Plasma Nitriding of Non-Ferrous Metals with Atmospheric-Pressure Plasma Jet

Y. Yoshimitsu¹, R. Ichiki¹,*, M. Yoshida², S. Akamine¹, S Kanazawa¹
¹Oita University, 700 Dannohara, Oita 870-1192, Japan
²Shizuoka Institute of Science and Technology, 2200-2 Toyosawa, Fukuroi, 437-8555, Japan
*Corresponding author

We performed plasma nitriding of aluminum with pulsed-arc (PA) atmospheric-pressure plasma jet where we used N₂/H₂ mixture gas as operating gas. We confirmed with EPMA that N atoms can be diffused into aluminum surface by spraying PA plasma jet.

1 Introduction
Non-ferrous metals such as aluminum and titanium find wide industrial application due to light-weight properties. For example, aluminum is used as a heatsink because of its high thermal conductivity and good radiation performance. Because aluminum heatsinks are much lighter than copper one, it is indispensable to the weight saving of parts. Moreover, when aluminum nitride (AlN) thin film is synthesized on the surface of aluminum, its thermal conductivity and radiation performance are improved better than aluminum itself. Since AlN also has electrical insulation, we do not need an electrical insulating material between power LED circuit and the heatsink.

However, aluminum is known as a difficult metal material for nitriding. This is attributed to a dense native oxide layer (passive state) that acts as a barrier against N atom diffusion into aluminum. Low-pressure plasma nitriding method is frequently used to overcome the problem by ion-sputtering. However, there are some shortcomings such as long treatment time, the need of vacuum equipment. Additionally, it is difficult to nitride complex-shaped workpieces such as a heatsink uniformly because of electric field concentration due to edge effects in low-pressure plasma nitriding.

In order to improve this situation, we have developed an original plasma nitriding method using the pulsed-arc (PA) plasma jet under atmospheric-pressure. We have achieved plasma nitriding of steels with PA plasma jet in the last study. Thus, we tried to apply the technology of plasma-jet nitriding to non-ferrous metals such as aluminum.

2 Experimental Procedure
2.1 Experimental Device
Fig. 1 shows the schematic view of PA plasma jet system. N₂/H₂ mixture gas as operating gas is introduced from the upper part of the coaxial cylindrical electrode nozzle at the flow rate of 20 slm, where the H₂ ratio is 1%. This N₂/H₂ mixture ratio is the optimal value for steel nitriding. Pulsed-arc discharge is generated by the high-frequency power source (4.5 kV in voltage, 1A in discharge current, and 21 kHz in frequency) between the inner and outer electrodes. The afterglow is injected through the orifice of 4 mm in diameter located at the tip of the nozzle. The distance between the nozzle of PA plasma jet and aluminum sample is 10 mm. Experiments are carried out in an airtight container to purge residual oxygen by introducing N₂/H₂ mixture gas for preventing reoxidation of sample as much as possible. The treatment duration is 2 h.

2.2 Aluminum Sample
We used aluminum alloys A5083 (Mg 4.5 %, Mn 0.73 %) as a sample. The sample size is 20×20×5 mm³. All sample surfaces are ground with #500 emery paper before treatment. Surface temperature of the sample is kept at 530 °C (The melting point is 574 °C) by spraying with PA plasma jet and heating with a ceramic heater located below the sample.

![Schematic view of pulsed-arc plasma jet](image-url)
3 Experimental Results

Fig. 2 shows photographs of untreated and treated samples. The treated area became black. It is reported that AlN synthesized by plasma nitriding takes on black\(^9\), as was observed here. Fig. 3 shows nitrogen and oxygen mapping with Electron Probe Micro Analyzer (EPMA). EPMA mapping is displayed with gray-scale. Darker color corresponds to higher concentration. Fig. 3(b) shows that nitrogen concentration of treated area is higher than that of untreated area. Consequently, we have achieved to diffuse N atoms into aluminum surface with PA plasma jet. However, Fig. 3(d) shows that oxygen concentration also became higher. In other words, spraying PA plasma jet has invoked not only N atom diffusion but also oxidation of aluminum.

4 Conclusion

We have achieved to diffuse N atoms into aluminum surface with PA plasma jet under atmospheric-pressure. However, we found that plasma-jet spraying also enhances oxidation of aluminum surface. We will attain optimization of a plasma source to overcome this issue. In the conference, we discuss effects of adding Ar gas to the operating gas. Moreover, we would like to report plasma-jet nitriding of titanium.

References