Program 6 Deformation and Fracture of Aluminum-Lithium Alloys: The Effect of Dissolved Hydrogen

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Objective

The objective of this study is to characterize and understand the effects of hydrogen on the deformation and fracture behavior of 2090 and 2219, especially at low temperatures. Additionally, 8090 and Weldalite will be included in this program.

HYDROGEN EMBRITTLEMENT OF Al-Li ALLOYS

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Abstract

The objective of this work is to study the effects of dissolved hydrogen on the mechanical properties of 2090 and 2219 alloys. The work done during this semi-annual period consists of the hydrogen charging study and some preliminary mechanical tests. Prior to SIMS analysis, several potentiostatic and galvanostatic experiments were performed for various times (going from 10 minutes to several hours) in the cathodic zone, and for the two aqueous solutions: 0.04N of HCl and 0.1N NaOH both combined with a small amount of As_2O_3. A study of the surface damage was conducted in parallel with the charging experiments. Those tests were performed to choose the best charging conditions without surface damage. Disk rupture tests and tensile tests are part of the study designed to investigate the effect of temperature, surface roughness, strain rate, and environment on the fracture behavior. In the present study, the importance of the roughness and environment have been shown using the disk rupture test as well as the importance of the strain rate under hydrogen environment. The tensile tests, without hydrogen effects, have not shown significant differences between low and room temperature.

Hydrogen Embrittlement of Al-Li Alloys

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Overview

- Objectives
- Approach
- Charging Experiments
  - Solutions tested
  - SIMS results
- Mechanical Tests
  - Disk Rupture
  - Tensile tests

Overview (Cont.)

- Aging experiments
  - PA for 2090T3 and W51
  - X-Ray Analysis
- Summary
- Need to Address
- Future work

Objectives

- Characterize effects of temperature, stress state, hydrogen on mechanical behavior.
- Correlate these effects with microstructure.

Approach

- Charpy Impact Test.
- Tensile Test
  control hydrostatic stress.
- Disk Rupture Test
  biaxial loading.
- Three Point Bend Test
  low strain rate.

Charging Experiments

- Methods to Charge Samples
- Electrochemical Solution
- Surface Analysis
- SIMS Results

Charging Experiments

Two principal methods can be used to charge samples:

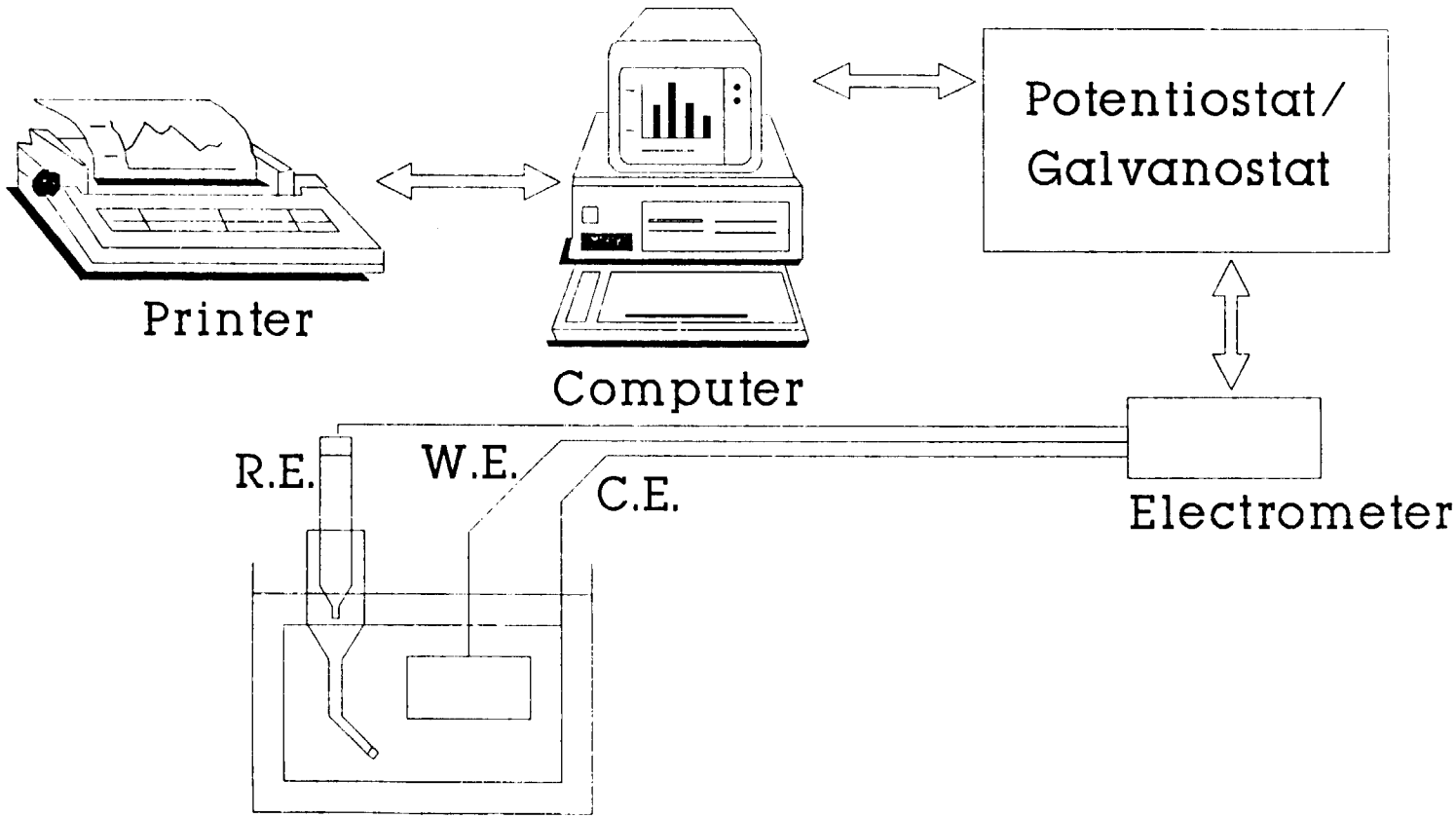
- Autoclave
- Electrochemical cell

Choice of the Aqueous Solution

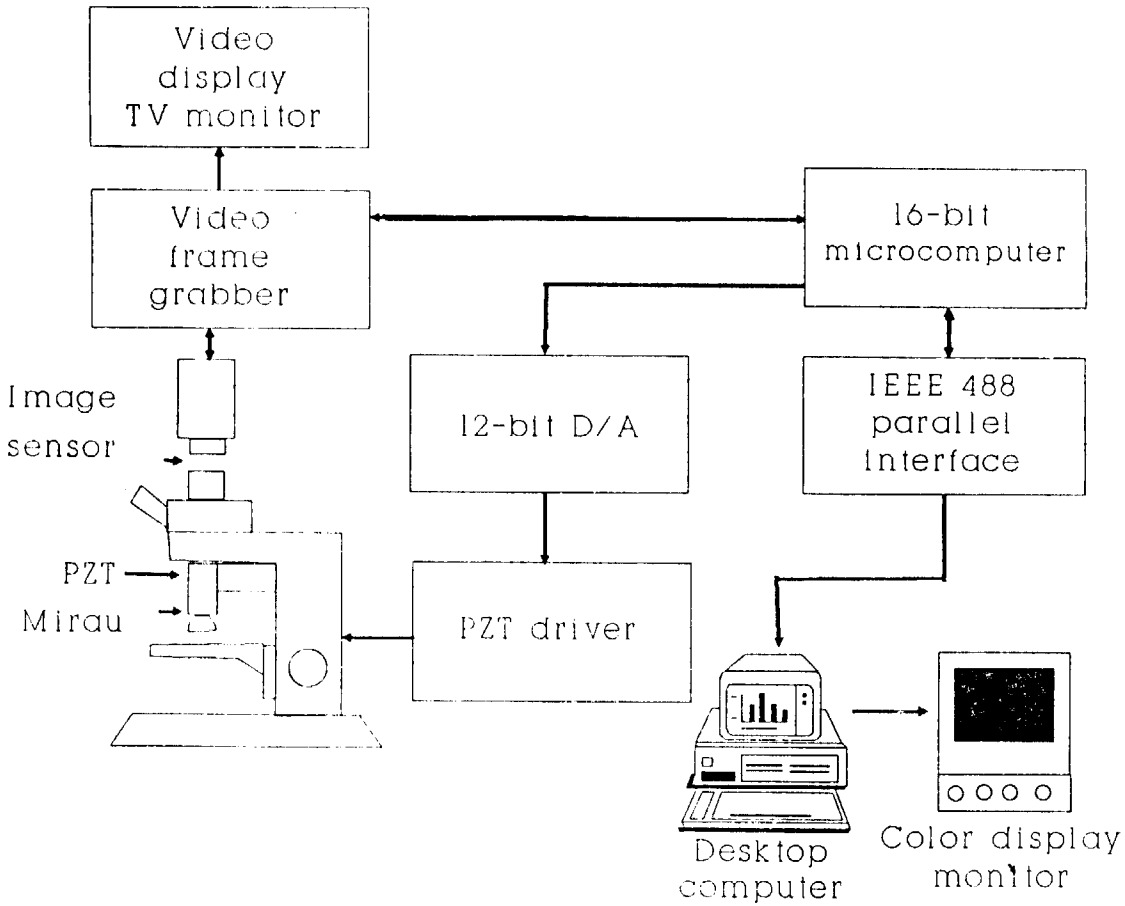
- Must contain H+
  => Low pH.

- Must not damage the sample
  => Choice of the charging voltage or current.

