Fatigue Crack Propagation and Stable Tearing in Friction-Stir-Welded Aluminum Sheet

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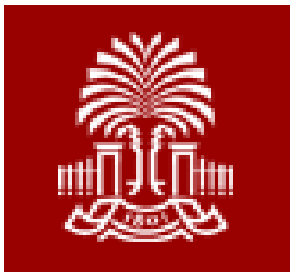
November 28, 2006

Collaborative Effort

Univ of So Carolina



Raphael Muzzolini
Jean-Christophe Ehrstrom, PhD

Nathalie Fuzier
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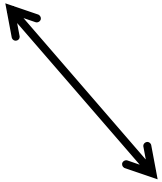

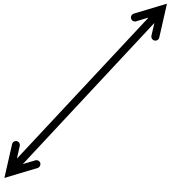

Kenneth K. Chan
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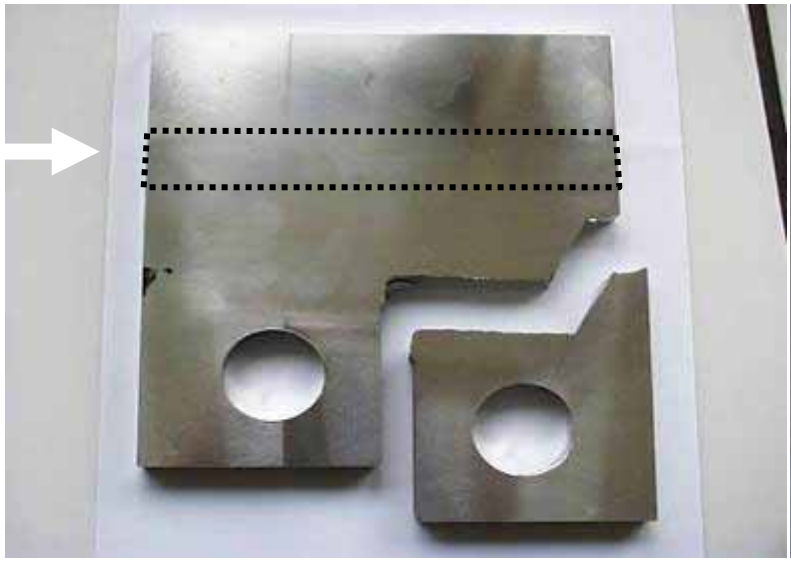
Initiation

- Seemingly Consistent Crack Turnings
  - FCGR test on 7xxx-T7 Sheet
  - 3 Samples each, from 3 Lots

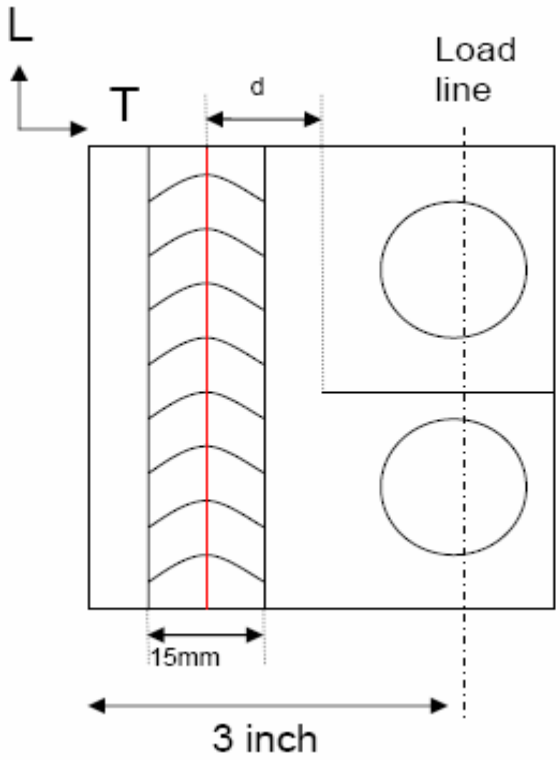


FSW sample

Base metal

Motivation

- Understand Phenomenon
  - Why did the Cracks Turned?
  - Can it be Captured, and Controlled?
- Via Experiments
  - FCGR and stable tearing
  - C(t) and M(t) coupons
  - Cracks to FSW @ 90º & 45º



Outline

1. Material and weld properties

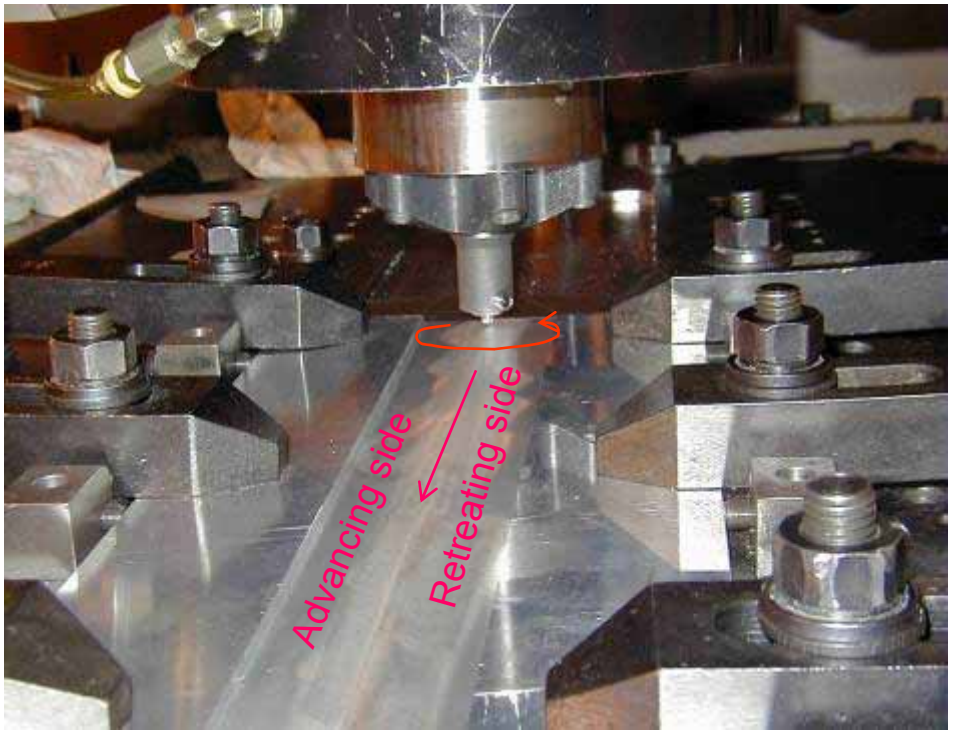
2. Fatigue tests
   - Geometry
   - Crack path
   - da/dN curves
   - Residual stress measurements

3. Stable tearing tests
   - Crack path
   - Properties

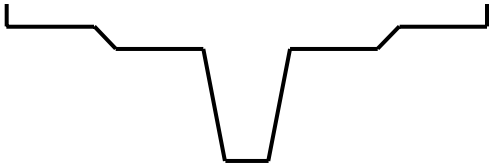
4. Fractography

Material and Welding Description

- Aluminum 7xxx-T7 Sheet , t = 5mm.
- Post Weld Aging heat treat to stabilize properties of the weld.

