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Residual Stress Distribution in Spherical Storage Tank Butt Weld

Ľuboš Mráz[1,a], Charles Hervoches[2,b], Miroslav Vrána[2,c], Pavol Mikula[2,d], Peter Baksa[1,e] and Ján Bošanský[1,f]

[1]Welding Research Institute – Industrial Inst., Račianska 71, 832 59 Bratislava, Slovak Rep.

[2]Nuclear Physics Institute ASCR, v.v.i. 250 68 Řež, Czech Rep.

[a]mrazl@mail.t-com.sk, [b]hervoches@ujf.cas.cz, [c]vrana@ujf.cas.cz, [d]mikula@ujf.cas.cz, [e]baksap@vuz.sk, [f]bosanskyj@vuz.sk

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Introduction

Residual stresses are typical phenomena associated with welding of any kind of structural material. Stresses are generally responsible for the deformation of welded structures during production and subsequently influence the behaviour of these structures during service. This factor directly influences the properties of real welds and sensitivity to the initiation of different type of service cracking such as reheat and stress corrosion cracking. It is generally known that the initiation of stress corrosion cracking is influenced by the combined effect of material quality, environment and level of stresses (internal – residual, external – service).
Spherical storage tanks are used for holding of anhydrous ammonia, LPG, NGL, gasoline, naphtha, butadiene, ethylene, hydrogen, oxygen, nitrogen, argon, LNG (liquefied natural gas), biogas, sewage gas and waste water.
There is a number of publications available in the related literature which report about the failures of this equipment [1]. The choice of a suitable structural material, modification of environment or lower stress level can help to avoid the failure. In this case the stresses play certainly an important role and the knowledge of their level can provide important information to designers. In order to clarify the role of stresses on individual failures it is important to identify their level. Subsequently, it opens possibilities to repair failed structure and to define the conditions for further service. The purpose of this contribution is to present the results of strain/stress distribution measurements in the vicinity of the butt weld from the spherical storage tank which was obtained by the neutron diffraction method.

Experimental part

Residual stress distribution of the manual metal arc butt weld of the spherical storage tank has been experimentally analyzed. The storage tank of the diameter of 900 mm has been manufactured of C-Mn unalloyed normalized steel of the strength of approx. 480 MPa and of the thickness of 30 mm to store liquid anhydrous ammonia. Chemical composition of steel is summarized in Table 1 and mechanical properties in Table 2. Covered basic electrodes E-44.83 have been used for the butt weld preparation. Macrostructure of the butt weld is shown in Fig. 1.

Table 1. Chemical composition of C-Mn steel.

Material	mass concentration [%]					
	C	**Mn**	**Si**	**P**	**S**	**Mo**
C-Mn steel	**0.224**	**0.49**	**0.24**	**0.024**	**0.043**	**-**
11 418.1 according to STN 41 1418	**max. 0,20**	**0,50 1,40**	**max. 0,35**	**max. 0,030**	**max. 0,025**	**max. 0,08**

Table 2. Mechanical properties of C-Mn steel according to STN 411418.

Material	R_e [MPa]	R_m [MPa]	A [%]	Z [%]
C-Mn steel	**259**	**421**	**-***	**-***
11 418.1 according to STN 41 1418	**Min. 255**	**410 530**	**Min. 26**	**-**

* not estimated

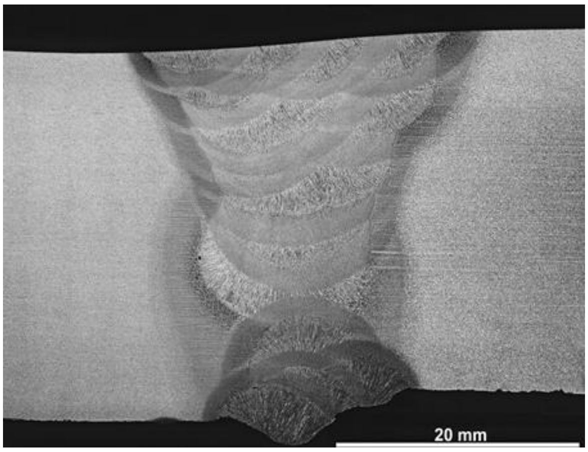

Fig. 1. Macrostructure of the test weld.

