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Effect of molybdenum on hardness of low-temperature plasma carburized austenitic stainless steel

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Abstract

The effect of molybdenum in hardening on low-temperature plasma carburized layer of austenitic stainless steel was investigated. This compared a low-temperature carburized layer of AISI 316 (Fe–17Cr–10Ni–2Mo) with that of AISI 304 (Fe–18Cr–8Ni) to evaluate the influence of molybdenum on carburizing. Samples were plasma carburized using DC plasma apparatus under 667 Pa of mixed gas flow of 5% CH_4+45% H_2+50% Ar at 673 K or 723 K for various durations. Depth profiles of hardness and micro-structural layer thickness were measured; GDOES, TEM, and XRD were subsequently used to characterize their microstructures. Surface hardness of 316 steel carburized at 673 K for 8 h reached 800 HK, but that of 304 steel remained at 530 HK. Results show no carbide formation in either steel treated at 673 K. The degree of lattice expansion by carburizing in the presence of molybdenum, 316 steel, is higher than that of 304 steel. Furthermore, the diffusion rate of carbon in the 316 steel is higher than that in the 304 steel. The higher hardness of carburized 316 steel is inferred to result from carbon super saturation enhanced by the effect of large molybdenum atoms, which can widen the octahedral sites.

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Keywords: Austenitic stainless steel; Plasma carburizing; Hardness

1. Introduction

Austenitic stainless steels are widely used in chemical plants, food industries, and mechanical engineering as steel materials with good corrosion resistance under widely ranging environmental conditions. However, the use of austenitic stainless steel is not considered in parts that are exposed to severe friction because they have low hardness and poor friction and wear properties. For that reason, surface engineering techniques for improving these properties have been attempted. Such methods have engendered depletion of chromium in the austenitic matrix because of formation of chromium compounds. Attempts have been made to develop surface engineering techniques for improving wear resistance of austenitic stainless steels without degrading their inherent corrosion resistance.

Low-temperature plasma nitriding conducted at temperatures below 723 K has brought about remarkable progress in steel design [1–6]. This has been achieved through formation of *S*-phase instead of the precipitate of chromium nitride at the low-temperature nitrided layer of austenitic stainless steels [1]. However low-temperature nitriding is limited in use because of the difficulties inherent in obtaining a thick layer. Research into plasma nitriding of austenitic stainless steels has been much reported. Although the nitriding-hardened layer offers sufficient hardness, cracks are generated under severe friction because the hardened surface layer is brittle; furthermore, the hardness profile drops sharply at the interface of the thin nitrided layer and substrate [7–9]. To solve the problem, a process has been attempted to replace nitrogen with carbon as an alloying element. The carburized layer has toughness. The hardness depth profile of low-temperature carburized austenitic steel shows a moderate change of hardness from surface to substrate. It also has

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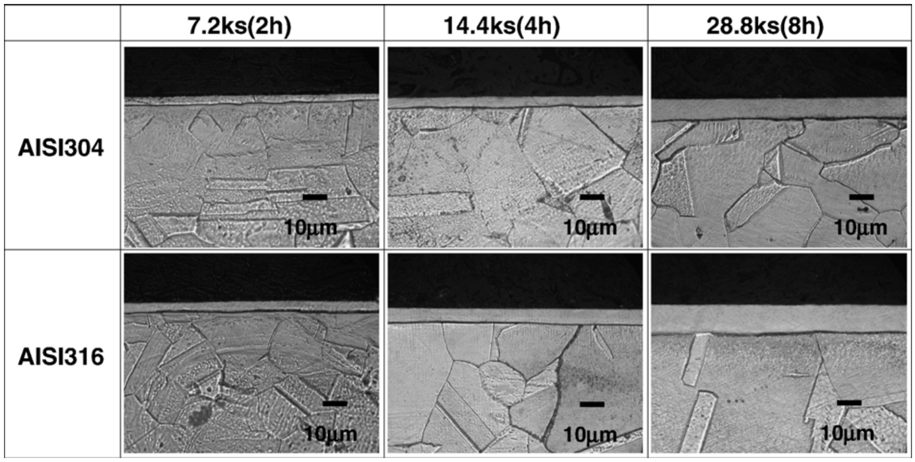

Fig. 1. Cross-section views of plasma carburized steels at 673 K.

precipitate-free hardening with high hardness and excellent corrosion resistance [10–14].

