

## Quantitative assessment of retained austenite in SAF 2507 dual stainless steel after shot peening

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### Abstract

In this study, the dual-phase (austenite-ferrite) stainless steel SAF 2507 was processed by the conventional shot peening. The grain size and content of retained austenite in material after shot peening was evaluated by using X-ray diffraction. The results show that the volume fraction of austenite phase at top surface are nearly 40% for the peened SAF 2507 steel, while the austenite contents in the matrix reaches about 65%. The grain size and retained austenite increase with the increase of depth from the surface.

**Keyword:** SAF2507; shot peening; retained austenite

### Introduction

Shot peening (SP) is a kind of cold working treatment, which is widely used in the automobile and aerospace industries to improve the fatigue life and surface strength of the component. The SP process is implemented by bombarding the surface of a metallic component with high velocity shots. [1-5]The compressive residual stress, grain refinement and deformation induced transformation induced by plastic strain in the shot peened material are well-known phenomenon.

Several researchers have already focused their attention on the martensitic transformation in the material such as AISI 316L or AISI 304 austenite stainless steel after severe shot peening (SSP) [6]. The investigations on martensitic transformation mechanism were carried out mainly by means of transmission electron microscope. So most of the research is a qualitative analysis, and the quantitative analysis is inadequate. Amar et al [7] had reported a single X-ray diffraction method which was used to identify and evaluate deformation-induced transformation in 304 austenitic stainless steel. This technique enables simultaneous measurement of all the phases from a single XRD scan.

### Objectives

In this paper, commercial duplex (austenitic-ferritic) stainless steel (DSS) plates SAF 2507 was treated by SP, we used the same way that introduced by Amar to measure the changes in the content of retained austenite in the peened SAF 2507 steel.

### Methodology

#### Material

The specimens used in this investigation are commercial duplex (austenitic-ferritic) stainless steel plates SAF 2507 (equivalent to UNS S32750 or 00Cr25Ni7Mo4N), its chemical composition is listed in Table 1. The solution treatment of this material was performed at 1030°C for an hour, and then water quenched. Fig. 1 exhibits the metallographic structure of the material. It can be seen that the elongated austenite islands are embedded in the gray etched ferrite matrix (the darker phase) without apparent secondary phase precipitation, so there are only two phases existed in the material.

Table.1. Chemical composition of DSS SAF2507 (wt %)

C	Si	Mn	P	S	N	Cr	Ni	Mo	Fe
0.015	0.55	0.69	0.029	0.002	0.24	25.15	6.74	3.43	Bal.

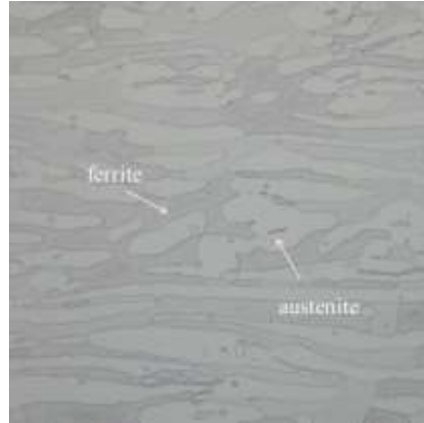


Fig. 1. Metallographic structure of the SAF 2507 steel

### Shot peening treatment

SP treatments were carried out by using the air blast machines (Carthing Machinery Company, Shanghai). The intensities of SP were set to 0.3 mmA that determined by the arc height of A-type Almen strip. The surface coverage was 200%. Cast steel balls with a diameter of 0.6 mm were selected as the SP media. The diameter of peening nozzle was 15 mm and the distance between the nozzle and the sample was 100 mm.

### Measurements and calculation

Electrolytic layer removals were carried out one by one in step from 0 to 250  $\mu\text{m}$  to determine the XRD profiles of the peened material. At each depth, XRD patterns were measured with Rigaku Ultima IV diffractometer (Cu  $K\alpha$  radiation) with a D/tex1D high speed detector. The voltage, current, scanning speed and step were 40 kV, 30 mA,  $1^\circ/\text{min}$  and  $0.01^\circ$ , respectively.

The quantitative estimation of phases by X-ray diffraction is based on the principle that the total integrated intensity of all diffraction peaks for each phase in the material is proportional to the volume fraction of that phase [7]. The integrated intensity ' $I$ ' of any diffraction peak from phase ' $i$ ' is given by [8]

$$I_i^{hkl} = KR_i^{hkl} V_i/2\mu \quad (1)$$

Where,  $K = \left(\frac{I_i A \lambda^3}{32\pi r}\right) \left[\left(\frac{\mu_0}{4\pi}\right) \frac{e^4}{m^2}\right]$  and  $R_{hkl} = \left(\frac{1}{v^2}\right) \left[|F|^2 p \left(\frac{1+\cos^2 2\theta}{\sin^2 \theta \cdot \cos \theta}\right)\right] (e^{-2M})$

