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The Effect of the Heat Treatment at 450 °C on Distribution of Residual Stresses of Modified Cr-Mo Steel Welds

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Abstract. The effect of low-temperature long-term heat treatment on distribution of residual stresses on the modified chromium-molybdenum steel of the type 7 CrMoVTiB10-10 and known as T24 steel which was studied by using neutron diffraction method, is presented. The investigation of residual stress measurement by neutron diffraction was concentrated on the identification of the effect of low temperature heat treatment on stress distribution close to the circumferential weld of the steel tube. It has been recognized that the applied heat treatment did not remarkable change local properties (hardness) of the weld. Despite of this the drop of residual stresses after heat treatment compared to as welded condition was remarkable. According to the obtained results it is assumed that low temperature heat treatment can influence final behaviour of circumferential welds in service.

Introduction

The modified chromium-molybdenum steel type 7 CrMoVTiB10-10 steel is a material that has attracted manufacturers´ attention for a long time. This steel belongs to the group of modified Cr-Mo low-alloyed creep resistant steels. The reasons for development of some properties of these steels is to increase the efficiency of thermal power equipment using higher media parameters in membrane walls of the super heater up to the creep zone. Post Weld Heat Treatment (PWHT) is usually applied when the conventional Cr-Mo steels are used for membrane walls. The intention is to develop and produce new steels, especially for super heaters, which themselves also in an as-welded condition would achieve better properties than the parent 10CrMo9-10 steel and be comparable to 9 Cr steel.

The leak of welds in pressure boiler systems for supercritical parameters represents an unexpected phenomenon which does not occur in conventional boilers during the development and testing. On the other hand, in certain cases, the defects, cracks, in welded joints were observed in huge components of membrane walls. The same can be stated also in case of circumferential welded joints in tubes of different dimensions. The leakage of welds in Cr-Mo steel did not occur everywhere, as e.g. in the region where the material of membrane walls is subject to maximum load. Even workshop or on-site welds has not to avoid the leakage. The cause of the leakage can be briefly summarised as: The quality and the type of the material, hydrogen diffusion effects and extremely high mechanical stresses. Moreover, the consequences of potential secondary hardening of welded joints in the early stages of their operation at working temperatures have to be considered. We assume that dealing with the above-mentioned large-sized leakage of the welds in the Cr-Mo steel could provide more information about this material and some experience with its welding as well as the manufacture of pressure parts of this steel.

The limit for maximum hardness in the vicinity of welds (HAZ) is associated with the potential risk of cold crack formation in the HAZ. The 2.25Cr1Mo steels with the maximum thickness of 15 mm are generally recommended for welding at the preheat temperature of 100 °C when diffusible hydrogen content is below 5 ml/100 g and of 150 °C when hydrogen content is from 5 to 10 ml/100 g. Due to the presence of vanadium, titanium and especially boron, these preheat temperatures can be considered as minimum ones and in some cases seem to be even insufficient.

Cold cracks, especially in the weld metal of long submerged arc welds which are oriented in transverse direction to the longitudinal weld axis, were also observed [1]. Hydrogen seems to be the most important factor for the cold cracking behaviour.

Remarkable secondary hardening for Cr-Mo steel after 100 hour exposure at 500 °C was identified. This phenomenon is typical for vanadium hardened steels during tempering [2]. According to these results, it is supposed that PWHT should be carried out in order to avoid a low ductility and low toughness properties mainly during operation.

The objective of the paper is to present the effect of low-temperature and long-term heat treatment on distribution of residual stresses using neutron diffraction method. The distribution of residual stresses in the vicinity of circumferential welded joints was measured in as welded conditions and subsequently, after low-temperature heat treatments at 450 °C for 48 hours.

Experimental part

Circumferential weld of two tubes made of 7 CrMoVTi10-10 creep resistant steel diameter of ∅ 38 mm and wall thickness of 6.3 mm has been prepared for this investigation. The TIG process, medium alloyed filler material WZ, CrMo2VTi/Nb (Union I P24) (typical content Cr = 2.2 %, W = 1.7 %) and argon as shielding gas have been used for welding. The heat input was in the range of 8.0 to 13.0 kJ cm, preheat temperature from 150 °C to 200 °C and interpass temperature of max. 250 °C have been applied.

