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**Program 2 Elevated Temperature Crack Growth in Advanced Powder Metallurgy
Aluminum Alloys**

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Objective

The goal of this PhD research is to characterize subcritical crack growth and fracture toughness in advanced aluminum alloys at elevated temperatures, with emphasis on crack tip damage mechanisms. As an extension of this goal, the effects of microstructure and the components of the moist air environment on crack growth and mechanisms will be examined.

Fracture of PM Al-Fe-V-Si at Elevated Temperature

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Abstract

Rapidly solidified Al-Fe-V-Si powder metallurgy alloy FVS0812, produced by Allied-Signal, is among the most promising of the elevated temperature aluminum alloys developed in recent years. The ultra fine grain size and high volume fraction of thermally stable dispersoids enable the alloy to maintain tensile properties at elevated temperatures. In contrast, this alloy displays complex and potentially deleterious damage tolerant and time dependent fracture behavior that varies with temperature.

J-Integral fracture mechanics were used to determine fracture toughness (K_{IC}) and crack growth resistance (tearing modulus, T) of extruded FVS0812 as a function of temperature. The alloy exhibits high fracture properties at room temperature ($K_{IC} = 36.6$ MPa/m, $T = 20.1$) when tested in the LT orientation, due to extensive delamination of prior ribbon particle boundaries perpendicular to the crack front. Delamination results in a loss of through thickness constraint along the crack front, raising the critical stress intensity necessary for precrack initiation. The fracture toughness and tensile ductility of this alloy decrease with increasing temperature, with minima observed at 200°C ($K_{IC} = 14.6$ MPa/m, $T = 2.1$). This behavior results from minima in the intrinsic toughness of the material, due to dynamic strain aging, and in the extent of prior particle boundary delaminations. (Dynamic strain aging, a dislocation-solute interaction, increases yield strength and decreases ductility and fracture toughness, only at intermediate temperatures.) At 200°C FVS0812 fails at K levels that are insufficient to cause through thickness delamination. As temperature increases beyond the minimum, strain aging is reduced and delamination returns. For the TL orientation, K_{IC} decreased (16.1 MPa/m to 9.5 MPa/m) and T increased slightly (0 to 1.4) with increasing temperature from 25°C to 316°C. Fracture in the TL orientation is governed by prior particle boundary toughness; increased strain localization at these boundaries may result in lower toughness with increasing temperature. Preliminary results demonstrate a complex effect of loading rate on K_{IC} and T at 175°C, and indicate that the combined effects of time dependent deformation, environment, and strain aging may play a role. Fractography showed that microvoid coalescence was the microscopic mode of fracture in FVS0812 under all testing conditions. However, the nature of the microvoids varied with test temperature and loading rate, and is complex for the fine grain and dispersoid sizes of FVS0812.

Future work will focus on determining the fracture behavior of FVS0812 as a function of temperature, loading rate, microstructure, stress state, and environment. Additionally, there will be an effort to determine the mechanism for the influence of strain aging on fracture.

**FRACTURE OF POWDER
METALLURGY Al-Fe-V-Si
AT ELEVATED TEMPERATURES**

William C. Porr, Jr. and Richard P. Gangloff

**Funded by NASA Langley Research Center
C. E. Harris, Project Monitor**

OUTLINE

- A. Background / Objective
- B. Materials
- C. Procedure
- D. Results and Discussion
- E. Conclusions
- F. Future Work

Background

- Much effort has gone into the development of elevated temperature aluminum alloys to replace titanium alloys with similar specific properties in aerospace applications.
- Among the most promising alloys developed include the Al-Fe-V-Si PM alloys produced by Allied-Signal, Inc.
- Before consideration for service, the unique damage tolerant and time dependent fracture behavior of these alloys as a function of temperature must be understood.

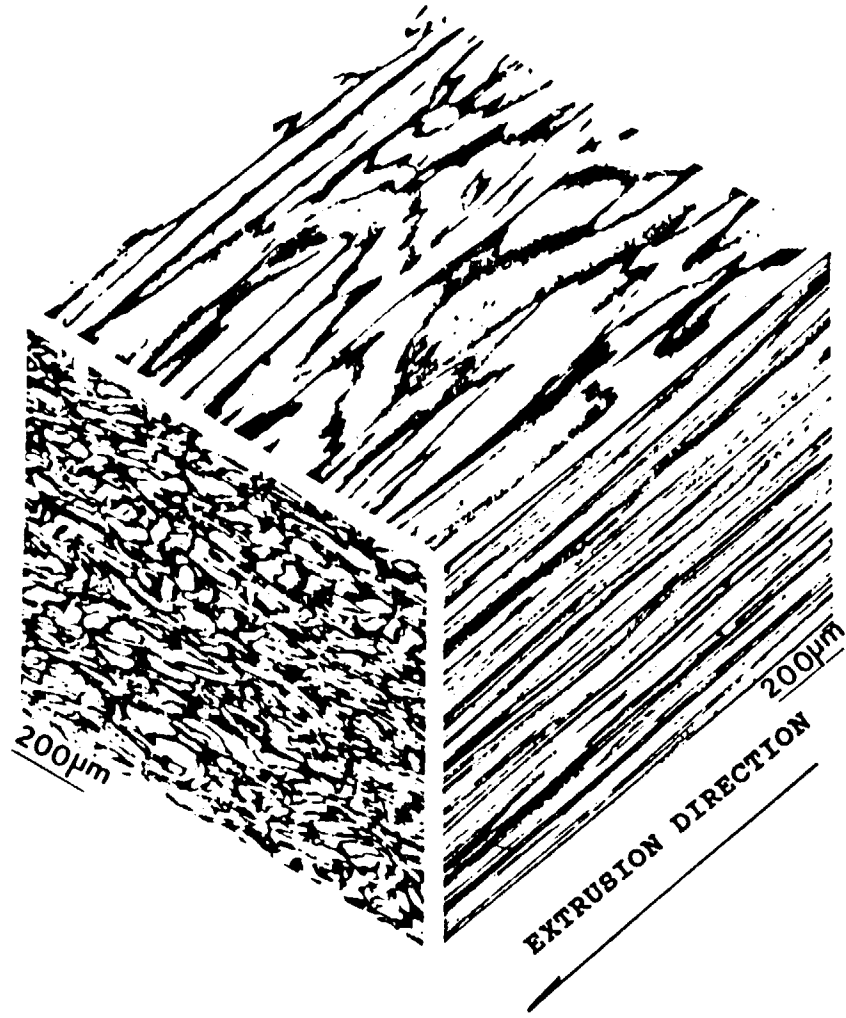
PROJECT OBJECTIVE

- ■ ■ Characterize subcritical crack growth and fracture toughness in advanced aluminum alloys as a function of temperature
 - ■ crack tip damage mechanisms
 - microstructure / metallurgy
 - components of moist air environment

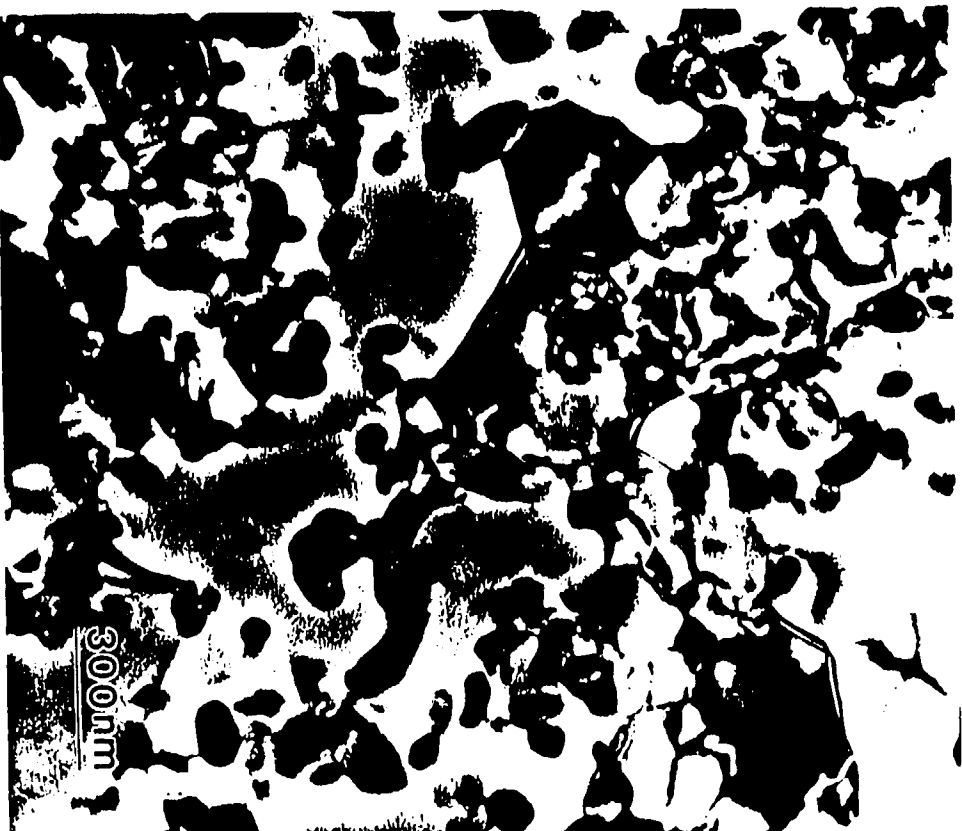
MATERIAL

FVS0812

- Powder metallurgy, Al-8.5Fe-1.3V-1.7Si
 - Rapidly solidified, planar flow casting process
 - ribbon mechanically comminuted
 - extruded, final particle dimensions:
1000 μm x 100 μm x 20 μm
 - Ultra fine dispersion strengthened microstructure
 - 300nm grain size
 - 24 v/o Al(Fe,V)Si dispersoids less than 100nm in size
- Provided by Allied-Signal, Inc.



