Application of Low Temperature Active-Screen Plasma Nitriding and Carburizing to an Austenitic Stainless Steel Small-Diameter Thin Pipe

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Surface hardening treatments such as nitriding can improve the mechanical properties to extend the applicability of austenitic stainless steel (ASS) fine and precise machining. Improving these characteristics without changing the design and material is highly advantageous, particularly for medical and surgical instruments. In particular, an improved bending rigidity of medical injection needles is desirable because a small needle diameter reduces invasiveness. However, no method has yet been reported for improving the bending strength of ASS without reducing its corrosion resistance. It is known that the low-temperature nitriding and carburizing generated expanded austenite (S phase) that can be hardened while maintaining the corrosion resistance of austenitic stainless steel. It would be very beneficial if these techniques could be applied to thin pipes with a small diameter such as medical injection needles. In the present study, low-temperature active-screen plasma nitriding (ASPN) and active-screen plasma carburizing (ASPC) are applied to improve the bending rigidity of an ASS pipe with a small diameter.

Keywords: *active screen plasma nitriding, active screen plasma carburizing, austenitic stainless steel, expanded austenite, small diameter thin pipe*

1. Introduction

Austenitic stainless steels are used in a wide range of items such as household products, construction materials and automobile parts as well as in applications related to power generation and chemical and food industries owing to its high functionality, excellent corrosion resistance, ductility and toughness. However, austenitic stainless steel (ASS) is limited by a low-hardness, poor bending rigidity, and wear resistance. An improvement of these characteristics without changing the design and material is highly advantageous, particularly for medical equipment and surgical instruments. In particular, an improved bending rigidity of medical injection needles is desirable because a small needle diameter reduces invasiveness.

Plasma nitriding and carburizing methods are considered suitable as surface modification treatments for ASS. Nitrided and carburized layers with hardness and corrosion resistance generated by low-temperature processing are called "extended austenite" or "S phase [1, 2]." Such layers have an expanded face-centered cubic structure and do not contain Cr compound precipitates. Due to the low processing temperature, it is difficult to generate a thick hardened layer by diffusion of nitrogen and carbon. Active screen plasma nitriding (ASPN) and carburizing (ASPC) are superior methods for producing active species and generating uniform heating regions [3-5].

The purpose of this study is to improve the bending strength of ASS small-diameter thin pipes for medical use as an example of expanding the application of nitriding and carburizing treatment to fine and small parts. S phase is generated using ASPN and ASPC methods to improve bending strength without sacrificing corrosion resistance. The nitrided and carburizing sample properties on layer thickness, layer structure, surface hardness, bending load, and corrosion resistance are evaluated by varying the changing processing temperature.

2. Experimental procedure

A small-diameter thin pipe composed of SUS 304 stainless steel was used as the sample material [5]. The inner and outer diameters of the pipe were ϕ0.3 and ϕ0.4 mm, respectively, and the pipe length was 50 mm. The samples of the small-diameter thin pipe were mounted at the circumference of a ring-shaped jig. The jig was suspended from a screen that was placed on the cathodic sample stage. Consequently, plasma was formed on both the sample pipe and screen. The screen material was an expanded mesh composed of SUS 304 stainless steel with a 22.7% open area, diameter of 90 mm and height of 400 mm. The distance between the pipe and screen was 12.5 mm. The jig temperature was measured using a thermocouple and adopted as the nitriding and carburizing temperature because measuring the temperature of a small-diameter pipe is difficult. Moreover, a pulsed power supply was used for plasma generation. The plasma nitriding and carburizing were conducted for 4 h at 578–638 K (305–365 °C) with a pressure of 200 Pa. The gas flow ratio were 50% N_2–50% H_2 for ASPN and 50% Ar-5% CH_4-45% H_2 for ASPC.

3. Results

Figure 1 shows the effect of the processing temperature on the layer thickness. The nitriding and carburizing layer thickness increased monotonically with the processing temperature. The nitrided layer thickness was thicker than the carburized layer thickness.

Figure 2 shows the effect of the processing temperature on the bending load. The bending load increased as the processing temperature increased. These results revealed that low temperature ASPN and ASPC is effective in improving the bending strength of small-diameter thin pipes composed of ASS.

