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# Tribocorrosion behaviors of AlN/$MoS_2$–phenolic resin duplex coatings on nitrogen implanted magnesium alloys

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ABSTRACT

Nitrogen ion implantation and AlN/$MoS_2$–phenolic resin duplex coating are designed to improve wear and corrosion resistance of magnesium alloys. The microstructure and tribocorrosion behaviors of as-fabricated coatings are characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier transform infrared spectroscopy (FTIR), tribocorrosion and electrochemical tests. Studies show that Cl ions induce severe corrosion degradation of magnesium alloy during the tribocorrosion test. $MoS_2$–phenolic resin coating has two phase composite structure consisting of $MoS_2$ crystalline and phenolic resin, but this coating shows poor tribocorrosion resistance because force–corrosion synergy interaction accelerates the degradation process. The introduction of nitrogen ion implantation and AlN interlayer remarkably retards the corrosion degradation process of magnesium alloy. AlN/$MoS_2$–phenolic resin duplex coating exhibits better tribocorrosion resistance. These present results indicating that gradient duplex coating might be a good candidate as protective coating in engineering applications of magnesium alloys.



## 1. Introduction

In recent years, magnesium alloys have received extensive attention in automotive and aerospace industries due to their characteristic properties, including high strength-to-weight ratio, excellent damping capacity, high thermal conductivity, good manufacturability and potential recycling capability [1–3]. However, poor corrosion resistance and unsatisfactory wear performance of magnesium alloys restrict their industrial applications [4].

Surface modifications are an effective method to improve anti-wear and anti-corrosion properties of magnesium alloys. Ceramic coatings fabricated by microarc oxidation (MAO) can improve wear and corrosion resistance of magnesium alloys. However, these hard ceramic coatings usually exhibit a high friction coefficient and suffer from corrosion failure due to the growth defects such as micro-pores and cracks [5–7]. Ion implantation can improve corrosion resistance of magnesium alloys, but the implanted layers are not as effectively thick as ceramic coatings [8,9]. Hard coatings synthesized by physical vapor deposition (PVD) benefit wear resistance improvement of magnesium alloys [10–12], but galvanic corrosion always occurs between coatings and substrates due to a large potential difference [13]. In addition, these hard coatings also show unsatisfactory wear performance due to low load-bearing capacity of magnesium alloys [14]. Duplex coatings, such as (Ti:N)-DLC/MAO, have been shown to possess excellent wear and corrosion resistance [15–17]. These present results indicate that duplex architecture seems to be a possible choice to not only reduce the effect of galvanic corrosion but also hold high load-bearing capacity.

Phenolic resins have been widely used in automobile and aviation industries due to their superior mechanical strength and corrosion resistance [18,19]. However, poor wear resistance of phenolic resins limits their tribological applications [20]. Many studies have reported that adding various filling constituents into phenolic resins can significantly improve their wear resistance [21,22]. These present results indicating that phenolic resin-based self-lubricating coatings show a great promise prospect to improve wear and corrosion resistance of magnesium alloys. In this study, nitrogen ion implantation and AlN/$MoS_2$–phenolic resin duplex coatings are designed to improve wear and corrosion resistance of magnesium alloys. The purpose of nitrogen ion implantation is to induce densification of the oxide layer. AlN interlayer is used to retard galvanic corrosion and provide load support for soft $MoS_2$–phenolic

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**Table 1**
Experimental details of as-fabricated coatings.

| Sample | Coatings |
|---|---|
| M0 | AM60 substrate |
| M1 | AM60 substrate/$MoS_2$–phenolic resin coating |
| M2 | Nitrogen implanted AM60 substrate/AlN/$MoS_2$–phenolic resin coating |

resin layer. In addition, the microstructure and tribocorrosion behaviors of as-fabricated coatings are investigated in detail.

## 2. Materials and methods

Si wafers and AM60 magnesium alloys are used as the substrate. The samples are mechanically polished by diamond paste and ultrasonically washed by using pure ethanol. High purity Al (99.99%) is as the targets. High purity nitrogen is as the working atmosphere. Nitrogen ion implantation and AlN interlayer are carried out in a plasma immersion ion implantation and deposition facility [23]. Prior to ion implantation, all the samples are cleaned by Ar+ sputtering at a bias voltage of 6 kV for 30 min to remove residual pollution and surface native oxide. Ion implantation is conducted in nitrogen atmosphere. Nitrogen plasma is produced by a radio-frequency method. Immersion ion implantation is conducted by applying a high pulsed bias voltage. The implantation parameters are displayed as follows, nitrogen flow — 50 sccm, pressure — 0.6 Pa, bias voltage — 30 kV, frequency — 200 Hz, bias voltage duration time — 20 μs and time — 2 h. Afterwards, the AlN interlayer is deposited on the surface of the implanted sample in nitrogen atmosphere. The Al metal plasma is produced by a pulse cathodic arc plasma source and is guided into the chamber through a magnetic filter duct. The metal plasma reacts with nitrogen plasma to form the AlN interlayer. The experimental parameters were displayed as follows, pressure — 0.3 Pa, bias voltage — 20 kV, frequency — 50 Hz, bias voltage

