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ANALYSIS OF RESIDUAL STRESS STATE IN WELDED STEEL PLATES BY X-RAY DIFFRACTION METHOD

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Abstract. There were investigated geometrical distortions of two steel plates jointed by metal inert gas welding. The distributions of residual stresses in this welded joint were measured by X-ray diffraction method. The measured residual stress distributions were compared with residual stress state obtained by means of finite element analysis with using of ABAQUS software. A good agreement was obtained between experimental and analytical data.

1. INTRODUCTION

Welding is one of the most important technologies widely used in various engineering fields such as civil engineering, shipbuilding, pipeline fabrication among others. Welding is a complicated process accompanied by shrinkage effects, phase transformations, intensification of corrosion and arising of residual stresses. Residual stresses after welding have considerable influence on the service characteristics of welded components; knowing of residual stress level allows avoid the failure of welded joints. The influence of residual stresses on service characteristics of welded components was analyzed in many original papers and books [1-3]. A wide variety of residual stress measurement techniques exist but one of the important is the X-ray diffraction technique which can be used to analyze the origin of residual stresses after welding, allows investigate 3-dimensional stress distributions in the weld region. There are numerous examples of stress measurements by X-ray diffraction method [1,4], but sometimes they contain contradictory results.

The objective of the present paper is to analyze the geometrical distortions of two welded steel plates caused by the residual stresses arising during welding process and study distributions of these stresses by means of X-ray diffraction method and finite element analysis.

2. MATERIAL, EQUIPMENT AND METHODOLOGY

Two A131 steel plates with dimensions 2200mm x 800mm x 19mm with single-V preparation joint were welded by metal inert gas (MIG) welding by 4 steps. Before the welding steel plates were restricted along all perimeters of plates. Geometrical measurements made by means of LASER TRACKER and stress measurements by diffraction technique were performed before and after restriction of plates and then all measurements were repeated after welding. Finite element analysis was made by means of commercial ABAQUS [5] software.

X-ray stress measurements were carried out by RAYSTRESS equipment which is shown in Fig. 1. The methodology of stress measurements used in the presented X-ray portable apparatus is based on the elasticity theory equations for strain in an arbitrary direction [6]:

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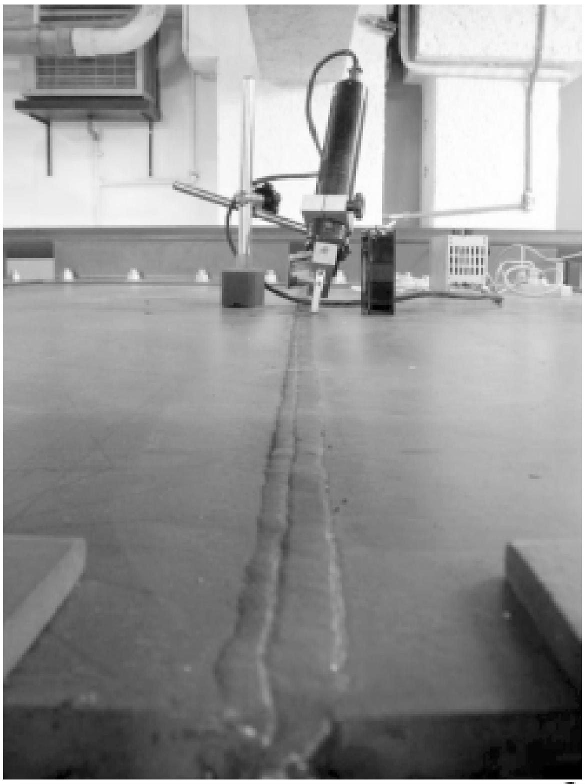

Fig. 1. General view of measurement procedure with RAYSTRESS equipment.

