Task 14

Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements

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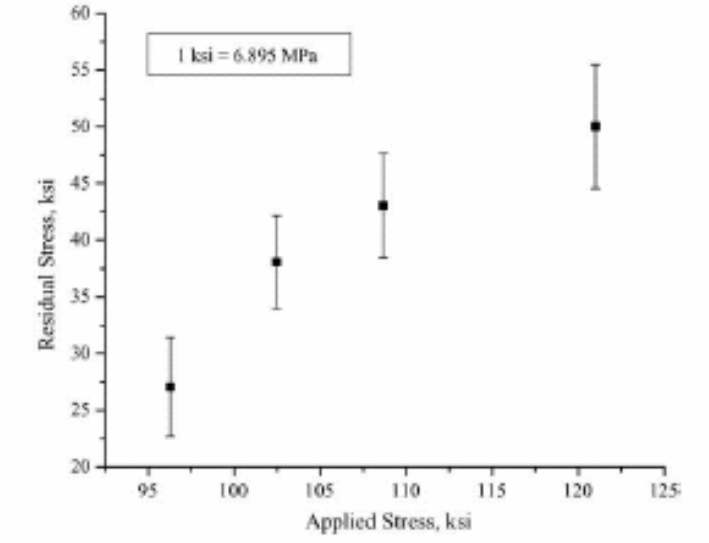
BACKGROUND

Engineering metals and alloys, when subjected to tensile loading beyond a limiting value, undergo plastic deformation resulting in lattice defects such as voids and dislocations. These imperfections interact with the crystal lattice, producing a higher state of internal stress, also known as residual stress, which can be associated with reduced ductility. Residual stresses are also generated in welded structures due to rapid solidification and resultant dissimilar metallurgical microstructures between the weld and the base metals. Development of these internal stresses is often influenced by incompatible permanent strain resulting from thermal and mechanical operations associated with welding and plastic deformation. These types of operations can cause premature failures in structural materials unless these stresses are relieved by thermal treatments, which are commonly known as stress-relief operations.

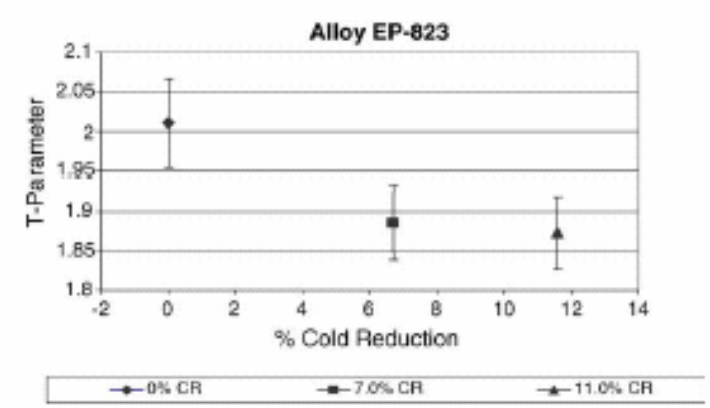
This project is focused on the evaluation of residual stresses in target structural materials by the state-of-the-art destructive and non-destructive techniques. In addition, microstructural evaluations have also been performed by metallographic techniques. More recently, the effect of post-weld-thermal-treatments (PWTT) on the internal stresses in welded specimens has been studied. Further, the characterization of defects by transmission electron microscopy (TEM) has been performed.

RESEARCH OBJECTIVES AND METHODS

The primary objective of this task is to evaluate the feasibility of the characterization of residual stresses in plastically-deformed and welded structural materials using a new nondestructive technique based on positron annihilation spectroscopy (PAS). The residual stresses measured by a modified PAS method have been compared to those measured by three other techniques namely, the ring-core (RC, destructive), X-ray diffraction (XRD, non-destructive), and neutron diffraction (ND, non-destructive).

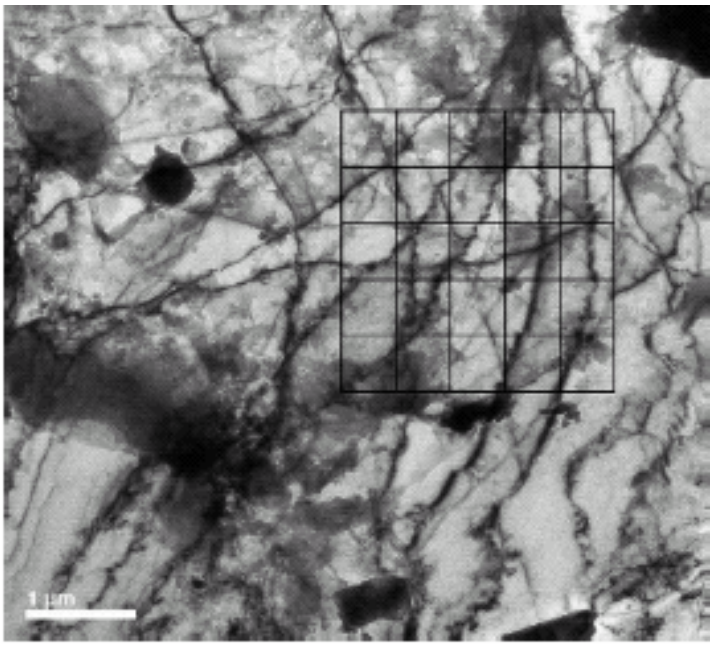


Residual stress versus applied stress using neutron diffraction.



