N90-22655

Program 3 **Deformation and Fracture of Thin Sheet Aluminum-Lithium Alloys: The Effect of Cryogenic Temperatures**

John A. Wagner and R.P. Gangloff

Objective

The objective of this PhD research program is to characterize and optimize the fracture resistance of Al-Cu-Li and Al-Cu-Li-In alloys, processed for thin sheet cryogenic tank applications, and through emphasis on micromechanical mechanisms for crack tip damage.

Fracture of Al-Li-Cu-Zr-X Alloys at Cryogenic Temperatures

John A. Wagner[1] and Richard P. Gangloff[2]

[1]Metallic Materials Branch, NASA-Langley Research Center
[2]Department of Materials Science

Abstract

The objective of this investigation is to characterize the fracture behavior and to define the fracture mechanisms for new Al-Li-Cu alloys, with emphasis on the role of indium additions and cryogenic temperatures. Three alloys have been investigated in rolled product form: 2090 baseline and 2090 + indium produced by Reynolds Metals, and commercial AA 2090-T81 produced by Alcoa. The experimental 2090 + In alloy exhibited increases in hardness and ultimate strength, but no change in tensile yield strength, compared to the baseline 2090 composition in the unstretched T6 condition. The reason for this behavior is not understood. Based on hardness and preliminary Kahn Tear fracture experiments, a nominally peak-aged condition (75 hours at 160°C) was employed for detailed fracture studies. Crack initiation and growth fracture toughnesses were examined as a function of stress state and microstructure using $J(\Delta a)$ methods applied to precracked compact tension specimens in the LT orientation. To date, $J(\Delta a)$ experiments have been limited to 23°C. Alcoa 2090-T81 exhibited the highest toughness regardless of stress state. Fracture was accompanied by extensive delamination associated with high angle grain boundaries normal to the fatigue precrack surface and progressed microscopically by a transgranular shear mechanism. In contrast the two peak-aged Reynolds alloys had lower toughnesses and fracture was intersubgranular without substantial delamination.

The influences of cryogenic temperature, microstructure, boundary precipitate structure, and deformation mode in governing the competing fracture mechanisms will be determined in future experiments. Results from this study will contribute to the development of predictive micromechanical models for fracture modes in Al-Li alloys, and to fracture resistant materials.

FRACTURE OF Al-Li-Cu-Zr-X ALLOYS AT CRYOGENIC TEMPERATURES

John A. Wagner

LA^2ST Program Review
NASA Langley Research Center

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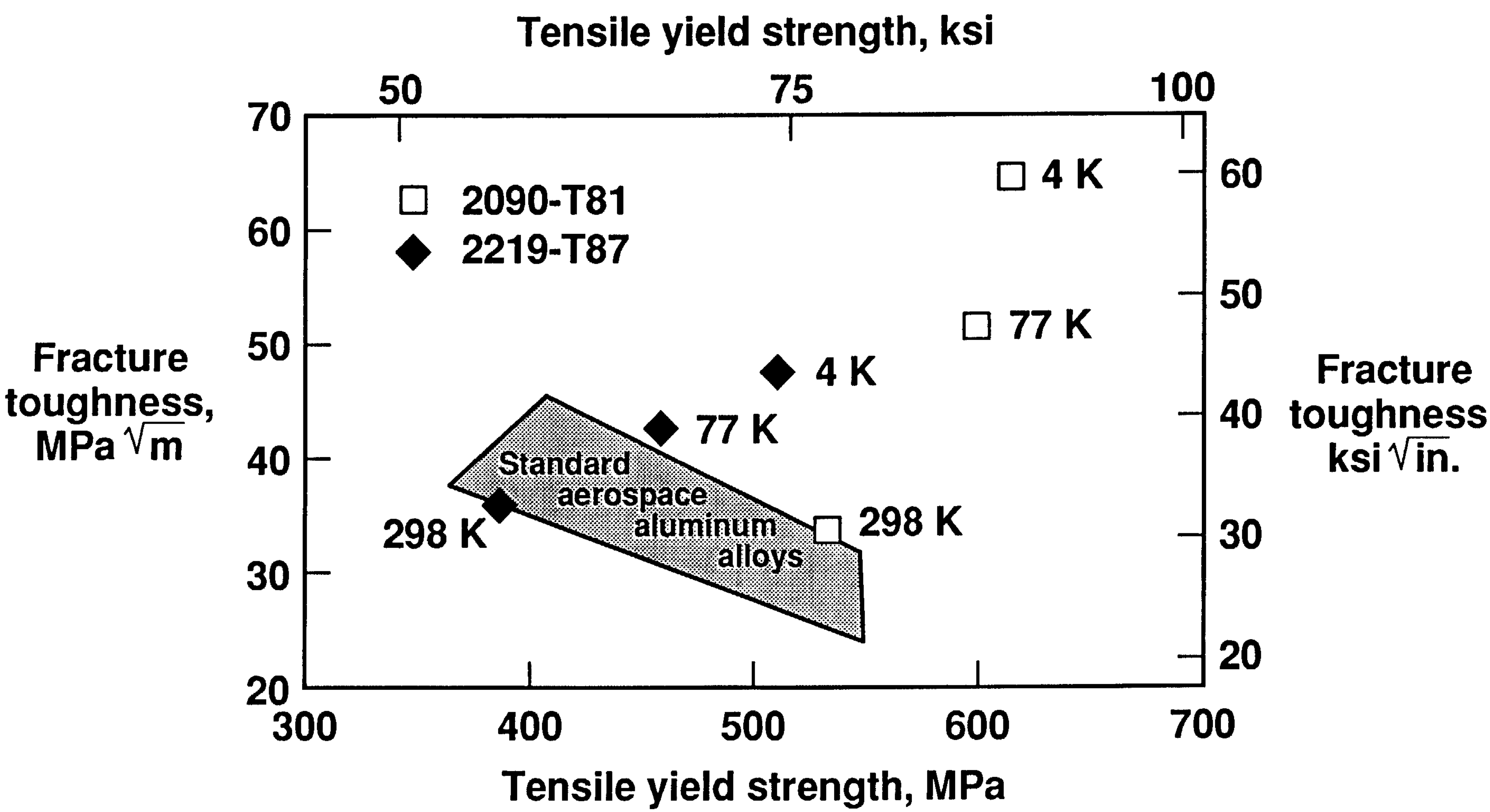
Al-Li ALLOYS FOR CRYOGENIC APPLICATIONS



FRACTURE OF Al-Li-Cu-Zr-X ALLOYS AT CRYOGENIC TEMPERATURES

Problem

- No systematic investigation conducted to determine the interactive effects of:
  - Temperature
  - Delamination
  - Indium addition
  - Microstructure

  on the deformation and fracture of Al-Li-Cu-Zr-X alloys

Objective

- Determine the influences of intragranular features & grain boundary structure in governing the occurrence of various fracture mechanisms in Al-Li-Cu-X alloys at ambient and cryogenic temperatures.

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FRACTURE OF Al-Li-Cu-Zr-X ALLOYS AT CRYOGENIC TEMPERATURES

Outline

- Initial experimentation (sheet)
- Proposed experiments (plate)
- Progress
- Future direction

CHEMICAL COMPOSITIONS AND PROCESS HISTORIES OF AVAILABLE ALLOYS

R2090: Al-2.65Cu-2.17Li-0.13Zr-0.06Fe-0.05Si (wt%)
R2090+In: Al-2.60Cu-2.34Li-0.16Zr-0.05Fe-0.04Si-017In (wt%)

Material available:

1. R2090 Base chemistry

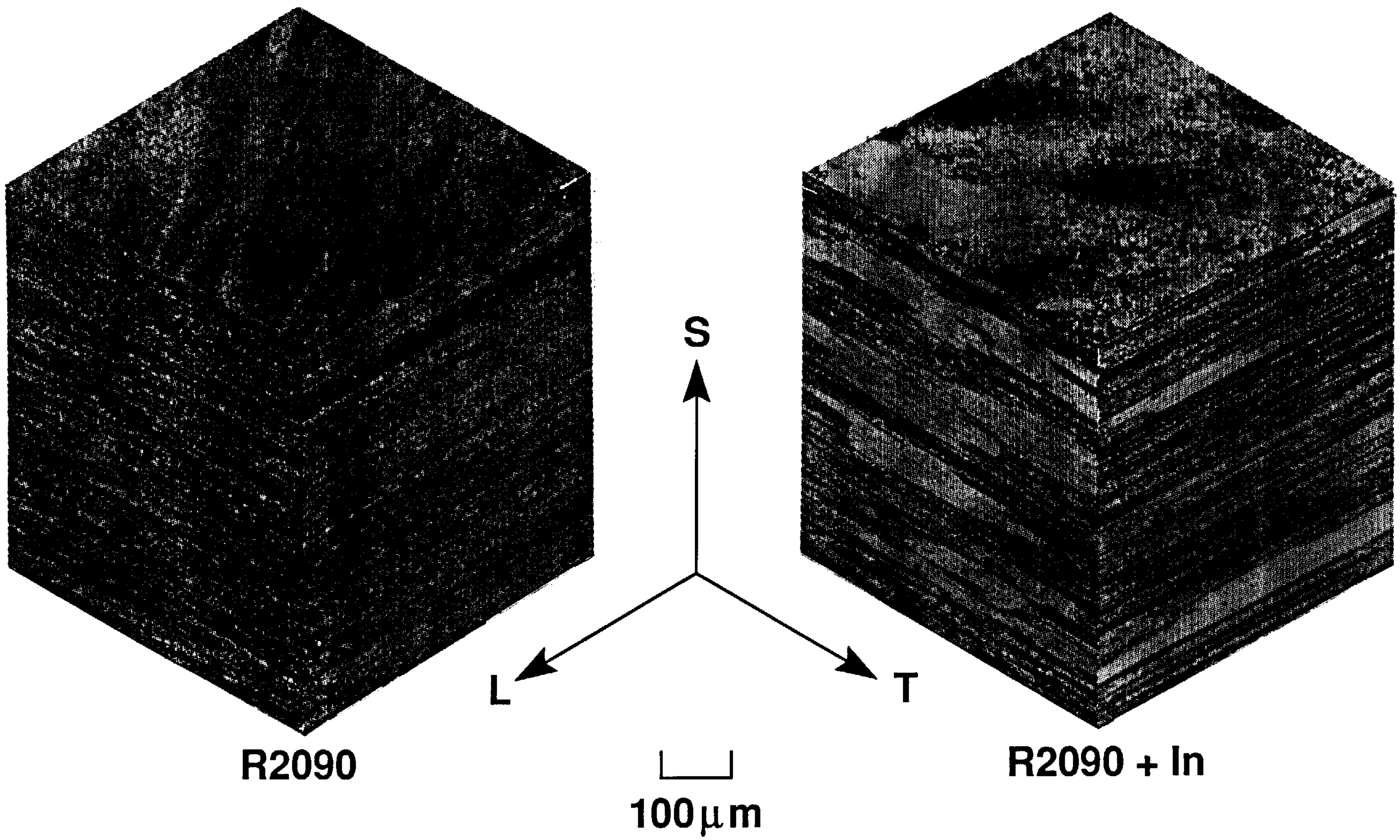
→	0.125 in. sheet	TMTC	SHT	3% stretch
→	0.125 in. sheet		TMT C	SHT @ LaRC
	0.500 in. plate		SHT	3% stretch

2. R2090+In

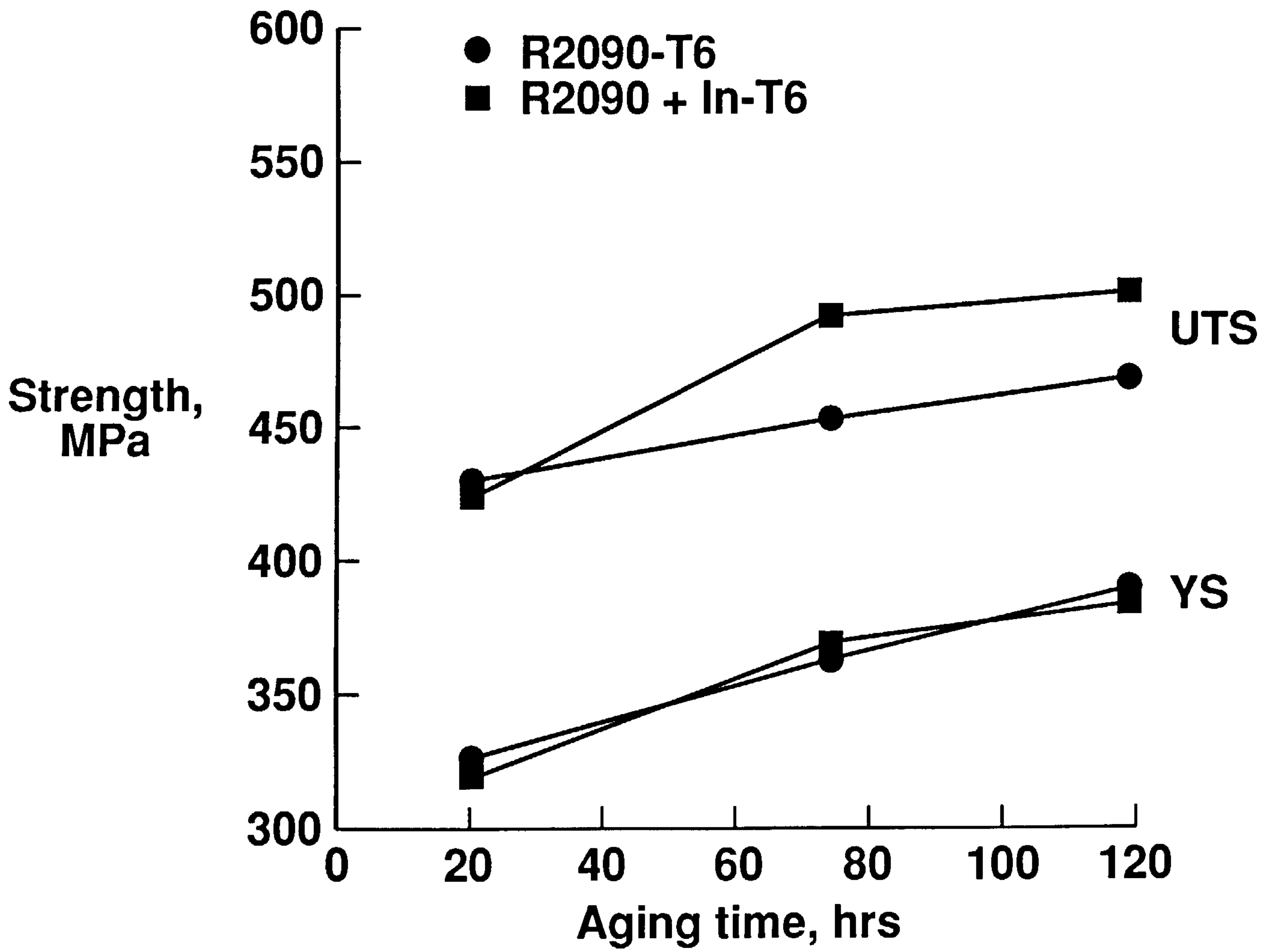
	0.125 in. sheet	TMTC	SHT	3% stretch
→	0.125 in. sheet		TMT C	SHT @ LaRC
	0.500 in. plate		SHT	3% stretch
	0.500 in. plate		SHT	0% stretch