Fig. 1: Circumferential test weld of 7 CrMoVTiB10-10 creep resistant steel

Hardness distribution across butt weld has been measured by Vickers method at the load of 98.1 N (HV10). Neutron diffraction has been performed in order to identify residual stress distribution in the vicinity of the circumferential weld. Hoop, radial and axial stresses have been estimated for as/welded conditions and after long term heat treatment at the temperature 450 °C for 48 hours.

Principles of the neutron diffraction method

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 [3,4]. 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 investigation of stress fields. When a specimen is strained elastically, the lattice

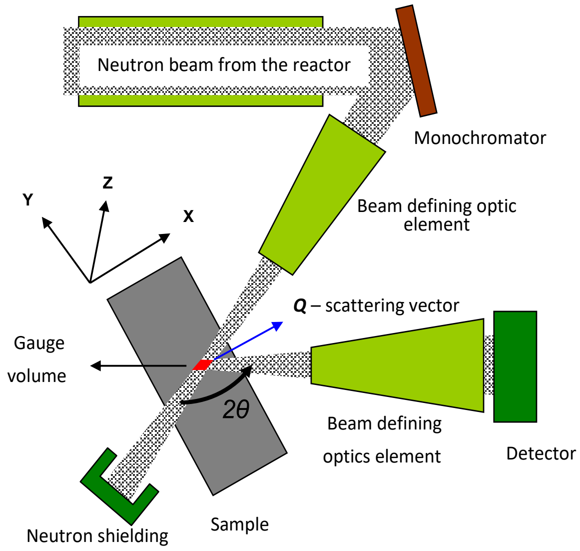

Fig. 2: Schematic illustration of a reactor source based diffractometer for strain measurement in parallel diffraction geometry.

spacing changes. Then, when defining the strain ε as $\varepsilon = \Delta d/d_{0,hkl}$ ($d_{0,hkl}$ is the lattice spacing of the strain-free material) 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 is a crucial task [3]. Then by differentiation of the Bragg condition we arrive at $\varepsilon = \text{-cotg } \theta_{hkl} \cdot \Delta\theta_{hkl}$. 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

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

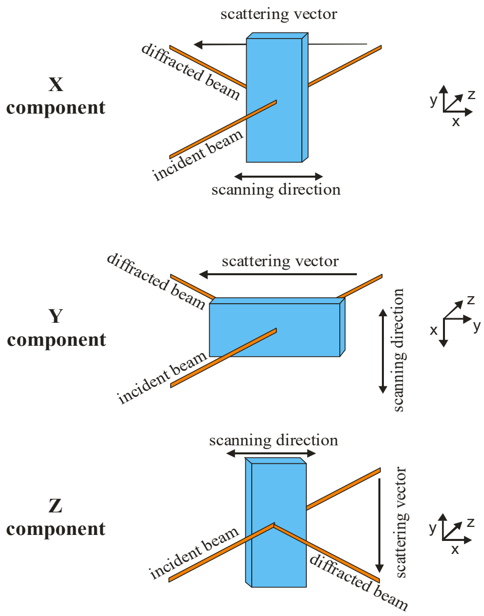

Fig. 3. Sketch of the sample setting for determination of three strain/stress components.

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. 3. The residual strain/stress experiment was carried out on the dedicated strain/stress scanning diffractometer (http://neutron.ujf.cas.cz/en/hk4) installed at the 10 MW medium power research reactor LVR-15 and operating at the neutron wavelength of 0.235 nm. Diffractometer uses optimally bent perfect crystal monochromator which provides necessary resolution and luminosity required for the experimental measurements [5,6].

Experimental results

Hardness distribution. Hardness distribution accross the circumferential test weld prior and after low temperature heat treatment is summarized in Fig. 4. No remarkable change has been noticed due to applied heat treatment.

