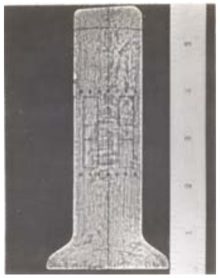
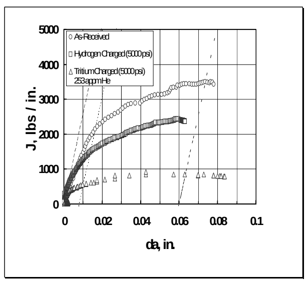
Tritium Aging Effects on Forged Stainless Steel





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SAVANNAH RIVER NATIONAL LABORATORY

We Put Science To Work

Michael Morgan

Background

- Pressure vessels for tritium service are constructed from stainless steel forgings.
- Tritium and its decay product, helium, change the structural properties of stainless steels and make them more susceptible to cracking.
- Material and forging specifications have been developed for optimal material compatibility with tritium. They include: Composition, tensile properties, and select microstructural characteristics like grain size, flow line orientation, inclusion content, and ferrite distribution and content.
- For years, the forming process of choice was high-energy-rate forging (HERF)
- Today, some reservoir forgings are being made that use a conventional, more common process known as press forging (PF or CF).
- Conventional hydraulic or mechanical forging presses deform metal at 4-8 ft/s, about ten-fold slower than the HERF process.
- The material specifications continue to provide successful stockpile performance by ensuring that the two forging processes produce similar reservoir microstructures.

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Purpose

The purpose of this study was to measure and compare the fracture toughness properties of Type 21-6-9 stainless steel for:

- High-energy-rate and conventional forgings; in the
- Unexposed, hydrogen-exposed and tritium-exposed-and-aged conditions.

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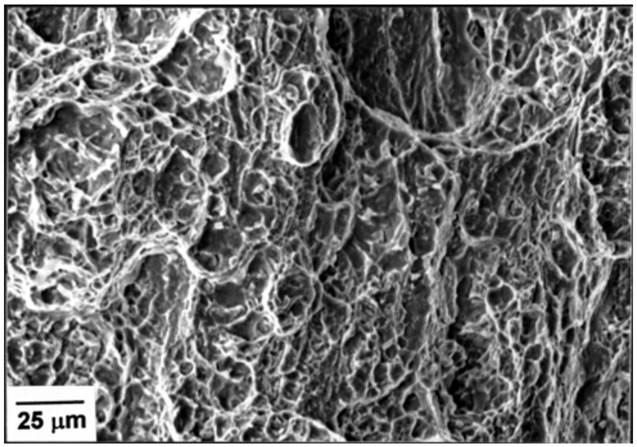
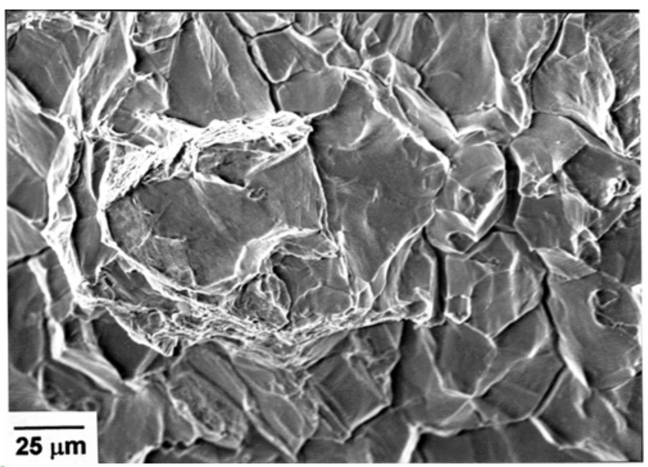
Effect of Tritium Exposure on Stainless Steels



Unexposed



Tritium-Exposed & Aged

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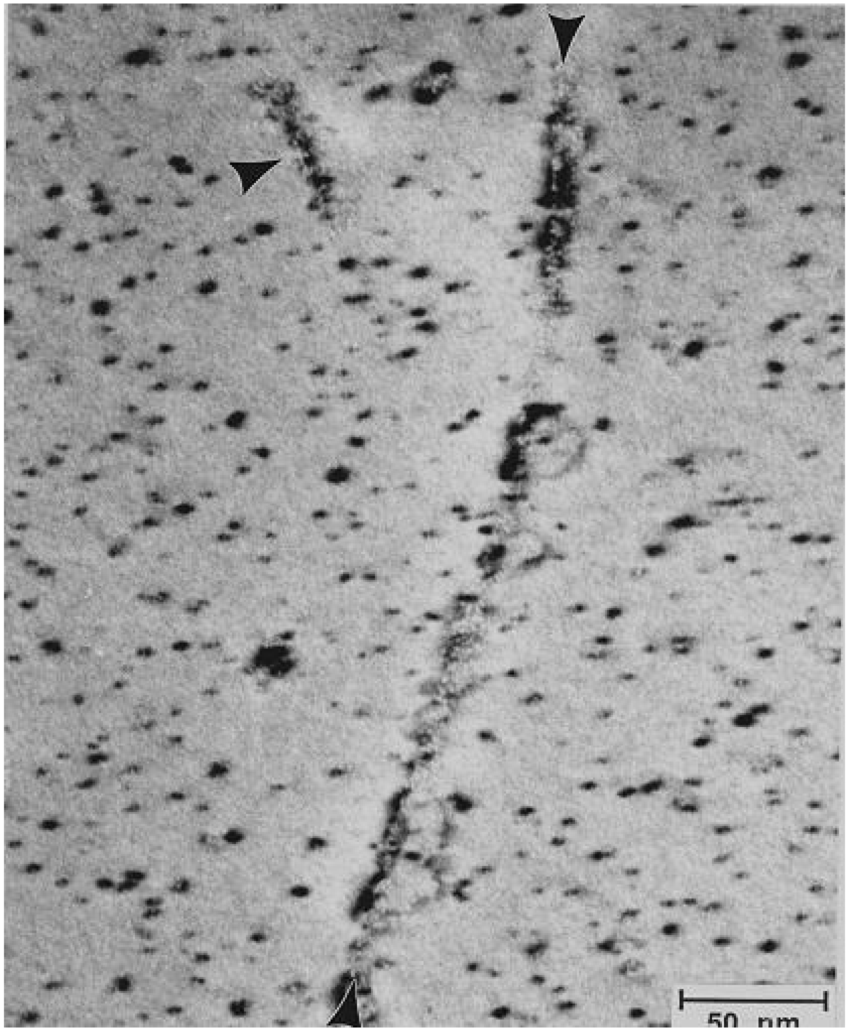
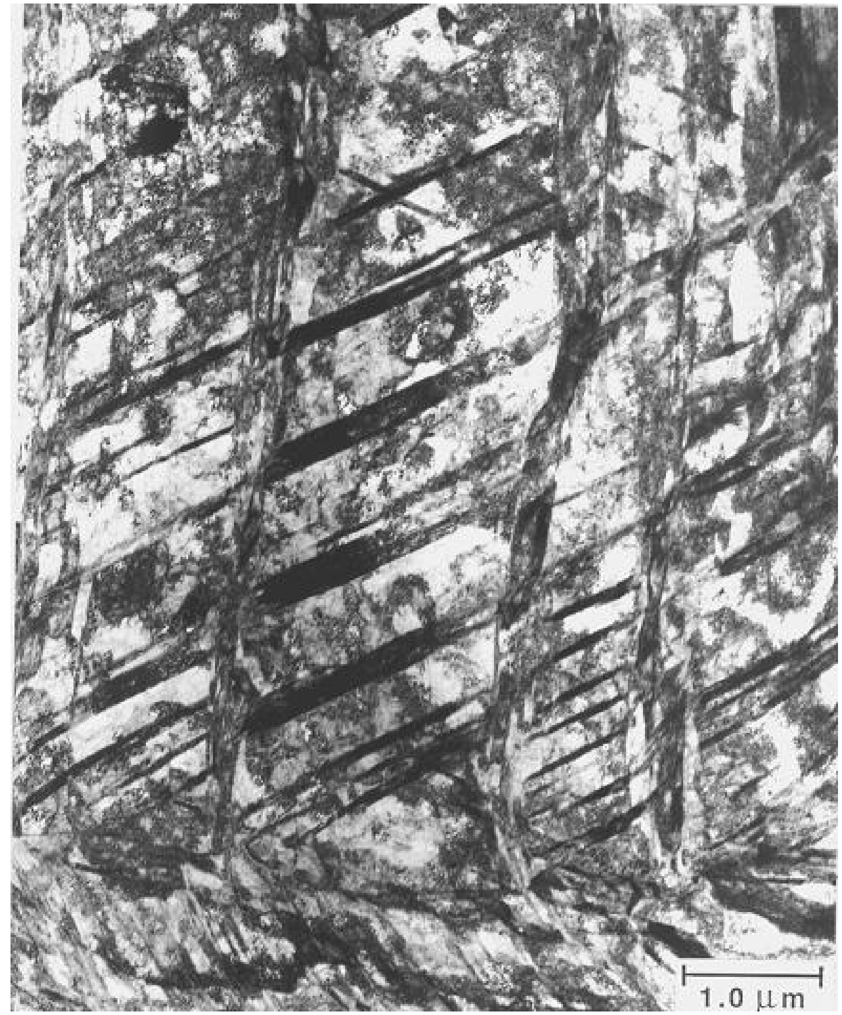
Helium Hardened Microstructure





Materials and Compositions

Table I. Compositions of Stainless Steel Forgings, Plates and Weld Filler Wires (Weight %)