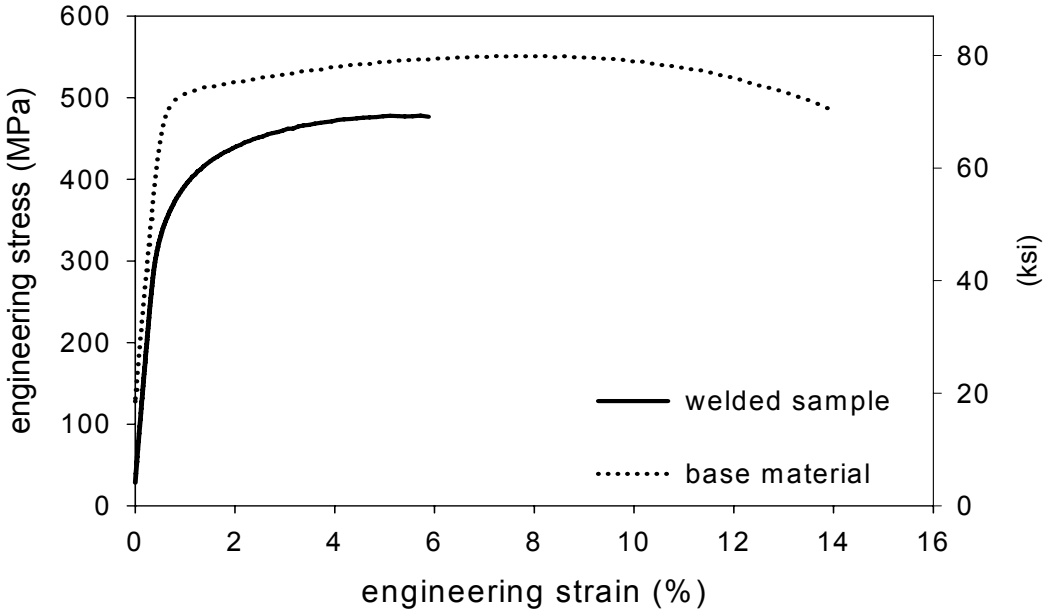


Profile of the Tool :

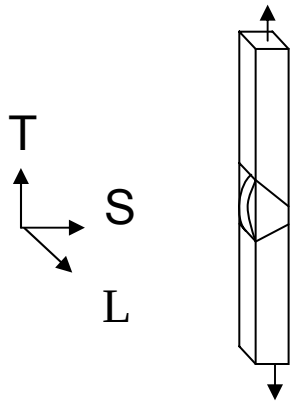


Weld Properties

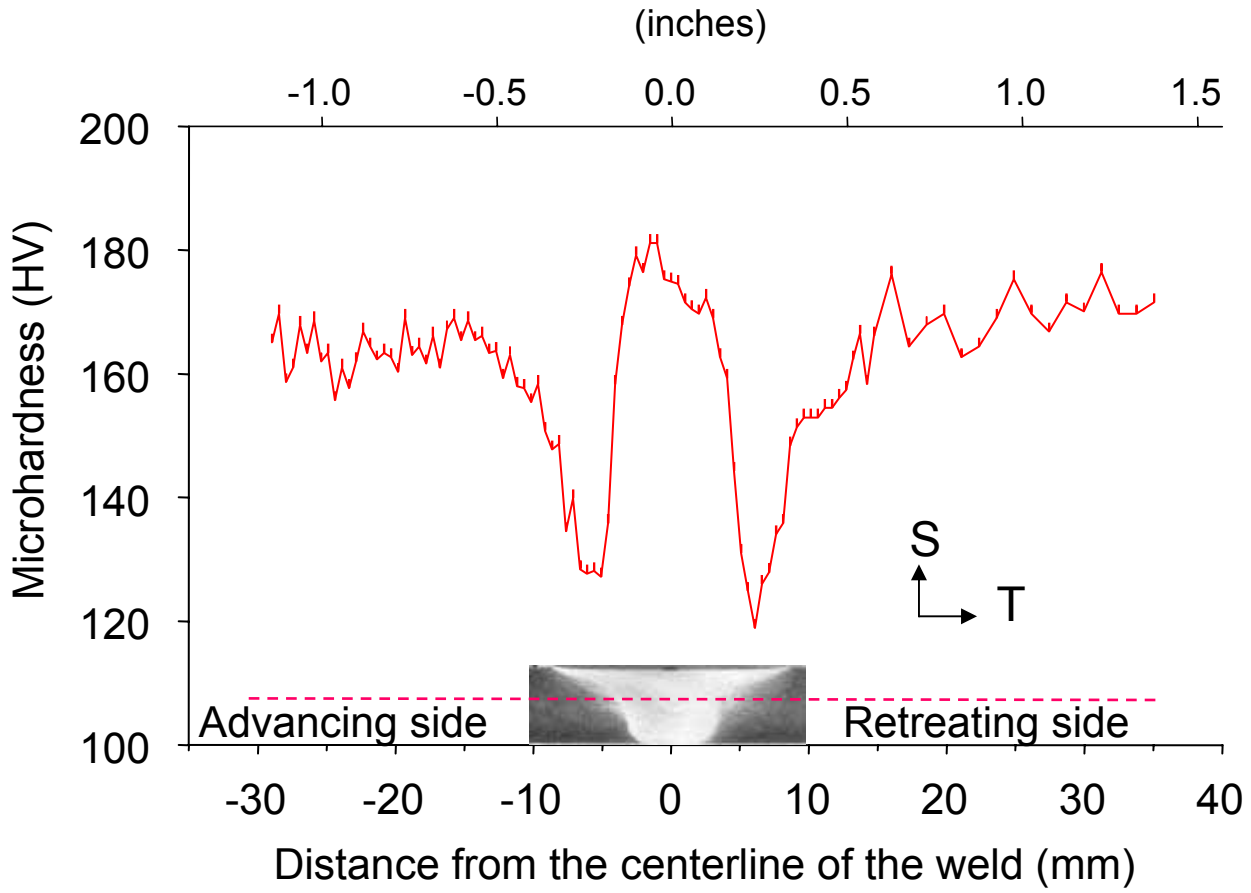
	UTS MPa (ksi)	Elongation at UTS (%)	Elongation at rupture (%)
Base metal (T-L)	552 (80)	8.1	13.9
Weld (T-L)	477 (69)	5	5.9



Weld UTS : 86% of base material



Hardness Profile



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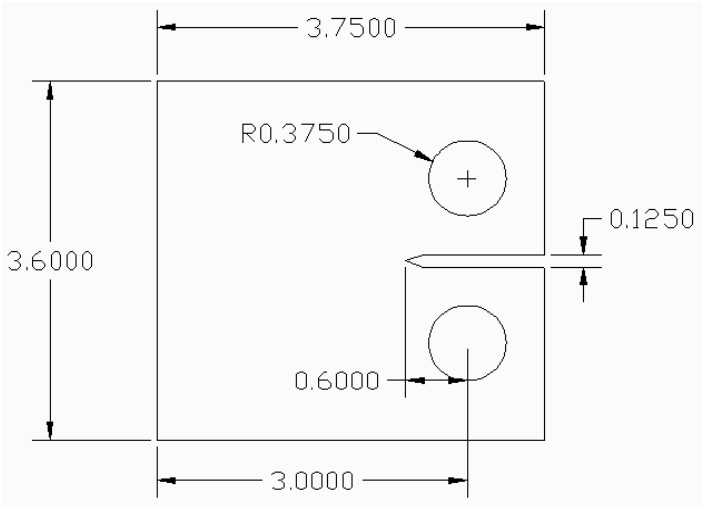
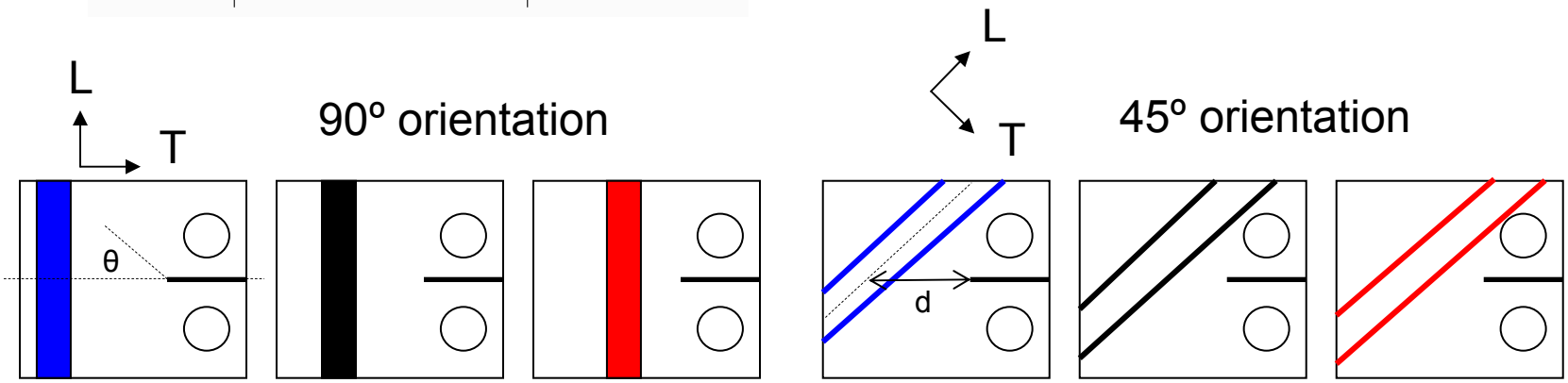
C(T) Samples



