Formation of Aluminum Nitride Layer on Aluminum Surfaces Using an Electric Discharge Process

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This study realized high-thickness aluminum nitride layer formation on pure aluminum surfaces using an electric discharge process within approximately 5 min of treatment. Furthermore, this study investigated the effect of electrical polarity on aluminum nitride layer formation and found that the microstructure of the layer was significantly influenced by the electric polarity. In addition, the mechanism of aluminum nitride formation is discussed.

Keywords: *aluminum nitride layer, aluminum, electric discharge, hardness*

1. Introduction

Aluminum alloys have poor wear resistance, making them unsuitable for use as sliding components. Therefore, surface treatments have been used to improve the wear resistance of these alloys. Plasma nitriding has traditionally been used to synthesize aluminum nitride films on aluminum surfaces. Aluminum nitride exhibits several attractive properties such as high hardness, electrical resistivity, and thermal conductivity. However, aluminum nitride formation is limited owing to oxide film formation on the aluminum surface. Moreover, an aluminum nitride (AlN) film with a high thickness cannot be obtained despite the high temperature and long treatment duration of the plasma process. To address this problem, a process with a relatively short processing time at low temperatures must be developed to realize AlN formation on Al substrates. Many researchers have attempted to fabricate AlN films. Thin AlN films can be synthesized via plasma nitriding; however, this process is time-consuming. To solve this problem, some researchers have successfully used electron-beam-excited plasma for synthesizing films at high speeds[1)]. However, a nitriding process is yet to be developed to synthesize AlN films on aluminum substrates suitable for practical applications. Therefore, it is necessary to develop a novel process for fabricating thick AlN films.

This study synthesized a high-thickness AlN layer on an aluminum substrate via an electron-discharge process in liquid nitrogen. Furthermore, the effect of electric polarity on AlN layer formation on an Al surface was investigated.

2. Experimental Procedure

2.1 Experimental condition

An electric discharge machine was used in this study, as shown in Fig. 1. A pure aluminum bar of φ 5 mm was used as the electrode. The tip shape of the bar was spherical. Pure Al with a thickness of 1 mm was used as the substrate. A potential difference of 250 V was applied over the electrodes, and a discharge was generated between the electrode and the substrate. The electrode and substrate were ultrasonically cleaned with acetone before treatment. Liquid nitrogen was used as the working fluid in this study.

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After installing the aluminum substrate, the processing vessel was filled with liquid nitrogen. A voltage of 250 V was applied between the electrode and substrate after reaching the liquid nitrogen temperature. Subsequently, the electrode was gradually moved closer to the substrate to generate a discharge. To sustain the discharge, the distance between the bar and the substrate was manually adjusted, and the discharge was conducted for a specified time.

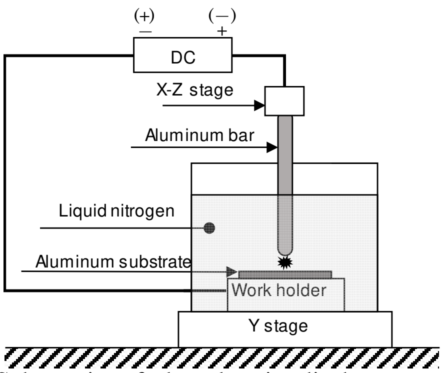


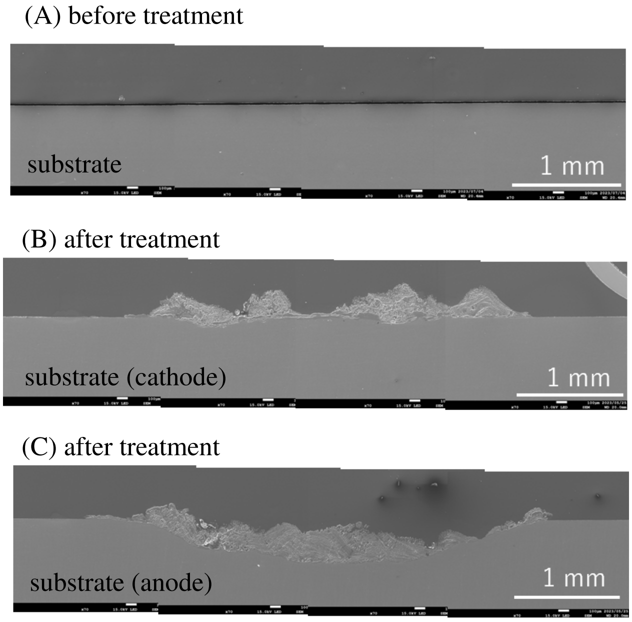
Fig. 1 Schematic of the electric discharge treatment system