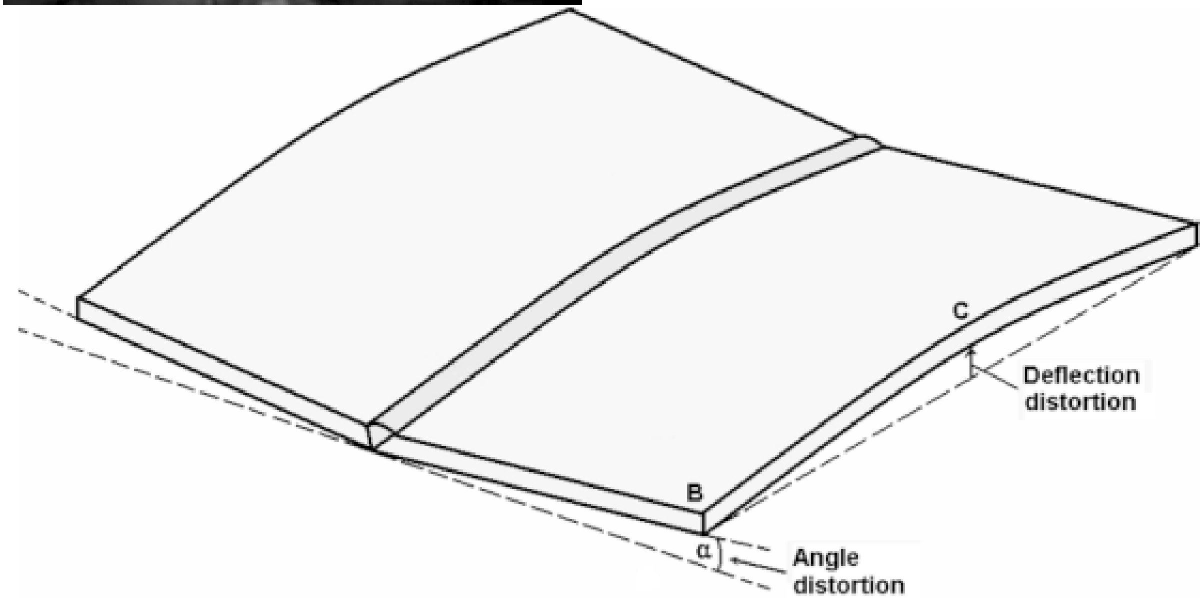

Fig. 2. Geometrical distortions of welded plates.

$$\varepsilon_{\varphi,\psi} = \frac{1+\nu}{E}\sigma_{\varphi}\sin^2\psi - \frac{\nu}{E}(\sigma_1 + \sigma_2),$$

where E, ν are the elastic constants, φ and ψ are the azimuthal and polar angles in a spherical coordinate system, σ_{φ} is the measured stress component in φ-direction, σ_1 and σ_2 are the principal stresses. The strain $\varepsilon_{\varphi,\psi}$ related to the diffraction experiment can be expressed as [3]:

$$\varepsilon_{\varphi,\psi} = \frac{d_{\varphi,\psi} - d_0}{d_0} = -\operatorname{ctg}\theta(\theta_{\varphi,\psi} - \theta_0),$$

where $d_{\varphi,\psi}$, d_0, $\theta_{\varphi,\psi}$, θ_0 are interplanar distances and diffraction angles for analyzed and free of stress material, respectively. From these equations the diffraction angle $\theta_{\varphi,\psi}$ corresponding to the strain in arbitrary direction can be written as:

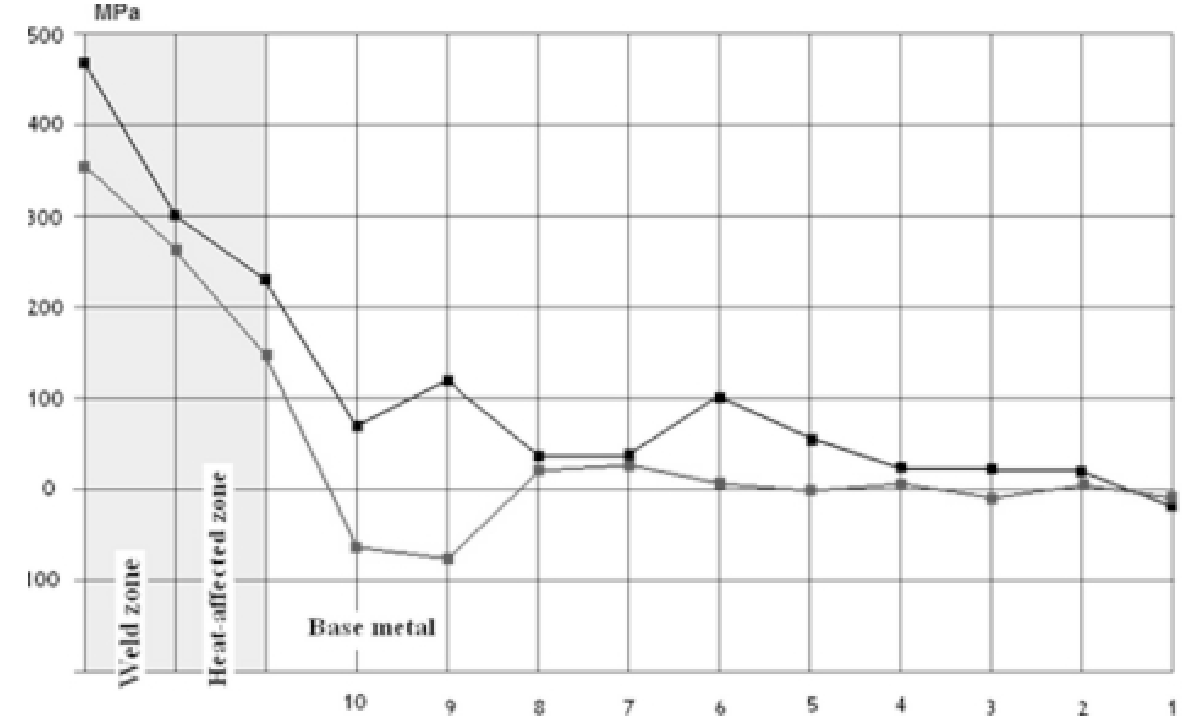

Fig. 3. Distribution of longitudinal residual stresses with (1) and without (2) restrictions.