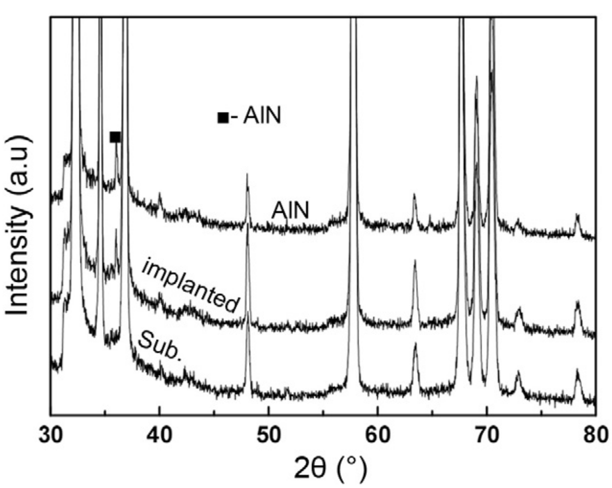


**Fig. 1.** XRD patterns of substrate, nitrogen implanted substrate and AlN interlayer.

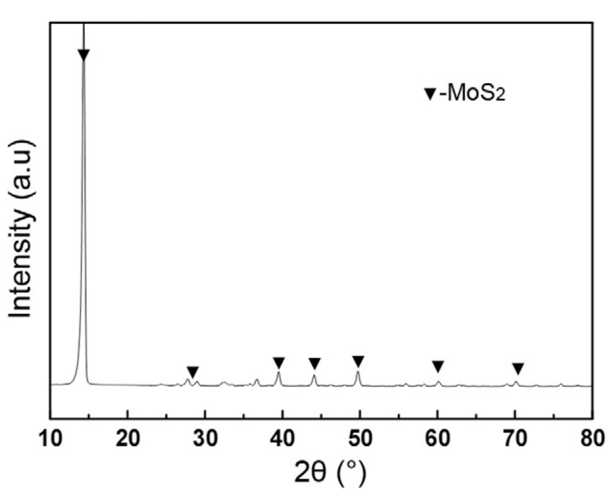


**Fig. 2.** XRD pattern of $MoS_2$–phenolic resin coating.

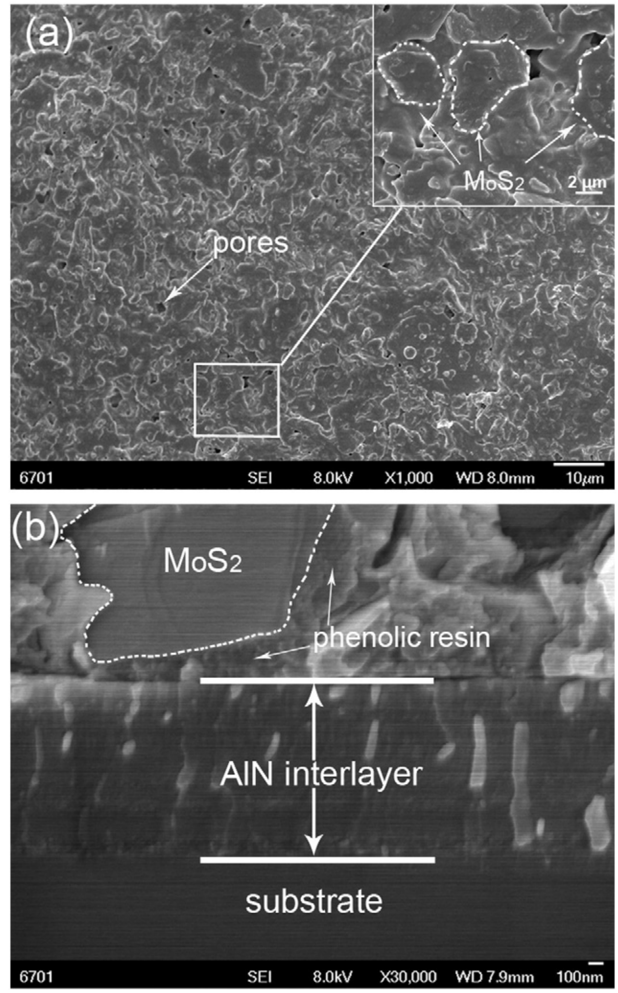


**Fig. 3.** (a) SEM surface image of $MoS_2$–phenolic resin coating; (b) SEM cross-section image of sample M2.

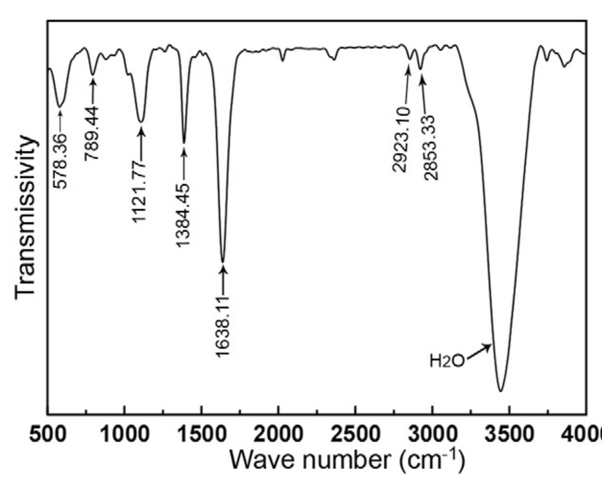


**Fig. 4.** FTIR spectrum of $MoS_2$–phenolic resin coating.