Development of Simplified Atmospheric-Pressure Plasma Nitriding

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We have developed atmospheric-pressure plasma jet nitriding which does not need vacuum equipments. We constructed a simplified treatment system for practical use, where even an air-tight container and an external heater are not required. Instead, plasma heating to increase treatment temperature and a simple cover to purge residual oxygen are utilized. In the simplified system NH radical production and steel surface hardening by nitrogen diffusion were achieved.

1. Introduction

Nitriding treatment is one of the surface hardening technologies, applied to dies and automobile components. In recent industry, low-pressure plasma nitriding treatment using vacuum system is mainstream. On the other hand, we have originally developed an atmospheric-pressure plasma nitriding which do not need vacuum system [1-3]. However, we needed an external heater to control treatment temperature and an air-tight container to purge residual oxygen. To make this technique practical, we addressed to construct a simplified treatment system, where treatment temperature is controlled by thermal plasma itself and oxygen purging is achieved by a simple cover. Here we report nitriding results in the simplified treatment system.

2. Experimental Setup

Schematic of the jet nozzle is shown in Fig. 1. N₂/H₂ gas mixture (flow ratio of 99:1) is introduced at 20 slm to the nozzle that is composed of a coaxial cylindrical electrode. Purposes of adding H₂ are generation of NH radicals and reduction of residual O₂ in treatment atmosphere. The low-frequency voltage pulse (4-5 kV in height and 21 kHz in repetition) is applied to the inner electrode using a high voltage power supply. The maximum of the discharge current is ca. 1A. Nitriding is operated by irradiating steel surface with the plasma jet.

Fig. 2 shows the schematic diagram of the simplified experimental setup. Quartz cover is employed to purge residual oxygen in treatment atmosphere. The Exhaust gap between quartz cover and stage is set at 1 mm. The sample surface temperature is controlled by changing treatment gap from nozzle tip to steel surface.

Die steel JIS SKD61 is used as a treatment sample (20 mm in diameter and 4 mm in thickness). The composition is the following: 0.38% C, 0.42% Mn, 0.92% Si, 5.12% Cr, 1.19% Mo, and 0.8% V. The hardness of samples has been adjusted to 550 Hv.0.1 by heat treatment.

3. Experimental Results

Controlling treatment temperature is summarized in Fig. 3. We see that a smaller treatment gap provides a higher treatment temperature.

Fig. 4 shows the dependence of the NH radical spectral intensity (366.1 nm) on H₂ flow ratio. The NH emission peaks at a very small H₂ ratio and then becomes smaller with increasing H₂ ratio. This tendency is quite analogous to the previous experiment using an air-tight container. Thus we conclude that a treatment atmosphere as appropriate as the air-tight one can be created by the use of simple cover, and here we adopted the H₂ ratio of 1% which was the optimal value in the air-tight container experiment.
Metallographic structures of sample cross-section are shown in Fig. 5. The outermost white layer corresponds to the compound layer. The dark layer below the compound layer corresponds to the diffusion layer. Thicknesses of these nitrided layers increase with treatment temperature.

Fig. 6 shows hardness profiles of sample cross-section. The depth of hard zone proved to increase with treatment temperature, corresponding to the growth of the diffusion layer.

4. Summary
We succeeded in constructing a simplified system for atmospheric-pressure plasma nitriding in which even an external heater and air-tight container are not required. As a result, we demonstrated that surface hardening of steel is possible and the nitrided layer thickness can be well controlled by adjusting treatment temperature. In the conference, we also discuss experimental results for hardening complex shaped materials by using our simplified nitriding.

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References