Improving the Fatigue Resistance of Thermite Railroad Rail Weldments

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Outline

- Fatigue problems with thermite welds
- Improving the rail head
- Improving the rail web and base

Metallic Fatigue

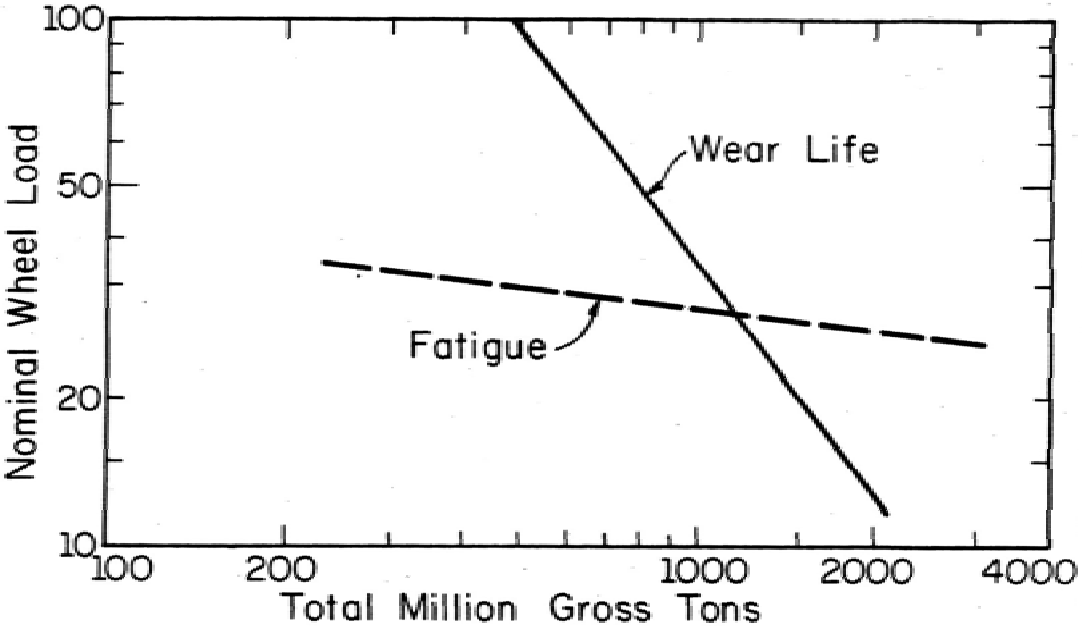
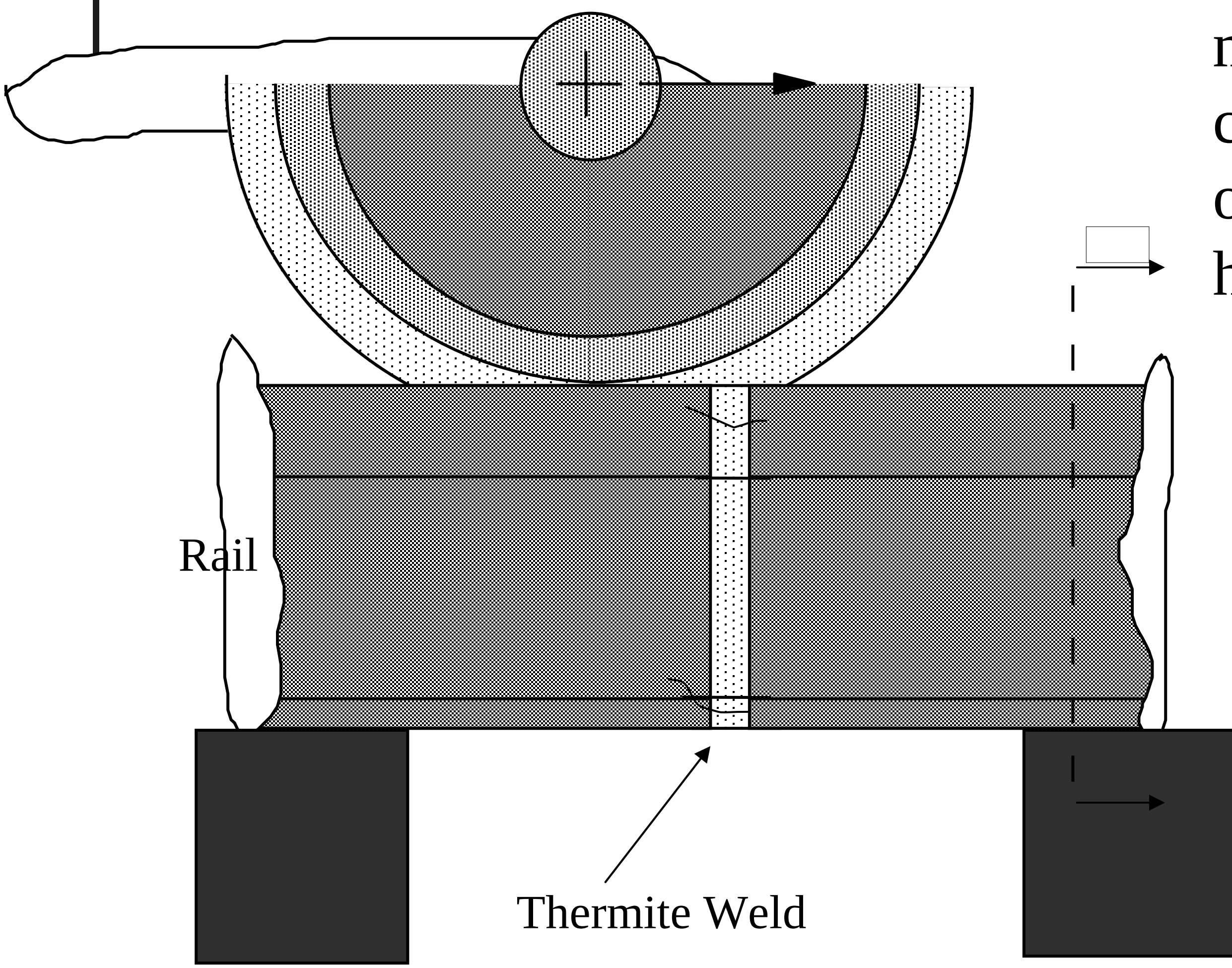


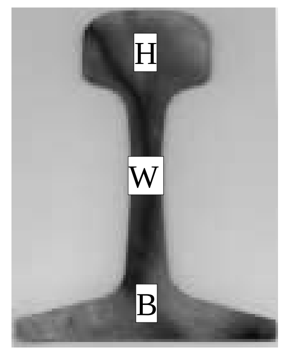
Figure 1 Wheel loads related to fatigue and wear service lives

A.M. Zarembski – Bulletin 673, 1979, Volume 80 of AREA proceedings

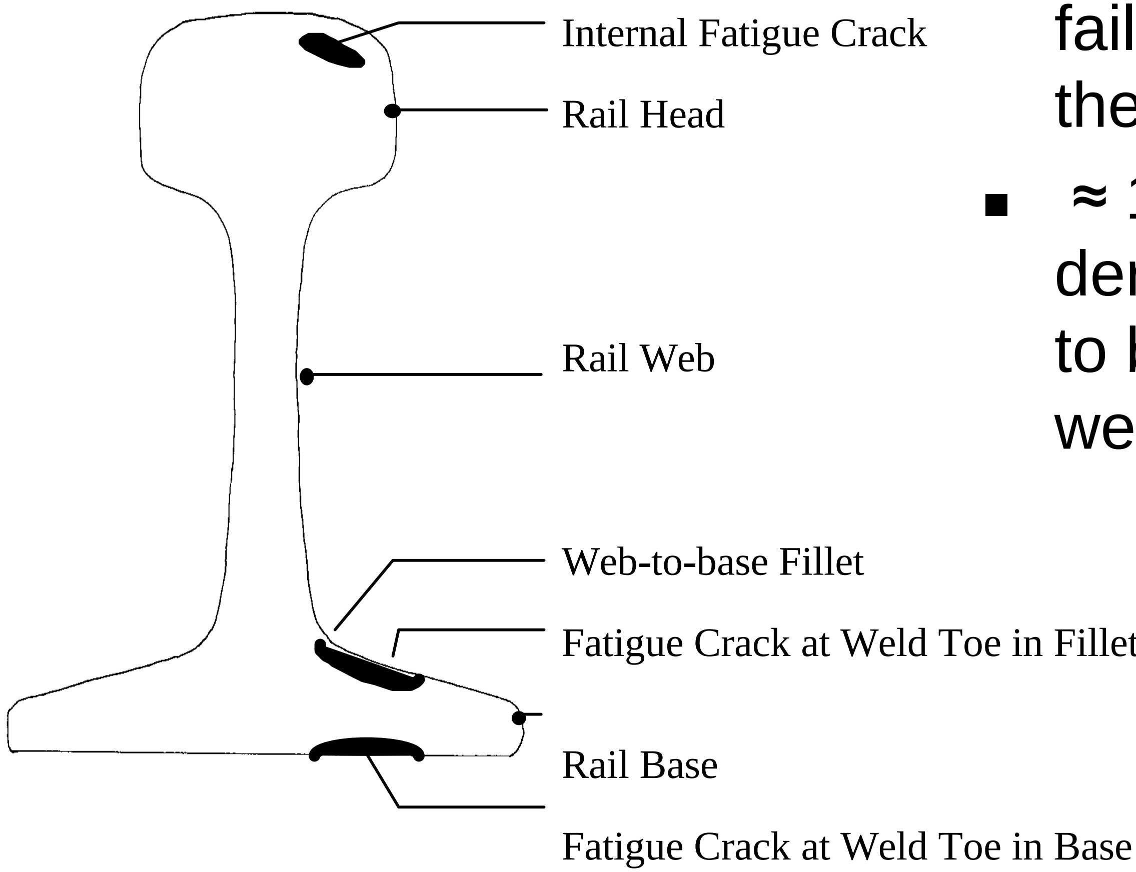
Rolling contact fatigue



Railroad car wheel moving over rail causes fatigue to occur in both the rail head and base.

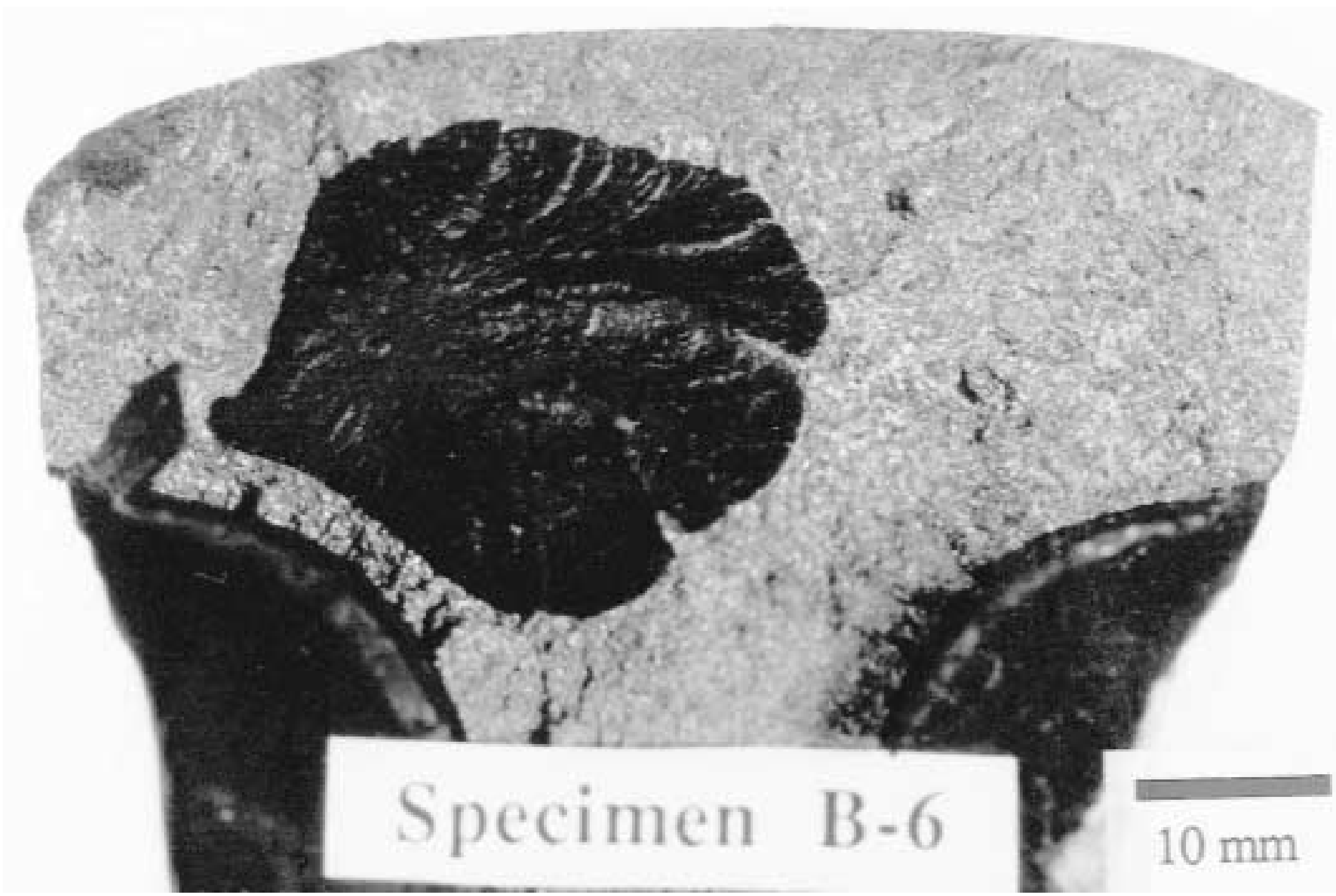


Fatigue crack initiation sites



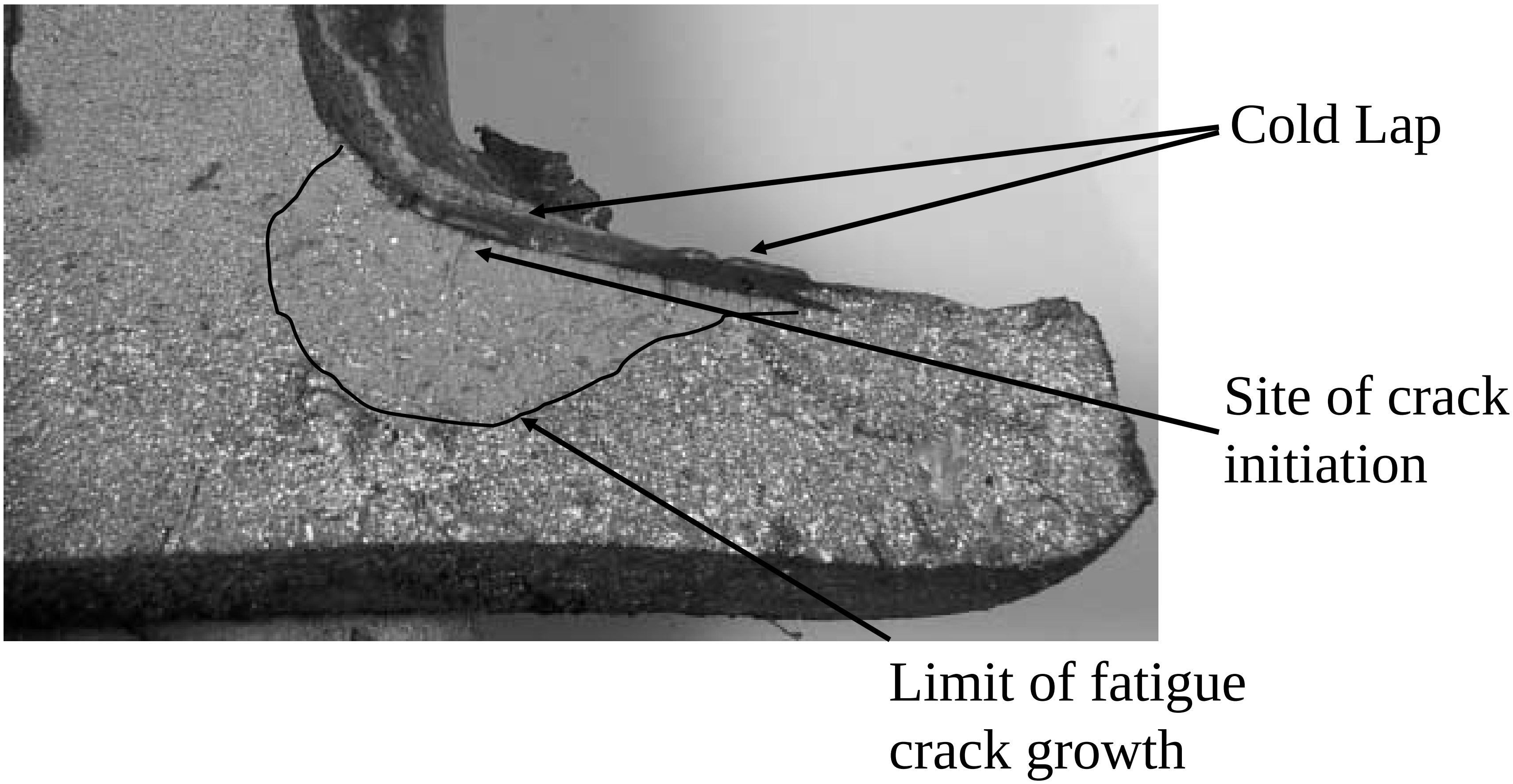
- ≈ 40% of all service failures are due to thermite field welds.
- ≈ 10% of all derailments are due to broken field welds.

Fatigue crack in rail head

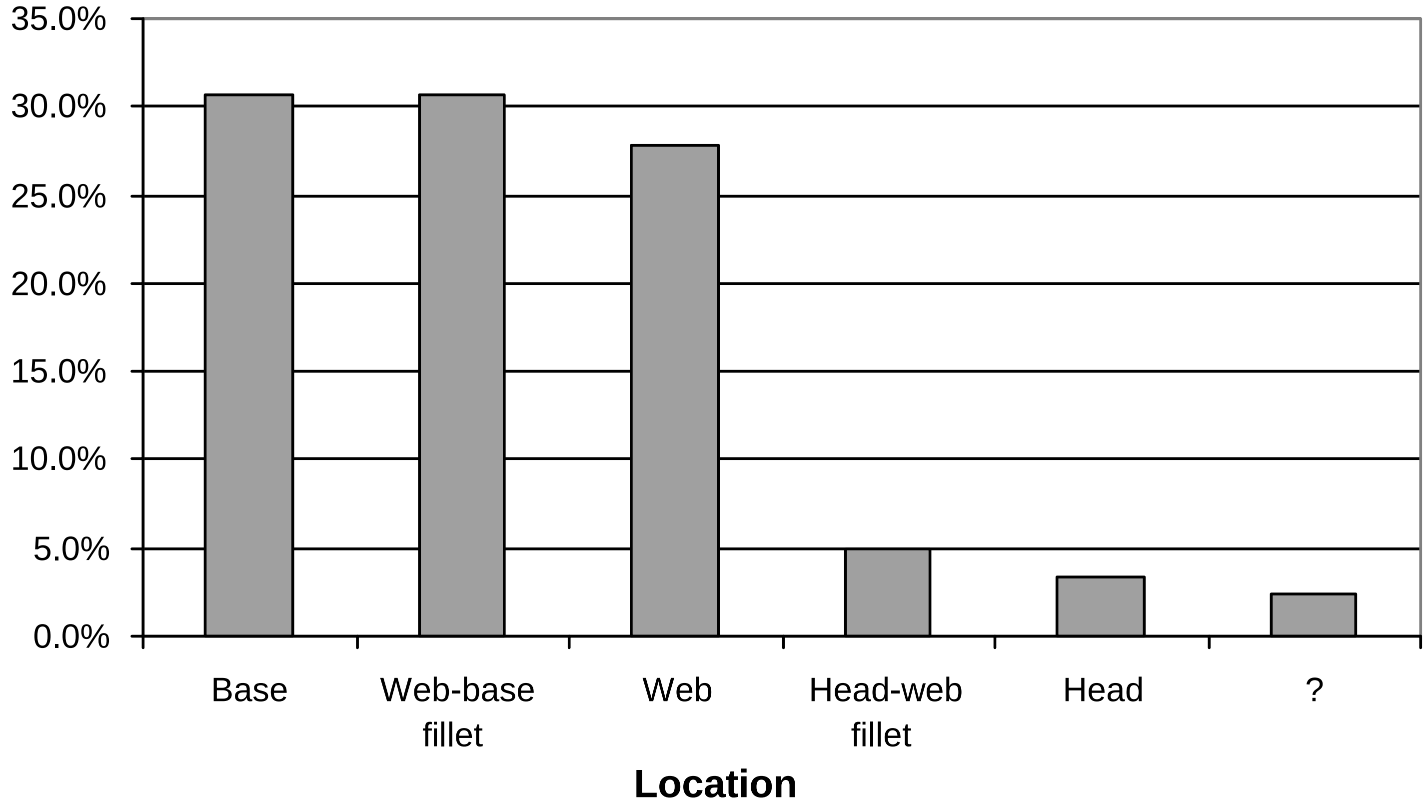


Internal fatigue crack initiation in rail head

Fatigue crack in rail base



Thermite weld service failures



Record of 244 service failures on a Class 1 railroad involving thermite field welds.