ccppn

SHEET MICROSTRUCTURES AFTER SOLUTION HEAT TREATMENT AND AGING



VARIATION OF ROOM TEMPERATURE STRENGTH WITH AGING TIME AT 160°C



INDIUM ADDITIONS TO Al-Li-Cu-Zr ALLOYS

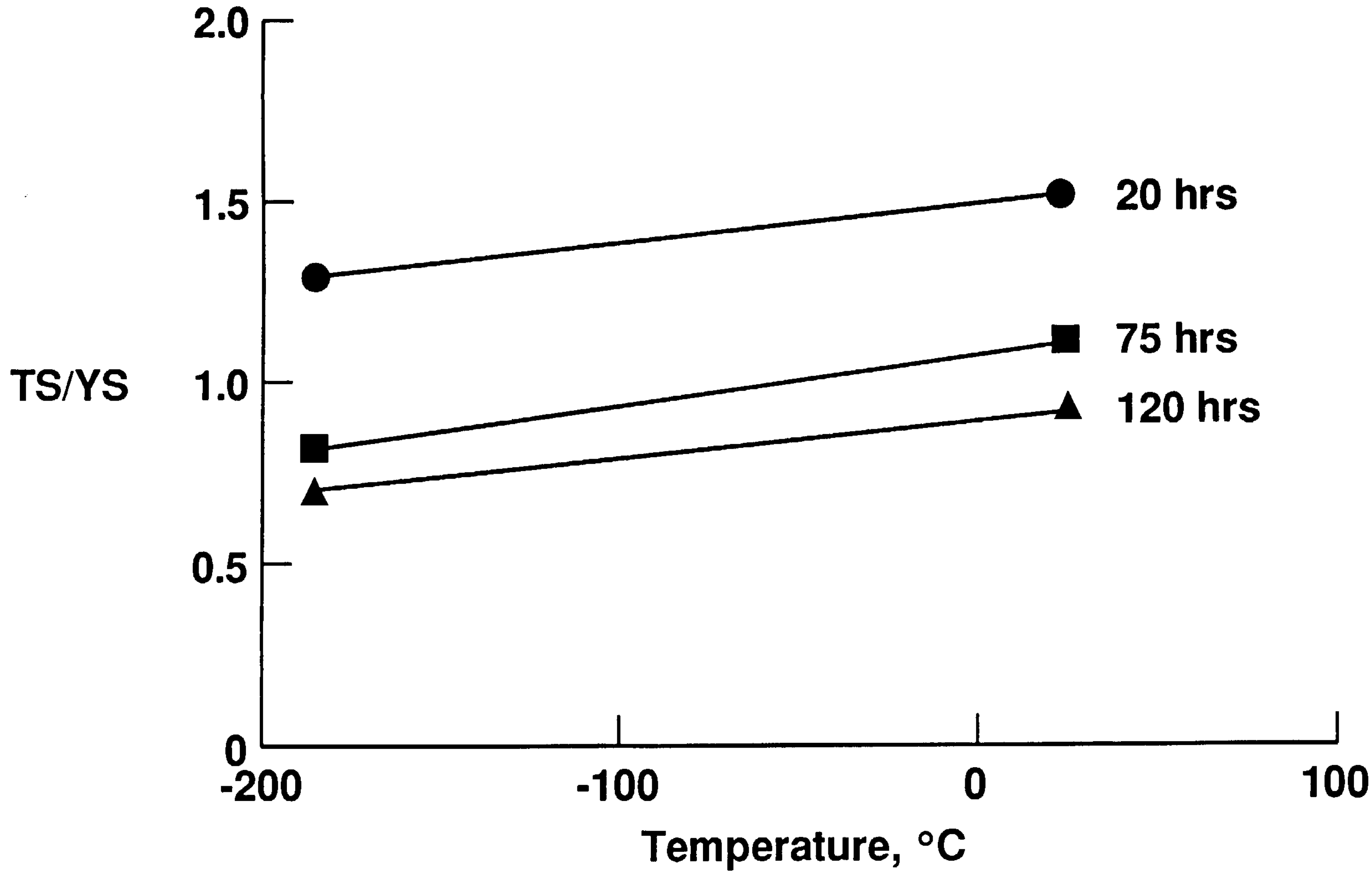
Observations

- Increased in σ_{ys} + σ_{ult} observed for 30 lb laboratory permanent mold casting attributed to increase number density of T_1

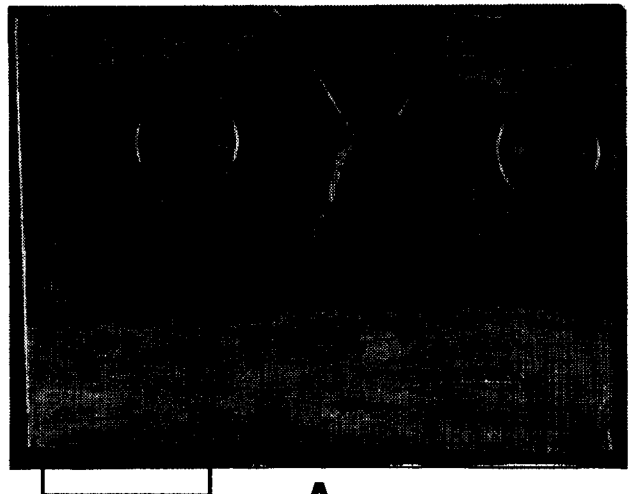
- For 350 lb DC castings indium additions increased σ_{ult} but had no effect on σ_{ys} regardless of product form

- Variation in recrystallization with processing variables requires further investigation

TEAR STRENGTH TO YIELD STRENGTH RATIO OF 2090 + In-T6

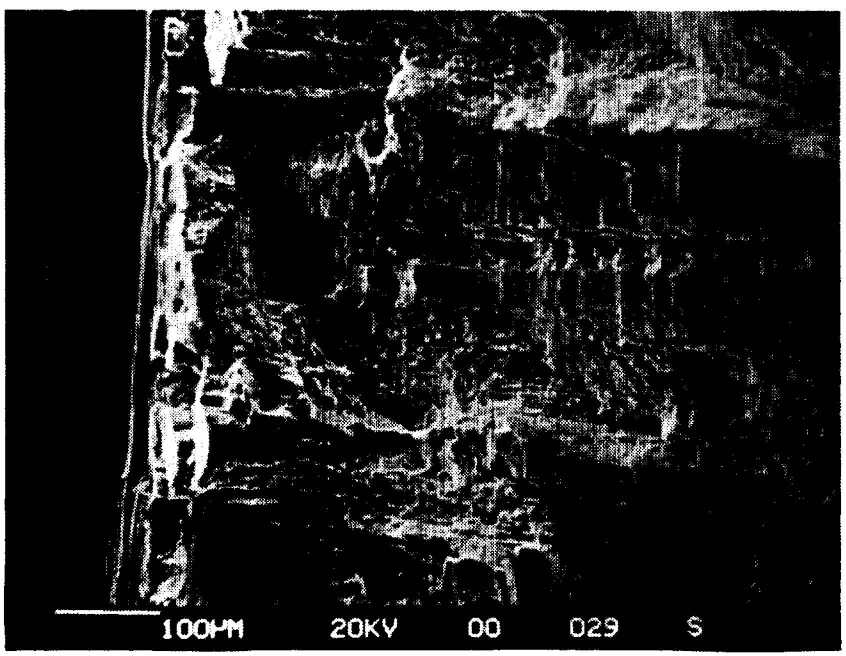


FRACTURE PATH AND FRACTURE SURFACE MORPHOLOGY OF R2090 BASELINE TESTED AT ROOM TEMPERATURE



0.562 in.

A



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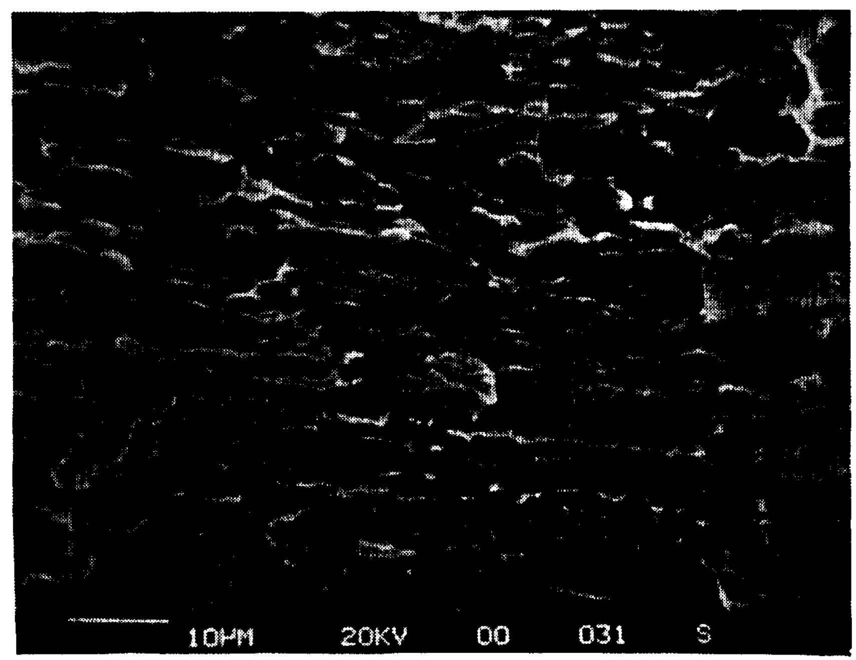

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CHEMICAL COMPOSITIONS AND PROCESS HISTORIES OF AVAILABLE ALLOYS

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→	0.500 in. plate		SHT	3% stretch

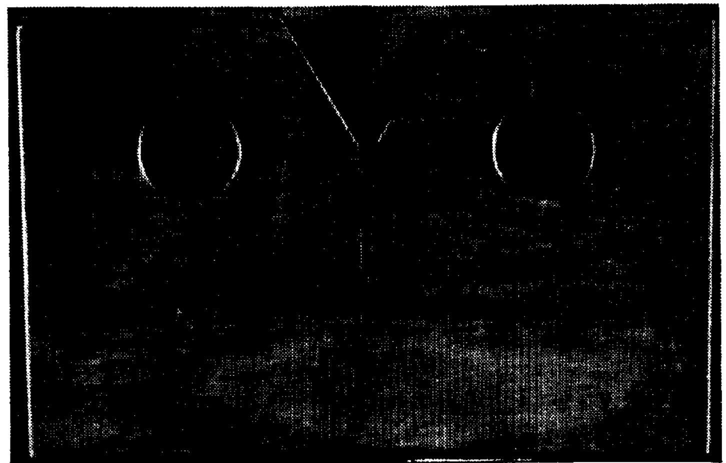
2. R2090+In

	0.125 in. sheet	TMTC	SHT	3% stretch
	0.125 in. sheet		TMT C	SHT @ LaRC
	0.500 in. plate		SHT	3% stretch
→	0.500 in. plate		SHT	0% stretch

3. A2090

→	0.750 in. sheet		T81 (T8E41)