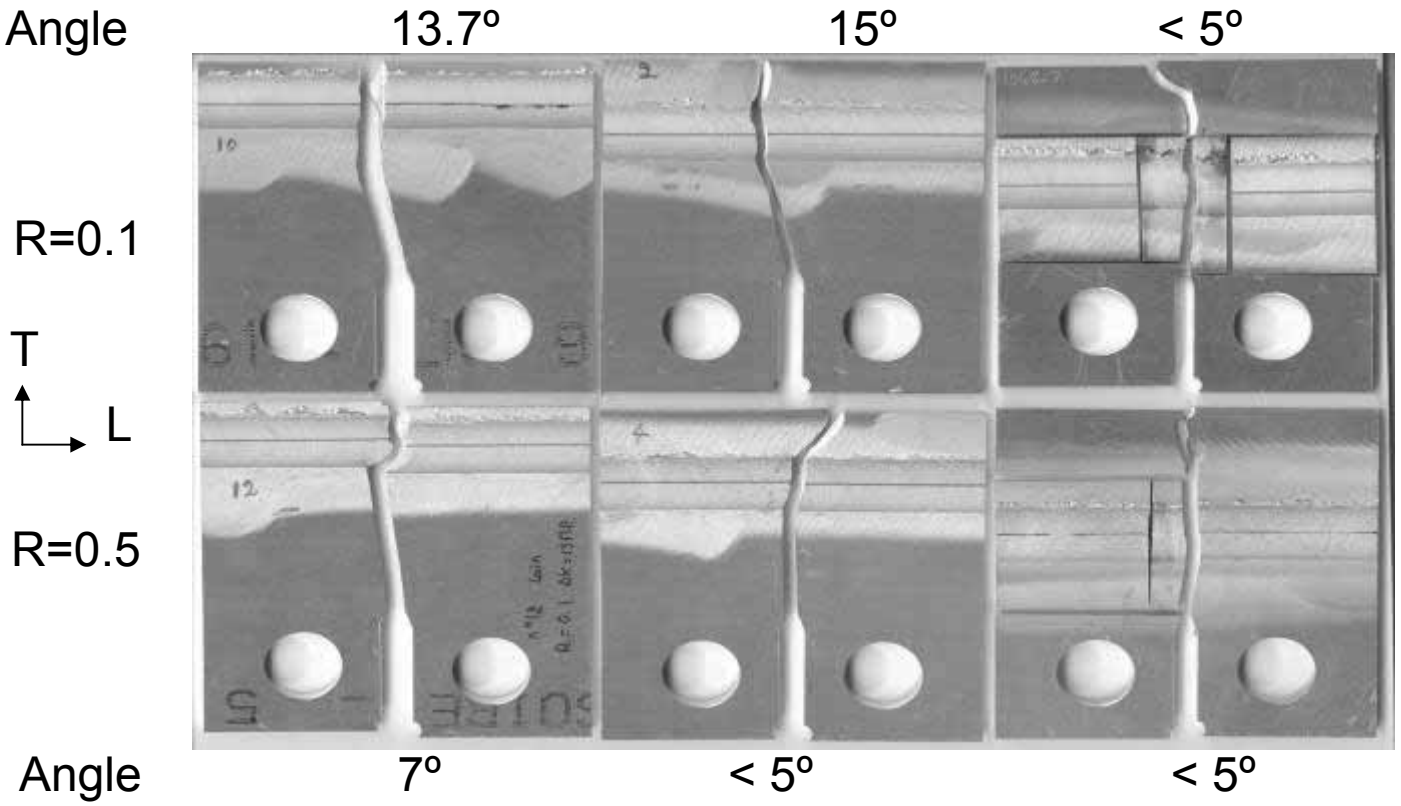
Dimensions are in inches.



Crack Path 90º Orientation

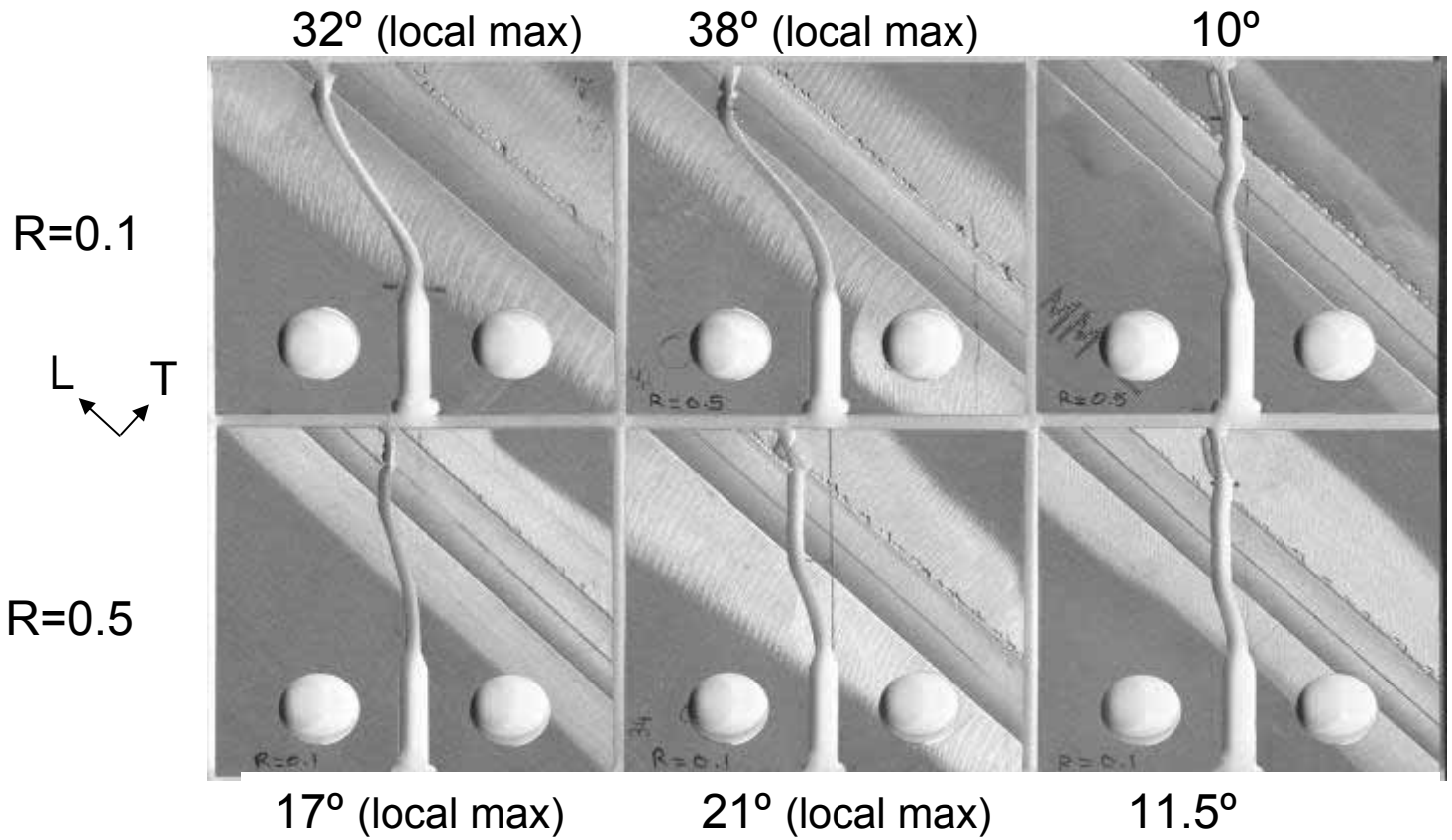
Fatigue cycling at constant $\Delta K = 15\ MPa*m^{1/2}$

Propagation along straight line, slight deviation angle.



