MEASUREMENT OF RESIDUAL STRESSES BY THE NEUTRON DIFFRACTION TECHNIQUE IN A WELDED JOINT

M. ZAOUI (1), M. SLAMANI (2)

(1)Laboratory of Materials Engineering, University of M'sila-Algeria
e-mail: m_zaouidz@yahoo.fr

(2) Laboratory of Mechanical Engineering, Polytechnic of Montreal-Canada
e-mail: mslamani@polymtl.ca

ABSTRACT

The welds are the site of high residual stresses, localized in the vicinity of the weld cracks. Their presence caused many type of damage modes as stress corrosion, fatigue, sudden failure and increasing the temperature of ductile-brittle transition. Residual stresses in restrained welds and weld repairs are very complex. The heat treatment affects the value and distribution of residual stresses in the specimen. This peak stress in all three samples occurred not at the toe, but in the middle of the weld bead, where the yield stress is higher. The transverse residual stresses of around half the maximum value of longitudinal stress have been observed. The use of the neutron diffraction (ND) technique for residual stress measurements is described. In addition, studies of macrostructure and hardness were conducted. The results of different tests conclude the influence of heat treatment on residual stresses in welds.

Key words: Welding, Heat treatment, Residual stresses, Neutron Diffraction Measurement,

1 INTRODUCTION

Residual stress is a macroscopic stress that is set up within a metal during non-uniform plastic deformation, as in cold drawing or thermal gradients, as in quenching or welding. The welding operation will result in local metallurgical modifications of the base metal. Thus, the experimental tests can lead to the creation of a molten zone from which the structure and the properties are more or less different from those of the base metal. In addition, the welding operation also establishes a state of residual stresses whose distribution and amplitude depend directly on the experimental methods. In fact, and due to the multiple roles that any heating or cooling cycle plays, the first type of treatment is to be metallurgical treatment which has a direct effect on the stress. The second type however, is mechanic and has metallurgical consequences. In welded structures residual stresses are formed primarily as the result of differential contractions which occur as the weld metal solidifies and cools to ambient temperature. residual stresses have a significant effect on corrosion, fracture resistance, creep and corrosion/fatigue performance and a full understanding of these stresses is desirable. Therefore, experimental measurements are essential to establish a quantitative understanding of the sign, magnitude and distribution of the residual stresses around the repair, within acceptable limits and to validate increasingly demanding finite-element models. Many non-destructive and destructive techniques are employed for detecting residual stresses in welded components such as whole drilling, conventional X-ray, neutron (ND), synchrotron diffraction (SD) or ultrasonic examination [1]. Non-destructive measurement is a key issue in the confirmation of the theoretical work. ND is outstanding in its stability to obtain residual stresses non-destructively within the subsurface and interior of components. A post weld heat treatment has generally two objectives, lower residual stresses and obtaining the desired shade of the melted zone and heat affected zone.

2 MATERIALS AND METHODS

2.1 Parent metal

The selected material used in this study is a low carbon steel which is largely employed in the construction industry of vehicles, cranes, containers and machinery, frames of machines and their elements, axles, pinions. The dimensions of the plates are shown in (Fig. 1).

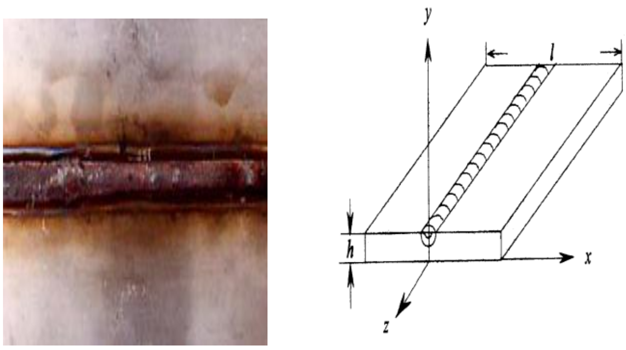

Figure1: Schematic diagram of the welding test plate

2.2 Chemical composition and mechanical properties of the material and weld

The chemical composition and mechanical properties of the material and weld metal are shown in Table 1 and Table 2.