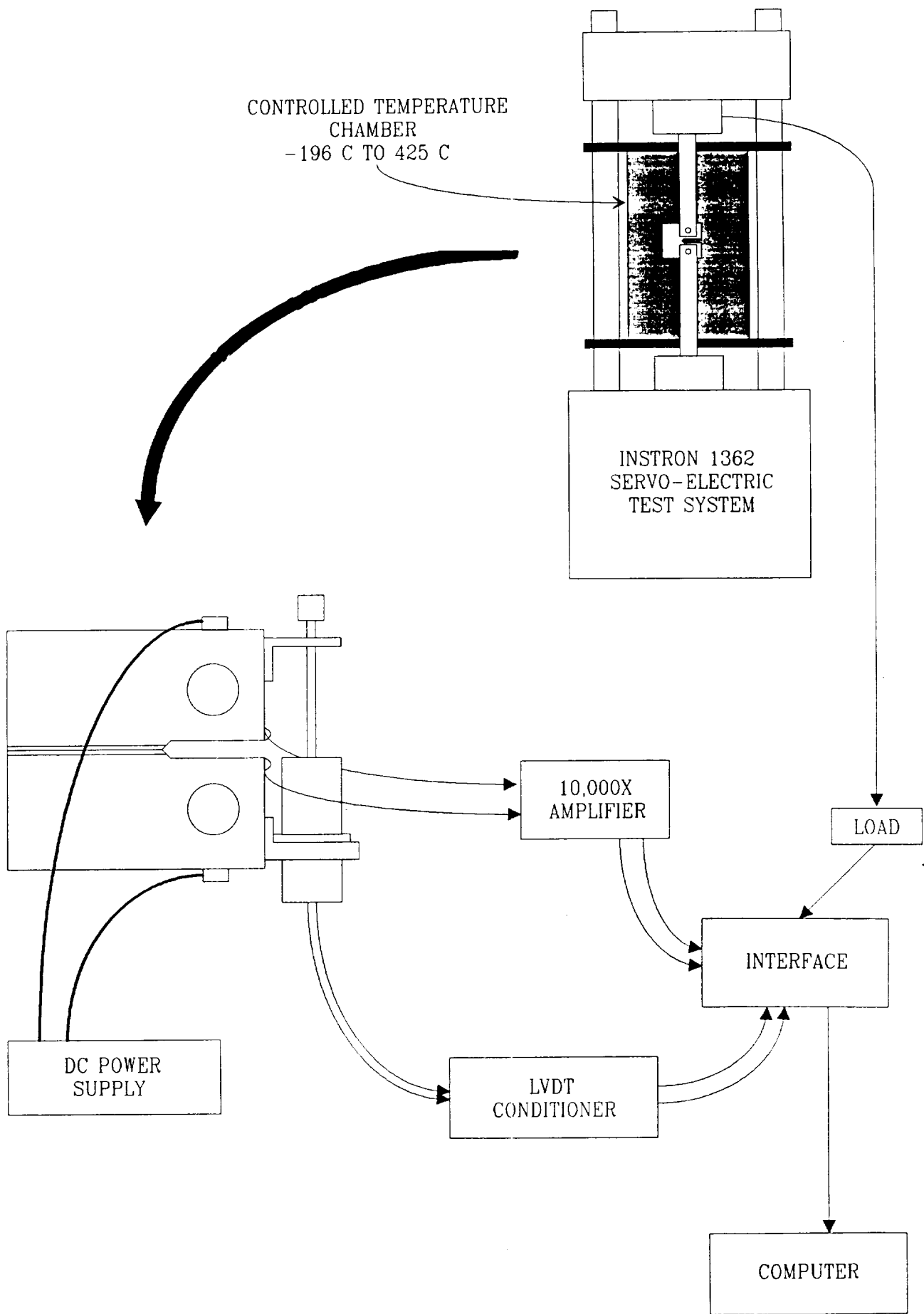
Optical micrographs (Bright field) of FVS0812 Al alloy