Service failures or “markouts”?

- Most field-weld service failures originate at <u>web or base</u>.

- But defects detected and removed from the <u>rail head</u> before a service failure can occur (“markouts”) exceed service failures by 2:1!

Implications

- Fatigue cracks in the web and base are less frequent but are the principal cause of service failures since they are difficult to detect. Crack initiation occurs at <u>external</u> stress concentration.

- Fatigue cracks in head are more frequent but are generally removed. Crack initiation occurs at <u>internal</u> stress concentration.

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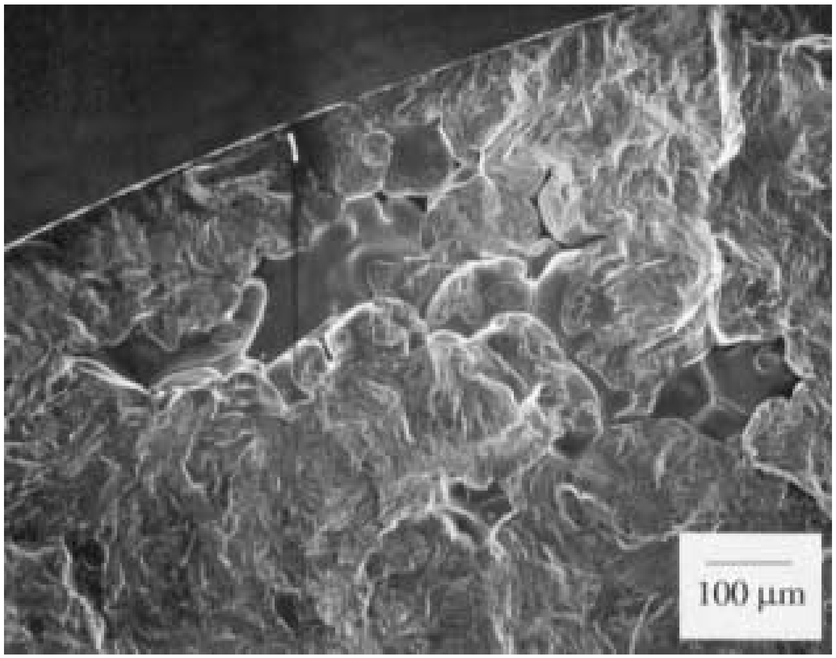
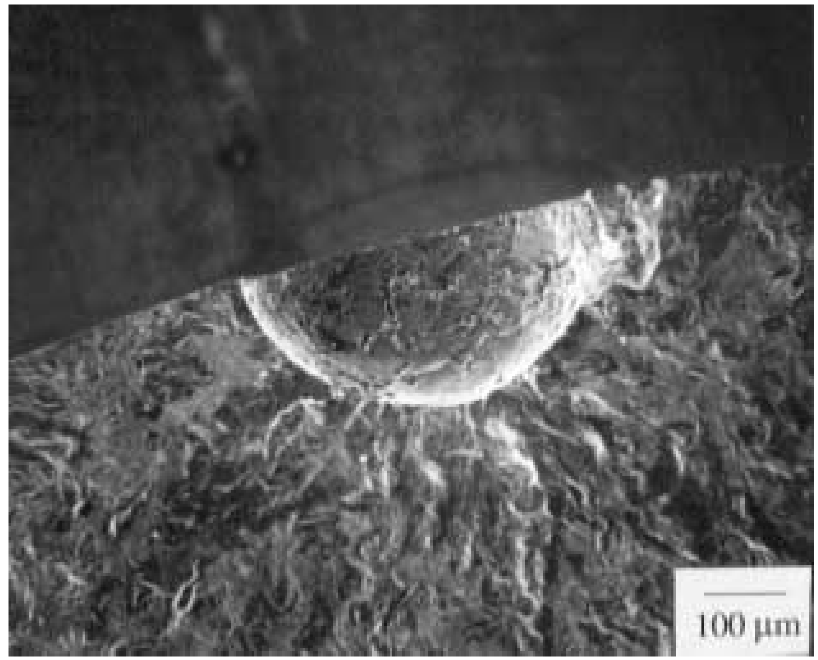
Porosity types



Shrinkage

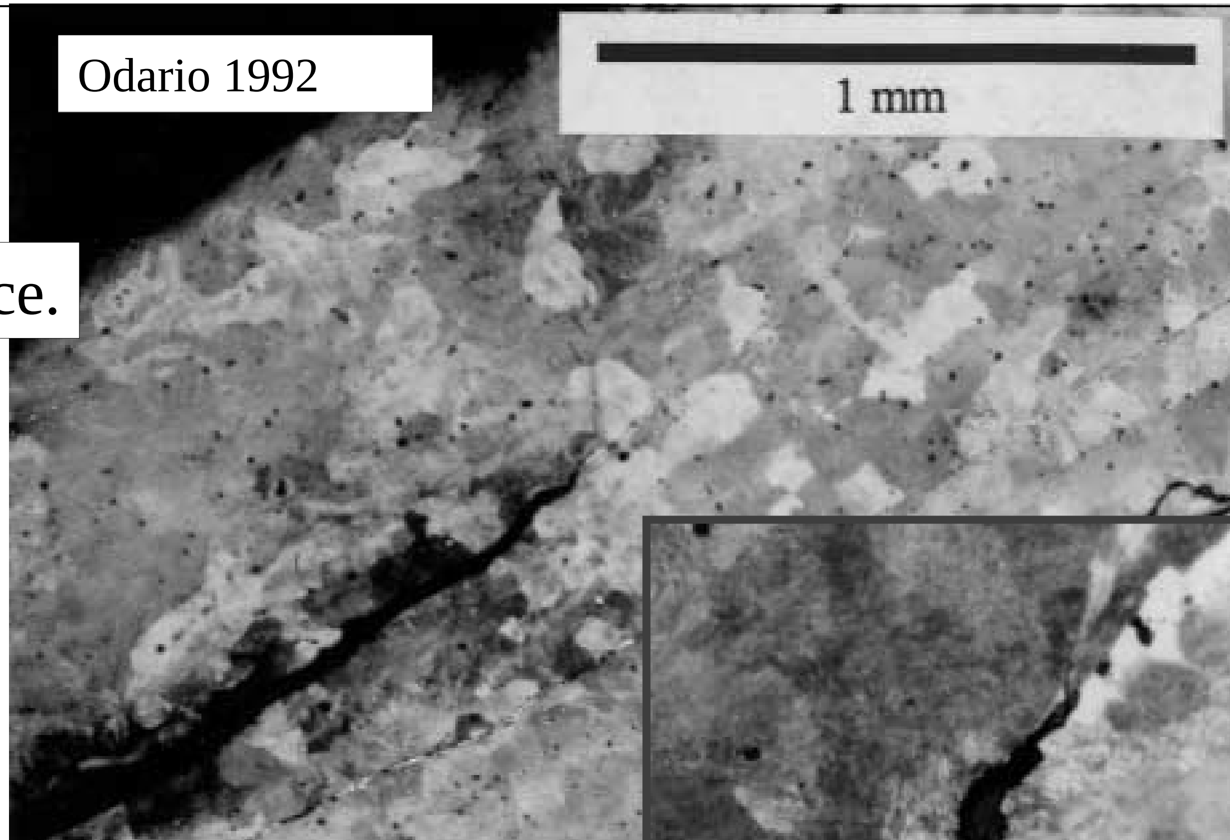


Gas (Spherical)

Thermite welds studied contain about 1.5% shrinkage porosity.

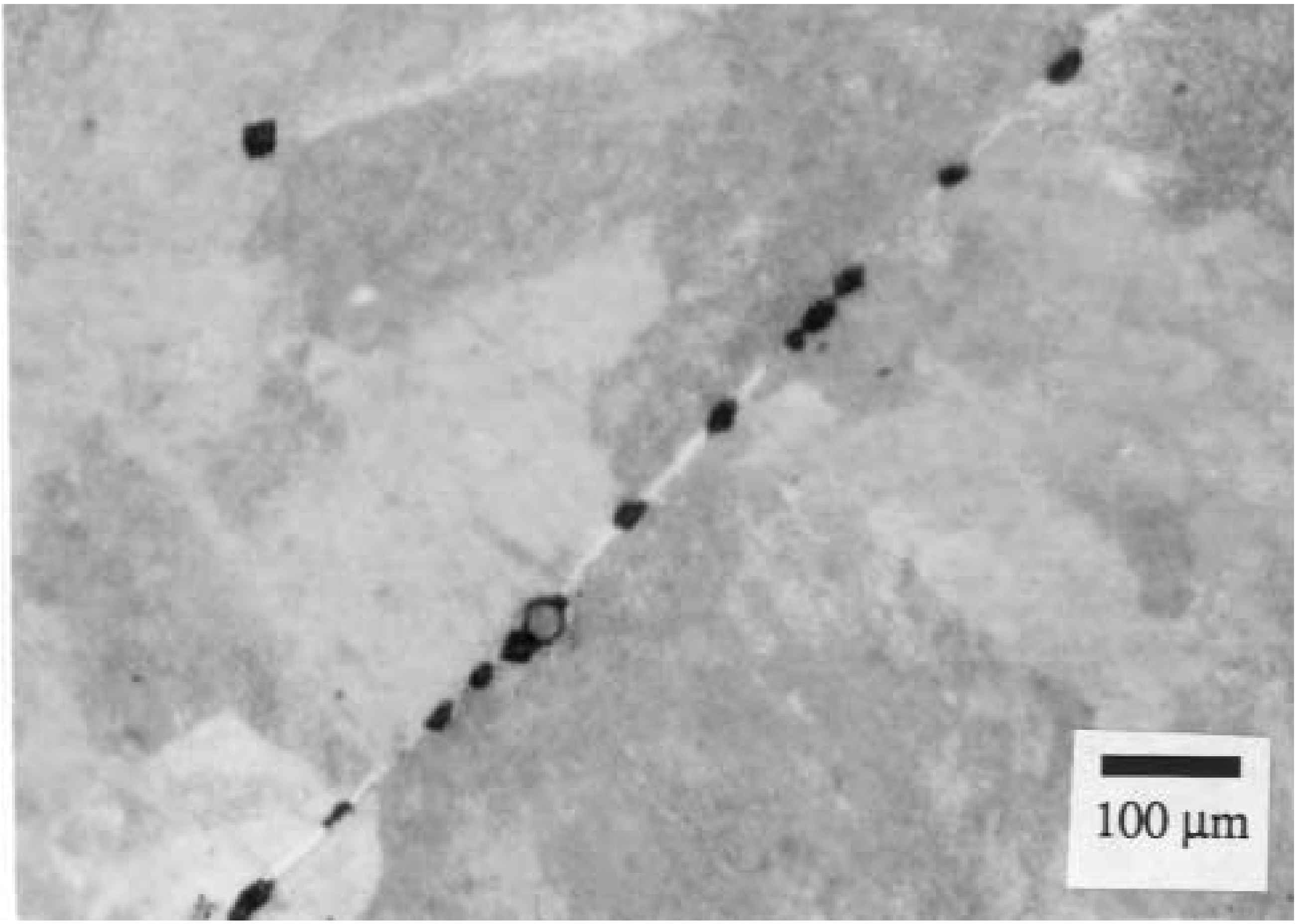
Porosity initiates fatigue

Running surface.



Formation of shells in tangent track at interdendritic shrinkage porosity.

Interdendritic shrinkage porosity

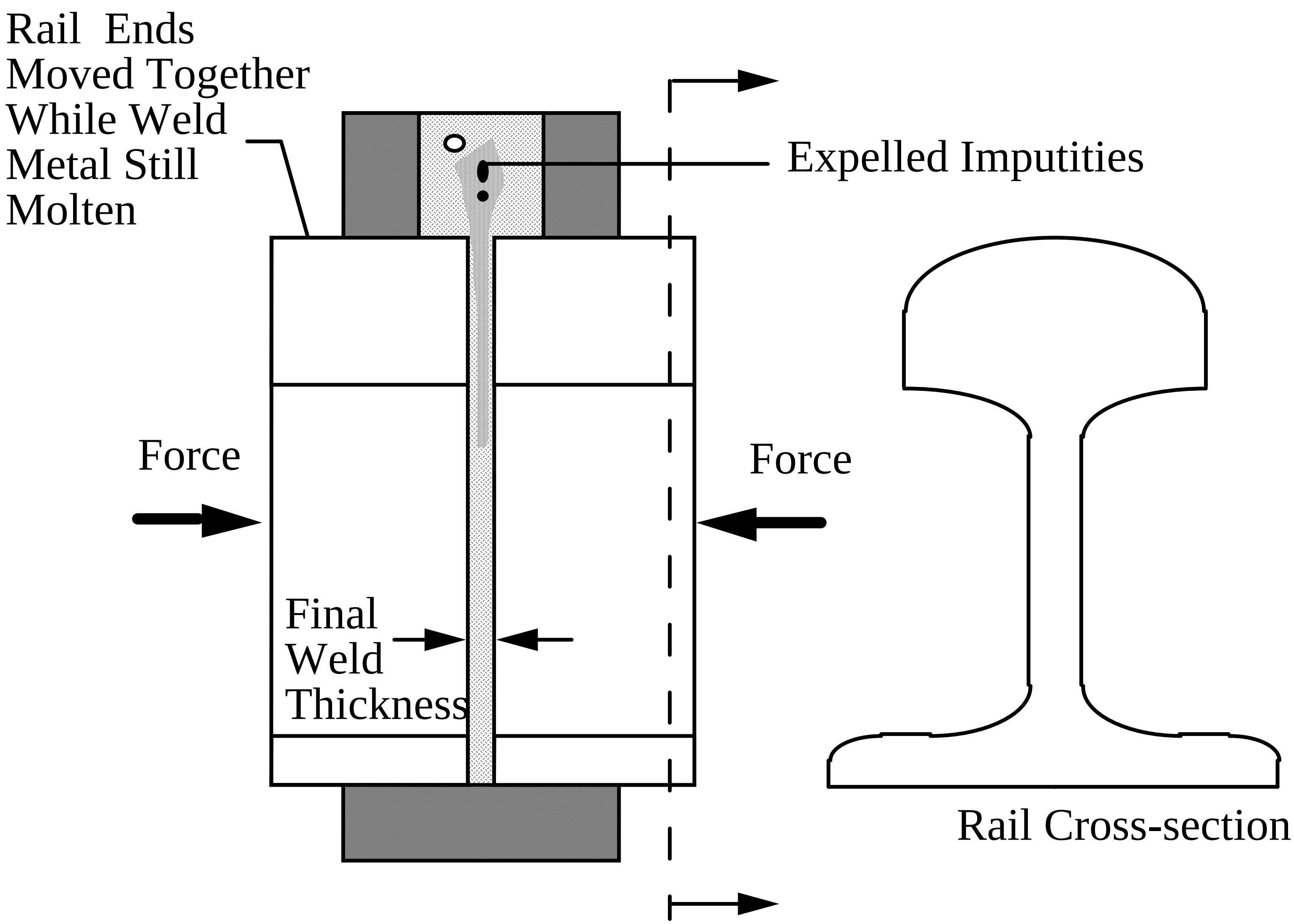


Possible solution?

- Eliminate weld metal! (?)

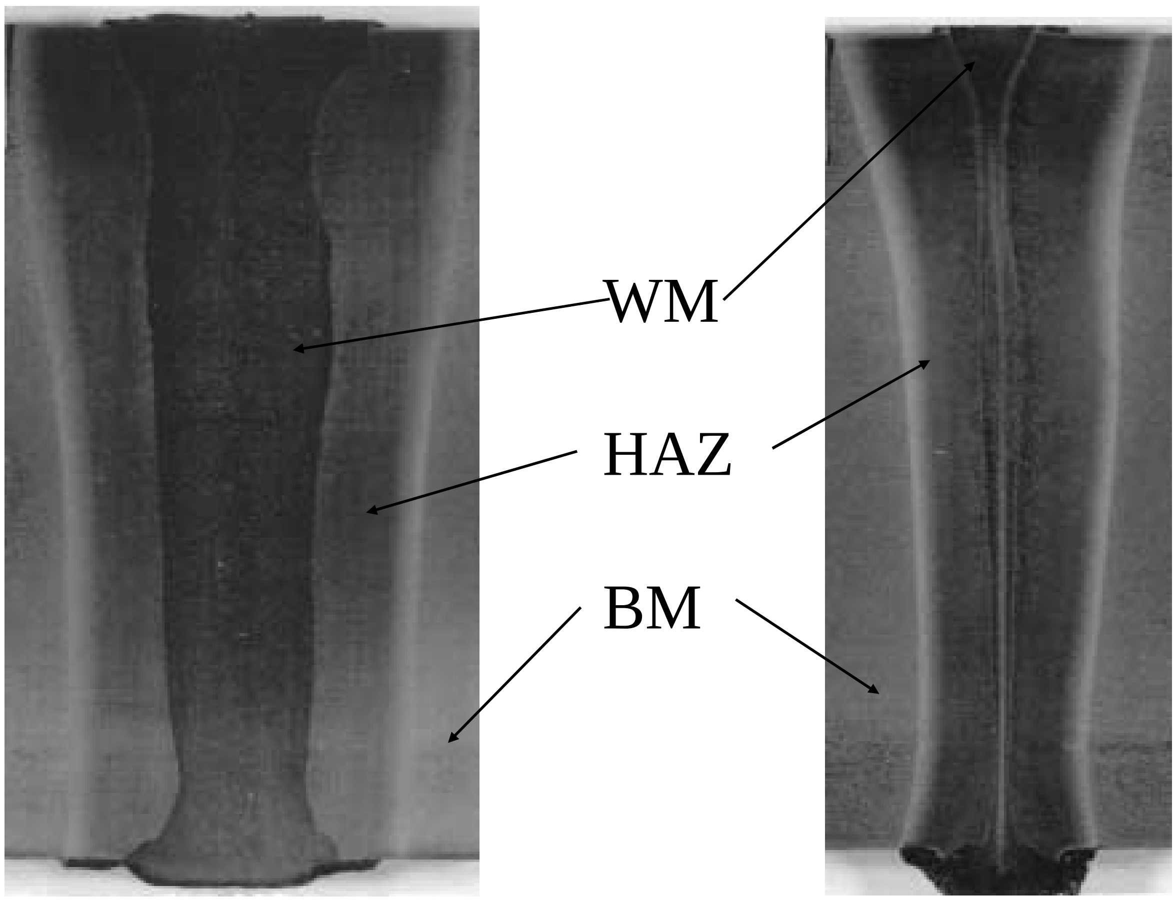
- Developed a modified thermite welding process called “Squeeze Welding” in which ends of joint forced together to expel most of the thermite weld metal.

