CONF-8907209--1-Vugraphs

WSRC-MS--90-173

DE91 004327

MICROSTRUCTURE AND YIELD STRENGTH EFFECTS ON HYDROGEN-AND-TRITIUM-INDUCED CRACKING IN 21-6-9 STAINLESS STEEL (U)

DEC 0 3 1990

by

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Signature Date

A paper proposed for presentation at
The Fifth Meeting of the
IMOG Subgroup on Mechanical Testing
Lawrence Livermore National Laboratory
Livermore, California
11-13 July 1989

and publication in the conference proceedings

MICROSTRUCTURE AND YIELD STRENGTH EFFECTS ON HYDROGEN-AND-TRITIUM-INDUCED CRACKING IN 21-6-9 STAINLESS STEEL (U)*

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High-energy-rate-forged (HERF) austenitic stainless steels are used for the containment of hydrogen and its isotopes. Embrittlement of these materials by hydrogen has been a source of concern for some time. The nature and the degree of embrittlement by hydrogen varies considerably and, among other factors, is a complicated function of material composition and processing variations. Helium, the radioactive decay product of tritium, will also embrittle stainless steels. Precipitation of microscopic helium bubbles tends to increase the material's flow stress, through dislocation pinning, as well as weaken interfaces like grain and twin boundaries. Since fracture toughness tends to decrease with increasing yield strength, at least part of the helium-embrittlement problem may be due to strength effects. The relationship between a material's yield strength and toughness and, the incremental strength increase and corresponding toughness decrease imparted by helium is not known.

The purpose of this study was to measure the combined effects of strength, hydrogen isotopes, and helium on the room temperature mechanical and fracture toughness properties of HERF 21-6-9 stainless steel.

Smooth round-bar tensile samples and precracked fracture toughness samples having yield strengths in the range 517-930 MPa were thermally charged with either hydrogen or tritium and tested at room temperature in either air or high pressure hydrogen gas. Fracture toughness measurements were made using two separate techniques: (1) Rising-load J-integral; and, (2) Falling-load Threshold Stress Intensity. The falling-load threshold stress intensity measurements were conducted using a compliance technique that was developed during the course of this work for use with C-shaped fracture toughness samples.

In general, hydrogen-charged and tritium-charged-and-aged samples had higher strengths and lower ductilities than uncharged samples. On a per-atom basis, helium was more effective than hydrogen in increasing strength and lowering

*This article was prepared in connection with work done under Contract No. DE-AC09-88SR18035 with the U.S. Department of Energy.

ductility. Ductility was not strongly affected by yield strength. HERF microstructures were less susceptible to helium embrittlement than annealed microstructures.

Fracture toughness values were also reduced by hydrogen and helium. The reductions in fracture toughness caused by hydrogen and helium were affected more by the presence of statically recrystallized grains from the HERF'ing process than yield strength. Static recrystallization in the HERF microstructures affected the fracture toughness reductions by changing the crack paths. Hydrogen-exposed samples had relatively high fracture toughness values when their microstructures contained patches of "soft" recrystallized grains and had relatively low fracture toughness when their microstructures were free of recrystallized grains. The patches of "soft" recrystallized grains seemed to act as barriers to hydrogen-induced intergranular fracture by blunting crack tips.

In the tritium-exposed-and-aged samples, crack paths were affected by the patches of recrystallized grains in the microstructure, but fracture toughness values were low and relatively unaffected by the presence of the recrystallized grains in the microstructure. The "soft" recrystallized grains were more susceptible to helium-induced intergranular fracture than the HERF grains. Thus the patches of recrystallized grains in the HERF microstructure did not act as barriers to cracking in the tritium-exposed-and-aged samples as they did in the hydrogen-exposed samples.

Microstructural and Strength Effects on Hydrogen and Tritium-Induced Cracking in HERF 21-6-9 Stainless Steel

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SAVANNAH RIVER COMPANY

Materials Technology
MTS
Section

Michael J. Morgan

Fifth Meeting of the IMOG Subgroup on Mechanical Testing

July 11-13, 1989

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MICROSTRUCTURE AND YIELD STRENGTH EFFECTS ON HYDROGEN AND TRITIUM INDUCED CRACKING IN HERF 21-6-9 STAINLESS STEEL

Background

Experimental Procedure

Results

Mechanical Properties
Fracture Toughness Properties
Fracture Paths
TEM Observations

Summary

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BACKGROUND

Tritium Reservoirs Are Constructed From HERF Stainless Steels.

Hydrogen Isotopes and Helium:

Increase flow properties;
Decrease fracture toughness.

Since fracture toughness decreases with increasing strength, at least part of the helium embrittlement phenomena may be due to strength effects.

What is the relationship between a material's yield strength and toughness and, the incremental strength increase and corresponding toughness decrease imparted by helium?

Experimental Procedures

- 21-6-9 Stainless Steel

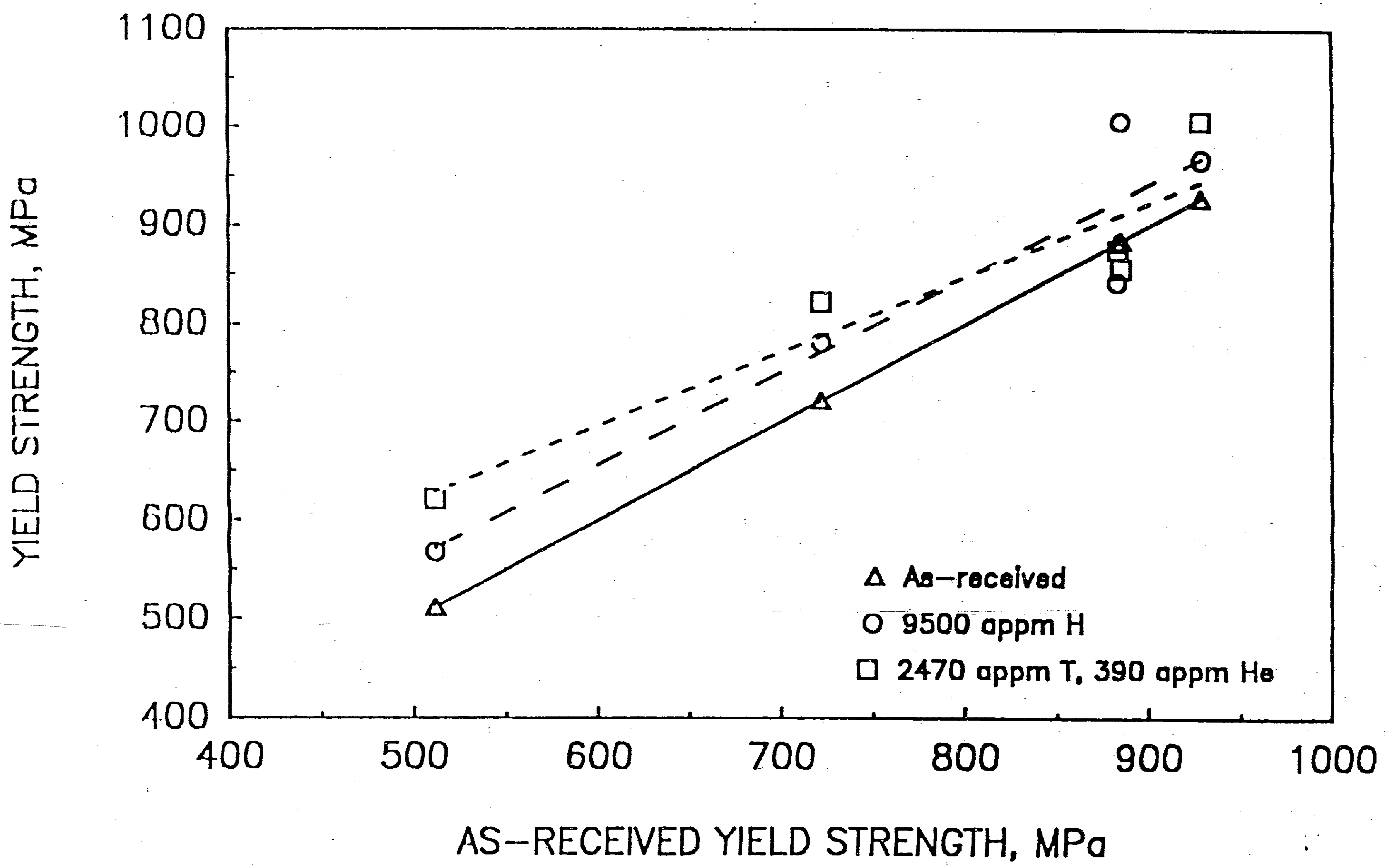
  Controls
  Hydrogen-Charged (350°C, 1000 psi): 9500 appm H
  Tritium-Charged (150°C, 7000 psi): 2250 appm T
  Aged @ 0°C: 0 - 300 appm He

