Temperature Dependence of Nitro-Quenching by Atmospheric-Pressure Plasma

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Position of martensite formation and consequent hardness profile have been successfully controlled in atmospheric-pressure plasma nitro-quenching by adjusting the distance of plasma-jet spraying. We found that the hardness profile is strongly related to the temperature profile of steel surface.

1. Introduction

Nitro-quenching (NQ) is a novel heat treatment technology for steels in which martensitic transformation is invoked by nitrogen instead of carbon. NQ treatment is composed of the following three steps: 1.[Heating] Heat steel up to the austenite range. 2.[Nitriding] Supply nitrogen atoms into the austenite area. 3.[Quenching] Cool the steel down rapidly enough to invoke martensite transformation. In this treatment, low-alloy steels can be hardened in contrast to ordinary nitriding process. As a new technology, we have researched surface hardening of low-alloy steel by NQ using an atmospheric-pressure plasma[1]. We have succeeded in producing iron-nitrogen martensite by spraying the pulsed-arc plasma jet onto steel surface and water quenching. However, center point of jet spraying was not hardened enough. Instead, only positions at the distance of 10 mm from the center were hardened by martensitic transformation [1]. We consider that such non-uniform hardness profile will be caused by the surface temperature. In this research, we change the treatment gap g (the gap from nozzle to sample surface) and investigate the relationship between hardness profile and treatment temperature. As a result, we achieved to increase the hardness at the center point of jet spraying.

2. Experimental Setup

We utilized the atmospheric-pressure pulsed-arc (PA) plasma jet. Schematic of the PA plasma jet system is shown in Fig. 1. N₂/H₂ gas mixture (H₂ ratio of 1%) is introduced from the upper part of the nozzle (the coaxial cylinder electrode). The gas flow rate is 20 slm. Pulsed arc discharge is generated by the low-frequency power source (5 kV in voltage, 21 kHz in reputation, 1.2 A in discharge current) between the internal electrode and the external electrode. The afterglow is generated through the orifice of 4 mm in diameter located at the trip of the nozzle. A simple cover is mounted at the tip of the nozzle to eliminate O₂ in the treatment atmosphere. As a sample, we used SPCC which is low-alloy steel containing almost no alloy elements. The thickness of SPCC is 1.2 mm. The hardness of SPCC base material is approximately 150 HV₀.₀₁. The plasma jet plume is sprayed on sample surface for 30 min and then the sample is dropped in distilled water to cool it down rapidly.

3. Experimental Results

Fig. 2 shows surface temperature profile of sample. The temperature at the center point of jet spraying (r = 0 mm) is highest and it decreases with increasing r, where r is the radial position of sample surface.

Fig.3 shows the hardness profile of sample surface. The sample was partially hardened up to 800 Hv by NQ treatment. However, the hardness profile is considerably non-uniform. More importantly, the profile is convex downward when g is small and the shape gradually changes to convex upward with increasing g. The tendency for g = 4 mm is the previously obtained profile in Refs. [1]. Note that we newly succeeded in increasing the hardness at the center of jet spraying by increasing g.

Fig. 2 Radial profile of surface temperature for several gaps g. Here the dashed line indicates the A₁ point of Fe-N binary alloy.
To find out the mechanism of such non-uniform hardness, metallographic structure of each point was observed as shown in Fig. 4. The metallographic structure indicates that the hardened area has iron-nitrogen martensite on the surface, e.g., Figs. 4(b) and 4(c). Note that the corresponding points had similar surface temperatures around 700°C (cf. Fig. 3). On the other hand, relatively soft region shown in Fig. 4(a) indicates a metallographic structure which seems martensite and retained austenite phases. As shown in Fig. 4(a) indicates a metallographic structure which seems martensite and retained austenite phases. Therefore, as one possibility we propose that the hardness depends on sample surface temperature. Our scenario is as follows: When $g = 4$ mm, the center point ($r = 0$ mm) is relatively soft because the temperature is so high that a large amount of austenite phase is retained to decrease hardness compared to pure martensite phase. On the other hand, when $g = 7$ mm the center point becomes hard because the temperature is suitable so that purer martensite phase is produced.

### 4. Summary

We have achieved to harden the aimed position, namely the jet spraying center, of low-alloy steel surface by the original atmospheric-pressure plasma NQ treatment. In the conference, we discuss a trial to control nitrogen potential in our system.

### References