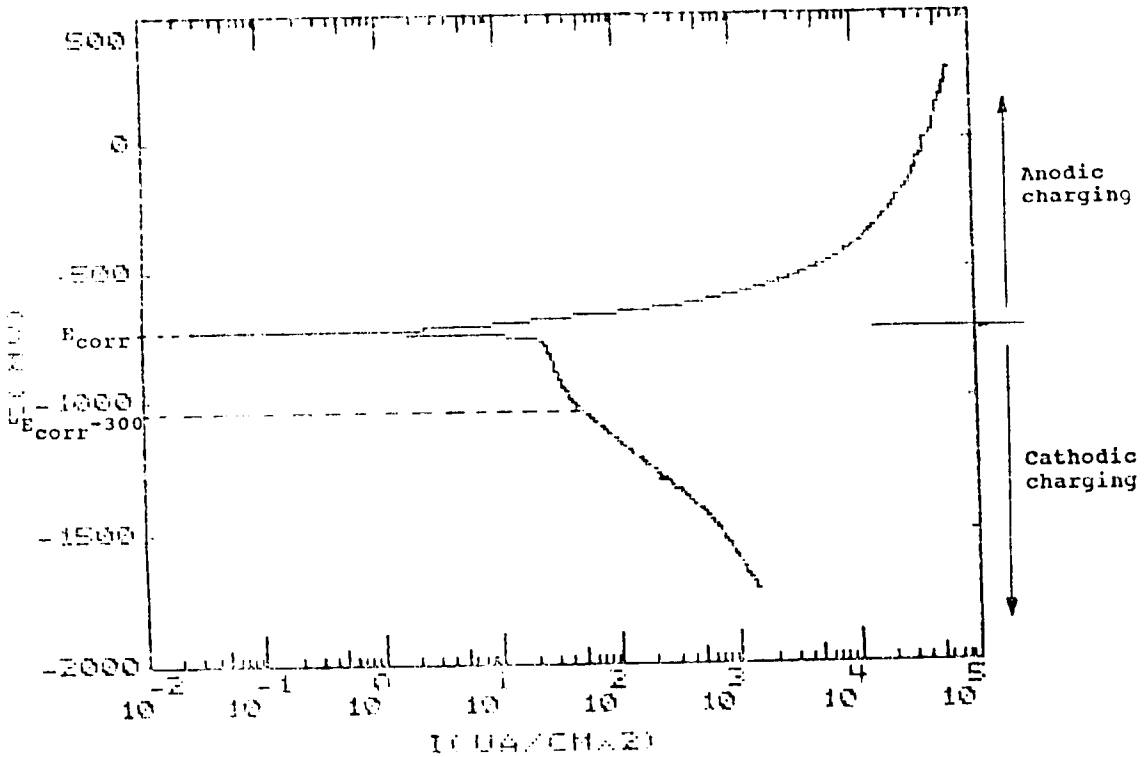
Instrumental Scheme



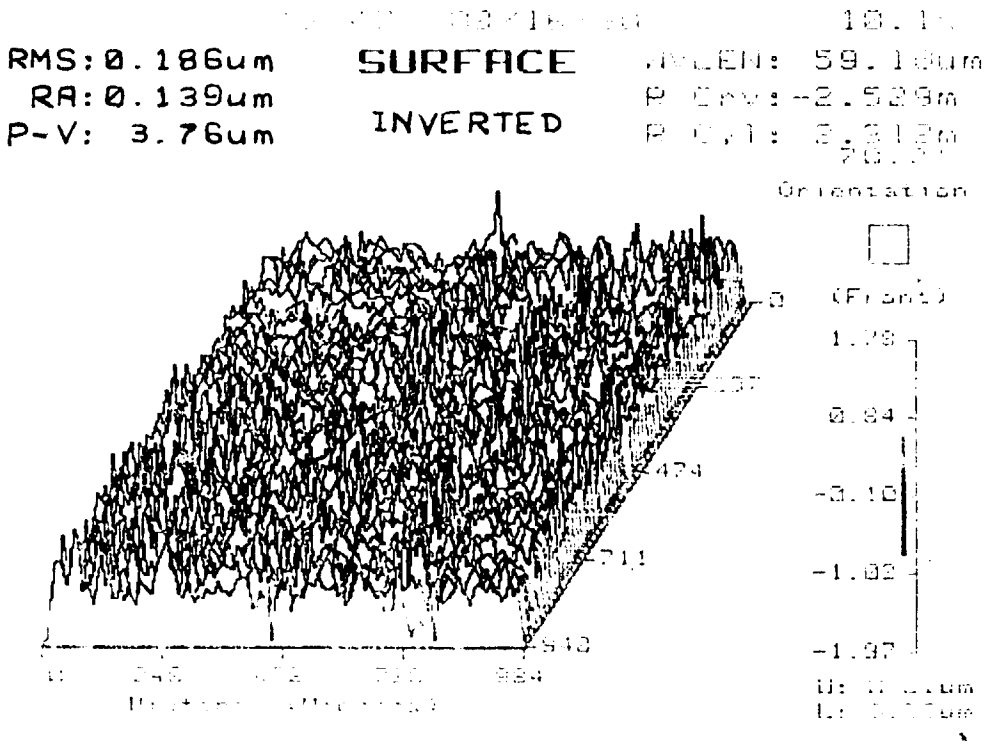
Optical Profilometer



