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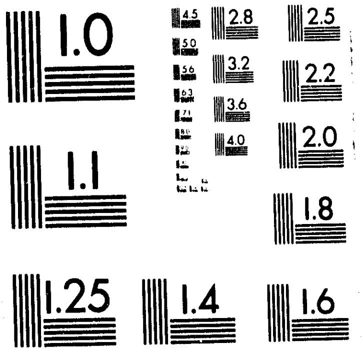
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EFFECT OF VIBRATORY STRESS RELIEF DURING WELDING OF THICK STAINLESS STEEL PLATE

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T. M. Holden,+ and J. H. Root+

ABSTRACT

Residual strains were measured in two welded 25-mm thick plates of type 304 stainless steel by the neutron diffraction technique. The filler metal employed to weld these plates was type 308 stainless steel. One of the two welds was prepared without any vibratory stress relief treatment and the other was vibrated at a frequency below the resonant condition which gives a fraction the resonant amplitude during welding. In both plates the largest residual stress component found in the heat affected zone and in the base metal is along the fusion joint (longitudinal) and is found at the boundary between the weld zone and the heat affected zone. This longitudinal component is 300 ± 50 MPa in tension. The associated normal stress was close to zero and the transverse stress was 80 ± 50 MPa. Variations in residual stresses with thickness through the base metal plate were small. The treated plate and untreated plate showed nearly identical patterns of stress distribution. Differences in the measured stresses between the vibratory-stress-relief treated and the untreated plates fall within the error bars of the stress determination in these particular 25 mm thick 300-type stainless steel plates.

INTRODUCTION

A major concern in welded structures is residual stress and distortion. Residual strains develop during welding due to local heating during welding, complex thermal cycling and phase transformations. Most of these strains get locked into the material as residual stresses. In combination with service stresses and microstructural characteristics of the weldment, residual stresses can lead to crack formation and ultimate failure of the structural member.

Several approaches to reducing the deleterious effects of welding are used. They include, for example, shot peening to generate compressive stresses at material surfaces, post-weld heat treatment which is commonly used and, increasingly, vibratory treatment which has accumulated a record in success in many applications. Because of these successes the vibratory technique has received a great deal of attention (1-3). This technique has the economic advantage over post-weld heat treatment by reducing the costs of heat treatment and there are examples of reduced re-work in weld repairs. However, there has been very little controlled laboratory investigation of vibratory treatment to measure the possible residual stress relief in welds. This may be due to the lack of appropriate techniques to measure and quantify the stress distributions in weldments. This report describes the use of neutron strain mapping which has been used recently to characterize the residual strains and stresses in welds (4-6). In neutron diffraction studies strains are measured by changes in lattice parameters throughout the volume of material containing a weldment. The spatial resolution is a few millimeters and the strong penetrating power of neutrons permits the measurement of diffraction at depths up to several centimeters. This paper presents the distribution of residual stresses calculated from residual strain measurements in austenitic stainless steel welds.

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The effect of vibration on the residual stress pattern in one weld is determined by comparison with the stress pattern in an untreated weld. Vibrations were induced into the weld assembly during welding rather than after the welding. In this paper the stress results are limited to the heat affected zone and the base metal. The conversion of strains to stresses in the weld zone is affected by lattice parameter changes due to weld metal chemistry. Further measurements of the lattice parameter variation in the weld due to weld composition and phase composition are needed before comparison of residual stresses in the weld zone can be made.

MATERIALS AND PROCEDURES

Two multipass welds were made using 305 mm by 305 mm by 25 mm type-304 stainless steel plates [0.016 wt% C, 0.39 wt% Si, 1.78 wt% Mn, 0.028 wt% P, 0.019 wt% S, 18.15 wt% Cr, 9.19 wt% Ni, bal. Fe] containing a single V-butt joint. The welds were made using type-308 stainless steel filler metal [0.015 wt% C, 0.39 wt% Si, 1.76 wt% Mn, 0.006 wt% P, 0.009 wt% S, 19.76 wt% Cr, 9.77 wt% Ni, bal. Fe] by a semiautomatic hot-wire gas tungsten arc welding process. During welding the plates were restrained. The weld consisted of 14 passes. In order to evaluate the effect of vibratory stress relieving, during welding, the first weld (RS-1) was made without inducing any vibration of the weld assembly. The second weld (RS-2) was made by depositing weld metal while the weld assembly was vibrated at a frequency below the resonant frequency which gives a vibration amplitude below the amplitude of the resonant vibration condition.

