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Development of a Mechanistic Understanding of High-Temperature Deformation of Alloy EP-823 for Transmutation Applications: Final Progress Report (September 2003 – August 2004)

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Final Progress Report
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Development of a Mechanistic Understanding of High-Temperature Deformation of Alloy EP-823 for Transmutation Applications

UNLV Transmutation Research Program Task 10

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Introduction

The purpose of this task is to evaluate the tensile properties of three martensitic alloys namely, Alloys EP-823, HT-9 and 422 at temperatures relevant to the transmutation processes. Testing has been performed to evaluate the tensile properties of all three alloys at temperatures ranging from ambient to 600°C. The test materials were thermally-treated (quenched and tempered) prior to the evaluation of their tensile properties. The deformation characteristics of these tensile specimens, upon completion of testing, were evaluated by scanning electron microscopy (SEM). Efforts were also made to identify and characterize defects such as dislocations using transmission electron microscopy (TEM). Additional TEM studies on the tested tensile specimens are being proposed in the near future.

Personnel

The following personnel were involved in this task.

Principal Investigator (PI):	Dr. Ajit K. Roy, Associate Professor
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Other UNLV Investigators:	Mr. Srinivasarao Kukatla, Completed M.S. (Mech. Eng.)
	Mr. Venkata N. Potluri, Completed M.S. (Mech. Eng.)
	Mr. Bhagath Yarlagadda, Completed M.S. (Mech. Eng.)
	Mr. Mark Jones, Completed M.S. (Mech. Eng.)
	Mr. Martin Lewis, M.S. Student (Mech. Eng.)
Collaborator (DOE):	Dr. Stuart A. Maloy, LANL, New Mexico
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Research Accomplishments

An MTS machine was modified to accommodate ambient and high-temperature tensile testing of all three martensitic alloys in the presence of nitrogen. A high-temperature chamber, capable of testing tensile specimens in the temperature range of 100 to 1000°C, was added to this machine. A pair of custom-built water-cooled specimen grips, made of maraging steel (M250), was attached to the MTS machine. This water-cooled assembly was designed to prevent the grips from being heated from temperature inside the chamber by conduction. A laser extensometer, added to the MTS unit, measured the displacement of the test specimens in their gage sections due to plastic deformation at temperatures up to 400°C. An LVDT was used to measure extension of the test specimens at temperatures above 400°C. Temperature profiles were developed to determine the times needed to achieve the desired temperature as a part of the furnace calibration process.

Tests were conducted at ambient temperature, 100, 300, 400, 500 and 600°C using cylindrical specimens, machined in the longitudinal rolling direction. These specimens were fabricated from materials that were quenched in oil, and subsequently tempered for three different times prior to the machining operation. The chemical compositions of all three tested alloys are given in Table I. The evaluation of the tensile properties was performed according to the ASTM Designation E 8. The resultant data include the percentage elongation (%El), percentage reduction in area (%RA), yield strength (YS), ultimate tensile strength (UTS) and failure stress (σ_f) as functions of the testing temperature and tempering time. At least two specimens per material were tested under each of the three metallurgical conditions at the desired temperatures. The significant conclusions drawn from this task are given below.

- Fine-grained and fully-tempered microstructure, characteristics of quenched and tempered martensitic stainless steel, was observed by optical microscopy. No significant effect of tempering time on the metallurgical microstructure in terms of grain size was observed.
- The hardness of the test materials was significantly reduced due to tempering, showing more pronounced effect at longer tempering times.
- The magnitude of the YS, UTS and σ_f for Alloy EP-823 was gradually reduced with increasing temperature, as shown in Figures 1 through 3. However, the extent of reduction of these parameters was more pronounced at temperatures beyond 400^{o}C. A similar effect of temperature on these parameters was observed with Alloys HT-9 and 422.
- The magnitude of strain was gradually reduced to some extent with increasing temperature in the temperature regime of ambient to 300^{o}C possibly due to dynamic strain ageing, as illustrated in Figures 1-3. However, the strain was significantly enhanced at temperatures beyond 400^{o}C.
- No significant effect of tempering time was observed on YS, UTS, uniform elongation, %El and %RA irrespective of the testing temperature, as shown in Figures 4-8.
- The gradual enhancement in ductility at elevated temperatures was characterized by larger dimpled area (figures 9 and 10), indicating increased plasticity.