Effect of % cold reduction on T-parameter (PAS).

All four techniques have been used to evaluate residual stresses in cold-worked, plastically deformed and welded specimens of austenitic Type 304L stainless steel (SS), and martensitic Alloys EP-823 and HT-9. Alloy EP-823 is a leading target structural material to contain the molten lead-bismuth-eutectic (LBE) nuclear coolant needed for fast spectrum operations of an accelerator-driven transmutation system (ADS). Type 304L SS is a universally-known corrosion resistant low-carbon iron-nickel-chrome



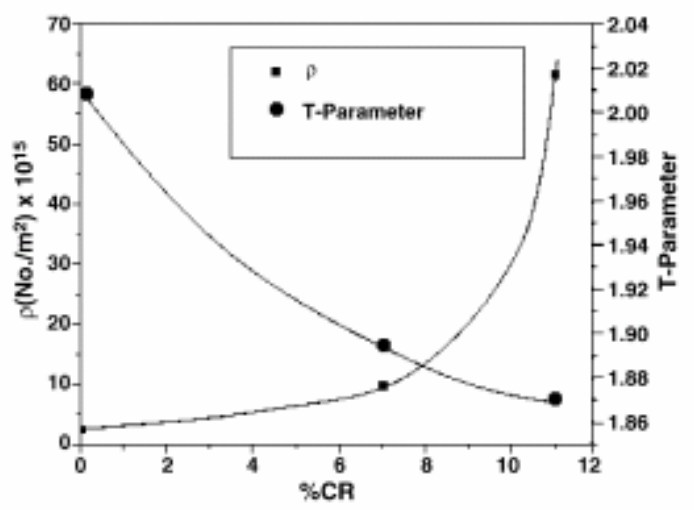
TEM micrograph of Alloy EP-823 used to determine ρ by the line intersection method.

alloy having optimum formability and weldability. Alloy HT-9 is known for its superior high temperature tensile properties. The metallurgical microstructures and the nature of defects have been analyzed by optical microscopy and TEM, respectively.

RESEARCH ACCOMPLISHMENTS

The significant results obtained to date are summarized as follows:

- The residual stresses, characterized in all three tested materials in terms of the PAS line-shape parameters (*S, W and* T) exhibited consistent patterns.
- The residual stresses in cylindrical calibration specimens under tensile loading were enhanced at increasing applied stresses, showing a gradual enhancement in the *S*-parameter.
- The extent of residual stress in terms of the *W*- and *T*-parameter was enhanced at higher applied stresses, showing a gradual reduction in both parameters.
- The overall data revealed that the residual stresses generated inside the cylindrical specimens of all tested materials were enhanced at higher applied loads, irrespective of the testing technique.
- The PAS data on the cold-reduced plates of Alloy EP-823 showed reduced *T*-parameter value with increasing level of cold deformation, indicating higher residual stresses .
- The TEM micrographs of the cold-reduced plates were characterized by the presence of dislocations and carbide precipitates, irrespective of the cold-reduction level.



Variation of ρ and T-parameter with percent cold-reduction.

ACADEMIC YEAR HIGHLIGHTS

- Theses Generated:

  Silpa B. Suresh, "Use of Neutron Diffraction and Microscopy for Characterization of Residual Stresses and Defects," M.S. Thesis, December 2005.

  Subhra Bandyopadhyay, "Residual Stress Characterization and Defects Analyses by Microscopy," M.S. Thesis, December 2005.

- Journal Publications:

  A. K. Roy, S. Bandyopadhyay, S. B. Suresh, and D. Wells, "Comparison of Residual Stress in Martensitic Alloys by Nondestructive Techniques," *Materials Science and Engineering A,* Elsevier Science, Vol. 419, March 2006, pp. 372-380.

  A. K. Roy, S. Bandyopadhyay, S. B. Suresh, D. Maitra, P. Kumar, D. Wells, L. Ma, "Relationship of Residual Stress to Dislocation Density in Cold-Worked Martensitic Alloy," *Materials Science and Engineering A,* Elsevier Science, Vol. 416, January 2006, pp. 134-138.

  A. K. Roy, A. Venkatesh, S. Dronavalli, V. Marthandam, D. Wells, F. Selim, and R. Rogge, "Residual Stress Measurements in Welded and Plastically Deformed Target Structural Materials," *Journal of ASTM International*, June 2005, Vol. 2, No. 6, pp. 1-13.

- Conference Publications:

  A. K. Roy, S. Bandyopadhyay, S. B. Suresh, and D. Wells, "Characterization of Residual Stresses in Structural Materials for Nuclear Applications," ASME Conference, PVP 2005, Denver, CO, July 2005.

- The dislocation density (ρ) was gradually enhanced almost by an order of magnitude due to the reduction of thickness by cold-rolling from 0 to 7-11%, respectively.

FUTURE WORK

- Characterization of residual stress by the PAS method in welded specimens before and after PWTT.
- Characterization of microstructures and defects (dislocations) in welded specimens of similar and dissimilar metals by TEM.

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