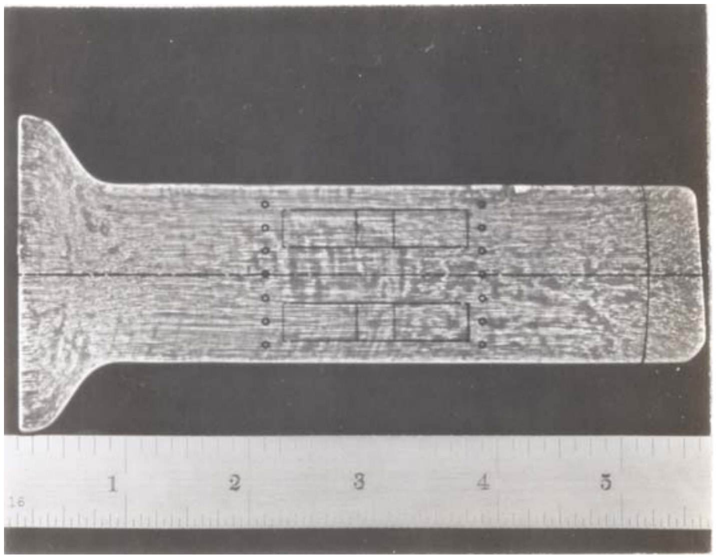
Material	Forging	Sample ID	Cr	Ni	Mn	P	Si	Co	Mo	C	S	N	O	Al	Cu
HERF* 21-6-9	A4582	F97-X	19.4	6.4	8.5	0.021	0.33			0.04	<.001	0.28	0.0022	<.001	
CF** 21-6-9	B7073	H94-X	19.1	6.7	9.9	0.01	0.41			0.03	0.004	0.28	0.001	0.005	
CF** 21-6-9	B6275	F9-X	19.3	6.7	9.9	0.01	0.38			0.03	0.001	0.28	0.002	0.004	
Filler Wire 308L	308L Weldment	98-X	20.5	10.3	1.56	0.006	0.5	0.068	<0.01	0.028	0.012	0.055	-	-	0.015

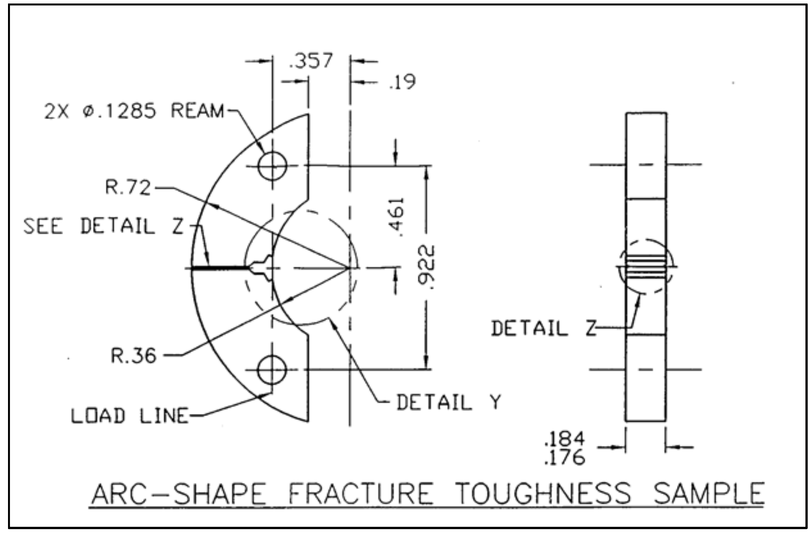
*High-Energy-Rate Forged

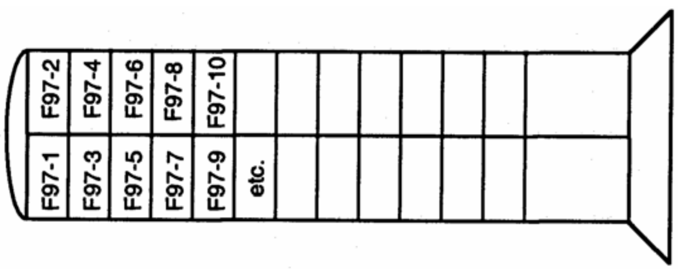
**Conventionally Forged

Manufacturers' supplied compositions

Forging and Sample Orientation







Forging A4582 - - 21-6-9 SS

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Mechanical Properties and Grain Size

Sample ID	Yield Strength psi	Ultimate Strength psi	% EL	Grain Size
F9 (CF)	87100	131400	48.3	10/7; 7 < 5%
H94 (CF)	99400	139300	44.3	10/7; 7 < 5%
F97 (HERF)	104800	139400	37.6	5/3

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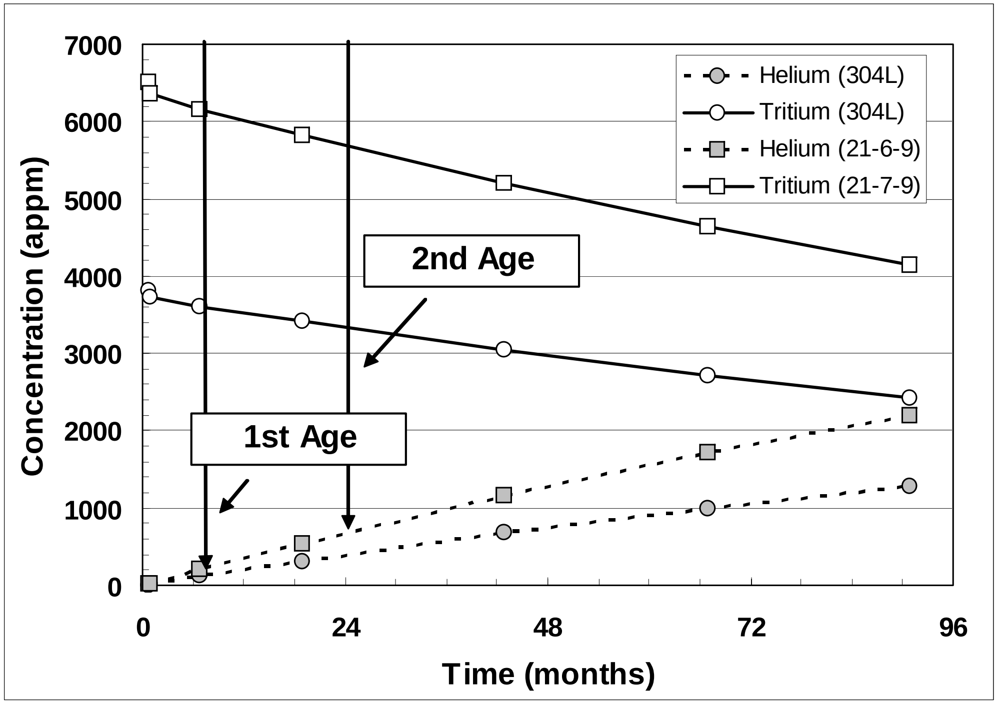
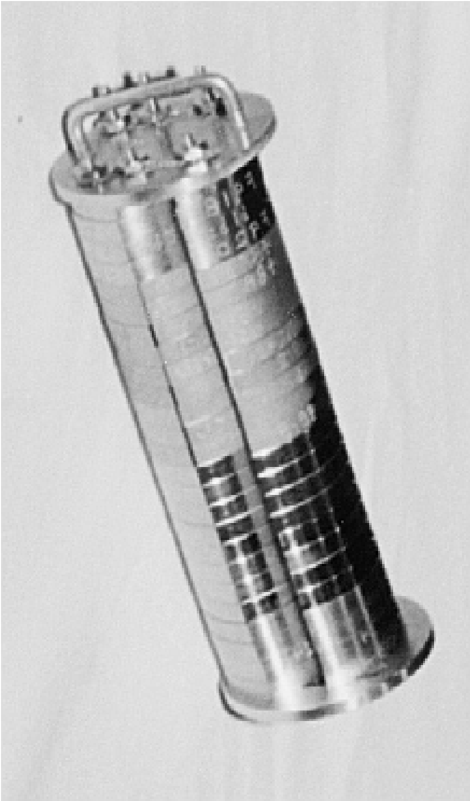
Sample Cartridge and Aging Calculation





- Hydrogen and Tritium exposures conducted at 350 C for three weeks
- Tritium samples aged at -40C to build-in decay helium
- All samples were tested at ambient temperature in air

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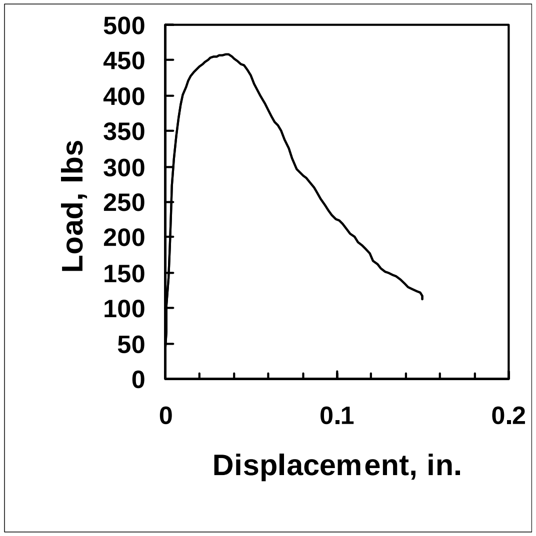
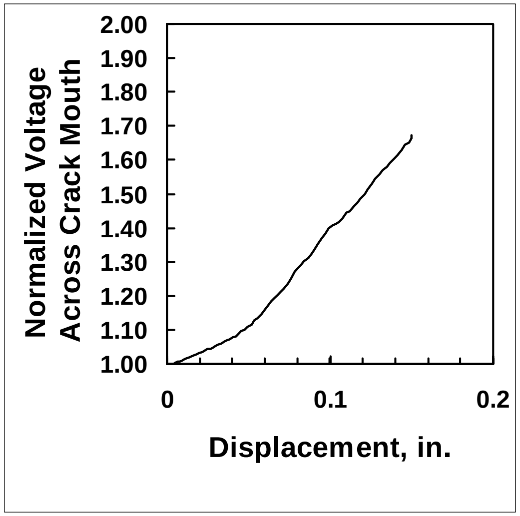
Fracture Toughness Testing





