Investigating the Tribological Properties of MoS$_2$/Ni Composite Coatings Produced by Magnetron Sputtering

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1. Introduction
MoS$_2$ is the predominant material used as a solid lubricant and has been widely used in many tribological applications. MoS$_2$ coating is strongly influenced by the test atmosphere. It has been mostly used as a solid lubricant in space and vacuum application. MoS$_2$ is too highly sensitive to humid air. The temperature limitation at 400ºC is restricted by oxidation.

In order to improve the properties of MoS$_2$ coating using the co-sputtering method, several authors have studied adding metals and materials into MoS$_2$ matrix structure. The composite coatings have shown better performance compared to pure MoS$_2$ coating in terms of hardness, wear resistance, and adhesion to the substrate. The addition of Ni into the MoS$_2$ coating in recent years has drawn attention because of the significant improvement of the oxidation resistance and tribological performance dependent on the humidity in ambient air. In this investigation, MoS$_2$/Ni composite coatings were investigated to give some insight into the effects Ni content in MoS$_2$/Ni composite coatings on the microstructure and mechanical properties and tribological performance in the ambient air.

2. Experiment
Samples of Ck45 (AISI 1045) plain carbon steel, measuring 10 mm×5 mm×2 mm were used as substrates. The MoS$_2$/Cr coating was fabricated in DC magnetron sputtering ion plating equipment. MoS$_2$ (99.8% purity) and Cr (99.99% purity) with 0, 5, 10, and 15 wt% composite targets of a 50 mm diameter fixed on a magnetron-effect cathode were used. The composite targets were fabricated by ball milling the mixture of pure MoS$_2$ and Cr powders, followed by pressing the mixture under a pressure of 60 MPa in an Ar atmosphere at 850ºC. The MoS$_2$/Cr ratio in the coatings was controlled by sputtering the composite targets. The chemical characterization was performed using EDX (energy dispersive X-ray analysis) and the structural characterization was accomplished by X-ray diffraction (XRD) studies. The mechanical properties of coatings were analyzed by nanoindentation experiments. The tribological behavior of the coatings was investigated using the pin on disc test at room temperature.

3. Results and Discussion
Figure 1 shows specific wear rate of MoS$_2$/Ni composite coatings as a function of Ni content. The results are typical of those obtained for the composite coatings with a performance better than the pure MoS$_2$ coating. In contrast, despite its high hardness and good coating cohesion, the MoS$_2$–Ni 22 at% coating shows a high friction coefficient and poor wear resistance.

Figure 2 shows the wear coefficients of MoS$_2$/Ni composite coatings. Within the Ni content region of 0–15 at%, increasing the Ni content led to a significant decrease of the coating’s wear coefficient. This indicates that the doped Ni improved the tribological properties of pure MoS$_2$ in the atmospheric environment. The optimum composition of coatings are MoS$_2$/Ni$_{x}$% with $x=13$% level. A reasonable explanation is due to the increase of both hardness and adhesion of the MoS$_2$/Ni coatings with the increase of chromium content to 15 at%.

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4. Conclusion
The MoS$_x$/Ni coatings exhibited a steady state friction coefficient from 0.15 to 0.19. Adding Ni to MoS$_2$ coatings improved their adhesion to steel substrate and hardness as well as increased the wear performance of MoS$_x$ coatings under atmospheric conditions. The main wear mechanisms in the MoS$_x$ and MoS$_x$/Ni coatings were therefore abrasive and adhesive, respectively.