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## Development of a Mechanistic Understanding of High-Temperature Deformation of Alloy EP-823

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## Task 10

# Development of a Mechanistic Understanding of High-Temperature Deformation of Alloy EP-823

A. K. Roy and B.J. O'Toole

### BACKGROUND

During the transmutation process, a significant amount of heat can be generated in a molten lead-bismuth-eutectic (LBE) target, which will be contained in a subsystem structural container made of a suitable martensitic iron-chromium-molybdenum (Fe-Cr-Mo) stainless steel such as Alloys EP-823, HT-9 and 422. These materials will be subjected to high tensile stresses while they are in contact with the molten LBE at temperatures ranging between 400 and 600°C. Therefore, a research program was conducted to evaluate the deformation characteristics of all three alloys in properly heat-treated conditions at temperatures relevant to the operating conditions.

### RESEARCH OBJECTIVES AND METHODS

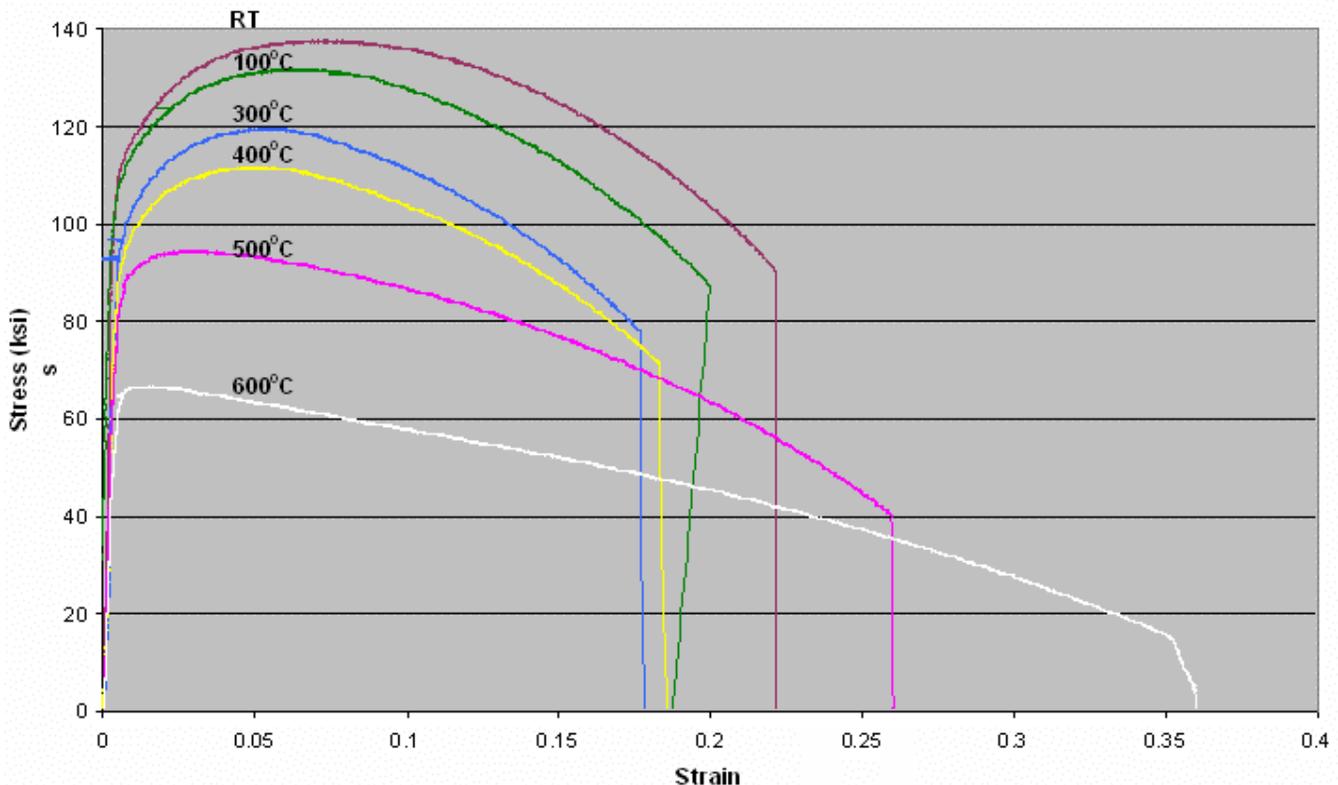
Experimental heats of Alloys EP-823, HT-9 and 422 were vacuum-induction-melted, followed by forging and hot rolling. The hot-rolled bars were subsequently thermally treated to produce a fully tempered and fine-grained martensitic microstructure without any retained austenite. They were austenitized at 1010°C, oil-quenched, and tempered at 621°C. The tempering operation was performed for 1.25, 1.75, and 2.25 hours, respectively, to study the effect of tempering time on the tensile properties. The hardness of all materials, before and after tempering, was measured

using the Rockwell hardness scale. The tensile properties were determined at temperatures ranging from ambient to 600°C using smooth cylindrical specimens at a strain rate of  $10^{-3} \text{ sec}^{-1}$  according to the ASTM Designation E 8. A minimum of two specimens was tested under each condition, with the average value recorded. The metallurgical microstructures of the tested specimens were evaluated by optical microscopy. The primary fracture surface of the tensile specimens was analyzed by scanning electron microscopy (SEM) to determine the extent and morphology of failure. The resultant data include the percentage elongation (%EI), percentage reduction in area (%RA), yield strength (YS), and ultimate tensile strength (UTS) as functions of the testing temperature and thermal-treatments. At least two specimens per material were tested under each of the three metallurgical conditions at the desired temperatures.