Squeeze welding



Weld longitudinal-sections

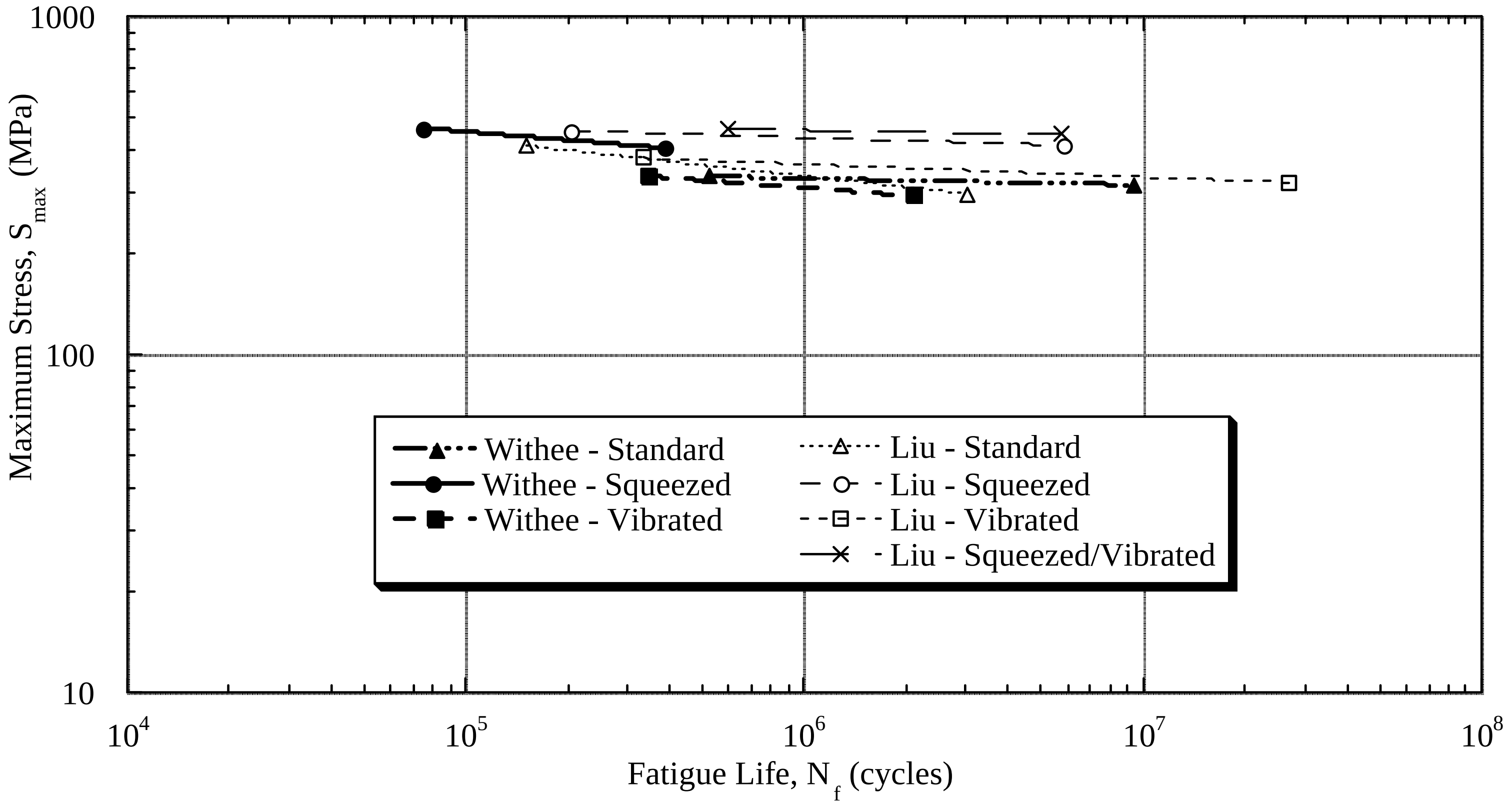
Standard Squeezed



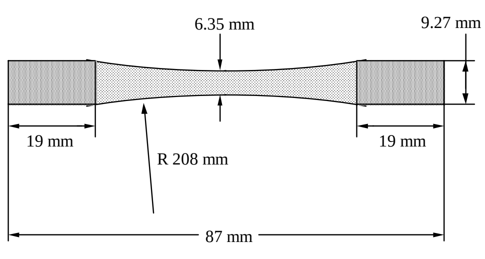
Fry 1992

Laboratory test results

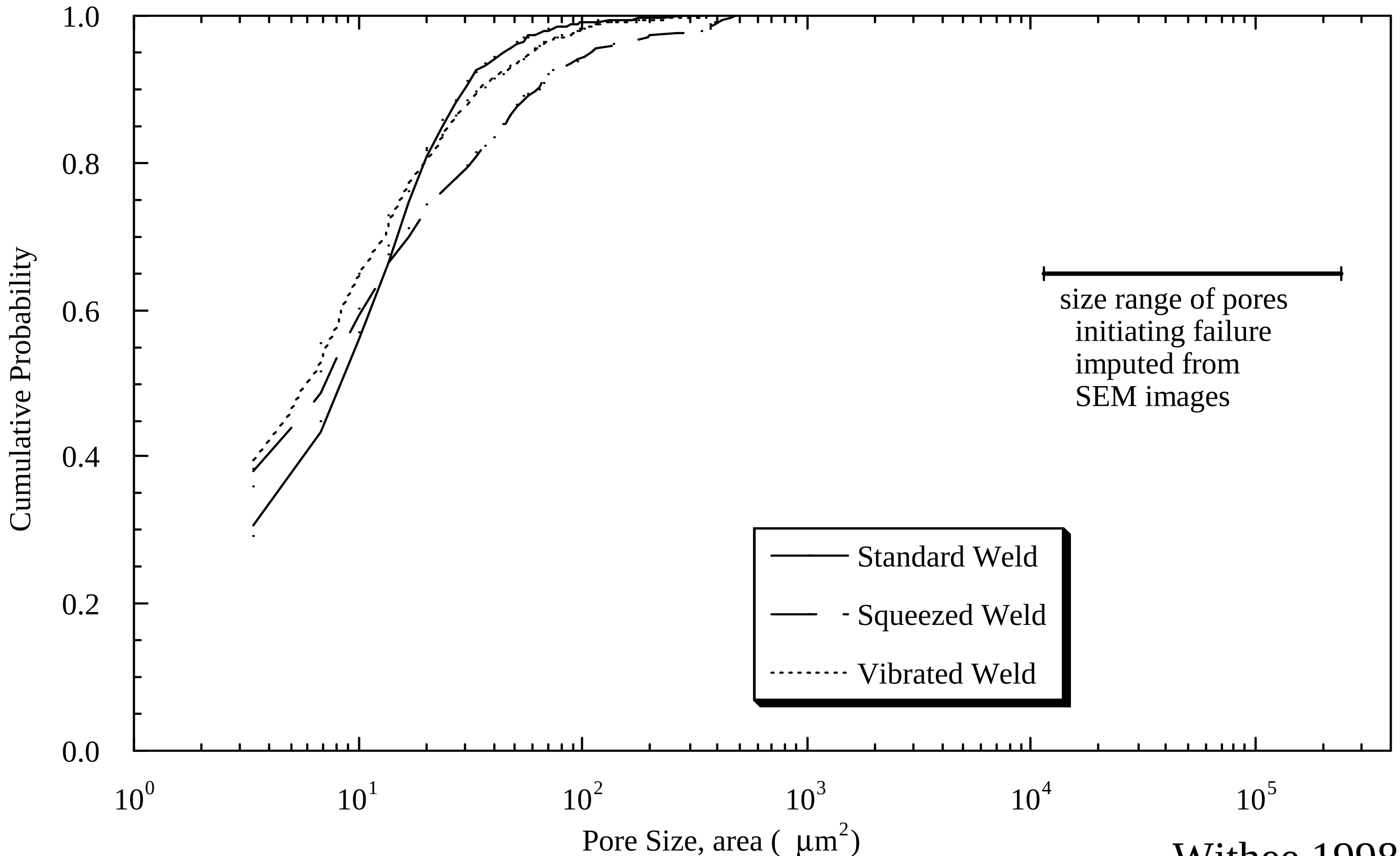
Withee 1998



Fatigue behavior of small specimens taken from head of weld shows some improvement.



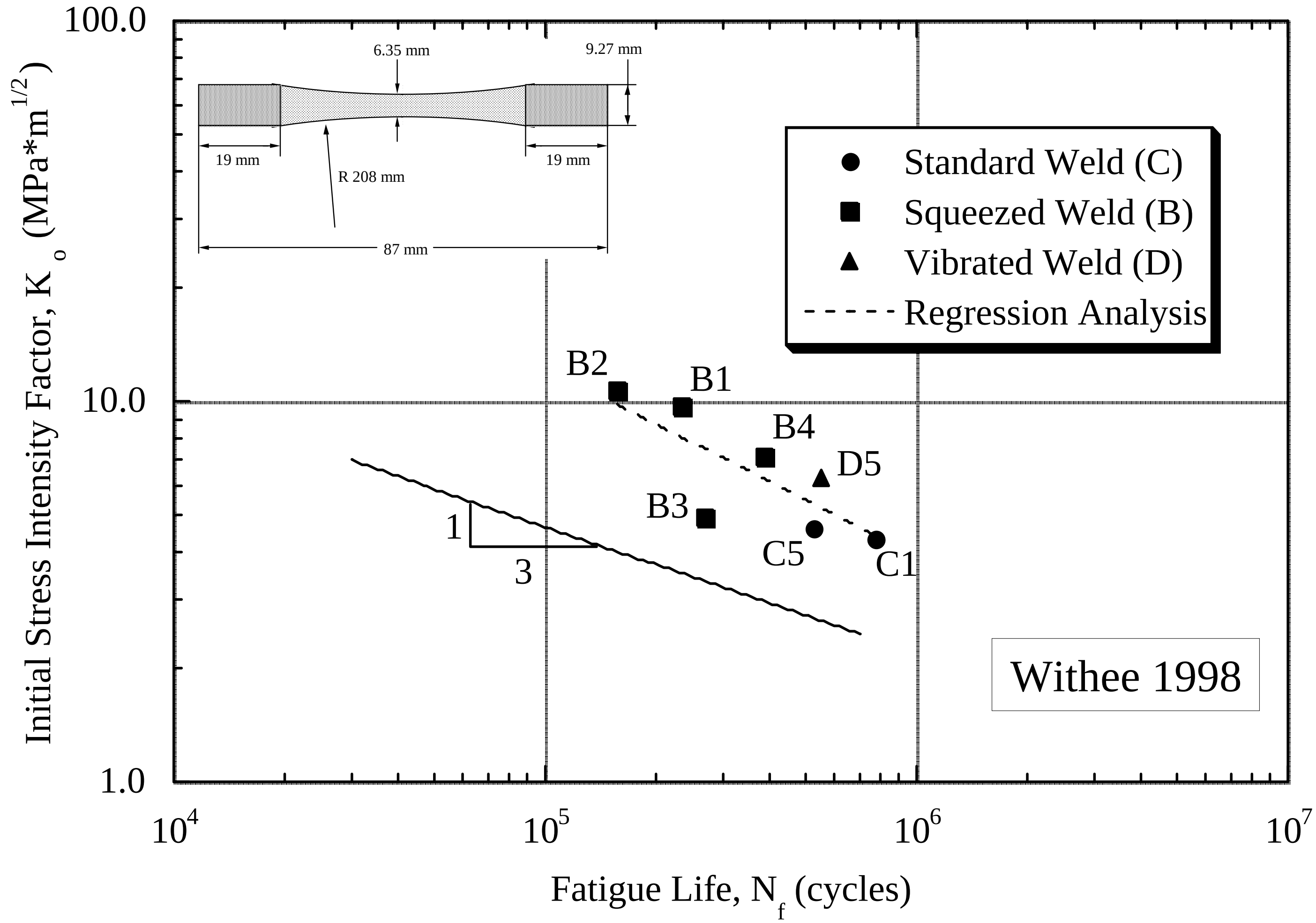
But distribution unchanged!



Withee 1998

Pore size distribution unchanged!

Largest pore size controls!



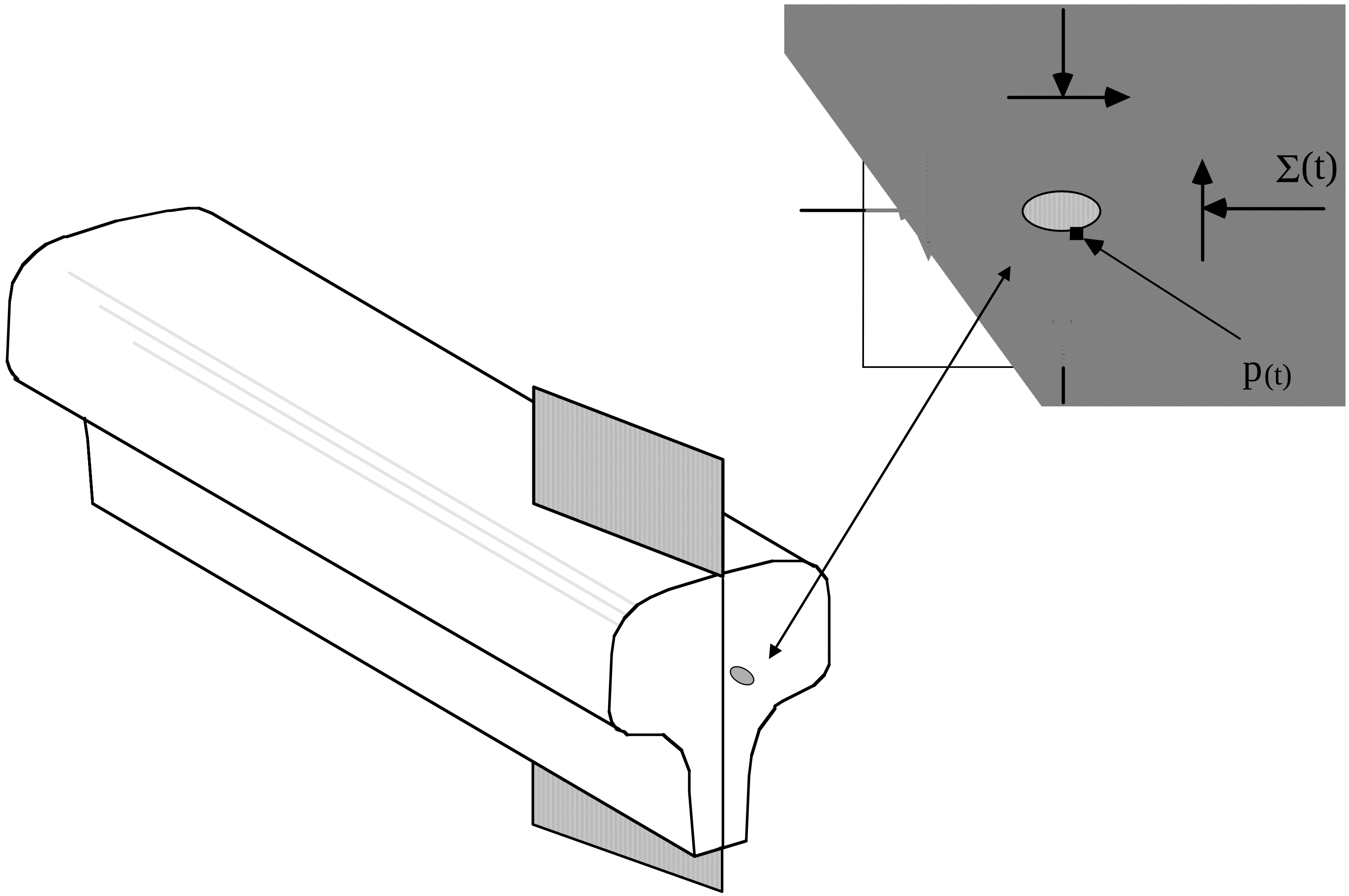
Single relation for all treatments depending only on pore size (and applied stress).

Implications

- Reducing the size of the largest pores and/or the volume of weld metal should increase in the (average) fatigue life.

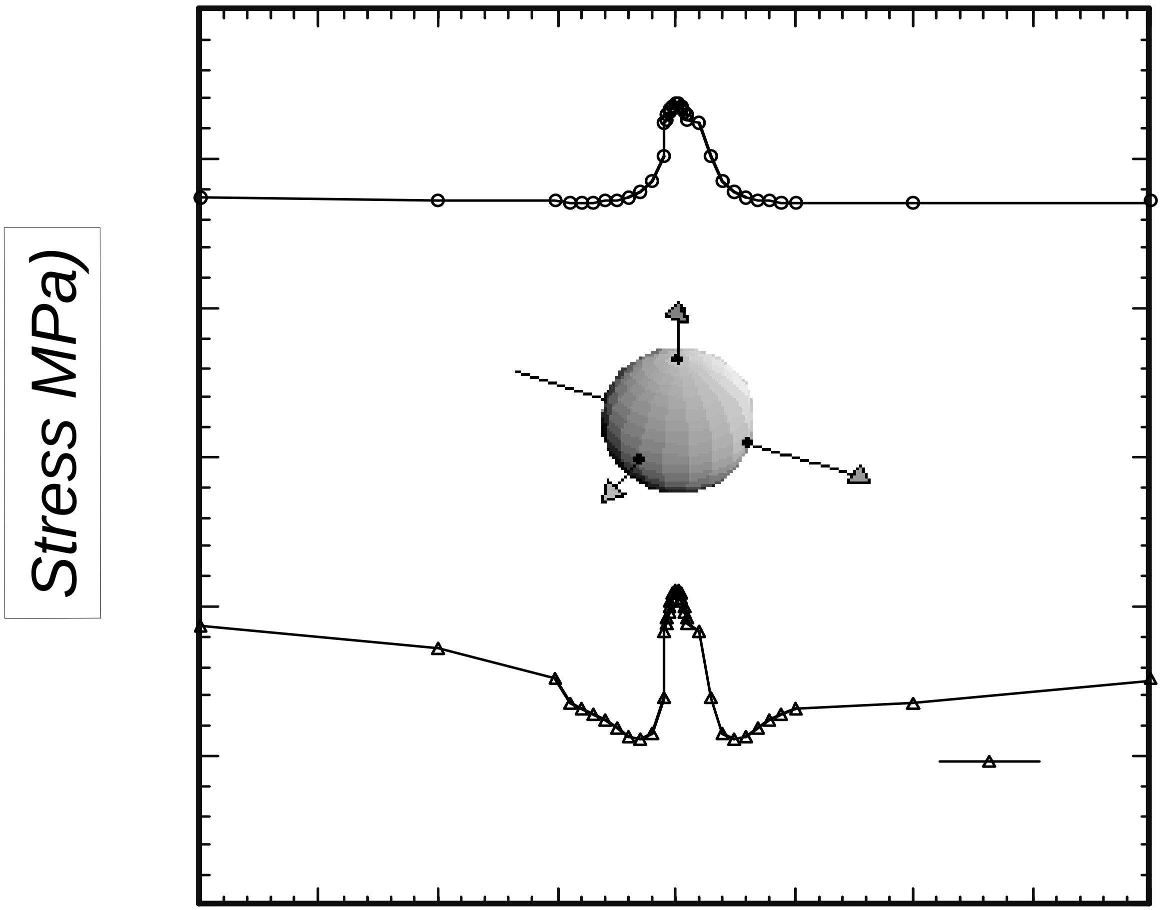
- Largest pore per unit volume (porosity) and the volume of weld metal jointly determine the fatigue strength.