Neutron diffraction measurements were made on the L3 spectrometer at the NRU reactor at Chalk River Laboratories. A germanium monochromator set for reflection from the (311) reflection, at an angle of 90.85° gave a wavelength of 0.243 nm. The (111) and (200) reflections from the austenitic weld were measured at scattering angles of 71.7° and 85.0° with a multi-wire detector. The data were fit by a Gaussian curve where intensity, peak position, background and the associated statistical errors were calculated. Three strain components were measured; the longitudinal component along the weld line, the transverse component perpendicular to the weld line and in the plane of the plate and the normal component perpendicular to the plate. The incident beam for the measurement of the transverse and normal components was collimated to an area 3-mm wide by 10-mm high while the receiving collimator was 3-mm wide. For the normal and transverse component measurements the weld line was perpendicular to the scattering plane defined by the incident and scattered beams. For the longitudinal component measurements the plate was remounted with the weld line in the scattering plane and the incident beam was collimated to 5 mm by 5 mm while the receiving slit was 5 mm wide. Bragg peak reference measurements were made on a 12 mm diameter cylinder machined from the base plate. These measurements, provide a stress-free calibration as well as a check on the diffraction instrument stability in the course of peak measurements.

The residual stresses were calculated with the assumption that the three strain components measured at each point correspond to the three principal strains of the strain tensor. The strains were measured with the shifts in the (111) and (200) Bragg reflection positions. The (111) diffraction vector is along an elastically hard direction, and the (200) diffraction vector is along a soft direction. At each point the two strains were combined to give an average strain. These strains were used in the calculation of stress (7),

$$\sigma_L = E/(1+\nu)[\varepsilon_L + \nu/(1-2\nu)(\varepsilon_L + \varepsilon_T + \varepsilon_N)]$$

where the subscripts L,T, and N refer to the three strain components measured in the experiment. The bulk elastic constants are E = 196 GPa and $\nu = 0.25$ (8).

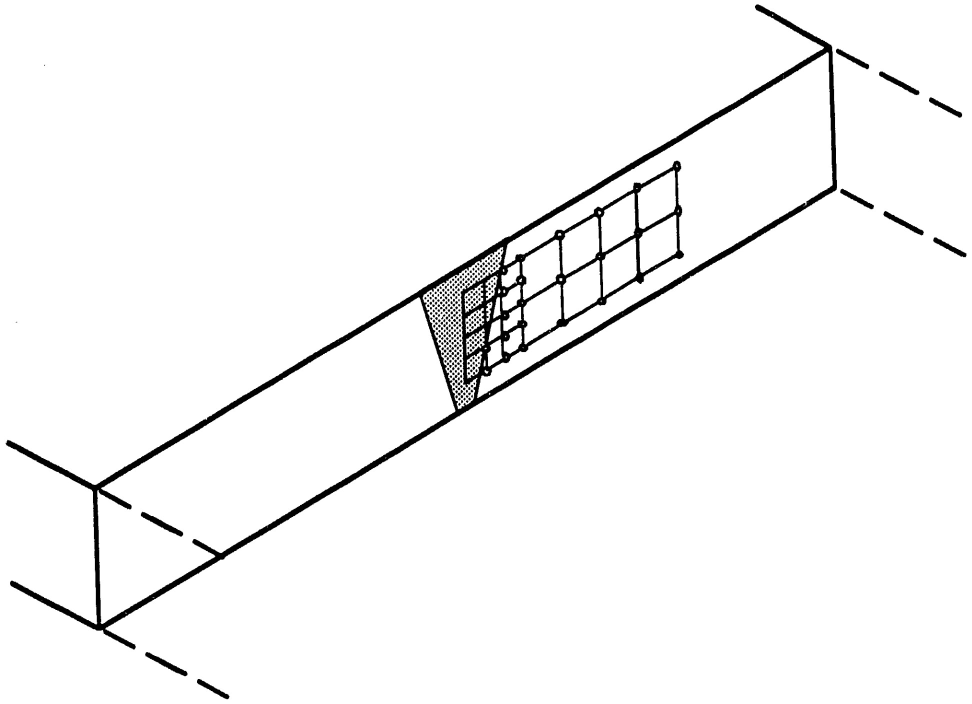

Figure 1. Schematic diagram showing the location of the sampling points on a section through the mid-section of the welded plate.