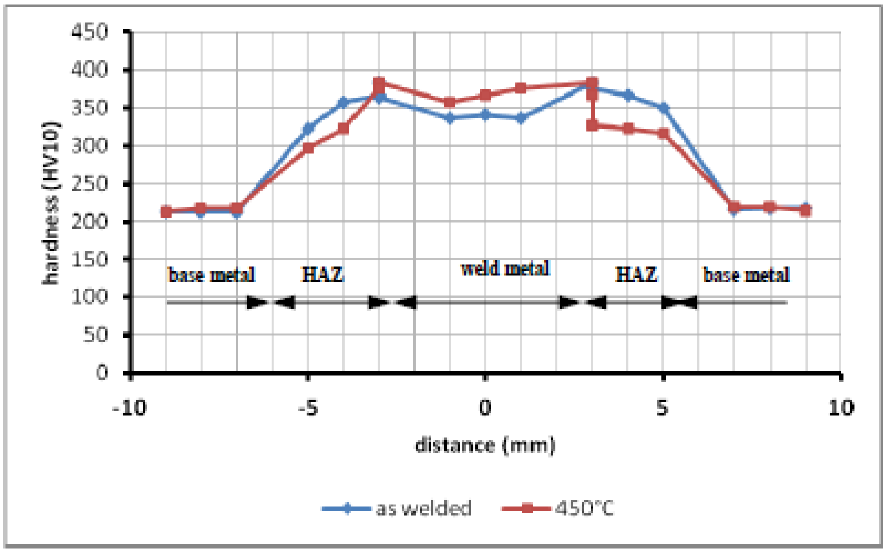

Fig. 4: Hardness distribution accross test weld prior and after heat treatment

Neutron diffraction measurements

Axial, radial and hoop stresses have been estimated in the vicinity of the test weld (see Figs. 5 to 7). The results show that all stress components of weld residual stresses clear dropped after low temperature long term heat treatment. The irradiated gauge volume had the dimensions of about 3x3x3 mm^3. In this case the measurements were carried out on the α-Fe(110) lattice planes.

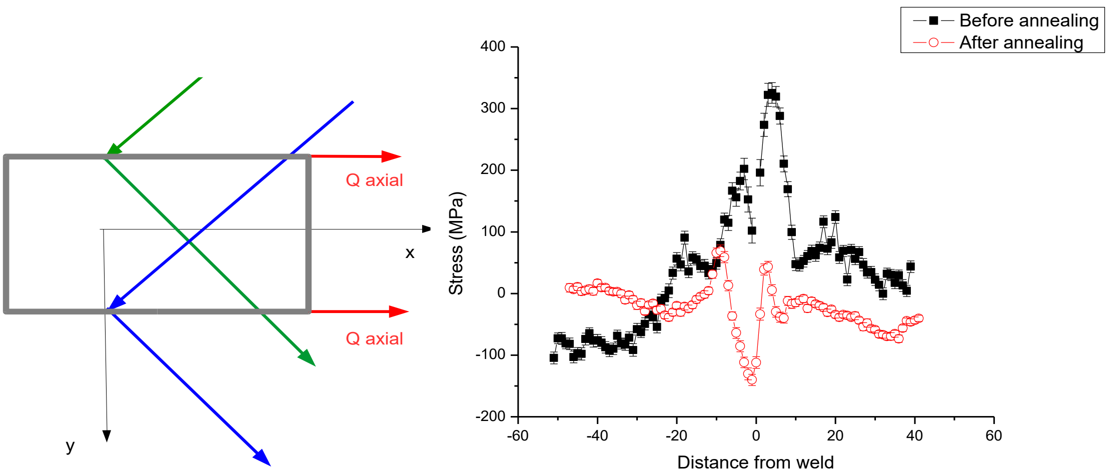

Fig. 5: Axial stresses (parallel to the z-axis) in the vicinity of the test weld; scheme of the measurement and the experimental results.