Theoretical study

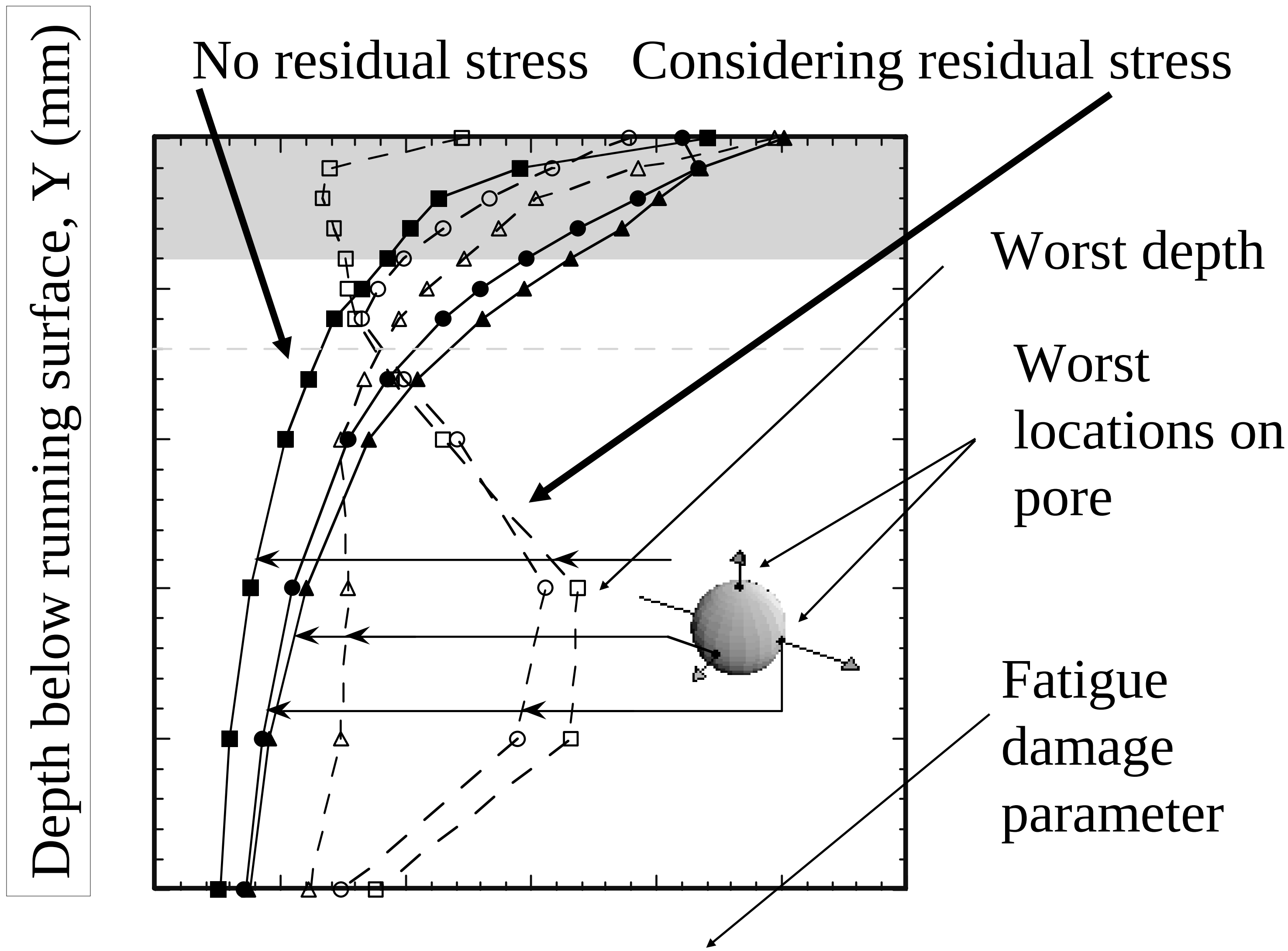


Fry 1995

Stress history experienced

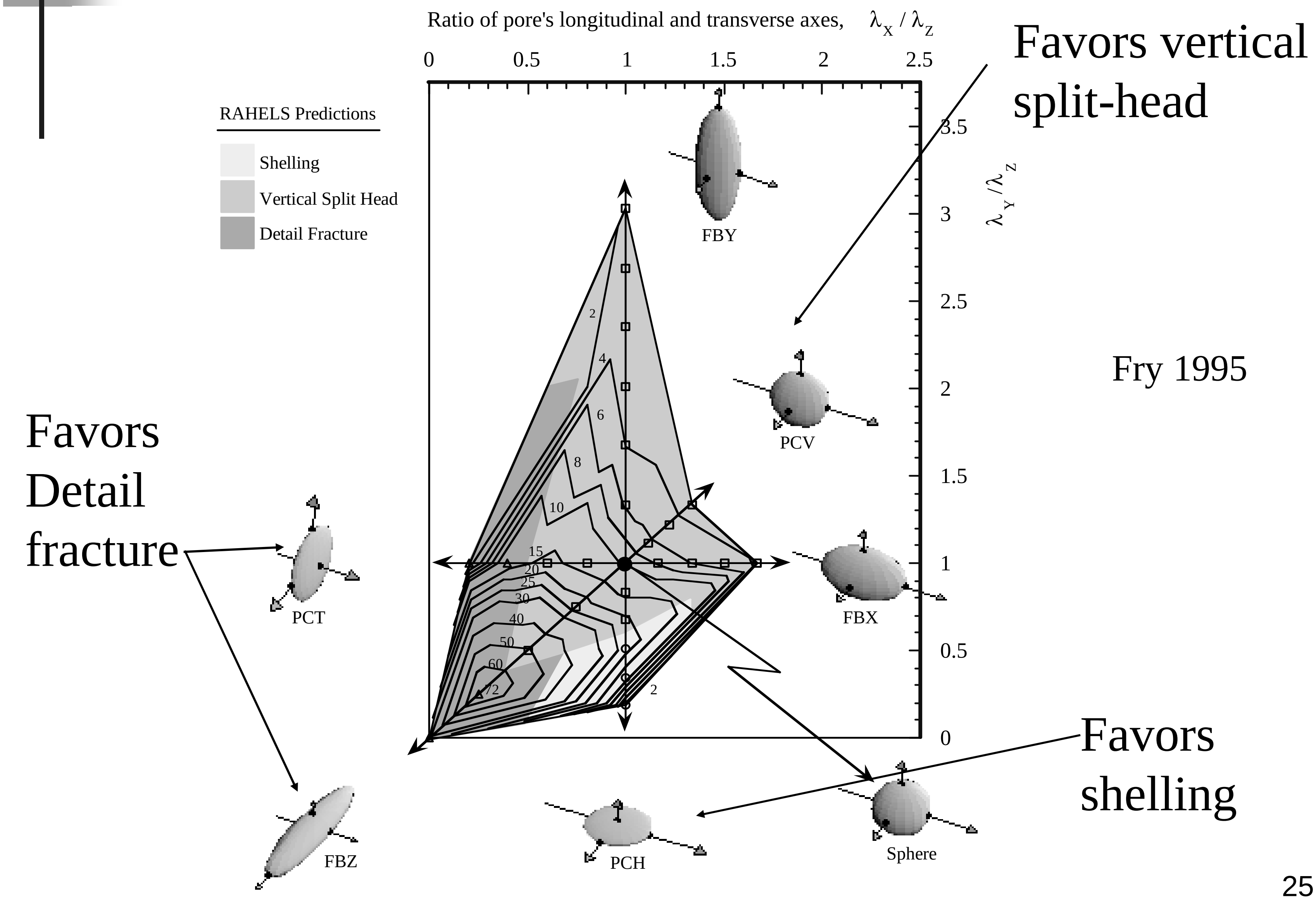


Fatigue occurs at critical depth



Fry 1995

Effects of pore shape?



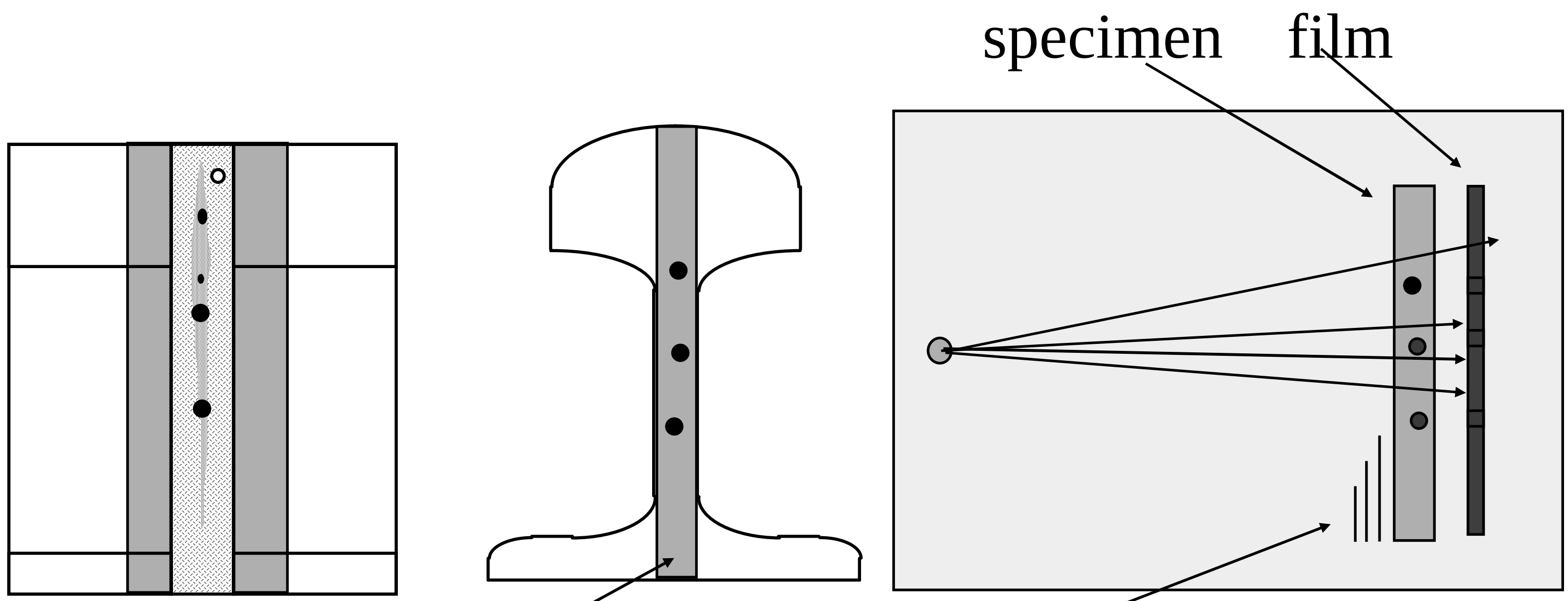
Fry 1995

Model predictions

- Critical depth for fatigue crack initiation (≈ 15mm) determined by wheel-contact-induced residual stresses.

- Model predicted that shelling, vertical split heads and detail fracture could all initiate at shrinkage pores depending upon the pore shape.

New measurement technique

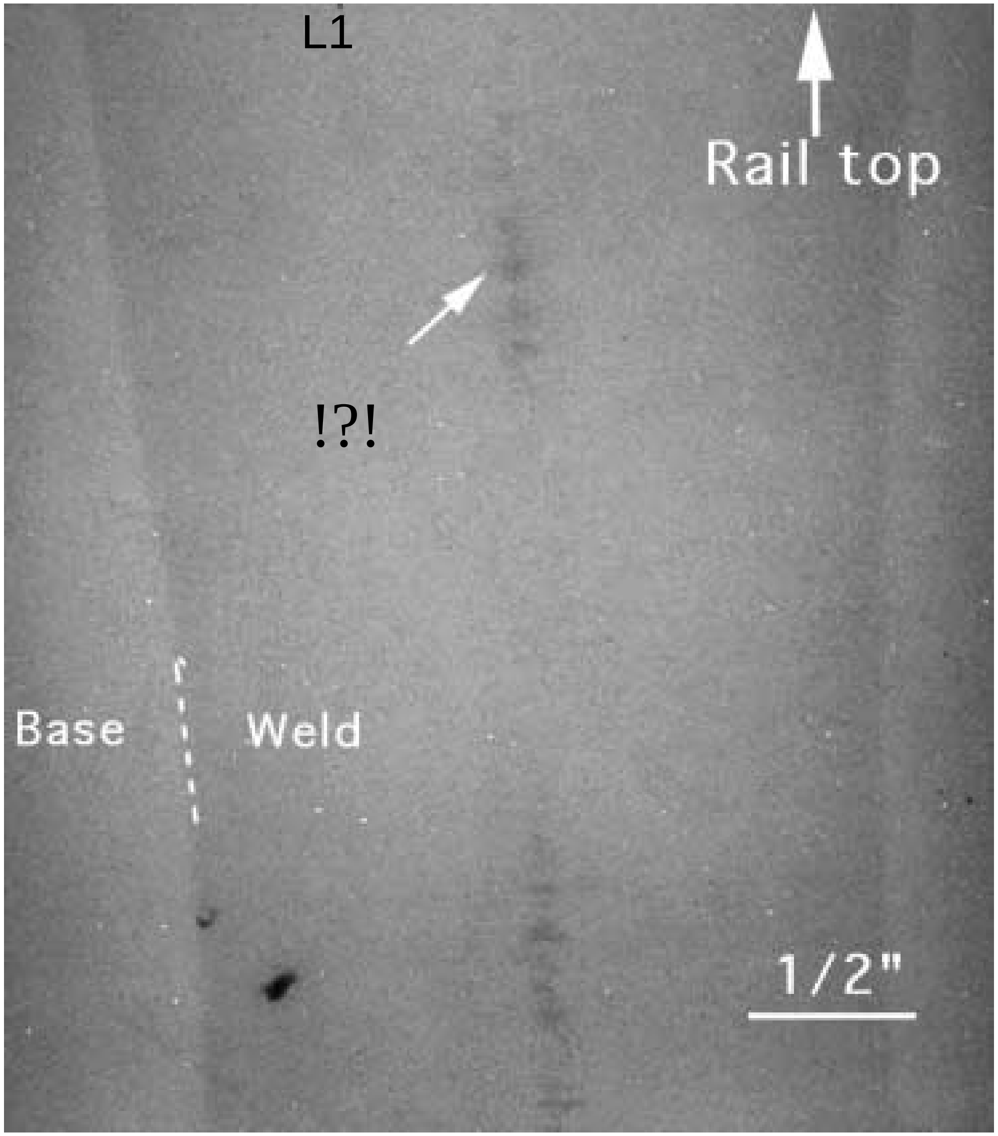


Central portion of weldment machined and ground flat to 12.7 mm thickness.

Stepped penetrameter.

Chen 2000

Typical radiograph

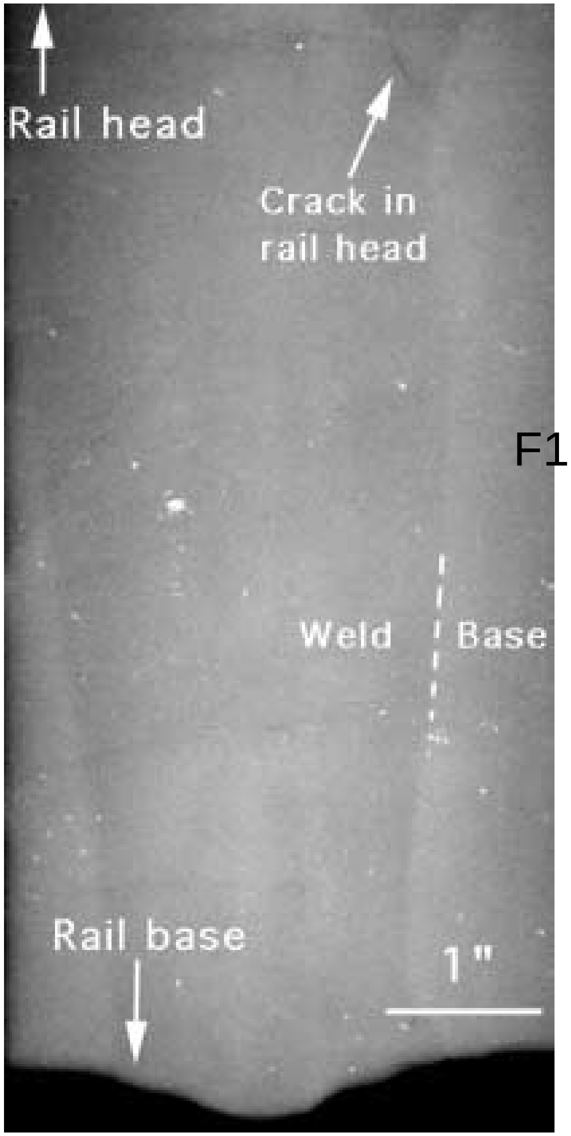


Difference in contrast due to micro-porosity (shrinkage porosity.

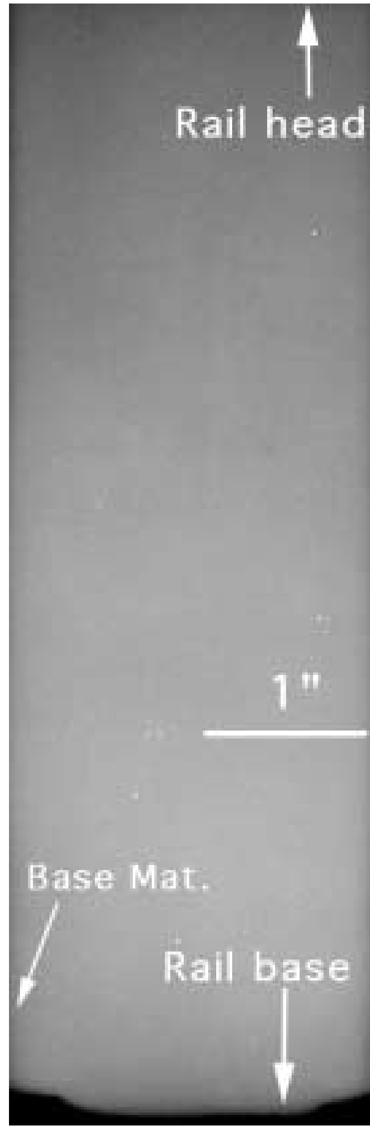
Porosity not uniformly distributed!