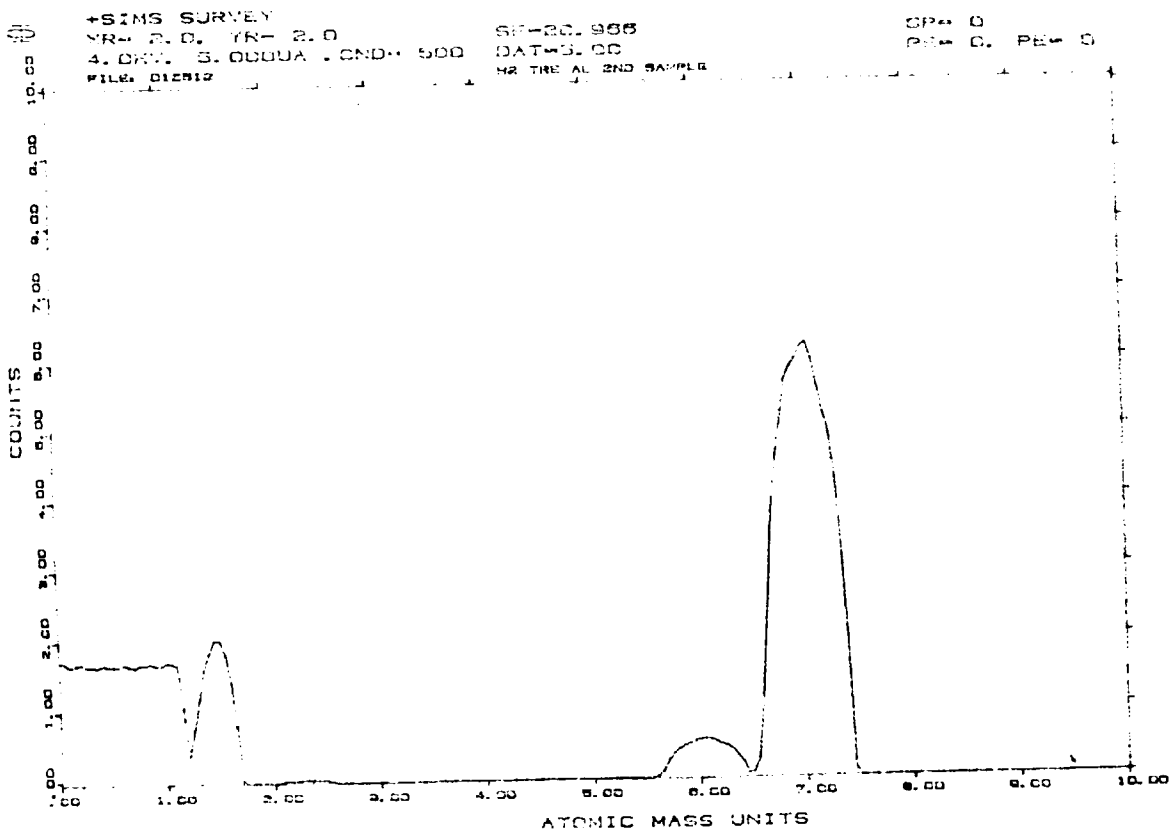
Choice of the Voltage



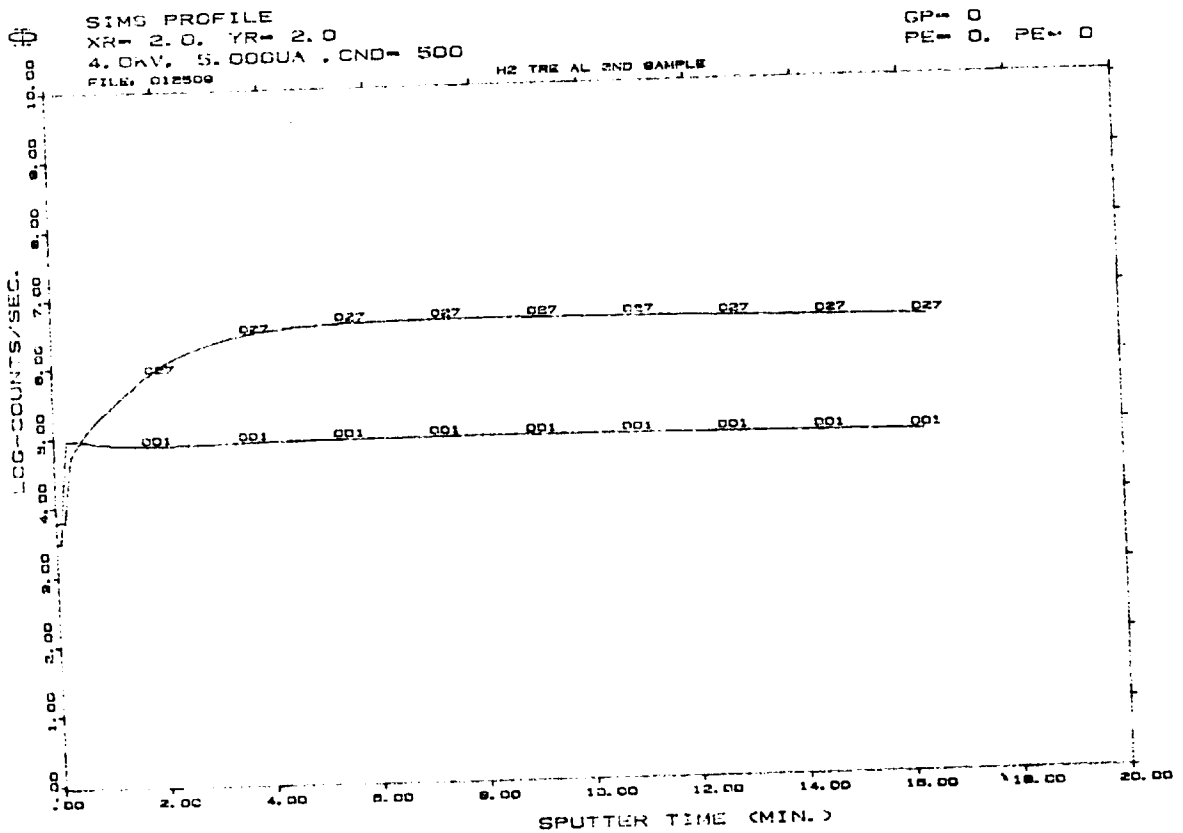
Optical Profilometer (Results)