$I_i^{hkl}$ : integrated intensity for  $(hkl)$  plane of austenite or ferrite phase.  $K$ : the instrument factor.  $R_i^{hkl}$ : material scattering factor and depends on  $\theta$ , interplanar spacing of  $(hkl)$ , composition and the crystal structure of the phase  $i$ .  $V_i$ : volume fraction of phase  $i$ .  $v$ : volume of unit cell.  $F_{hkl}$ : structure factor for reflecting plane  $(hkl)$ .  $p$ : multiplicity factor,  $e^{-2M}$ : temperature factor.  $\lambda$ : the wavelength of incident X-ray beam.  $\mu$ : linear absorption coefficient.  $A$ : cross sectional area of incident X-ray beam.  $I_0$ : intensity of the incident beam.  $r$ : radius of diffractometer circle.  $e$  and  $m$ : charge and mass of electron. Therefore, for a steel containing austenite ( $\gamma$ ) and ferrite ( $\alpha$ ), Eq. (1) may be written as,

$$I_\gamma = \frac{KR_\gamma V_\gamma}{2\mu}, I_\alpha = \frac{KR_\alpha V_\alpha}{2\mu}$$

because there are only two phases in the SAF2507 steel, so

$$V_\gamma + V_\alpha = 1$$

From the above equations, and  $K/2\mu$  is constant in a given X-ray diffraction, the volume fraction of austenite and ferrite can be derived for numerous peaks as,

$$V_i = \frac{\frac{\frac{1}{n} \sum_{j=1}^n I_{R_i}^j}{I_{R_i}^j}}{\frac{\frac{1}{n} \sum_{j=1}^n I_{\gamma}^j + \frac{1}{n} \sum_{j=1}^n I_{\alpha}^j}{I_{\gamma}^j}} \quad (2)$$

Where  $i = \gamma$  or  $\alpha$  in this instance and  $n$  is the number of peaks examined. Eq. 2 enables simultaneous assessment of retained austenite volume fraction in ferrite-austenite mixtures such as dual-phase (DP) or transformation-induced plasticity (TRIP) steels.

### Results and analysis

Fig. 2 shows the metallographic structures of cross section of the SAF2507 steel before (a) and after (b) SP. It can be seen that the original surface profile was straight, and the austenite ( $\gamma$ ) phase was coarse, the interface of austenite and ferrite was smooth. After SP, there were many small caves on the rough profile. The impingement caused significant deformation of  $\gamma$  phase. The surface microstructure became more compact due to the repeated shot impingement. The depth of the plastic deformation layer was approximately 100  $\mu\text{m}$  that observed from the optical image.

Fig. 3 shows a typical XRD pattern of the SAF2 507 duplex stainless steel. The diffraction was carried out at room temperature using Cu  $K\alpha$  radiation. All the characteristic peaks were from the fcc-austenite and bcc-ferrite and were labeled in the figure. The XRD profile demonstrates that only two phases existed in the material.

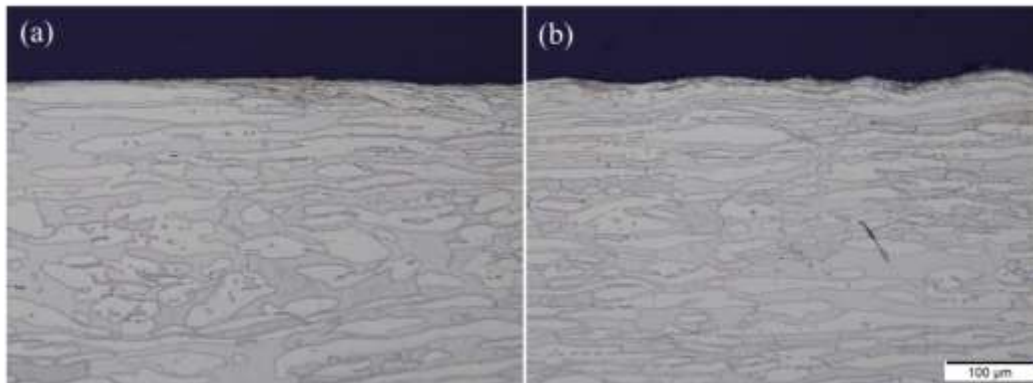


Fig. 2. Metallographic structures of cross section of the Specimen before (a) and after (b) shot peening

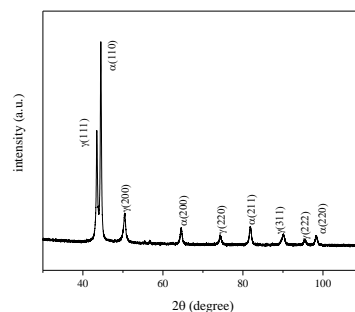


Fig. 3. X-ray diffraction using Cu  $K\alpha$  radiation of specimen.