Table 1: Chemical composition of the material and weld

Composition	C	Mn	Si	S	P	Ni	Cr	Mo	V	Al
Parent metal	0.14	0.43	0.11	0.015	0.03	0.03	0.02	0.01	0.008	0.02
Weld metal	0.12	1.5	0.62	0.03	0.01	0.06	0.04	0.03	0.02	0.03

Table 2: Mechanical properties of the material and weld

Mechanical properties	Yield Stress [MPa]	Tensile Strength [MPa]	Elongation [%]
Parent metal	280-320	410-450	32-40
Weld metal	420-500	510-540	25-30

2.3 Welding procedure and post weld head treatment

The welds were produced using a semi–automatic flux core arc welding process. Post weld heat treatment was used for pipe butt welds. Hardness profiles were measured before and after PWHT. These measurements were taken 2 hours at 600°C to establish the influence of heat treatment on the hardness of the welding (Fig. 3).

The optical micrograph is illustrated in (Fig. 2): parent metal (ferrite & pearlite), in HAZ (predominantly bainite), weld metal (martensite & bainite).

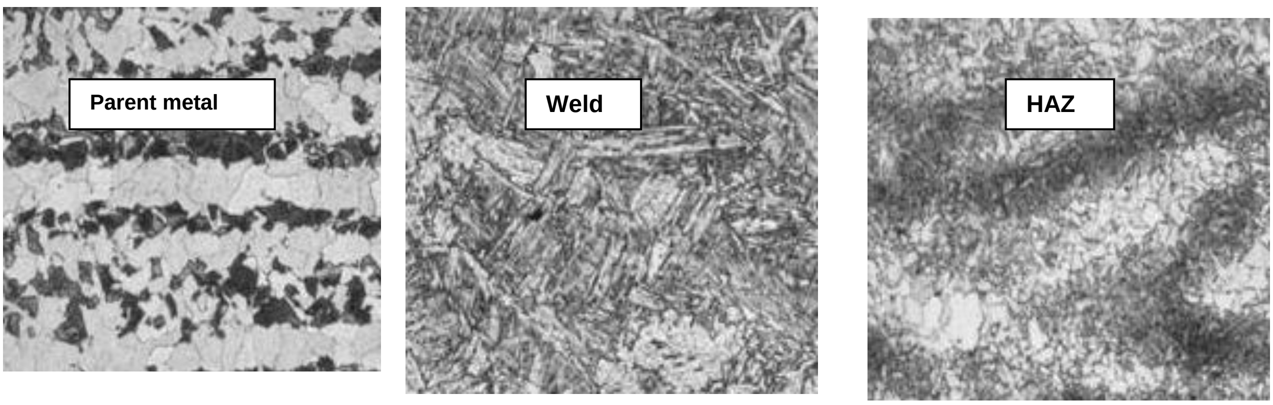

Figure2: Optical micrographs through welded section after PWHT

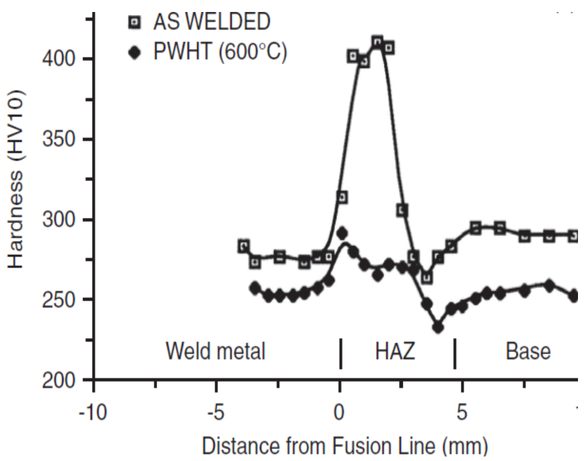

Figure3: Profile of Vickers hardness before PWHT and after PWHT of 2 hours at 600°C

3 RESIDUAL STRESSES EVALUATION

Different techniques were used for the evaluation of residual stresses in target structural materials. Both non destructive and destructive methods were used. The non destructive techniques used were: Positron Annihilation Spectroscopy (PAS), Neutron Diffraction (ND) and X-ray Diffraction (XRD). On the other hand, the ring-core technique falls under the destructive category [2].

3.1 Neutron Diffraction Technique

The Neutron Diffraction (ND) method relies on elastic deformations within a polycrystalline material that cause changes in the spacing of the lattice planes from their stress-free value. Although stress measurements by XRD method are well established, they are practically limited to the near-surface stresses. A major advantage that neutrons have over x-rays is their capability to penetrate into greater depths that can make them suitable for measurements at depths ranging from around 0.2 mm to about 10 mm.