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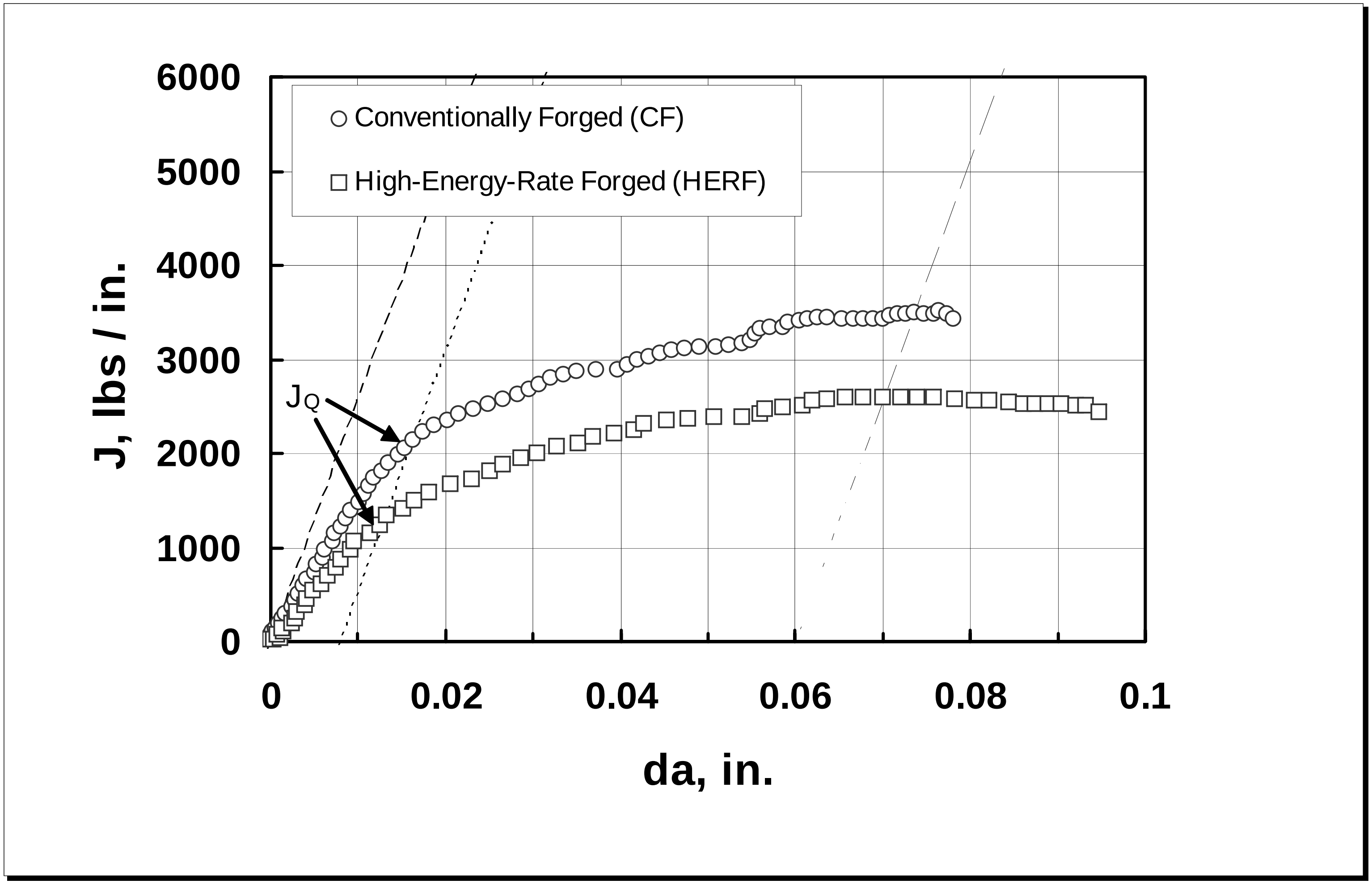
J-R Curves for CF and HERF Steels



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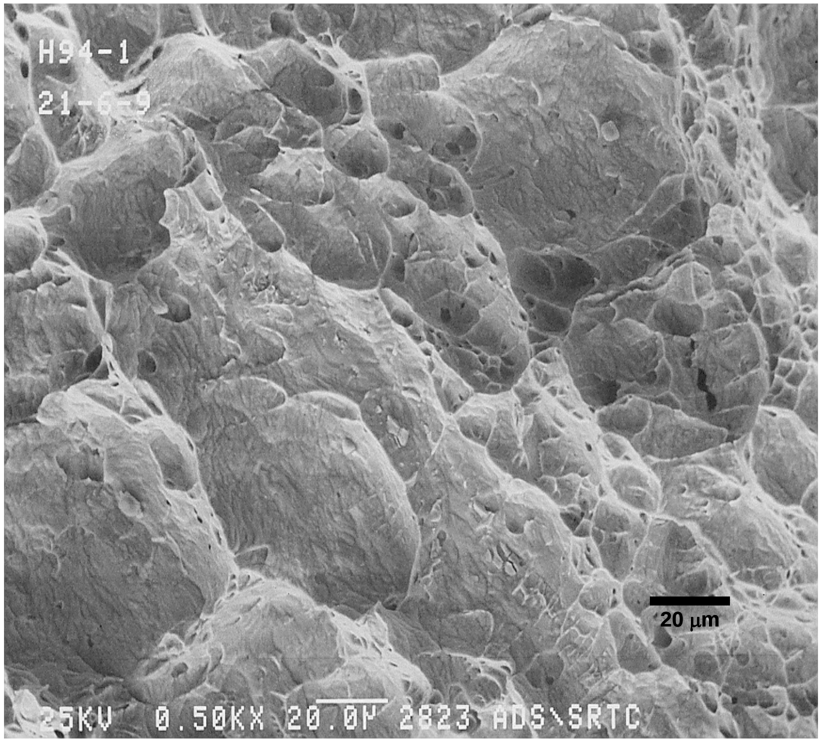
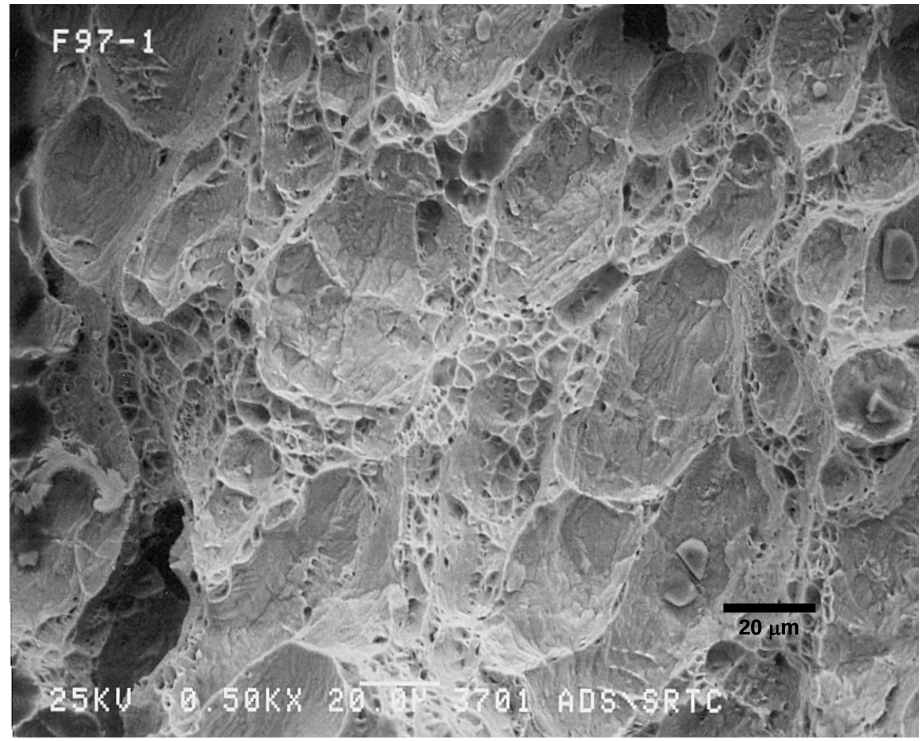
Fracture Appearance Unexposed Heats