The specimen dimension of 150 x 200 x 15 mm^3 was cut off the circumferential weld of the storage tank for residual stress distribution measurements. 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 [2,3]. In neutron and X-ray diffraction the angular positions of the diffraction maxima are directly related to the values of the 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 the 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 crucial task [3]. Then, by the differentiation of the Bragg condition we arrive at $\varepsilon = -\cot \theta_{hkl} \cdot \Delta\theta_{hkl}$. 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. 2). The conversion of strains to stresses is carried out by means of the relation

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

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 the steel sample, three strain components should be determined as schematically shown in Fig. 3. Experimental measurements were carried out on the dedicated neutron strain scanner installed at the medium-power (10 MW) research reactor LVR-15 in Řež, Czech Republic [4,5].
The strain/stress instrument schematically shown in Fig. 2 is equipped with a focusing curved Si(111) monochromator and a high-resolution position-sensitive detector for fast recording of diffraction profiles. The monochromator provides the neutron beam with the wavelength of 0.232 nm. The measurement of the shift in the Bragg angle θ relative to that of the stress-free material θ_o permits determination of the average lattice macro-strain over the irradiated gauge volume. The strain scanning was carried when using diffraction on α-Fe(110) lattice planes at the scattering angle $2\cdot\theta_{110}$ = 70°. For the evaluation of the strains it was necessary to determine the angular position $2\cdot\theta_{0,\mathrm{hkl}}$ of the diffracted neutron beam for the strain free

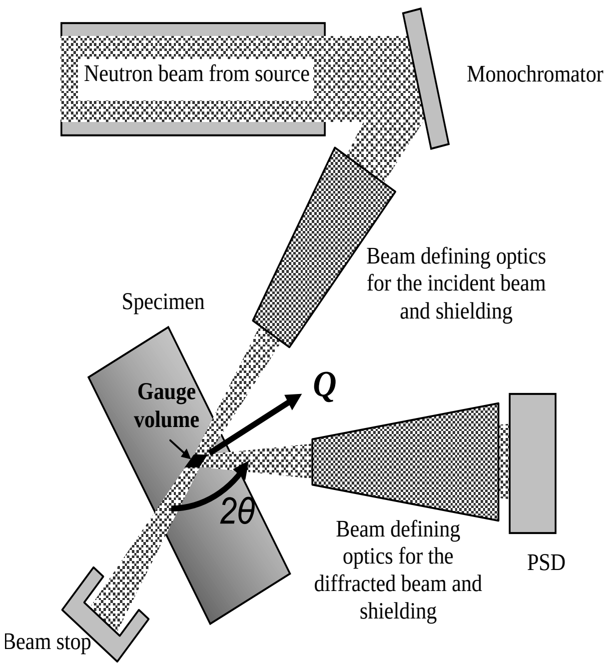

Fig. 2. Schematic illustration of a reactor source based diffractometer for strain measurement in parallel diffraction geometry.

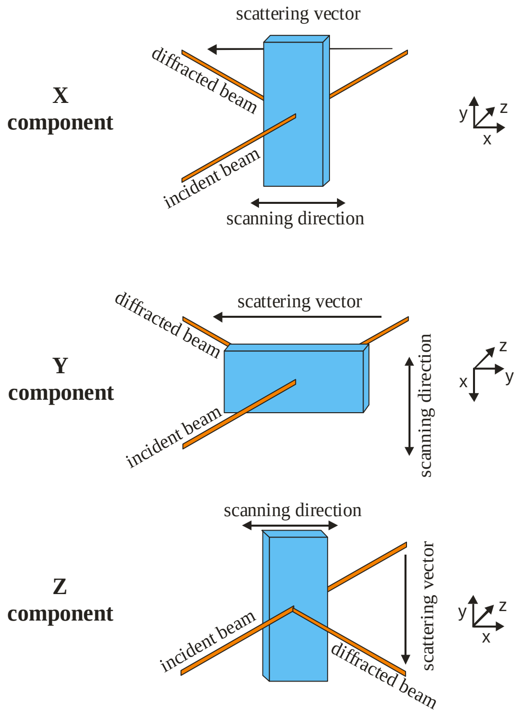

Fig. 3. Sketch of the sample setting for determination of three strain/stress components.

material. Normal, transversal and longitudinal strain components were estimated for three through thickness positions 3.5 mm, 7.5 mm and 11.5 mm below the weld root surface of the test specimen (see Fig. 4). Then, the results of residual stress estimation are summarized in Fig. 5, Fig. 6 and Fig. 7.

