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

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Austenitic stainless steel has excellent corrosion resistance, ductility, and toughness and is used in a wide variety of industrial applications. However, due to its low hardness and poor wear resistance, the use of austenitic stainless steel is limited. Surface hardening of austenitic stainless steel is expected to improve its mechanical properties and expand its application as a high-performance material. One of the most desirable fields of application is medical and surgical parts. There is a strong demand for improving the bending rigidity of medical injection needles, which are becoming small in diameter to be minimally invasive. Higher functionality through surface modification without changing the design and material can save the time and the cost of reviewing the manufacturing process and design compared to changing to a new material. In this study, low-temperature active screen plasma carburizing (ASPC) was used to improve the bending rigidity of a small-diameter thin pipe composed of austenitic stainless steel (SUS304).

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

1. Introduction

Austenitic stainless steel (ASS) has excellent corrosion resistance, ductility, and toughness and is used in a wide variety of industrial applications. ASS surface hardening is expected to improve its mechanical properties and expand its application as a high-performance material. There is a strong demand for improving the bending rigidity of medical injection needles, which are becoming small in diameter to be minimally invasive.

Plasma nitriding and carburizing methods are considered suitable as surface modification treatments for ASS. However, high temperatures may significantly reduce corrosion resistance because solute Cr in steel binds to N and C diffused from the surface and precipitates, reducing the amount of Cr in the solid solution. The deterioration of corrosion resistance can be prevented by lowering the processing temperature below 698 K [1-4)]. Nitrided and carburized layers with hardness and corrosion resistance generated by low-temperature processing are called "extended austenite" or "S phase." 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) [5-8)] and carburizing (ASPC) [8)] are superior methods for producing active species and generating uniform heating regions. The screen increases the supply of active species and uniformly heats the sample surface. We have previously reported the application of ASPN to a small-diameter thin austenitic stainless steel pipe [7)].

In this study, low-temperature ASPC was used to improve the bending rigidity of small-diameter thin austenitic stainless steel pipes. The effect of processing temperature and processing time on S phase formation process and mechanical properties were investigated.

2. Experimental procedure

A small-diameter thin pipe composed of SUS 304 stainless steel was used as the sample material. The inner and outer diameters of the pipe were ϕ0.3 and ϕ0.4 mm, respectively, and the pipe length was 50 mm [7)].

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 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 was conducted for 2-8 h at 578–638 K (305–365 °C) with a pressure of 200 Pa. The gas flow ratio was 50% Ar-5% CH_4-45% H_2 for ASPC.

3. Results

The small-diameter pipe used in this study contains strain-induced martensite generated during the drawing process [7)]. In order to investigate the effect of strain-induced martensite on S phase formation, the layer thickness of S phase was compared between pipes with and without solution heat treatment in Figure 1. The ASPC processing time was 4 h. The layer thickness of S phase was obtained from the micrograph of the cross sections at the center position in the length direction. The layer thickness of S phase increased with processing temperature and little difference was observed depending on whether the solid solution heat treatment was performed or not. It was found that the strain-induced martensite does not affect

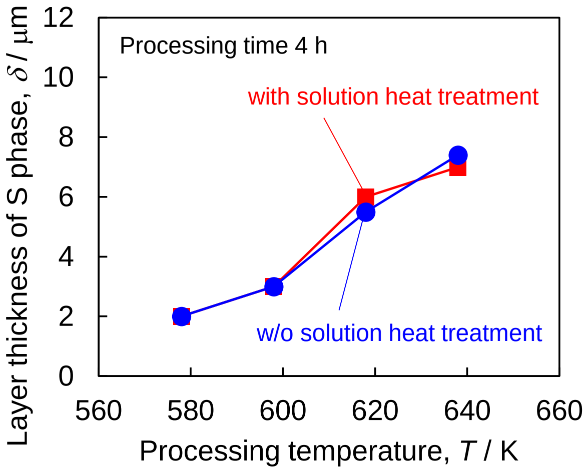
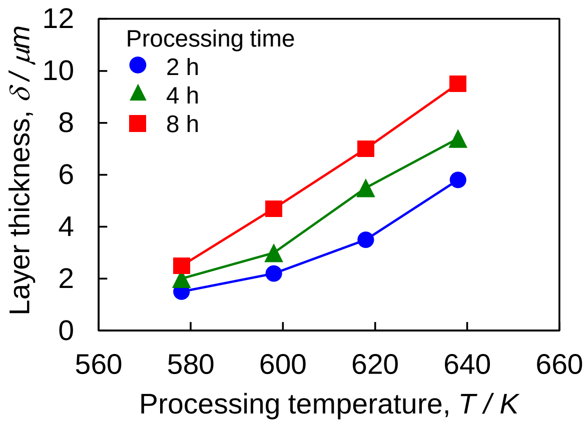
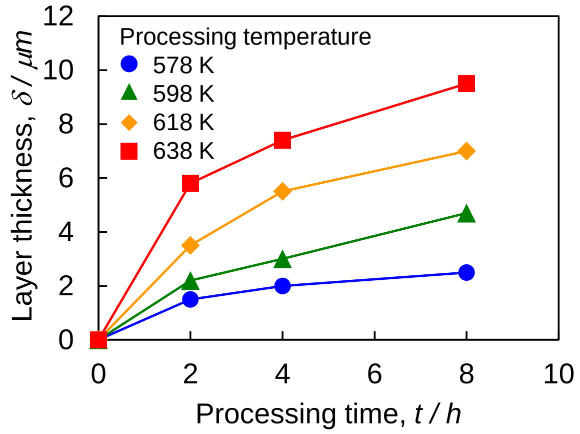


Figure 1 Effect of solution heat treatment on layer thickness of S phase at 4 h processing time.



(a) Effect of processing temperature



(b) Effect of processing time

Figure 2 Effect of processing temperatures and times on layer thickness of S phase.

the formation of the S phase under the present test conditions.

Figure 2 shows the effect of processing temperature and time on layer thickness of S-phase. Here, the small-diameter pipes without solution heat treatment were used. The layer thickness of S phase increased monotonically with processing temperature as shown in Figure 2(a). On the other hand, the layer thickness of S-phase increases as the treatment time increases, but the slope became smaller as shown in Figure 2(b). It does not lead to efficient S-phase formation.

By clarifying the relationship between the processing conditions and the layer thickness of S phase using these results, efficient S phase formation can be achieved.

4. Summary

In this study, low-temperature ASPC was used to improve the bending rigidity of small-diameter thin austenitic stainless steel pipe. The carburized layer thickness was investigated by varying the carburizing conditions.

An austenitic stainless steel small-diameter thin pipe was successfully carburized using low-temperature ASPC. The thickness of the carburizing layer increased as the carburizing temperature increased from 578 K to 638 K. The layer thickness was also increased with the processing time from 2 h to 8 h. The bending load increased as the S phase layer thickness increased.

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