Annual Progress Report
(September 2002 – August 2003)

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

TRP Task-10

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October 28, 2003

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Introduction

The purpose of this project is to evaluate the elevated temperature tensile properties of Alloy EP-823, a leading structural target material for accelerator-driven waste transmutation applications. This alloy has been proven to be an excellent structural material to contain the molten lead-bismuth-eutectic (LBE) nuclear coolant needed for fast spectrum operations. Very little data exist in the open literature on the tensile properties of this martensitic alloy. Three different heats of this material, produced by vacuum induction melting, were thermally treated to produce fully-tempered martensitic microstructure without any retained austenite (Table I). Cylindrical specimens were fabricated from the heat-treated round bars to evaluate the tensile properties at temperatures relevant to the transmutation applications. Testing so far has been performed at ambient temperature, 100, 300 and 400^{o}C in the presence of nitrogen. Additional tensile testing will be conducted at 500 and 600^{o}C. The deformation characteristics of all specimens, upon completion of their testing, will be analyzed by surface analytical techniques including scanning electron microscopy (SEM) and transmission electron microscopy (TEM). It is anticipated that the resultant testing data will lead to the development of a mechanistic understanding of the elevated-temperature deformation processes as a function of thermal treatment in all three heats of Alloy EP-823. Further, these results may provide guidance in developing other materials possessing the improved metallurgical and corrosion properties for LBE applications.

Personnel

The current project participants are listed below.

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Accomplishments

- Tensile tests have been performed at ambient temperature, 100, 300 and 400^{o}C using cylindrical specimens fabricated from quenched and tempered Alloy EP-823 (heat number 2054). Three different tempering times (1.25, 1.75 and 2.25 hours) were used followed by an air-cooling. These test materials were identified as 2054S, 2054T and 2054U, respectively. The comprehensive test results are shown in Tables II through IV.

- The data presented in Tables II-IV are reproduced in graphical format (Figures 1-4) showing the effect of testing temperature on the resultant yield strength (YS), ultimate tensile strength (UTS), percent elongation (%El) and percent reduction in area (%RA) as a function of the tempering times. An examination of the Figures 1 and 2 clearly indicates that both the YS and UTS were gradually reduced with increasing testing temperature, as anticipated. On the other hand, the ductility parameters (%El and %RA) were not significantly affected due to the increased testing temperature. Additional tests are in progress at 500 and 600^{o}C involving similar materials. It is well known that for martensitic stainless steels, there may be a sudden drop in YS and UTS at temperatures exceeding 400^{o}C. Simultaneously, the ductility parameters may be enhanced due to the increased plastic flow of the test materials at temperatures above 400^{o}C.

- Fractographic evaluations of the broken tensile specimens by SEM have just been initiated.

Table I

Chemical Composition of Alloy EP-823+

Material/Heat No.	Elements (wt %)													
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V	W	Cb	B	Ce
Alloy EP-823/2054*	0.16	0.55	0.014	0.004	1.09	11.70	0.66	0.74	0.002	0.30	0.60	0.24	0.009	0.04
Alloy EP-823/2055	0.16	0.57	0.014	0.004	1.14	11.71	0.67	0.74	0.002	0..31	0.58	0.23	0.009	0.04
Alloy 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

+ Austenitized: 1850^{o}F / 1 Hour / Oil-Quenched
Tempered: 1150^{o}F / 1.25 Hour / Air-Cooled (Coded as S)
(In 3 Batches) 1150^{o}F / 1.75 Hour / Air-Cooled (Coded as T)
1150^{o}F / 2.25 Hour / Air-Cooled (Coded as U)

Table II: Results of Tensile Testing using 2054S Material

Test Temp, °C	UTS, ksi	YS , ksi	% El	% RA
27	130.7	110.0	23.89	62.59
27	133.2	112.8	23.75	63.40
27	133.4	112.8	23.54	65.02
100	123.6	103.5	22.51	63.85
100	123.8	104.5	22.80	63.57
100	123.6	104.0	22.64	63.50
300	116.8	95.9	19.75	61.26
300	116.9	96.2	19.74	62.42
300	117.2	96.2	19.78	62.93
400	109.4	88.6	21.9	63.2
400	111.5	90.0	21.3	63.7
400	110.2	89.2	22.1	63.1