SIMS Results



SIMS Results



Interim Results

Hydrogen Charging Parameters

- 0.04 N HCL + As2O3 at -3V (1)
- 0.1 N NaOH + As2O3 at -3V (2)
- 0.04 N HCl + As2O3 at -500 μA (3)
- 0.04 N HCl + As2O3 at -5000 μA (4)

Interim Results

Hydrogen Charging Parameters

Solution	Time	Dif. of counts/sec	H content	Surface Roughness RMS (μm)
(1)	5 hrs	0.057		0.0795
(2)	.5 hrs	------		0.185
(3)	20 hrs	0.059		0.0772
(4)	20 hrs	0.0185		0.0861
Uncharged	-----	------		0.0752

Interim Results

Hydrogen Charging Parameters

The two selected charging solutions are:

- 0.04 N HCl+As2O3 at -3 V for 5 hrs
- 0.04 N HCl+As2O3 at -500 μA for 20hrs

Charging Experiments

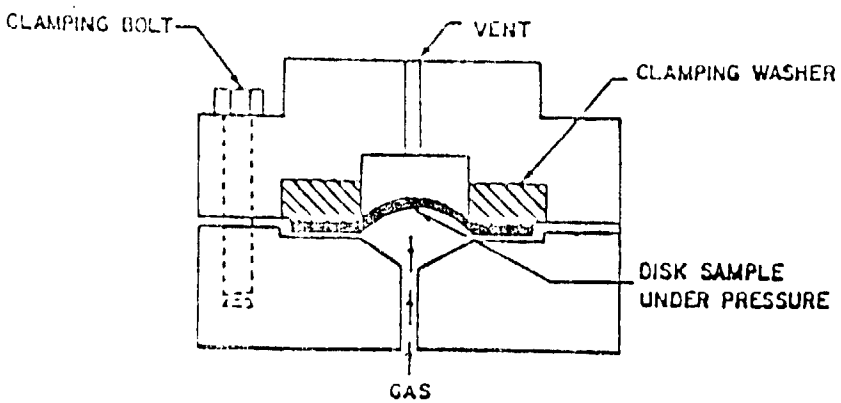
- SIMS technique has not yet been successful
- Evaluating other surface analytical techniques for hydrogen content and hydrogen profile

Disk Rupture Tests

- vary strain rate
- compare effect of nitrogen vs. effect of hydrogen
- vary surface finish

Disk Rupture tests

SCHEMATIC OF DISK PRESSURIZING ASSEMBLY



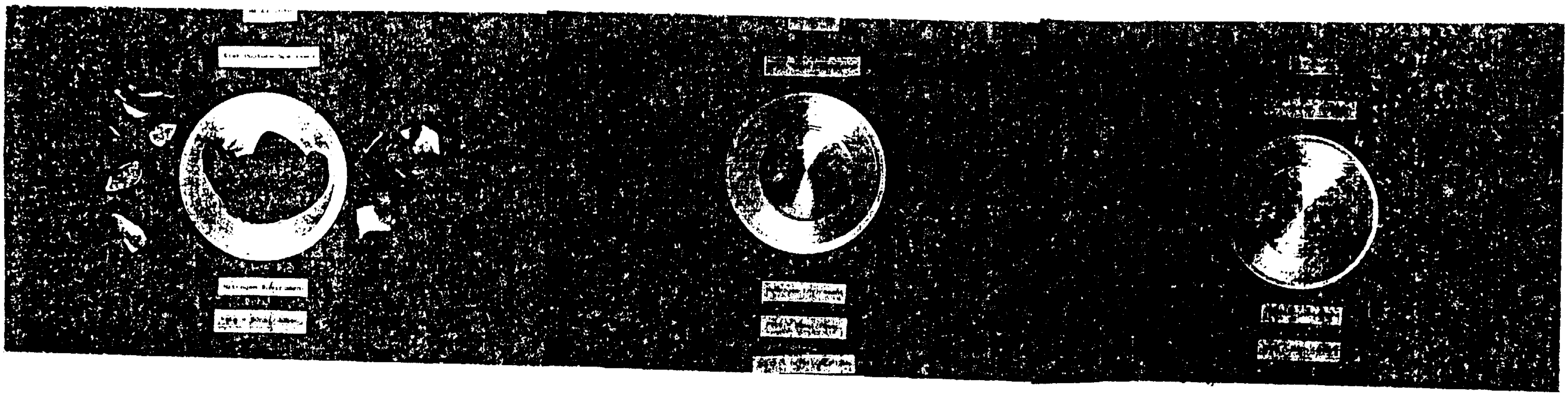
Interim Results

Disk Rupture Tests

Specimen	Hydrogen	Nitrogen
50psi/20sec	0.16in/.85ksi *	0.22in/1.6ksi
50psi/200sec	0.2in/1.15ksi *	0.19in/1.65ksi
50psi/300sec	0.14in/.7ksi	0.18in/1.45ksi
50psi/20sec(60 grit)	0.15in/.6ksi	= = = = = = = =
50psi/200sec(60 grit)	0.18in/.8ksi	= = = = = = = =
50psi/300sec(60 grit)	0.13in/.6ksi	= = = = = = = =

