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Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements

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Task 14

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BACKGROUND

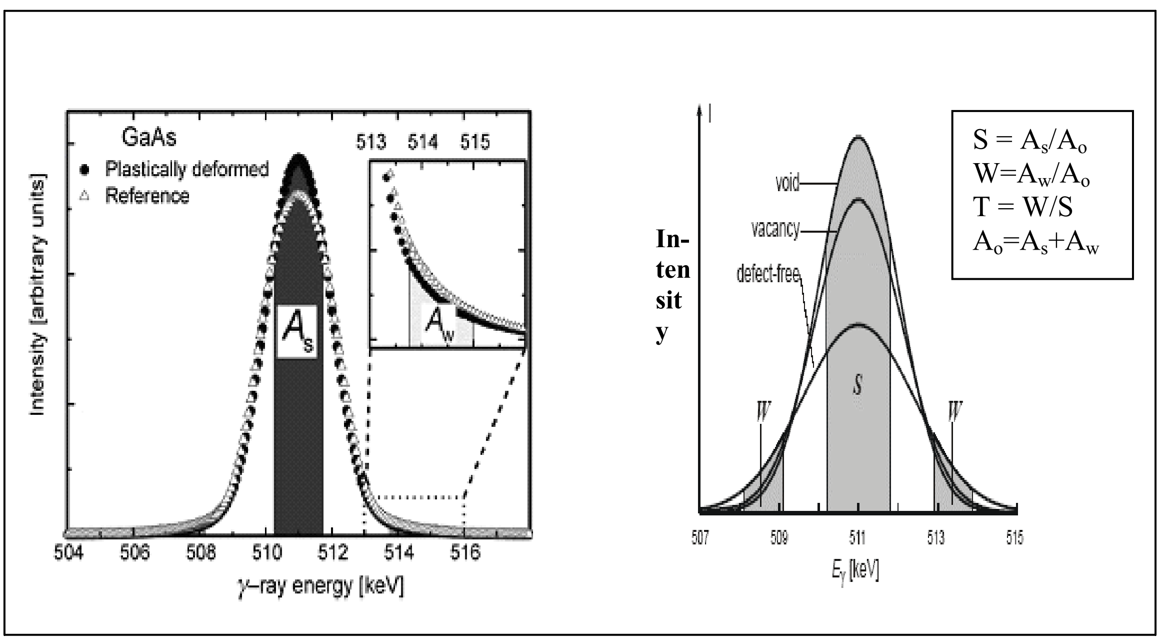
Engineering metals and alloys, when subjected to tensile loading beyond a limiting value, undergo plastic deformation resulting in lattice defects such as voids and dislocations. These imperfections interact with the crystal lattice, producing a higher state of internal stress, also known as residual 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.

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.

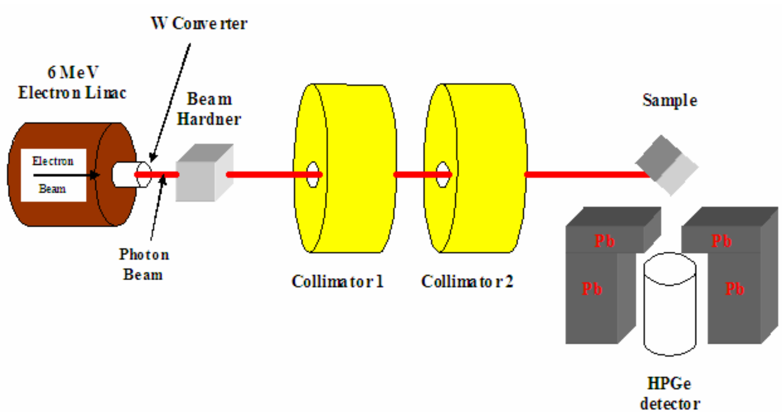
RESEARCH OBJECTIVES AND METHODS

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).

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 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.



Characteristics of 511 KeV Gamma-Ray Energy Spectrum.



PAS Test Setup.

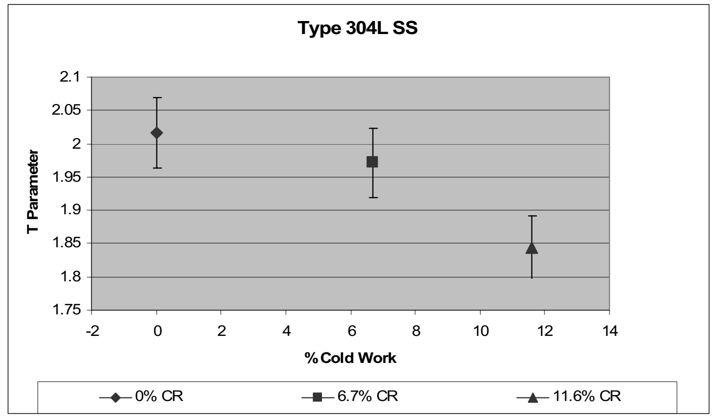
ACADEMIC YEAR HIGHLIGHTS

- Satish B. Dronavalli completed his M.S. thesis entitled "Residual Stress Measurements and Analysis by Destructive and Nondestructive Techniques," August 2004.
- Vikram Marthandam completed his M.S. thesis entitled "Metallurgical Characterization and Residual Stress Measurements of Target Structural Materials," August 2004.
- Anand Venkatesh completed his M.S. thesis entitled "Comparative Analyses of Residual Stresses in Target Sub-System Materials," August 2004.
- "Residual Stress Characterization in Structural Materials by Destructive and Nondestructive Techniques" was published in the *Journal of Materials Engineering and Performance*, ASM International, April 2005, Vol. 14, No. 2, pp. 203-211.
- "Residual Stress Measurements in Structural Materials by Nondestructive Technique" was presented at SAMPE 2005, Long Beach, CA, April 2005.

RESEARCH ACCOMPLISHMENTS

The significant results obtained to date are summarized as follows:

- The RC measurements on cold-worked (CW) specimens of Type 304L SS revealed tensile residual stresses, whereas compressive stresses were observed in Alloys EP-823 and HT-9 at a comparable cold-reduction (CR) level. This difference is attributed to different metallurgical characteristics of austenitic versus martensitic alloys.
- The PAS data were analyzed from the 511 keV energy spectrum in terms of three line-shape parameters S, W, and T. The S-parameter is sensitive to the annihilation with valence electrons and is defined as the ratio of the counts in the central region of the peak to the total counts in the peak. The W-parameter is more sensitive to the annihilation with high momentum core electrons and is defined as the ratio of the counts in the wings regions to the total counts in the peak. The T-parameter is simply the ratio of W to S. While the S parameter is directly proportional to the residual stress, the T parameter is inversely proportional to this stress. The PAS results indicate that, for Type 304L SS and Alloy EP-823, the T-parameter value was reduced with increased level of CR indicating higher residual stresses.
- The RC and ND data on welded specimens consisting of similar materials on both sides of the weld revealed tensile residual stresses adjacent to the fusion line. Reduced residual stresses were observed at locations away from the fusion line.
- The results of the PAS measurements on a welded specimen of Type 304L SS showed an enhanced S-parameter value near the fusion line indicating higher stresses.



T-Parameter vs Percent Cold Work.

- The ND measurements on the three-point-bent specimens showed compressive residual stresses at the convex surface and tensile stresses at locations close to the concave surface.
- The TEM micrographs revealed dislocations in Alloy EP-823, which was plastically deformed by CR.

FUTURE WORK

- Development of calibration curves for S and T parameters versus stress or strain.
- Characterization of residual stresses by the PAS and ND methods in welded specimens after PWTT.
- Characterization of defects by TEM.

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