- Microstructures

  HERF
  Annealed (870°C, 5 Min.)
  Yield Strengths: 75 - 135 ksi

- Room Temperature Tests

  Tensile Tests
  J-Integral Tests
  KTH Tests - Falling-Load



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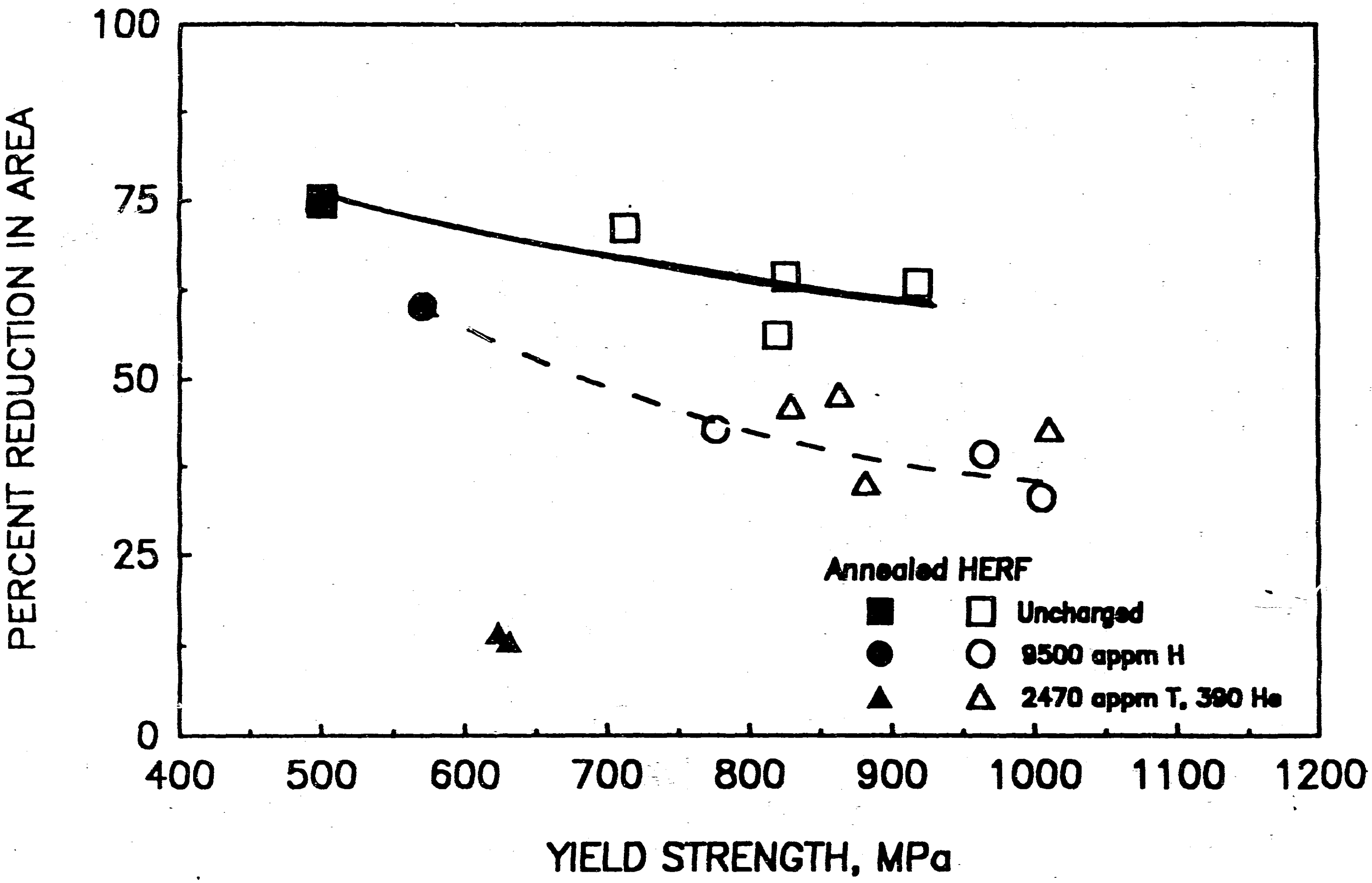
Ductility Decreased by Hydrogen and Helium



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Summary of Tensile Results

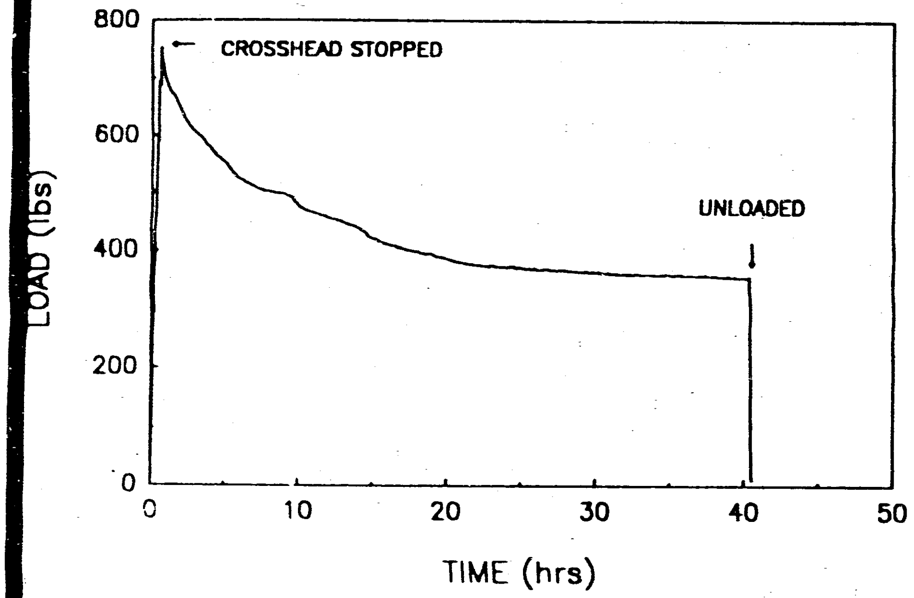
- Flow stress increased by H and He
- Ductility reduced by H and He
- Annealed microstructures much more susceptible to helium embrittlement than HERF microstructures.