* Leaked instead of rupture

Typical Failures for the Disk Rupture Tests



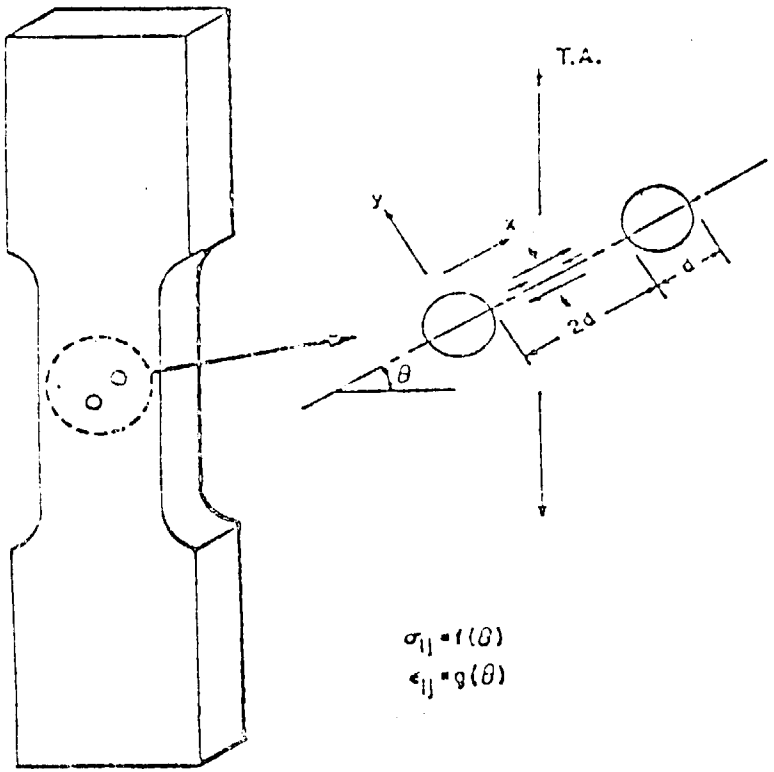
Interim Results
Disk Rupture Tests

- Minimized hydrogen embrittlement at intermediate strain rate.
- Rough surface results in burst type failure
- Rough surface decreased failure pressure
- The strain rate had no effect in nitrogen

Tensile Tests

- charged and uncharged
- vary σ_H
- vary temperature
- vary gas pressure

Tensile Tests



Schematic or Two-Hole Flat Tensile Specimen

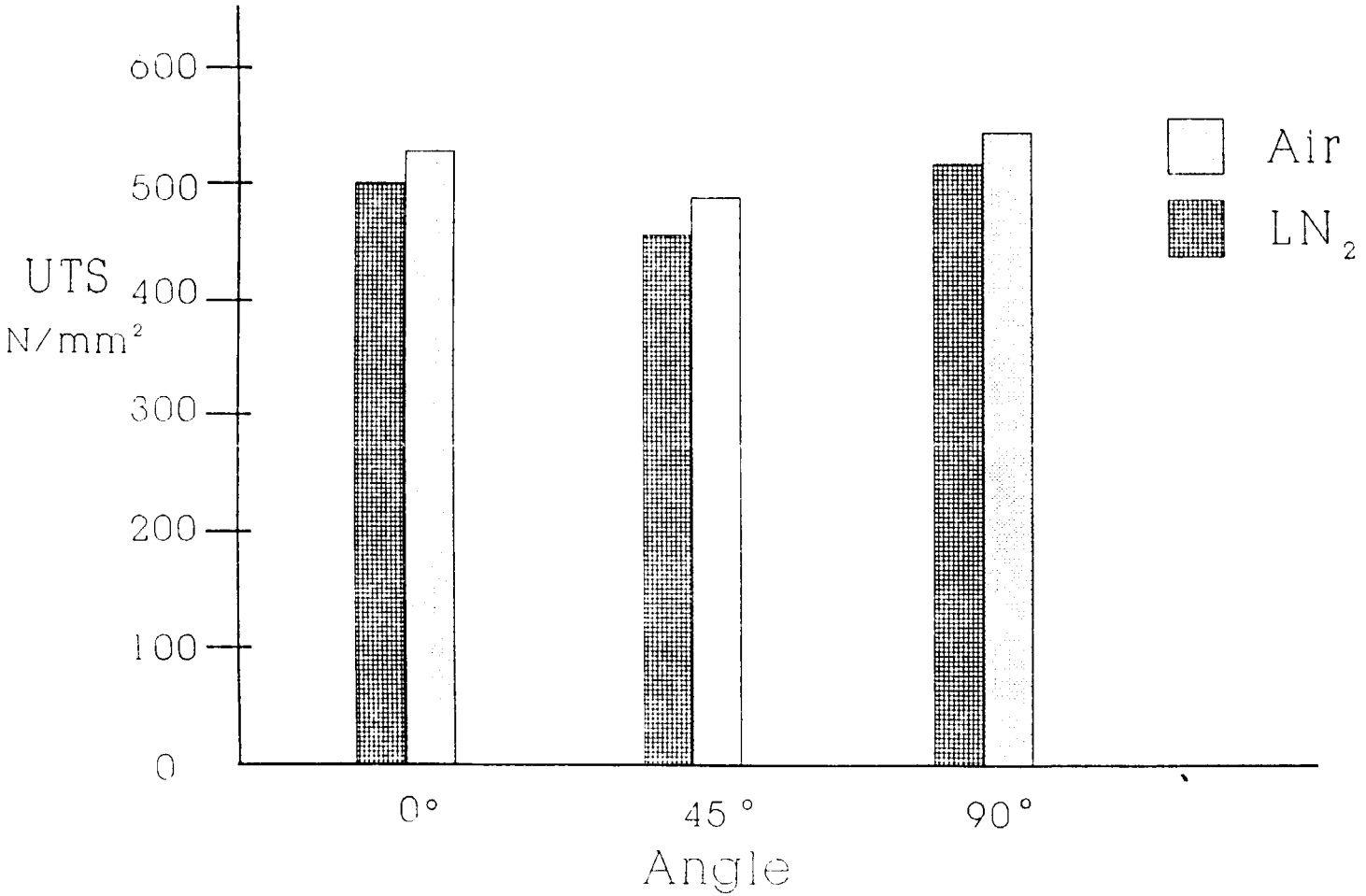
Interim Results

Tensile tests

Angle	Envir.	UTS, N/mm2	TD, mm	Ef, %
0 deg	Air	500	1.626	3.4
	LN_2	528	1.321	2.8
45 deg	Air	456	1.232	2.6
	LN_2	489	1.016	2.1
90 deg	Air	516	1.626	3.4
	LN_2	546	1.854	3.9