Conventionally Forged

High-Energy-Rate Forged

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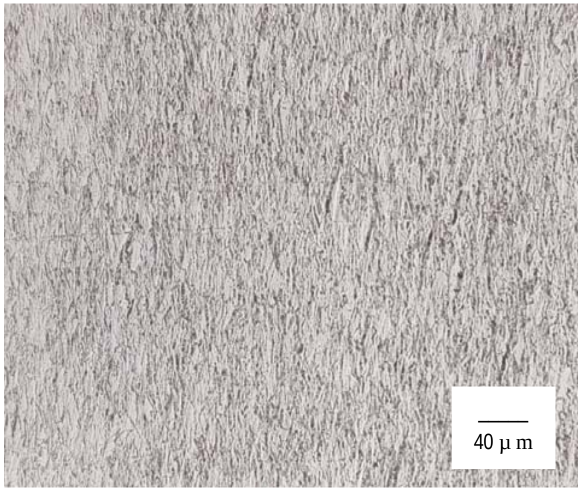
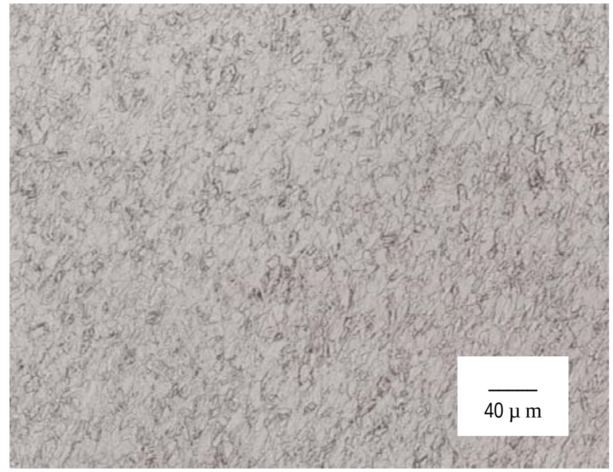
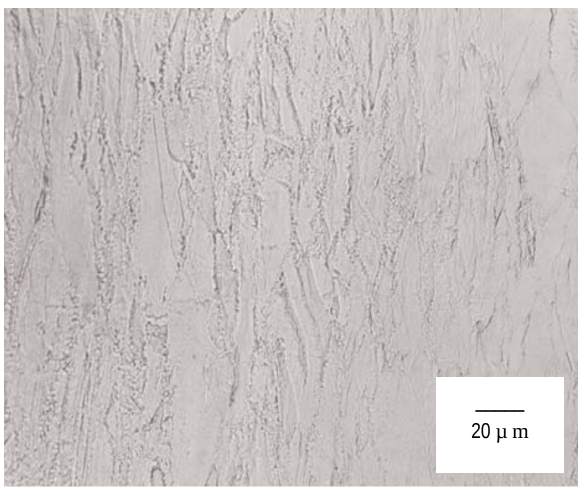
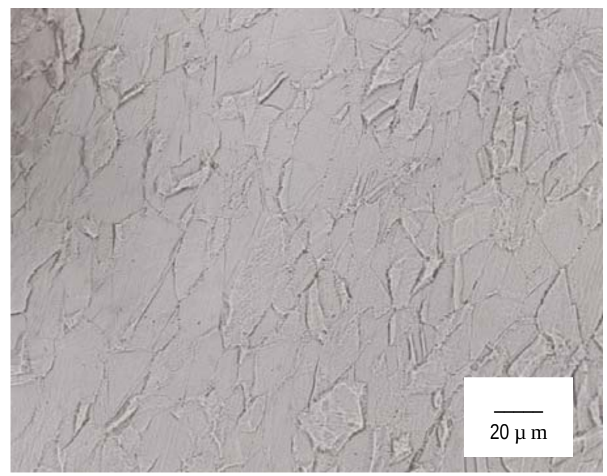
Conventionally Forged Microstructures