Fracture Toughness Test Techniques

FALLING LOAD FRACTURE TOUGHNESS

SAMPLE ID: 126R11

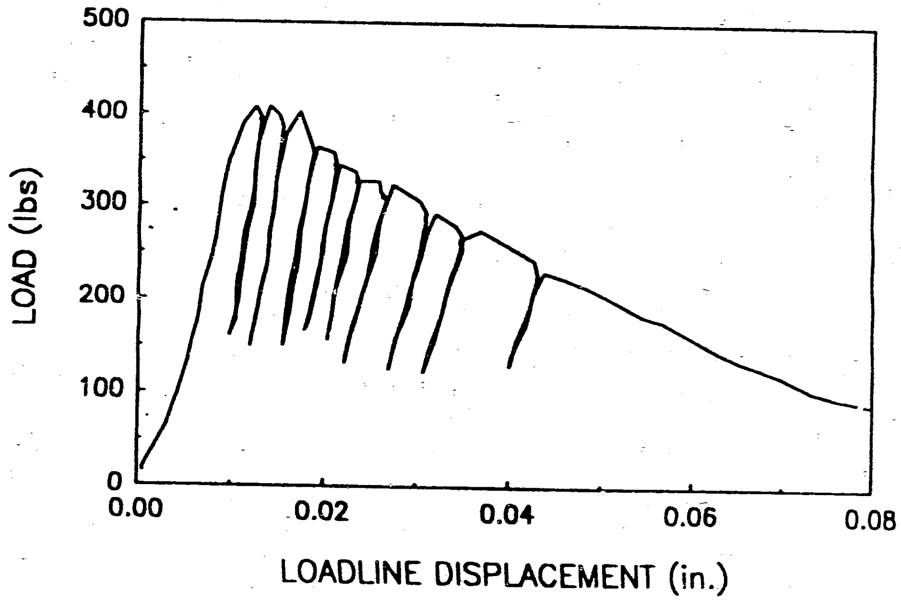
TEST DATE: 12/1/88



RISING LOAD FRACTURE TOUGHNESS

SAMPLE ID: 126R11

TEST DATE: 12/30/88



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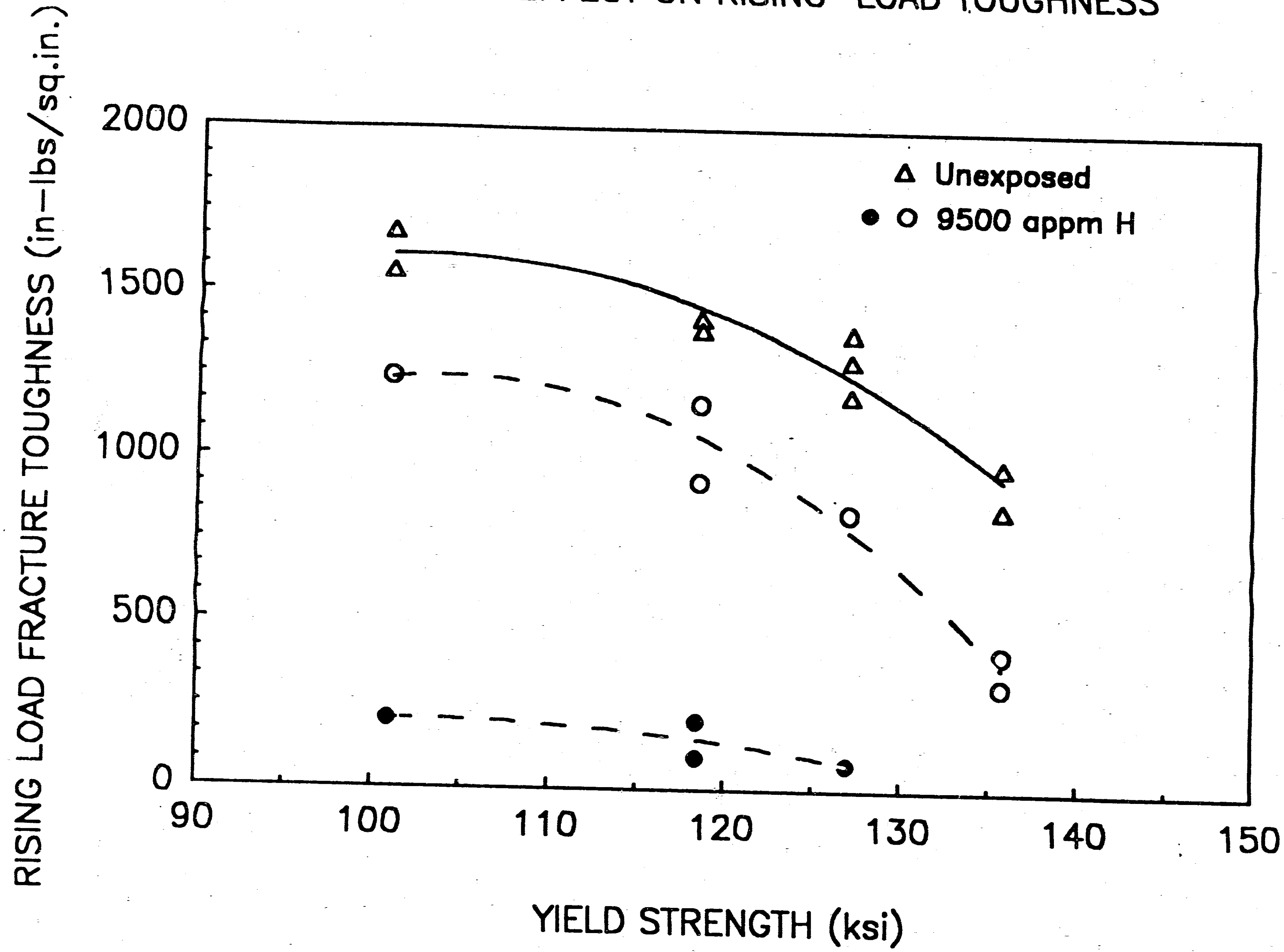
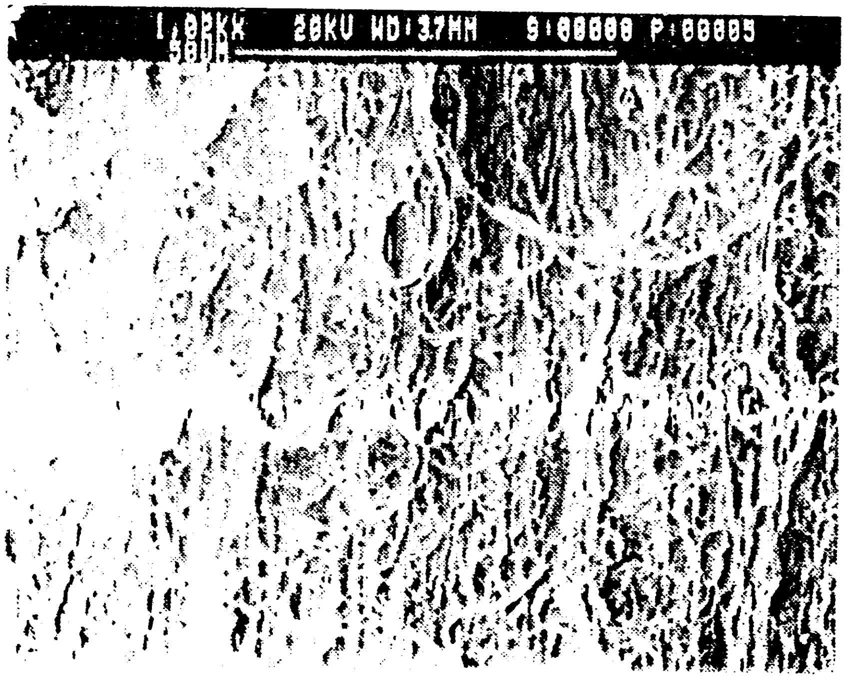
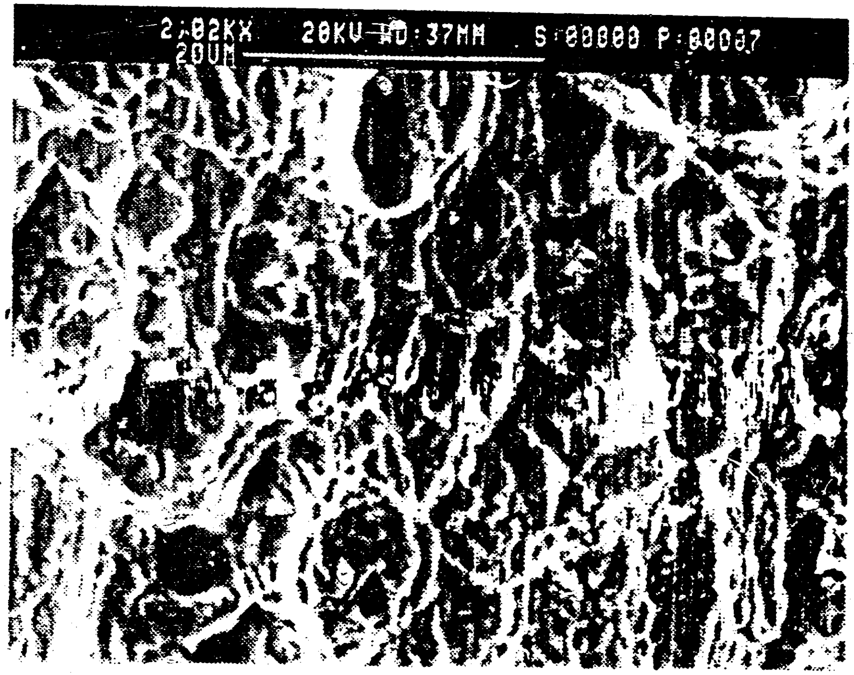
HYDROGEN EFFECT ON RISING-LOAD TOUGHNESS