Table I
Chemical Compositions of Materials Tested (wt%)

Material (Heat No)	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	W	Cb	B	Ce
HT-9 (2049)	0.19	0.41	0.012	0.004	0.20	12.31	0.50	1.00	0.01	0.30	0.47	-	-	-
EP-823 (2056)	0.14	0.56	0.013	0.005	1.11	11.68	0.66	0.73	0.002	0.30	0.62	0.22	0.009	0.05
422 (2053)	0.20	0.54	0.012	0.004	0.49	12.76	0.74	0.97	0.002	0.22	0.92	-	-	-

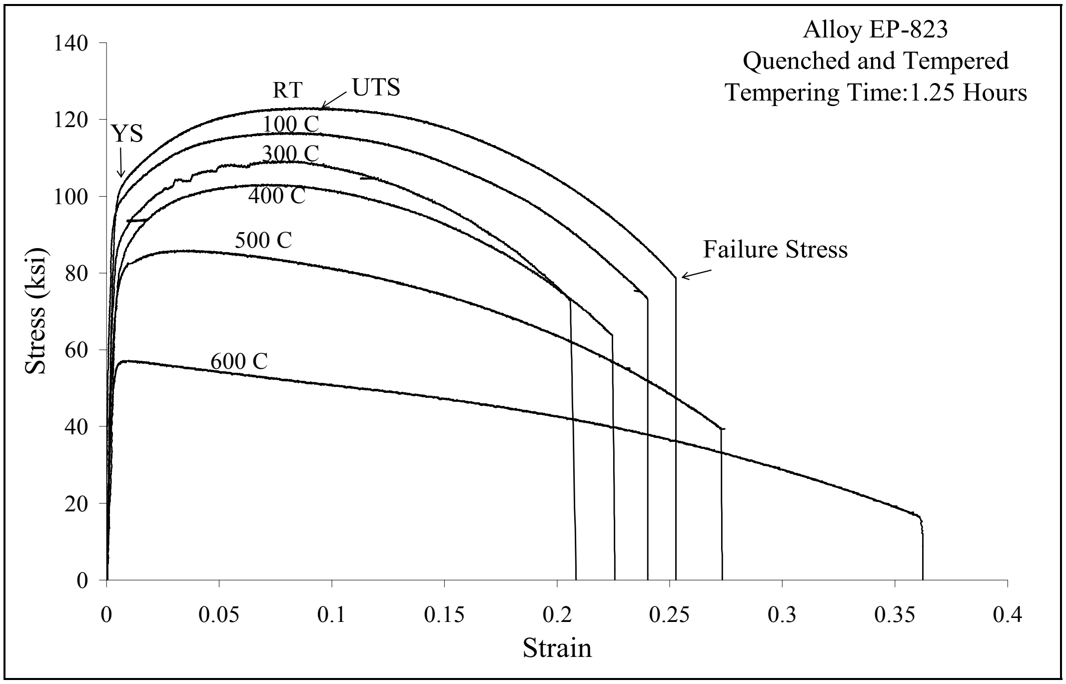


Figure 1. Comparison of Stress-Strain Diagrams at Different Testing Temperatures

