EAN 2013
51th conference on experimental stress analysis

Residual Stress Investigations of Electron Beam Welds on Samples Prepared by Reconstitution Method

Pavol Mikula[a] and Miroslav Vrána[b]

Nuclear Physics Institute ASCR, v.v.i., 250 68 Řež, Czech Republic

[a]mikula@ujf.cas.cz, [b]vrana@ujf.cas.cz

Keywords: Reconstitution method, residual stress, neutron diffraction.

Abstract. This paper deals with the residual strain/stress measurements in the vicinity of electron beam welds of Charpy-V notched specimen by neutron diffraction. Specimen with welds on one side as well as with welds on two opposite sides were prepared by reconstitution method. Welding was performed with electron beam in a vacuum and proceeded in accordance with the ASTM E 1253 standard.

Introduction

The technique of constructing specimens from small pieces of material is usually called reconstitution. Such miniaturized specimen technology permits the characterization of mechanical behaviour while using a minimum volume of material. The compound specimen is achieved by attaching an additional material (studs) around a material of interest (the insert material) which results in a test specimen of standard dimensions. The incorporation of a small piece from a previously tested specimen into a compound one, allows e.g. to multiply the number of tests. This can be especially important if the amount of the available material is restricted and mechanical parameters have to be determined. Very often one can meet with such necessity in the nuclear power plant industry e.g. nuclear pressure vessel surveillance, failure analysis, and post irradiation testing. The interface between the stud and the insert is created by using welding techniques. However, before testing the mechanical properties the microstructure after welding has to be examined to ensure that the material in the vicinity of the notch is from the point of the presence of residual stresses essentially unchanged after the welding process. For example, it is well known that the residual stresses resulting from the welding process can be nonnegligible even at the distance up to several millimetres from the notch and thus significantly influence the mechanical properties of the material and in this case of the stud. In our case electron-beam welding (EBW) was used. Welded pieces were of low-alloy ferritic steel material.

Experiment Procedure

Experimental measurements were carried out on the neutron strain scanner installed at the medium-power (10 MW) research reactor LWR-15 in Řež, Czech Republic [1,2]. The total dimensions of the samples were 10 x 10 x 55 mm^3. Fig. 1 displays the photo of a specimen prepared by joining three pieces (stud + insert + stud) by welding on one side. Fig. 2 shows the same sample installed at the neutron beam defined by input and output slits. It should be pointed out that residual stresses are not measured directly by diffraction methods but they are determined from measurement of residual strains, which are then converted to stresses using appropriate moduli [3,4]. The principle of the neutron diffraction method is quite simple. It consists in the precise determination of the d_{hkl}-spacing of particularly oriented crystal planes. In neutron and X-ray diffraction the angular positions of the diffraction maxima are directly related to the values of the

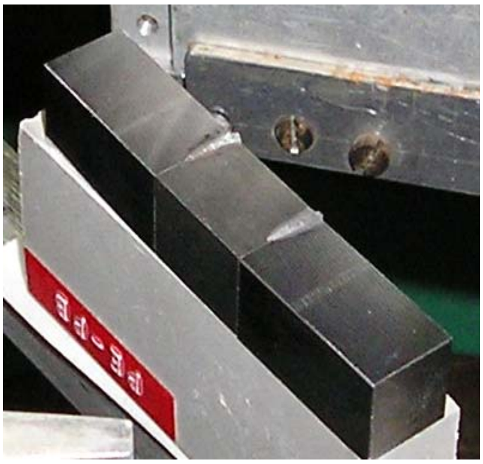

Fig. 1. Photo of one of the specimens with the weld on one side.

Fig. 2. Photo of the specimen installed on the neutron beam defined by slits.

lattice spacing through the Bragg equation $2d_{hkl} \cdot \sin\theta_{hkl} = \lambda$ (d_{hkl} -lattice spacing, θ_{hkl} - Bragg angle, λ - the neutron wavelength) and thus offer a unique non-destructive technique for investigation of stress fields. When a specimen is strained elastically, the lattice spacing changes. Then, when defining the strain ε as $\varepsilon = \Delta d/d_{0,hkl}$, it is related to a change in the lattice spacing, i.e. to a component parallel to the scattering vector $\boldsymbol{Q}$ perpendicular to the reflecting set of planes. Therefore, the knowledge of the $d_{0,hkl}$ value ($d_{0,hkl}$ is the lattice spacing of the strain-free material) is a key task [5,6]. Then by differentiation of the Bragg condition we arrive at $\varepsilon = -\cot\theta_{\mathrm{hkl}} \cdot \Delta\theta_{\mathrm{hkl}}$. The relation for the strain ε indicates that it gives rise to a change in the scattering angle $2\theta_{hkl}$ resulting in an angular shift $\Delta(2\theta_{hkl})$ of the peak position for a particular reflecting plane illuminated by a fixed wavelength. In such a way, the shift in the Bragg angle (relative to that of the stress-free material) permits the determination of the average lattice macrostrain over the irradiated gauge volume (see Fig. 3). The conversion of strains to stresses is carried out by means of the relation

$$\sigma_x = \frac{E_{hkl}}{(1-2\nu_{hkl})(1+\nu_{hkl})}\left[(1-\nu_{hkl})\varepsilon_x^{hkl} + \nu_{hkl}(\varepsilon_y^{hkl} + \varepsilon_z^{hkl})\right] , \qquad (1)$$