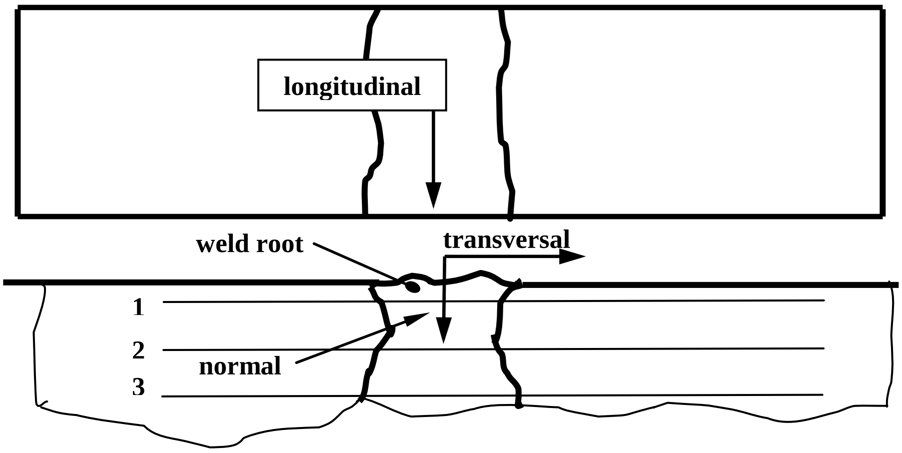

Fig. 4. Residual stress components

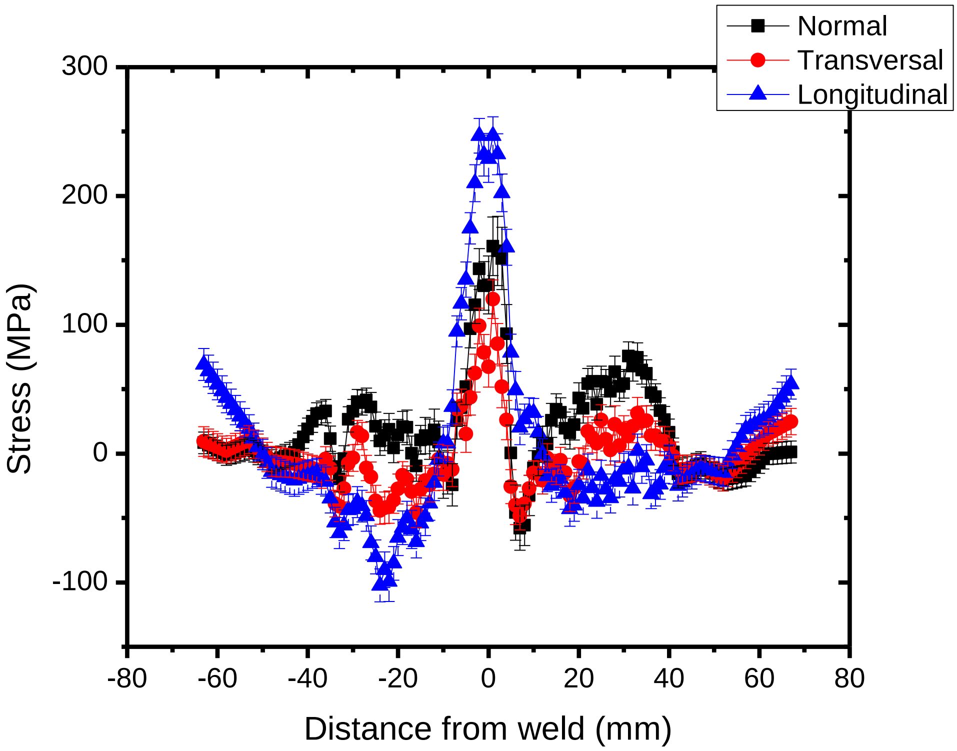

Fig. 5 Residual stress distribution 3.5 mm below the weld root surface (line 1 in Fig. 4).