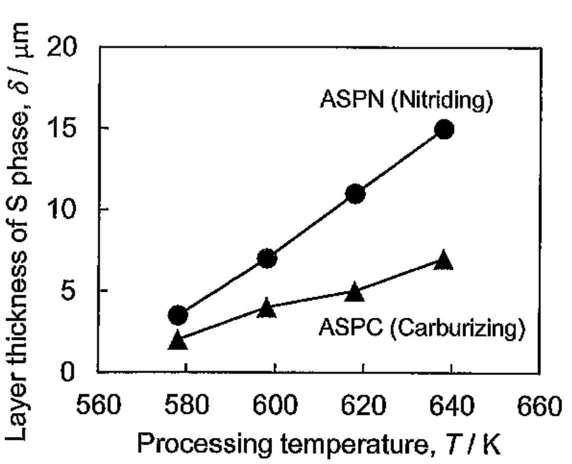

Figure 1 Effect of ASPN and ASPC temperatures on layer thickness of S phase.

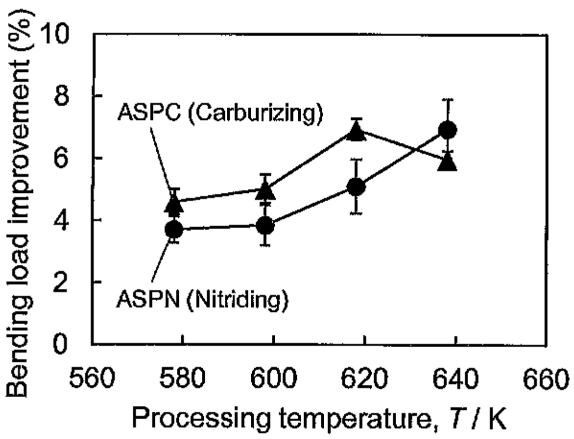

Figure 2 Effect of ASPN and ASPC temperatures on bending load.

Figure 3 shows the effect of the processing temperature on the surface hardness. The surface hardness was higher in the nitrided and carburizing samples than in the untreated sample. For the nitrided sample, the surface hardness increased with processing temperature and was saturated at 1100 HV owning to the N-supersaturated solid solution under nitriding temperature above 598 K. At a nitriding temperature of 578 K, the surface hardness was influenced by the base metal because the nitrided layer was thin. For the carburized sample, the surface hardness was lower than that of nitrided sample and reached around 800 HV after being carburized at 638 K.

Figure 4 shows the distribution of Young's modulus near the surface. For the nitrided sample, the Young's modulus was the same as that of the untreated sample under the low processing temperature of 578 K, but the Young's modulus tended to increase as a whole as the processing temperature increased. For the carburized sample, the Young's modulus was almost constant, with little difference from the untreated sample. It was found that even in the S phase formed at the same processing temperature, the mechanical properties of the formed layer differ between ASPN and ASPC.

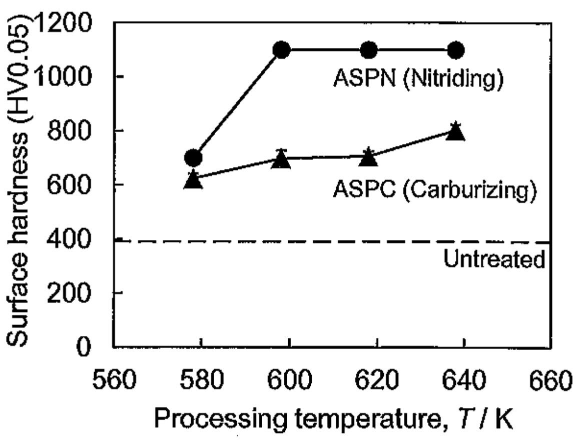

Figure 3 Effect of ASPN and ASPC temperatures on surface hardness.

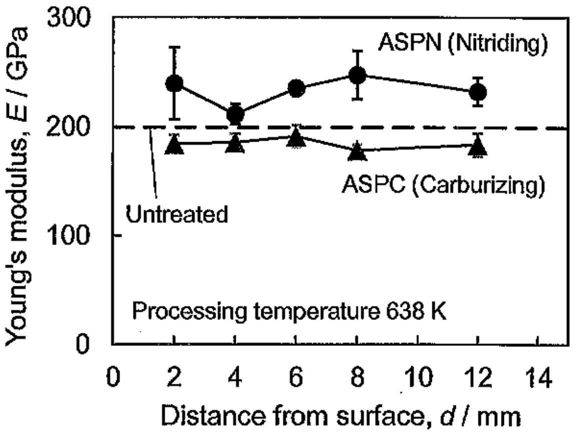

Figure 4 Effect of ASPN and ASPC temperatures on Young's modulus at 638 K.

4. Summary

A small-diameter thin pipe made of ASS was treated, and an S phase was formed by low-temperature ASPN andASPC. The S-phase thickness of ASPN was approximately twice as thick as that of ASPC. In addition, although the Young's modulus did not change in ASPC, it was confirmed that the Young's modulus tended to increase as the processing temperature increased in ASPN. It became clear that there is a difference in the mechanical properties of the S phase obtained between ASPN and ASPC.

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