With high spatial resolution, ND can provide complete three-dimensional strain maps of many engineered components. This is achieved through translational and rotational movements of the component. A collimated neutron beam of wavelength γ is diffracted at an angle of 2θ by the polycrystalline sample. The collimated beam then passes through a second collimator and finally reaches the detector as shown in (Figs. 4-6). The stress values can, therefore, be determined from these strain readings using appropriate mathematical formulae. This method of stress evaluation, with a capability of collecting large quantities of data over the whole surface and depth has made ND a particularly useful technique for the validation of theoretical and numerical models.

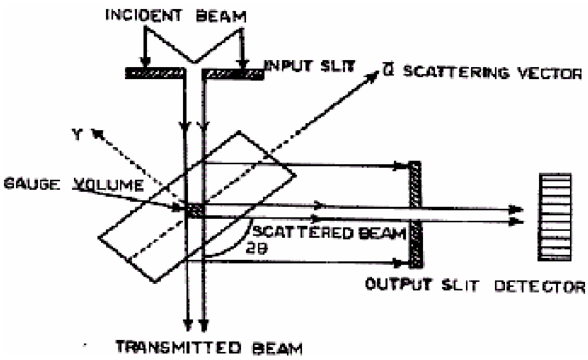

Figure 4: Neutron Diffraction Experimental Setup

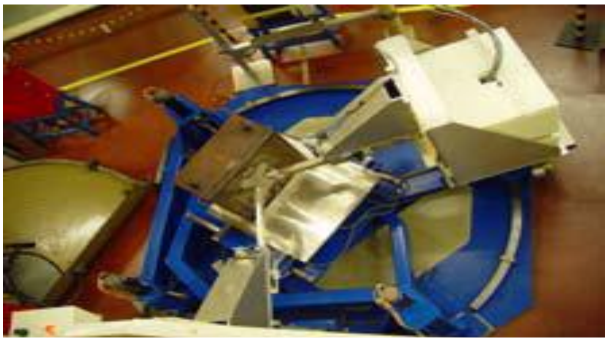

Figure 5: Large Component Neutron Diffraction Facility

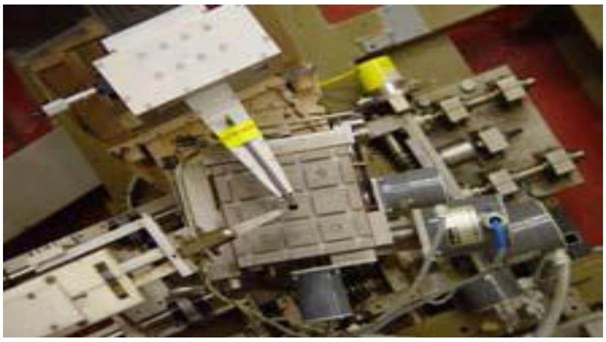

Figure 6: Combined Powder and Stress Diffractometer

3.2 Residual stress measurements using Neutron Diffraction

The neutron diffraction technique is now well-established for sub-surface and interior stress measurements in metallic components. The orientation of the principal strains in any specimen is determined by specimen geometry. The measurement of residual strain using the Neutron Diffraction Technique relies on the determination of a change in lattice parameter relative to a reference or supposedly (strainfree) lattice parameter (do). Obtaining a relevant reference lattice parameter is an important part of the experiment and for this reason some care was taken to prepare and measure do specimens. The comb was made from the middle of the weld, in order to establish any variation in (do) between the parent metal, heat affected zones (HAZ) and weld metal [3].

4 RESULTS AND DISCUSSION

The residual stresses were derived from the elastic strain measurements using a Young's modulus of 207 GPa, and Poisson's ratio of 0.3. The results for axial residual stress in weld area at 157.5 degree and 337.5 degree from welding start point are shown in figure 7 [4].

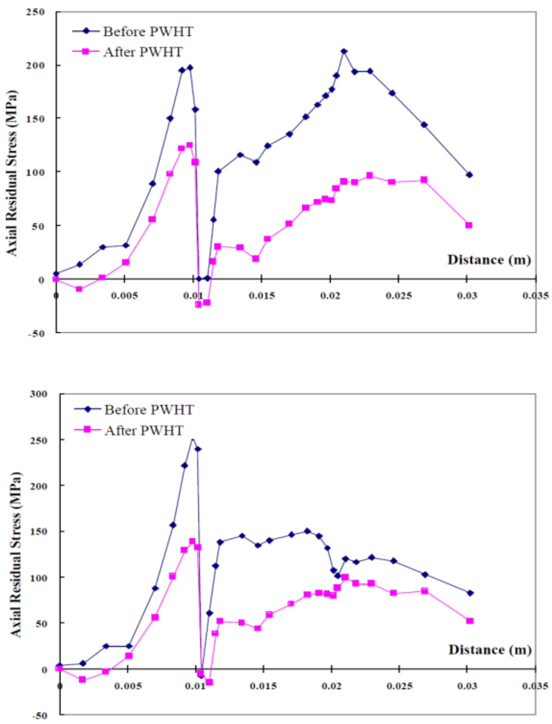

Figure7: Axial residual stress in weld area at 157.5 and 337.5 degree from welding start point