HERF 21-6-9 Stainless Steel





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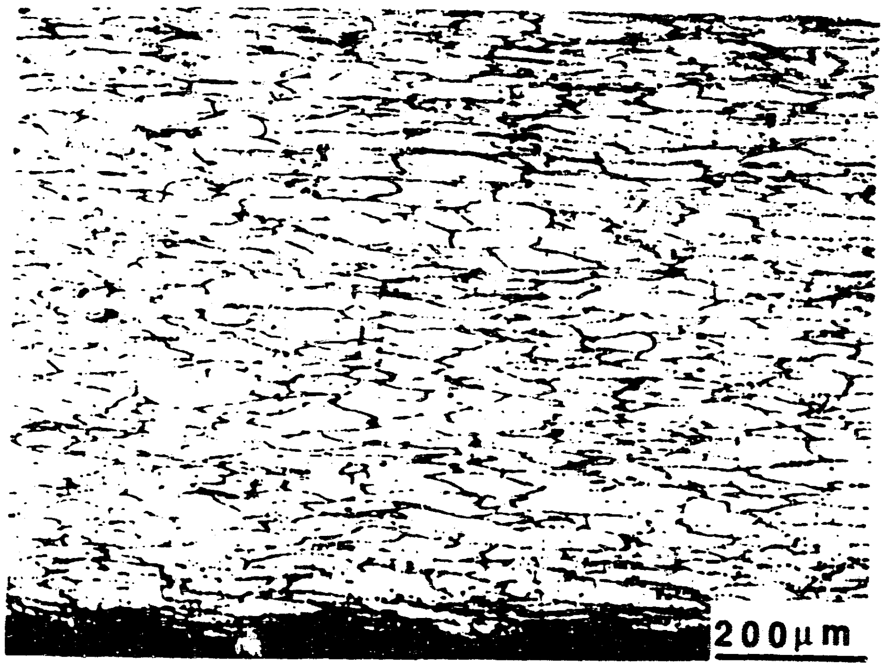
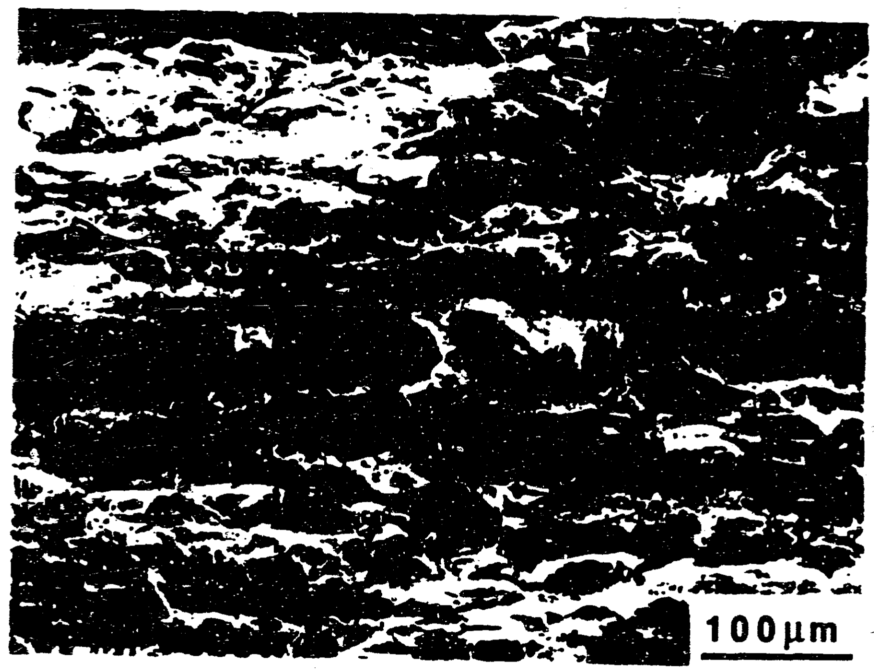
Hydrogen-Induced Cracking in HERFed 21-6-9

Low Toughness Microstructure



Uniform Microstructure



Intergranular Fracture

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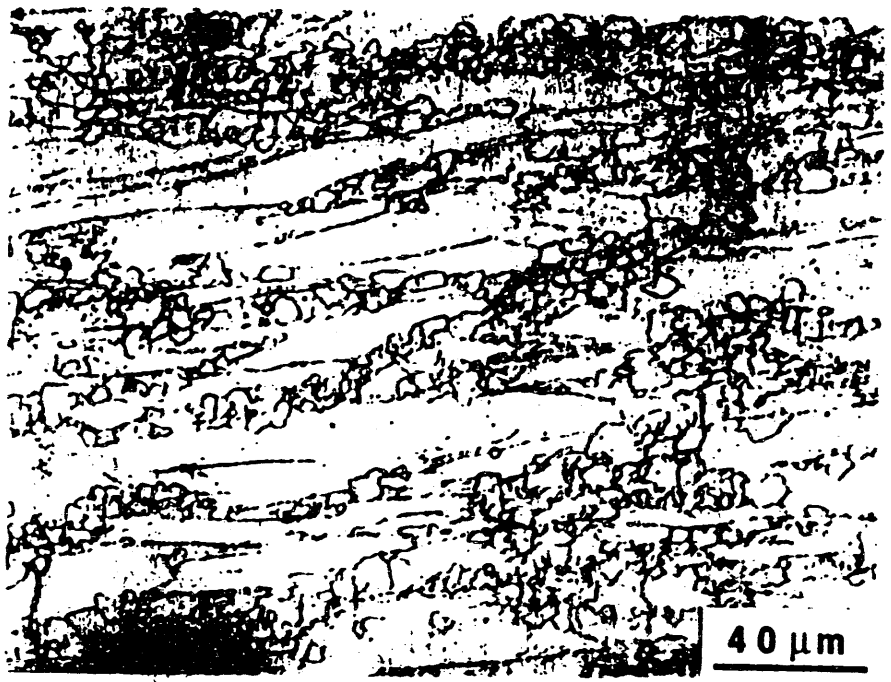
Hydrogen-Induced Cracking in HERFed 21-6-9