FRACTURE PATH AND FRACTURE SURFACE MORPHOLOGY OF R2090 BASELINE TESTED AT CRYOGENIC TEMPERATURES



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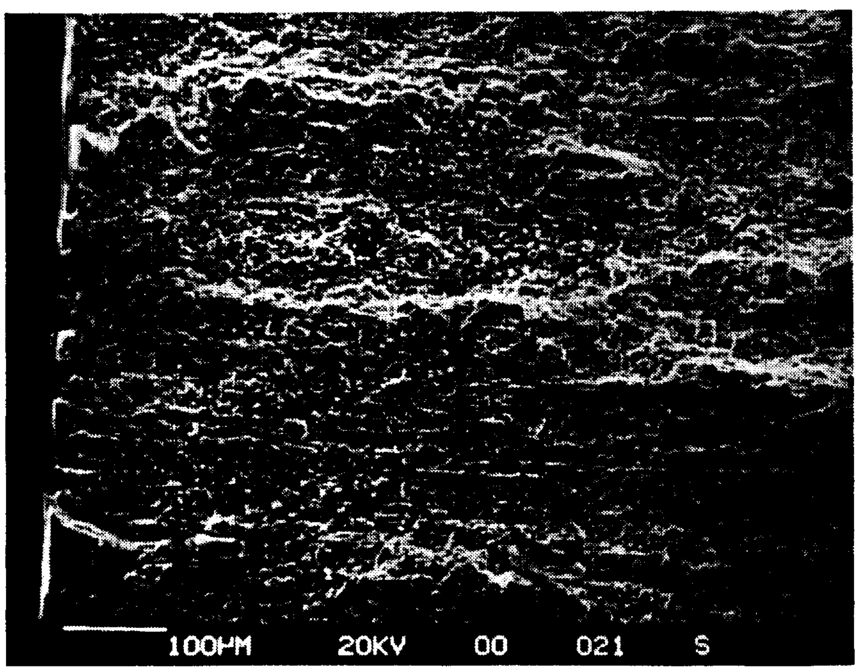

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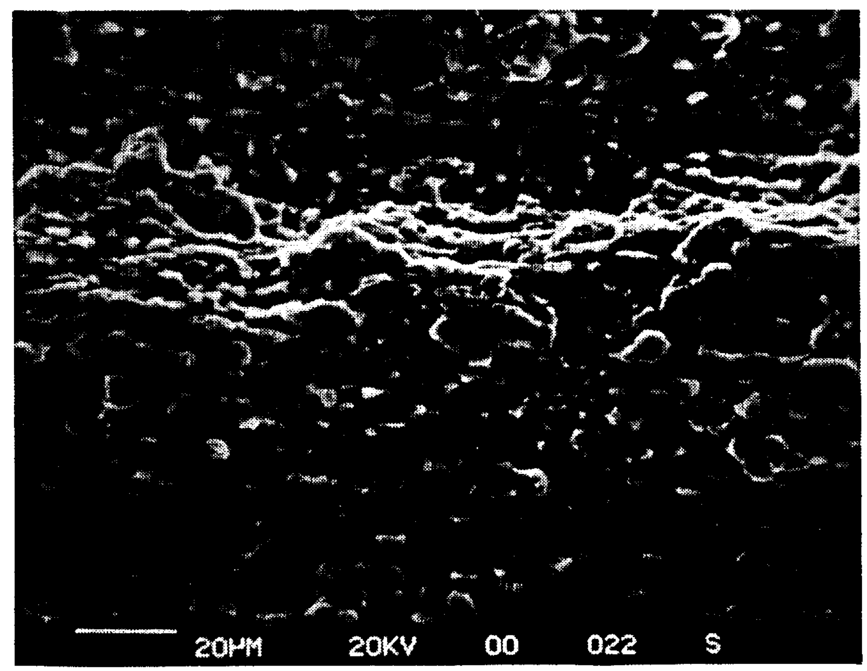

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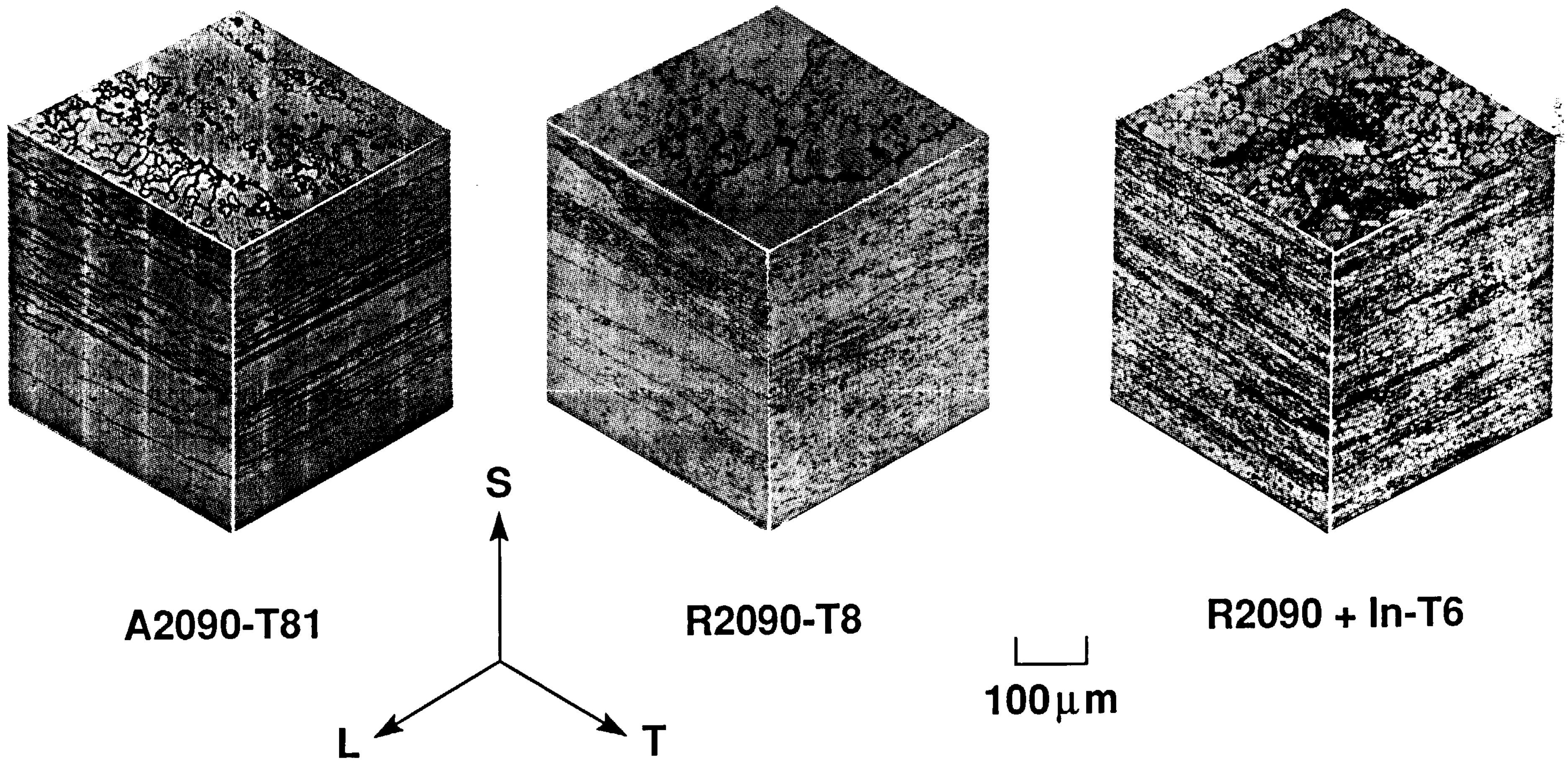
MICROSTRUCTURES OF PLATE ALLOYS



OBJECTIVES OF EXPERIMENTAL TEST MATRIX

Primary objective

- Determine the effect of key variables on J (Δa) behavior, fracture path and fracture mode of Al-Li-Cu-Zr-X alloys
    - Temperature
    - Constraint
    - In addition

Secondary objective

- Examine the general deformation & fracture behavior of Al-Li-Cu-Zr-X alloys with respect to:
    - Orientation
    - Process history
    - Material vendor

