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Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements

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Task 14

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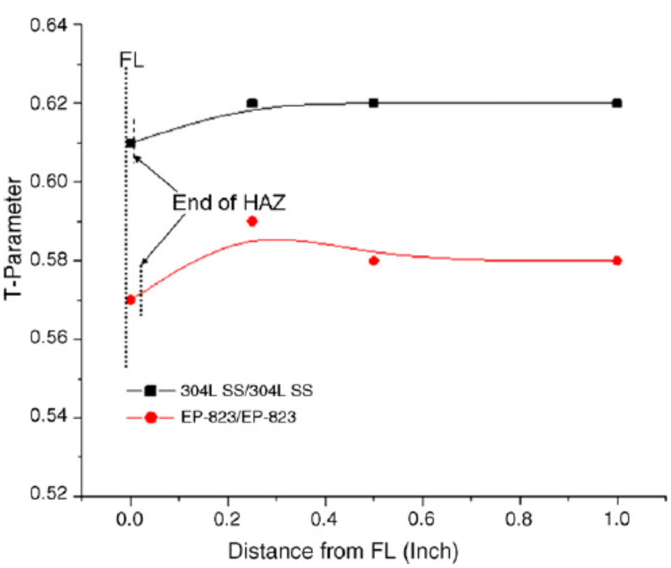
BACKGROUND

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.

During the past academic year, this project was focused on the characterization of residual stress in welded specimens consisting of austenitic and martensitic stainless steels using an activation technique based on the Positron Annihilation Spectroscopic (PAS) method. The extent of residual stress was expressed in terms of three line-shape parameters (S-, W- and T-). Further, efforts were made to characterize linear lattice defects such as dislocations in the vicinity of Fusion-Line (FL), Heat-Affected-Zone (HAZ), and the base material of the welded specimens using Transmission Electron Microscopy (TEM). The metallurgical microstructures at these three regions have also been evaluated by optical microscopy.



T-Parameter versus Distance from FL for Welded Specimens of Similar Materials

RESEARCH OBJECTIVES AND METHODS

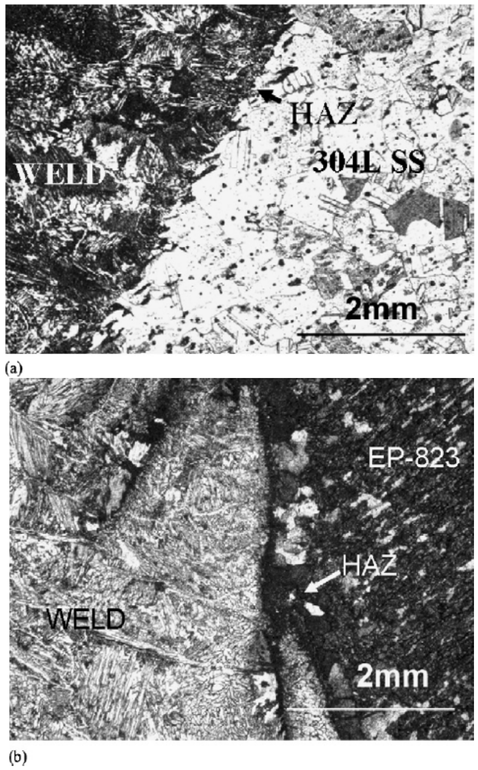
The primary objective of this task was to evaluate the feasibility of the characterization of residual stresses in plastically-deformed and welded structural materials using a new nondestructive technique based on PAS. The residual stresses measured by a modified PAS method have been compared to those measured by three other techniques, namely the Ring-Core (destructive), X-Ray Diffraction (non-destructive), and Neutron Diffraction (non-destructive).

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 nuclear coolant needed for fast spectrum operations of an Accelerator-Driven Transmutation System. Type 304L SS is a universally-known corrosion resistant low-carbon iron-nickel-chrome 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, scanning electron microscopy, and TEM.

RESEARCH ACCOMPLISHMENTS

The significant results obtained from this investigation during the past academic year are summarized below.