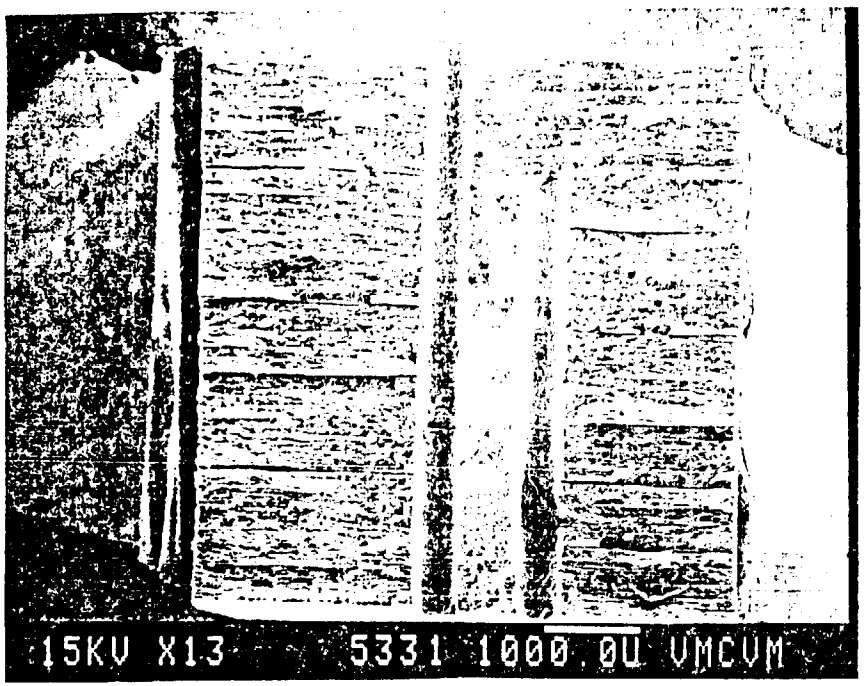
Interim Results

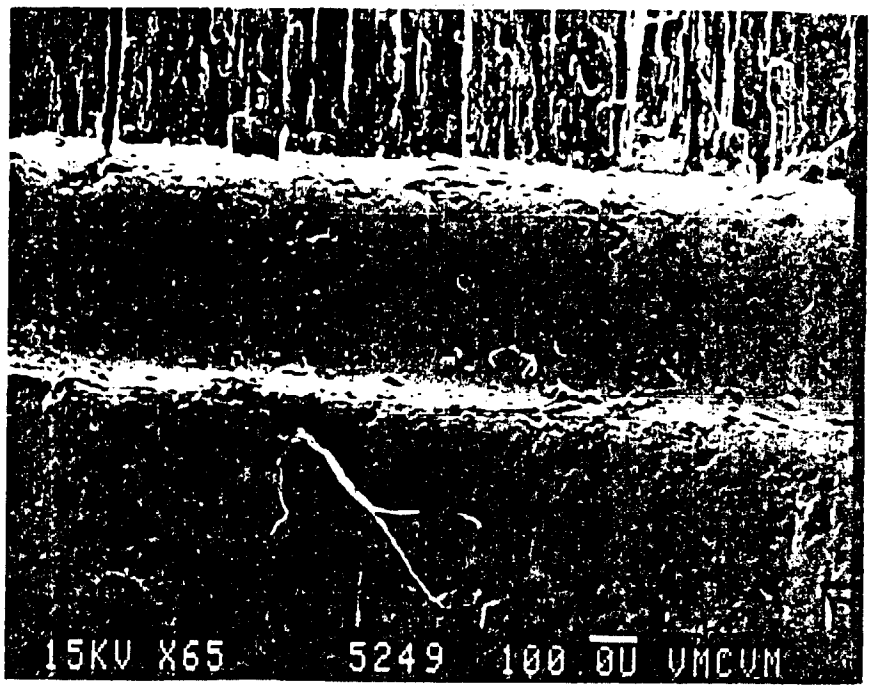
Tensile Tests



Fractography

Tensile Test Specimen at 45





Interim Results

Tensile tests

- Greatest UTS for 90 ,
  lowest for 45 .

- No difference between room temperature and low temperature.

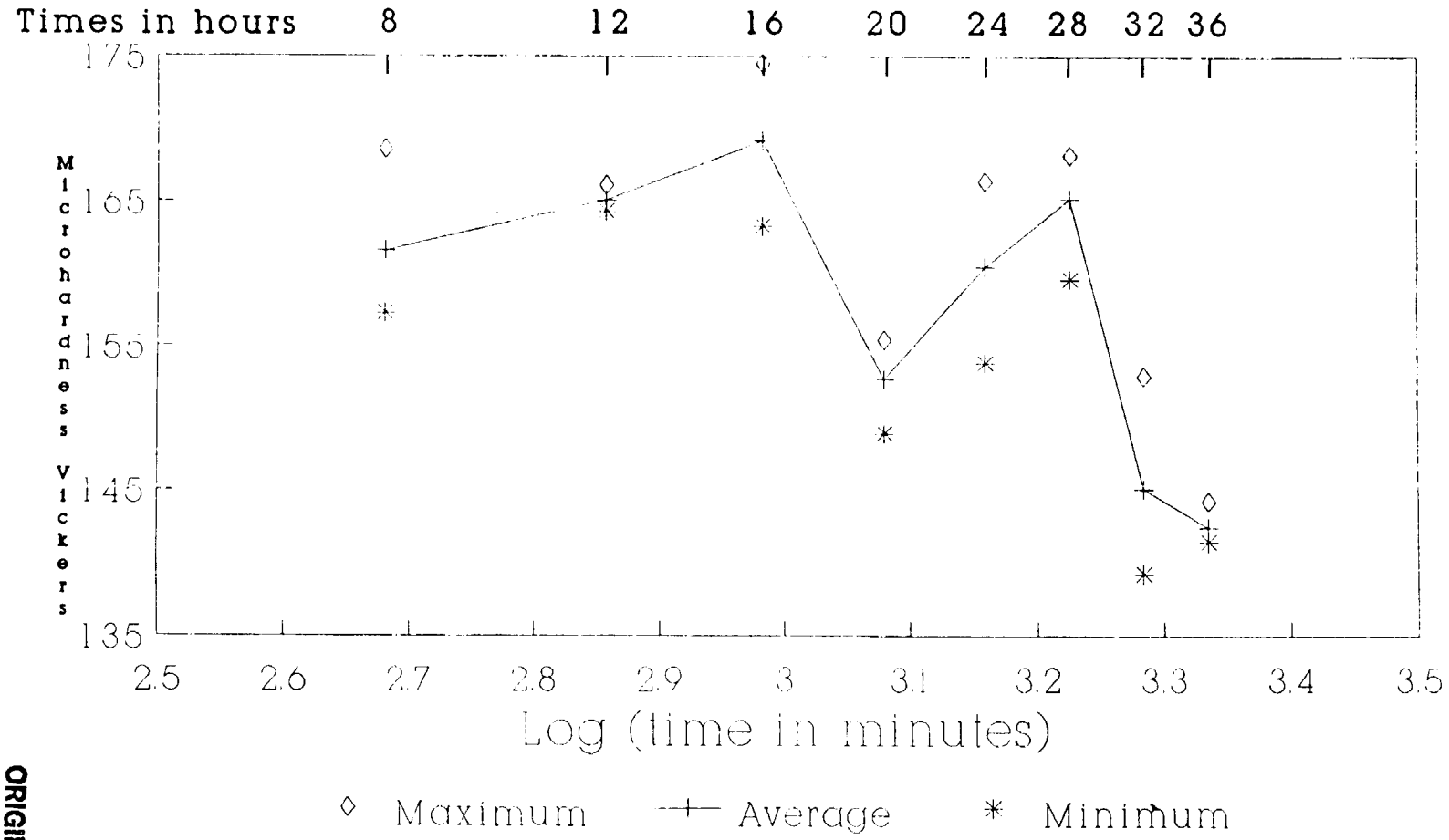
- Fracture initiation close to the hole and rapid propagation.