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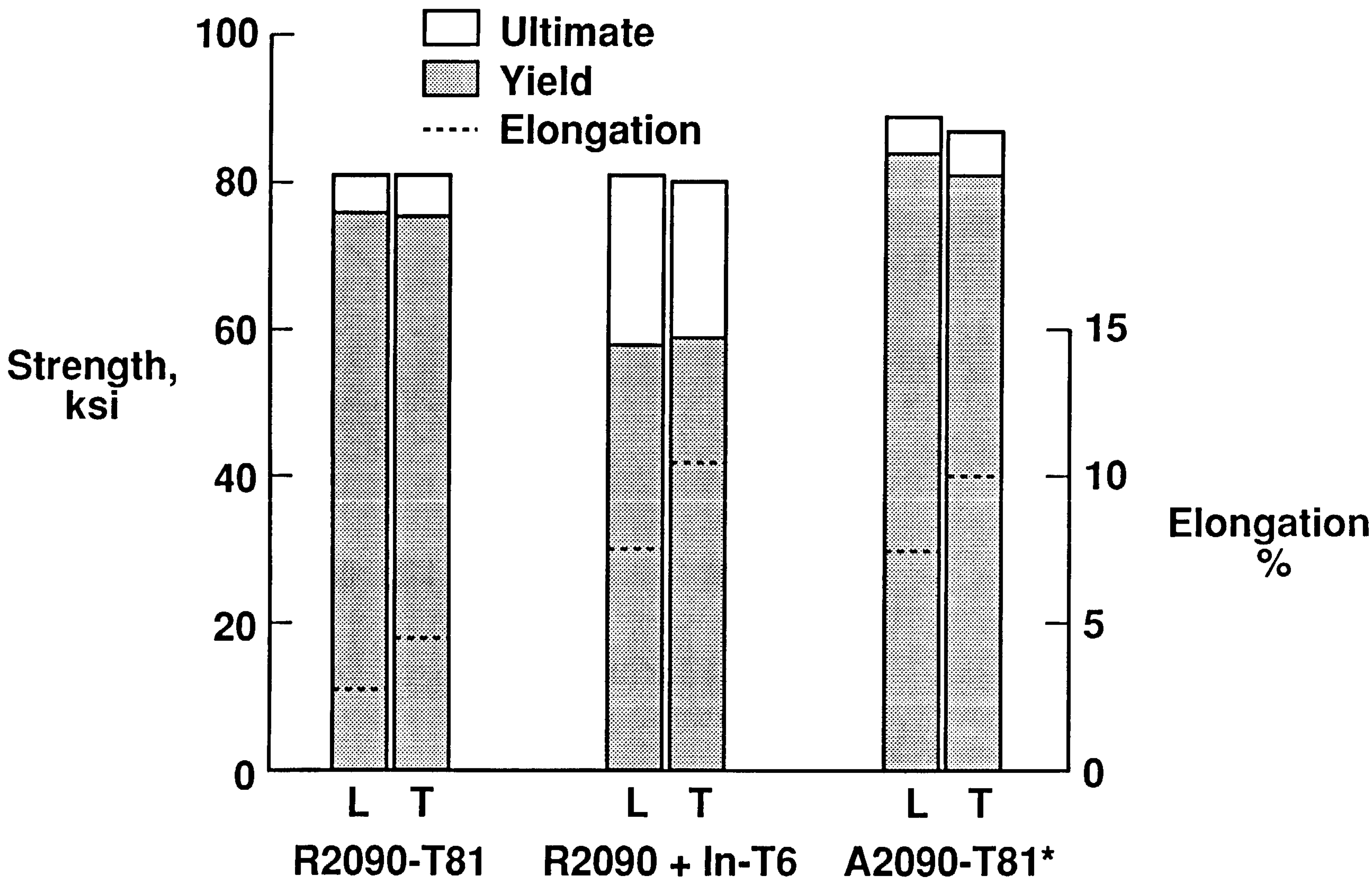
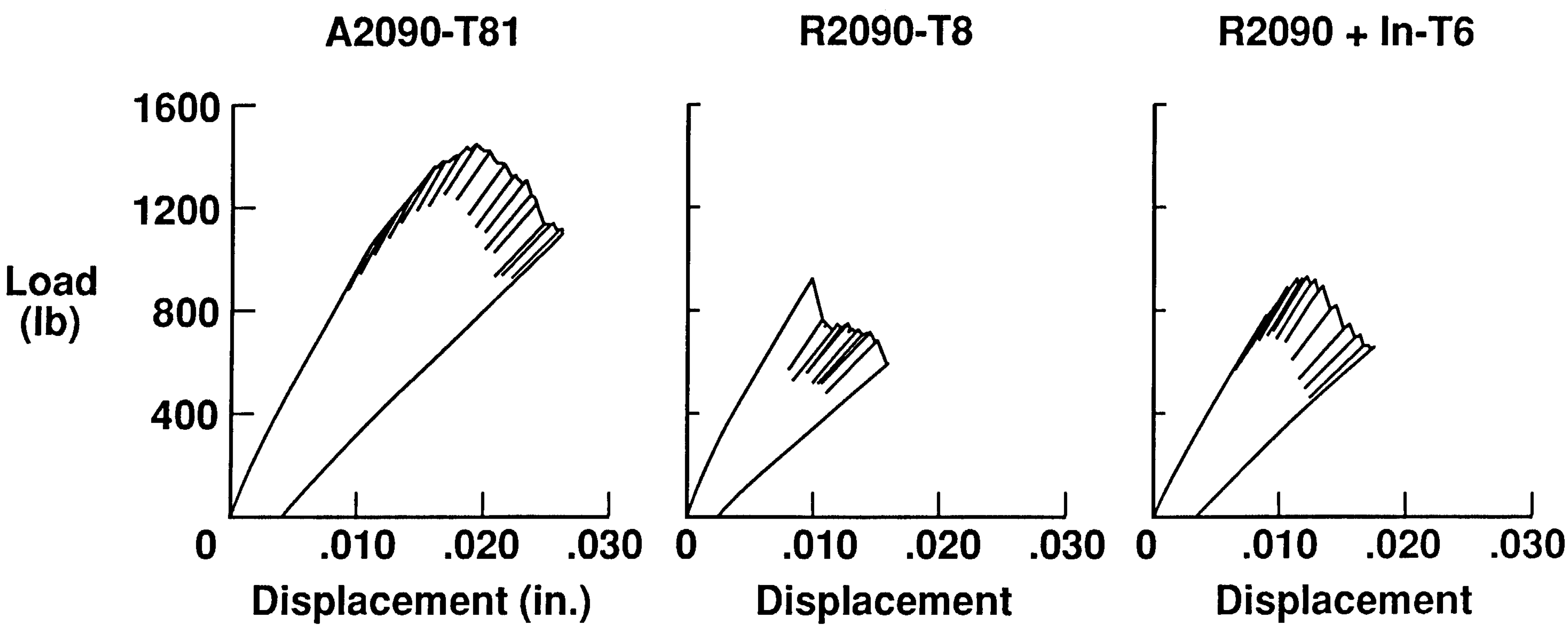
TENSILE PROPERTIES Al-Li-Cu-Zr ALLOYS