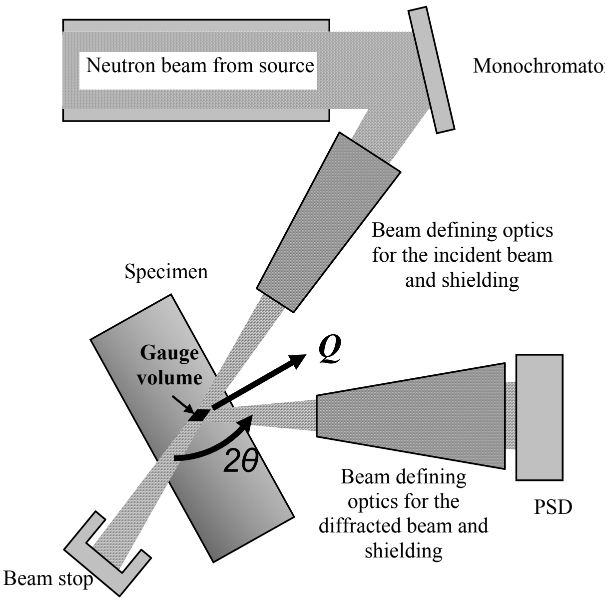

Fig. 3. Schematic illustration of a reactor source based diffractometer for strain measurement in parallel diffraction geometry.

where $\varepsilon_{x,y,z}^{hkl}$ is the *x,y,z*-component of the lattice strain measured at the *hkl* crystal lattice planes, E_{hkl} and ν_{hkl} are the diffraction elastic Young modulus and diffraction Poisson ratio, respectively. For the determination of the stress tensor in this case of steel samples, three strain components should be determined as schematically shown in Fig. 4.

Experimental results

The central part of the samples was made of reactor pressure wessel steel (surveillance material). Welding was performed with electron beam in a vacuum and proceeded in accordance with the ASTM E 1253 standard. After the residual strain/stress measurements, the Ch-V specimens were used for performing the impact tests in accordance with the standards ČSN ISO 148-1 and ASTM E 23. In the present case the strain/stress measurements should map the internal stresses after welding, especially in the middle part of the testing sample, which will be then a subject of the mechanical tests. Figs. 5 and 6 show the obtained results.

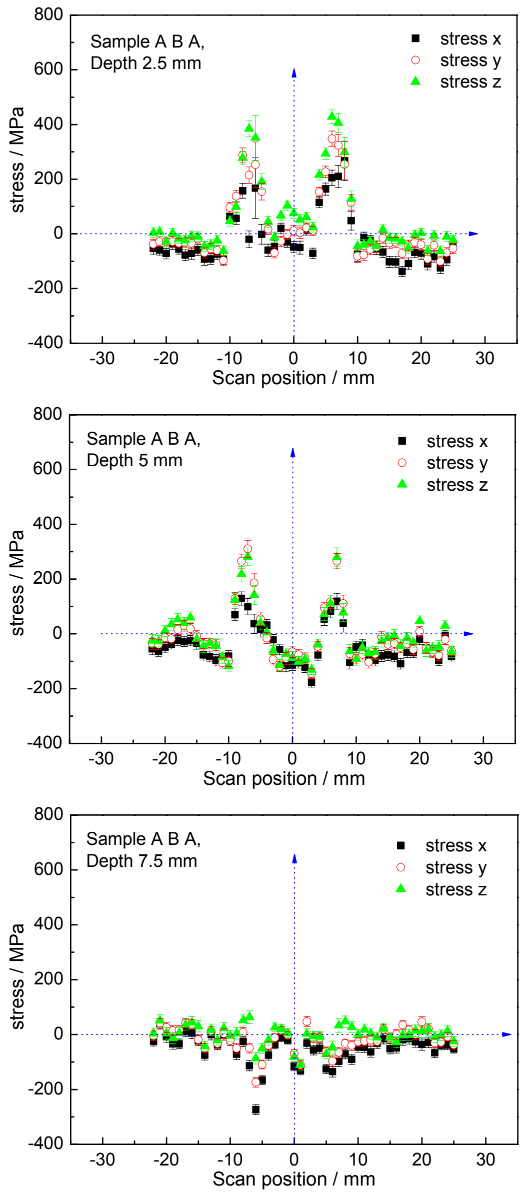

Fig. 5. Residual stress scans performed at different depths in the material for the sample with the weld on one side.