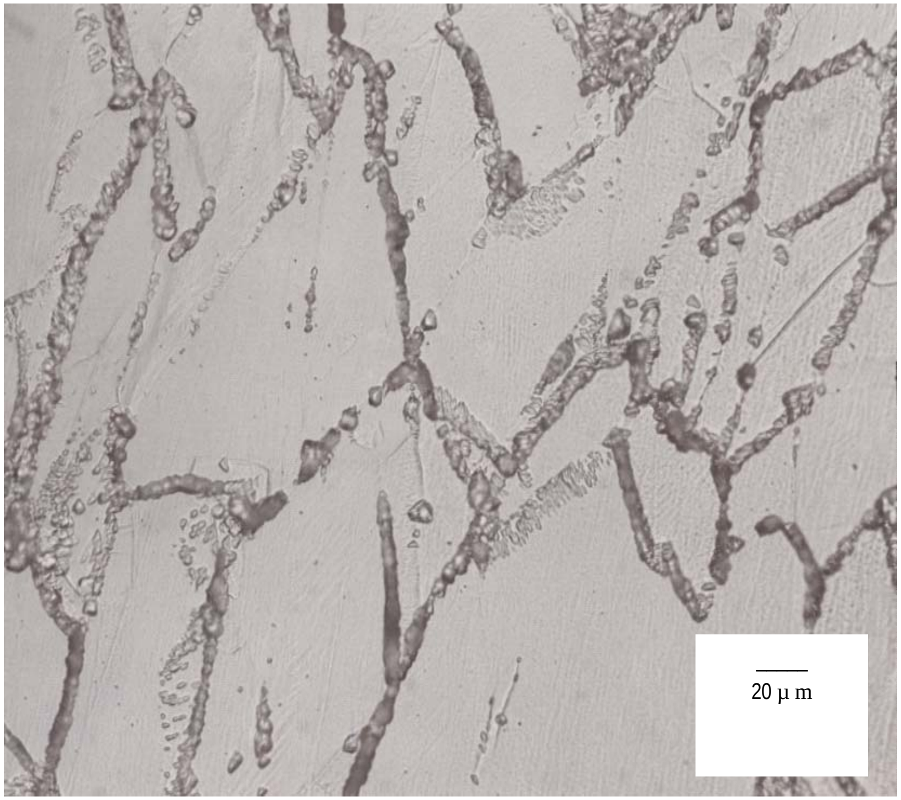




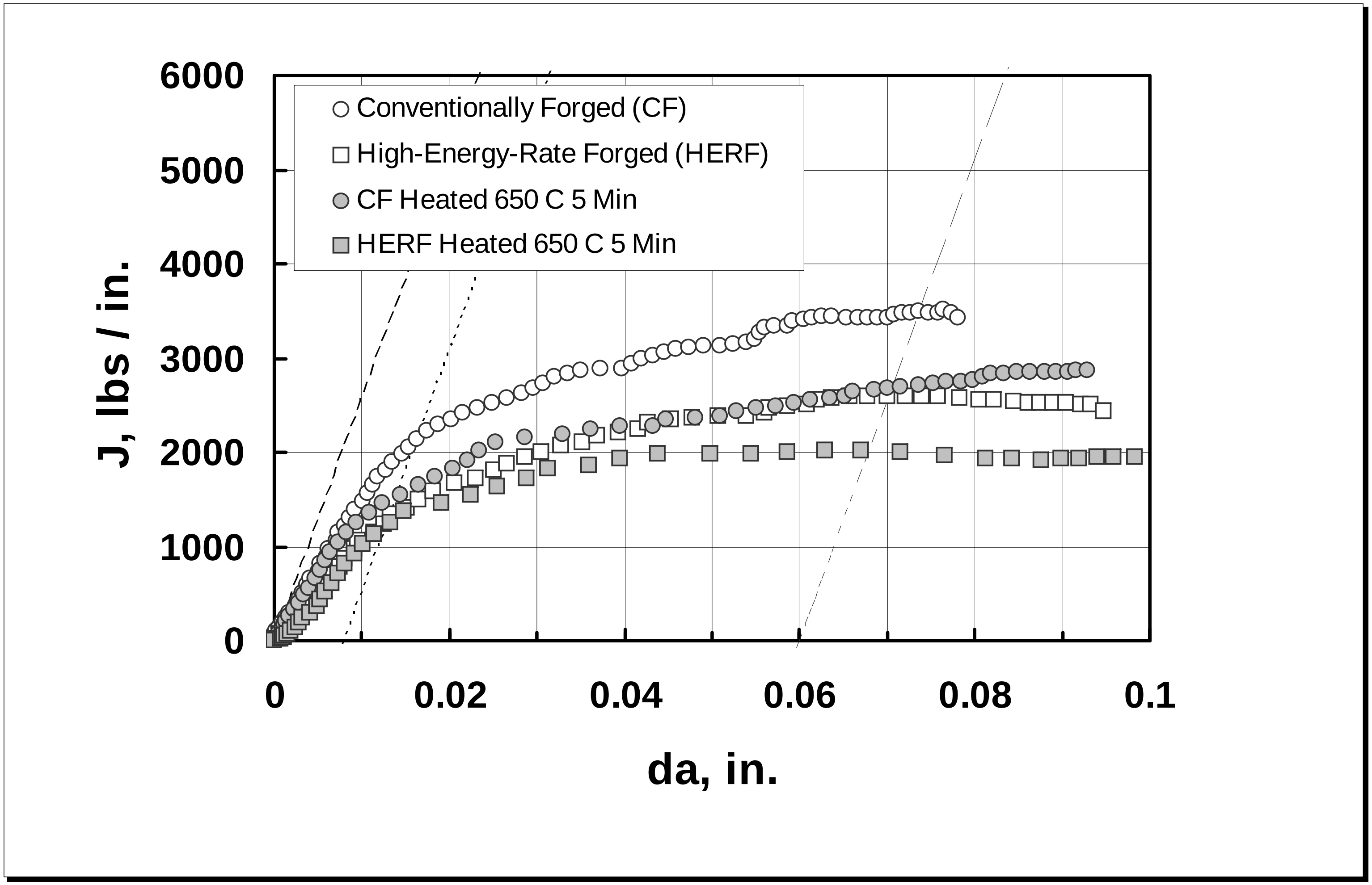
90 ksi Y.S. Heat

100 ksi Y.S. Heat

HERF Microstructures



J-R Curves for As-Received and Heat-Treated Steels



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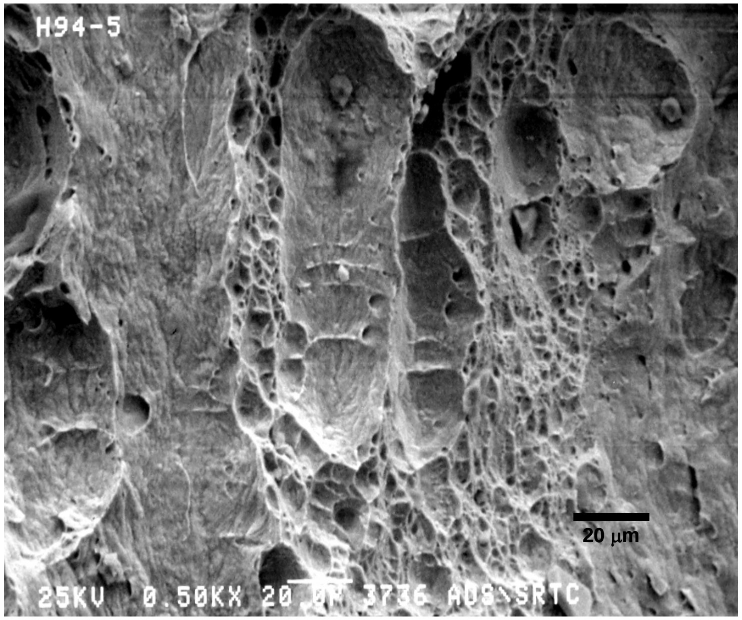
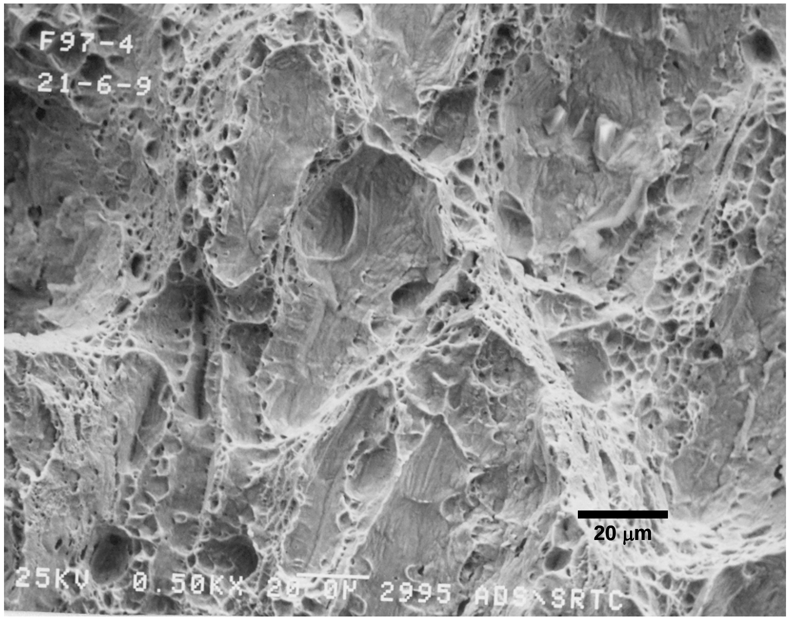
Fracture Appearance Heat Treated Steels





Conventionally Forged

High-Energy-Rate Forged

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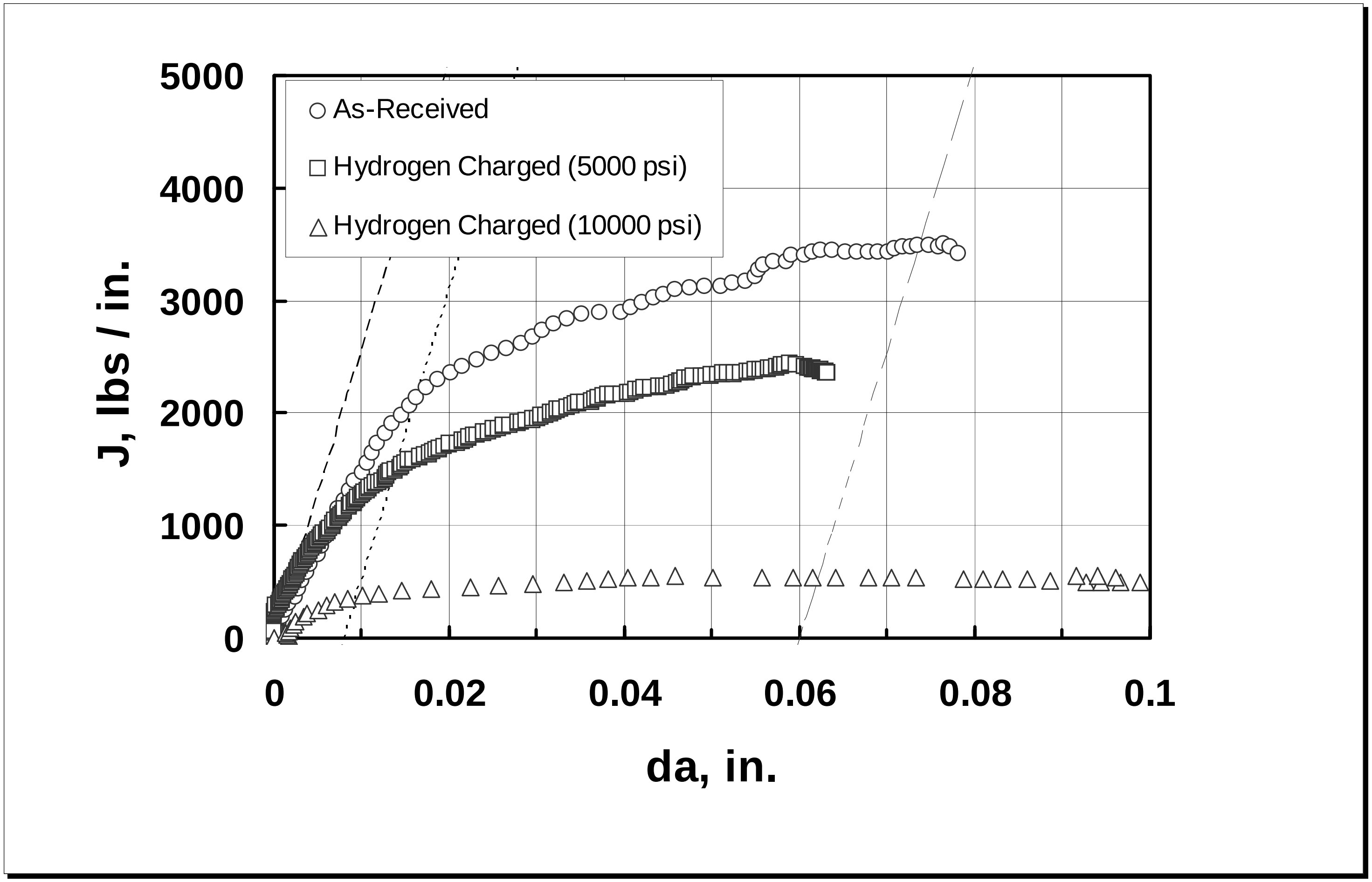
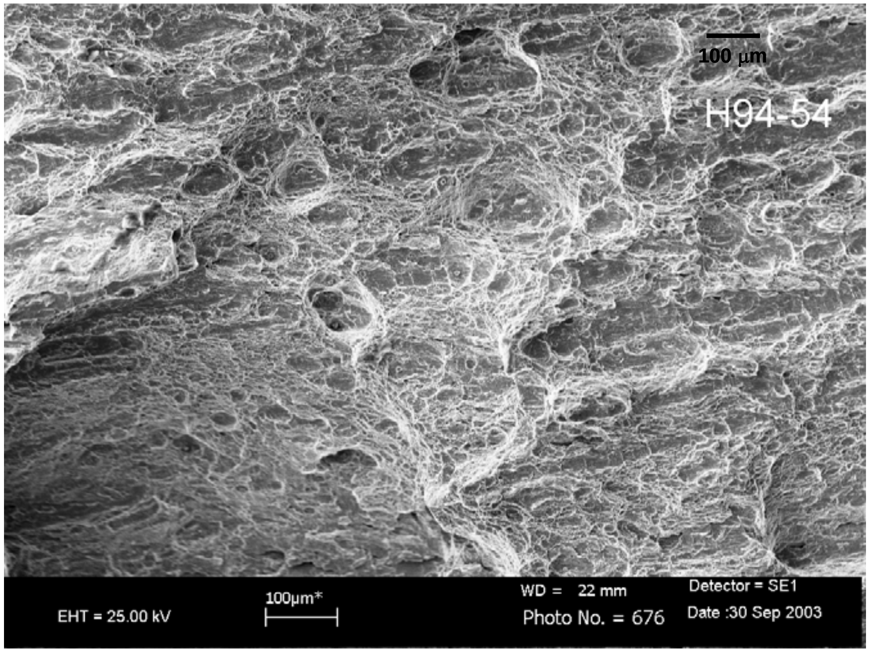
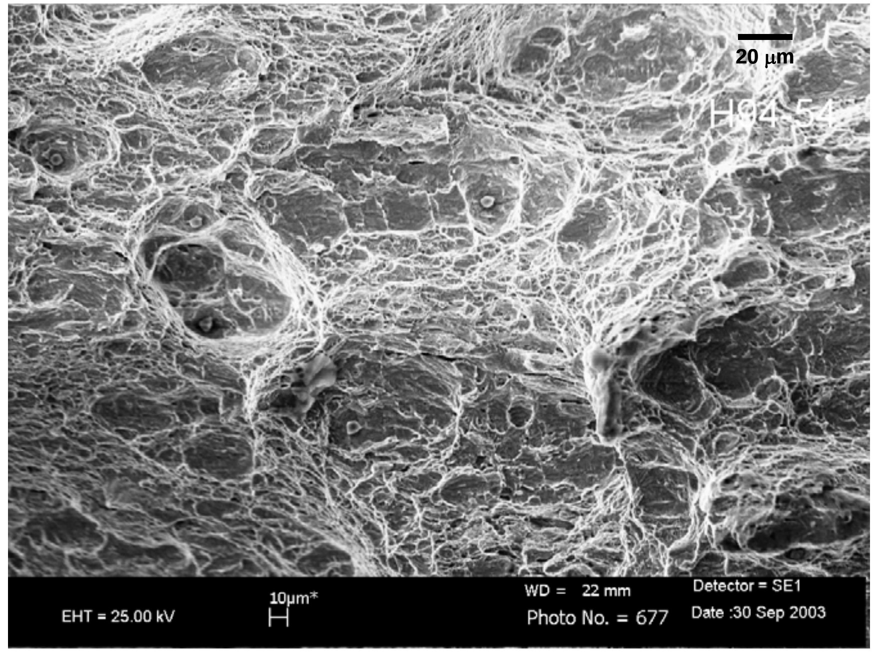
Effect of Hydrogen Exposure on J-R Behavior



