Task 20

Effect of Silicon Content on the Corrosion Resistance and Radiation-Induced Embrittlement of Materials for Advanced Heavy Liquid Metal Nuclear Systems

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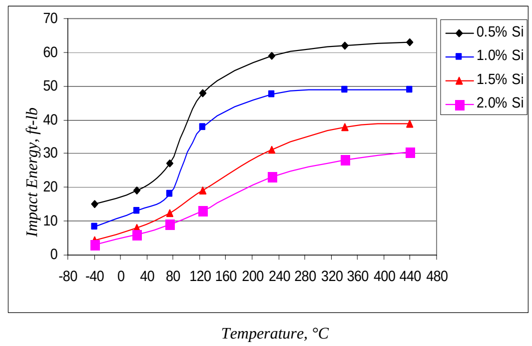
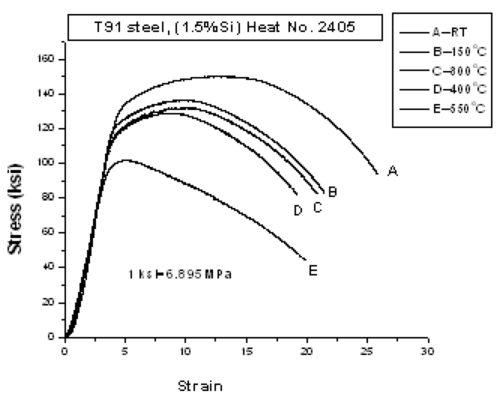
BACKGROUND

This task is focused on the evaluation of the effects of silicon content on both the corrosion behavior and radiation-induced-embrittlement of martensitic stainless steels having compositions similar to that of modified 9Cr-1Mo steel, also known as T91 grade steel. T91 grade steel was selected to be a candidate structural material to contain molten lead-bismuth eutectic (LBE), which can act both as a target material and a coolant during the spallation process in an accelerator-driven system. The operating temperature during this process may range from 420-550 °C. Thus, moderate tensile strength of the containment material (T91) is a major requirement.

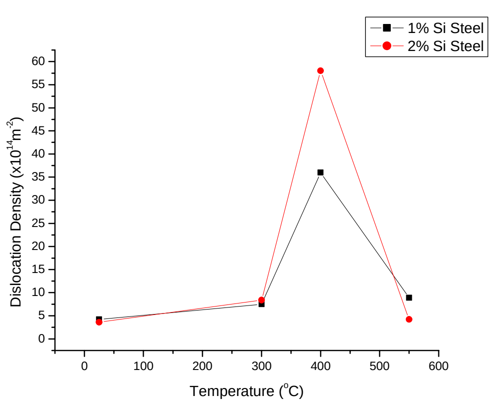


Impact Energy (ft-lb) vs. Temperature (°C)/

The beneficial effects of Si on both the metallurgical and corrosion properties of Cr-Mo steels have previously been demonstrated at UNLV. Therefore, additions of Si ranging from 0.5-2.0 weight percent (wt%) was attempted in this investigation to explore Si effect on both the high temperature tensile properties and corrosion behavior of T91 grade steel. Corrosion studies in the presence of molten LBE could not be performed due to a lack of proper experimental facilities at UNLV. Therefore, detailed corrosion studies involving Si-containing T91 grade steels were performed in an aggressive aqueous solution of acidic pH. Further, significant efforts have been made to determine both the impact and fracture toughness of the tested materials as a function of Si content.



Stress-Strain Diagrams of T91 Steel with 1.5 wt% Si.



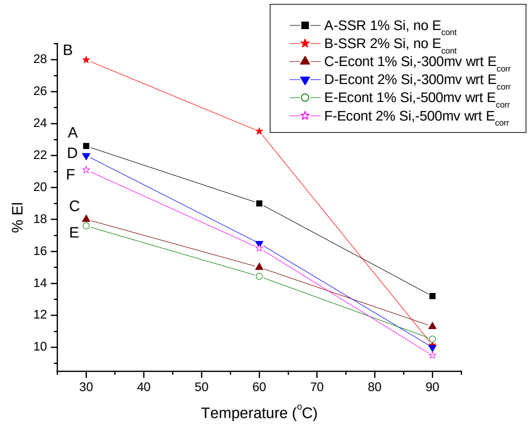
Dislocation Density vs. Temperature (°C).

RESEARCH OBJECTIVES AND METHODS

Four heats of T91 grade steel having Si levels of 0.5, 1.0, 1.5 and 2.0 wt% were custom-melted by a vacuum-induction-melting practice. They were subsequently processed and thermally treated to achieve fully-tempered martensitic microstructures. These materials were then machined to fabricate desired types of specimens for evaluation of tensile properties, impact toughness, fracture toughness, resistance to localized corrosion, stress corrosion cracking (SCC), and crack propagation behavior. Limited tensile testing was also performed on T91 grade steels under different levels of radiation. Numerous state-of-the-art experimental techniques were employed to evaluate the desired properties. The relevant experimental techniques have been described in previous annual reports. The significant results obtained during the past year are summarized below.

