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SPIE.

Event: 2003 Chapter books, 2003, Bellingham, WA, United States

X-ray analysis of stress distribution in ferrite and austenite of duplex steel during tensile loading

Vladimir I. Monin[1], Joaquim T. de Assis[1], Sergei Filipov[1], Tatiana Gurova[2], Joel R. Teodósio[2], H.F.Abreu[3]

[1] *Instituto Politécnico, Universidade do Estado do Rio de Janeiro, Nova Friburgo, Brazil*
E-mail: joaquim@iprj.uerj.br monin@iprj.uerj.br sfilippov@iprj.uerj.br

[2] *Department of Metallurgical and Materials Engineering*
Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil
E-mail: teodosio@metalmat.iprj.uerj.br

[3] *Mechanics and Production Department, Universidade Federal do Ceara, Brazil*

ABSTRACT

One of characteristic feature of stress determination by X-ray diffraction technique is the possibility to analyze stress state in individual phases of a multiphase material. Duplex steel widely used in chemistry and oil refinery equipments is an example of this kind multiphase material consisting of approximately equal quantities of ferrite and austenite. These phases have different mechanical properties that cause a different stress distribution under loading. In the present paper mechanical behavior of a duplex steel and their ferrite and austenite phases have been studied by X-ray diffraction technique. Stress distribution has been analyzed both in elastic and plastic region.

1. INTRODUCTION

Duplex steel used in this paper is a standard stainless steel composed of approximately equal volume fractions of ferrite and austenite. Stress distribution of this kind multiphase material can be expressed by the following equation:

$$\sigma_{dup} = \sigma_\alpha * f_\alpha + \sigma_\gamma * f_\gamma \qquad (1)$$

where $\sigma_{dup.}$ is the applied stress, σ_α, σ_γ are the stresses acting, respectively, in ferrite and in austenite; f_α, f_γ are the fraction volumes of α- and γ- components. But this equation is not sufficient to predict stress distribution in a duplex steel because its mechanical behavior depends of initial residual stress state of components. Therefore, a study of stress-strain dependence described by equation (1) is important to understand the mechanism of plastic deformation of the multiphase material and to evaluate the contribution of each component in formation of mechanical properties. Stress determination by X-ray diffraction method can be used for this aim because it allows to measure individual stress state both in ferrite and in austenite.

The aim of the present paper is to study mechanical behavior of each component of a duplex steel under loading in elastic and plastic regions using X-ray diffraction method.

2. MATERIAL AND EXPERIMENTAL TECHNIQUE

The studied duplex steel, fabricated by hot rolling and quenching at high temperature, contents approximately equal volume fractions of ferrite and austenite. After machining the analyzed surface was polished by electrolytic method to remove 0,15 – 0,20 mm of distorted surface layer. Loading of samples was made by pure bending test using portable loading device allowing to control the applied stress and to measure the sample strain. The scheme of loading device is shown in *Figure 1*. Portability of this device permits to mount it on X-ray diffractometer and to carry out in-situ measurements of individual stresses in each phase during loading.

Diffraction measurements were performed using portable diffractometer [1] developed by authors with position sensitive detector. Reflections $(211)_\alpha$ and $(220)_\gamma$ with Cr - K_α wavelength were used for X-ray stress analysis. The magnitudes of X-ray elastic constants were taken from [2].

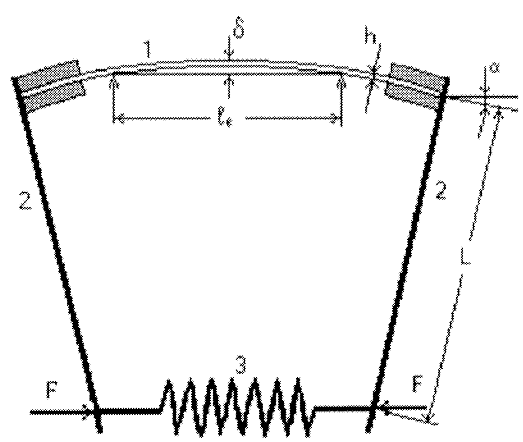

Fig. 1. *Scheme of a loading device: 1 – analyzed sample, 2 – sample support, 3 – loading spring l.*

Seventh International Workshop on Nondestructive Testing and Computer Simulations in Science and Engineering, edited by Alexander I. Melker, Proc. of SPIE Vol. 5400 (SPIE, Bellingham, WA, 2003) · 0277-786X/03/$15 doi: 10.1117/12.555470

3. METHODOLOGY AND EXPERIMENTAL RESULTS

In accordance with the definition of principal parameters of bending test the following equations were used to calculate the applied stress and strain of surface layer of sample:

$$F = k^*\Delta l_{spr.} \quad (2)$$

$$\sigma_{appl.} = 6k\Delta l_{spr.}{}^*(L+h/2)^*\cos\alpha/bh^2 \quad (3)$$

$$\varepsilon = h^*\sin\alpha/L_{base} \quad (4)$$

$$tg\alpha/2 = 2\delta/l_{base} \quad (5)$$

where k is the load coefficient of the spring, used for loading of samples; δ is the deflection of a banded sample; α is the distance between contact points to measure the magnitude of deflection; L is the arm of an applied force creating a bending moment. Testing of the bend loading device was made on a sample of the duplex steel. *Figure 2* shows the elastic region of a stress-strain diagram.