- For welded specimens consisting of similar materials on both sides, the residual stress in terms of the S-, W-, and T-parameters was maximum at the FL. A gradual drop in residual stress was observed with these specimens at locations away from the FL.
- The extent of residual stress was higher in martensitic Alloy EP-823 compared to that of austenitic Type 304L SS, irrespective of the weld configuration.
- Compressive residual stresses were observed in Alloy EP-823, when welded to Type 304L SS.
- The magnitude of dislocation density (ρ) was substantially higher at the HAZ compared to that of the base material of the welded specimens consisting of similar materials (Type 304L SS or Alloy EP-823) on both sides.
- In the case of the welded specimen of dissimilar materials (Type 304L SS and Alloy EP-823) on the opposite side, the concentration of dislocation in terms of ρ was greater at the HAZ on the Alloy EP-823 side of the weld.
- The enhanced value of ρ at the HAZ on the Alloy EP-823 side of the weld may be attributed to the faster rate of solidification of this alloy compared to that of the austenitic SS.
- The sizes of the HAZ on the Alloy EP-823 sides of the welded specimens were relatively larger, irrespective of the weld configuration.



Optical micrographs of welded specimens of similar materials. (a) Type 304L SS/Type 304L SS, $HNO_3+CH_3COOH+C_3H_5(OH)_3$; (b) Alloy EP-823/Alloy EP-823, Fry's reagent.

TASK 14 PROFILE

Start Date: May 2002
Completion Date: December 2006

Theses Generated

Srinivas Chanda, M.S., Mechanical Engineering, "Characterization of Residual Stress and Defects in Welded Specimens," December 2006.

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

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

Anand Venkatesh, M.S., Mechanical Engineering, "Comparative Analyses of Residual Stresses in Target Sub-System Materials," August 2004.

Vikram Marthandam, M.S., Mechanical Engineering, "Metallurgical Characterization and Residual Stress Measurements of Target Structural Materials," August 2004.

Satish B. Dronavalli, M.S., Mechanical Engineering, "Residual Stress Measurements and Analyses by Destructive and Nondestructive Techniques," August 2004.

Journal Articles

A.K. Roy, S. Chanda, A. Ghosh, P. Kumar, and L. Ma , "Defects Characterization of Welded Specimens by Transmission Electron Microscopy," *Materials Science and Engineering A*, Elsevier Science, Vol. 464/1-2, pp. 274-280, 2007.

A.K. Roy, S. Chanda, D.P. Wells, A. Ghosh, and C.K. Mukhopadhyay, "Residual Stress Characterization of Welded Specimens by Nondestructive Activation Technique," *Materials Science and Engineering A*, Elsevier Science, Vol. 464/1-2, pp. 281-287, 2007.

D.P. Wells, et al., "Gamma-induced Positron Annihilation Spectroscopy and Application to Radiation-damaged Alloys," *Nuclear Instruments and Methods in Physics Research A*, Elsevier Science, Vol. 562, pp. 688-691, 2006.

A.K. Roy, et al., "Comparison of Residual Stress in Martensitic Alloys by Nondestructive Techniques," *Materials Science and Engineering A*, Elsevier Science, Vol. 419, pp. 372-380, 2006.

A.K. Roy, et al., "Relationship of Residual Stress to Dislocation Density in Cold-Worked Martensitic Alloy," *Materials Science and Engineering A*, Elsevier Science, Vol. 416 , pp. 134-138, 2006.

A.K. Roy, et al., "Residual Stress Measurements in Welded and Plastically Deformed Target Structural Materials," *Journal of ASTM International*, Vol. 2, No. 6, pp. 1-13, June 2005.

A.K. Roy, et al., "Residual Stress Characterization in Structural Materials by Destructive and Nondestructive Techniques," *Journal of Materials Engineering and Performance*, ASM International, Vol. 14, No. 2, pp. 203-211, April 2005.

F.A. Selim, et al., "Stress Analysis using Bremsstrahlung Radiation," *Advances in X-ray Analysis*, Joint Committee on Powder Diffraction Standards, Vol. 46, pp. 106-111, 2003.

Conference Proceedings

Ten conference papers were also published. See TRP website at http://aaa.nevada.edu for more information.

Dislocation density (ρ) in welded specimens of different configurations

Weld configuration	ρ (no./m^2)	
	Base material	HAZ
304L SS/304L SS	5.1×10^{13}	2.4×10^{14}
EP-823/EP-823	7.6×10^{13}	1.3×10^{14}
304L SS side of 304L SS/EP-823	1.7×10^{13}	3.2×10^{13}
EP-823 side of 304L SS/EP-823	6.5×10^{13}	2.2×10^{14}

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