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Effect of high energy shot peening pressure on the stress corrosion cracking of the weld joint of 304 austenitic stainless steel

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ABSTRACT

The weld joint of 304 stainless steel is treated using high energy shot peening(HESP) with various shot peening pressures. The grain size and metallographic microstructure of the specimen surface layer are analyzed using the X-ray diffraction method, and the surface hardness is measured. Slow strain rate tension tests are then performed to investigate the effect of shot peening pressure on the stress corrosion sensitivity. The results show that in the surface layer of the specimen, the grain refinement, hardness and the strain-induced plastic deformation all increase with the increasing shot peening pressure. Martensitic transformation is observed in the surface layer after being treated with HESP. The martensite phase ratio is found to increase with increasing shot peening pressure. The result also shows that the effects of the shot peening treatment on the stress corrosion sensitivity index depend on the shot peening pressure. When the shot peening pressure is less than 0.4 MPa, the grain refinement effect plays the main role, and the stress corrosion sensitivity index decreases with the increasing shot peening pressure. In contrast, when the shot peening pressure is higher than 0.4 MPa, the martensite transformation effect plays the main role, the stress corrosion sensitivity index increases with increasing shot peening pressure.

1. Introduction

The high energy shot peening (HESP) treatment is an effective surface strengthening technology to change the metallurgical structure and mechanical properties of material in the surface layer of the components. Different from the general mechanical shot peening treatment, the component is impacted with higher speed and higher energy metal projectiles in the HESP treatment and better surface strengthening effects could be obtained [1].

ANSI 304 austenitic stainless steel has good corrosion resistance in many mediums but is sensitive to intergranular corrosion and stress corrosion cracking in chloride solution. Especially for the weld joints, the metallurgical structure changes and welding residual stress would increase the trends to the stress corrosion cracking. There are many ways to improve stress corrosion resistance of the 304 stainless steel weld joints, for example, improving the structure of weld joint to reduce stress concentration, performing post-weld heat treatment to eliminate welding residual stresses, treating surface using shot peening, etc. The shot peening treatment may both refine grains in the surface layer and produce compressive residual stresses, and therefore can more effectively improve the stress corrosion resistance of the weld joint.

Many researches have been done for the effects of shot peening on the mechanical properties, fatigue performance, corrosion resistance and friction performance of the stainless steels [2–6]. Li et al. [7] reported that the nanostructure surface layer was obtained by HESP treatment on SS400 steel weld joints and the stress corrosion behavior of the weld joints in nitrate solution was studied using slow strain rate test (SSRT). The experimental results showed that the grains of the surface layer could be refined to 10 nm scale after the HESP treatment, and the stress corrosion cracking resistance could be improved obviously. Peng et al. [8] treated the 304 stainless steel weld joint surface using laser peening (LP), and the results showed that the LP treatment was an effective technique for protecting 304 stainless steel welded joints against stress corrosion cracking in chloride solutions owing to the positive contributions of compressive residual stress. Xiong et al. [9] treated the surface of 0Cr18Ni9Ti stainless steel by supersonic particles bombarding (SSPB) and the constant loading method was adopted for stress corrosion tests. The results showed that the surface could be nanocrystallized and the stress corrosion resistance of the stainless steel in the wet H_2S solution could be significantly increased. Zhang et al. [10] treated the weld joint surface of AISI 304 stainless steel by shot peening treatment, the results

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showed that the tensile residual stress of weld joint was changed to compressive one, and the stress corrosion crack sensitivity was decreased obviously. From the above research results, the surface shot peening treatment can refine grains, induce compressive residual stresses and improve the stress corrosion resistance properties of the materials. However, research results about the shot peening pressures on the stress corrosion properties and the mechanism of HESP treatment for improving weld joint resistance to stress corrosion cracking are not widely available in the literature.

In this paper, the 304 stainless steel weld joint specimens are treated using HESP at various shot peening pressures, The grain size and metallographic microstructure of the specimen surface layer are analyzed using the X-ray diffraction method, and the surface hardness is measured. The effect of shot peening pressure on the stress corrosion sensitivity is investigated by slow strain rate tests, and mechanism of HESP treatment to improve stress corrosion cracking resistance of the weld joint is studied.

2. Experimental

The specimens are made from a commercial ANSI 304 stainless steel plate of thickness 2mm, the chemical compositions of the steel are 0.068C–0.58Si–1.65Mn–0.024P–0.004S–18.86Cr–8.35Ni–Fe(wt%). Two pieces of plate are butt-welded using the plasma arc welding method. The weld joints are formed by one side welding and double-sided molding.

The weld joints are treated using HESP method on a pneumatic shot peening machine. The stainless steel projectiles of diameter 5 mm are adopted, the distance from the nozzle to specimen surface is 150 mm. In order to study the effect of shot peening pressures on the properties of weld joints, the shot peening time is fixed to 5 min, and the shot peening pressure values 0, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55 and 0.6 MPa are applied.