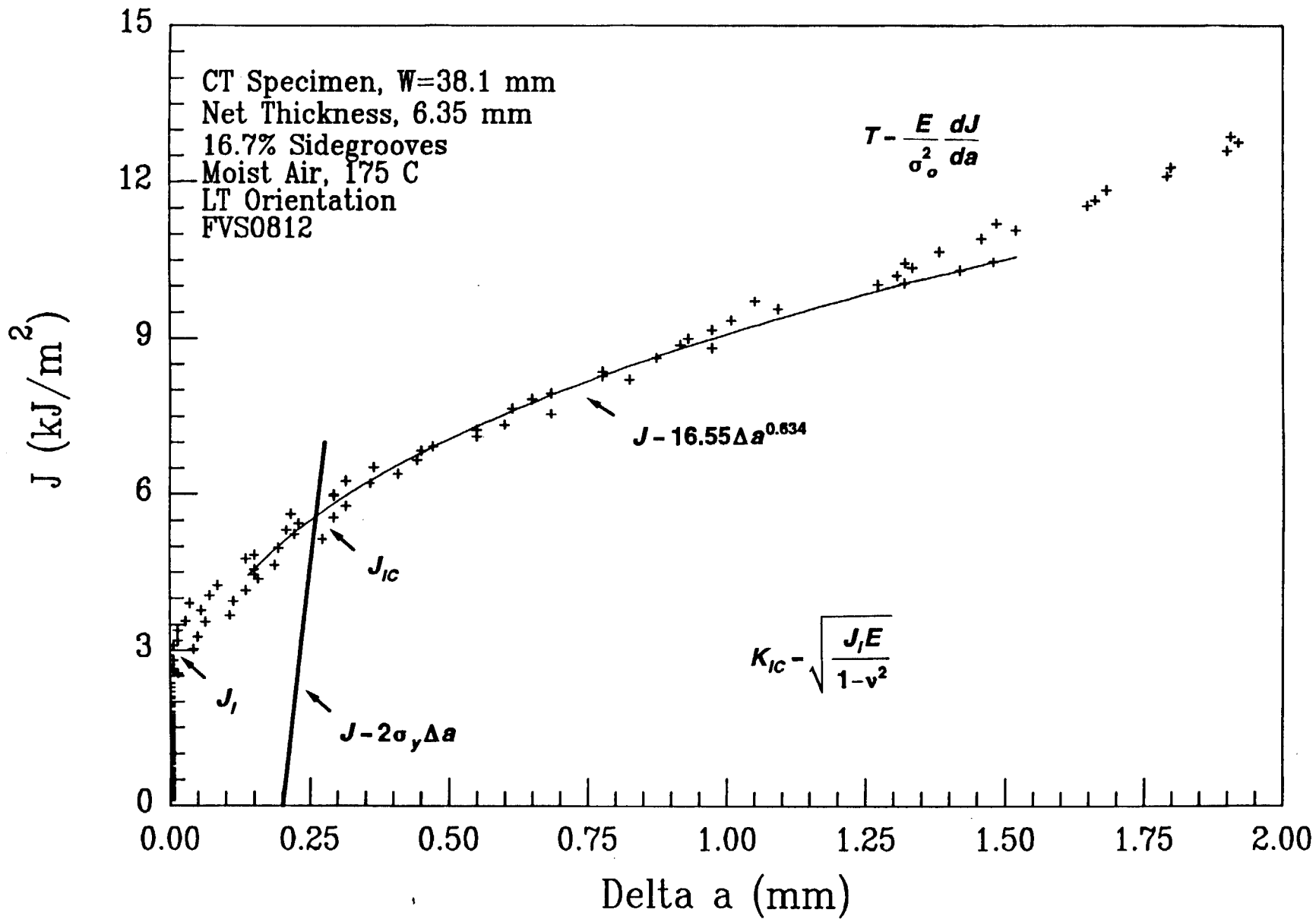


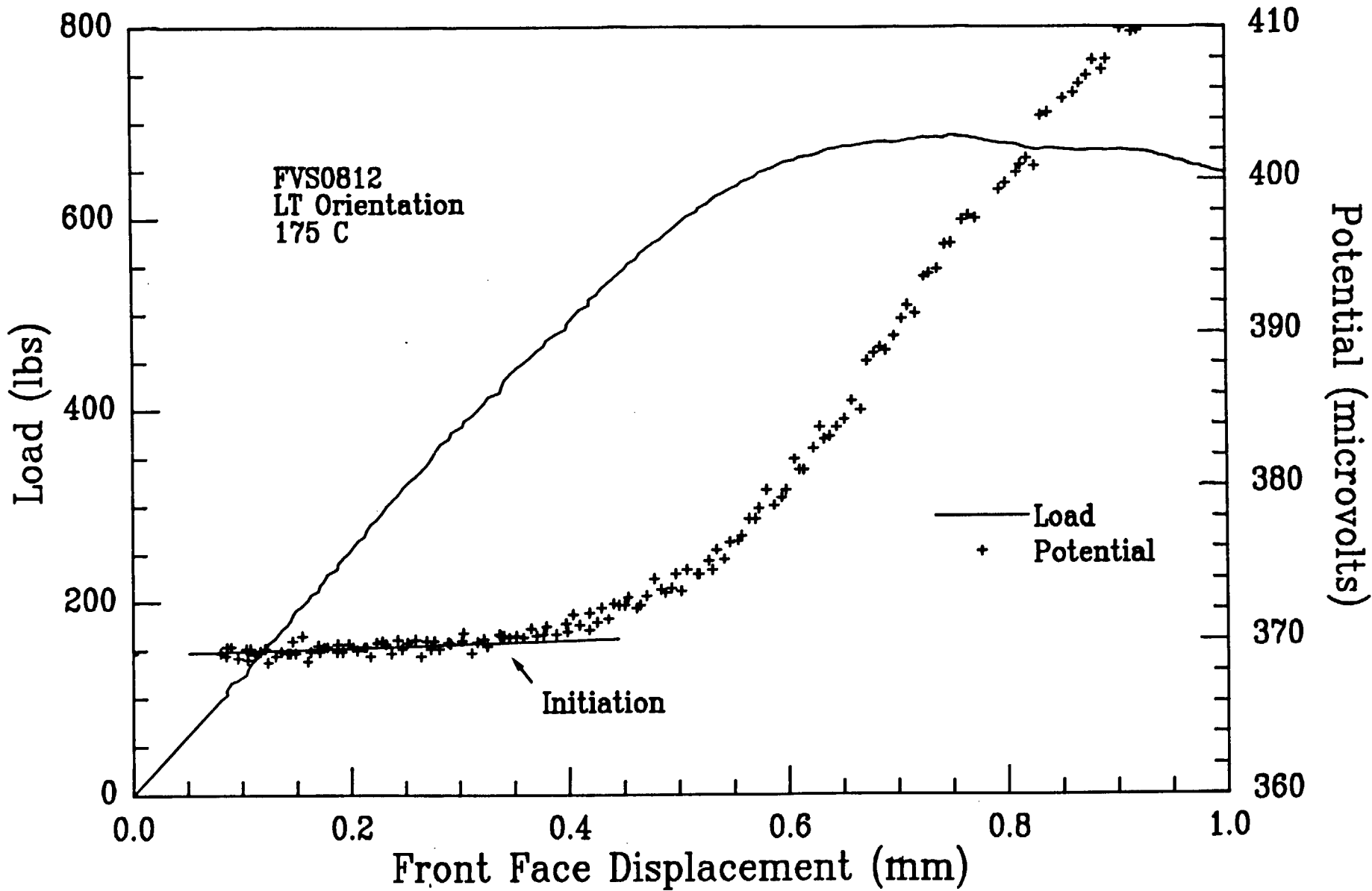
TEM micrograph of FVS0812 Al alloy

PROCEDURE

- J integral fracture mechanics used for fracture toughness testing
 - Plane strain requirements not as stringent
 - Valid under both linear elastic and elastic-plastic conditions
- Determined J- Δa curves by measuring load, load-line displacement, and crack length (from DCPD)
 - J from P, δ , and calculated compliance (from a) using area method
 - Δa from DCPD
- Determined initiation J according to:
 - ASTM E813-89 (J_{IC})
 - Alternative (J_i)







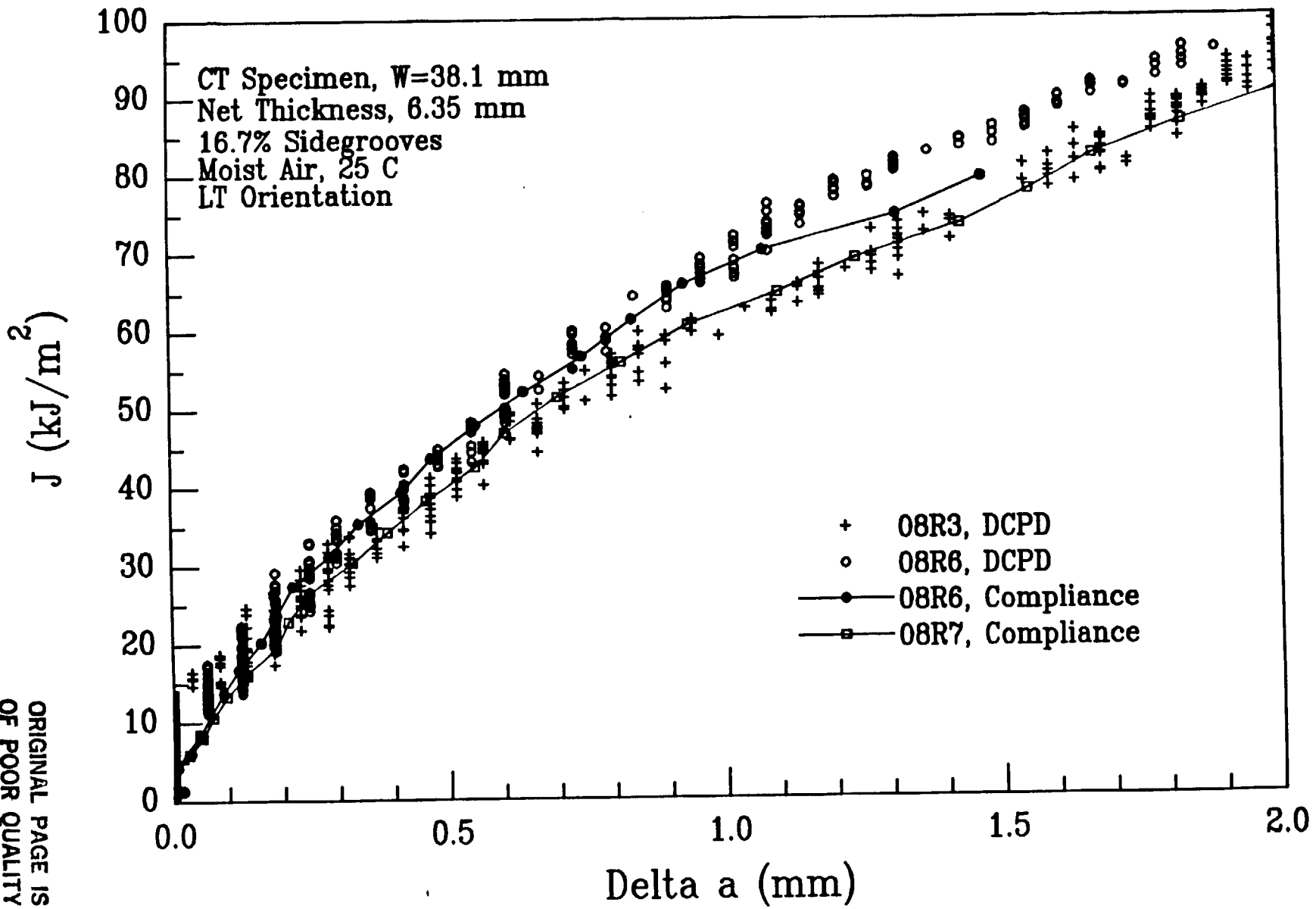
Advantage of DCPD for crack length determination

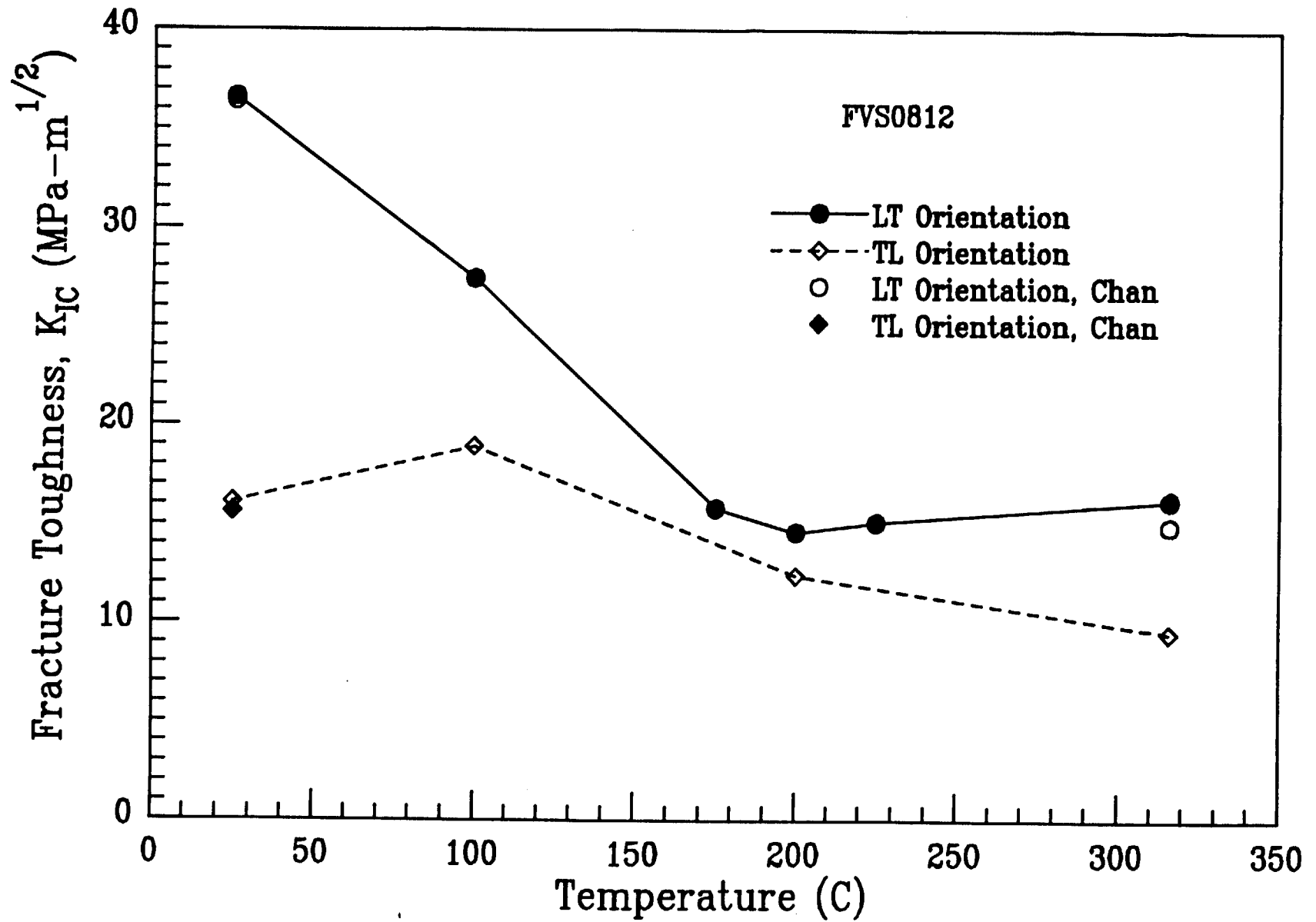
- No need to unload
- More accurate determination of crack growth initiation
 - K_{IC} determined from initiation J_i