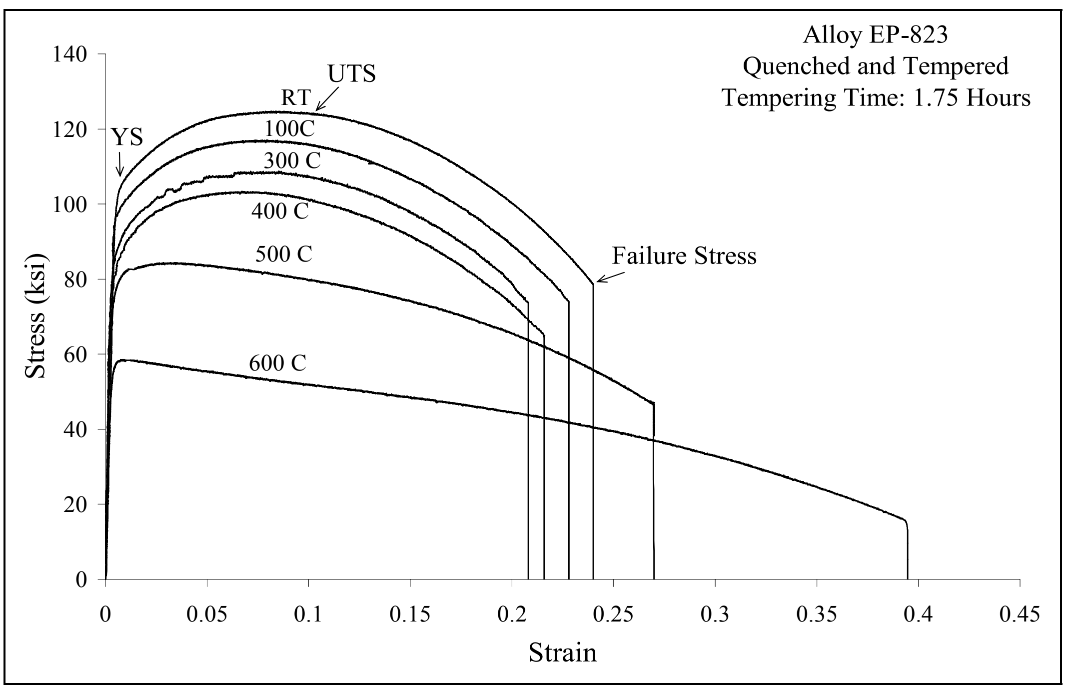


Figure 2. Comparison of Stress-Strain Diagrams at Different Testing Temperatures

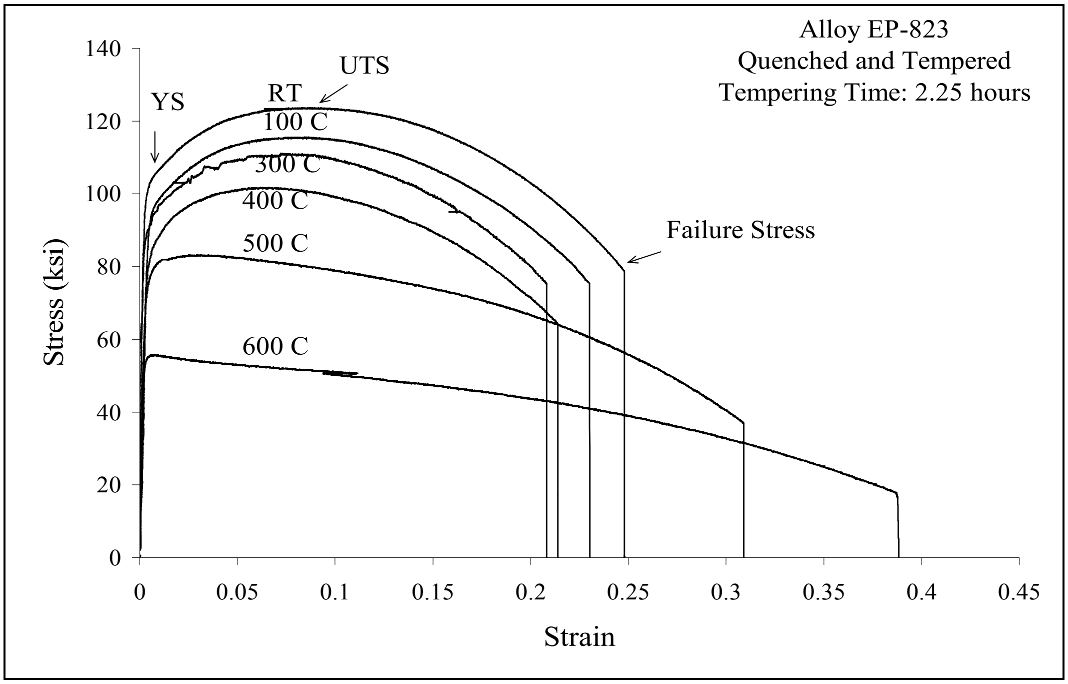


Figure 3. Comparison of Stress-Strain Diagrams at Different Testing Temperatures