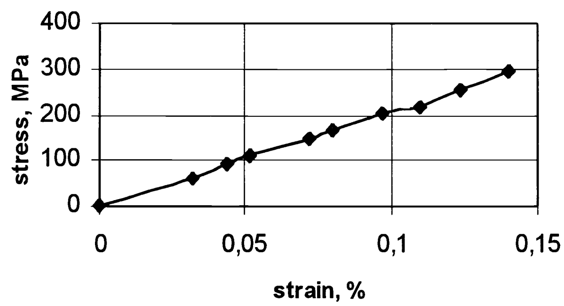

***Fig.** 2. Stress – strain diagram for duplex steel.*

The value of modulus of elasticity for duplex steel determined from this diagram is equal to $E = 205300$ Mpa that corresponds to the value of modulus obtained on a Instron loading machine. This fact means that portable loading device and experimental technique have high accuracy and precision to be used stress-strain analysis. Stress determination by X-ray diffraction technique was made by traditional $sin^2\psi$ - method for unidimensional stress state. Principal equation for calculation of stress component in axial direction both for ferrite and austenite is the following [2]:

$$\sigma = E^*ctg\theta\,(\theta_{90} - \theta_0)\,/(\,1+\nu), \quad (6)$$

where E, ν are the X-ray elastic constants, respectively for ferrite and austenite components; θ is the magnitude of a diffraction angle; θ^{90} and θ^{0} are the magnitudes of diffraction angles calculated by a linear regression from the experimental dependence $2\theta = f(sin^2\psi)$, where ψ is the angle between the normal to a surface and the normal to reflecting lattice planes.

Diffraction experimental data contain determination of residual stresses in post-fabrication samples of the duplex steel and measurements in-situ stress distribution in elastic and plastic regions of the stress-strain diagram. *Figure 3* represents the experimental stress-strain curves obtained by bend testing and by X-ray diffraction technique. Initial residual stresses obtained for ferrite and austenite phases are equal to $\sigma_\alpha^{res} = -120$ *Mpa* and $\sigma_\gamma^{res} = +110$ *Mpa*. Stress measurements in each phase under loading in the elastic region can be characterized by linear functions with quasi – parallel slopes of the stress-strain diagram. This means that ferrite and austenite phases have similar values of elastic constants. Yield stresses for components of duplex steel from the stress-strain curves obtained by X-ray diffraction method are equal to *490 MPa* for austenite and *650 MPa* for ferrite.

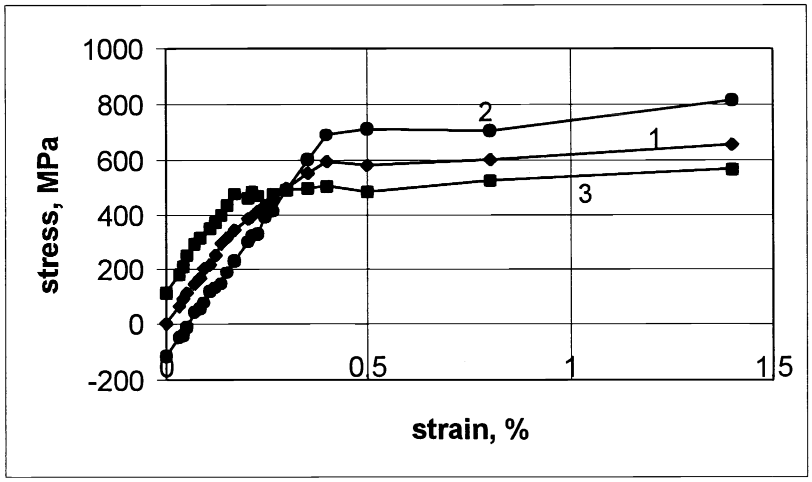

Fig. 3. Stress – strain curves: 1 – duplex steel; 2 – ferrite; 3 – austenite.

4. CONCLUSION

Stress state in ferrite – austenite phases of duplex steel have been analyzed before and during loading. Initial residual stress state in the phases is characterized by compressive stress in ferrite phase and tensile – in austenite. Elastic region is characterized by quasi-parallel linear functions both for ferrite and austenite. Plastic region has shown difference between applied – and phase stresses. This difference increases with an increment of plastic deformation.

5. REFERENCES

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