High Toughness Microstructure



Partially Recrystallized Microstructure

Mixed Mode Fracture

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High Toughness Microstructure

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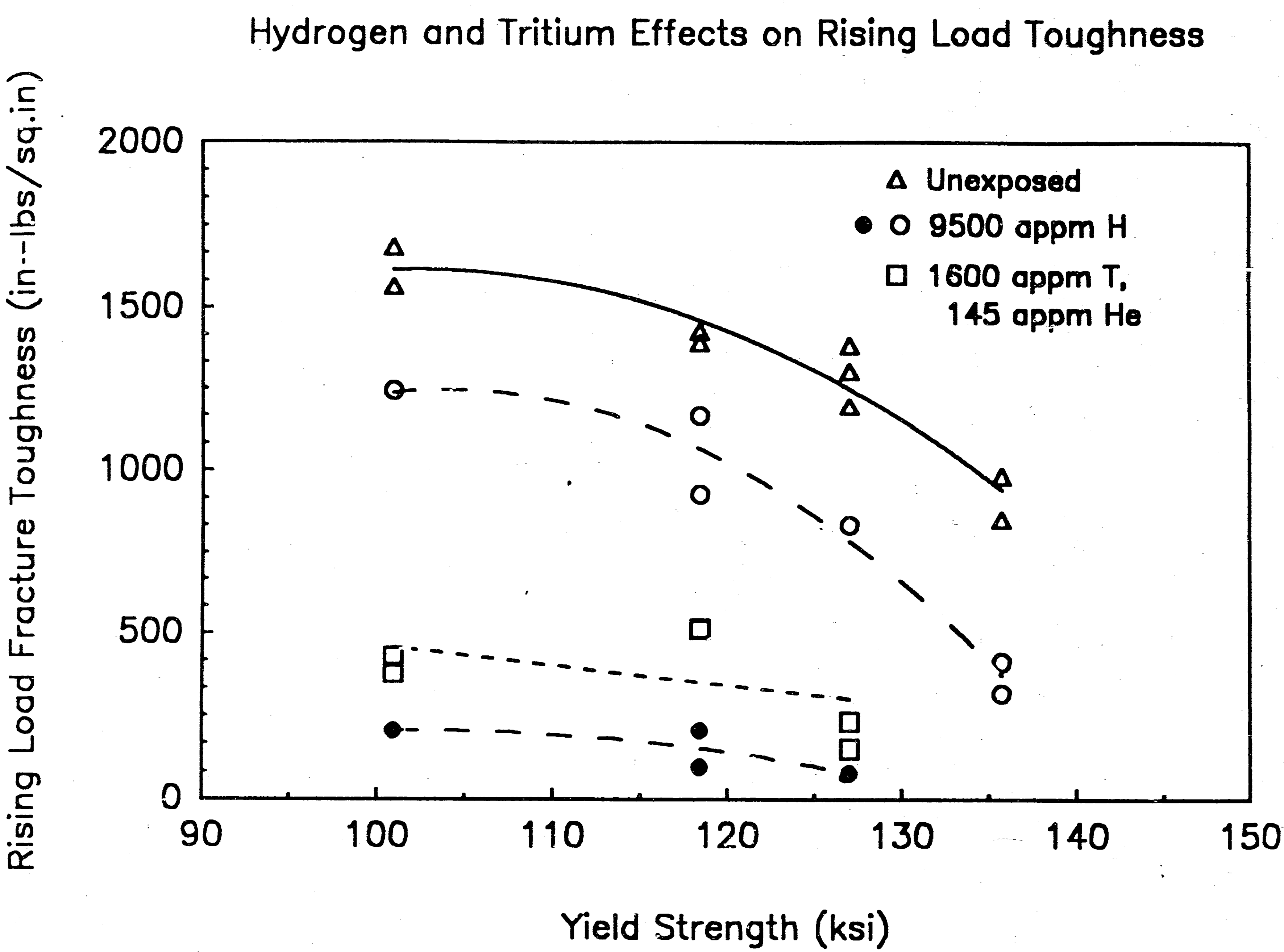
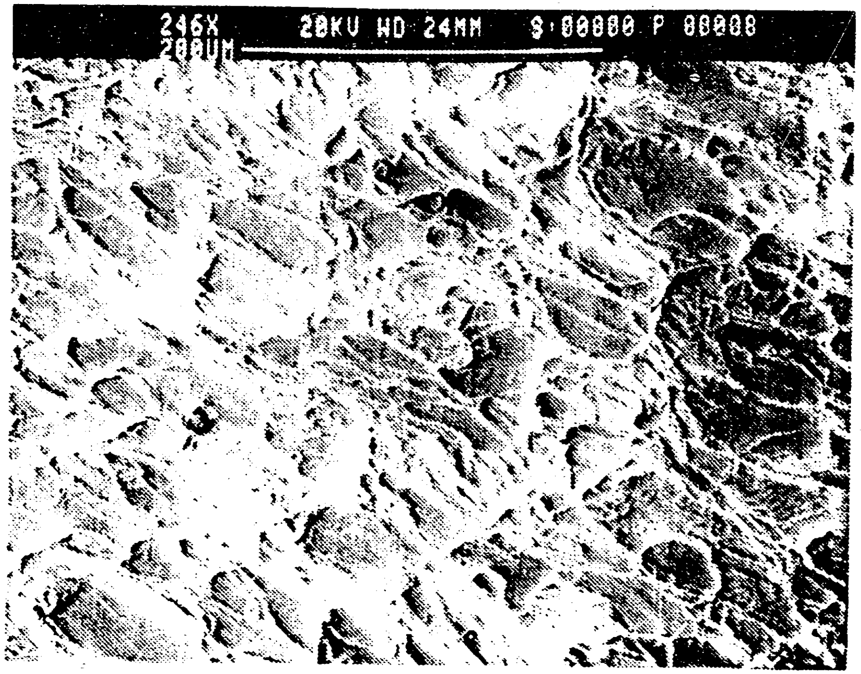
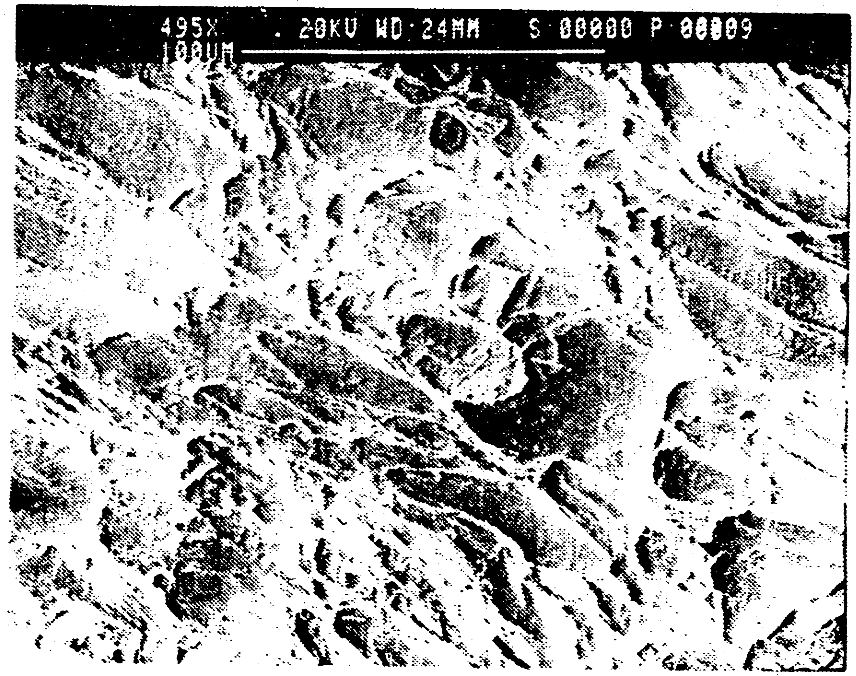