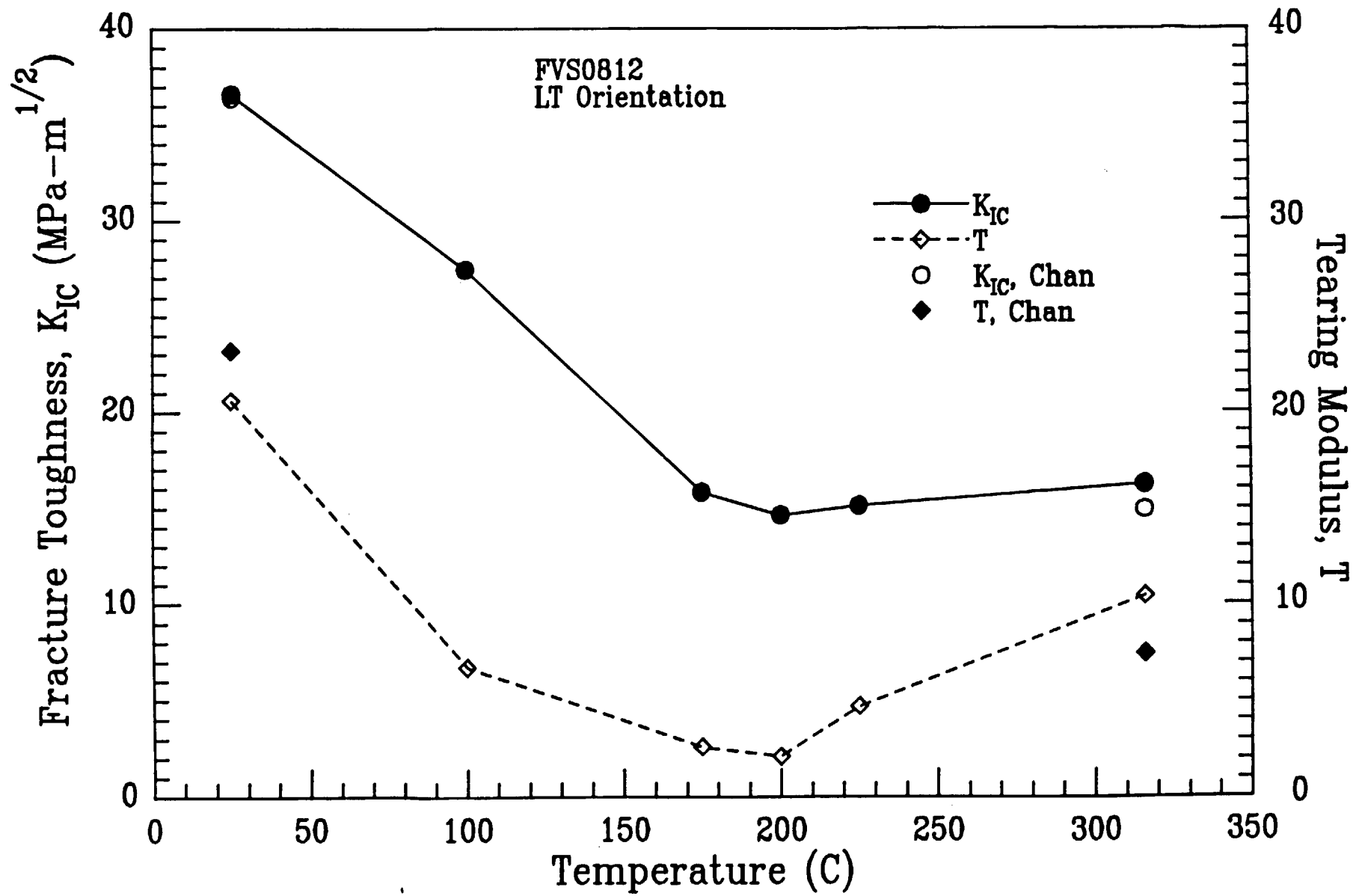
Verification of Procedure Accuracy

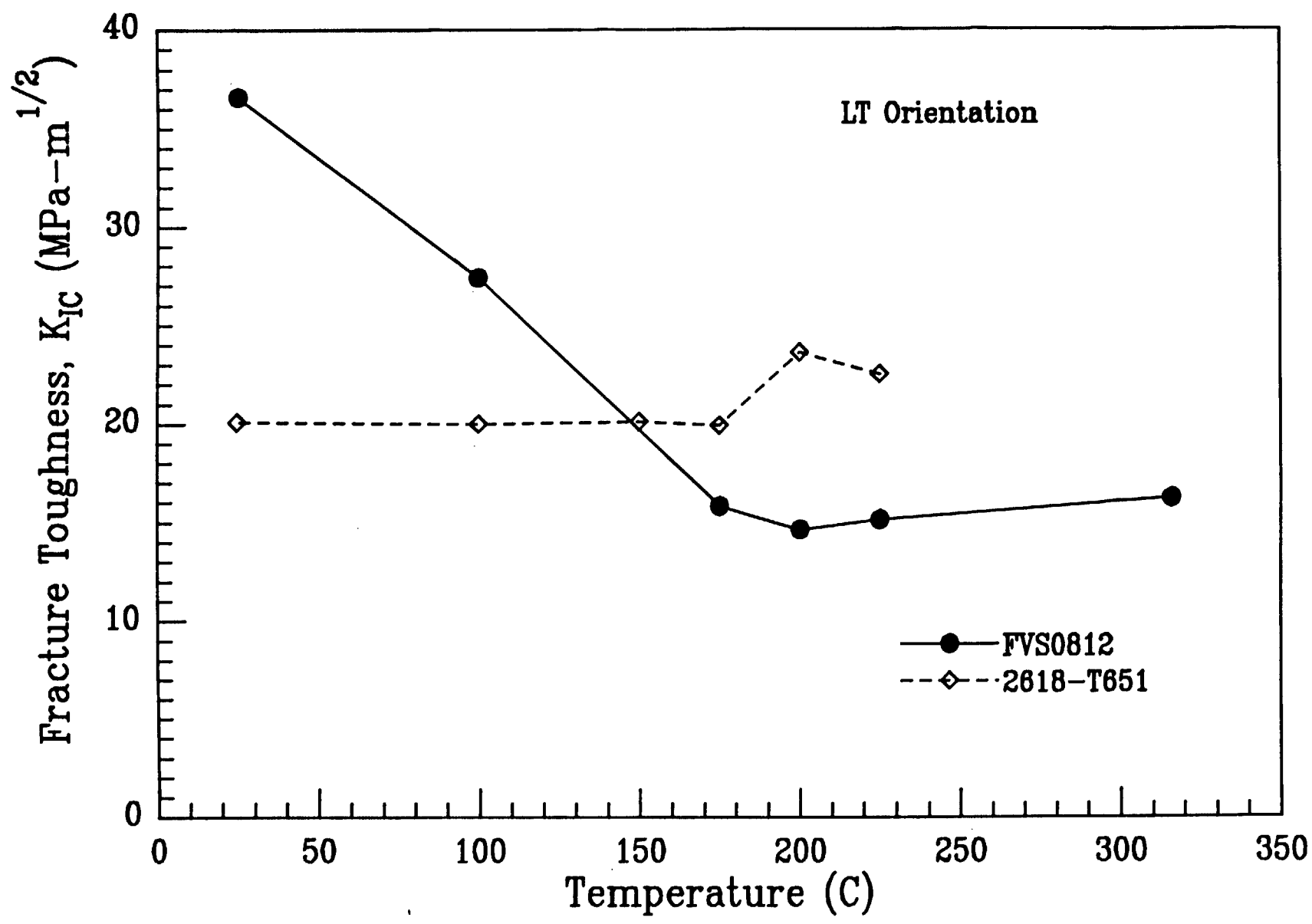
- Compared to standardized unloading compliance technique
- Excellent agreement and reproducibility