The depth distribution of the XRD patterns of the SAF 2507 steel after SP were shown in Fig. 4(a). Several studies have demonstrated that strain-induced martensite can be formed by SP in some austenitic stainless steels. Two types of the martensite may form in austenitic stainless steels:  $\epsilon$  and  $\alpha'$ .  $\epsilon$ -martensite has a hcp crystal structure, while  $\alpha'$  has a bcc one. The typical transformation sequence can be summarized as  $\gamma$ - $\epsilon$ - $\alpha'$ , where the  $\gamma$ - $\epsilon$  transformation has been proposed for austenitic stainless steels deformed under tension [1]. In this study, it can be seen from the XRD spectra (see Fig. 4(a)) that no  $\epsilon$ -martensite peaks have been detected, and due to strain-induced  $\alpha'$ -martensite has the same crystallographic structure with ferrite, it is difficult to distinguish them from the original  $\delta$ -ferrite phase.

However, it is possible to measure the deformation-induced martensite quantitatively after SP by X-ray diffraction according to Eq. (2). Fig. 4(b) shows the retained austenite distributions along depths, the results show that austenite content greatly changed as increasing in the depth. It can be seen that volume fraction of austenite phase at top surface are nearly 40% for the shot peened steel, the austenite contents in the matrix reaches about 65%. That demonstrates that almost 30% of the austenite transform to  $\alpha'$ -martensite. As the depth increasing, the retained austenite contents of the sample after SP increase sharply, and then the increment is slowed down when the depths are larger than 200  $\mu\text{m}$ .

The FWHM of  $\gamma$  (111) and  $\alpha$  (110) peak was used to calculated the domain size according to Scherrer equation. Fig. 5 displays the variation of the FWHM and domain size of peened SAF2507 steel with the depth. The FWHM decreases gradually with the increase of the depths, indicating that the microstructures of the samples along the layer depths have changed. It also can be obtained that the domain sizes of the two phases attain the minimum (about 20 nm or lower) at the top surface, and then increase gradually along the depths.

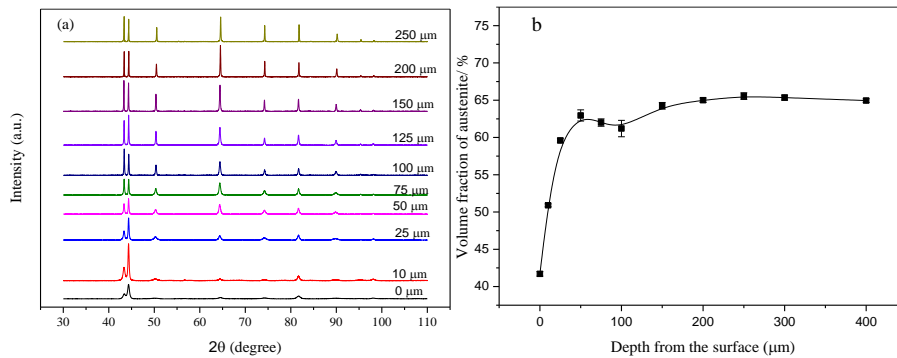


Fig. 4. Depth distribution of the XRD patterns (a) and depth profiles of retained austenite content (b) of SAF2507 steel after shot peening

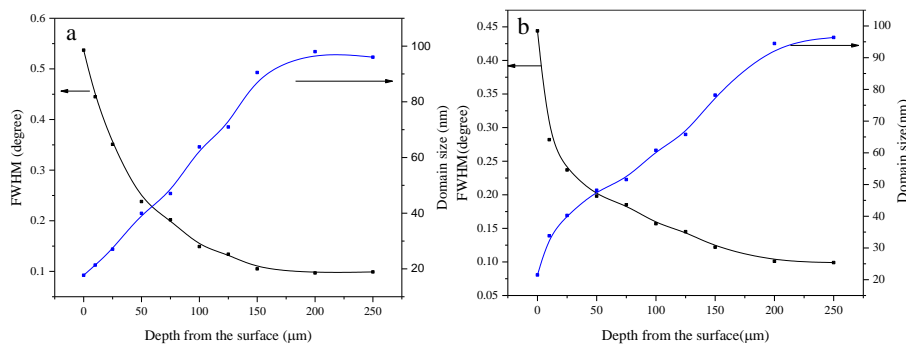


Fig. 5. Variation of FWHM and domain size of the shot peened specimen with the depth from the surface. a) austenite, b) ferrite.

## Conclusions

The duplex stainless steel SAF2507 was processed by conventional shot peening, the variation of the retained austenite with the depth from the surface was evaluated by XRD diffraction scan. The results showed that the volume fraction of austenite phase at top surface was nearly 40% for the peened SAF2507 steel, while the austenite contents in the matrix reached about 65%. That demonstrated that almost 30% of the austenite transformed to deformation-induced martensite after shot peening. The grain size analysis indicated that shot peening can refine the grain effectively, small nanocrystallites were formed on the impacted surface.

## Reference

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