RESULTS AND DISCUSSION

Using the neutron diffraction measurements, lattice strains were measured on a grid of points on the transverse section of the weldment shown in Figure 1. The weld metal composition is slightly different from that of the base metal and contains up to 8% of ferrite. So to avoid any misinterpretation of lattice parameter changes in the weld zone, no residual stresses were calculated for the weld zone. The neutron scattering experiments were made in three separate measurements over three years after welding. In the first and third experiments the treated and untreated plates were compared. The results in this report come from complete data for the two plates taken in the third experiment set. No changes in composition or phase distribution are known to occur in austenitic stainless steel at room temperature which would cause lattice parameter changes. It is thus assumed that residual strain and stress results would not change in the three year period after the welds were made.

The normal and transverse stress components were observed to vary rather little over the area of the welded plate. The transverse stresses lie between 60 and 80 MPa in tension. The normal components lie between 0 and 50 MPa in compression. The longitudinal stress component, which is in tension and shows the largest variation, is used as the basis for comparison of the two welds in this report.

The longitudinal stress observations for the weld without vibration treatment and with vibratory treatment are shown in Figures 2 and 3. For both welds, within the HAZ, the highest stresses are tensile. At distances beyond 40 mm from the weld center line the stresses become small and compressive. The trends in the variation of the stresses are the same in both welds and are shown in contour plots in Figure 4 for RS-1 with no treatment and Figure 5 for RS-2 with vibratory treatment. The contours are estimated by a linear interpolation between adjacent

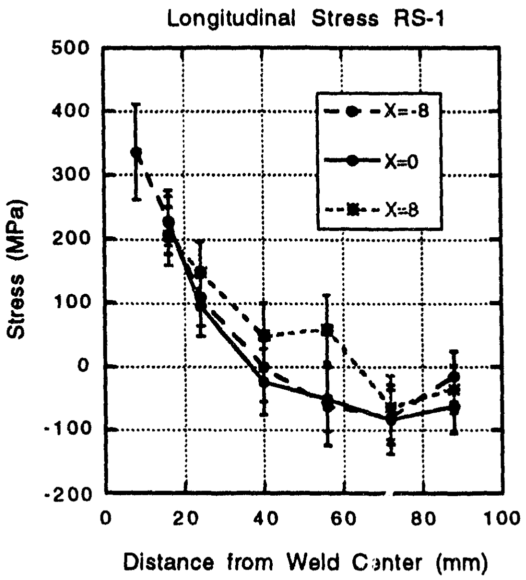

Figure 2. A plot of the longitudinal residual stresses in the RS-1 plate (as-welded) at the top (X=-8), middle (X=0), and bottom (X=8) of the plate. The distances are measure from the center of the fusion zone in the plate.

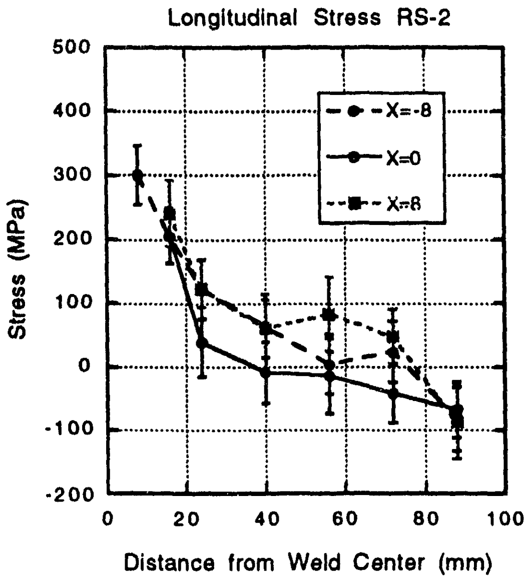

Figure 3. The same plot as in Figure 2. for the plate (RS-2) which was given vibratory treatment during the welding process.

measurements. In both welds the stress reaches 300 ±50 MPa in the HAZ at the bottom surfaces of the plate. The stresses at mid-thickness tend to be more compressive than the stresses at the top and bottom of the plate. The contour plots shows small differences between the two welds. A comparison between the longitudinal stresses in Figures 4 and 5 shows that differences between the two welds at each point fall within the error bars of the stress determinations.