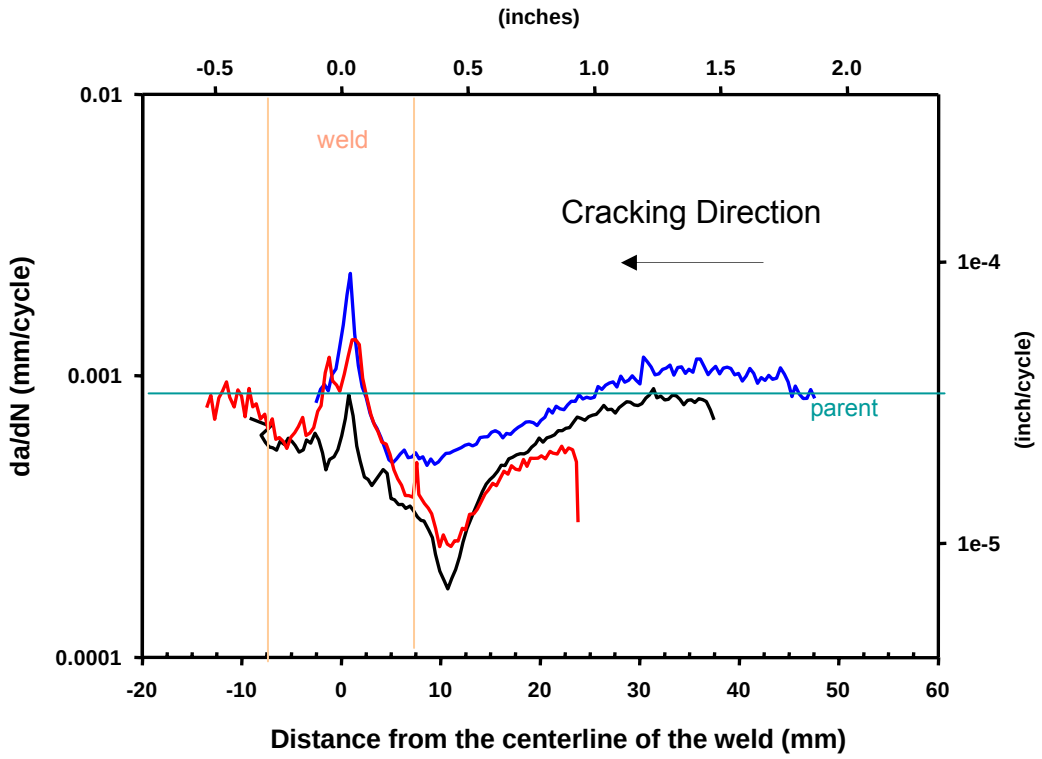
Crack Path 45º Orientation

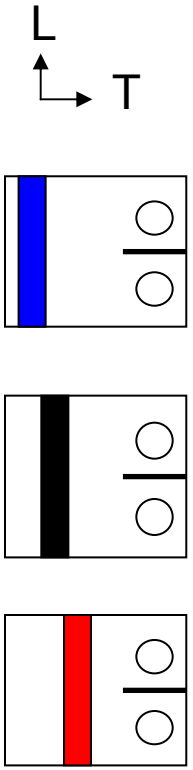
Curved crack path.