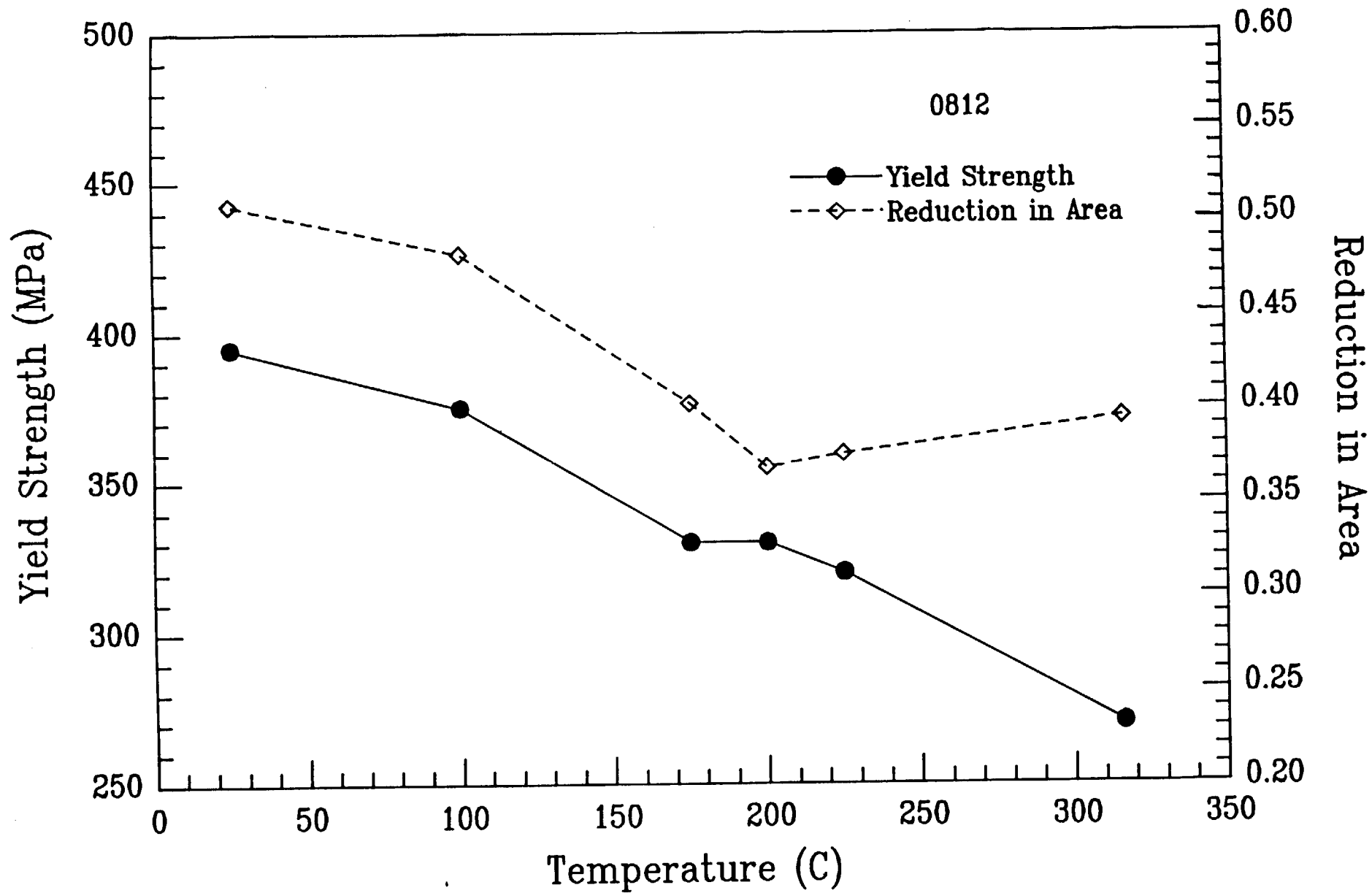
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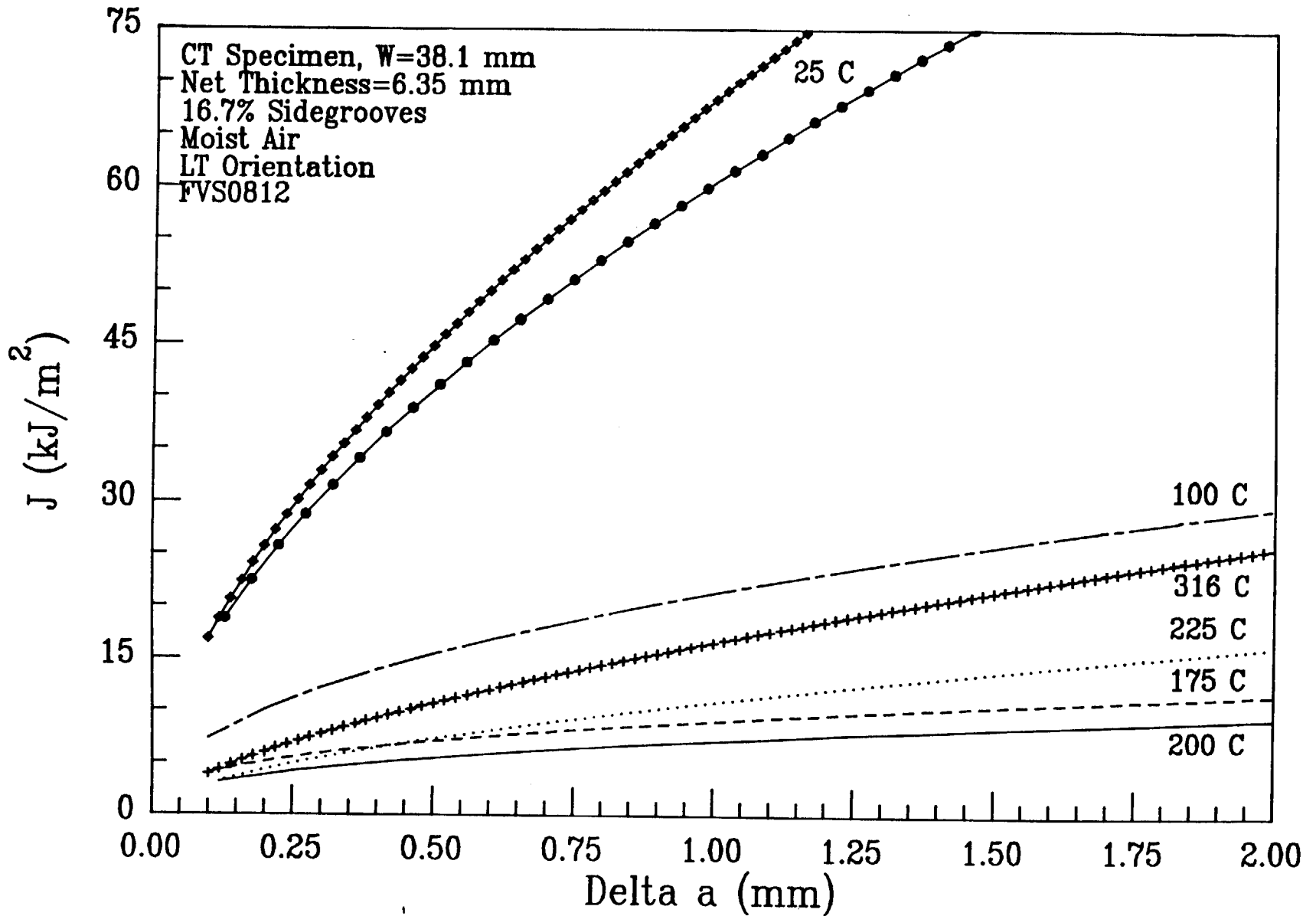