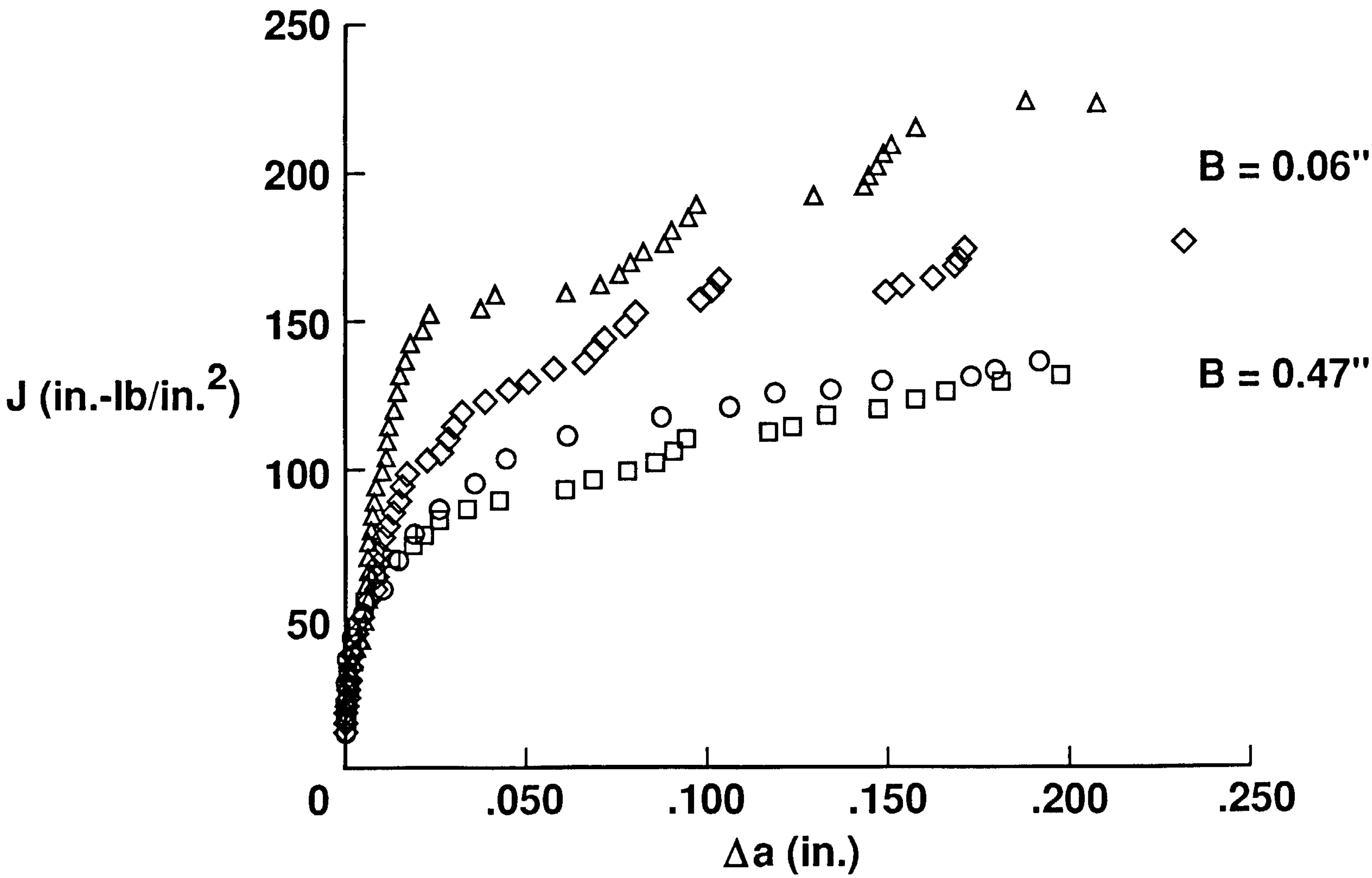
* Values from NIST

TYPICAL LOAD VERSUS DISPLACEMENT CURVES FOR 0.473 IN. SPECIMENS WITH SIDEGROOVES

LT orientation
Compact tension

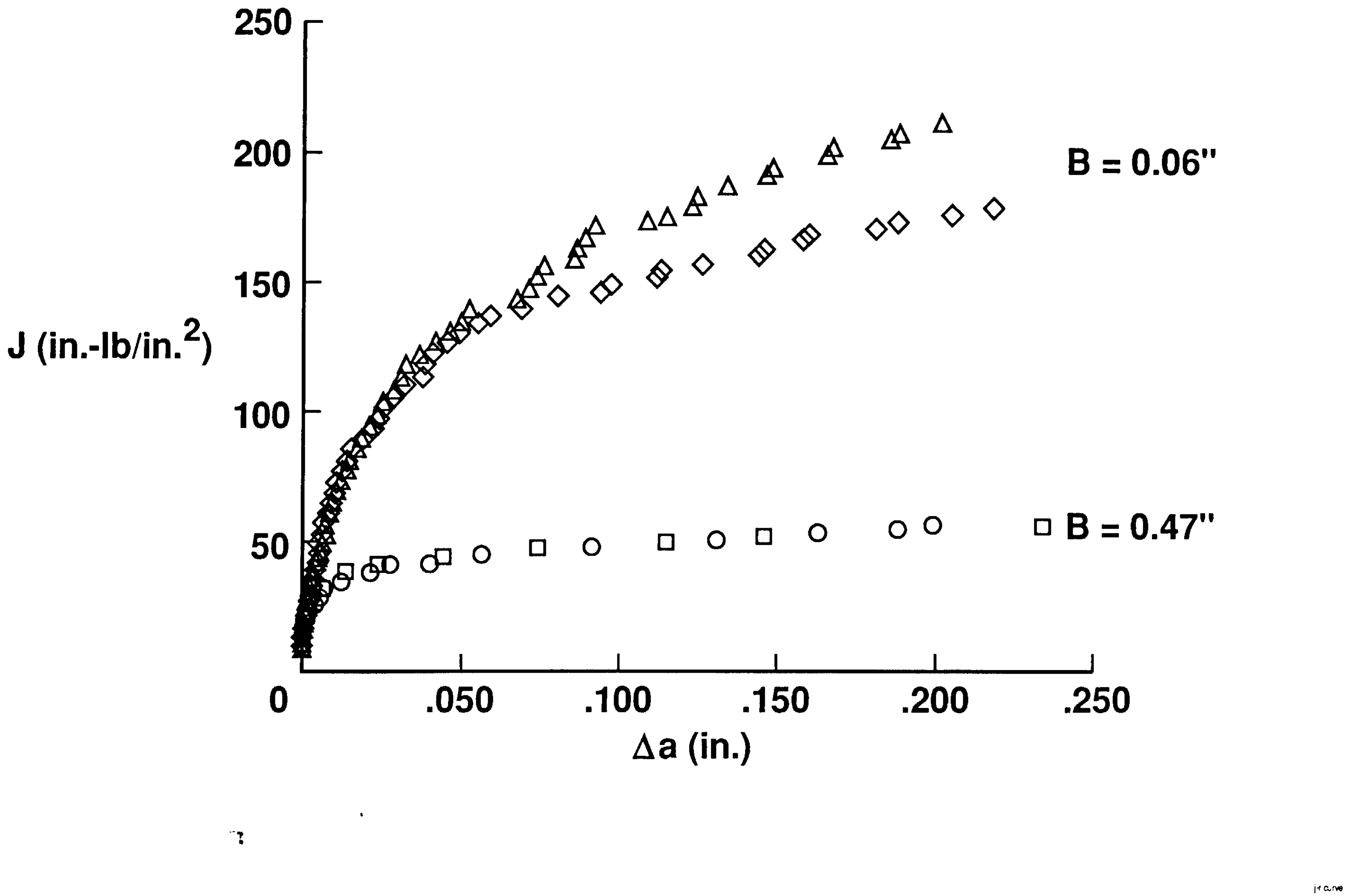


J-R CURVE FOR A2090-T81

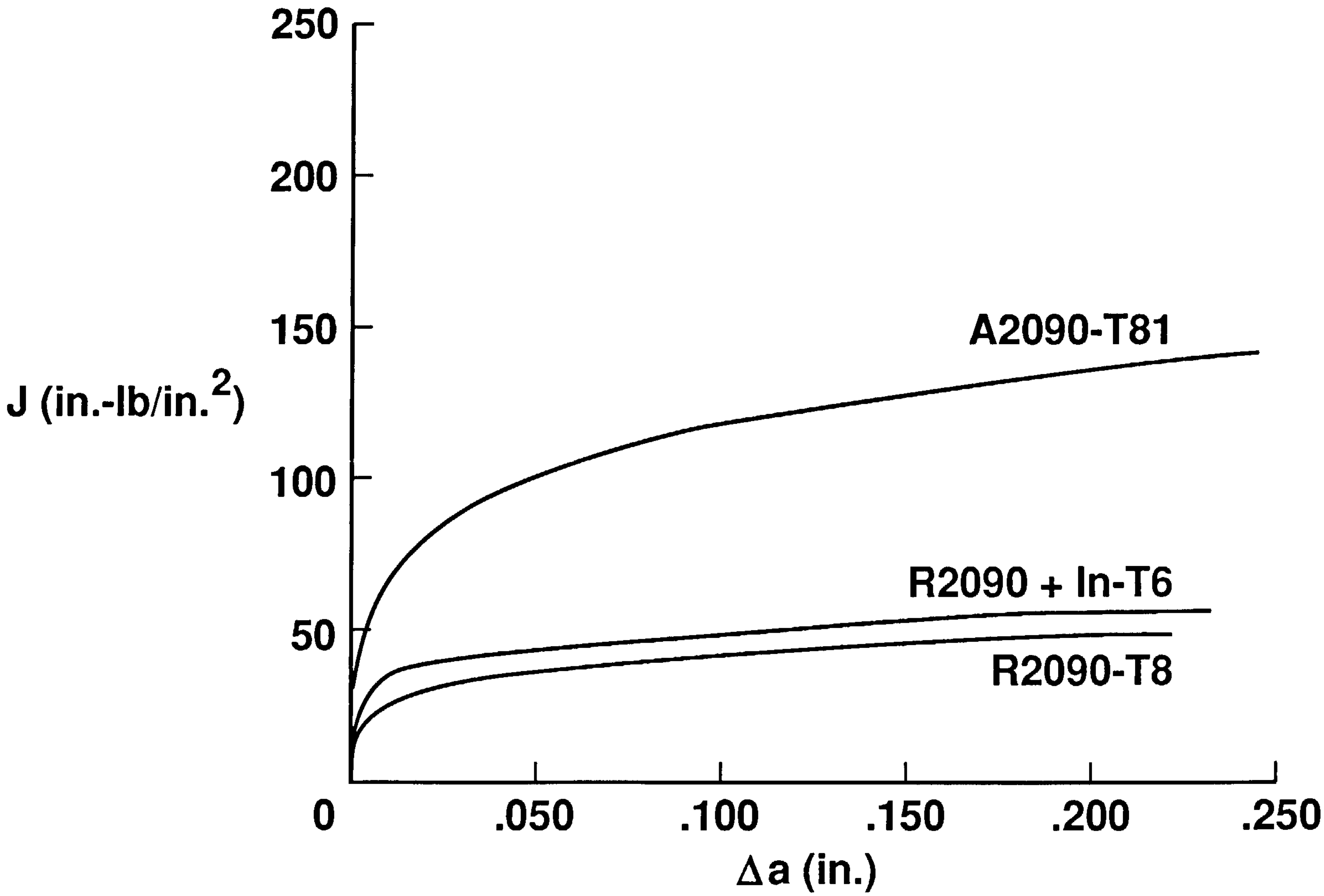


j-r curve a2090

J-R CURVE FOR R2090 + In-T6

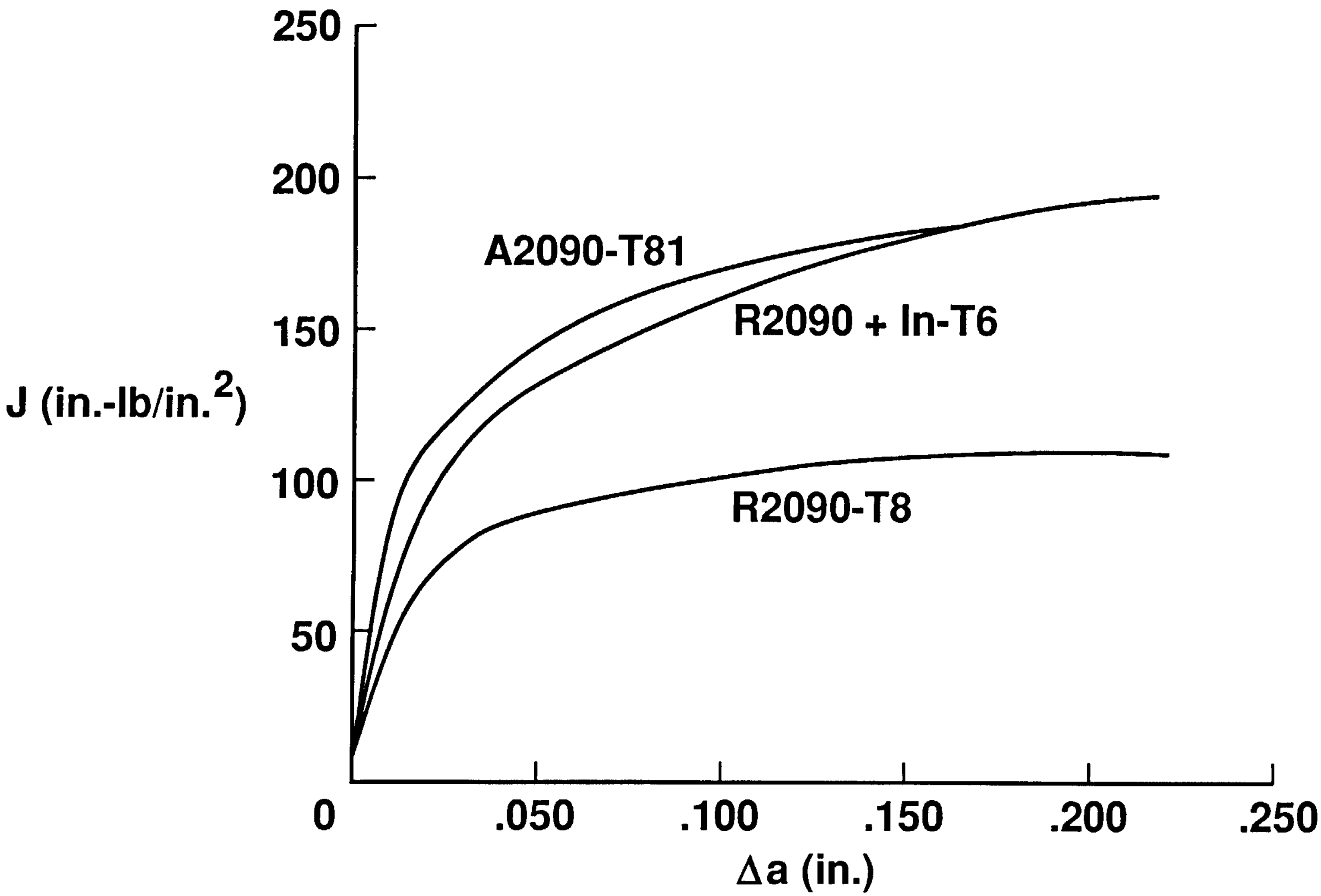


FRACTURE TOUGHNESS R-CURVE FOR 0.47" THICK SPECIMENS



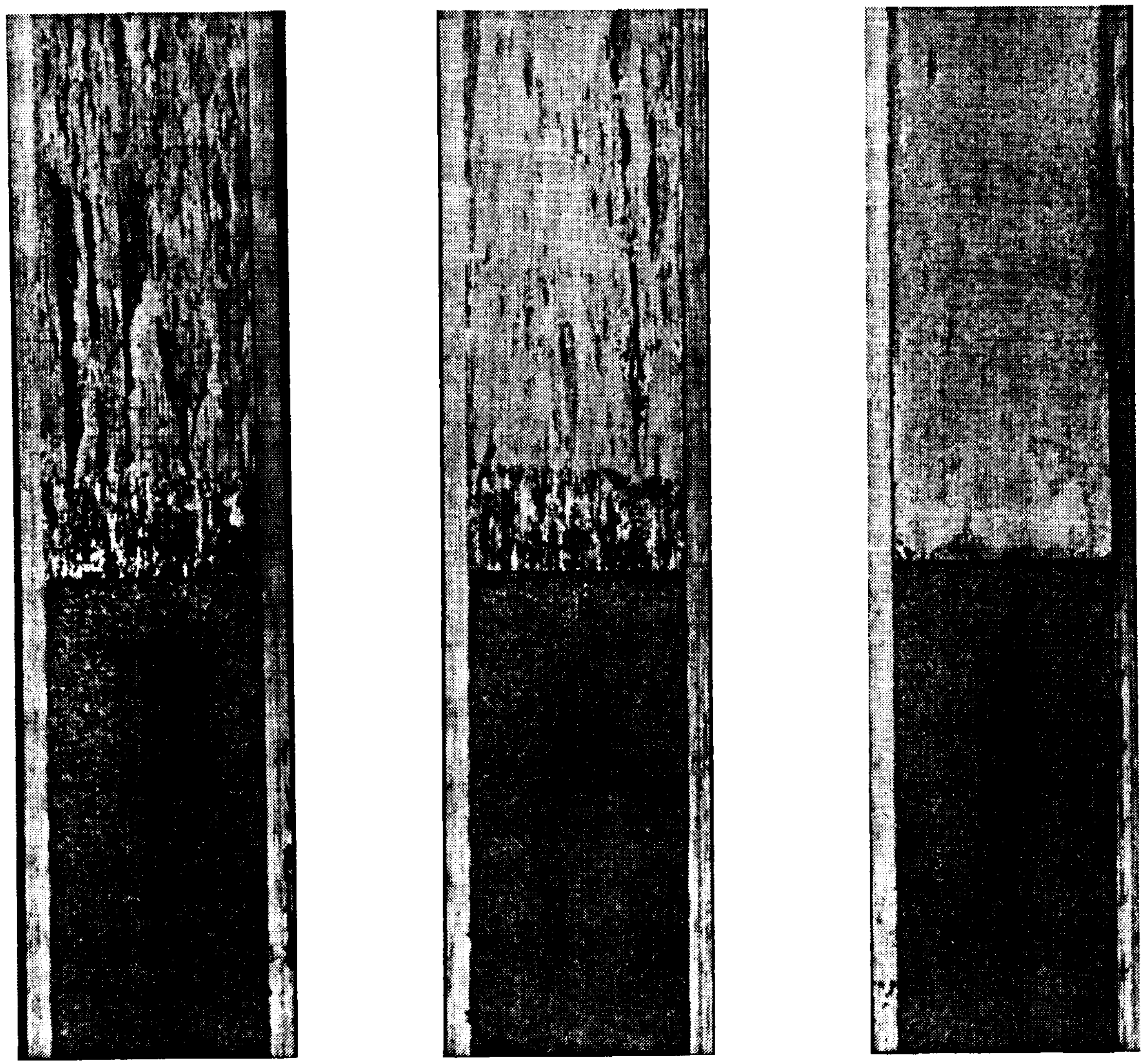
ft r-curve

FRACTURE TOUGHNESS R-CURVE FOR 0.06" THICK SPECIMENS



ft r-curve 0.06

FRACTURE MORPHOLOGY OF 0.47" THICK COMPACT TENSION SPECIMENS



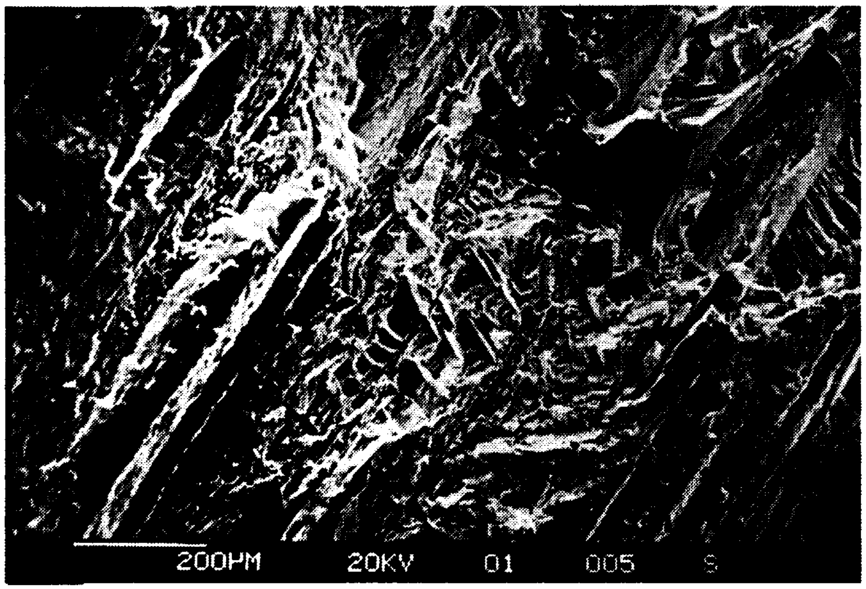
A2090-T81 R2090-T8 R2090 + In-T6

FRACTURE MODE AND AVERAGE J_{Ic} FOR PLATE 2090

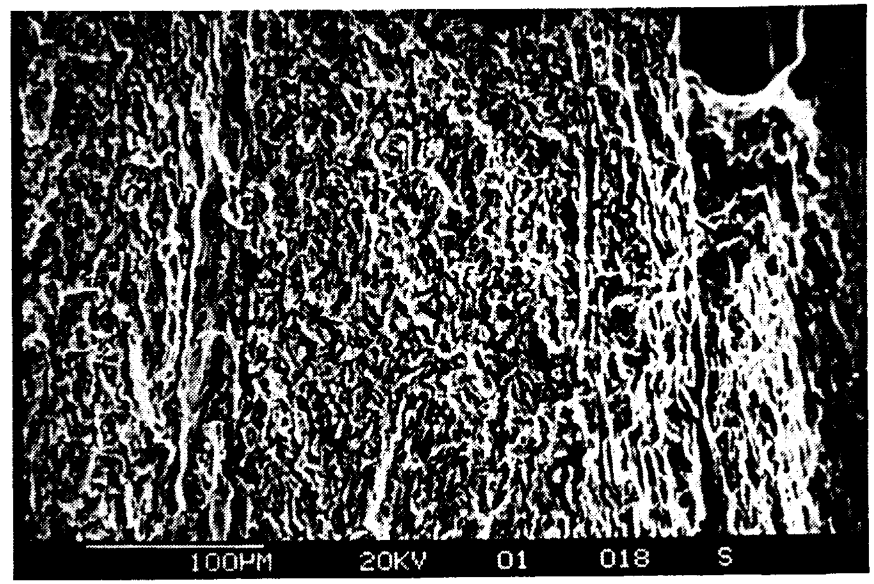