Fatigue Results

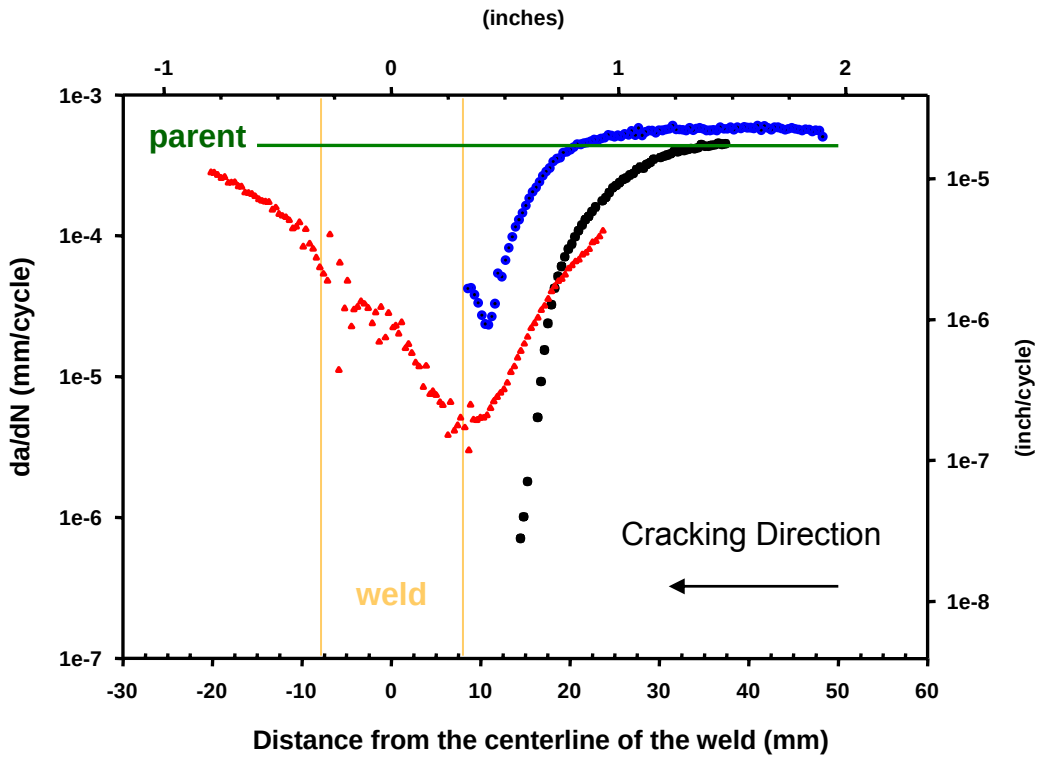
R=0.5 $\Delta K=15MPa*m^{1/2}$

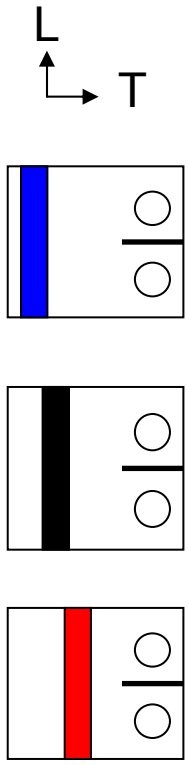




Fatigue Results

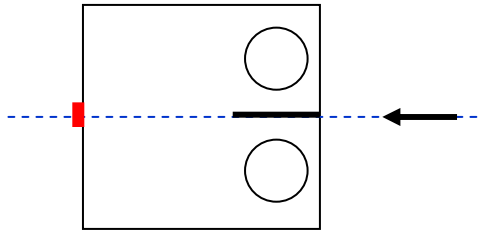
R=0.1 $\Delta K=15MPa*m^{1/2}$

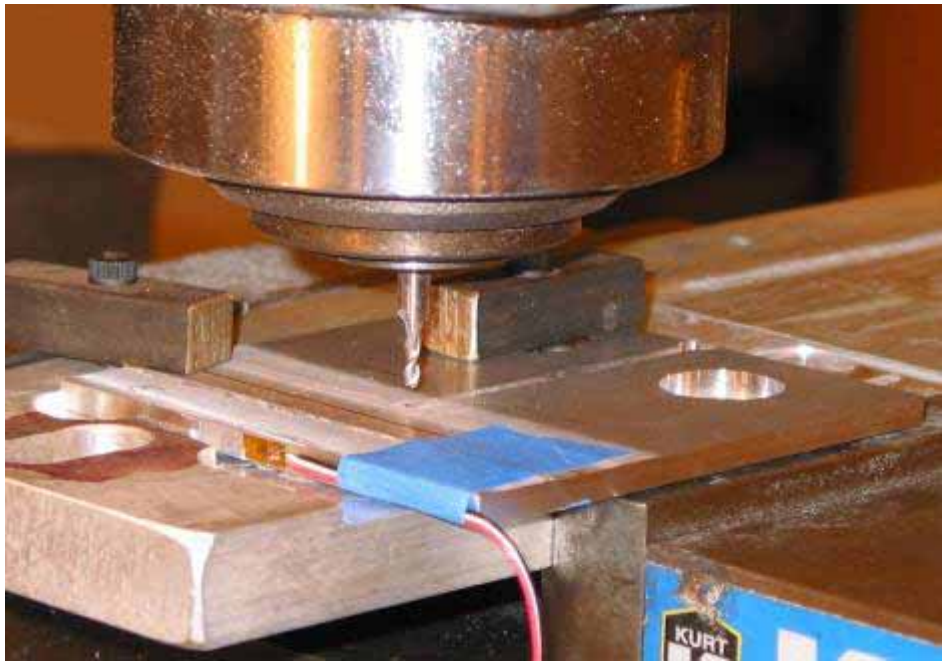




Residual Stress Evaluation

By "Cut Compliance" technique - Measure Δε at each additional cut



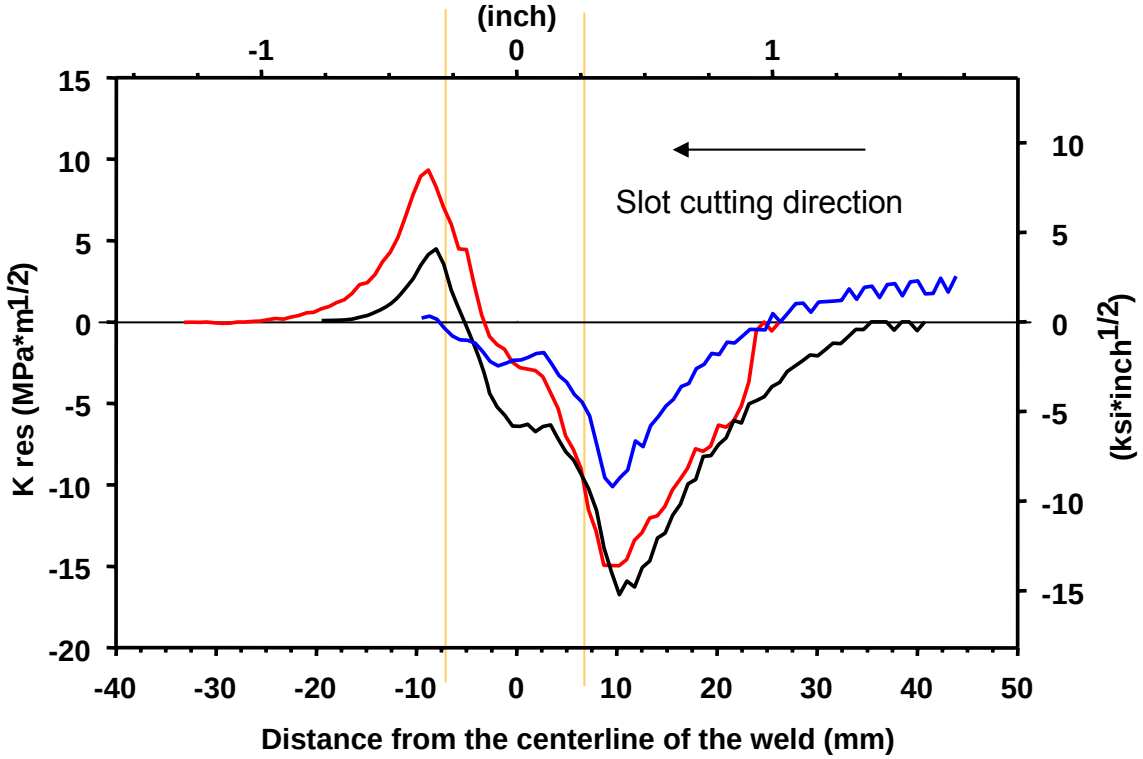


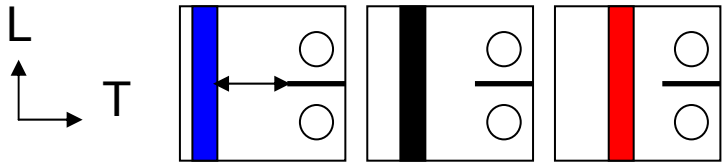
Forward determination of the stress intensity factor due to residual stresses :

$$K_{I\,res}(a) = \frac{E'}{Z(a)}\frac{d\varepsilon}{da}$$

where Z(a): a geometrical function

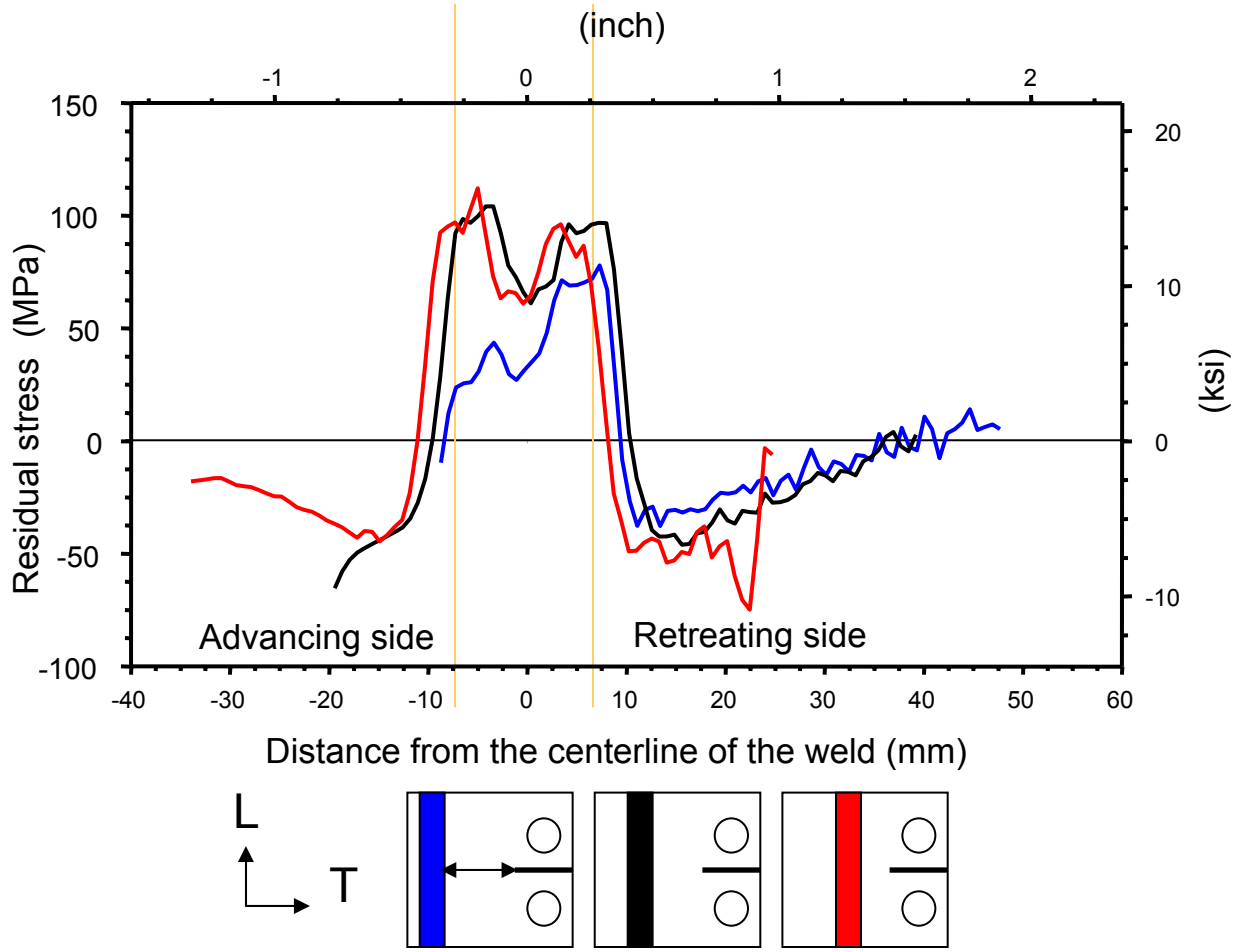
Kresidual





True Kmax applied at the crack tip, Kmaxtotal, is a summation of Kresidual and Kmax generated by loading.