(a) 25 C

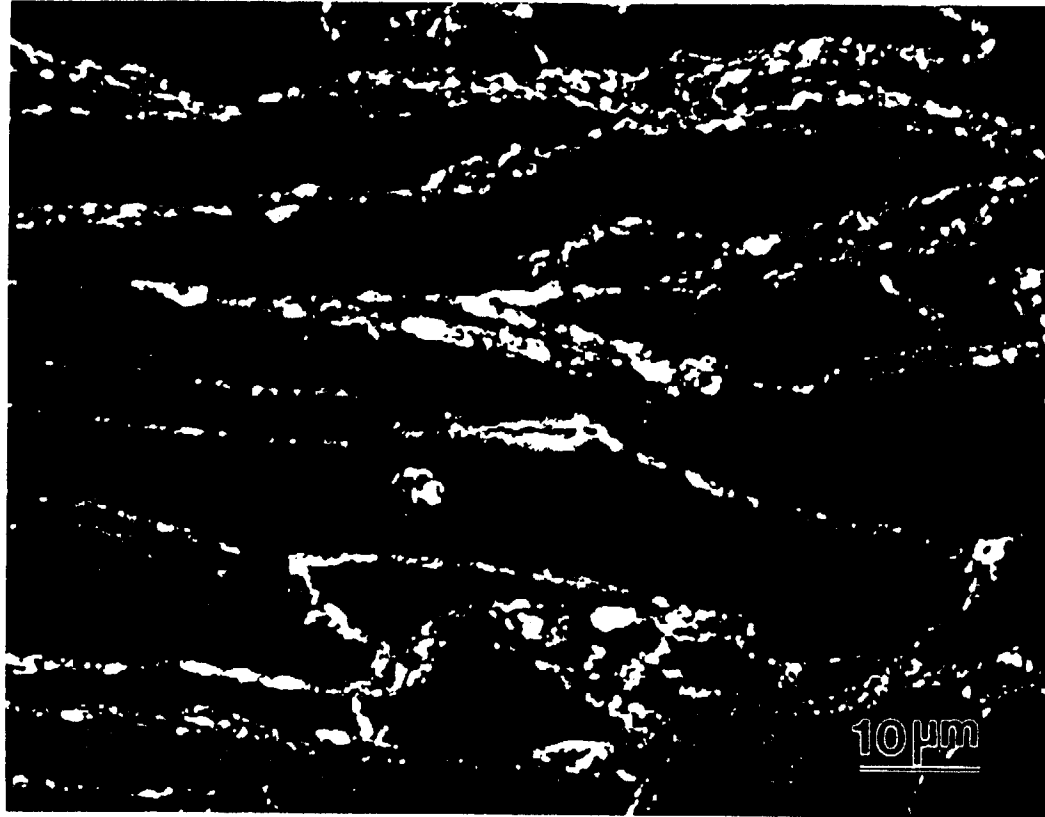


(b) 200 C

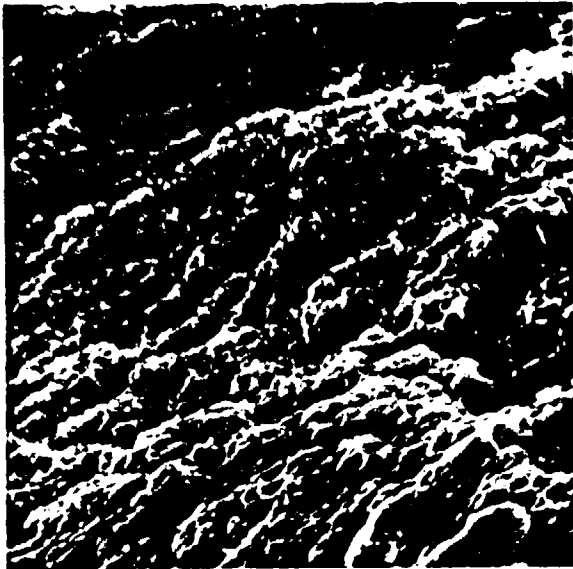


(c) 316 C

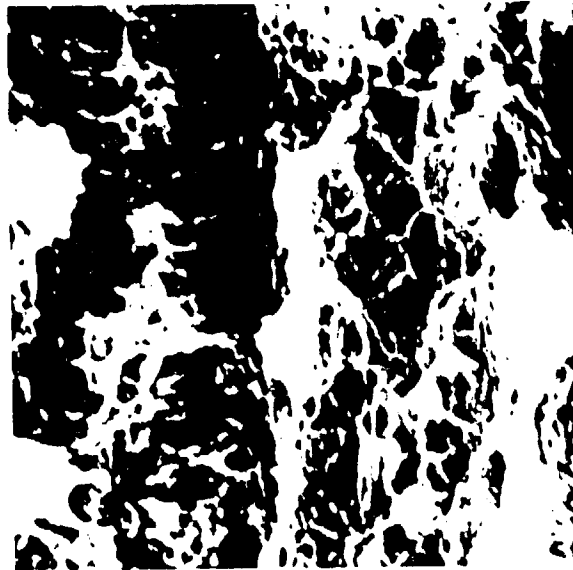
Low magnification SEM photographs of FVS0812 fracture surfaces for different test temperatures.



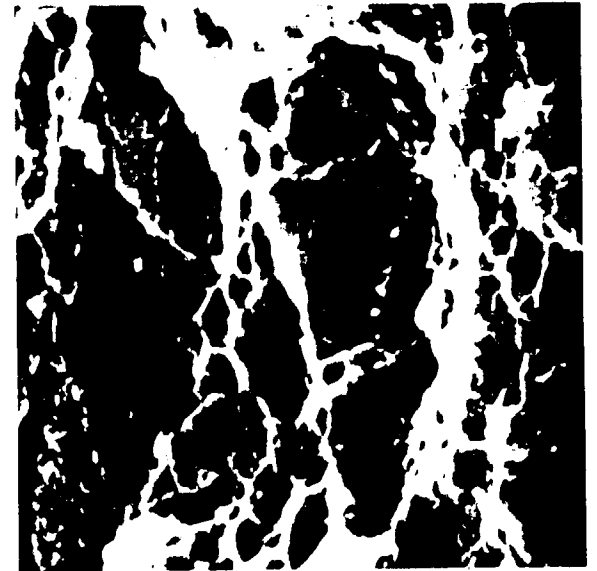
SEM micrograph of FVS0812 Al alloy (S-T surface)



(a) 25 C



(b) 200 C



(c) 316 C

High magnification SEM photographs of FVS0812 fracture surfaces for different test temperatures.

DISCUSSION

- Why, in the L-T orientation, does FVS0812 exhibit a high K_{IC} and T at room temperature?

- Thin sheet toughening mechanism:

Delamination perpendicular to the crack front along prior particle boundaries results in a loss of through thickness constraint.

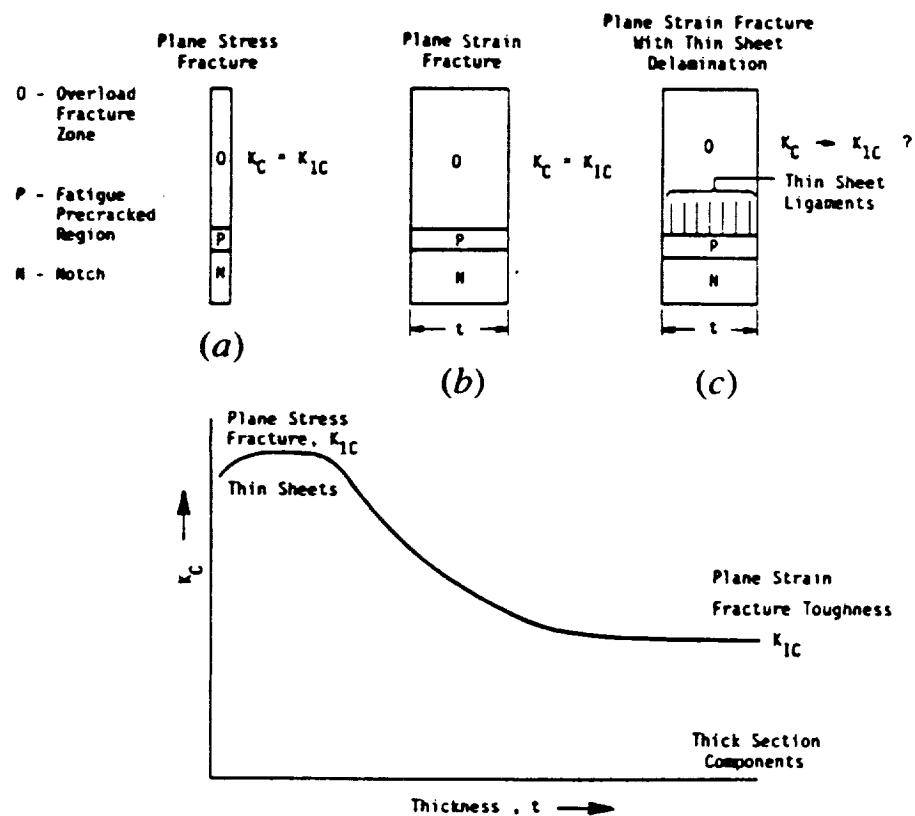


Fig. 1—A schematic showing the dependence of K_c on thickness: (a) a plane stress fracture toughness of K_{IC} for thin sheets; (b) a plane strain fracture toughness of K_{IC} for thick-section components; (c) a potential toughness value of K_{IC} for plane strain fracture with thin sheet ligament formations in the process zone.

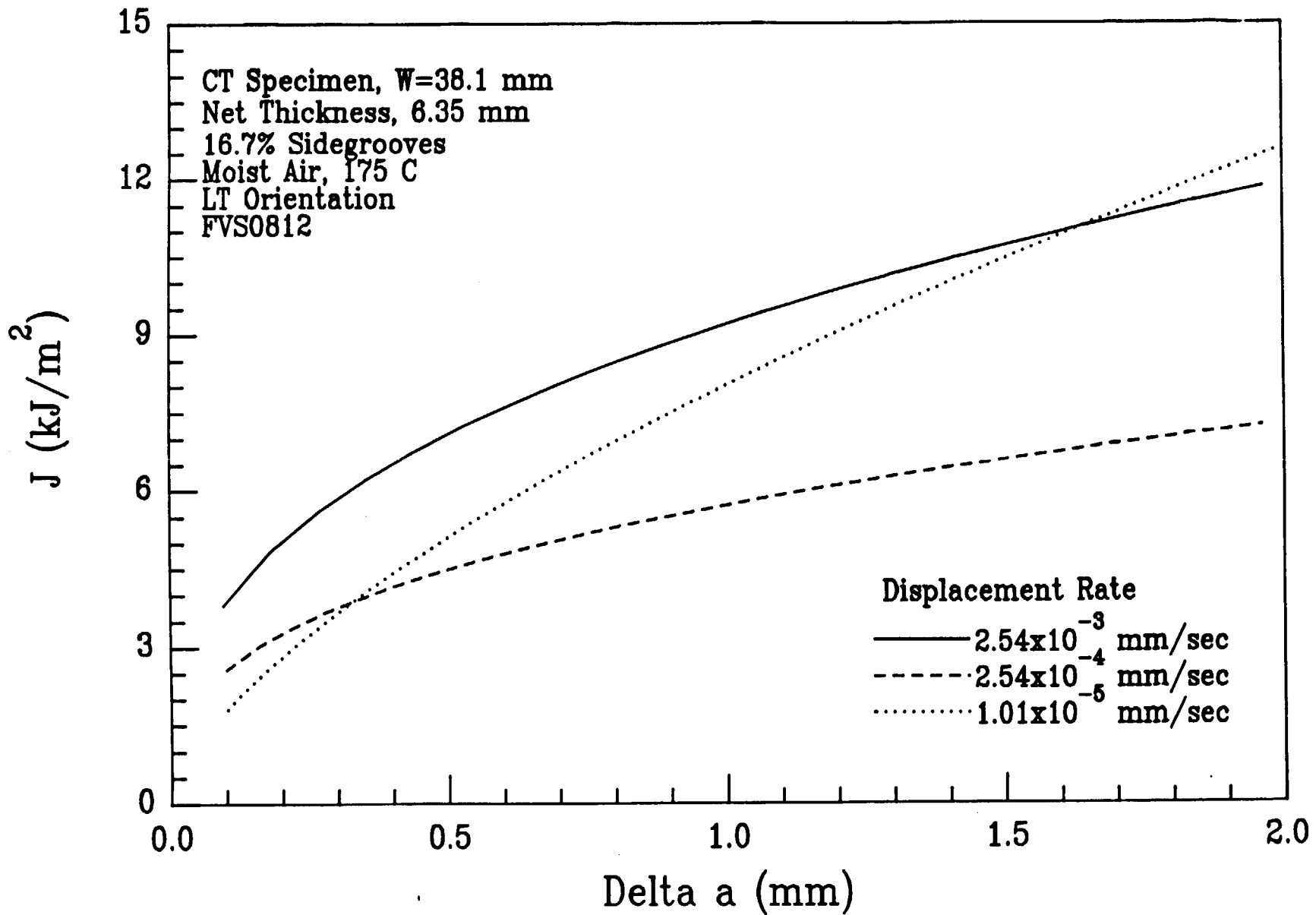
- Why, in the L-T orientation, do K_{IC} and T *decrease* with increasing temperature, reaching a minimum at 200°C?
 - Decreased intrinsic toughness
 - dynamic strain aging
 - other?
 - Decreases in prior particle boundary delaminations up to 200°C
 - decrease in intrinsic toughness leads to failure of the matrix at lower K levels than necessary to develop transverse stresses for delamination to occur.