Hydrogen and Tritium Effects on Rising Load Toughness
Rising Load Fracture Toughness (in--lbs/sq.in)
2000
1500
1000
500
0
90
100
110
120
130
140
150
Yield Strength (ksi)
Unexposed
9500 appm H
1600 appm T,
145 appm He

Slow Crack Growth in

Tritium-Exposed 21-6-9





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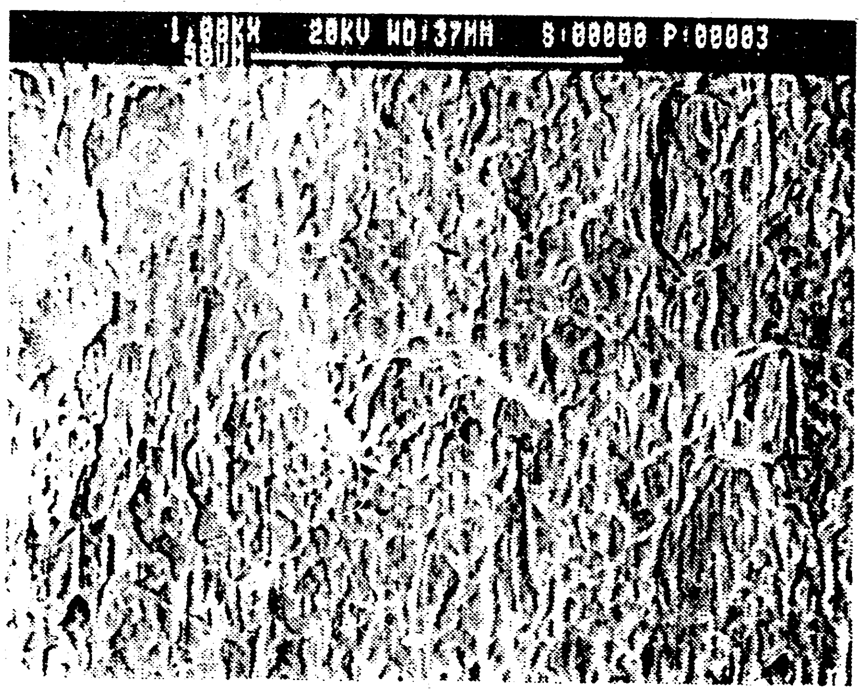
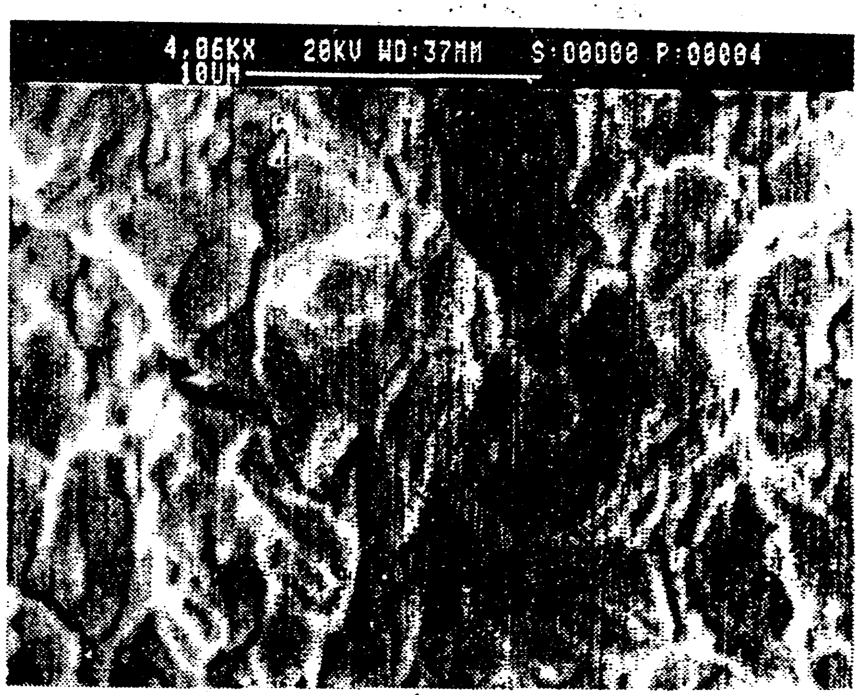
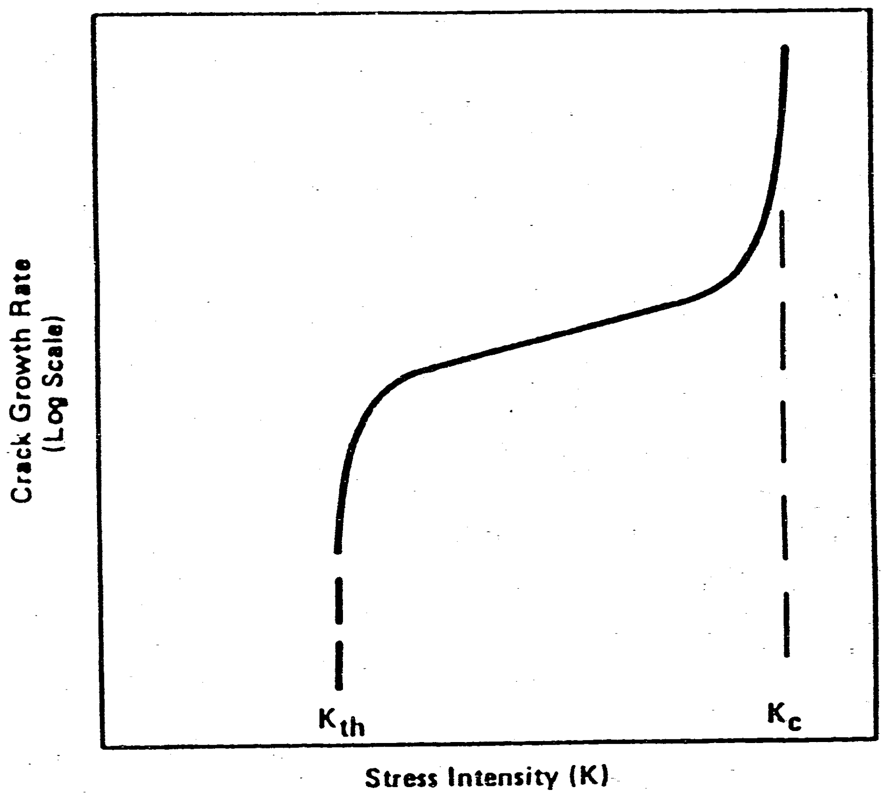
Slow Crack Growth in