4.1 Thermal and Residual Stress Analyses

The simplified method for residual stress determination through uncoupling of thermal and stress analyses is shown to work reasonably well. High tensile residual stresses, at or above the yield stress level, exist near the weld toe area, especially at the weld start/stop location. The magnitude of the residual stresses reduces quickly as the distance from the weld toe increases. Post Weld Heat Treatment (PWHT) does not relax residual stresses completely from the socket welded piping joints; the maximum tensile residual stress relaxes about 42%, where as the maximum compressive residual stress relaxes 58%. The reason that the residual stresses do not relax completely by PWHT is the different cooling rates at different locations of the welded joint, especially near the weld area. Different cooling rates regenerate residual stresses which are not much different from those originally introduced by welding [5]. The residual stress distribution does not change much when the slip-on gap in the socket weld joint is reduced to zero. Hence, the increase in fatigue life of socket welds with no slip-on gap is unrelated to residual stress. The improvement in fatigue life may come from the change in failure mode, which in turn, may be influenced by the change of the external load stress or strain distribution [6].

4.2 Microstructure and hardness

Microstructure does not change significantly after PWHT (Fig 2). Vickers hardness measurements (Fig. 3) are in good agreement after PWHT softening in the parent metal and in the weld have been observed.

It is to be noted that the high hardness on the surface of the weld before PWHT indicates quite severe cooling conditions in the last bead. The hardness permitted under the Australian Standard for Structural Steel Welding is a maximum of 380 HV0.5 in the heat affected zone and weld metal may not exceed parent metal by more than 200 HV0.5. The hardness in the HAZ after PWHT does not exceed 250 HV [7, 8].

4.3 Residual stress and extension of fatigue life

The welded construction of the cluster is highly restrained and is rapidly cooled. This means that the weld is likely to have high residual stresses before heat treatment. Measurements of residual stress were taken close to the welded region for the main chord before and after the heat treatment procedure. The measurements verify that stress levels in the axial direction were reduced by approximately 40% while tensile stresses in the hoop direction were removed or made compressive [9, 10].

Reduction in residual stress is believed to help prolong the fatigue life of the structure, since high tensile surface residual stress levels are known to contribute to crack initiation and propagation.

REFERENCES

[1] Auzoux, Q., 2004. Cracking in relieving of the austenitic stainless steels influences work hardening on intergranular damage. ENSM of Paris.

[2] Hausild, P., 2002. Ductile-brittle transition in a low alloy steel,thesis of doctorate, central School of bets.

[3] Lamberd, P. A., 2001. Rupture by cleavage of microstructure of bainitic steels obtained in conditions of welding, thesis of doctorate, ENS of the Mines of Paris.

[4] Lu, X. Y., 2002. Influence of Residual Stress on Fatigue Failure of Welded Joint. Faculty of N of Paris orth Carolina State University.

[5] Zaoui, M., Bouchoucha, A, 2008. Influence of heat treatment on brittle fracture welding crds of constructionnal steels. World Journal of Engineering 5(2), 34-40.

[6] Anne-Sophie., B.2007. Estimating the risk of brittle fracture of welds of pipelines in high-grade steels: characterization and modeling , ENSMP of Paris.

[7] Gaffard, V, 2004. Experimental study and modelling of high temperature creep flow and damage behaviour of 9Cr1Mo-NbV steel weldments, ENSEEG of Paris.

[8] Tanguy, B, 2001. Modeling of the Charpy test by the local approach of the rupture, application to the case of steel 16MND5 in the field of transition. ENS of Paris.

[9] Barsoum, Z, 2008. Residual Stress Analysis and Fatigue Assessment of Welded Steel Structures. School of Engineering Sciences, Stockholm, Sweden.

[10] Withers, P.J., Bhadeshia H.K., 2001, Residual Stress – I: Measurement Techniques, Materials Science & Techn.17, 355-365.