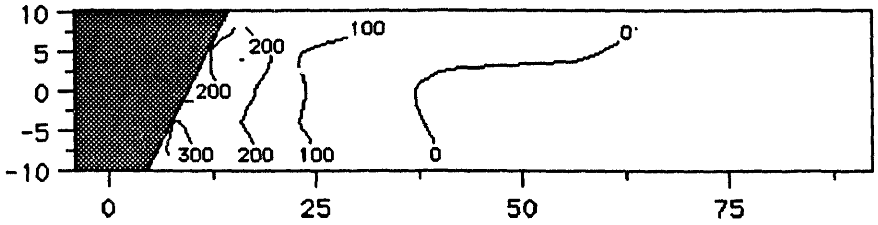

Figure 4. Contour plot of the longitudinal residual stresses in the RS-1 plate. Stresses to the right of the zero line are compressive and small.

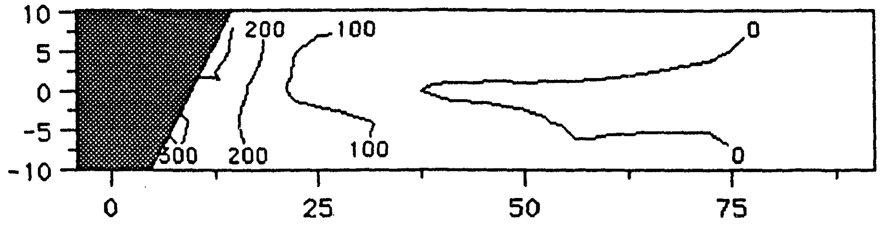

Figure 5. The same contour plot as Figure 4. for the RS-2 plate. The general pattern is the same for the two plates. Note that the 300, 200 and 100 MPa contours fall at nearly the same locations in the two plates.

CONCLUSIONS

This study of 300-type stainless steel plates indicates that the residual stresses within the HAZ and base metal in the conventionally welded plate and in the vibratory-treated plate exhibit small differences which are comparable to the estimate of experimental error . This comparison is limited to results in the HAZ and base metal. On the basis of these residual stress measurements no degradation of mechanical properties from vibratory treatment during welding is expected. Work on the comparison of the weld metal in the two plates is progress. While the welding conditions for each of the plates were identical, no exploration of the parameters of the vibrational stress relief process was undertaken in this study. Such variations would include variation of eccentric force adjustment on the force inducer, use of different operating amplitudes, use of higher vibration harmonics as well as adjustments in welding parameters to be used in a weld property comparison.

REFERENCES

1. R. D. Ohol, B. V. Nagendra Kumar, and R. A. Noras, "Mechanical Relaxation of Residual Stresses," ed. L. Mordfin, ASTM STP993, p. 48 (1987)
2. C. Bouhelier, P. Barbarin, J. P. Deville, and B. Miege, "Mechanical Relaxation of Residual Stresses," ed. L. Mordfiu, ASTM STP993, p. 58 (1987)
3. D. C. Brown, F. A. Crossley, J. F. Rudy, and H. Schwartzbart, Weld J., vol. 41, no. 6, p.241 (1962)
4. A. J. Allen, M. T. Hutchings, C. G. Windsor and C. Andreani, Adv. Phys. 54 445-473 (1985)
5. T. M. Holden, J. H. Root, V. Fidleris, R. A. Holt and G. Roy, Materials Science Forum 27/28 359-370 (1988)
6. S. Spooner, S. A. David, J. H. Root, T. M. Holden, M. A. M. Bourke and J. A. Goldstone, 3rd Intern. Conf. Trends in Welding Research, ASM International, Metals Park, pp. 139-143 (1993)
7. M. Kikuchi, Trans. Japan. Inst.. Metals, 12 417-421 (1971)
8. Smithells Metals Reference Book, 6th Edition, E. A. Brandes ed., Butterworth & Co., Ltd. (1983)

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