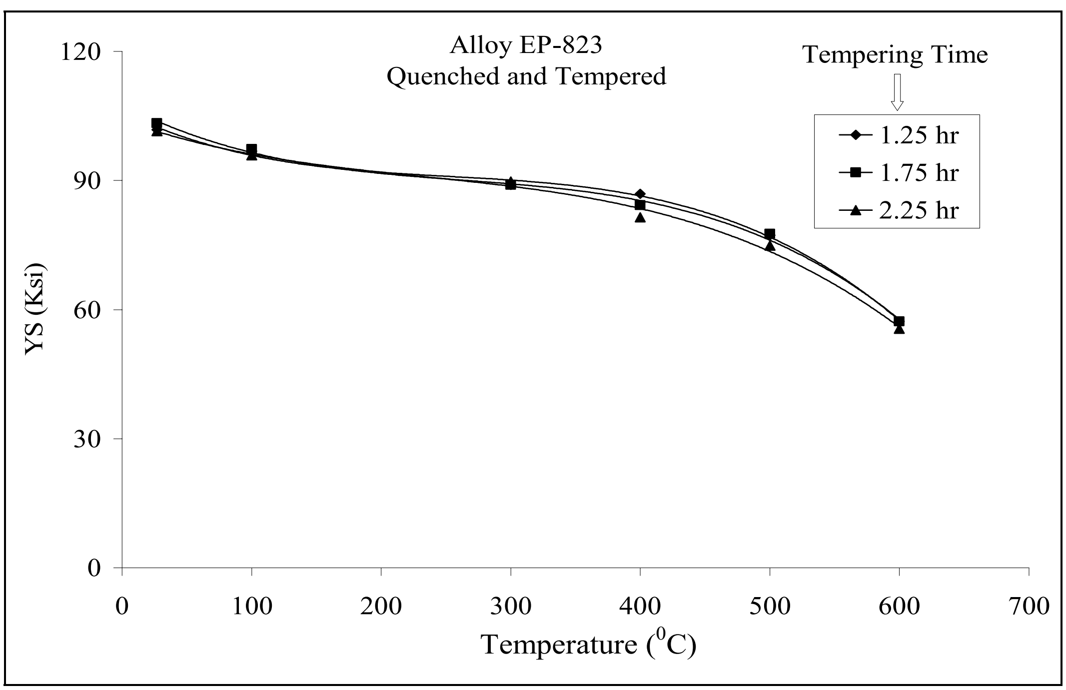


Figure 4. YS versus Temperature

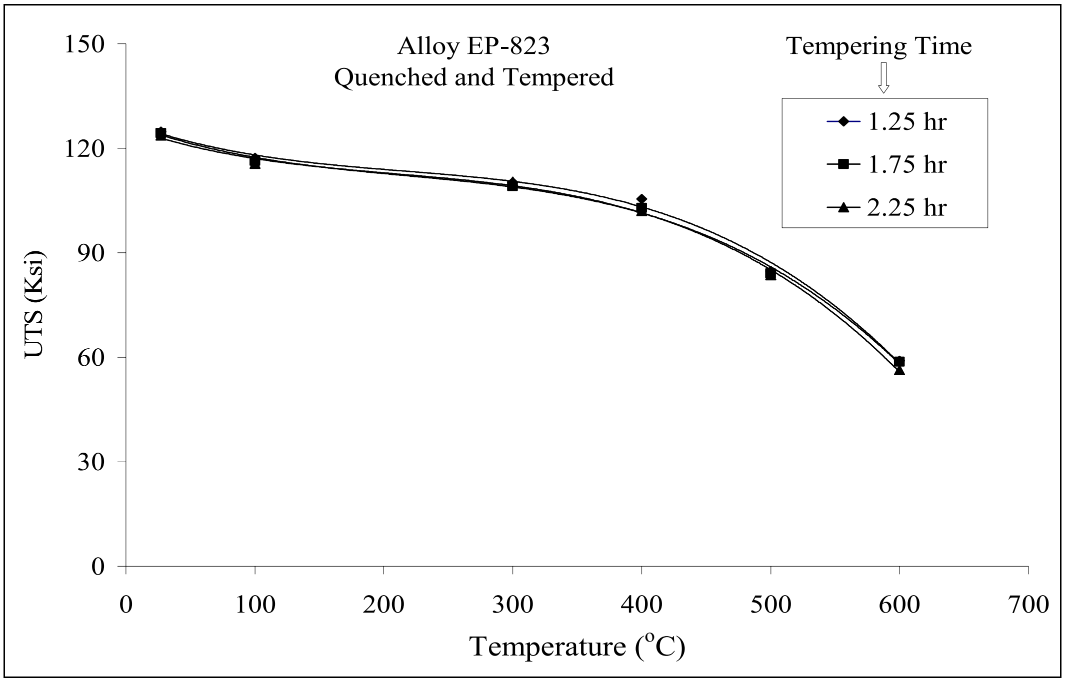


Figure 5. UTS versus Temperature

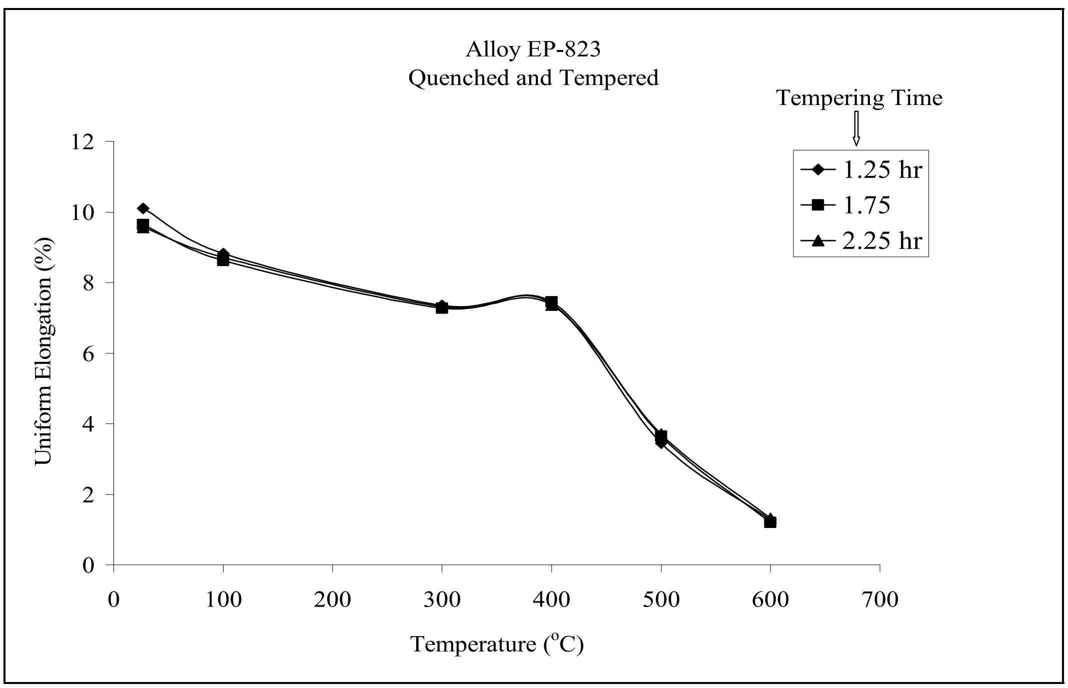