Tritium-Exposed 21-6-9





Kinetics of Cracking



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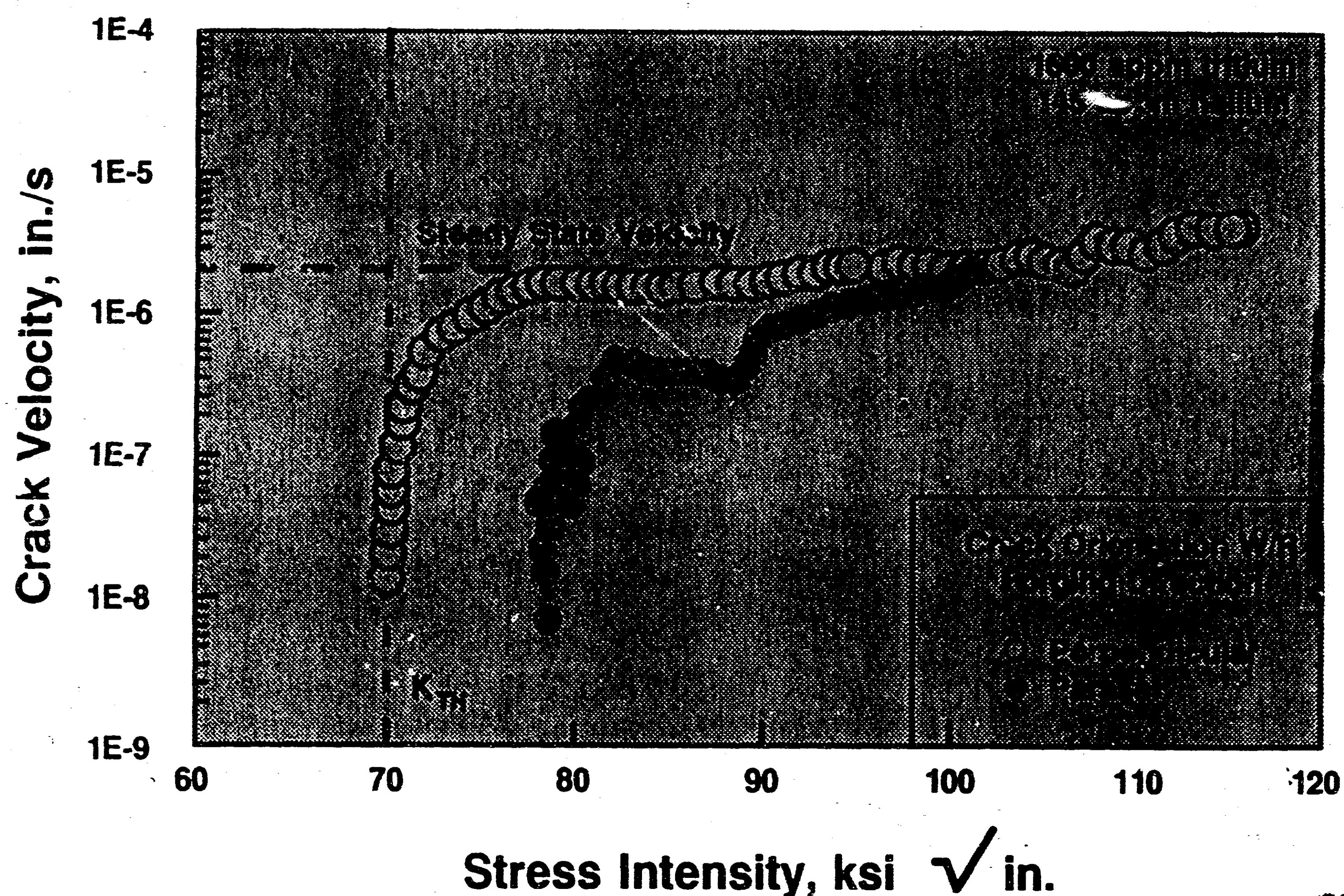
Tritium-Exposed-and-Aged HERF 21-6-9



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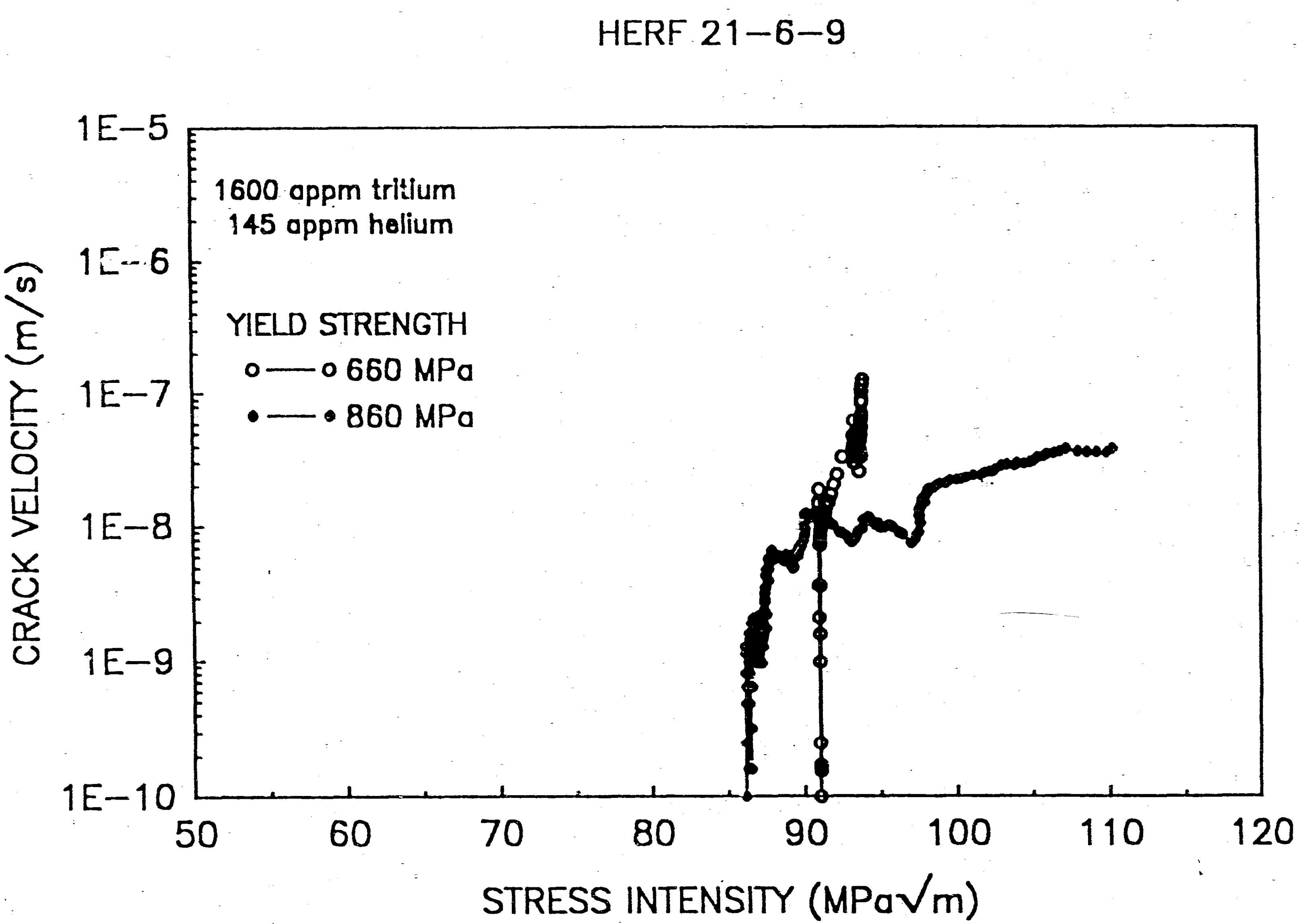