Chen 2000

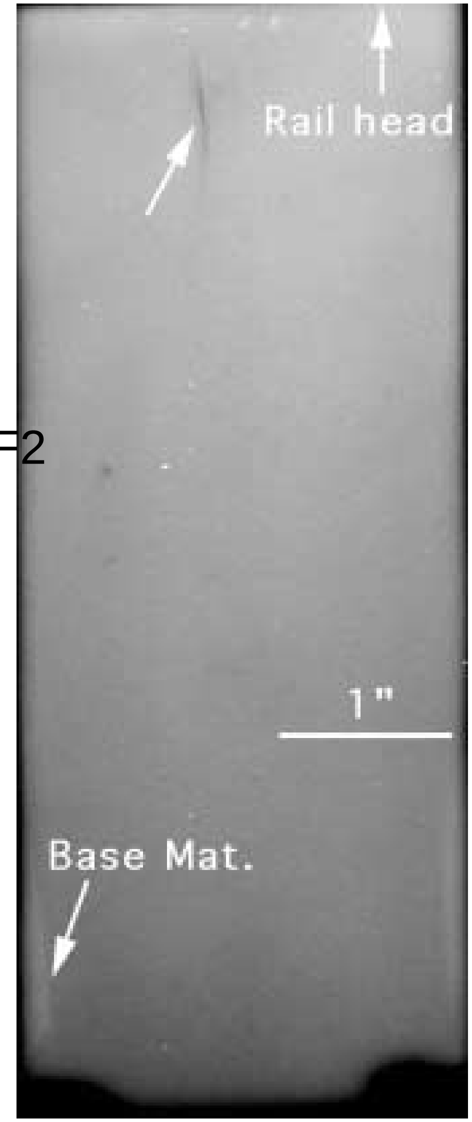
Radiographs of field welds



F1

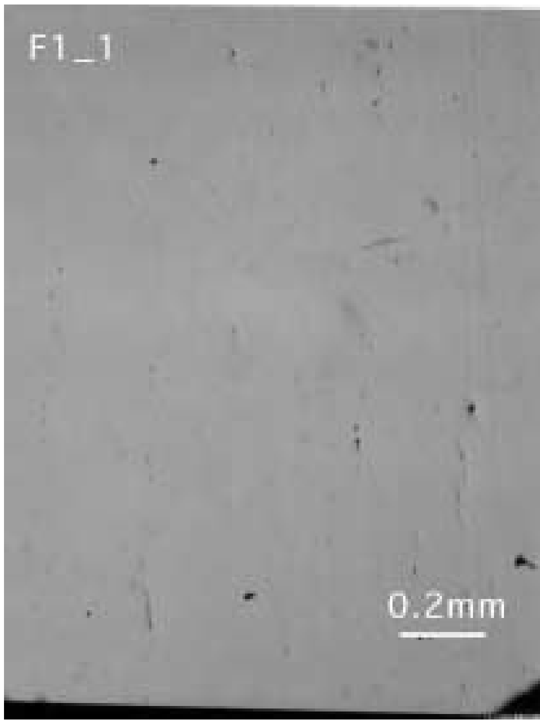


F2



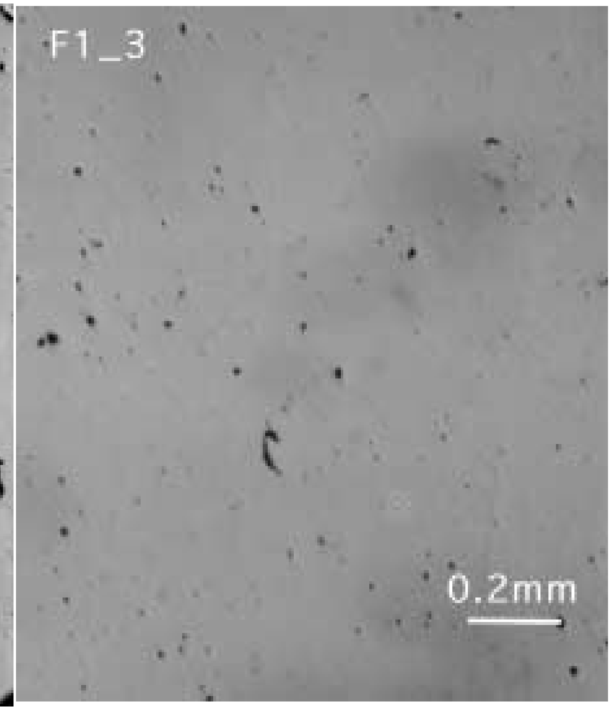
F3

Optical determination of porosity



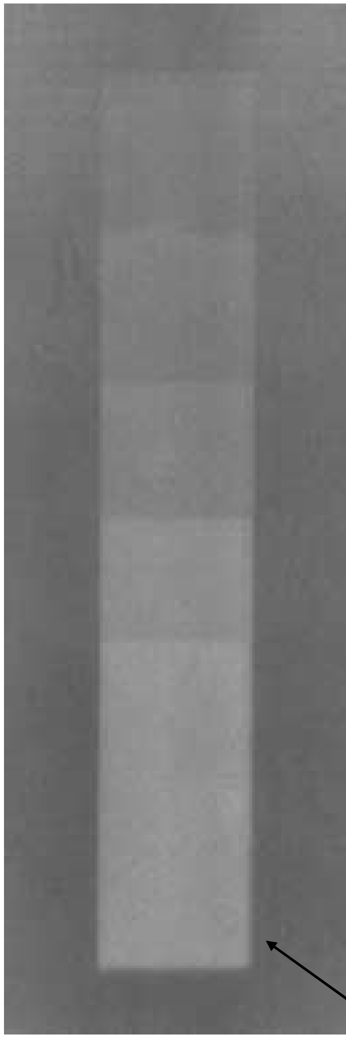
0.52%

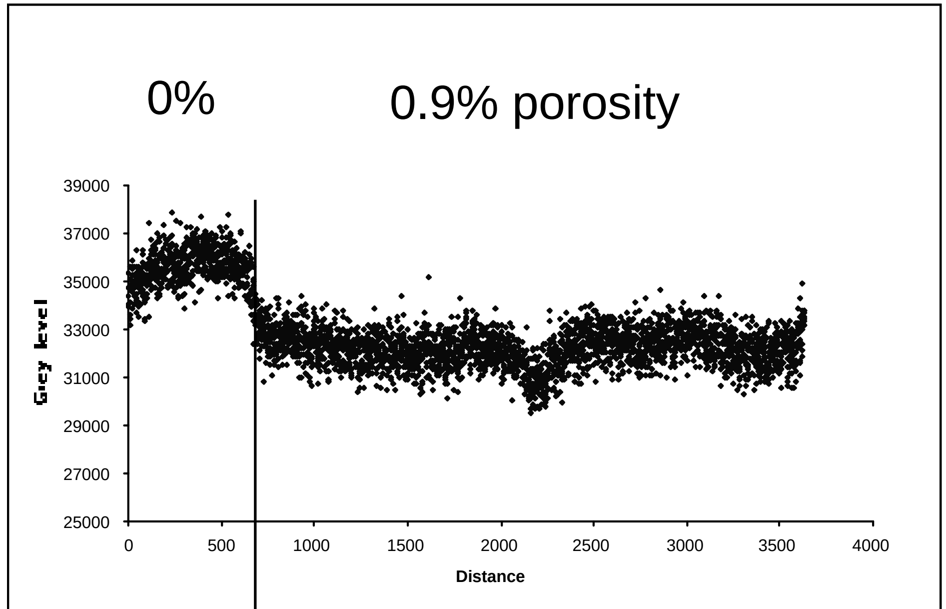
interface

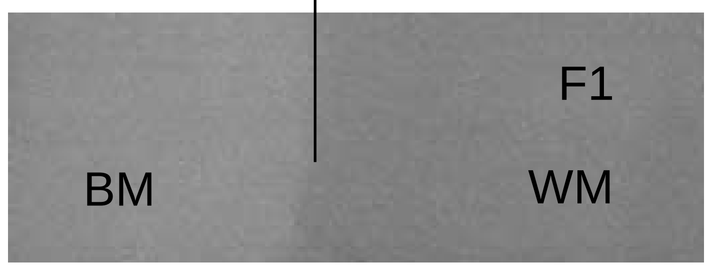


1.72%

Radiographic image density





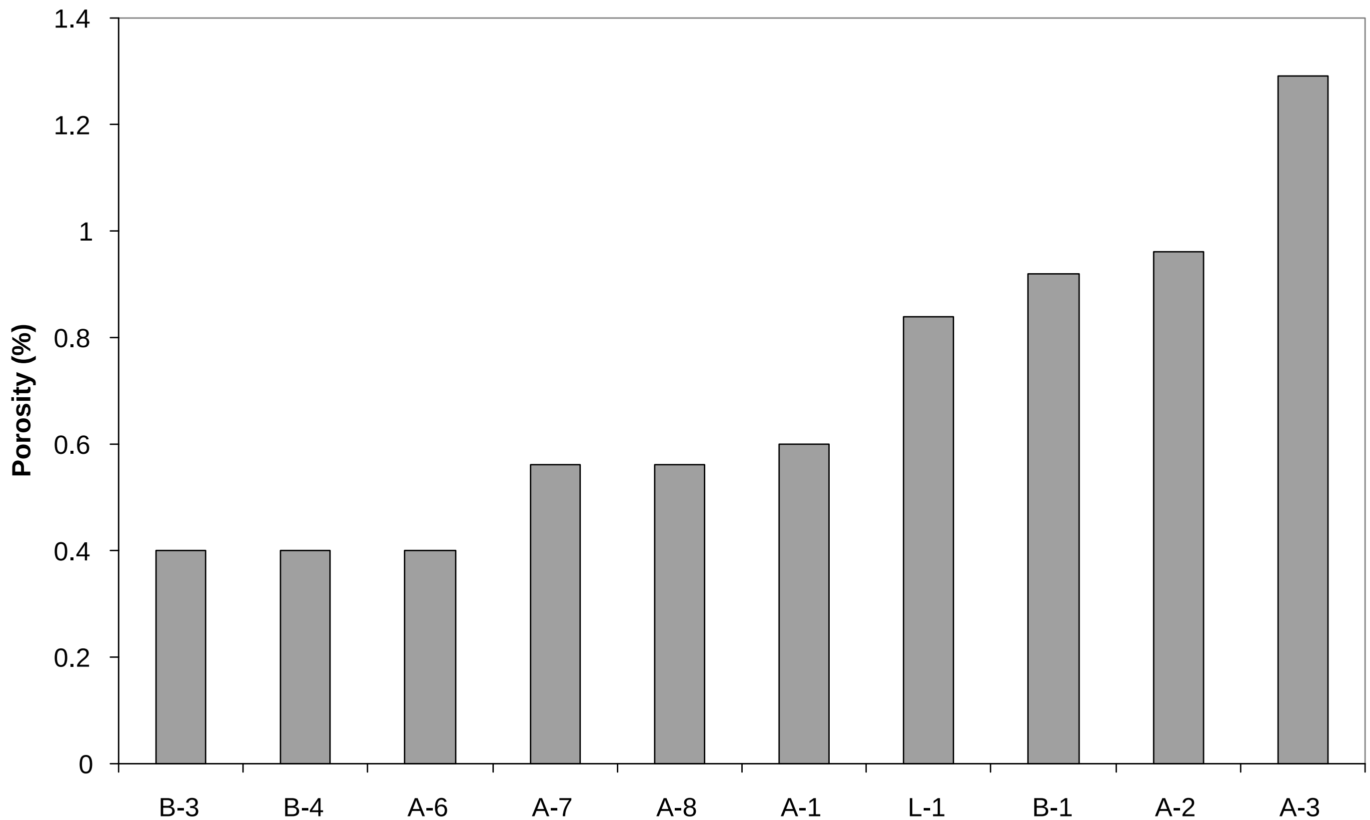


Measured changes in grey scale in photoshop.

Penetrameter with 0.11 mm steps indicate at least 1% sensitivity

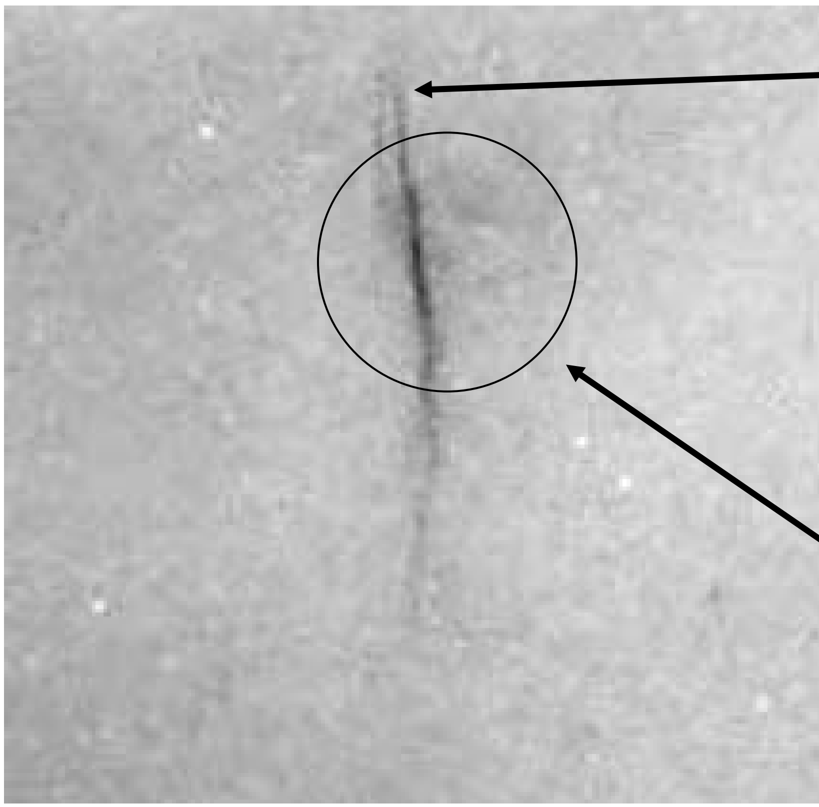
Porosity in 10 thermite welds

Chen 2000



Average porosity in 10 “markouts” varies considerably!

Developing detail fracture



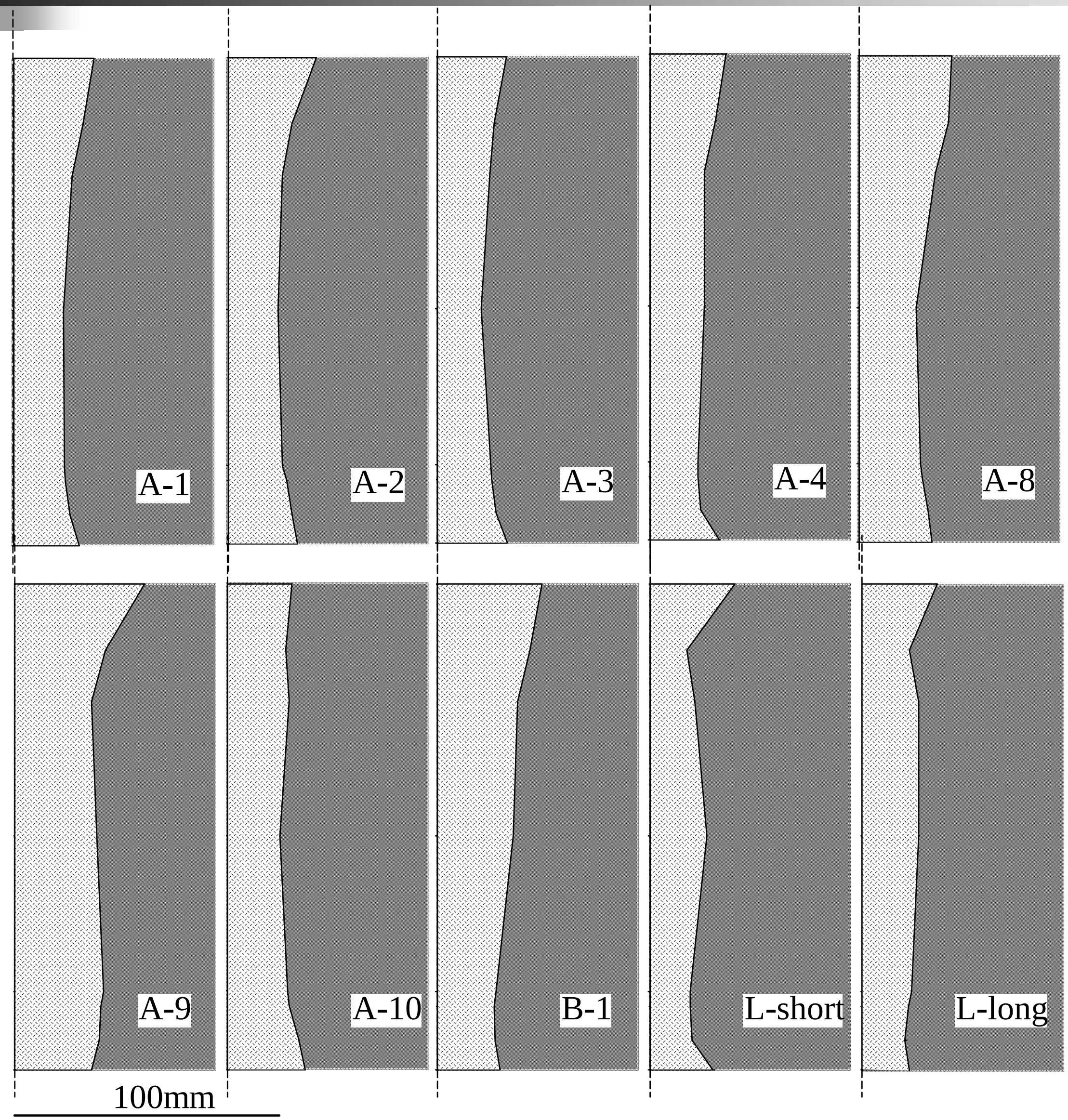
Detail fracture in head of rail appears to be developing in association with an area with a high concentration of shrinkage porosity?

Conclusions

- Large variation in porosity from weld to weld. Porosity not uniformly distributed.

- Porosity clusters at weld centerline frequently seen. Fatigue cracks in head often associated with associated with porosity clusters.

Why?

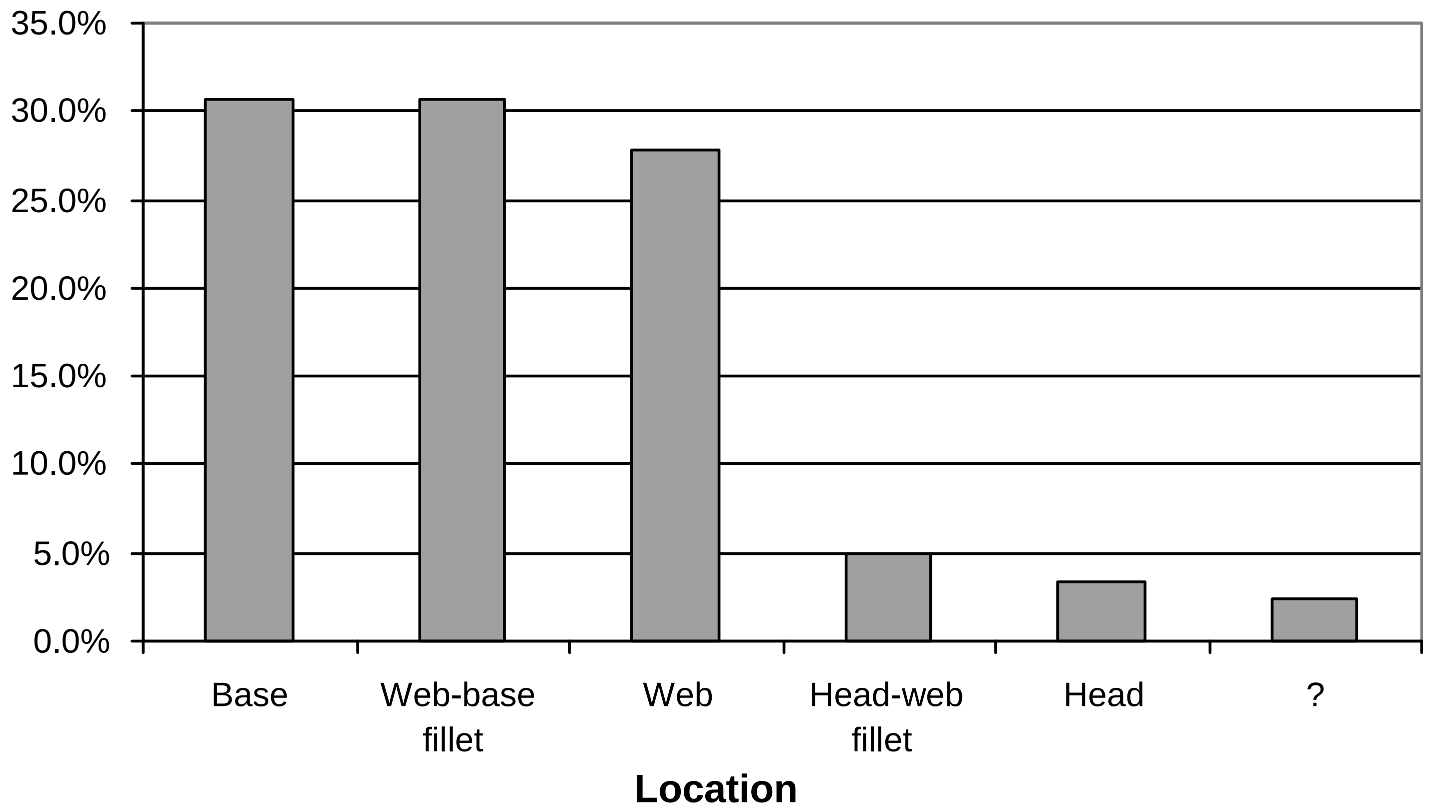


Apparently there are large variations in thermal conditions during thermite welding. Observed variations in melt-back (weld profile) on radiographs.