Residual Stress Profile Calculated from K



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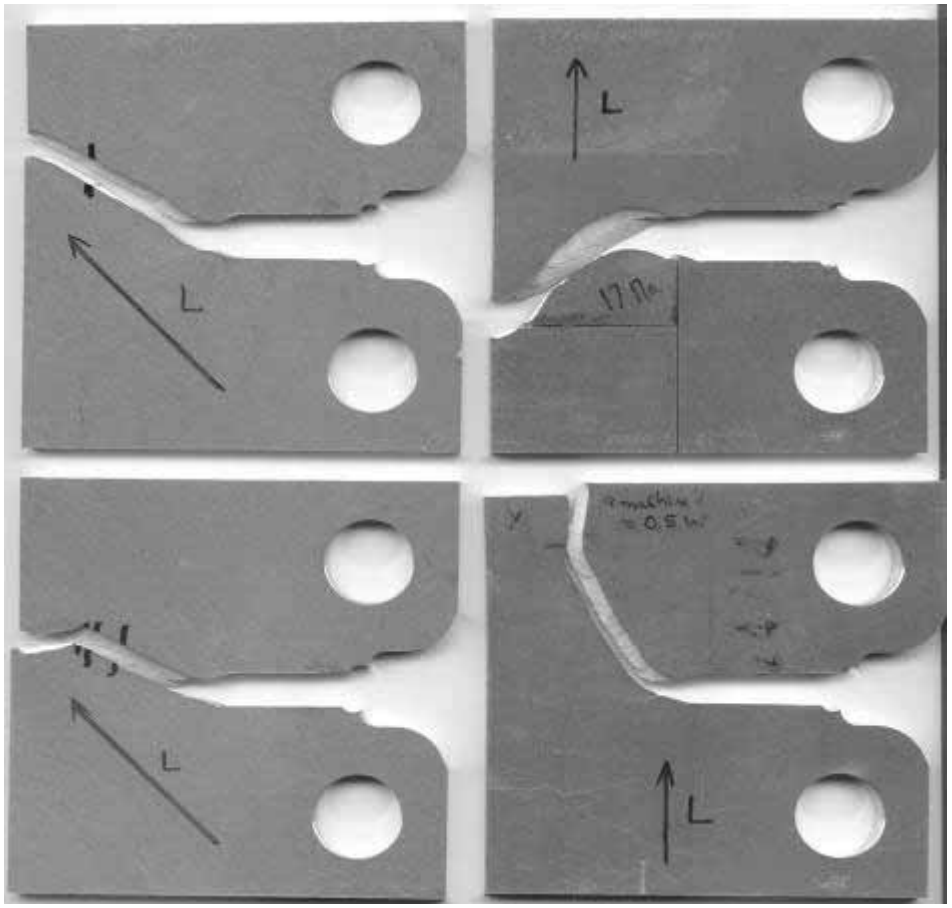
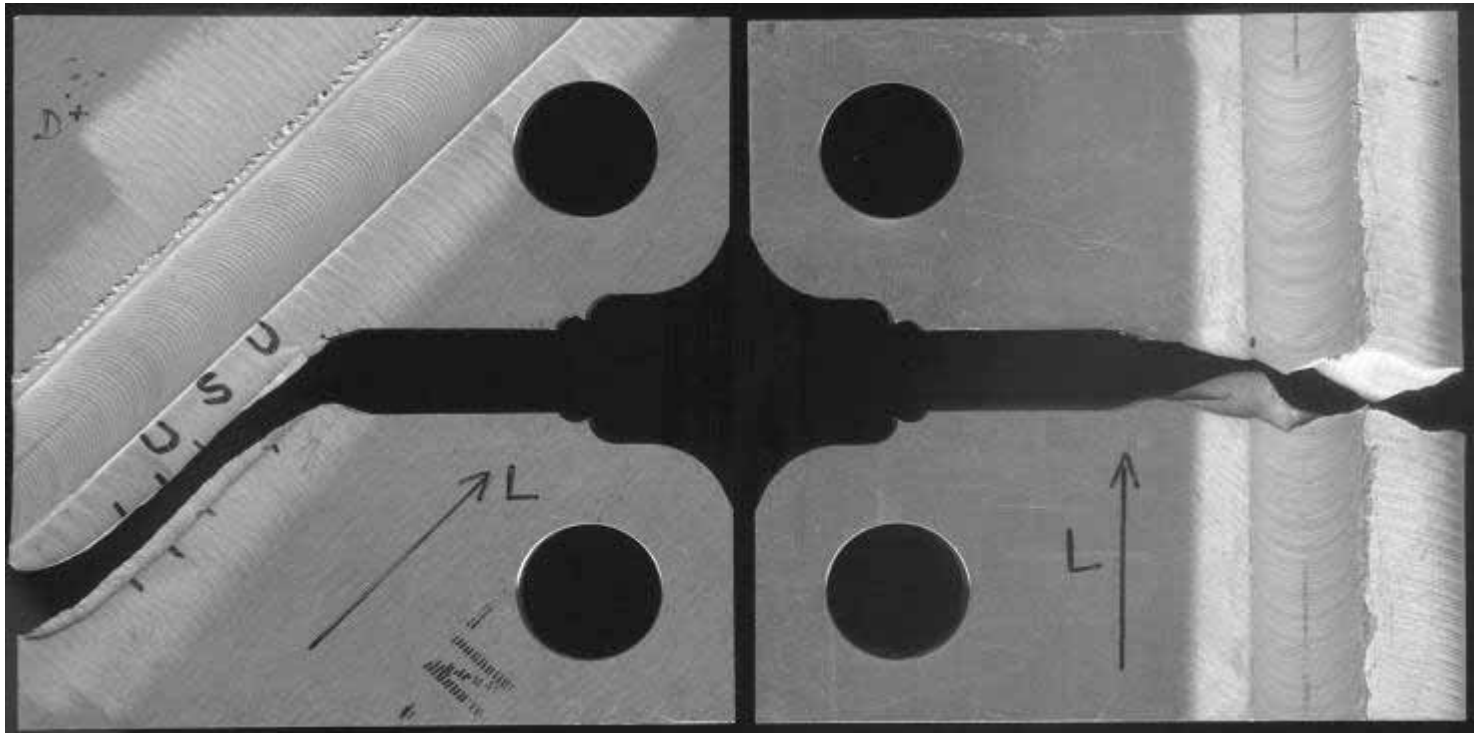
Stable Tearing - Parent Material



Rolling Direction appears to be the Preferred Path for Crack Extension.