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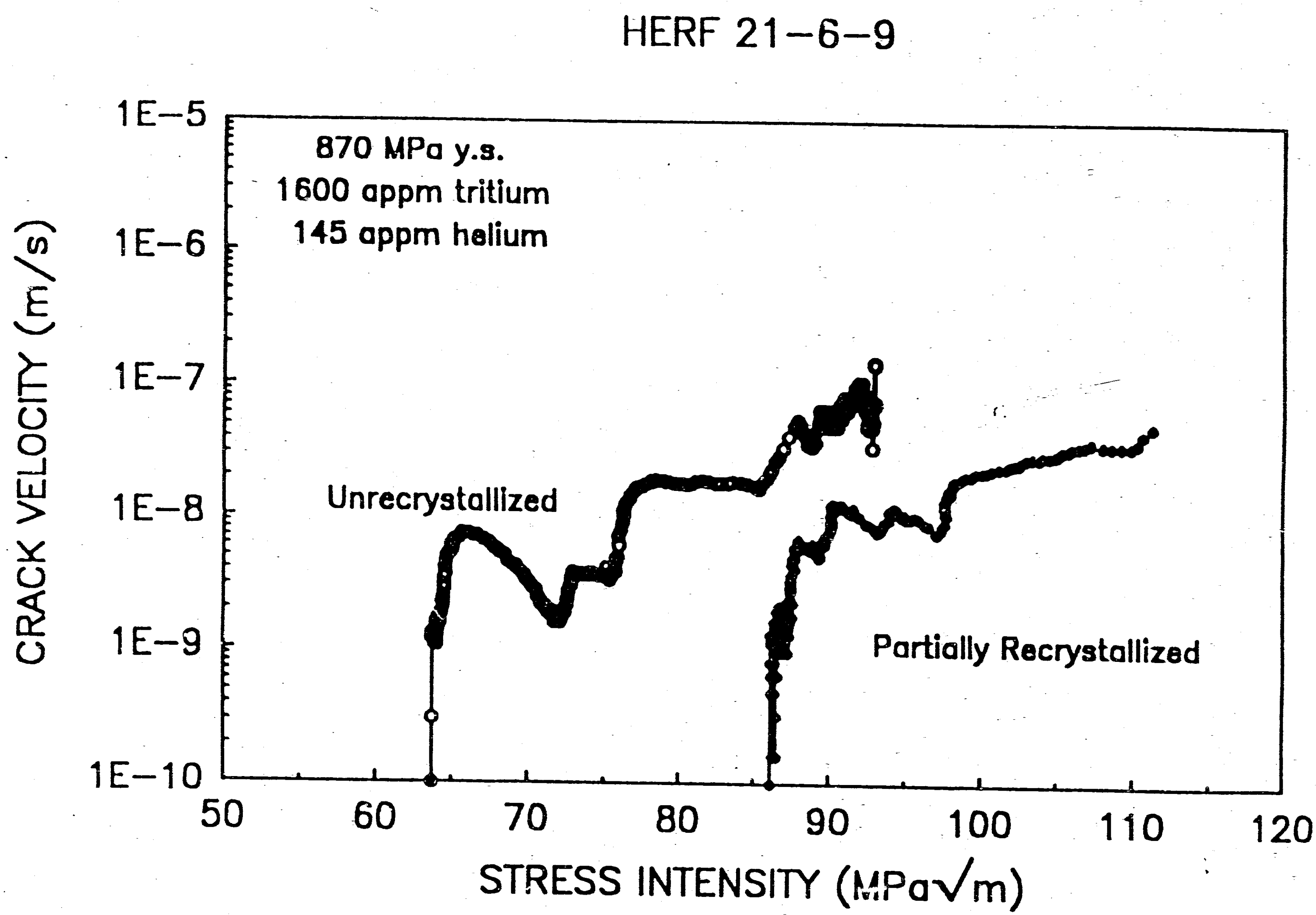

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Microstructural Effects on Fracture Toughness

- Presence of recrystallized grains in HERF microstructure improved the resistance to hydrogen-induced-cracking.

- The fracture toughness of tritium-exposed-and-aged samples was not affected by the presence of recrystallized grains in the microstructure.

Conclusions

The susceptibility of 21-6-9 stainless steel to hydrogen and helium embrittlement was greatly affected by microstructure.

"Soft" recrystallized grains imbedded in "hard" HERF microstructure acted as barriers to hydrogen-induced crack growth.

"Soft" recrystallized grains were <u>not</u> effective as barriers to crack growth in tritium-exposed-and-aged samples because of helium effects.

Dislocations in HERF microstructures reduced helium embrittlement by reducing grain-boundary helium concentrations.

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CC: H. Hancock, 703-43A
File(WSRC-MS-90-173
BSF-TIM-90-0296

May 21, 1990

Ms. W. F. Perrin, Technical Information Officer
U. S. Department of Energy
Savannah River Operations Office
Aiken, SC 29801

Dear Ms. Perrin:

REQUEST FOR APPROVAL TO RELEASE SCIENTIFIC/TECHNICAL INFORMATION

The attached document is submitted for approval for external release. Please complete Part II of this letter and return the letter to the undersigned by 06/05/90. Patent clearance is requested and received via direct communication between DOE Patent Counsel and Patent Reviewer. The document has been reviewed for classification by the WSRC Classification Officer and a designated WSRC Derivative Classifier and has been determined to be unclassified/~~UCNI~~.

J. A. Duschinski, WSRC Technical Information Manager

I. DETAILS OF REQUESTFOR RELEASE

WSRC-MS-90-173, "MICROSTRUCTURE AND YIELD STRENGTH EFFECTS ON HYDROGEN-AND TRITIUM-INDUCED CRACKING IN 21-6-9 STAINLESS STEEL (U), By M. J. Morgan.

A paper that was presented at the 5th Meeting of the IMOG DOE Subgroup on Mechanical Testing in Livermore, CA on July 11-13, 1989, and now proposed for publication in the proceedings of that meeting.

Technical questions pertaining to the contents of this document should be addressed to the author(s) or

J. M. Stone, Manager
Materials Technology
Savannah River Site

Questions concerning processing of this document should be addressed to the WSRC Technical Information Manager, 5-3992 or 5-2846.

II. DOE-SR ACTION

DATE RECEIVED BY TIO________________

____Approved as written .
___Remarks.

_____Not approved as written;_____revise and resubmit to DOE.
_____ Approved upon completion of changes marked on document.

____

____

_______________________________ Date______________
W. F. Perrin, Technical Information Officer, DOE-SR

OSR 25-82-W(4-89)

Westinghouse
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P.O. Box 616
Aiken, SC 29802

BSF-TIM-89-0296

May 21, 1990

Mr. Harold M. Dixon, Patent Counsel
U. S. Department of Energy
Aiken, South Carolina 29802

Dear Mr. Dixon:

REQUEST FOR PATENT REVIEW

Please review for patent matters:

WSRC-MS-90-173, "MICROSTRUCTURE AND YIELD STRENGTH EFFECTS ON HYDROGEN-AND TRITIUM-INDUCED CRACKING IN 21-6-9 STAINLESS STEEL (U), " By M. J. Morgan.

A paper that was presented at the 5th Meeting of the IMOG DOE Subgroup on Mechanical Testing in Livermore, CA on July 11-13, 1989, and now proposed for publication in the proceedings of that meeting.

If you decide to pursue a patent on any development covered, I shall be happy to supply additional information required such as appropriate reference and the names of persons responsible for the development. A copy of this document review letter is attached to indicate that the document was reviewed by the WSRC Patent Reviewer. If any clarification is needed you may call me at 5-3992.

Very truly yours,

J. A. Duschinski (JD)

J. A. Duschinski,
Technical Information Management

The above document is approved for release.

____________________ __________
Patent Counsel Date
DOE-SR

BSF-TIM-89-0296

May 21, 1990

TO: J. A. DUSCHINSKI

FROM: C. J. BANICK

DOCUMENT REVIEW

Document(s): WSRC-MS-90-173

Title(s): MICROSTRUCTURE AND YIELD STRENGTH EFFECTS ON HYDROGEN-AND TRITIUM-INDUCED CRACKING IN 21-6-9 STAINLESS STEEL (U)

Author: M. J. Morgan

Contractual Origin: DE-AC09-89SR18035

Present Classification: Unclassified Paper

References:

No items were noted that, in my opinion, should be called to the attention of the DOE for patent consideration.

cc: H. M. Dixon, DOE-SR Patent Counsel

END

DATE FILMED

12 / 27 / 90