The Effect of Welding Process on the Residual Stress Distribution in Welded Cruciform Parts

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Objectives

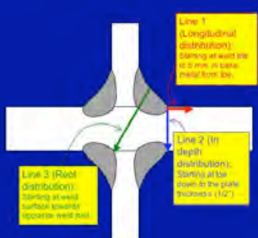
Attempts to improve fuel economy in both on-highway and off-highway vehicles are accelerating due to energy shortage and environmental factors. Design and producing lighter weight structures for these vehicles by using high strength materials is limited by the low fatigue strength of welded joints. As one of the major technical barriers to developing fatigue-resistant welds, high tensile residual stresses, which accelerate the fatigue crack propagation and reduce weld fatigue life, are usually formed in high-strength steel welds. A systematic approach to improve the fatigue life of a welded joint by 10 times and to reduce energy use by 25 percent involved developing special welding wires and evaluating the weld process with the goal to introduce compressive residual stress at the weld toe of high strength steel welds.

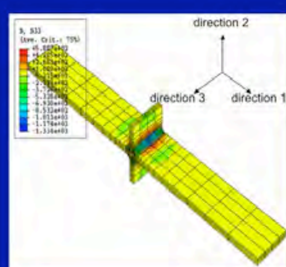
Experimental Approach

Through-thickness residual stress and surface stress measurements on small cruciform samples cut from large welded specimens were used to evaluate the residual stress distribution around the weld toe produced by conventional welding wire and by special welding wire.

- Second generation neutron stress mapping facility (NRSF2) at the High Flux Isotope Reactor (HFIR) was used for through thickness residual stress mapping.
- Large specimen X-ray residual stress mapping facility at High Temperature Materials Laboratory was used for sample surface stress measurement.
- Both neutron and X-ray instruments can map residual stress as a function of location under full computer control.

Welded cruciform specimen mounted on NRSF2 for stress mapping.



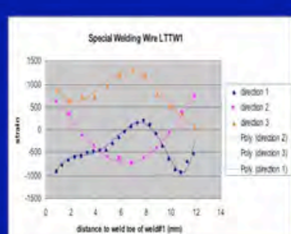


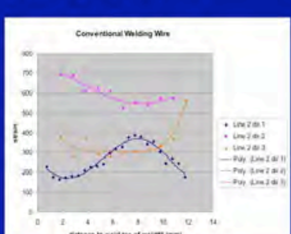
- Line 1 was measured using x-ray diffraction,
- Lines 2 and 3 were measured using neutron diffraction,
- The residual stress data along line 2 were used for fatigue life prediction with weld toe failure,
- The residual stress along line 3 can be used for fatigue life prediction with weld root failure.

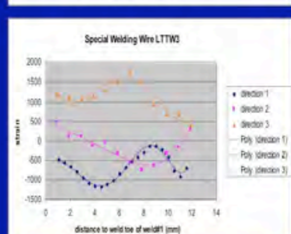
Neutron Strain Mapping Results

Three specimens welded using conventional and low temperature martensite transformation welding (LTTW) wires to produce smooth weld bead shape and compressive weld toe residual stress.

Neutron strain mapping results along line 2 for
- (bottom left) conventional welding wire
- (upper left) LTTW 1 wire
- (bottom right) LTTW 3 wire





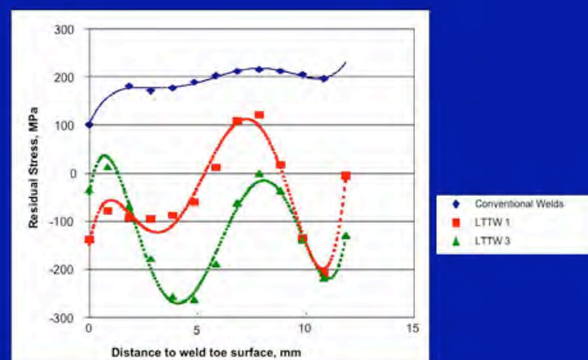


Strain to Stress Conversion

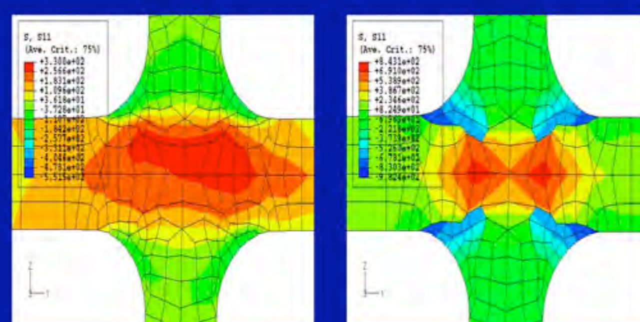
Neutron diffraction maps the residual strain through thickness, which is converted to stress using the following equation:

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

E_{hkl}: diffraction elastic constant
ν_{hkl}: Poisson's ratio
ε_x, ε_y, ε_z: Measured strains



Measured residual stresses for line 2 direction 1 for the welds made using conventional wire and special welding wires, along with the polynomial fitted stress profiles. Surface residual stress were obtained by averaging extrapolated neutron diffraction stress and X-ray stress.



3-D FEM simulated residual stress in line 2 direction 1 in the welds with (a) conventional welding wire and (b) LTTW 1 special welding wire. Stress along line 2 direction 1 is the major loading stress for the welded structure, therefore this stress component was used as input to fatigue model for life prediction, which predict an increase of > 10x in fatigue life.

Summary

The patterns of the measured residual stresses on and near the surface for the investigated three types of welded-joints are consistent with those from the simulation, i.e., tensile residual stress at weld toe with conventional welding wire and compressive residual stress at weld toe with special welding wires.

The predicted fatigue life using two-stage crack growth model considering the effect of compressive residual stress with special welding wire welds are in reasonable agreement with the high end of fatigue test results, which show more than 10x fatigue life improvement in high strength steel welded-joints.

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