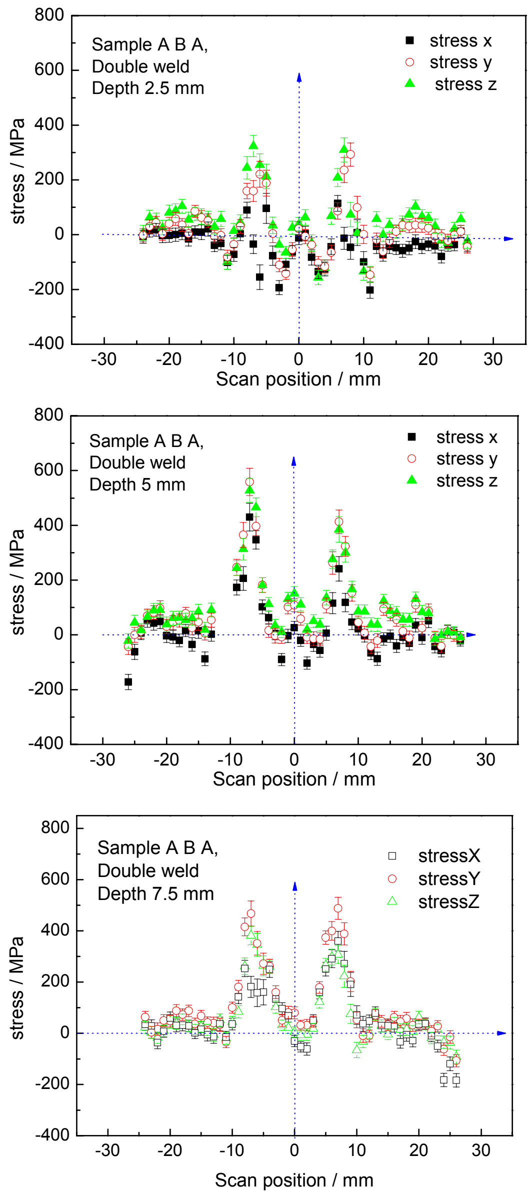

Fig. 6. Residual stress scans performed at different depths in the material for the sample with the weld on both sides.

Summary

Residual stresses in the vicinity of the welds made by electron beam on the samples prepared by the reconstitution method were investigated by neutron diffraction. A large penetration depth and selective absorption of neutrons make the technique a powerful tool in non-destructive testing of materials. In fact, neutron diffraction is one of few nondestructive methods that can facilitate 3-D mapping of residual stress in bulk components. In this case of testing the samples prepared by the reconstitution method, Figs. 5 and 6 document that quite significant residual stresses are present in the vicinity of electron beam weld. Their maximum achieves the value 400-500 MPa. They are, of course, not present at the depth of 7.5 mm of the sample with the weld only on one side where the heat affected zone is missing (see Fig. 5c). Taking into account stress distribution along the scan-axis in the material (along the longest edge of the sample) it can be seen that significant stresses are extended in the area of the length of about 5 mm and in the case of the welding on both sides, the stresses reach even the middle area of the stud, where mechanical tests should be carried out.

Acknowledgement

The residual stress measurements were carried out at the CANAM infrastructure of the NPI ASCR Rez and were in the Czech Republic also supported by the projects MPO FR-TI1/378 and GACR P204/12/1360.

References

[1] P. Mikula, M. Vrána, P. Lukáš, J. Šaroun, P. Strunz, H.J. Ullrich and V. Wagner, Neutron Diffractometer Exploiting Bragg Diffraction Optics - A High Resolution Strain Scanner, in: T. Ericsson, M. Odén and A. Andersson (Eds.), Proc. of ICRS-5, June 16-18, 1997, Linköping, Vol. 2, 1997, pp. 721-725.

[2] P. Mikula, M. Vrána, P. Lukáš, J. Šaroun and V. Wagner, High-Resolution Neutron Powder Diffractometry on Samples of Small Dimensions, Materials Science Forum, 228-231 (1996) 269-274.

[3] L. Pinchovius, V. Jung, E. Macherauch and O. Vöhringer, Residual stress measurements by means of neutron diffraction, Materials Science and Enginnering, 61 (1983) 43-50.

[4] Hutchings M.T. and Krawitz, A.D. (Eds.), Measurement of Residual and Applied Stress Using Neutron Diffraction, Kluwer Acad. Publ., 1992, NATO ASI Series, Applied Sciences Vol. 26 .

[5] A.D. Krawitz and R.A. Winholtz, Use of Position-Dependent Stress-Free Standards for Diffraction Stress Measurements, Materials Science and Enginnering, A185 (1994) 123-130.

[6] V. Stelmukh, L. Edwards, J.R. Santisteban, S. Ganguly and M.E. Fitzpatrick, Weld stress mapping using neutron and synchrotron x-ray diffraction, Materials Science Forum, 404-407 (2002) 599-604.