Table III: Results of Tensile Testing using 2054T Material

Test Temp, °C	UTS, ksi	YS , ksi	% El	% RA
27	130.2	108.9	23.72	61.79
27	131.3	109.7	24.03	62.88
27	129.9	108.8	23.76	62.47
100	122.7	102.6	22.58	64.20
100	122.5	101.2	22.59	63.66
100	122.6	102.4	23.05	63.33
300	116.5	93.7	19.93	62.40
300	115.6	93.7	20.13	62.99
300	115.3	94.2	19.20	61.88
400	109.9	89.9	21.32	64.26

Table IV: Results of Tensile Testing using 2054U Material

Test Temp, °C	UTS, ksi	YS , ksi	% El	%RA
27	128.5	108.3	20.94	61.46
27	129.4	108.2	20.76	61.34
27	128.6	107.5	24.25	61.38
100	121.3	101.4	20.04	62.14
100	120.8	100.7	19.93	63.76
100	121.3	102.1	19.95	63.81
300	113.7	94.5	17.06	62.96
300	113.9	93.8	18.19	63.03
300	113.9	91.9	19.91	63.64
400	107.3	86.8	18.90	63.98
400	107.7	84.2	20.63	63.26
400	107.0	87.4	20.90	63.90

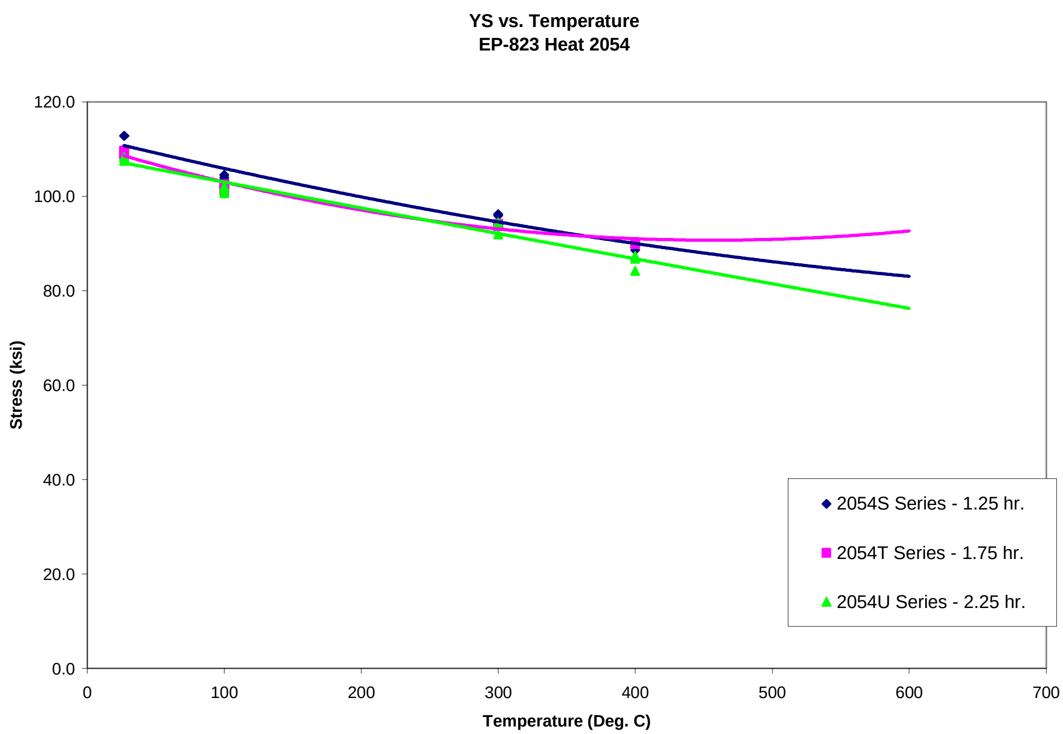

Figure 1. YS versus Test Temperature

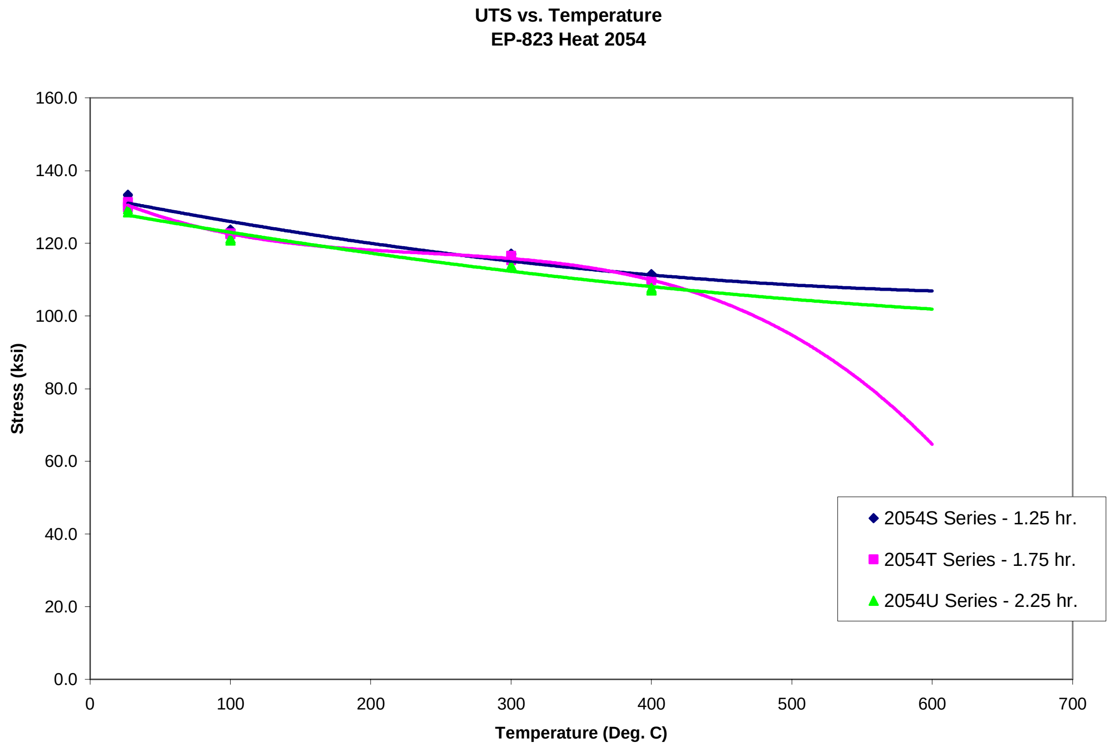

Figure 2. UTS versus Test Temperature

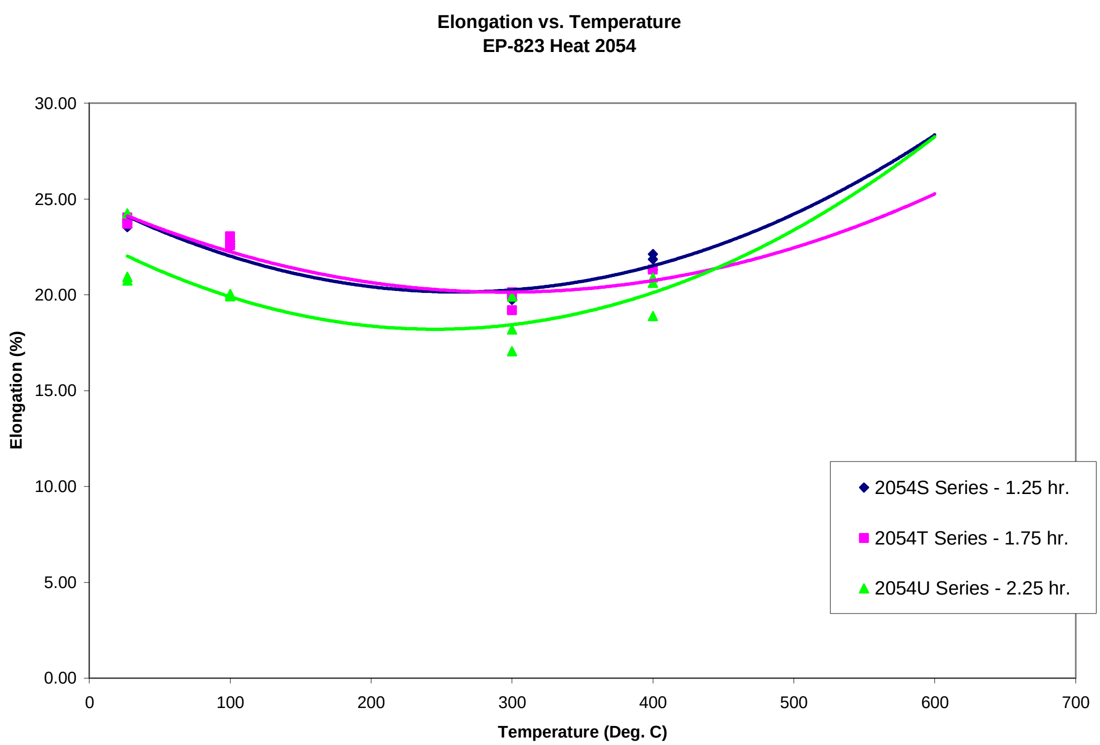

Figure 3. %El versus Test Temperature

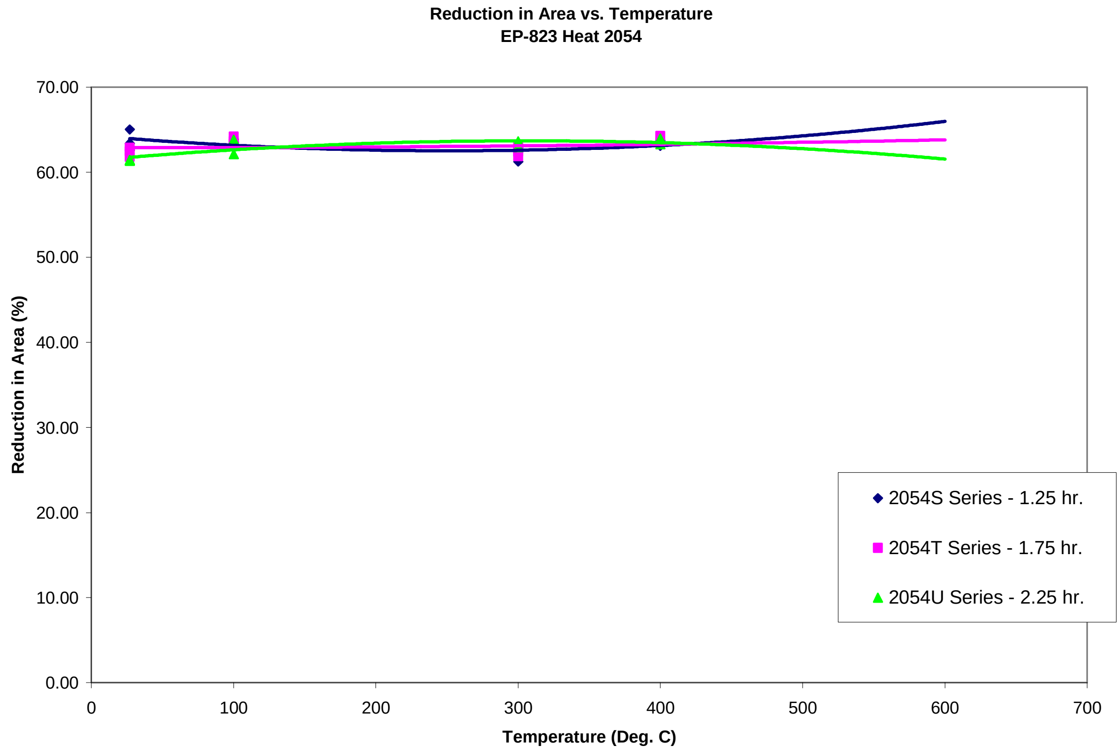

Figure 4. %RA versus Test Temperature