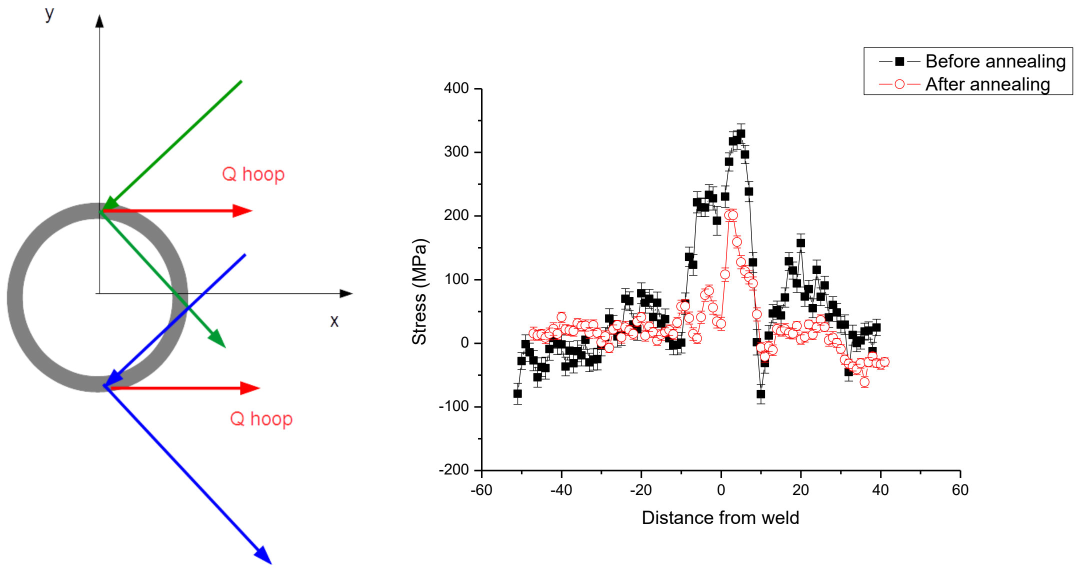

Fig. 6: Hoop (tangential) stresses in the vicinity of the test weld;
scheme of the measurement and the experimental results.

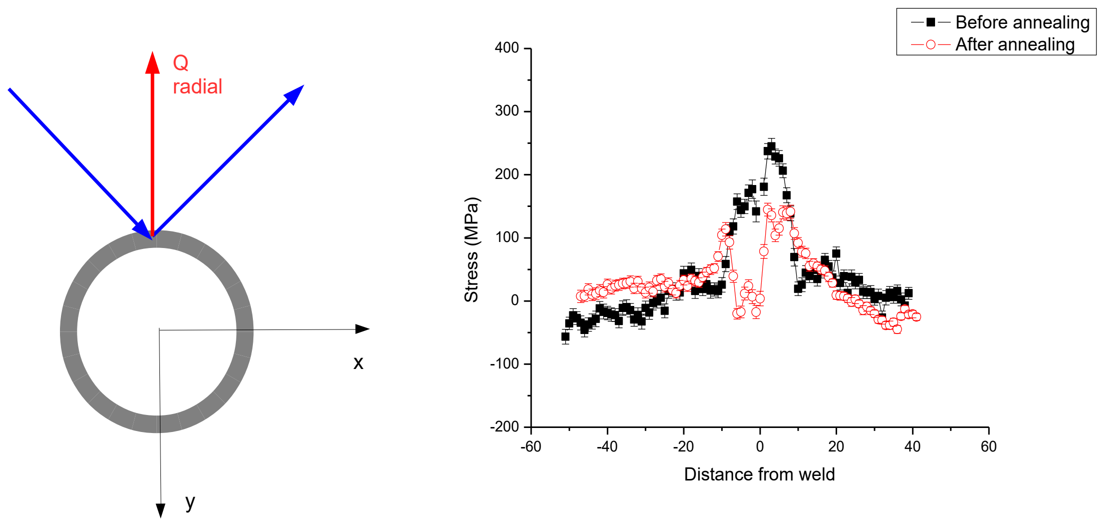

Fig. 7: Radial stresses in the vicinity of the test weld;
scheme of the measurement and the experimental results.

Discussion

The investigation of residual stress measurement by neutron diffraction has been concentrated on the identification of the effect of low temperature heat treatment on stress distribution close to the circumferential weld of T24 steel tube. It has been recognized that the applied heat treatment did not remarkable change local properties (hardness) of the weld. Despite of this the drop of residual stresses after heat treatment compared to as welded condition is clear and remarkable. According to these results we assume that low temperature heat treatment can influence final behaviour of circumferential welds in service. We expect that the results will contribute to the extension of knowledge about the behaviour of welded joints of the creep resistant T24 steel during the start-up period of power stations.

Conclusion

The contribution summarizes the results of neutron diffraction measurements for the estimation of residual stresses distribution in the circumferential weld of creep resistant Cr-Mo steel. The results show that the even low-temperature and long-term heat treatment can have an influence on the level of residual stresses. It can be supposed that this effect can play an important role in the behaviour of the weld during the initial period of a power station start up.

Acknowledgements

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