- Ductile fracture only for 45 , and between the holes.

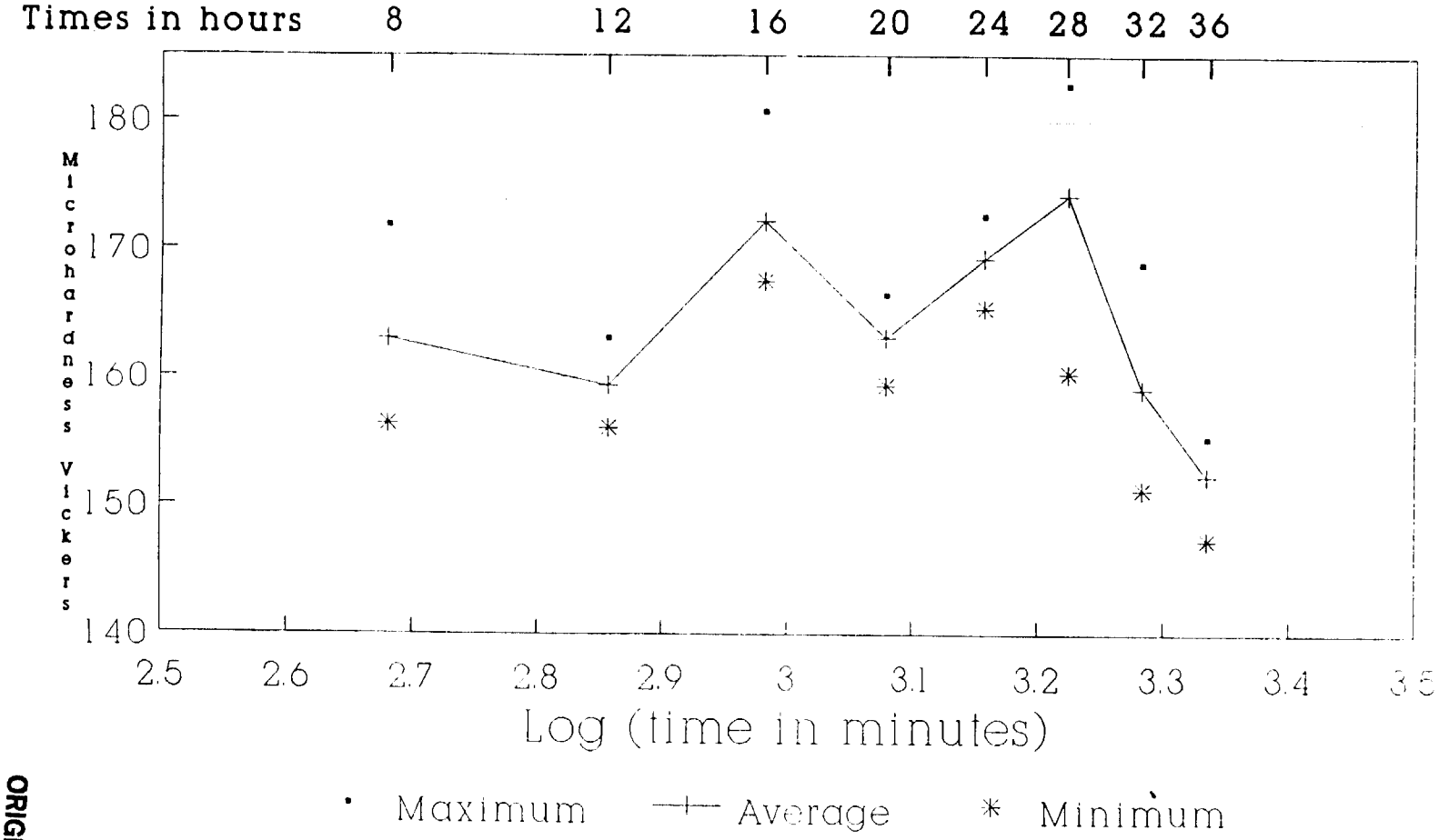
Aging Experiments

- Aging curves for 2090 T3 & W51
- X-Ray analysis

Aging curve of 2090 T3 at 170 C



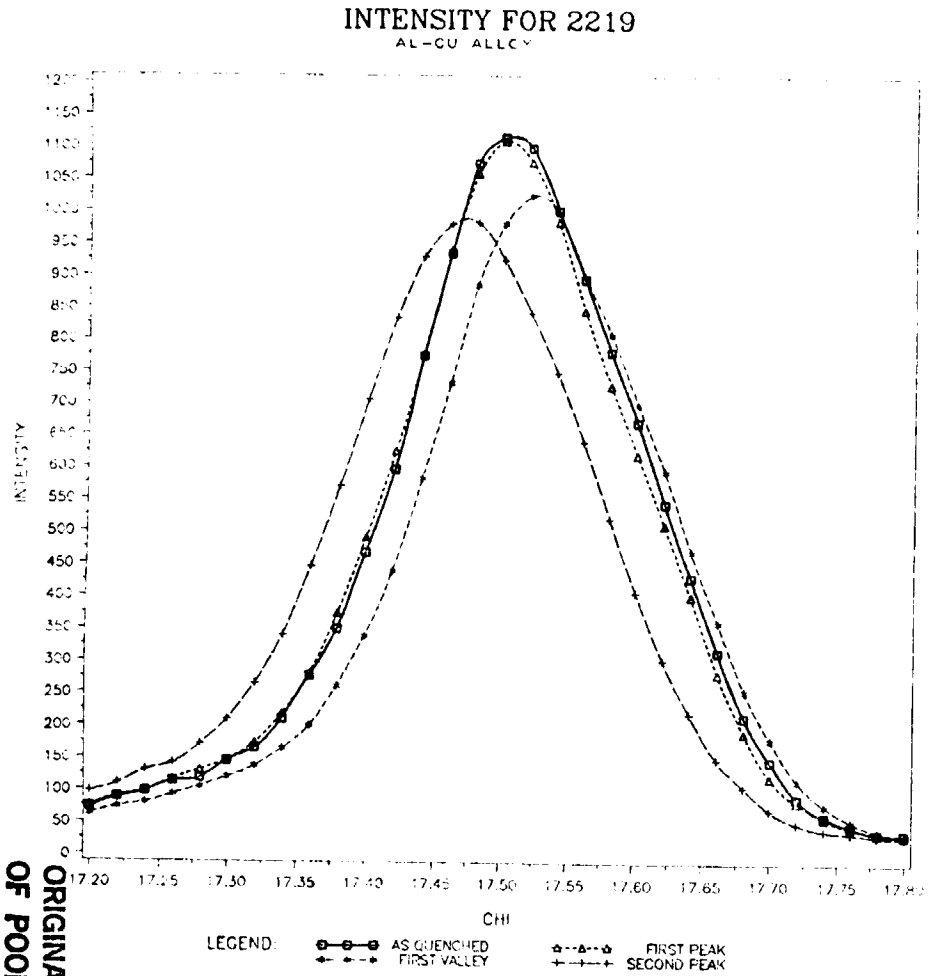
Aging curve of 2090 W51 at 170 C

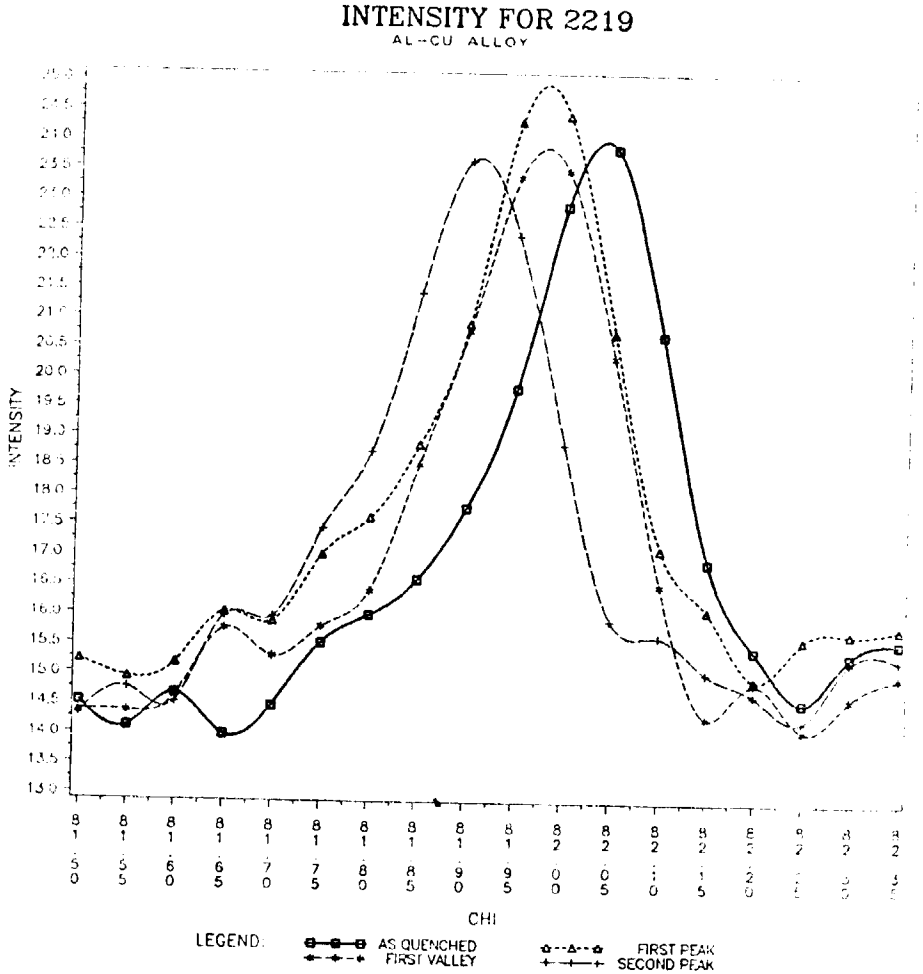


Aging Conditions for 2090 T3 & W51

- 16 hrs at 170 C for 2090 T3
- 16 hrs at 170 C for 2090 W51

X-Ray results





X-Ray results

The shift corresponds to a variation of the lattice parameter of:

8.9*10-4 for the 1st peak
6.4*10-4 for the 1st valley
7.9*10-4 for the 2nd peak

Summary

- *Disk Rupture tests:*
  Rough surface => burst failure.
  Intermediate strain rate => less embrittlement.

- *Tensile tests:*
  45 => lower ductility.
  No apparent difference at low temperature.

Summary
(Cont.)

- *Charpy impact tests:*
  Nearly same impact initiation energy
  for all orientations.
  Higher propagation energy for L-S and T-S
  than for T- L and L-T orientations.
  Substantial tearring for T-S and L-S orientations.

- *Charging solutions:*
  Two give embrittlement without surface damage.

Hydrogen Embrittlement
Need to Address

- Orientation of samples for the mechanical tests
- Additional material needed:
  - 2219
  - 2090
  - 8090
  - Weldalite
- 2090 T83 or T84 ??

Inventory

- 2091 T3: - 1/2"x5.9"x13.5"
  - 1/4"x11.8"x31.5"
  - 1/10"x15.7"x39.4"
- 2090 W51: 1/2"x12"x14"
- 2219 T87: 1/4"x12"x36"

Hydrogen Embrittlement
Future work

- Confirmation of SIMS results and quantification of hydrogen content
- Mechanical tests on : 2090
  2091
  2219
- Fractography