3. Results and Discussions

3.1 Effect of an electric polarity

3.1.1 Cross-section micrographs of the substrate after the electron discharge process

Figure 2 shows the cross-sectional micrographs of the substrates before and after electric discharge for 5 min. Figure 3 shows the X-ray diffraction pattern of the treated surface. The results show that the modified layer consists of AlN. As shown in Fig. 2, when the substrate has cathode polarity, almost no substrate is removed, and a layer is formed on the upper side of the substrate. However, when the substrate has anode polarity, it is eliminated via the discharge. However, a layer is formed on the upper side of the substrate, similar to the case in which the substrate has cathode polarity. The same tendency is observed when the electrode is used as the anode or the cathode. Further, material removal continues to occur on the anode side, regardless of the arrangement of the electrode and substrate, and AlN is formed with both polarities. Therefore, it can be confirmed that film formation is significantly affected by polarity. H. Xia et al. investigated the effect of polarity in electric discharge machining and found that more discharge energy is distributed in the case of anode than that of cathode polarity[2]. Therefore, the temperature in the case of anode polarity increases more than that of cathode polarity. Material removal is more advanced in the case of anode polarity, as shown in Fig. 2. It is believed that the same phenomenon as that in conventional electric discharge machines occurs in liquid nitrogen. Material removal occurs due to the melting of the substrate owing to the increase in the temperature in the case of anode polarity.



The results of (B) and (C) show the effect of polarity.

Fig. 2 Cross-sectional micrographs of substrates before and after electric discharge for 5 min

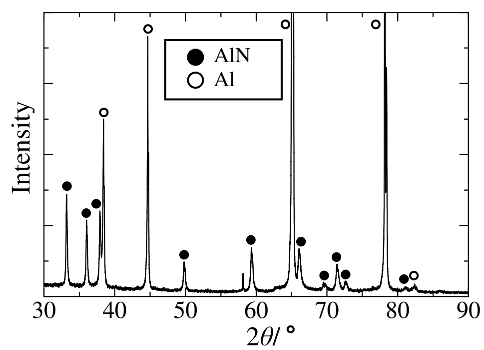


Fig. 3 X-ray diffraction pattern of the modified layer

3.1.2 Microstructure of AlN formed by an electric discharge process

The microstructures are significantly different, as shown in Fig. 4, and the microstructures at both the cathode and anode are complex. Dendritic structures are observed in the cases of both cathode and anode polarities. The cathode has a random dendritic structure, whereas the anode has a dendritic structure that grows in a single direction from the base material.

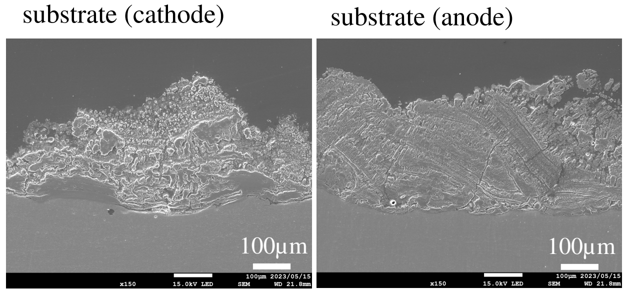


Fig. 4 Microstructure of the AlN layer formed by the electric discharge for 5 min

3.1.3 Formation mechanism of AlN via the electric discharge process

As shown in Fig. 2, the layer is convex on the cathode substrate. However, the thicknesses of the layers are uniform on the anode substrate. The material at the anode melts as it gains high discharge energy. As the substrate surface melted by the electric discharge is solidified in situ, an AlN layer with a relatively uniform thickness is formed. The aluminum on the substrate surface does not melt significantly owing to the electric discharge. Therefore, the source of aluminum of the AlN formed on the cathode side is considered to be the Al on the anode side migrating to the cathode. When a discharge arc occurs between the poles, the surfaces of the electrode and substrate melt. The electrode material on the anode side becomes a molten droplet and migrates onto the cathode substrate, similar to a sprayed particle[3]. In the present study, the cathode side too melts slightly, owing to the discharge; however, it is believed that AlN is formed mainly because of the migration of Al melted at the anode to the cathode side.

4. Conclusion

Aluminum nitride layers were formed on pure aluminum surfaces via an electric discharge process. This study successfully synthesized a thick AlN layer within a relatively short time. The microstructure of the layer was significantly influenced by electric polarity.

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