Conventionally Forged Type 21-6-9 Stainless Steel

Effect of Hydrogen on Fracture Appearance





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Conventionally Forged Type 21-6-9 Stainless Steel

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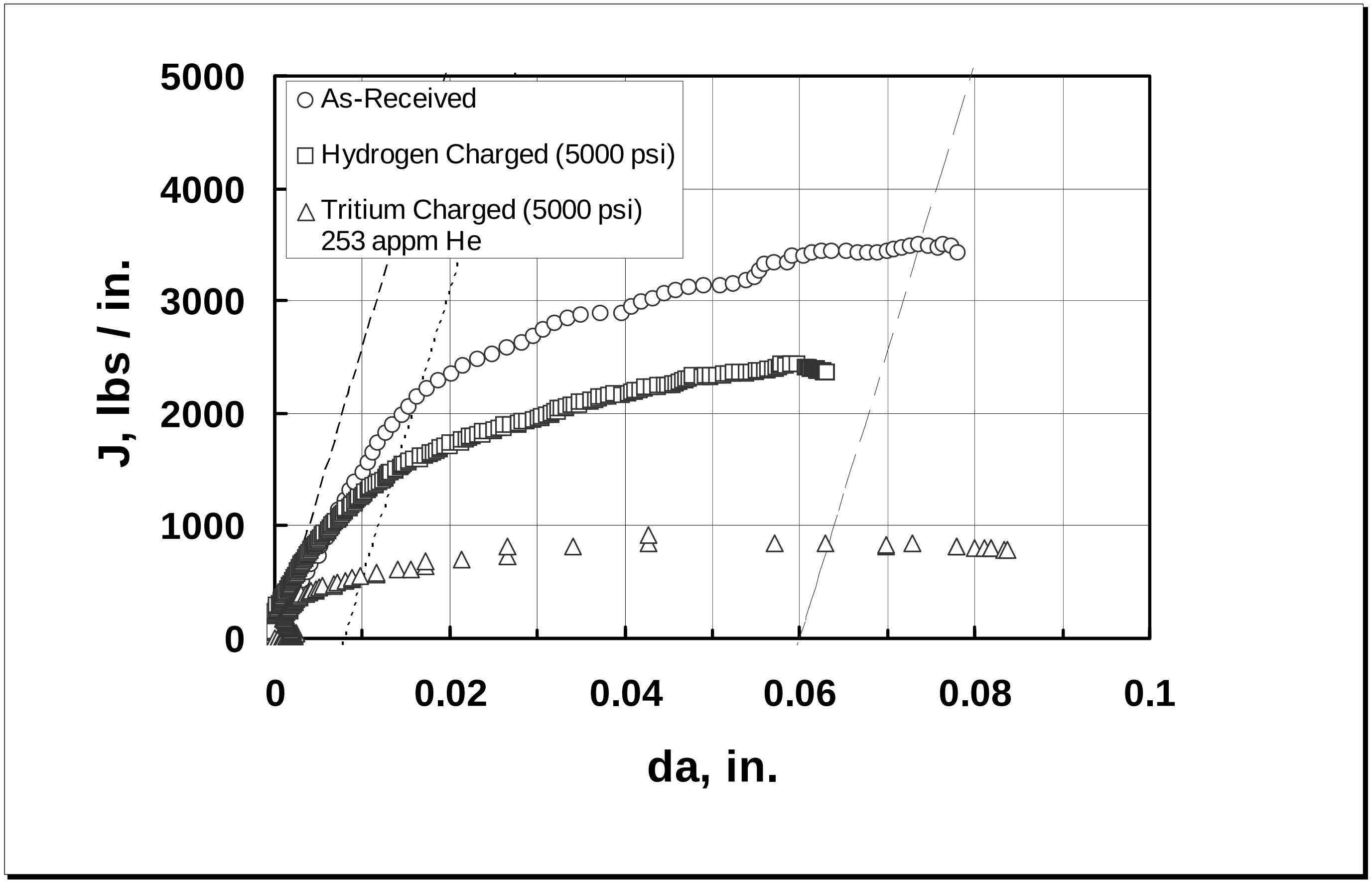
Effect of Hydrogen, Tritium, and Decay Helium on J-R Behavior



Conventionally Forged Type 21-6-9 Stainless Steel

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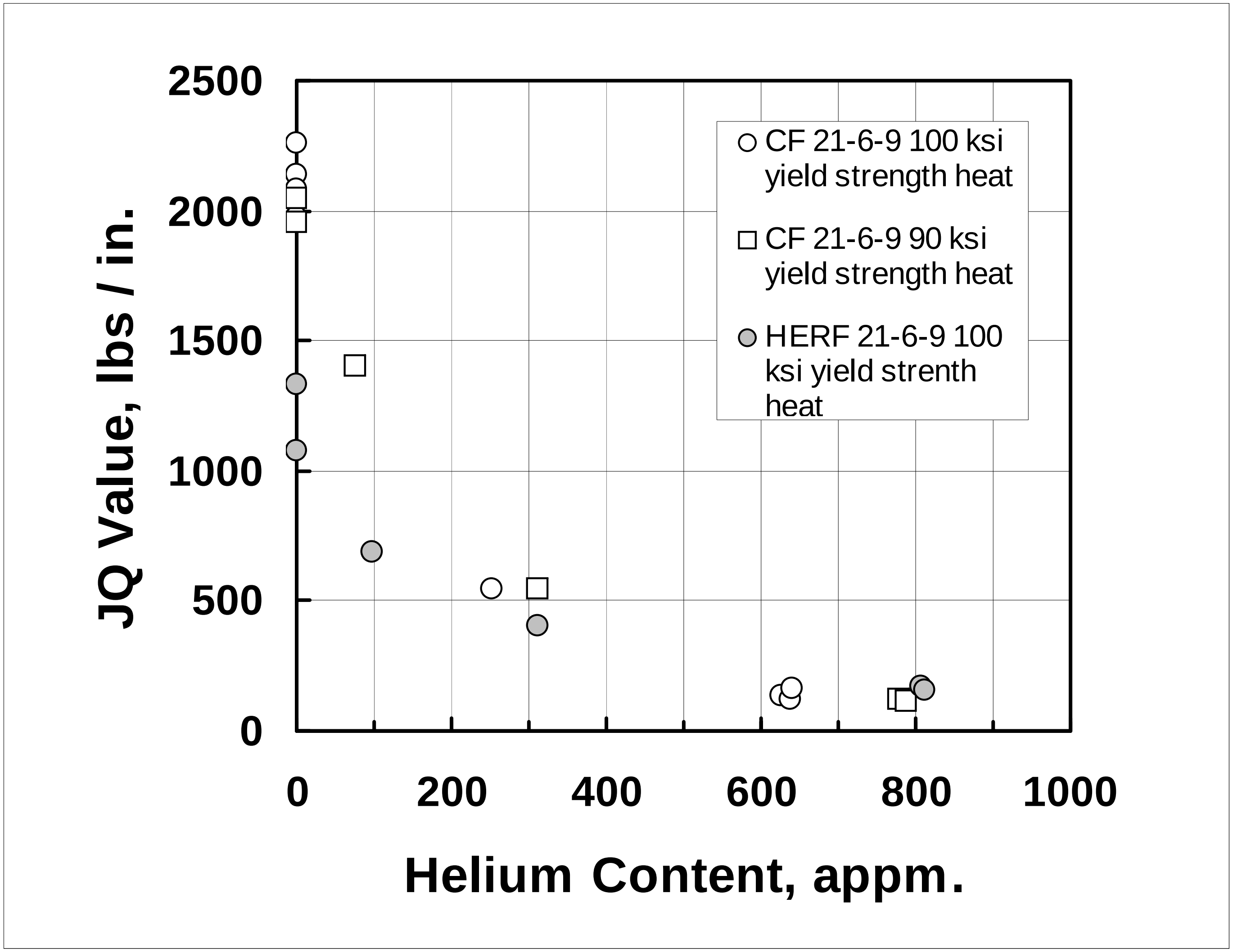
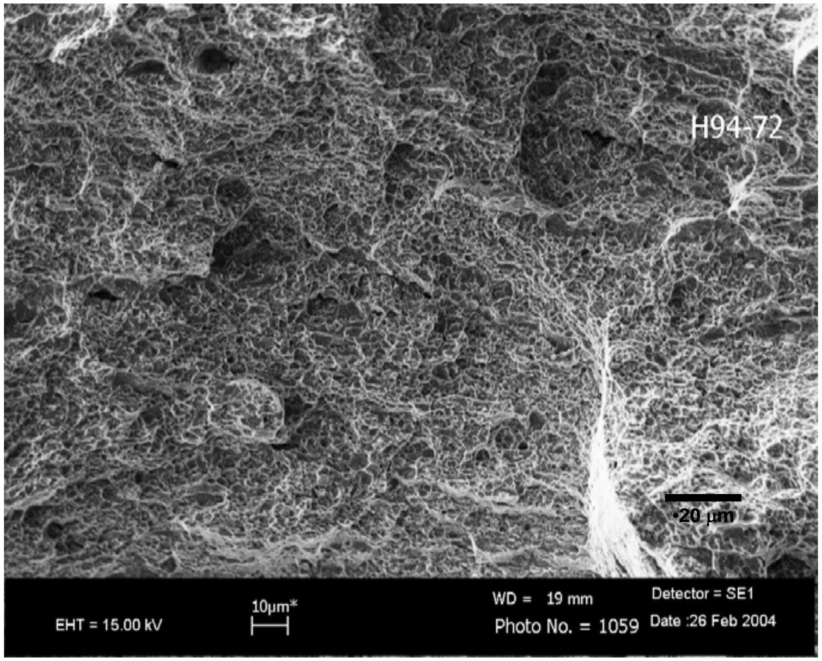
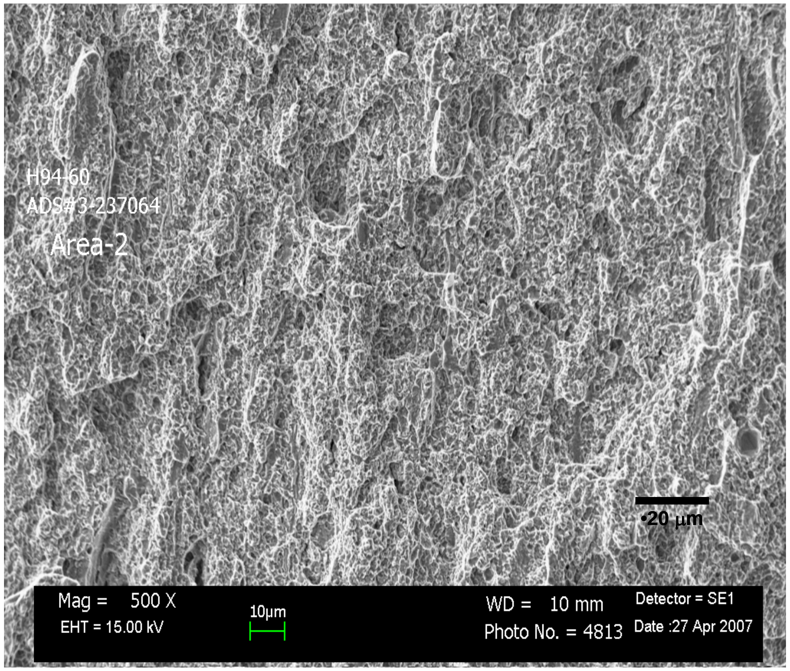
Effect of Decay Helium on Fracture Toughness