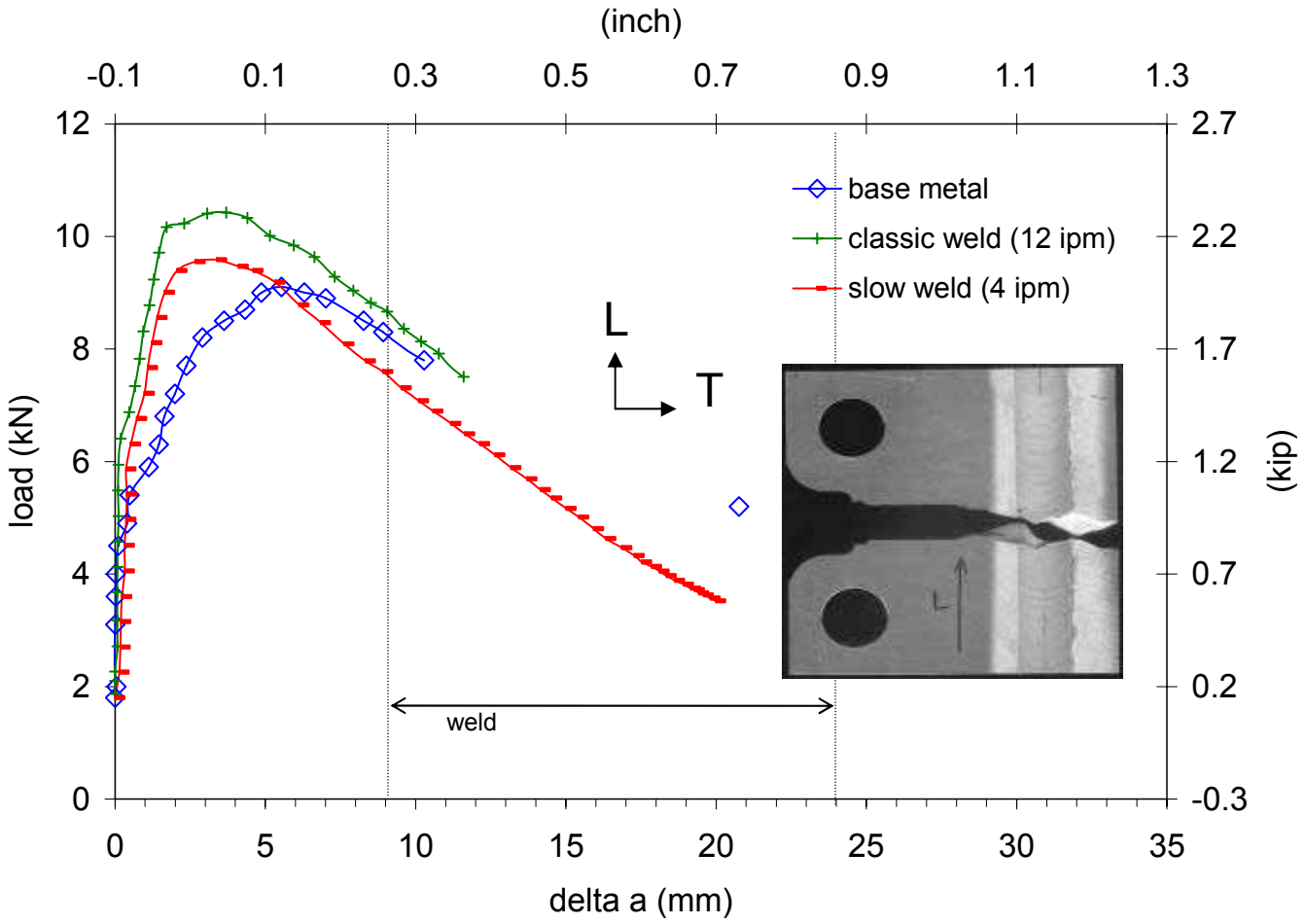
Stable Tearing - Welded Samples



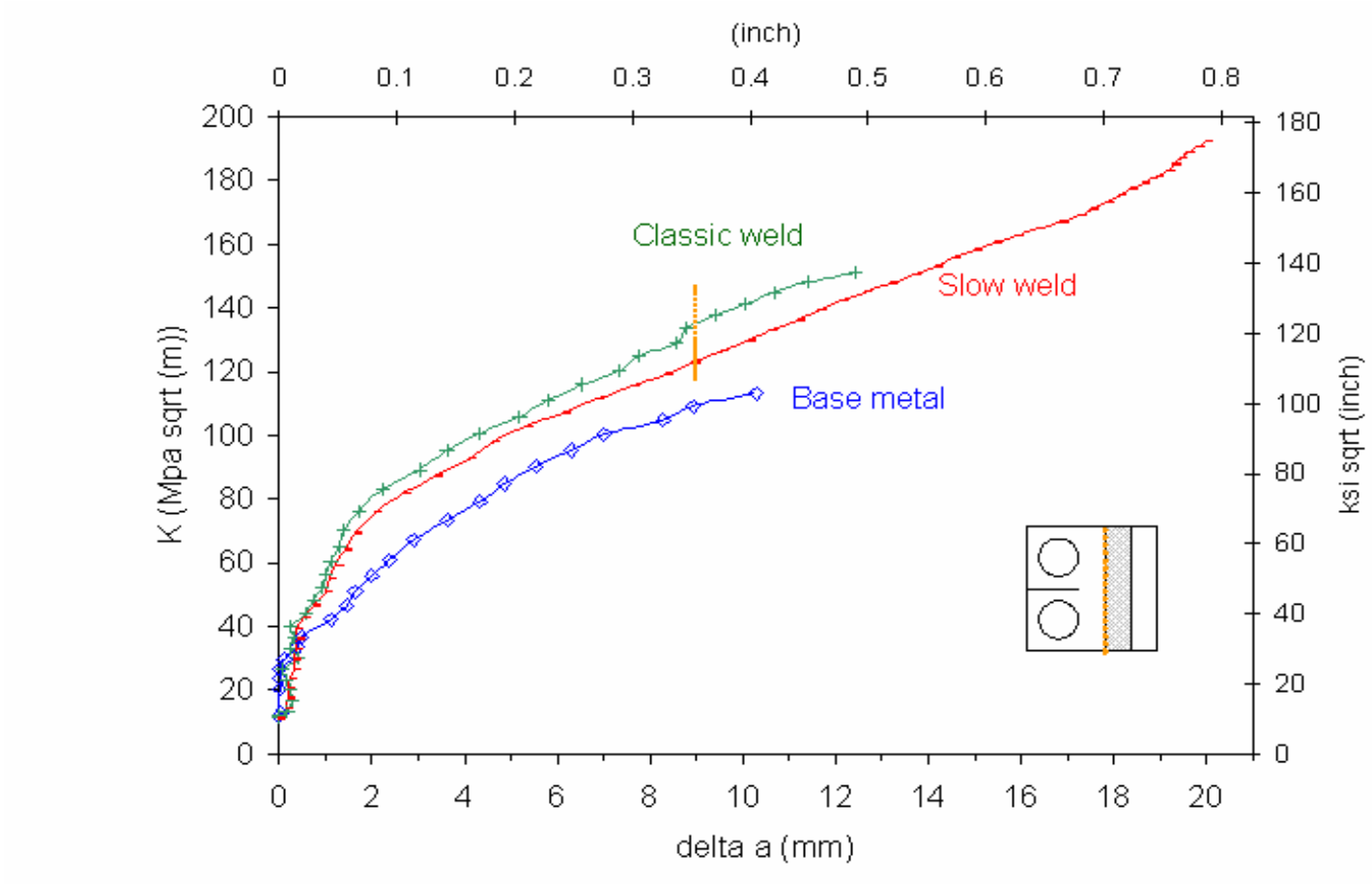
Crack turns so it extends along the L direction.

Combined effect of the microstructure and the welding?

Stable Tearing Data



Stable tearing data



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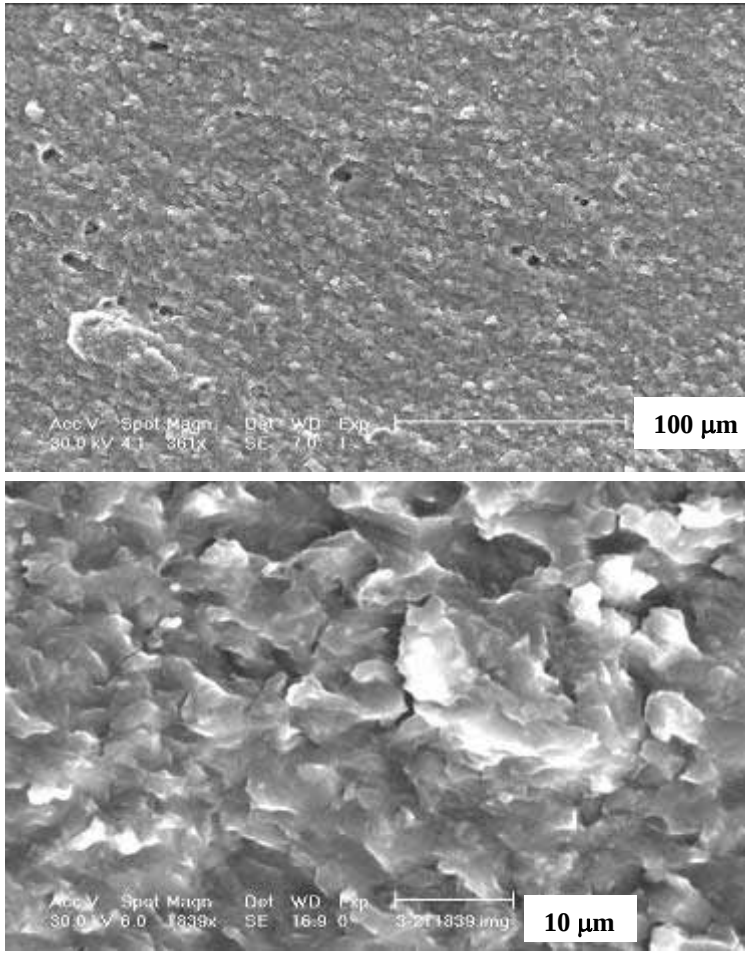
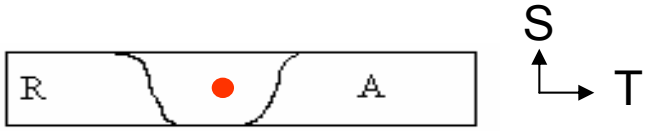
Fractography – Fatigue R=0.1



