKH51 specimens were with a disk shape and used as substrates for growing coatings for every stage of experiments. Two dimensions were needed for SKH51 specimens to fit the fixtures of two different tribometers (described later on): one was of diameter 24 mm and thickness 7.9 mm, and the other one of diameter 40 mm and thickness 6.0 mm. S45C specimens had a shape of cylinder and a dimension of diameter 15 mm and length 22 mm. SUJ2 specimens are a commercial product with a

Table 1
Nominal chemical composition (wt.%) of JIS S45C, SKH 51 and SUJ2 steels

	C	Mn	Cr	W	V	Mo	Si	P	S	Ni	Cu	Fe
SKH51	0.82	0.24	4.20	6.50	2.05	5.78	0.23	0.02	0.01	0.08	0.12	Bal.
S45C	0.46	0.75	0.21	–	–	–	0.24	0.02	0.01	0.06	0.05	Bal.
SUJ2	1.03	0.31	1.39	–	–	–	0.22	0.01	0.01	0.07	0.06	Bal.