Tritium Aging Effects on Fracture Appearance





253 appm Helium

627 appm Helium

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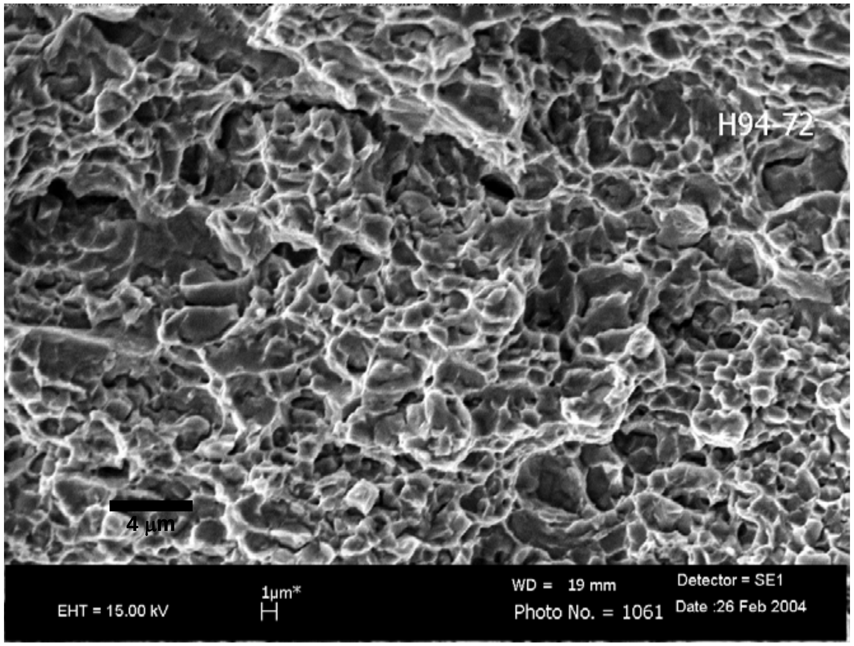
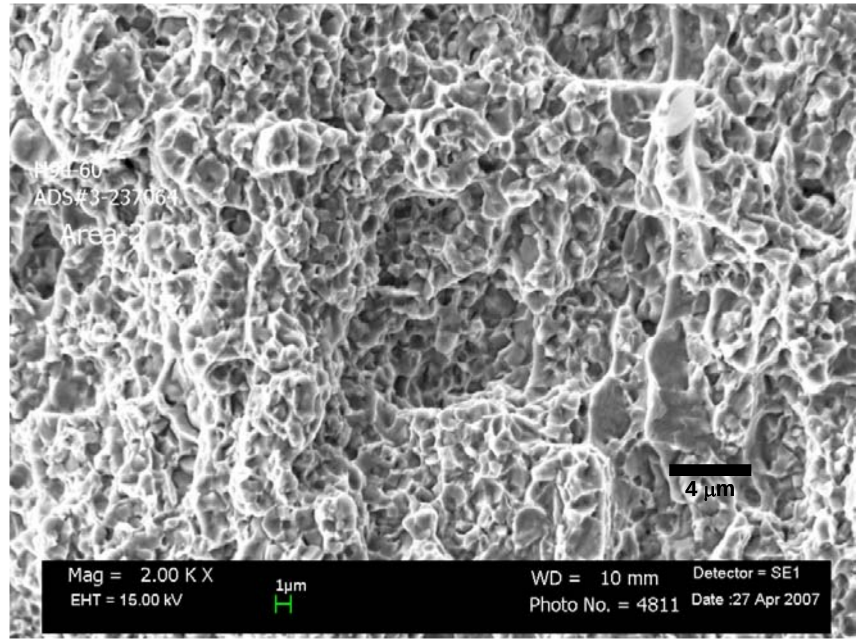
Tritium Aging Effects on Fracture Appearance





