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Influence of surface modifications by laser shock processing on the acid chloride stress corrosion cracking susceptibility of AISI 304 stainless steel

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ABSTRACT

The effects of laser shock processing (LSP) on stress corrosion cracking (SCC) behavior of AISI 304 stainless steel have been investigated using slow strain rate tests (SSRT) in acid chloride solution. Modifications of surface microstructure are characterized by scanning electron microscopy (SEM) and transmission electron microscope (TEM). Results show that LSP generate deformation twins and refined microstructures in the surface layer of AISI 304 stainless steel. Results of SSRT tests reveal that significant improvements in stress corrosion cracking (SCC) resistance are observed in acid chloride solution. These improvements have been attributed to surface microstructure changes and compressive residual stress induced by LSP. The results confirm that the application of LSP is of a practical option to improve SCC resistance of AISI 304 stainless steel.

1. Introduction

Austenitic stainless steel is a very important category of materials for their outstanding mechanical properties and wide range of industrial applications. Despite the intrinsic high resistance of austenitic stainless steel to corrosion, it is critical to minimize corrosion for stable operation because austenitic stainless steel is extremely susceptible to local corrosion such as pitting and SCC in severe conditions of corrosive environment like chloride solution and tensile stresses [1–9].

Laser shock processing (LSP) is a new surface modification technology with rapid development of laser science and technology. LSP treatment consists in irradiating surface of materials with nanosecond laser pulses that generate shock waves driven by plasma, which in turn lead to a certain amount of local plastic deformation. Thermal effects are avoided by covering the surface with an absorptive overlay. Deep and high compressive residual stresses, limited roughening, and refined microstructure are usually the main characteristics of surfaces after LSP treatment.

With rapid developments of LSP, its potential to improve fatigue properties by laser driven shock waves has been related many times on metallic materials [10–14]. LSP treatment is also expected to improve the corrosion resistance of metallic materials. Peyre et al. [15] investigated the effect of LSP on SCC of AISI 316 L stainless steel and confirmed the applicability of LSP to suppress cracks. Later, they [16] reported that LSP with protecting coating of AISI 316L stainless steel resulted in a better pitting corrosion resistance as compared with LSP without protecting coating. Sano et al. [17] also showed that LSP of SUS304 without protective coating prevented the initiation of stress corrosion cracking and the propagation of small pre-cracks. Amar et al. [18] studied the corrosion

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Table 1
Chemical composition of AISI 304 stainless steel.

Element	C	Si	Mn	S	P	Cr	Ni	Fe
Content (wt%)	0.058	0.35	1.32	0.007	0.032	17.45	8.28	Balance

behavior of AA2050-T8 after polishing and after laser shock processing treatment. Results showed that after polishing, pitting and intergranular corrosion were observed, however, no intergranular corrosion developed after LSP. Nevertheless, the effects of LSP on SCC behavior of austenitic stainless steel are still not fully identified, especially in condition of acid chloride solution.

In this work, we present the effects of laser shock processing (LSP) on SCC resistance of AISI 304 stainless steel in acid chloride solution. Modifications of microstructure are characterized. Furthermore, slow strain rate tests (SSRT) is used to evaluate the effects of LSP on the SCC resistance of AISI 304 stainless steel. The results are discussed and explained in detail.

2. Experimental details

2.1. Specimens and LSP experimental procedure

Specimens were made from AISI 304 stainless steel plate with a thickness of 3 mm. The chemical composition of AISI 304 stainless steel was shown in Table 1. Prior to LSP treatment, specimens were grinded with silicon carbide (SiC) papers from 600 grit to 1500 grit, followed by cleaning in deionized water. Subsequently, the surfaces of specimens were degreased in ethanol by using ultrasonic cleaning.

A Q-switched Nd: YAG laser (wavelength 1064 nm, pulse width 15 ns, repetition rate 1 Hz) was used for treatment of all the coupons prior to SSRT testing and other characterization. Specimens were treated by LSP on two opposite sides of the gage section as shown in Fig. 1. In this work, the conditions of 30 J laser pulse, 6 mm diameter spot size and 50% overlapping rate were used. To avoid possible damage or roughening of sample surface by laser irradiation and also initiate plasma, the 3 M aluminum foil with a thickness of 0.15 mm was applied as the protective coating on the surface. In addition, the water layer with a thickness of 1–2 mm was used as the transparent confining layer during LSP process.

2.2. Surface microstructure observations

Microstructures of cross sections cut perpendicular to the treated surface were determined by scanning electron microscopy (SEM) experiments. The samples were sectioned close to the treated area and carefully grinded to the mid-section and polished until there were no scratches on sample surface. After that, samples were etched using 10% mass fraction of oxalic acid solution in condition of 3 V voltage for 80 s at room temperature.

TEM studies were carried out on foils cut parallel to the top surface using a JEM 2010 transmission electron microscope (TEM) operated at a voltage of 200 kV. The TEM foils were prepared by mechanical polishing to the thickness bellow 50 μm, and further ion thinned to the thickness suitable for observation.

2.3. SSRT performance

The stress corrosion cracking (SCC) behavior of AISI 304 stainless steel before and after LSP was investigated using slow strain rate test (SSRT) method. SSRT was carried out by a universal tensile testing machine (INSTRON 5869). The schematic representation of SSRT sample was shown in Fig. 1. The SSRT tests were carried out in 5% NaCl + 0.6 mol/L H_2SO_4 solution, 10% NaCl + 0.6 mol/L H_2SO_4 solution and 15% NaCl + 0.6 mol/L H_2SO_4 solution at 30 °C respectively remaining constant of a strain rate of $10^{-5}\,s^{-1}$. The test solution was a very aggressive environment for the 304 stainless steel due to its acid character and the presence of chlorides. All tests were conducted under open circuit potential conditions. Fractographic examinations of specimens after completion of SSRT tests were carried out using scanning electron microscopy (SEM) in order to investigate the fractographic features of SCC.

In order to quantify the effect of LSP on the SCC behavior of austenitic stainless steel in acid chloride solution, the SCC susceptibility is described as follows [19]:

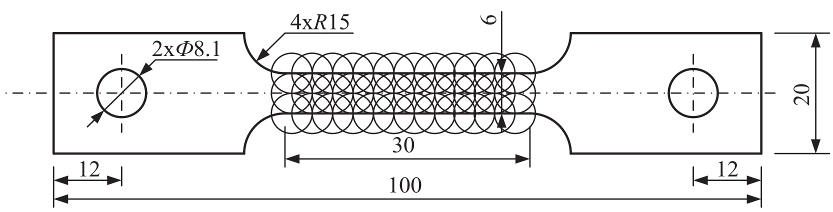

Fig. 1. Schematic of SSRT sample.