- Why, in the L-T orientation, do K_{IC} and T increase again above 200°C?
 - Intrinsic toughness increases
 - dynamic strain aging effects are lessened; solute no longer impedes dislocation motion
 - Delaminations return
 - prior particle boundaries weaken as temperature increases; K levels rise sufficiently prior to crack growth for delamination to occur, raising K_{IC} and T.

- Why, in the T-L orientation, does K_{IC} decrease with increasing temperature, while T increases slightly?
 - Represents a measure of prior particle boundary toughness
 - Strain localization at prior particle boundaries may result in lower toughness with increasing temperature

Strain Rate Effects

- K_{IC} decreases with decreasing displacement rate, while T exhibits a minimum over the range tested at 175°C.
 - combined effects of time dependent deformation, environment, and dynamic strain aging may be playing a role



CONCLUSIONS

- PM alloy FVS0812 shows very high fracture toughness and tearing modulus at room temperature due to thin sheet toughening mechanism.
- Fracture toughness and tearing modulus of 0812 decrease with increasing temperature, with minima at 200°C, due to dynamic strain aging and decreased delamination.
- Toughness of prior particle boundaries, as measured by T-L toughness, decreases with increasing temperature as a result of strain localization at boundaries.

FUTURE RESEARCH

- Two questions:
 - What is the fracture behavior of FVS0812 in terms of $J-\Delta a$ versus:
Temperature, loading rate,
microstructure, stress state,
and environment.

Tasks: Continue fracture testing,
fractographic analysis, and
micromechanical modelling

- cryogenic temperatures
- rolled plate
- thinned specimens
- vacuum

C-R

- What is the mechanism by which dynamic strain aging contributes to fracture?

Tasks: Develop mechanical testing, microscopy, and metallurgical techniques to explore this.

- interrupted tests
- sectioning, TEM studies
- lower Fe,V chemistry
- heat treatments

ACADEMIC TIMETABLE

- April 1990; Completed comprehensive exam.
- Mid-summer 1990; Present and defend a PhD. dissertation proposal.
- Late summer 1991; Present and defend PhD. dissertation.

APPENDIX

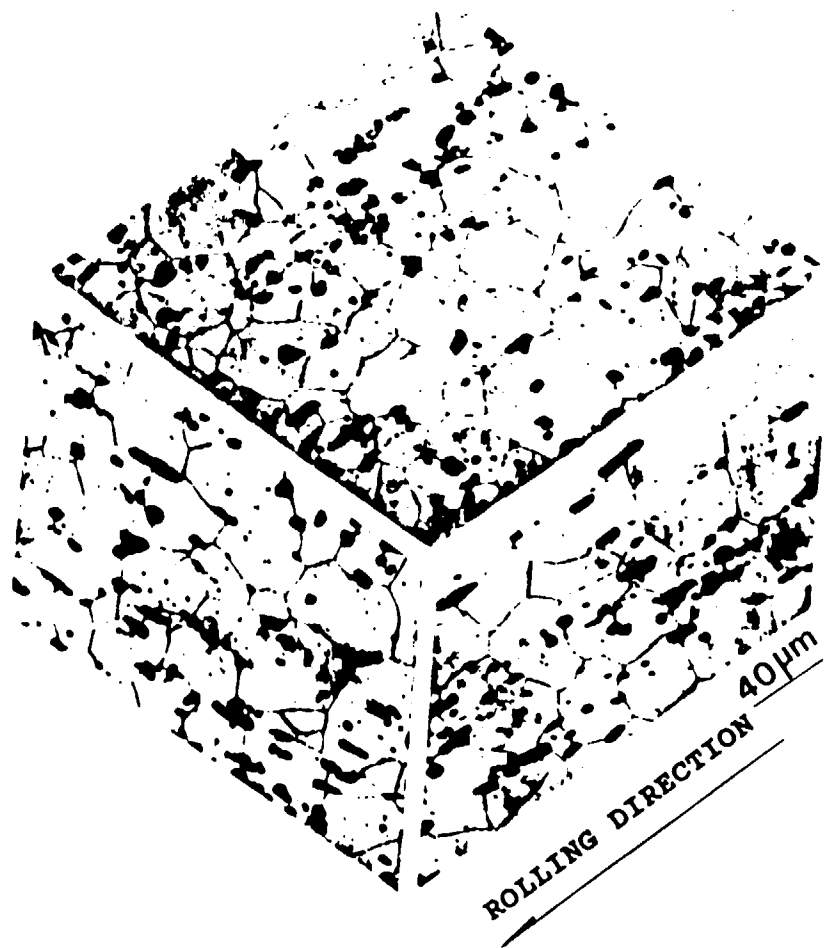
Results of Fracture Toughness Testing of Aluminum Alloy 2618

MATERIAL

2618

- Ingot metallurgy, Al-Cu-Mg with substantial Fe, Ni, and Si
 - S' primary strengthening phase
 - 5-10 μm Fe-Ni-Al particles for mechanical property retention at elevated temperatures
 - 30-50 μm equiaxed grain structure
- Provided by Cegedur Pechiney

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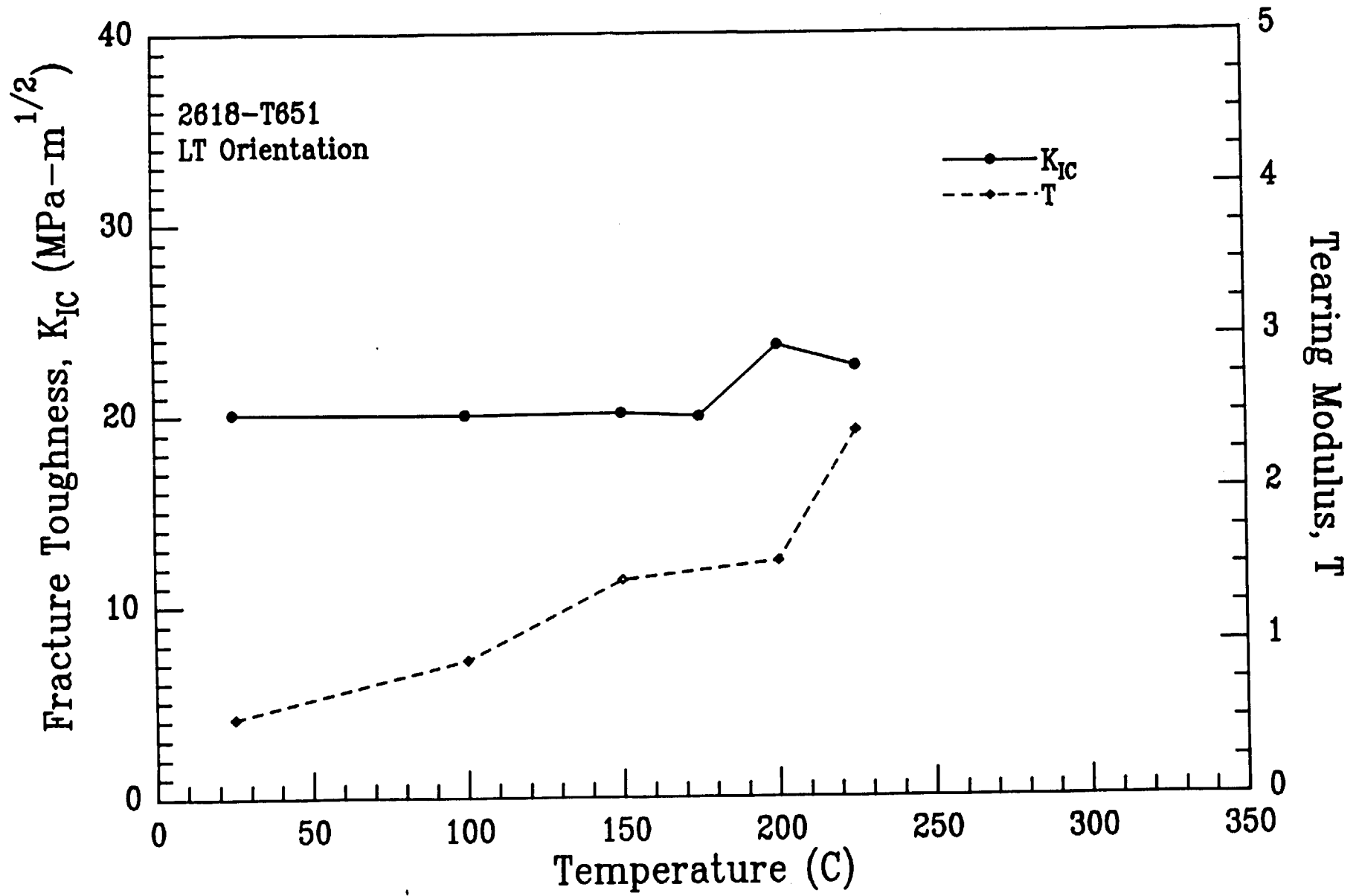