253 appm Helium

627 appm Helium

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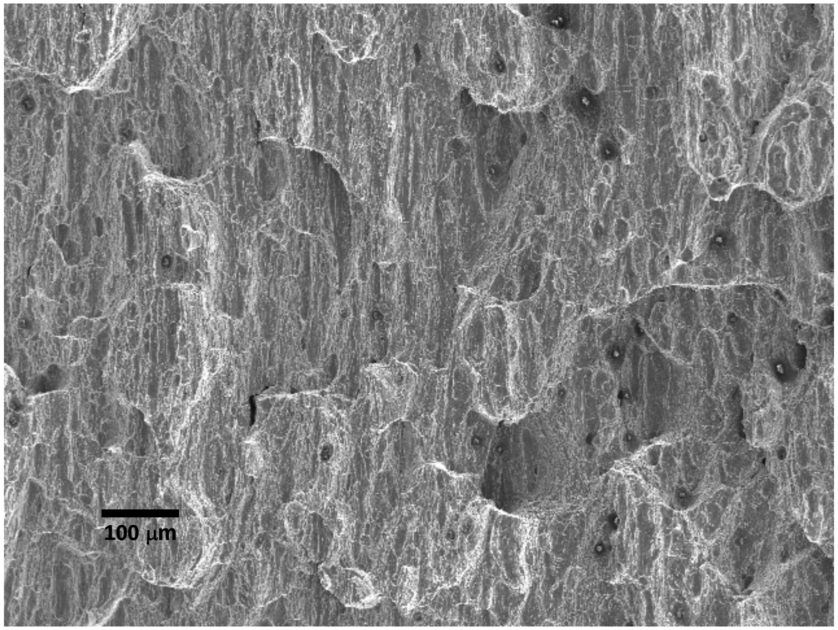
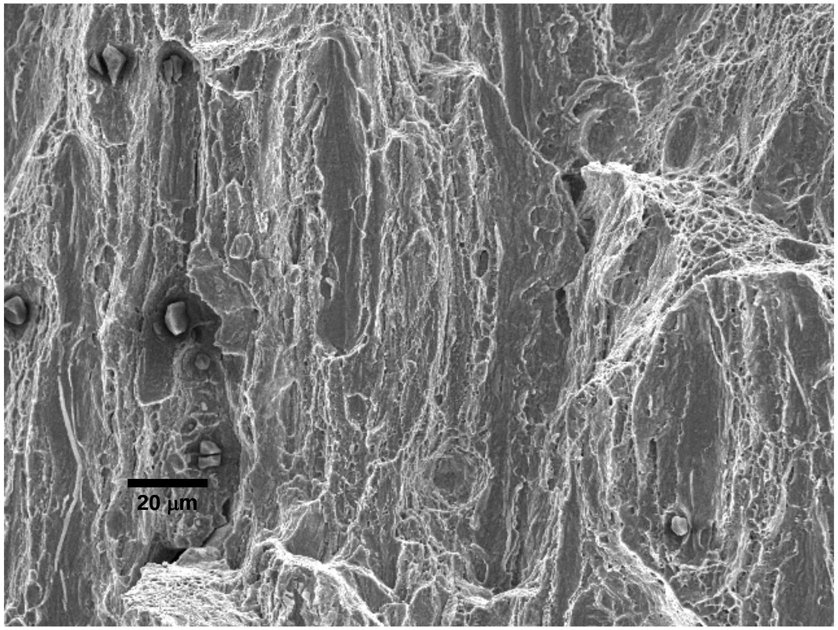
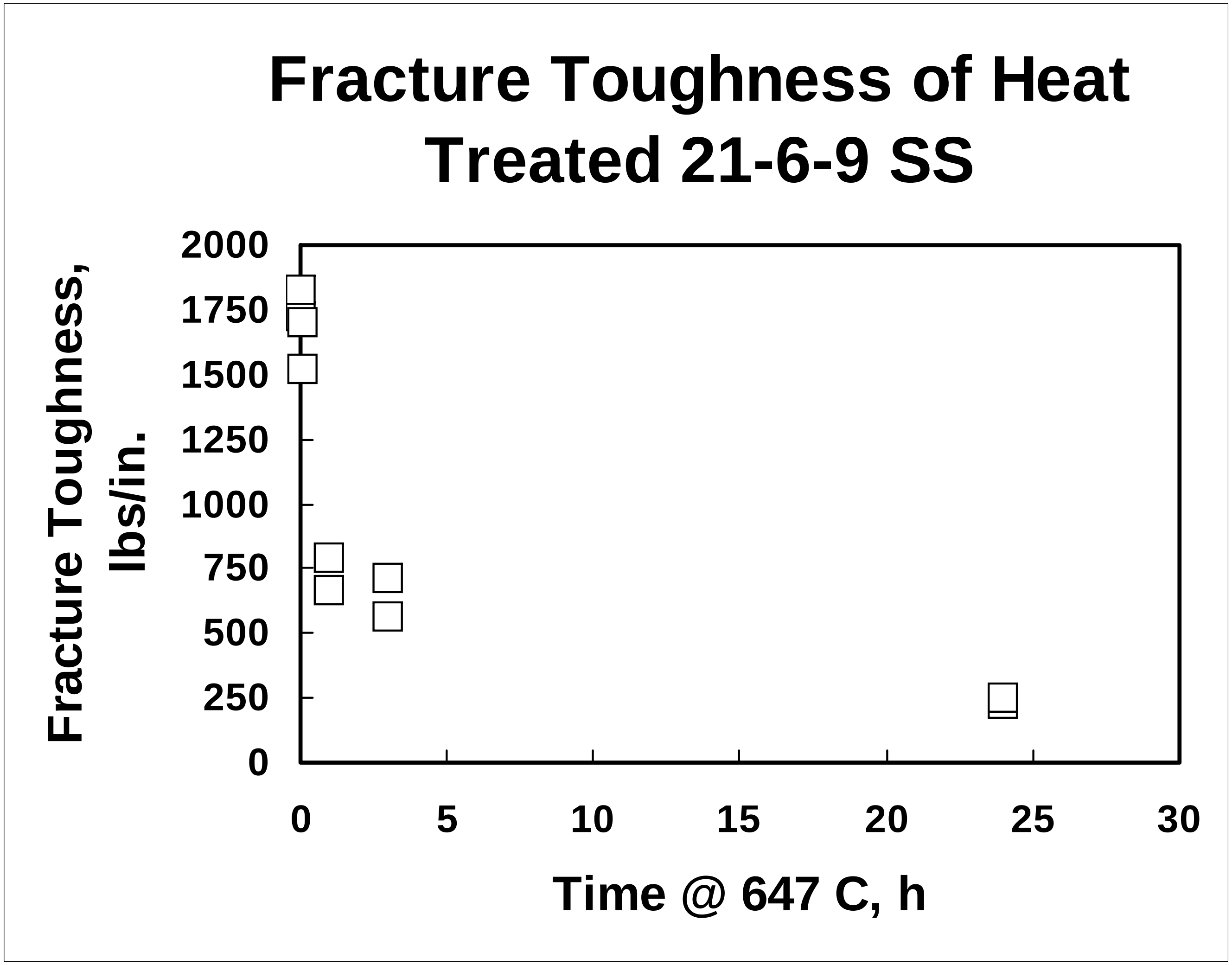
Fracture Appearance of Tritium Exposed HERF Type 21-6-9 Stainless Steel





627 appm Helium

Fracture Toughness - Heat Treated



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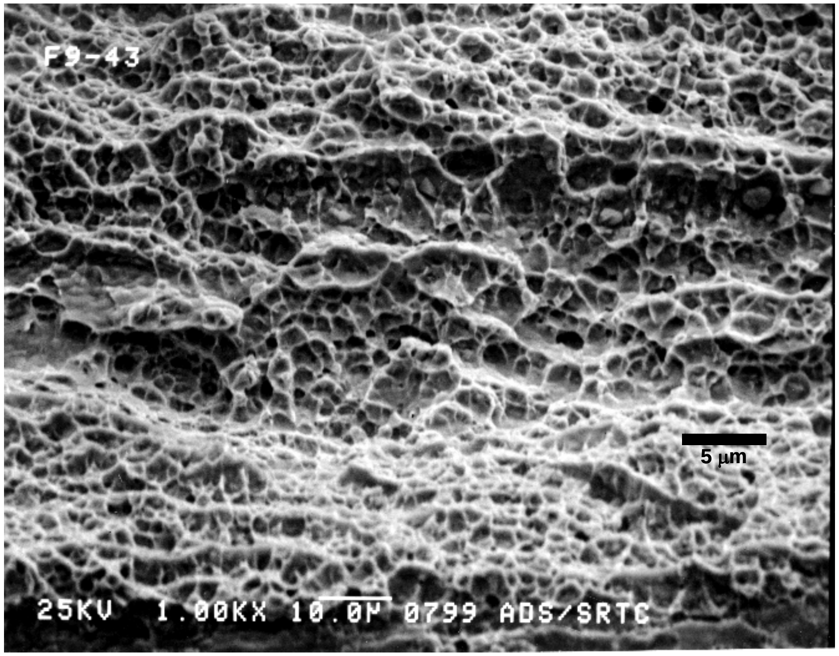
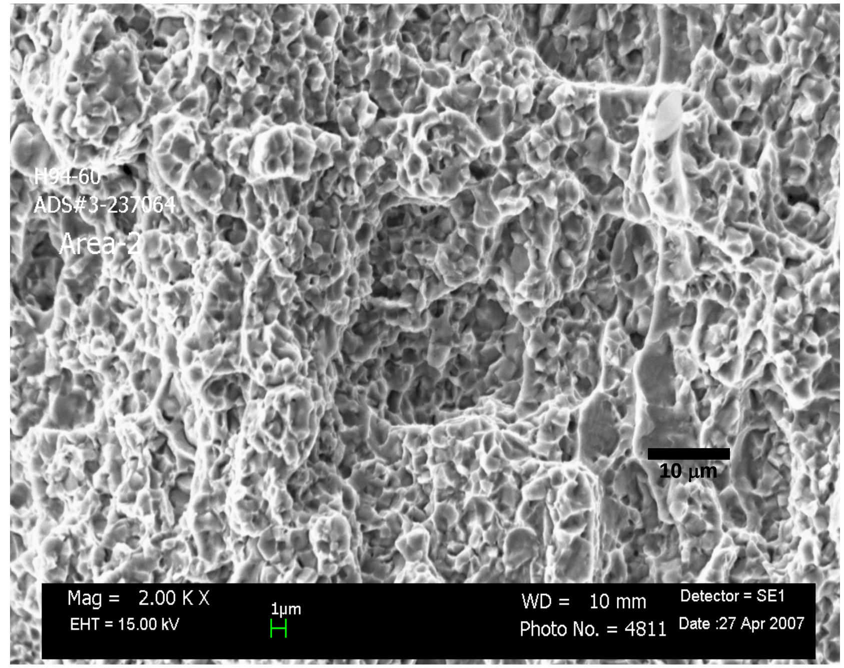
Comparison of Fracture Appearance – Heat Treated vs. Tritium-Exposed-and-Aged





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Heat Treated 650 C 24 h

Tritium-Exposed-Aged for Seven Years (627 appm helium)

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Conclusions

- HERF Type 21-6-9 stainless steels had lower fracture toughness values than Conventionally Forged Type 21-6-9 steel because of its larger grain size and sensitization that occurred during the forging process.
- Hydrogen and tritium exposures lowered the JQ values and J-da curves. The degree of sensitization did not seem to affect the fracture toughness at high helium levels.
- Fracture modes of the forged steels were dominated by the dimpled rupture process in unexposed, hydrogen-exposed and tritium-exposed steels and welds.
- Heavily sensitized steels had a similar fracture appearance as tritium-exposed-and-aged steels

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