Outline

- Fatigue problems with thermite welds
- Improving the rail head
- Improving the rail web and base

Thermite weld service failures



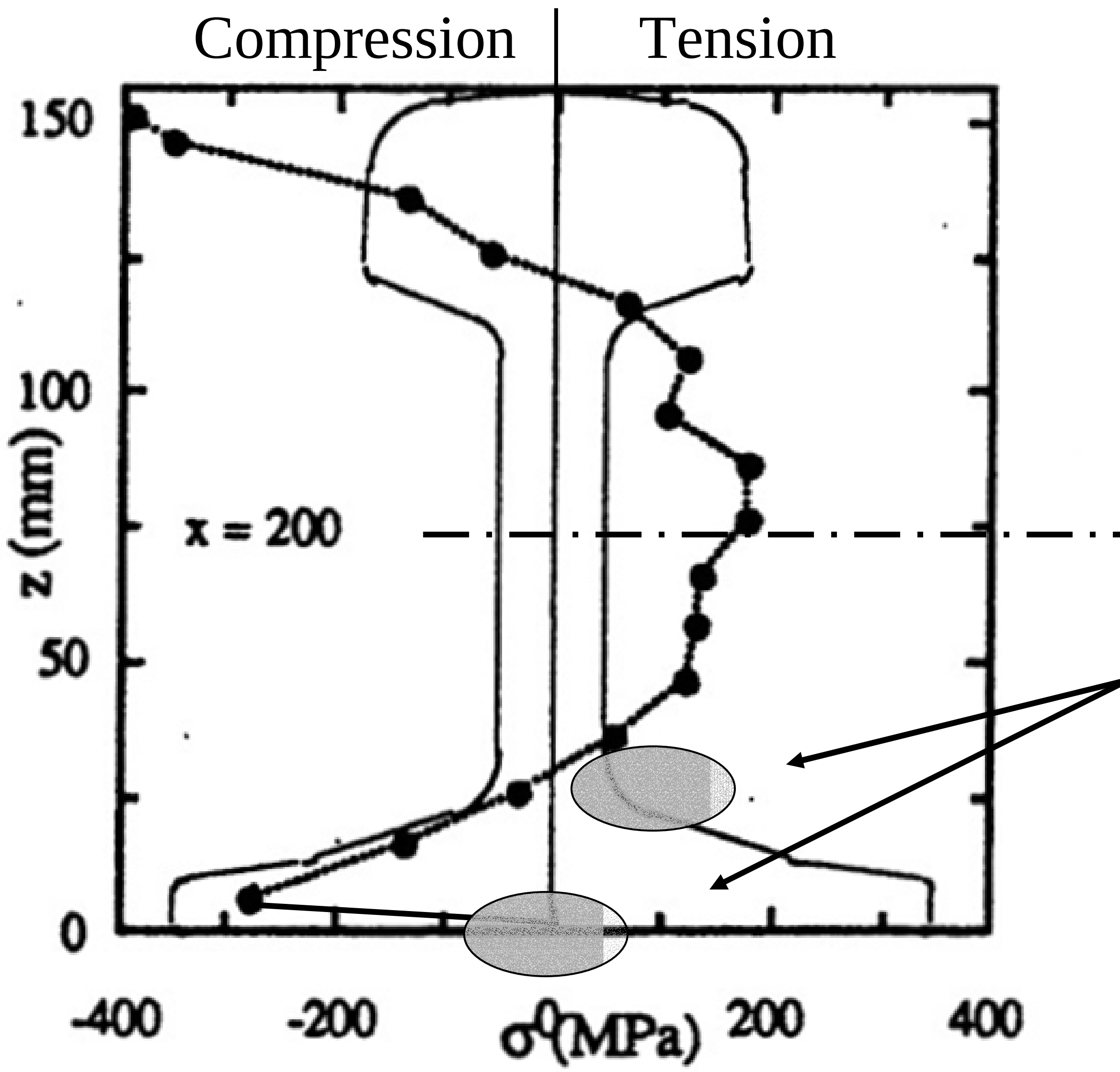
Record of 244 service failures on a Class 1 railroad involving thermite welds.

Web-to-base fillet !?!

- Why does this happen ?????

- Answer:
  - Residual stresses!
  - Weld toe geometry!
    - Flank angle.
    - Cold laps.

Residual stresses



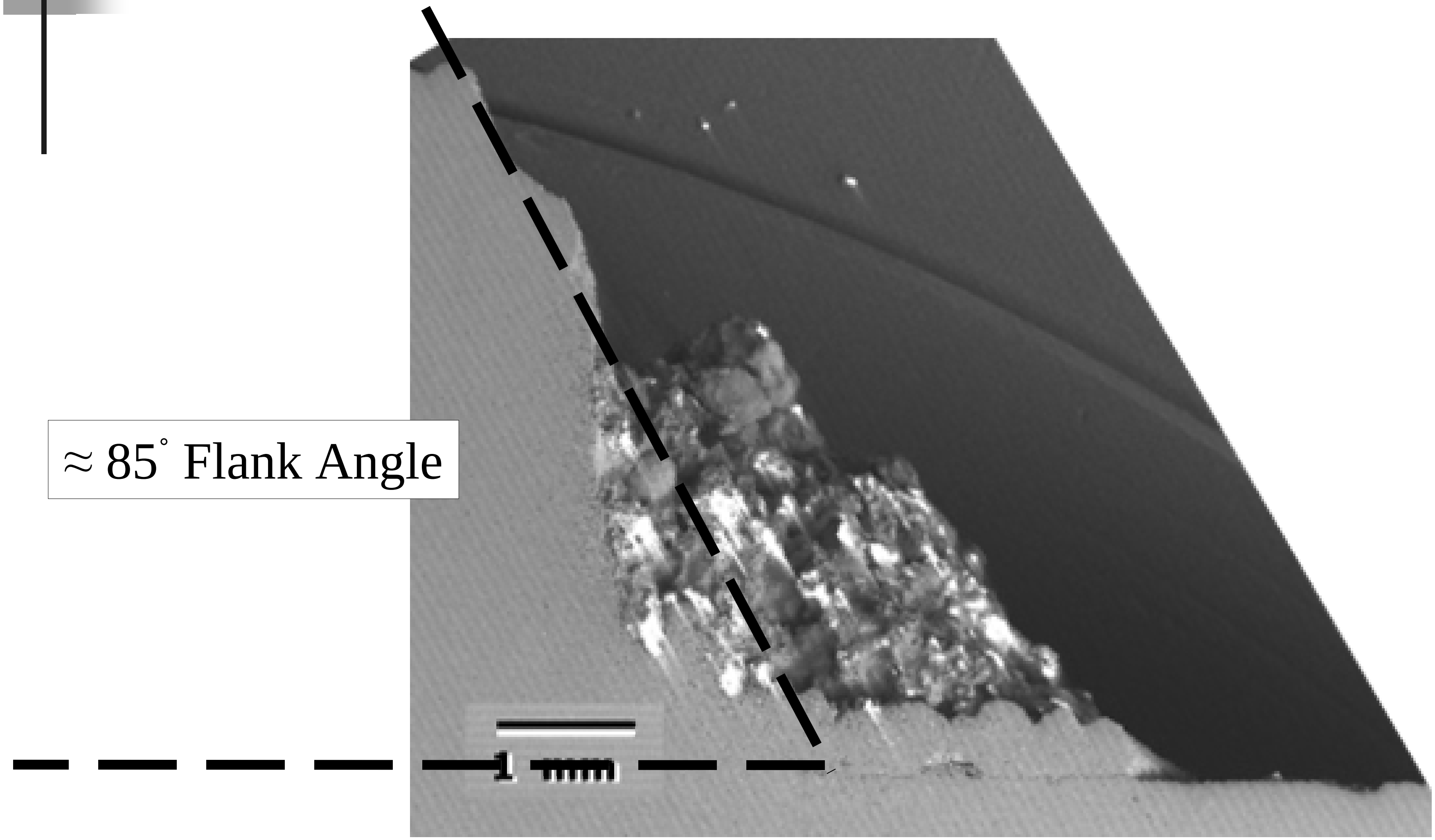
Neutral Axis

Critical locations:

- Web-to base fillet
- Rail base

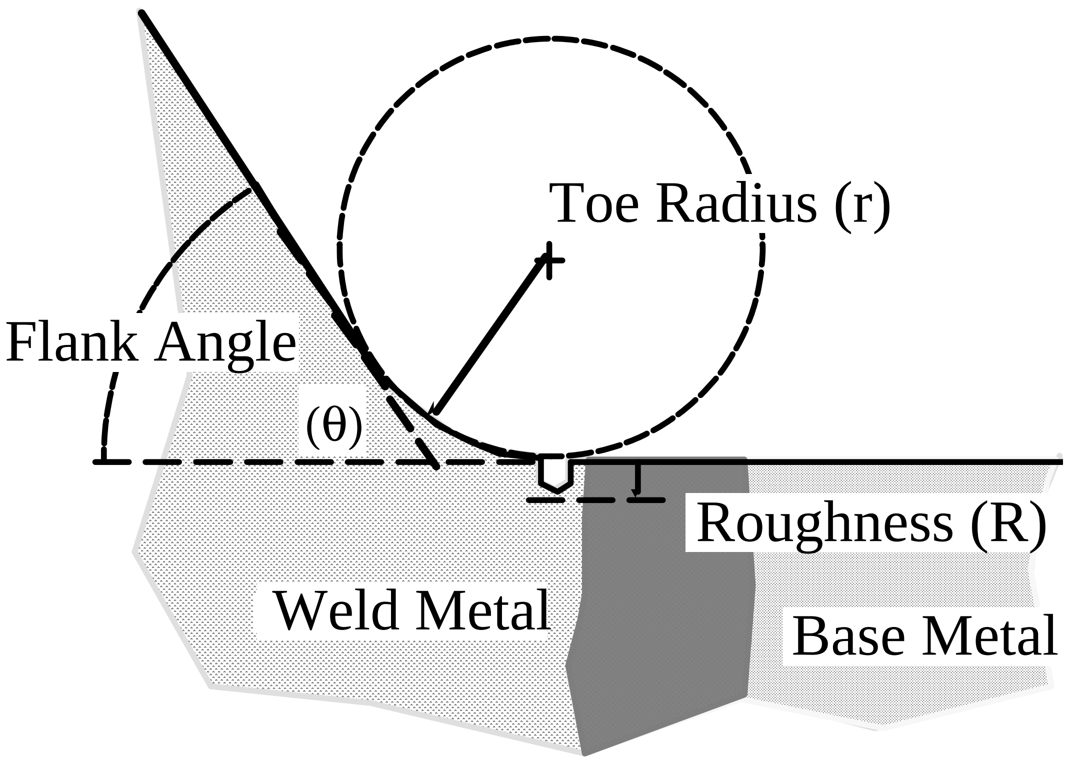
Webster et al.

Weld toe flank angle



≈ 85˚ Flank Angle

Weld toe geometry



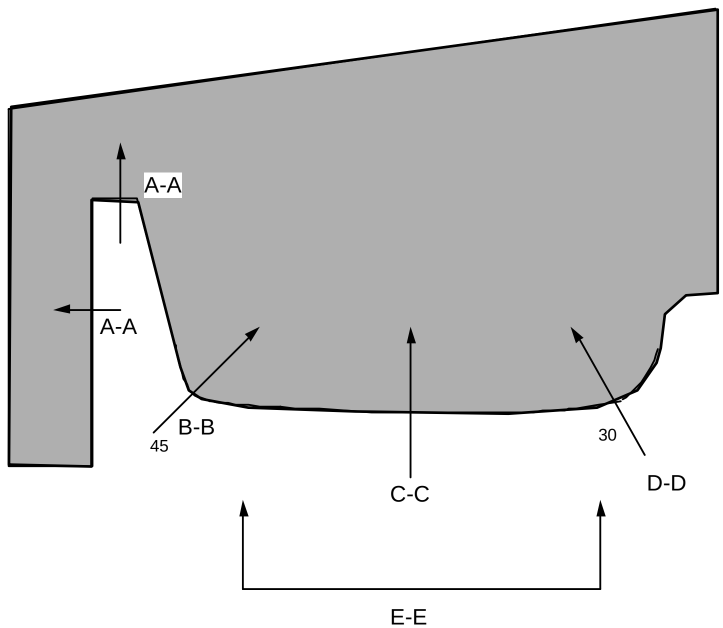
Improve by:

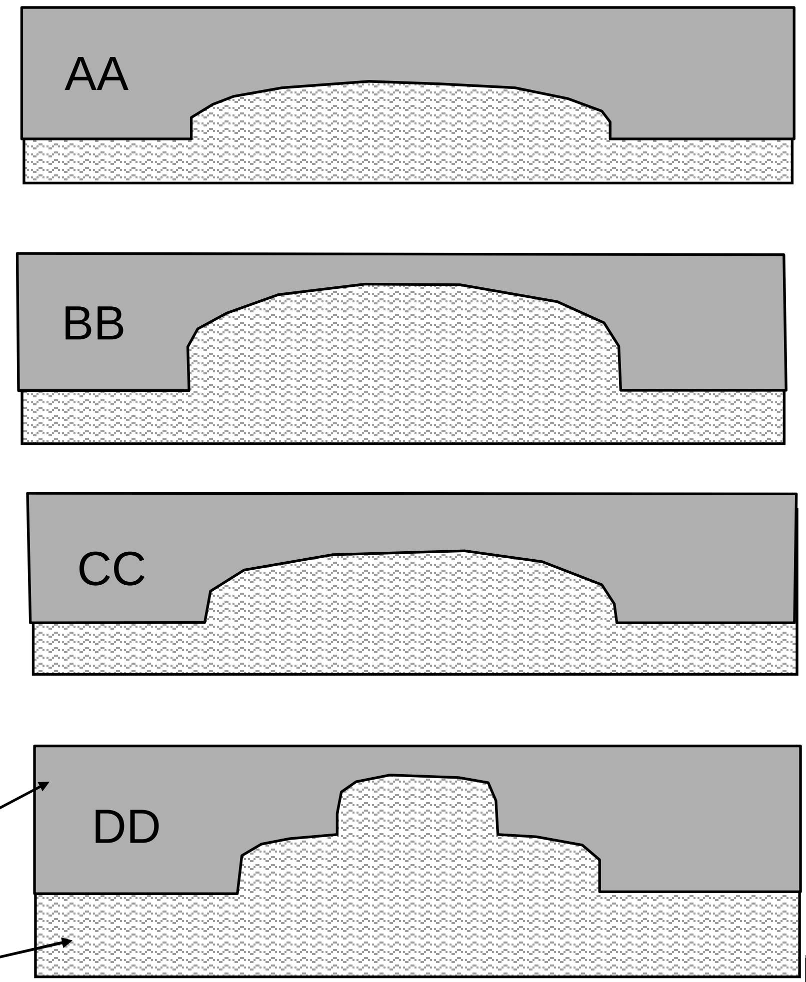
- Flank angle ↓
- □□□̣□□□□□□ ↑
- □□□□□□□□□̣ ↓

$$Fatigue\,Severity = \left(1+0.27\tan\theta^{0.25}\sqrt{\frac{t}{r}}\right)\left(1+0.1054S_u\sqrt{R}\right)-1$$