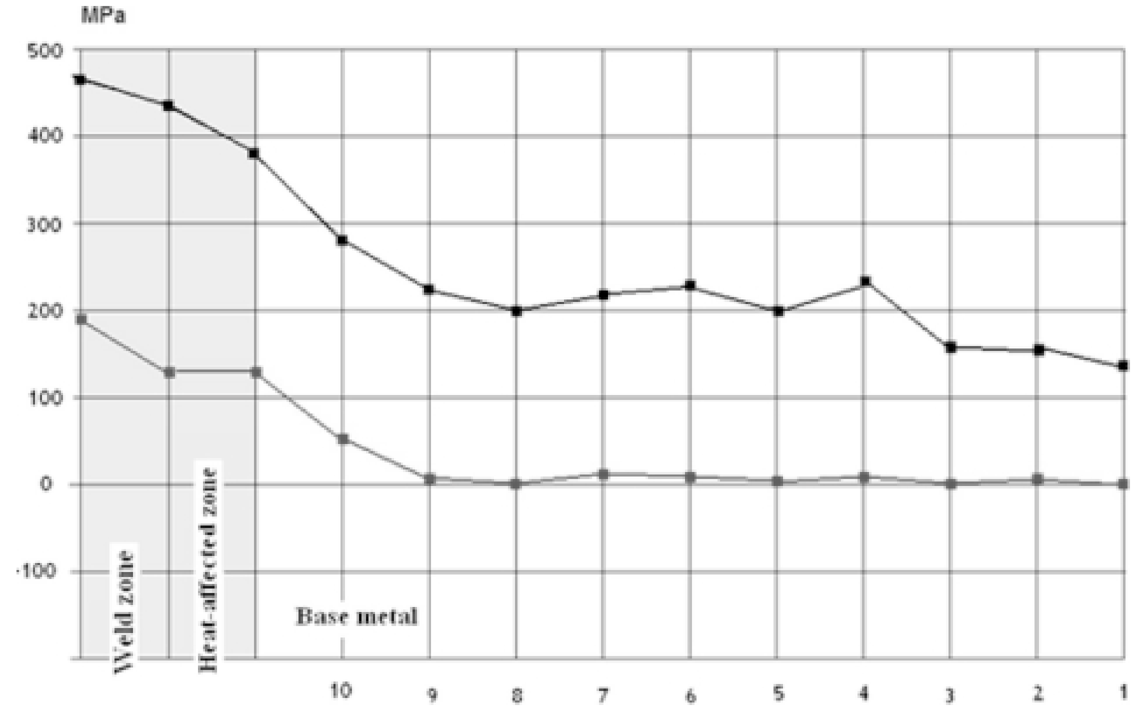

Fig. 4. Distribution of transversal residual stresses with (1) and without (2) restrictions.

$$\theta_{\varphi,\psi} = \theta_0 - \frac{1+\nu}{E}\frac{\sigma_\varphi}{\mathrm{ctg}\,\theta_0}\sin^2\psi + \frac{\nu}{E}\frac{(\sigma_1+\sigma_2)}{\mathrm{ctg}\,\theta_0},$$

If to use the diffraction angle difference for two ψ angles then the following equation for double-expose technique of stress measurements can be obtained:

$$\sigma_\varphi = -\frac{E}{1+\nu}\frac{\mathrm{ctg}\,\theta\left(\theta_{\psi_2} - \theta_{\psi_1}\right)}{\left(\sin^2\psi_2 - \sin^2\psi_1\right)}.$$

The magnitudes of ψ angles used in RAYSTRESS equipment are ψ_2=50° and ψ_1=0°

3. EXPERIMENTAL RESULTS

Geometrical distortions of welded plates are shown in Fig. 2. Maximal displacement observed in the point B is 14.41 mm that corresponds to the angle deformation α = 1.03° and displacement in the point C is equal to 3.17 mm. Stress measurements were made in the longitudinal and transversal directions (parallel and perpendicular to the weld zone, respectively). Figs. 3 and 4 represent the stress distributions in the weld region of steel plates with restrictions and after their removal. It can be seen from Figs. 3 and 4 that the stress state of weld zone and near weld zone region is characterized by tensile residual stresses but the origin of these stresses is different. Tension of the weld zone is the result of shrinkage effect and tensile stresses of near weld region are caused by its thermal expansion and compressive plastic deformation. Thermal expansion of near weld zone region can provoke the bending of welded plates that is shown in Fig. 2.

Residual stress distributions for longitudinal and transversal directions obtained by finite element analysis are in good agreement with distributions measured by X-ray diffraction method which are shown in Figs. 3 and 4. This fact was used for correlation of absolute magnitudes of stresses determined by finite element analysis.

4. CONCLUSION

We have analyzed distributions of longitudinal and transversal residual stresses in weld region of two steel plates jointed by metal inert gas welding. Experimental results obtained by X-ray diffraction method and determined analytically by finite element analysis are in a satisfied agreement.

REFERENCES

[1] E. Macherauch and H. Wolfahrt, In: *Residual Stresses in Welding Constructions and their Effects* (Welding Institute Reprint, 1977), p. 267.

[2] V. Hauk, *Structural and Residual Stress Analysis by Nondestructive Methods. Evaluation, Application, Assessment* (Elsevier, Amsterdam,1997).

[3] W. Pfeiffer, In: *International Symposium Safety in Application of High Strength Steel* (Trondheim, 1-2 July, 1997).

[4] V. Monin, J.T. Assis and T. Gurova // *The e-Journal of Nondestructive Testing and Ultrasonics* **5** (2000) 1.

[5] ABAQUS *User´s and Theory Manual*, Version 6.5 (Hibbitt, Karlsson, Sorensen, Inc., 2004).

[6] I.S. Noyan and J.B. Cohen, *Residual Stress Measurement by Diffraction and Interpretation* (Springer Verlag, New York, Berlin. 1987).