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Effect of Hydrogen on Nitriding using Atmospheric-Pressure Plasma Jet
大気圧プラズマジェットを用いた窒化処理における水素の効果

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The nitriding treatment is important surface hardening technology of metals in industry. We performed nitriding using atmospheric-pressure plasma jet. By adding hydrogen gas to prevent oxidization, we succeeded in hardening steel surface. Moreover, we found that the hardness profile is changed by the way of hydrogen gas introduction.

1. Introduction

We paid attention to the plasma nitriding which is one of the surface hardening technology of metals. As a new surface-hardening treatment under atmospheric pressure, we are researching nitriding by the atmospheric-pressure pulsed-arc (PA) plasma jet. We have adopted the PA plasma jet for the following reasons. First, the generation of N atoms has been confirmed in the PA plasma jet plume [1,2]. Second, the gas temperature in the plume is relatively low so that sample surface will be neither melted nor roughened. We have recently succeeded in nitriding for steels using PA plasma jet [3-5]. Here, we present the details of the nitriding such as the hardened area of the samples surface, dependence of nitriding on several experimental parameters, especially, the effects of hydrogen gas introduction on nitriding.

2. Experimental Procedure

We treat disk-shaped samples (20 mm in diameter, 4 mm in thickness) of SKD61 steel (AISI H13), the surface of which has been polished to mirror finish. Experiments are performed in a closed container. The steel sample is set on the ceramic heater mounted in the container. The nozzle of the PA plasma jet is inserted into the container from the upper end. The jet nozzle is composed of the inner and outer electrodes, as shown in Fig. 1. Nitrogen gas (20 L/min) is introduced through the jet nozzle. The container is purged by the nitrogen gas prior to nitriding treatment. The pulsed-arc discharge is generated in the nozzle, where the applied voltage is 4 kV, the frequency is 21 kHz, and the discharge current is 1 A, as shown in Fig. 2. Afterglow of the pulsed-arc discharge is forced out by nitrogen gas through the nozzle orifice of 4 mm in diameter. This develops to the plasma jet plume, the length of which becomes around 20 cm in N_2 atmosphere [1]. The temperature of the steel sample is maintained at approximately 500 ºC by the ceramic heater. The nitrogen plasma jet is sprayed to the samples surface. The treatment duration is 2 h.

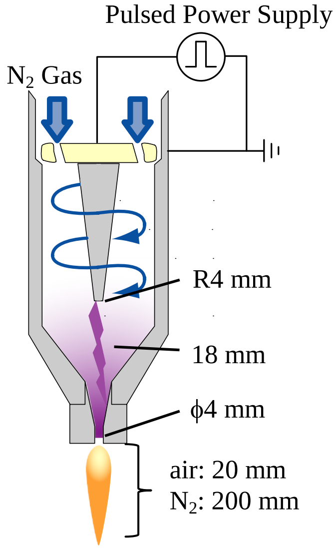

Fig.1. Schematic of the pulsed-arc plasma jet nozzle.

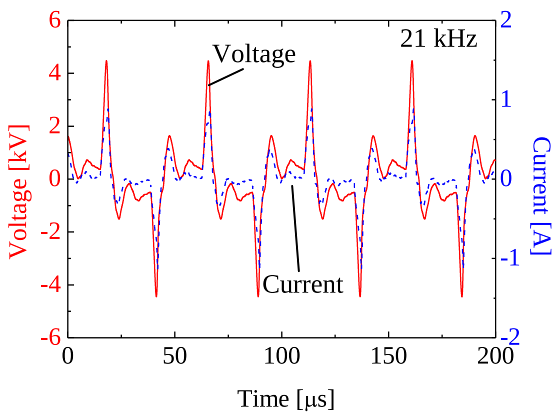

Fig.2. Typical voltage-current wavefoms.