RESEARCH ACCOMPLISHMENTS

- The results of tensile testing indicate that the magnitude of failure strain (e_f) was gradually reduced with increasing temperature within a susceptible temperature range, irrespective of the Si content. Serrations were noted in the engineering stress vs. strain diagrams.
- The reduced e_f values and the occurrence of serrations within a specific temperature regime can be attributed to a metallurgical phenomenon known as Dynamic Strain Ageing (DSA). Irrespective of the Si content, the susceptibility to DSA was predominant at temperatures ranging from ambient to 400 °C.
- The DSA phenomenon, as seen in this investigation, is commonly associated with the diffusion of solute elements into the matrix of the material at elevated temperatures, thus impeding the movement of dislocations through the matrix and grain boundaries. Such reduction in dislocation mobilities can



Variation of %El with temperature for steels (1 and 2 wt% Si), with and without cathodic E_{cont}.

significantly impair the plastic deformation, which is manifested by reduced e_f values, as seen in this study.

- A maximum dislocation density (ρ), determined from transmission electron micrographs, was seen at 400 °C, irrespective of Si content.
- The work hardening index (n) and activation energy for diffusion are two key parameters influencing the DSA behavior of engineering materials. Simultaneously, both temperature and strain rate can influence the DSA behavior. The variation of n with temperature at a strain rate of 5 x 10^{-4} sec^{-1} is shown in the table (opposite page). A gradual increase in the n value was observed at temperatures up to 400 °C, as expected.
- A longer activation time using an electron beam resulted in reduced ductility in terms of e_f.
- The presence of higher Si content in T91 grade steel resulted in reduced impact energy and higher ductile-brittle transition temperature, indicating reduced impact resistance.
- The susceptibility to SCC was enhanced at more cathodic (active) controlled potentials (E_{cont}) and higher testing temperature, implying a synergistic effect of cathodic potential and temperature on SCC.
- The morphology of failure in double-cantilever-beam specimen used in SCC testing was characterized by a combination of striations (fatigue), SCC (intergranular/transgranular), and fast fracture (dimples).

Variation of n with Temperature (RT: Room Temperature).

Heat no. / Temp.(°C)	RT	150	300	400	550
2403 (0.5%Si)	0.1643	0.1698	0.1784	0.1984	0.1432
2404 (1.0%Si)	0.1716	0.1794	0.1945	0.2143	0.1564
2405 (1.5%Si)	0.1586	0.1702	0.1794	0.1802	0.1642
2406 (2.0%Si)	0.1669	0.1709	0.1772	0.1997	0.0994

TASK 20 PROFILE

Start Date: July 2004
Completion Date: December 2007

Thesis Generated:

Pankaj Kumar, Ph.D. Dissertation, Mechanical Engineering, "Effects of Temperature, Strain Rate and Si Content on Dynamic Strain Ageing of Modified 9Cr-1Mo Steel," December 2007.

Debajyoti Maitra, Ph.D. Dissertation, Mechanical Engineering, "Tensile Deformation and Environmental Degradation of T91 Grade Steels with Different Silicon Content," August 2007.

Sreenivas Kohir, M.S. Thesis, Mechanical Engineering, "Characterization of Martensitic Stainless Steels with High Silicon Content," December 2007.

Harish Krishnamurthy, M.S. Thesis, Mechanical Engineering, "Metallurgical and Corrosion Characterization of a Martensitic Stainless Steel as a Function of Silicon Content," December 2005.

Journal Articles:

A.K. Roy, D. Maitra, and P. Kumar, "The Role of Silicon Content on Environmental Degradations of T91 Steels," Journal of Materials Engineering and Performance, ASM International, in press.

A.K. Roy, P. Kumar, and D. Maitra, "The Effect of Silicon Content on Impact Toughness of T91 Grade Steels," Journal of Materials Engineering and Performance, ASM International, in press.

Conference Proceedings:

S. Kohir, "Tensile Properties and Environmental Degradation of martensitic and Austenitic Stainless Steels," ISRS-2006, Madras, India, December 18-20, 2006.

P. Kumar, D. Maitra, and A. Roy, "Temperature and Silicon Content Effects on Tensile deformation of T91 Grade Steel," Society for the Advancement of Materials and Process Engineering, Fall meeting, Dallas, TX, November 2006.

D. Maitra, P. Kumar, and A. Roy, "The Role of Silicon Content on Tensile and Corrosion Properties of T91 Grade Steels," MS&T, Fall meeting, Cincinnati, OH, October 2006.

D. Maitra, A. Roy, "Environmental Cracking and Localized Corrosion of T91 Grade Steel with Different Silicon Content," AMPT 2006, Las Vegas, NV, July 2006.

P. Kumar, A. Roy, "Tensile Properties of T91 Grade Steel as a Function of Silicon Content," AMPT-2006, Advances in Materials and Processing Technology, Las Vegas, NV, July 2006.

P. Kumar, D. Maitra, and A. Roy, "Metallurgical and Corrosion Studies of Modified T91 Grade Steel," Materials Research Symposium Proceedings, v 929, pp 149-154, 2006.

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