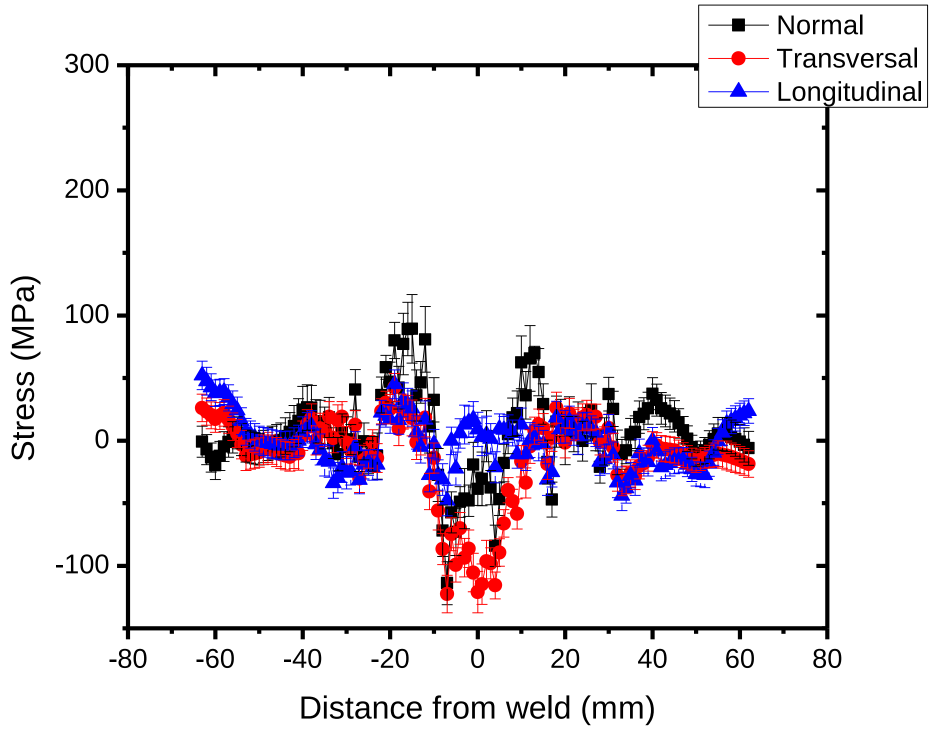

Fig. 6. Residual stress distribution 7.5 mm below the weld root surface (line 2 in Fig. 4).

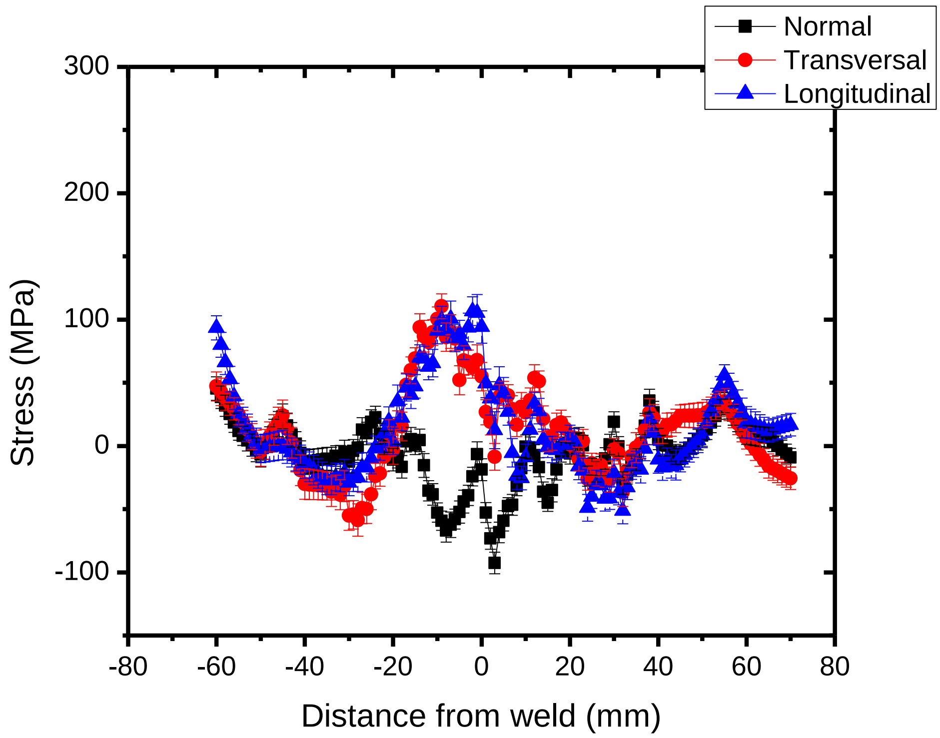

Fig. 7. Residual stress distribution 11.5 mm below the weld root surface (line 3 in Fig. 4).

Discussion

The purpose of the residual stress measurements of the storage tank butt weld was to identify maximum stress level in the vicinity of the weld. Generally it has been recognized that maximum stresses are concentrated in the weld centre 3.5 mm below the surface and in the weld HAZ (heat affected zone) 7.5 mm below the surface. Maximum stresses are in the weld metal close to the weld surface. The level of 250 MPa has been estimated, which is practically the same as yield strength level of the parent material (259 MPa). Residual stresses 7.5 mm and 11.5 mm below the weld root surface are much lower (approx. 100 MPa). Compressive normal and transversal stresses have been identified especially 7.5 mm below the surface. According to the service of the storage tank the most critical seem to be stresses close to the weld root surface due to the fact that shallow stress corrosion cracks were observed at the surface of the weld root in the weld metal after long term exposure.

Conclusions

Residual stress distribution in the vicinity of the weld taken out of spherical tank used for storage of anhydrous ammonia has been estimated using neutron diffraction. It has been recognized that the highest tensile stresses at the level of 250 MPa have been identified close to the weld root surface in the weld metal.

Acknowledgement

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