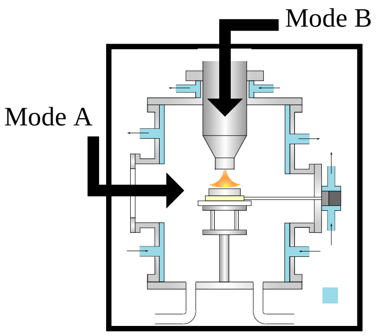

Fig.3. Illustration of the way of H_2 introduction. Mode A: addition of H_2 gas from container side. Mode B: introduction of H_2 gas through the jet nozzle with N_2 gas.

In our previous investigation, we found that only spraying nitrogen plasma jet leads to oxidization of the sample surface. Therefore, it is necessary to add hydrogen gas to the treatment atmosphere from container side to prevent oxidization, as shown in Mode A of Fig. 3 [3-5]. Moreover, we have investigated another way of hydrogen gas introduction through the jet nozzle with nitrogen gas, as shown in Mode B of Fig. 3. Mode B has a potential to decrease the hydrogen gas flow rate needed for nitriding.

3. Results

The hardness profiles of SKD61 cross-section in the case of Mode A and Mode B are shown in Fig. 4 (a) and (b), respectively. Fig. 4 (a) shows that the hardened layer is the thickest under the center of plasma jet plume irradiation (r = 0 mm). However, the thickness becomes smaller with increasing r. On the other hand, Fig. 4 (b) shows that the nitrided area for Mode B is considerably different from the nitrided area for Mode A.

We performed optical emission spectrometry of the plasma jet plume for investigating elementary process. As a result, we observed that the spectral intensity of NH radical (336.1 nm in wavelength) is prominent. The dependence of NH spectrum intensity on the H_2 gas flow rate is shown in Fig. 5, where H_2 gas is introduced by Mode B. The intensity is the highest when the H_2 gas flow rate is 19 mL/min, which becomes smaller with decreasing H_2 gas flow rate. The finite intensity at 0 mL/min of H_2 is due to residual H_2O. The dependence of nitriding on NH radical is under investigation.

Acknowledgments

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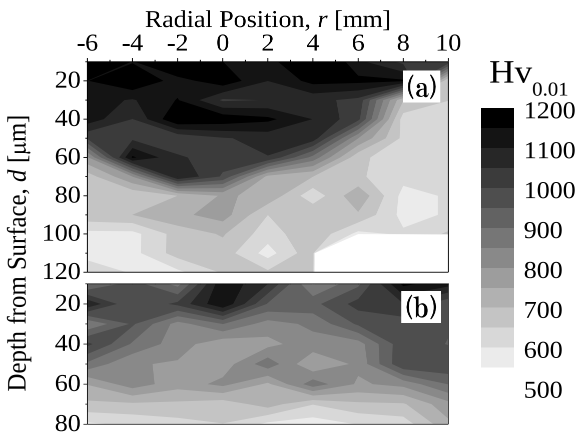

Fig.4. Hardness profile of SKD61 sample. (a): Mode A (H_2: 3.7 L/min). (b): Mode B (H_2: 0.9 L/min)

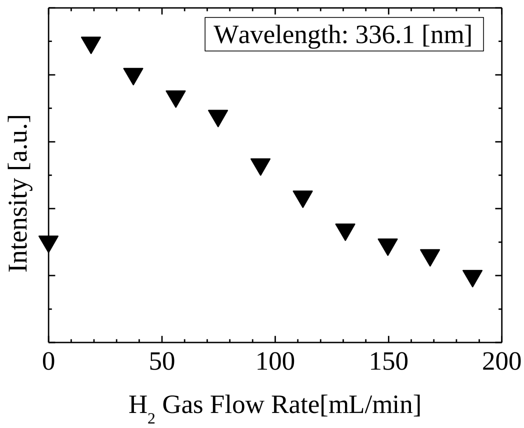

Fig.5. Dependence of NH radical spectral intensity on H_2 gas flow rate in the case of Mode B.

References

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