The specimens are cleaned by anhydrous ethanol after the HESP treatment, and the metallographic phases of the surface layer are then analyzed using X ray diffractometer (XRD) (X-ray source for Cu target, K alpha rays (λ=0.154056 nm)). According to the XRD spectrum of specimens, the grain size and lattice distortion can be calculated.

The specimens for slow strain rate tests are cut along the center of welds, such that the material in gauge length is all weld metal, as shown in Fig. 1. The stress corrosion cracking tests are carried out on slow strain rate tensile machine in 3.5 wt% NaCl solution with a fixed strain rate of 2.6×10^{-5} mm/s.

The material resistance to stress corrosion cracking can be quantitatively expressed with the stress corrosion sensitivity index which is the relative ratio of the parameters experimentally obtained in the inert medium (air) and corrosion medium (3.5% NaCl solution). Stress corrosion sensitivity index can be defined as follows.

The selected parameters can be elongation, reduction of area and absorbing energy (the area under the stress–strain curve) of the specimen. We use the absorbing energy to assess the stress corrosion sensitivity in this work because the absorbing energy reflects both the effects of mechanics and deformation, and the stress corrosion sensitivity index used in this paper can be defined as

$$F(A)=\frac{(A_0-A)}{A_0}\times100\% \quad (1)$$

where $F(A)$ is the stress corrosion sensitivity index; A_0 and A are the areas under the stress–strain curves obtained in air and in the corrosion medium respectively.

3. Experimental results

The shot peening pressure which depends on the bombarding speed of projectile is the main factor affecting the peening energy directly [11]. The shot peening pressure values: 0.3, 0.35, 0.4, 0.45, 0.5, 0.55 and 0.6 MPa are adopted in this work, and the effects of shot peening pressures on the metallographic phase, grain size, surface hardness and stress corrosion cracking index are analyzed below.

3.1. Effect of HESP pressures on the surface performance

3.1.1. Martensite phase transformation

The XRD spectrum obtained from the treated specimen surfaces for various shot peening pressures are shown in Fig. 2. It could be seen from the figure that the surface of the untreated specimen is austenitic phase, and the austenitic phase reduce gradually with the increasing shot peening pressure. When the shot peening pressure reaches 0.35 MPa, the martensite phase appears. When pressure is increased to 0.5 MPa, the martensite phase dominates and the austenitic phase become less residual one. With the shot peening pressure increasing, the martensite phase increases and austenitic phase decreases gradually. The martensitic transformation is induced by the serious plastic deformation of specimen surface which is bombarded by the high-speed metal projectiles during the shot peening treatment [12].

3.1.2. Nanocrystallization of the surface layer

As shown in Fig. 2, the specimen Bragg diffraction peaks become wider after HESP treatment, which means that the grain size of the treated specimen is smaller than the untreated one and the lattice distortion has occurred. Based on the half width of the diffraction peaks, the grain size and lattice distortion level can be calculated, and the results are listed in Table 1.

It could be seen from Table 1 that the grains in the surface layer of the specimens are obviously refined after being treated with HESP

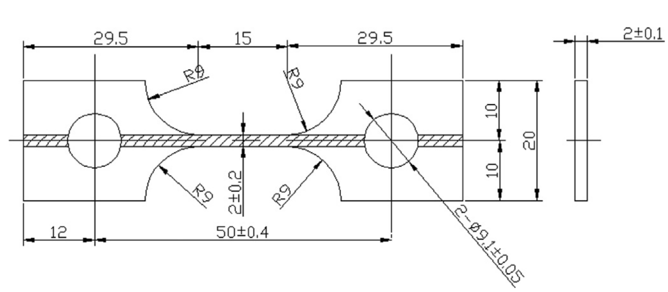

Fig. 1. Specimen design for slow strain rate tensile tests.

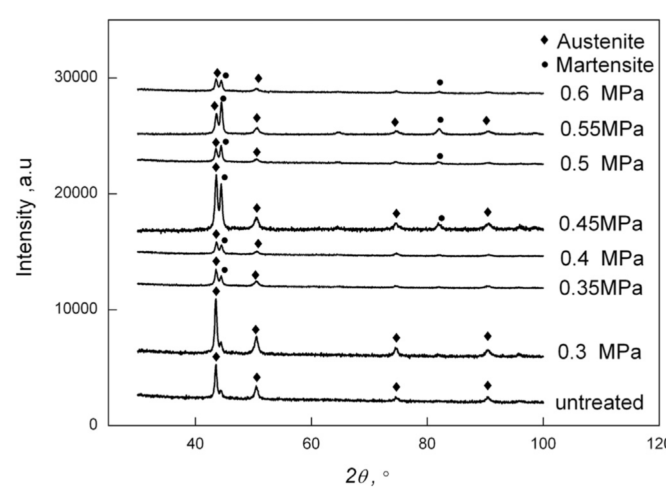

Fig. 2. XRD spectrum of the specimen surface tested at different peening pressures.