2 Cr + CrN multilayer coating deposited by straight-tube magnetic filtering arc ion plating to improve wearability of 304 stainless steel

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As the most widely used stainless steel and heat-resistant steel, 304 stainless steel is commonly used for food processing equipment, chemical equipment and nuclear industry. However, due to the restriction of its hardness and anti-friction and anti-wear capabilities, 304 stainless steel cannot meet the requirement for the industry production under unfavorable conditions. Thus, it is important to perform the modification treatment towards its surface.

Currently, the preparation of CrN coating is subdivided into following types: magnetron sputtering, cathodic vacuum arc source, arc bond sputtering (ABS) and ion beam assisted deposition. The coating prepared through these methods, however, always generates larger grains (droplet phase). Thus, the surface lacks smoothness and the film-substrate cohesion. By using the straight-tube magnetic filtering cathodic vacuum arc (FCVA) deposition technology, the magnetic filter can effectively decrease or eliminate the larger grains (droplet phase), thus obtaining smoother, harder, more compact coating, which has a good combination with the substrate and is hard to flake off. Due to the guiding role of the magnetic filed to the ion current, the FCVA deposition devices can be employed to decrease the relative proportion of larger grains in the plasma flow; increase the target-substrate distance in space, so as to reduce the arc emission angle and to trap the droplets from the small angle; compress the plasma beam, so as to increase the collision probability between particles, further deepen the physicochemical orientation of neutral particles, and even to refine and evaporate larger grains, thus effectively reduce the generation of large grains. This paper describes the application of FVCA deposition technique in preparing the CrN/Gr multilayer coating on the 304 stainless steel, and studies the microstructure and the anti-friction and anti-wear capabilities of the coating.

304 stainless steel with the size of 50 mm × 20 mm × 5 mm (0Cr18N9) is selected as the base material. After the selection, we grind the base materials with sand papers of different particle size, polish them with the metallographical polishing machine, and dip them into acetone and clean with ultrasonic washer. Before the deposition of the base materials, we clean them with the Ar⁺ sputtering source under the 800 V negative bias voltage for ten minutes, so as to clean the surface and to increase the activity.

In the experiment, the X’Pert PRO MPD manufactured by the PHILIPS in Netherlands is used to test the phase composition of the Cr/CrN multilayer coating; the optical microscope is used to observe and analyze the micro-structure of the coating and the cross section; HXD-1000TME microhardness tester is used to measure each specimen from nine perspectives under the loads of 50 gf (equaling 0.49 N) and 100 gf (equaling 0.98 N) and take the average; the MS-T3000 friction and wear testing machine is used to perform the dry friction test under the load of 100 gf and the rotating speed of 300 r·m⁻¹ so as to test the anti-friction and anti-wear capabilities of the coating.

Fig. 1 shows the XRD pattern of Cr/CrN multilayer coating. The multilayer coating is composed of CrN and β-Cr₂N in the face-centered cubic lattice structure. In addition, the characteristic spectrum line of CrN and β-Cr₂N is presented on the (111) surface, and the strong peaks are also presented on the (111) surface. It is thus concluded that the coating is preferentially grown on the (111)-oriented surface.

Fig. 2 shows the morphology of the Cr/CrN multilayer
coating. There are few grains on the coating surface which is comparatively compact and smooth. During the filtering coating procedure, some larger grains (droplet) fail to be filtered. Thus, there are some larger grains on the surface.

![Fig. 2. Surface and Cross-section of CrN and Cr/ CrN multilayer films.](image)

Table 1 shows the average microhardness value of the nine-perspective measurement of the substrate and Cr/CrN multilayer coating. As shown in Table 1, the hardness of the substrate after being deposited with the Cr/CrN multilayer coating, is increased by more than ten times the hardness of the original substrate no matter under the load of 50 gf or the load of 100 gf. Koehler has proposed two components with comparatively greater elastic constants and the multilayer structure in the 1970s, on the basis of which the solid model with great strength can be obtained. Through the dislocation theory, the deposited coating functions as a barrier to the generation and movement of dislocation. The existing literatures prove that the when the chemical modulation wavelength ($\lambda$) used by the representation multilayer structure is within the um range, the hardness of the multilayer film increases with the decrease of $\lambda$ according to the Hall-Petch equation ($\sigma_2 = \sigma + K\lambda^{-1/2}$). The mechanism is called Hall-Petch effect. When $\lambda$ is within the um range, a peak value appears on the hardness curve, the mechanism of which should be further elaborated. In addition, the multilayer structure can also enhance the anti-friction and anti-wear capabilities and refine crystal grains. CrN + β-Cr3N is the main component of the Cr/CrN multilayer coating. The crystal structures of these two materials are different, thus hindering the generation and movement of dislocation, enhancing the pinning force, refining crystal grains, and enabling the coating to have greater hardness.

<table>
<thead>
<tr>
<th>Specimen Name</th>
<th>HV$_{50gf}$</th>
<th>HV$_{100gf}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>238</td>
<td>212</td>
</tr>
<tr>
<td>Cr/CrN coating processing</td>
<td>2485</td>
<td>2218</td>
</tr>
</tbody>
</table>

The Cr/CrN multilayer coating is prepared through the FCVA technology. The crystals in the coating is grown on the (111) surface, focusing on CrN and β-Cr$_3$N. The surface structure of the coating is smooth and compact with refined crystal grains, thus featuring higher hardness and superb anti-friction and anti-wear capabilities. Therefore, the Cr/CrN multilayer coating prepared through the FCVA technology can significantly change the mechanical properties of 304 stainless steel, thus leading to an even broader prospect for the application of 304 stainless steel.