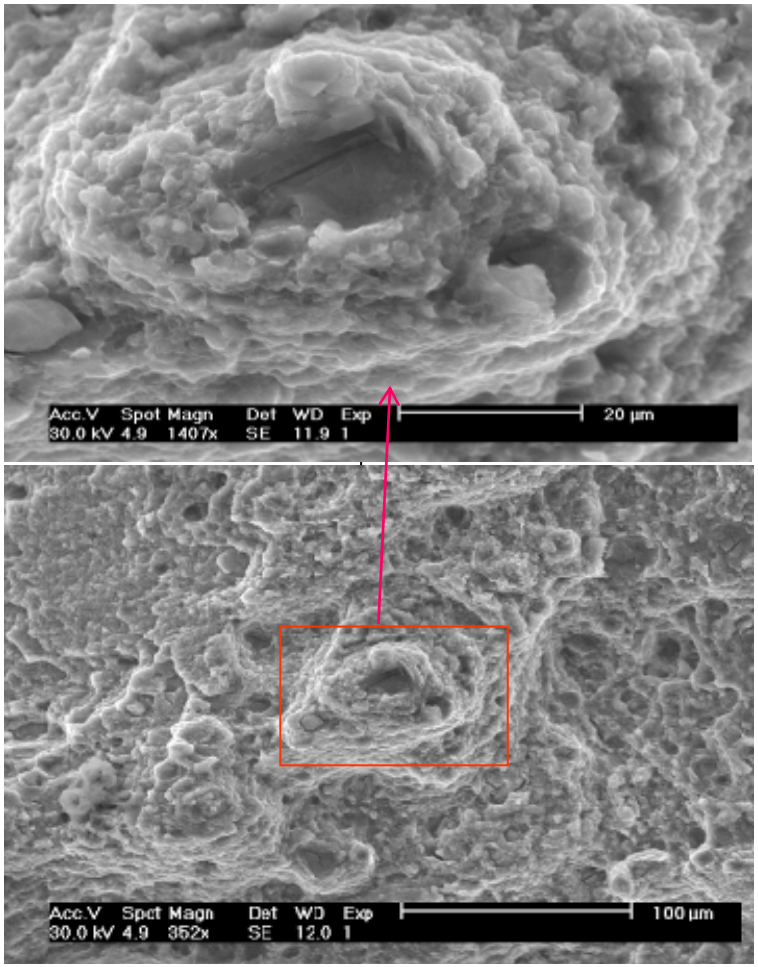
SEM pictures of Fracture Surface

Inside the nugget

Appears mostly inter-granular

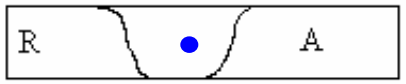


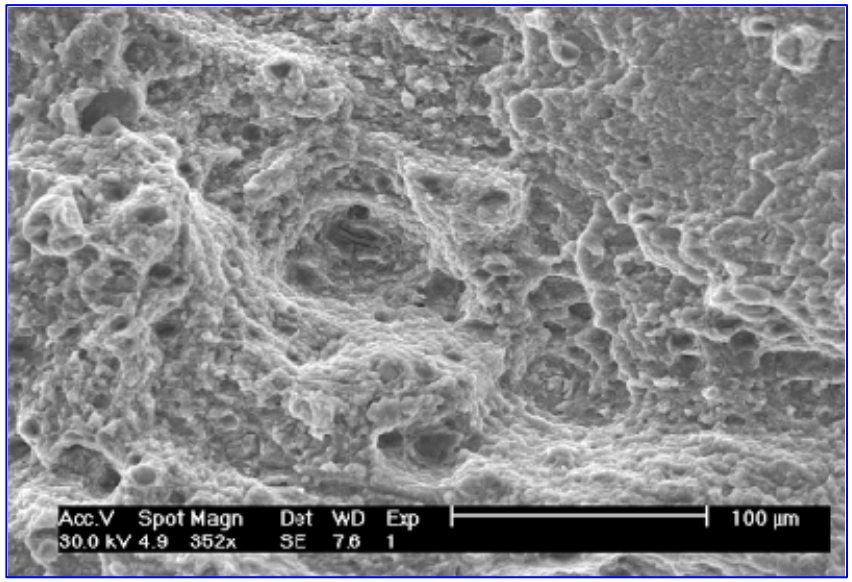
Fractography – Fatigue R=0.5



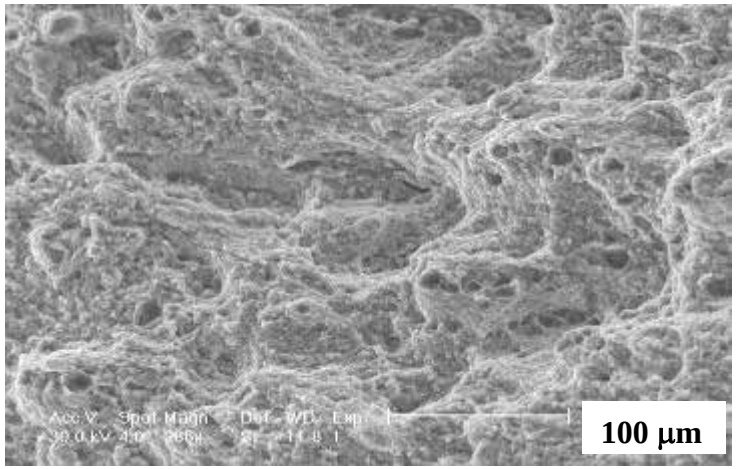
Inter-granular Fracture

Surface rougher than for R=0.1

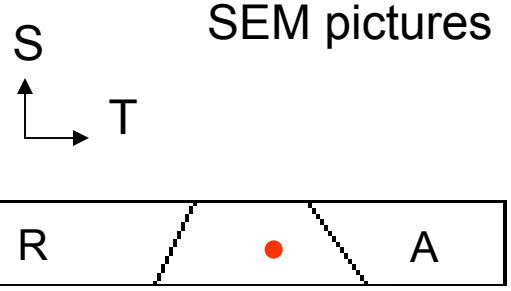


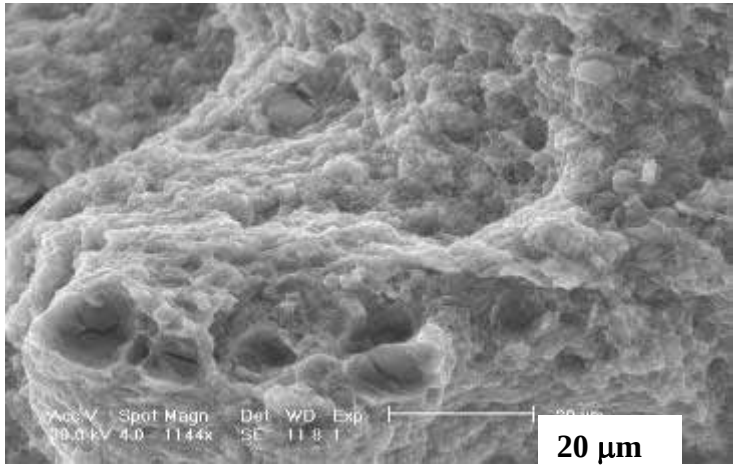


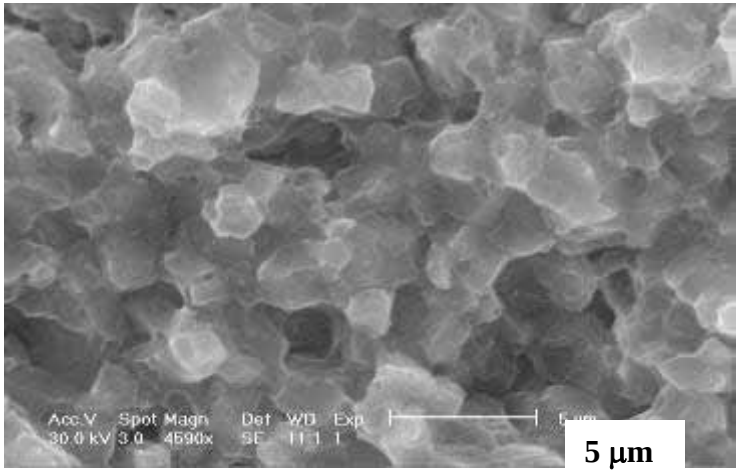
Stable Tearing – Nugget



SEM pictures







Summary

- Weld characterization:
  - With appropriate welding parameters, weld UTS would be 86% of the base material.

- Crack path:
  - For 90º oriented fatigue samples, propagation along a straight line, with sometimes a slight deviation angle observed.
  - For 45º oriented fatigue sample, curved crack path.
  - In base metal stable tearing tests, the rolling direction is often a preferred path direction for the crack.

Summary

- Fatigue crack growth rate :
  - Compared to parent material, reduced crack growth rate is observed in the HAZ. This reduction is higher for lower R.
  - Residual stress seem to have a predominant effect in this variation. Closure and microstructure might also be involved.

- Fractography:
  - In fatigue, fracture is mostly inter-granular. The surface is rougher for higher R.
  - In stable tearing, the fracture is also clearly inter-granular.

Future Work

- Investigate Residual Stress Affect due to FSW
- Acquire Crack Growth Properties Along the Weld, HAZ from both the Advancing Side and the Retreating Side of the Weld
- Acquire Crack Growth Properties Across the Weld, HAZ from both the Advancing Side and the Retreating Side of the Weld
- Repeat Testing and Data Acquisitions for other Materials Commonly used in FSW