Carburized surfaces of austenitic stainless steel are not as hard as nitrided surfaces. Austenitic stainless steel is an ideal surface design for stressed parts of austenitic stainless steel: the surface hardness of the low-temperature carburized surface is as high as that of a nitrided surface.

It has been reported that the hardness of carburized AISI 316 steel (Fe–17Cr–10Ni–2Mo) is higher than that of AISI 304 steel (Fe–18Cr–8Ni) [7]. The major difference between the two steels is the content of molybdenum (Mo). Increasing the surface hardness might precipitate molybdenum carbide, precipitate chromium carbide, or induce strain hardening caused by lattice expansion. This study is intended to clarify the mechanism of the hardening of 316 steel by comparing its properties to those of 304 steels of identical processing. Results will suggest a means for developing an ideal austenitic stainless steel surface.

2. Experimental procedure

Austenitic stainless steels AISI 304 (18.8 mass% Cr–8.3 mass% Ni–0.21 mass% Mo) and AISI 316 (17.0 mass% Cr–10.2 mass% Ni–2.34 mass% Mo) were used as substrates for experiments. The most clear difference between the austenitic steels are the concentration Mo. The Mo contents for 304 steel and 316 steel are 0.21 mass% and 2.34 mass%, respectively. The respective atomic radii of elements are the following: Fe: 0.124 nm, Cr: 0.125 nm, Ni: 0.125 nm, and Mo: 0.36 nm. Lattice parameters measured using XRD for these two austenitic steels show that the value of 316 steel is identical to that of the 0.84% expansion from the 304 steel. The differences agreed with calculated values of the content and atomic radii.

These specimens were solution heat-treated for 2.7 ks at 1303 K. Then they were dry-ground slightly to the specimen shape of 25 mm width, 50 mm length and 5 mm thickness. These preparations made specimens fully austenitic, as confirmed by X-ray diffraction analyses.

Plasma carburizing was carried out using a DC power source. After the specimen was mounted on the cathode in a furnace and its vacuum-bell jar was evacuated to 1.33×10^{-1} Pa, the mixed gas pressure for each specimen was adjusted to 6.67×10^{2} Pa. Then a DC glow discharge was generated. The specimens mounted on the cathode were heated by plasma bombardment and the carburizing temperature of the specimens was measured using a thermocouple.

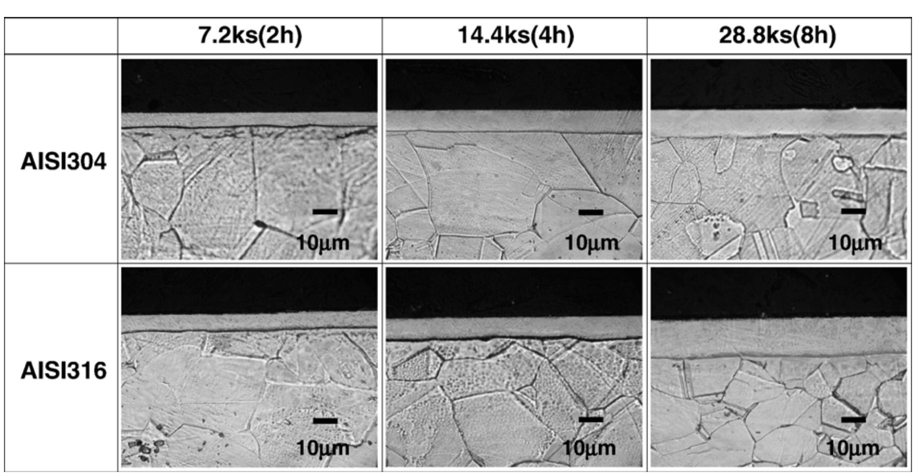

Fig. 2. Cross-section views of plasma carburized steels at 723 K.