Current Orgo-thermit mold profiles

Measured profiles of Orgo-thermit molds



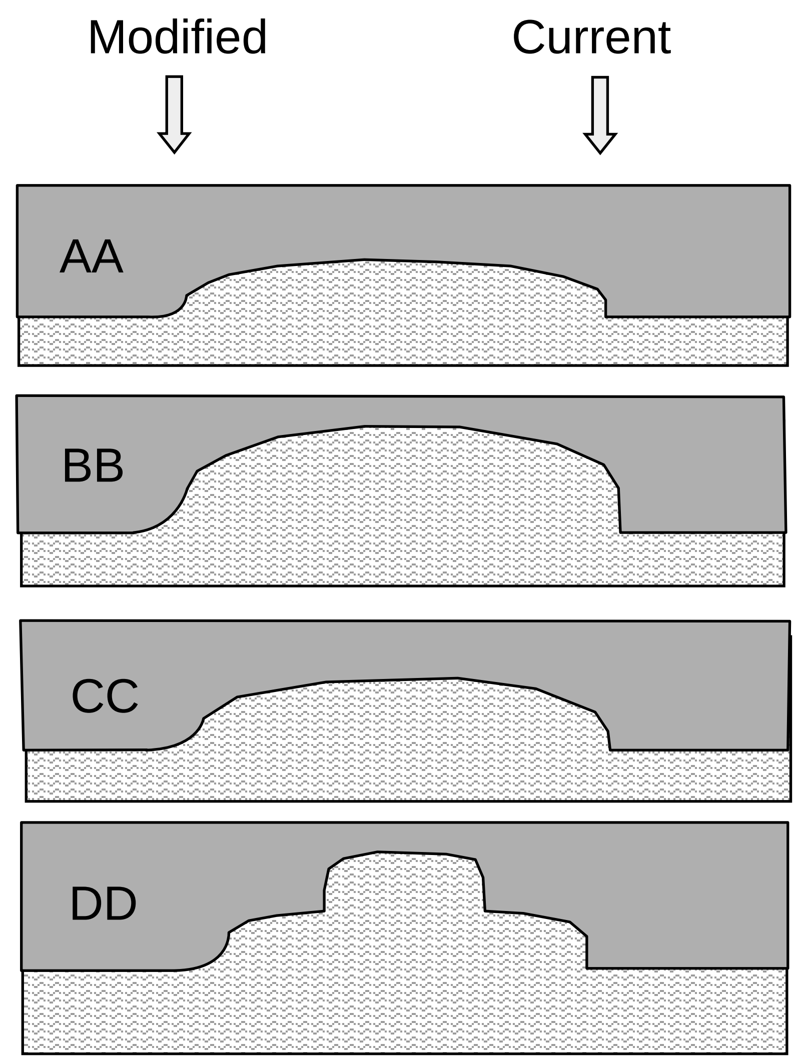


Mold

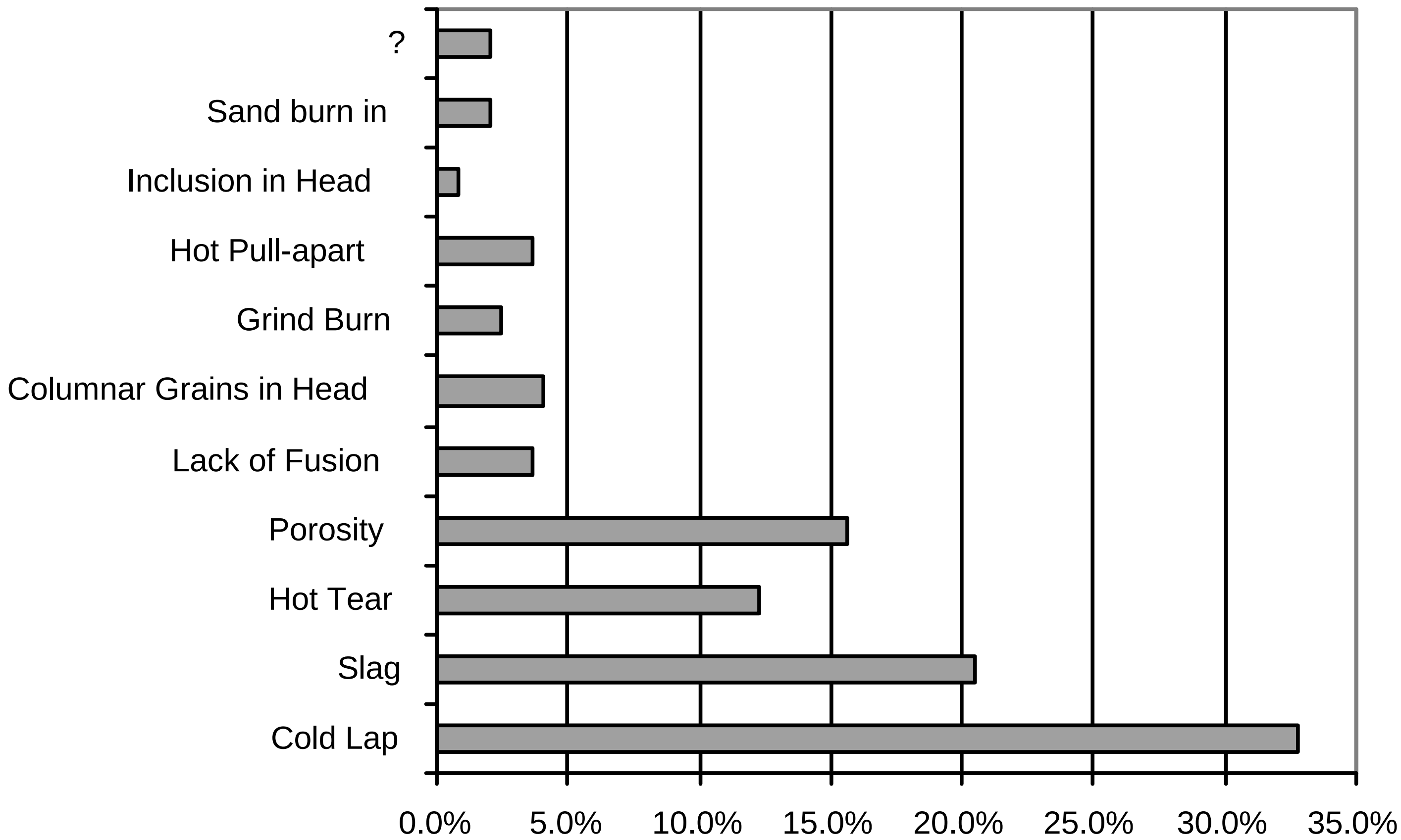
Rail and weld

Modified Orgo-thermit mold profiles

Suggested modifications to Orgothermit molds

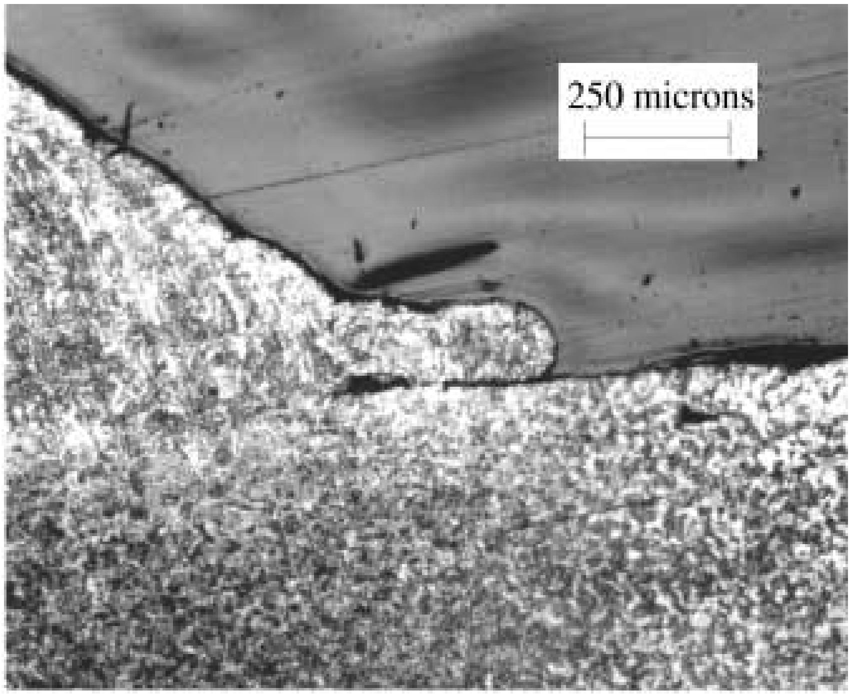


Nature of critical defects

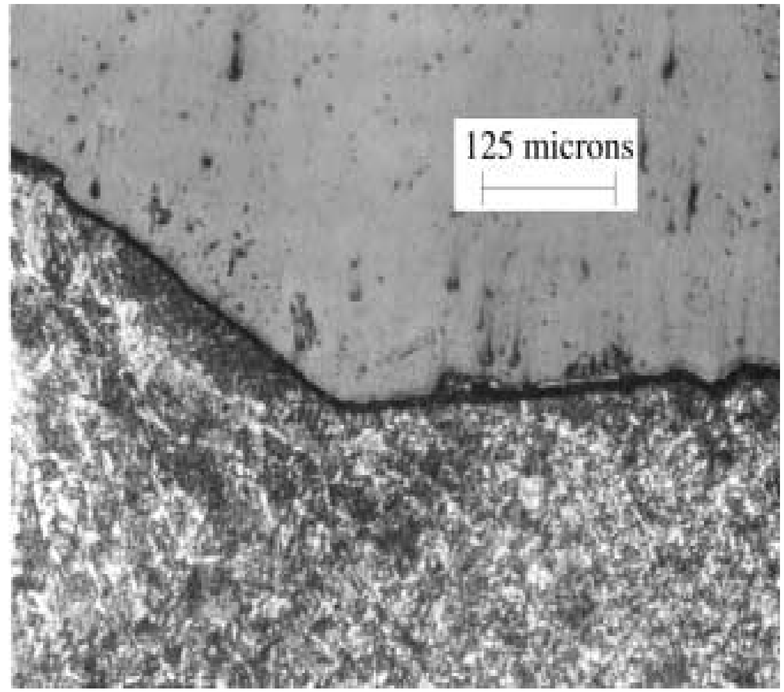


Analysis of 244 service failures on a Class 1 railroad involving thermite welds.

Cold laps - Dimitrakis



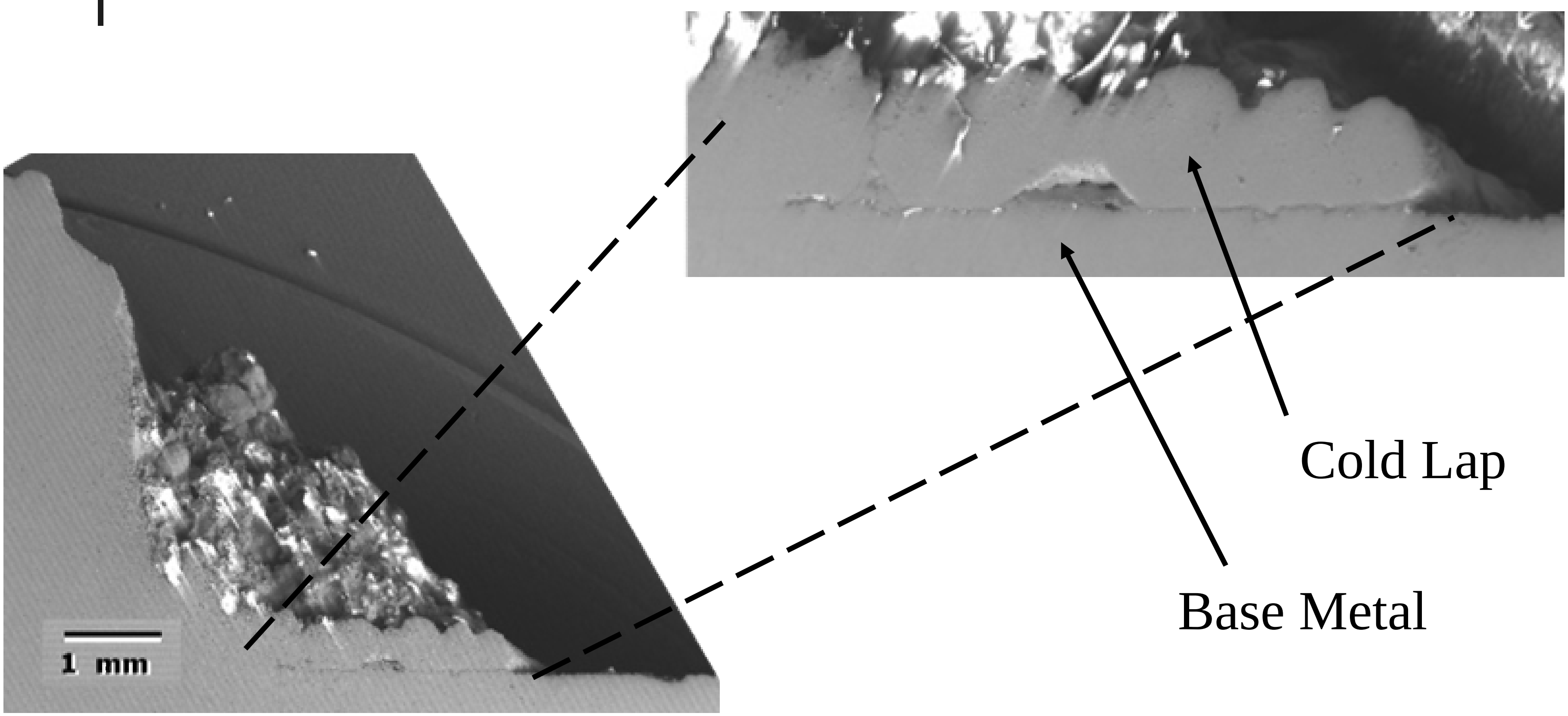
Cold lap



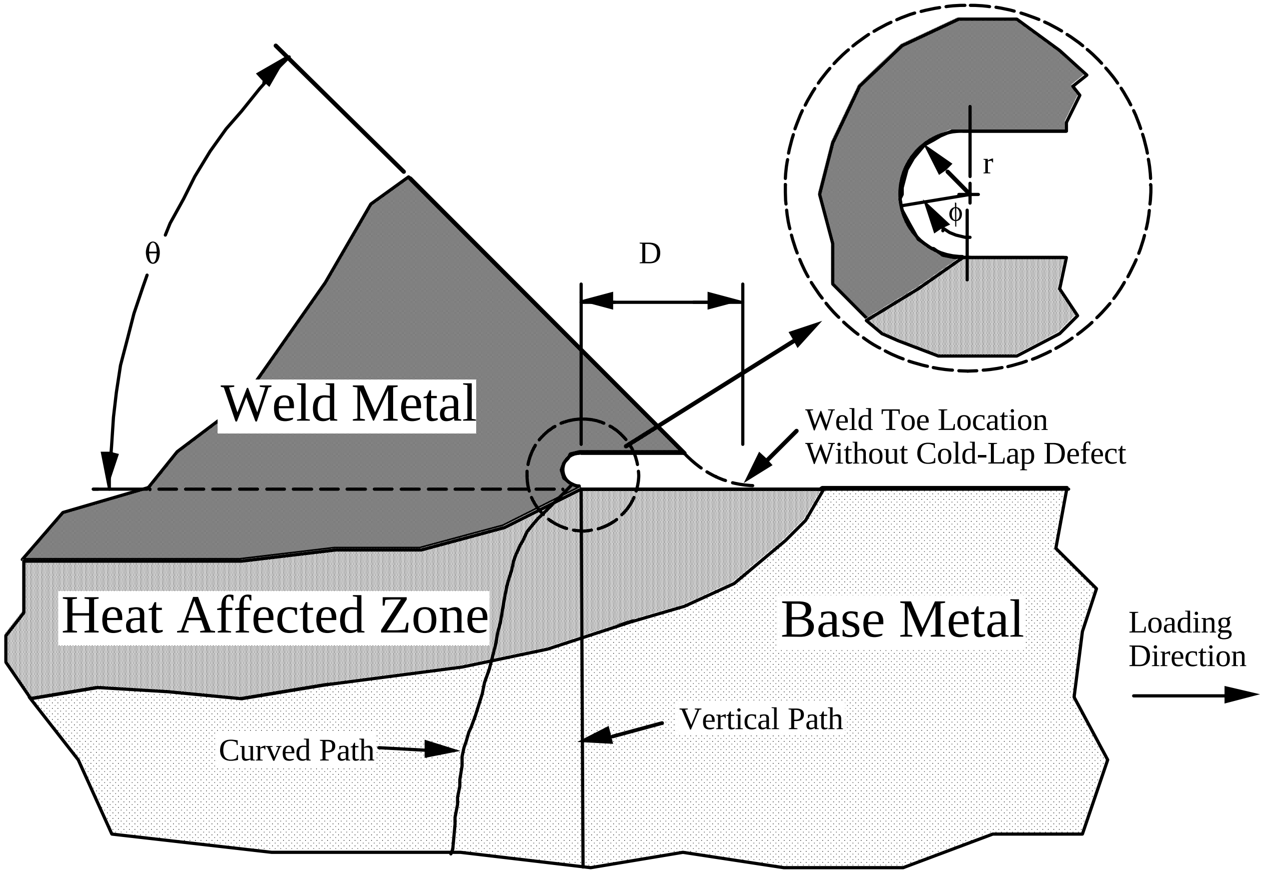
No cold lap

Cold laps greatly reduce the fatigue life of a weldment

Cold laps at thermite weld toe



Weld toe cold laps



Effect of cold laps

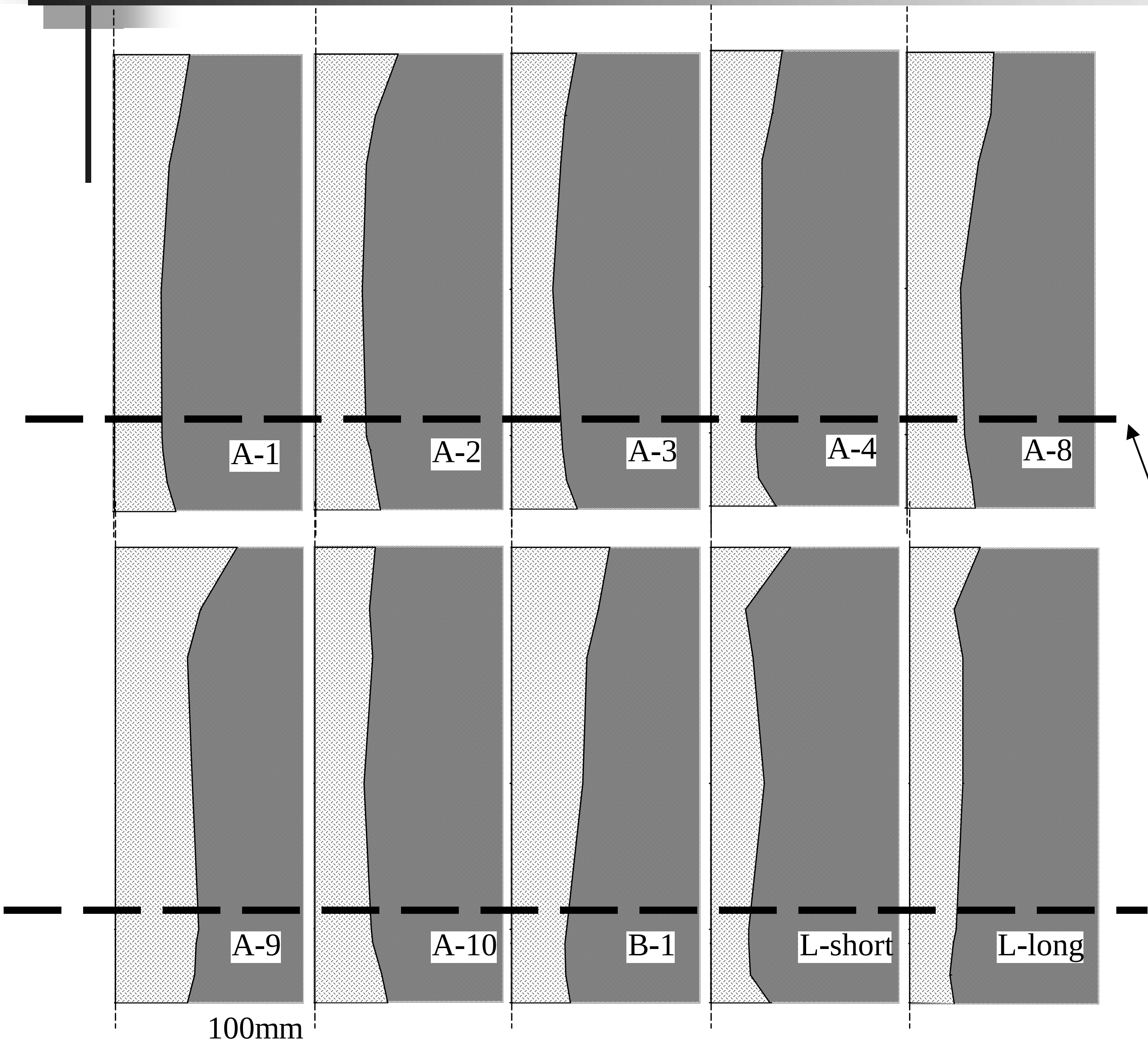
Condition	Percentage of Fatigue Life
Flank angle (θ) = 30Þ	**100%**
Flank angle (θ) = 45Þ	56%
Flank angle (θ) = 60Þ	44%
Cold lap depth (D) = 0	**100%**
Cold lap depth (D) = 1mm	20%
Cold lap depth (D) = 2mm	15%

Causes of cold laps

- Gap between mold and rail in the critical web-to-base fillet area.

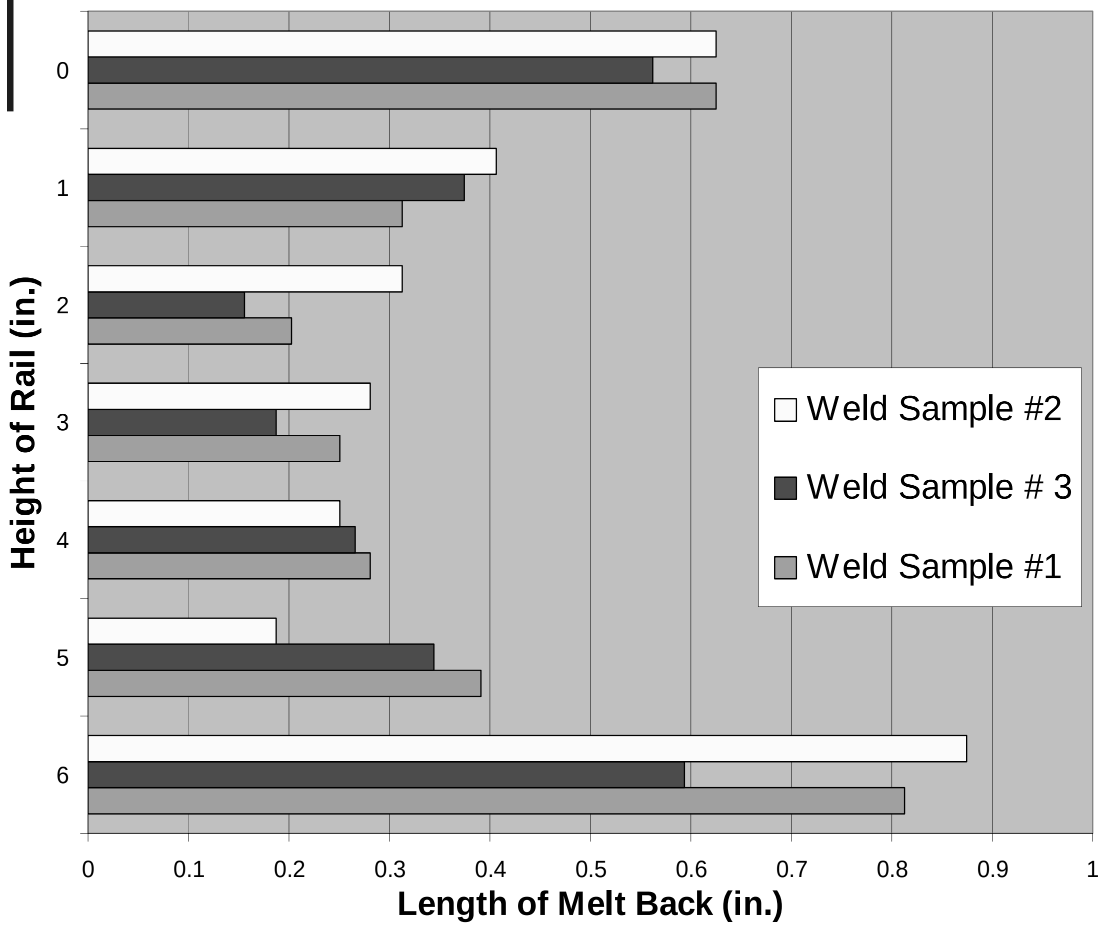
- Inadequate melt back causing incomplete fusion at the weld toe?