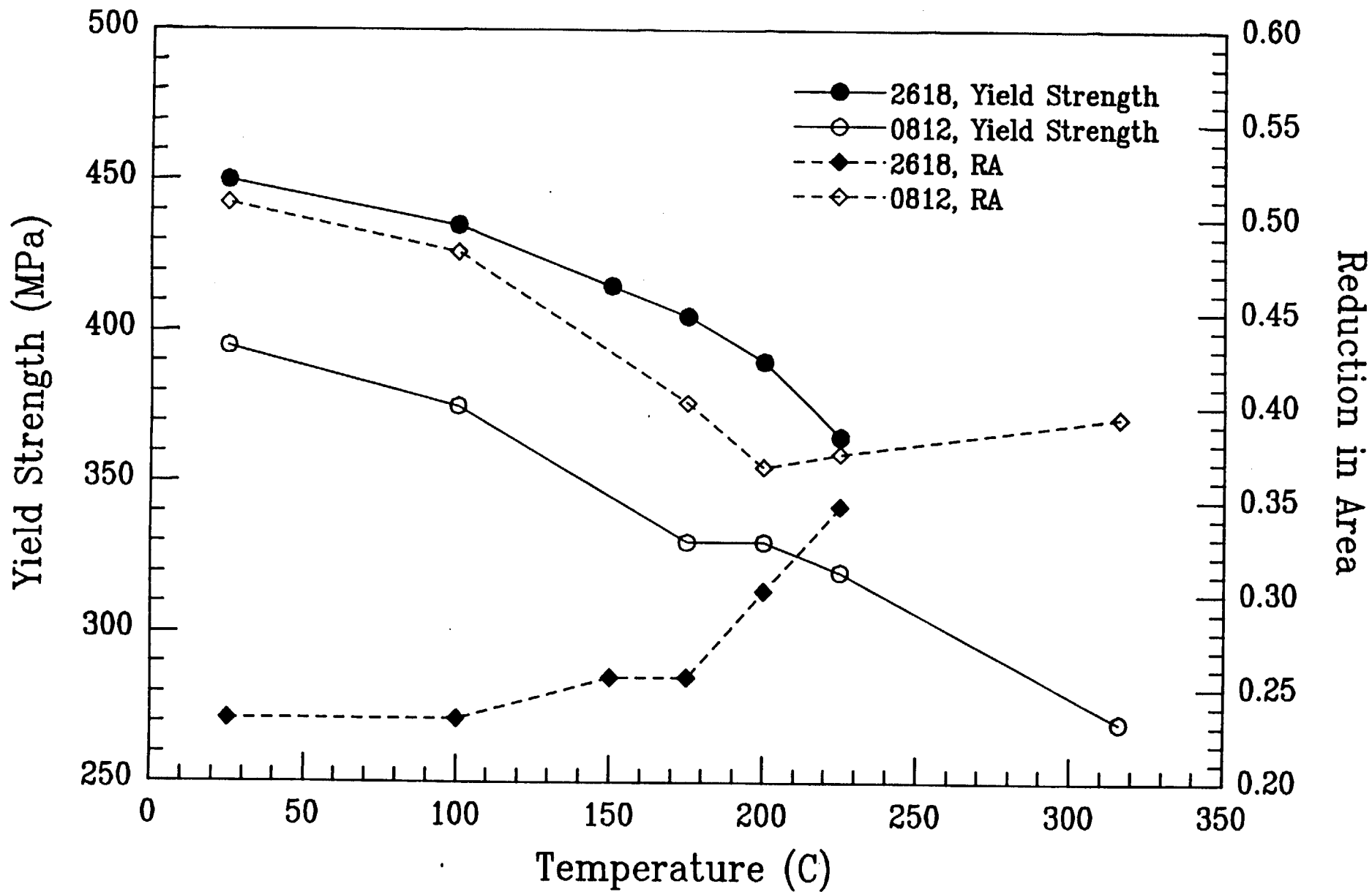
Optical micrograph of 2618 Al alloy

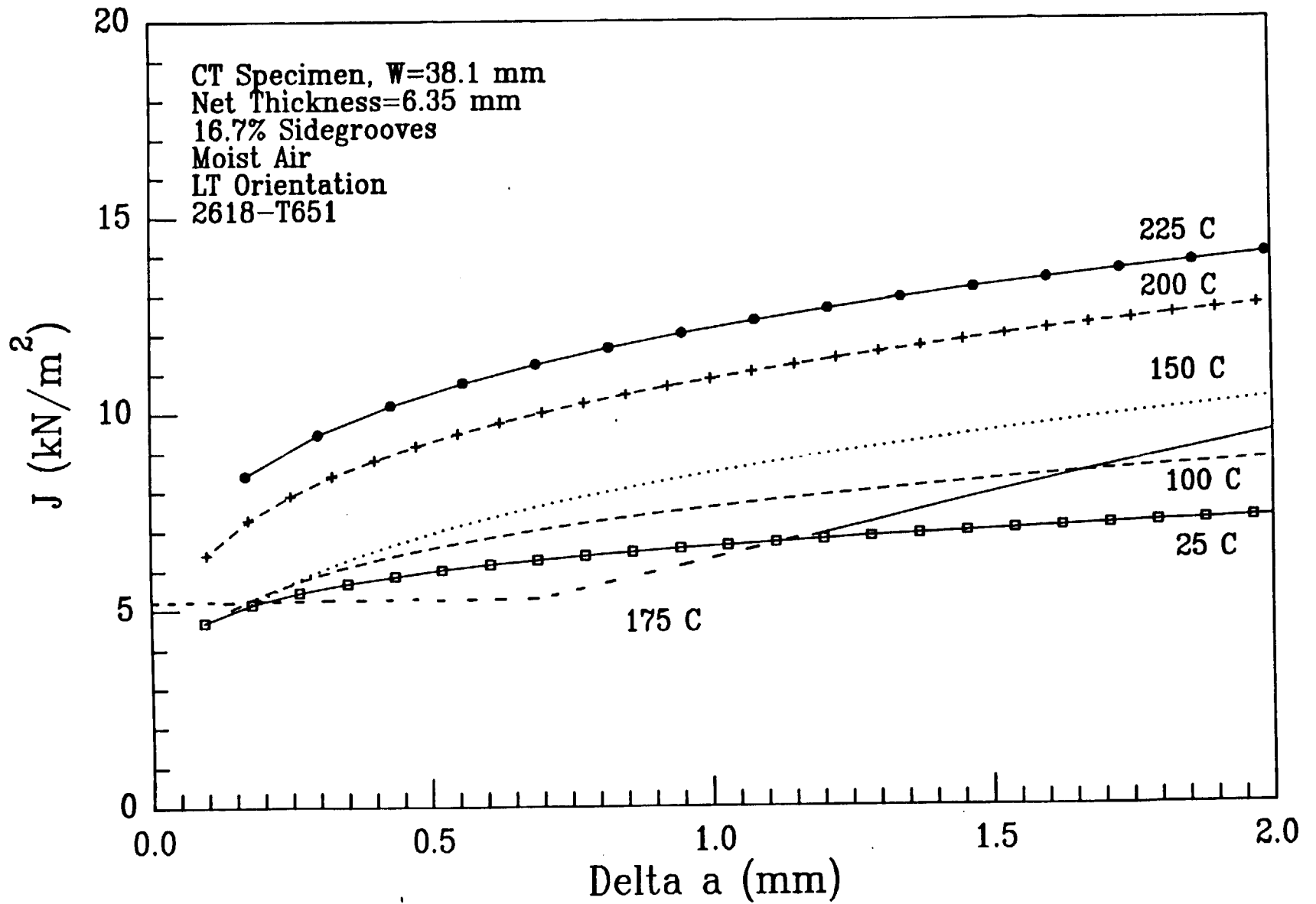


TEM micrograph of 2618 Al alloy

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RESULTS

2618

- K_{IC} increases slightly with increasing temperature
- Tearing modulus, T , increases with increasing temperature
- Insufficient stable crack growth at 175°C for valid $J-\Delta a$ curve
- Fractography showed microvoid coalescence to be the mode of fracture in all specimens

Implications: The increase of fracture toughness with increasing temperature is consistent with the decrease in yield strength.

The inability to sustain stable crack growth at 175°C may be from dynamic strain aging due to solid solution Fe.

1