Material	Thickness (in.)	J_{Ic} (in.-lb/in.^{2})	K_{Ic} (ksi $\sqrt{\text{in.}}$)	$\frac{\text{Plastic zone}}{\text{thickness}}$	Amount of delamination	Primary fracture mode
A2090-T81	0.06	75	31	0.37	Medium	TGS/min. ISG
	0.47	56	27	0.03	High	TGS/min. ISG
R2090-T8	0.06	44	24	0.25	Low	ISG
	0.47	30*	20	0.02	Medium	ISG
R2090 + In-T6	0.06	55	27	0.57	Low	ISG
	0.47	32	21	0.05	Low	ISG

TGS $\equiv$ transgranular shear
ISG $\equiv$ intersubgranular
* Invalid according to ASTM E813

FRACTURE SURFACE MORPHOLOGY OF PRECRACK/FAST FRACTURE TRANSITION REGION

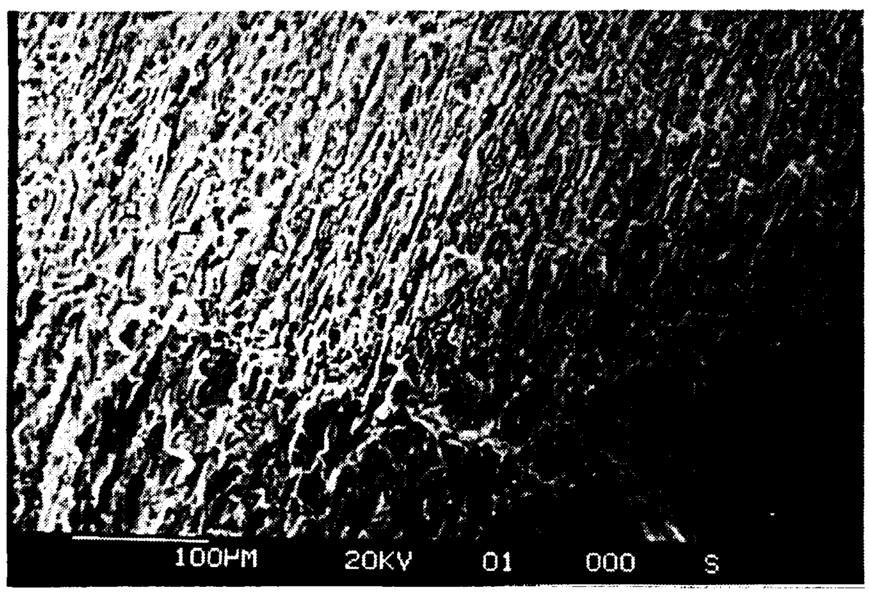


A2090-T81

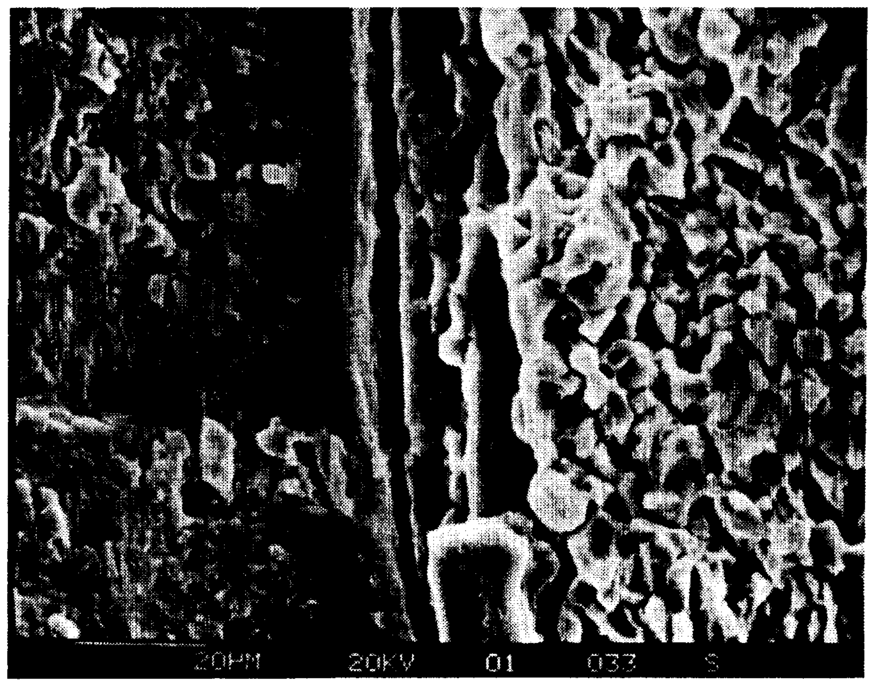


R2090-T8

R2090 + In-T6



SEM PHOTOMICROGRAPH OF REGION ADJACENT TO DELAMINATION IN R2090-T8



SUMMARY

- Increase in σ_{ult} and no change in σ_{ys} observed for both sheet and plate alloys of R2090 + In-T6
- Alcoa 2090-T81 0.75" plate exhibited excellent tensile properties with moderate toughness
- Moderate toughness associated with A2090-T81 associated with large amount of delamination and transgranular shear
- Fracture toughness was lower in R2090 + In-T6 and R2090-T8 and characterized by intersubgranular fracture
- Difference in toughness between A2090-T81 and R2090 + In-T6 decreases in plane stress regime

FUTURE PLANS

What is the influence of microstructure and stress state in controlling the toughness and fracture mode of Al-Li-Cu-Zr-X alloys at cryogenic temperatures? Specifically, what promotes transgranular shear mode of failure?

- Grain structure
- Temperature
- Delamination
- Stress state
- In addition