Figure 6. Uniform Elongation versus Temperature

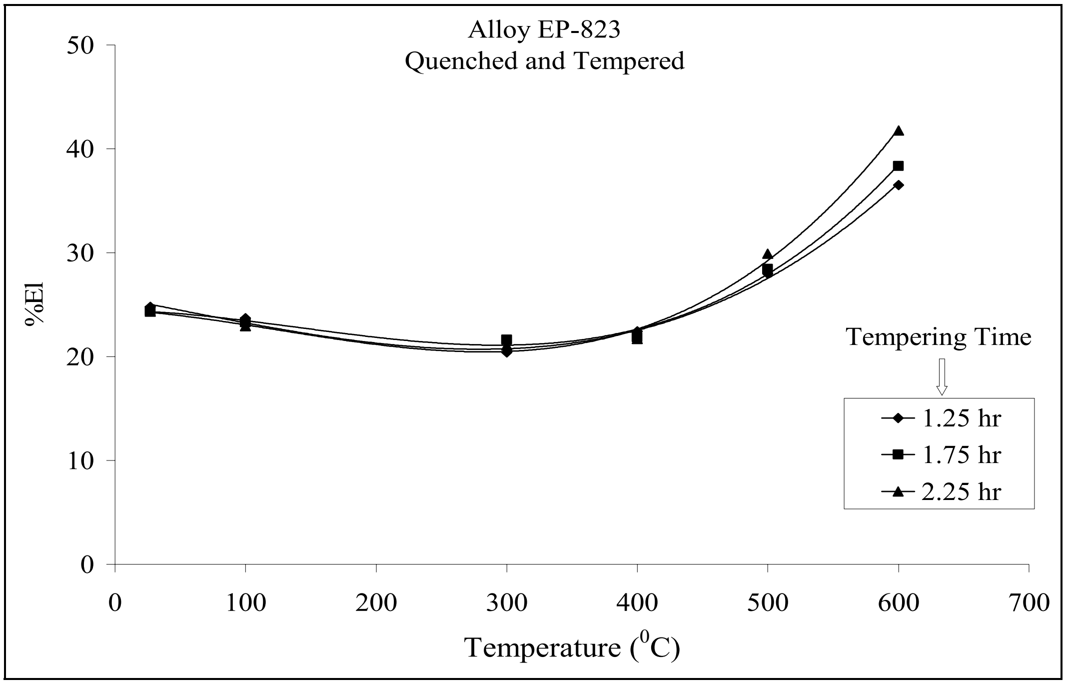


Figure 7. %El versus Temperature

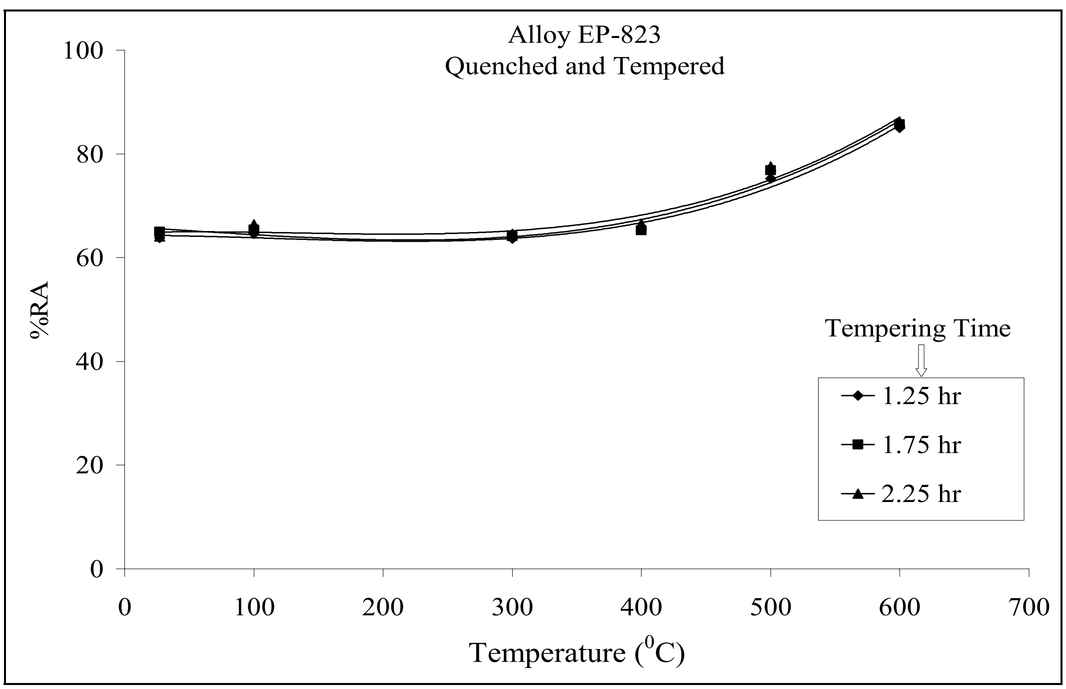
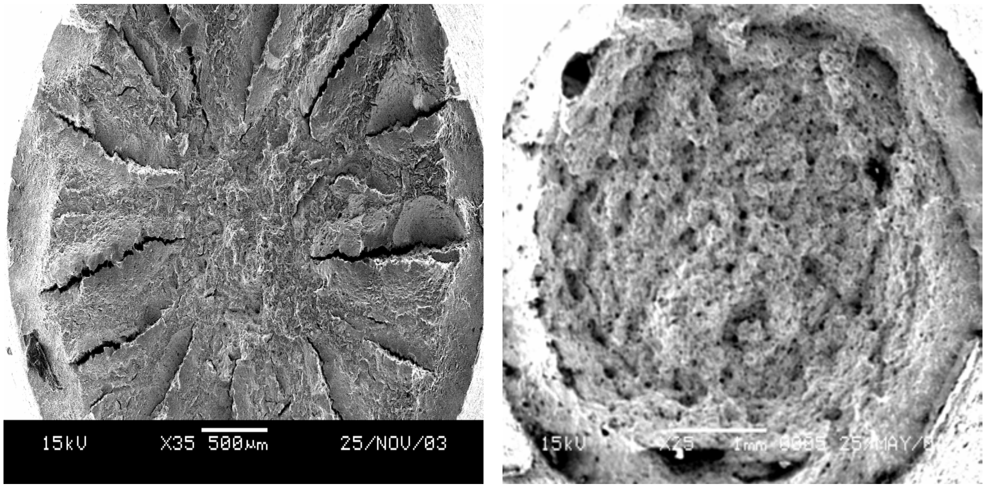
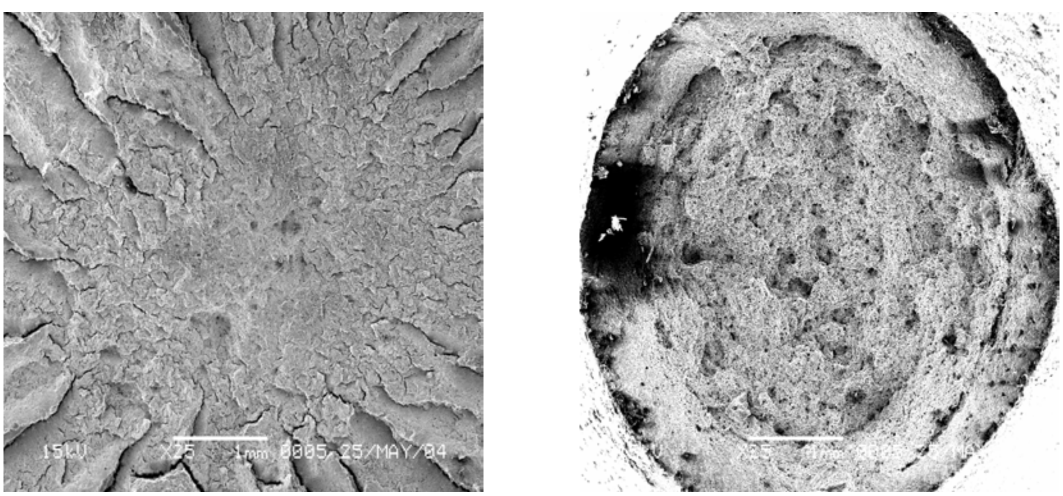