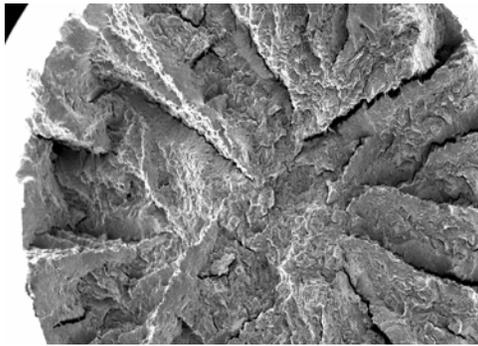
### RESEARCH ACCOMPLISHMENTS

The significant conclusions drawn from this investigation are summarized below:

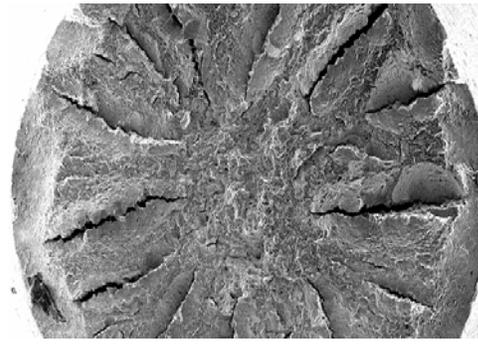
- The hardness of all three austenitized and quenched alloys was significantly reduced due to tempering, showing a gradual reduction with increasing tempering time.
- The magnitude of the yield, ultimate and failure stress was gradually reduced with increasing temperature, showing significant reductions at temperatures above 400°C.



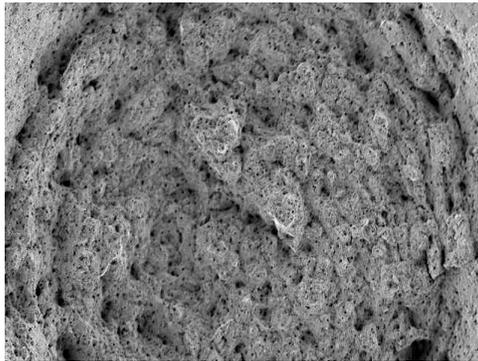
Stress-strain curves for Alloy HT-9 at different temperatures.



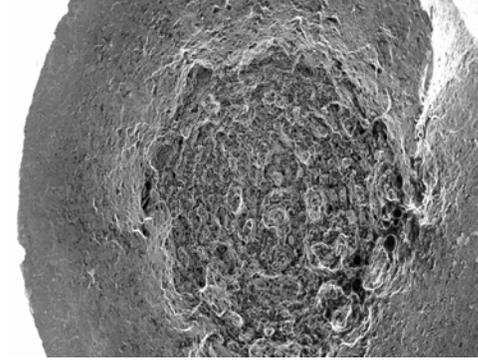
Room Temperature



100°C



300°C



600°C

Scanning Electron Microscope micrographs of Alloy HT-9 at various temperatures (35X).

- The extent of ductility in terms of %El and %RA was reduced to some extent in the temperature regime of ambient to 300°C due to strain hardening. However, beyond 300°C, the magnitude of these parameters was enhanced due to increased plastic flow.
- The morphology of failure was characterized by increased plastic deformation at elevated temperatures. Reduced cracking and dimpled microstructures were observed on the fracture surfaces indicating improved ductility at higher temperatures.
- The tempering time did not influence the metallurgical microstructure and the resultant tensile properties to any great extent irrespective of the testing temperature.

### TASK 10 PROFILE

Start Date: August 2001

Completion Date: August 2004

#### Theses Generated:

Srinivasa R. Kukatla, M.S., Department of Mechanical Engineering, "Corrosion and High-Temperature Deformation Characteristics of a Target Structural Material for Transmutation Applications," June 2004.

Venkata Nagarjuna Potluri, M.S., Department of Mechanical En-

gineering, "Effect of Heat Treatment on Deformation and Corrosion Behavior of Type 422 Stainless Steel," August 2004.

Bhagath Yarlagadda, M.S., Department of Mechanical Engineering, "Elevated Temperature Mechanical Properties and Corrosion Characteristics Evaluation of Alloy HT-9," August 2004.

#### Journal Article:

A.K. Roy, S. R. Kukatla, B. Yarlagadda, V. N. Potluri, M. Lewis, M. Jones and B. J. O'Toole, "Tensile Properties of Martensitic Stainless Steels at Elevated Temperatures," *Journal of Materials Engineering and Performance, ASM International*, April 2005, Vol. 14, No. 2, pp. 212-218.

#### Conference Proceedings:

A.K. Roy, S.R. Kukatla, and B. Yarlagadda, "High Temperature Deformation Characteristics of Martensitic Stainless Steels," Society for the Advancement of Material and Process Engineering (SAMPE) International Technical Conference, Long Beach, CA, May 16-20, 2004.

S.R. Kujatla, V.N. Potluri, and B. Yarlagadda, "Temperature Effect on Mechanical Properties of Target Structural Materials," full technical paper, ANS Student Conference, Madison, WI, April 1-4, 2004 .

M. Lewis, M. Jones, A.K. Roy, and B.J. O'Toole, "High-Temperature Deformation of Alloy EP-823 for Transmutation Applications," American Nuclear Society Conference, San Diego, CA, June 1-5, 2003 .

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