Figure 8. %RA versus Temperature



(a) (b)

Figure 9. SEM Micrographs of Specimens Tempered for 1.25 hours and Tested at (a) Ambient Temperature, and (b) 600°C



(a) (b)

Figure 10. SEM Micrographs of Specimens Tempered for 1.75 hours and Tested at (a) Ambient Temperature, and (b) 600°C

Other Accomplishments

M.S. Thesis/Project Report

Three M.S. theses were defended, and subsequently approved by the graduate college. The particulars are given below.

- Venkata N. Potluri, "Effect of Heat Treatment on Deformation and Corrosion Behavior of Type 422 Stainless Steel," July 22, 2004
- Bhagath Yarlagadda, "Elevated Temperature Mechanical Properties and Corrosion Characteristics Evaluation of Alloy HT-9," July 15, 2004
- Srinivas R. Kukatla, "Corrosion and High-Temperature Deformation Characteristics of a Target Structural Material for Transmutation Applications," June 17, 2004

In addition, a M.S. project report titled "Development of a Mechanistic Understanding of High-Temperature Deformation of Alloy EP-823, 2054-U Series" by Mark Jones was approved by the graduate college.

Publications

- "High Temperature Deformation Characteristics of Martensitic Stainless Steels," SAMPE 2004 Symposium & Exhibition, Paper No. 58, May 16-20, 2004, Long Beach, CA
- "Temperature Effect on Mechanical properties of Target Structural Materials," ANS Student Conference 2004, April 1-3, 2004, Madison, WI (Full Paper and Presentation)
- "High-Temperature Deformation of Alloy EP-823 for Transmutation Applications" ANS Student Conference, April 2-6, 2003, Berkeley, CA (Presentation)