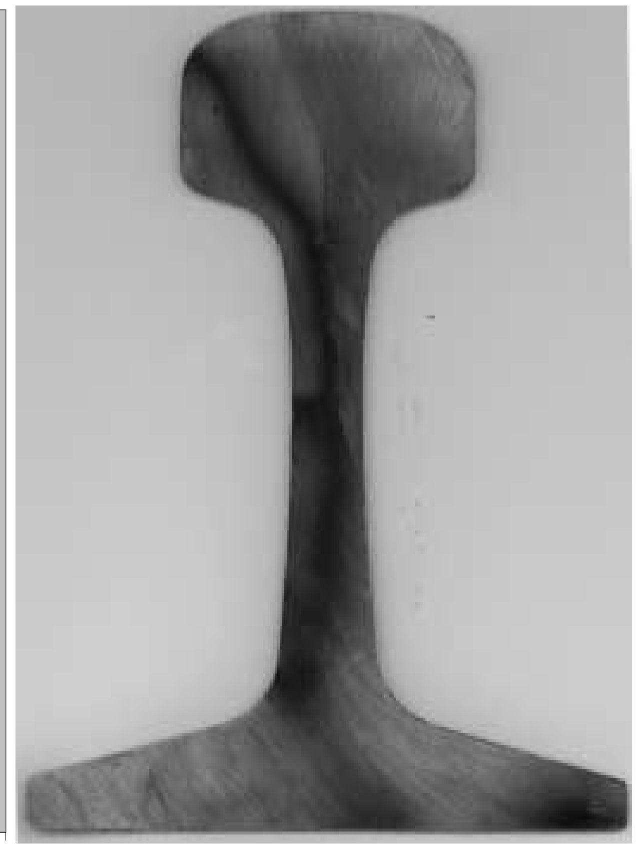
Variations in melt-back



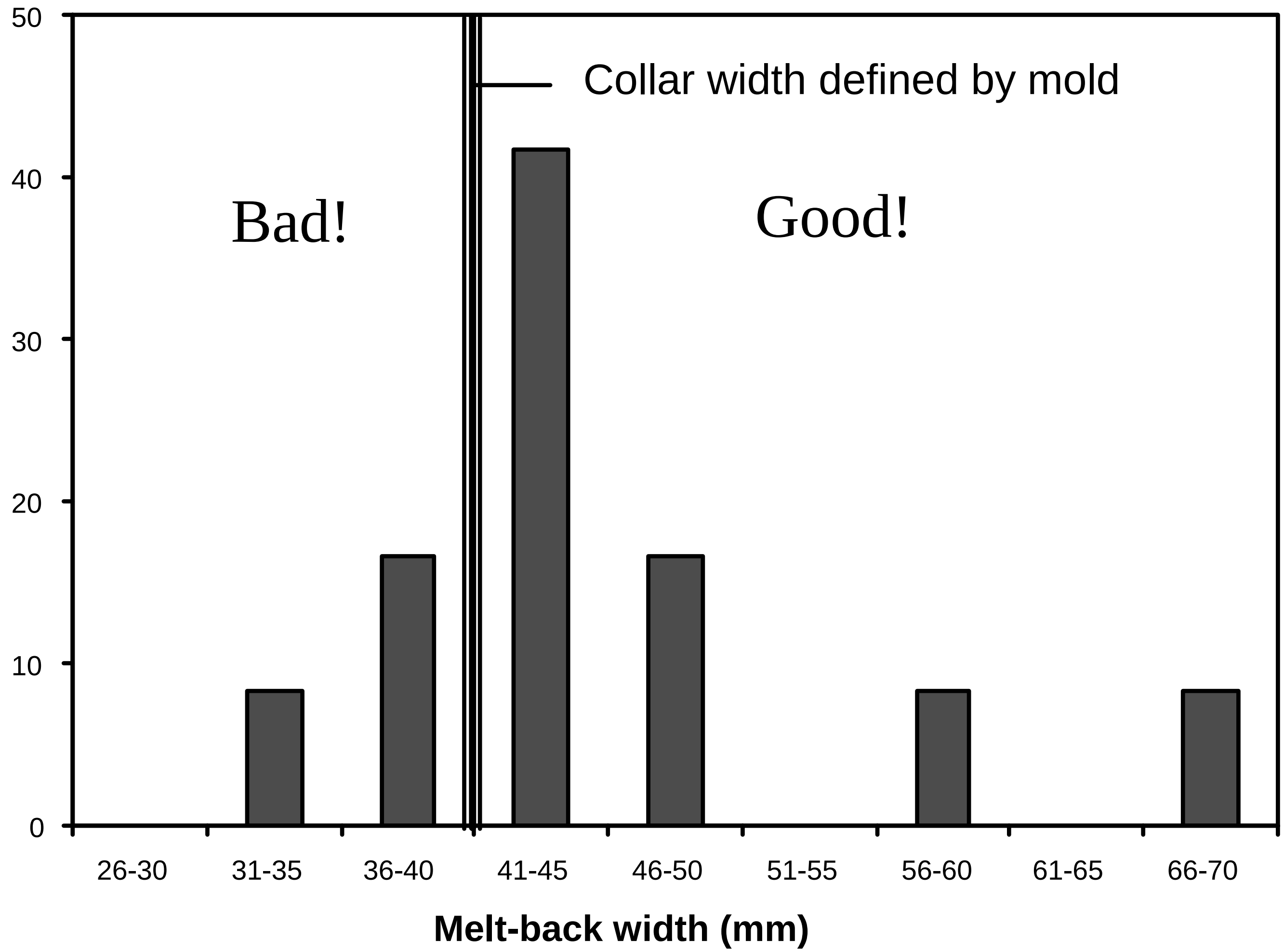
Melt back varies considerably in the location of the web-to base fillet

Melt back dimensions

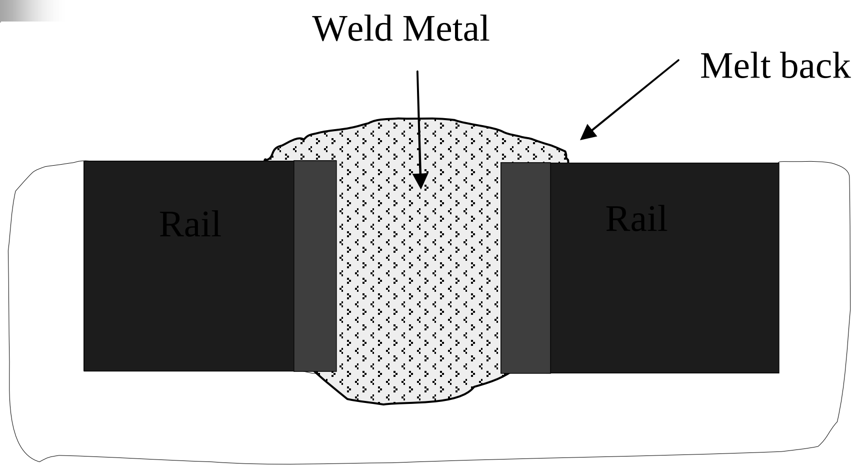




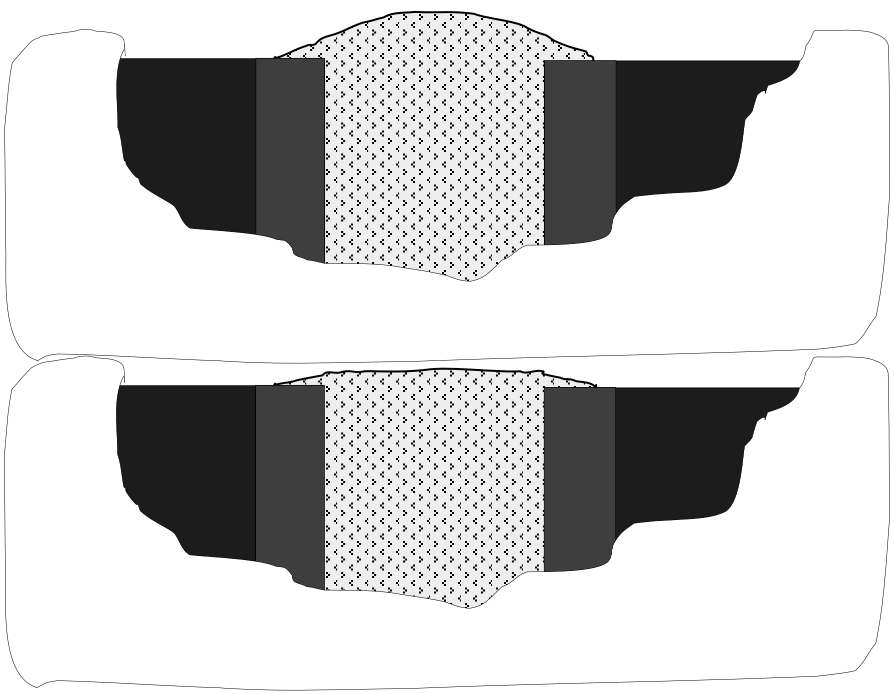
Melt back at web-to-base fillet



UIUC Experimental Program



Standard 1” thermite weld: Large flank angle and cold laps.



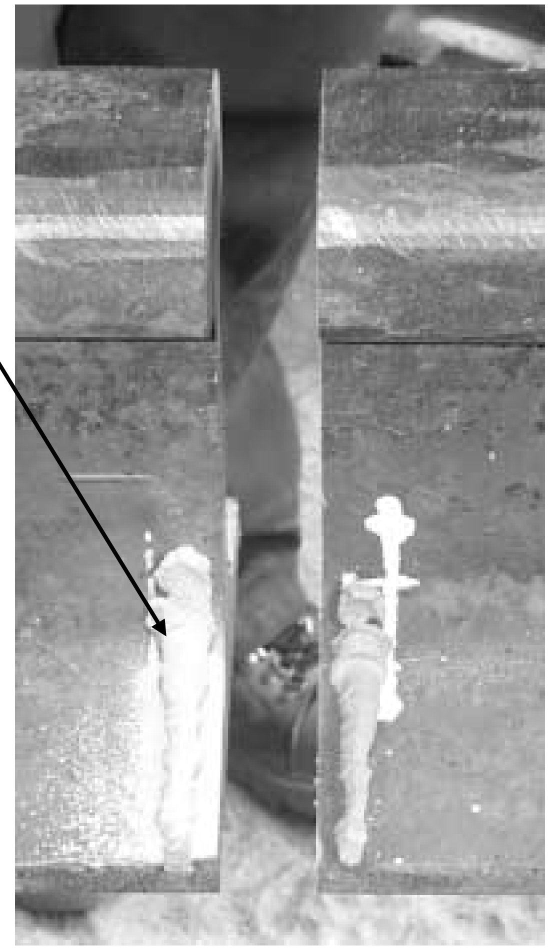
UIUC modified 1” thermite
weld molds are used with a 1.4” rail gap. Mold sealed at weld toe with refractory paste.

And: Reduced flank angle!

UIUC Experimental Program

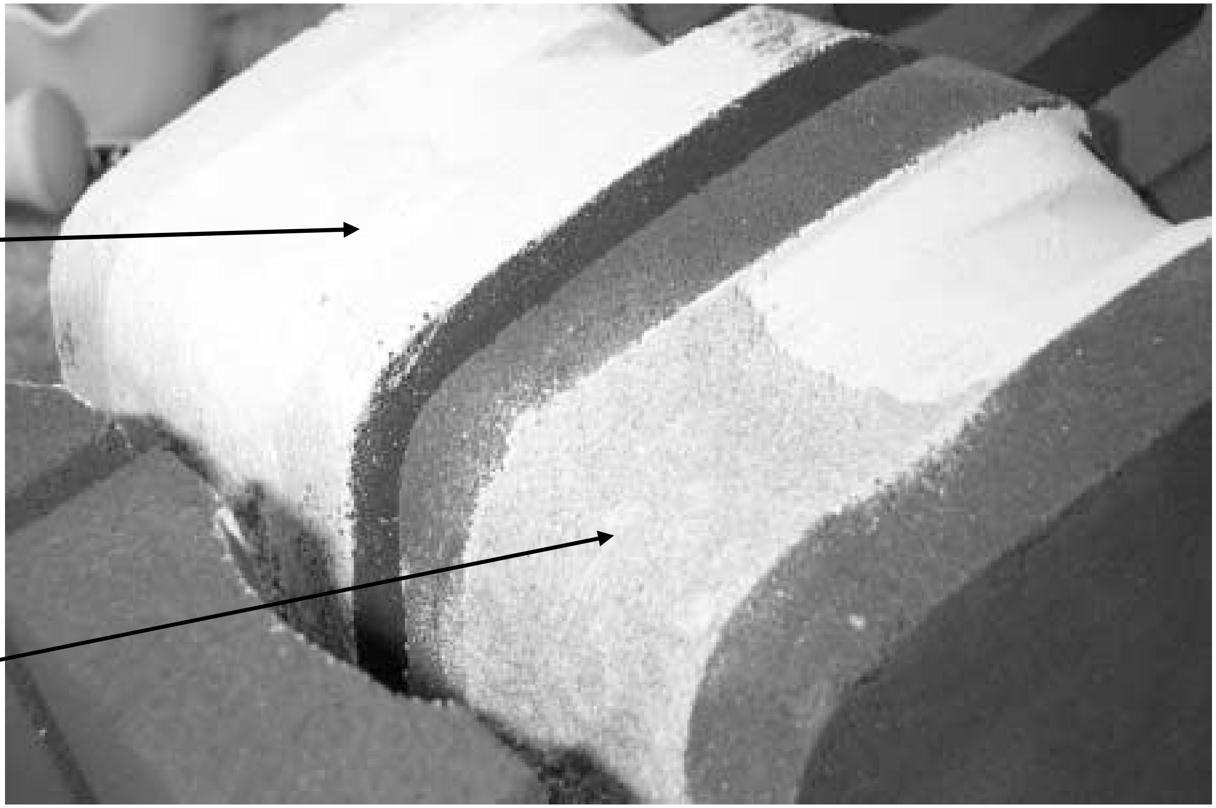
Sealing paste from Railtech w/ Brazing Flux.

Lutting paste from Railtech.

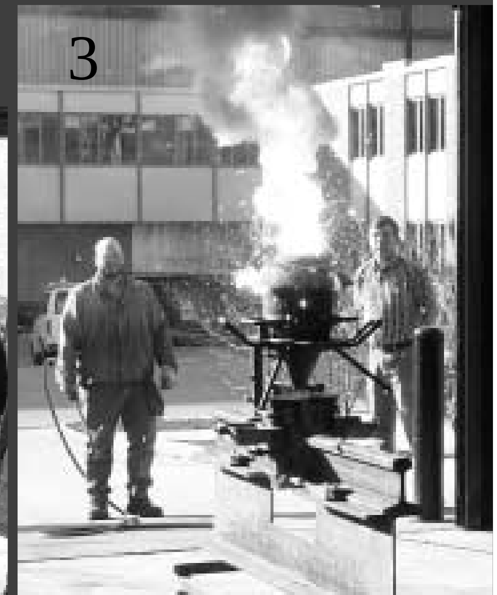


UIUC Experimental Program

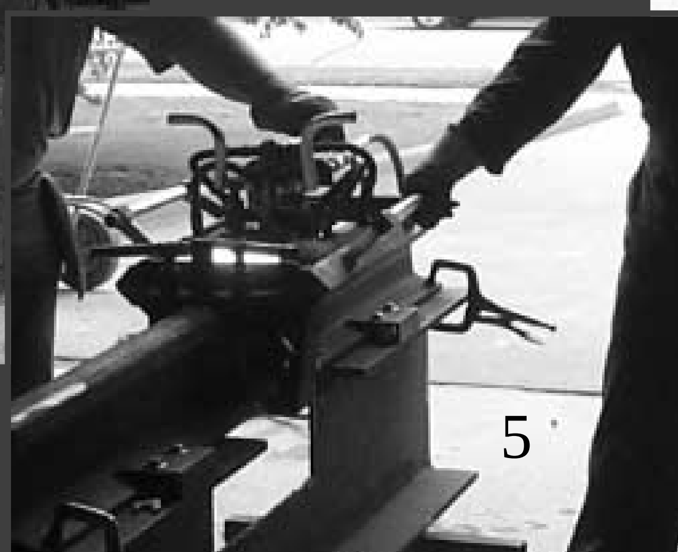
Leecote mold wash and Uni Ram Blu refractory paste.



Uni Ram Blu refractory paste.



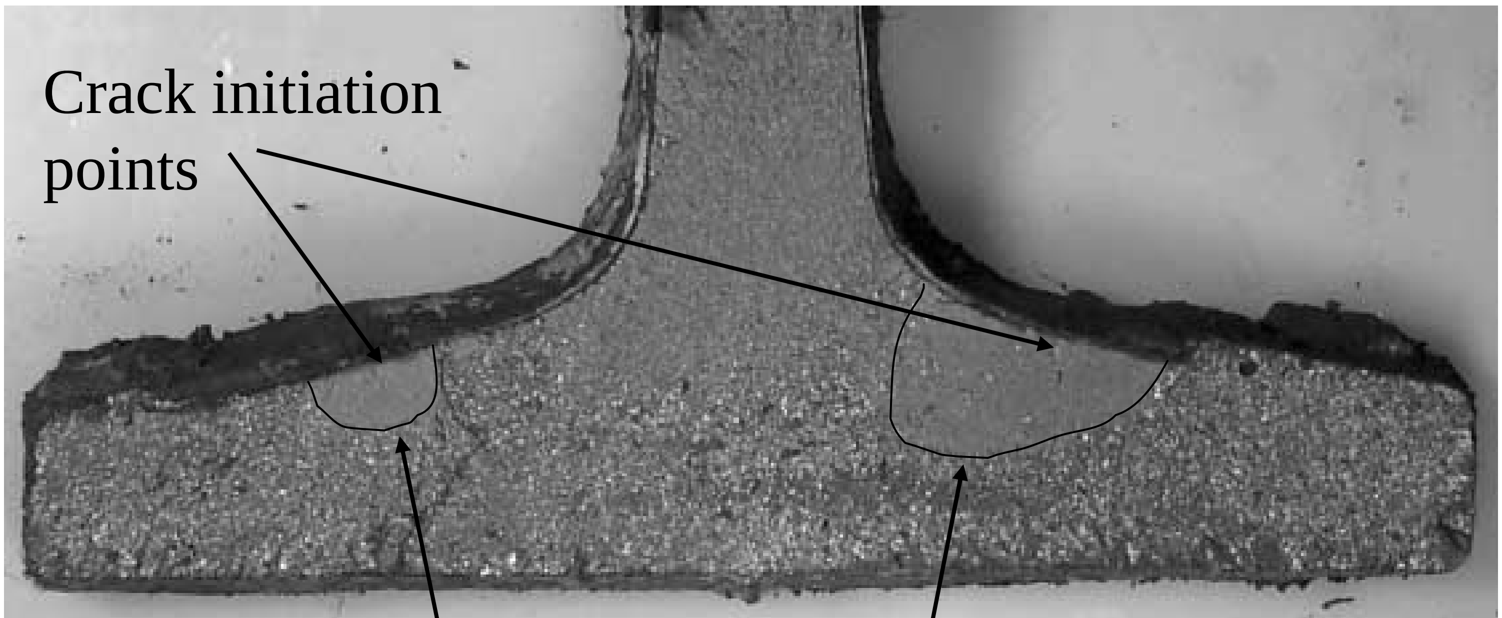
Weld Fabrication



Fatigue testing

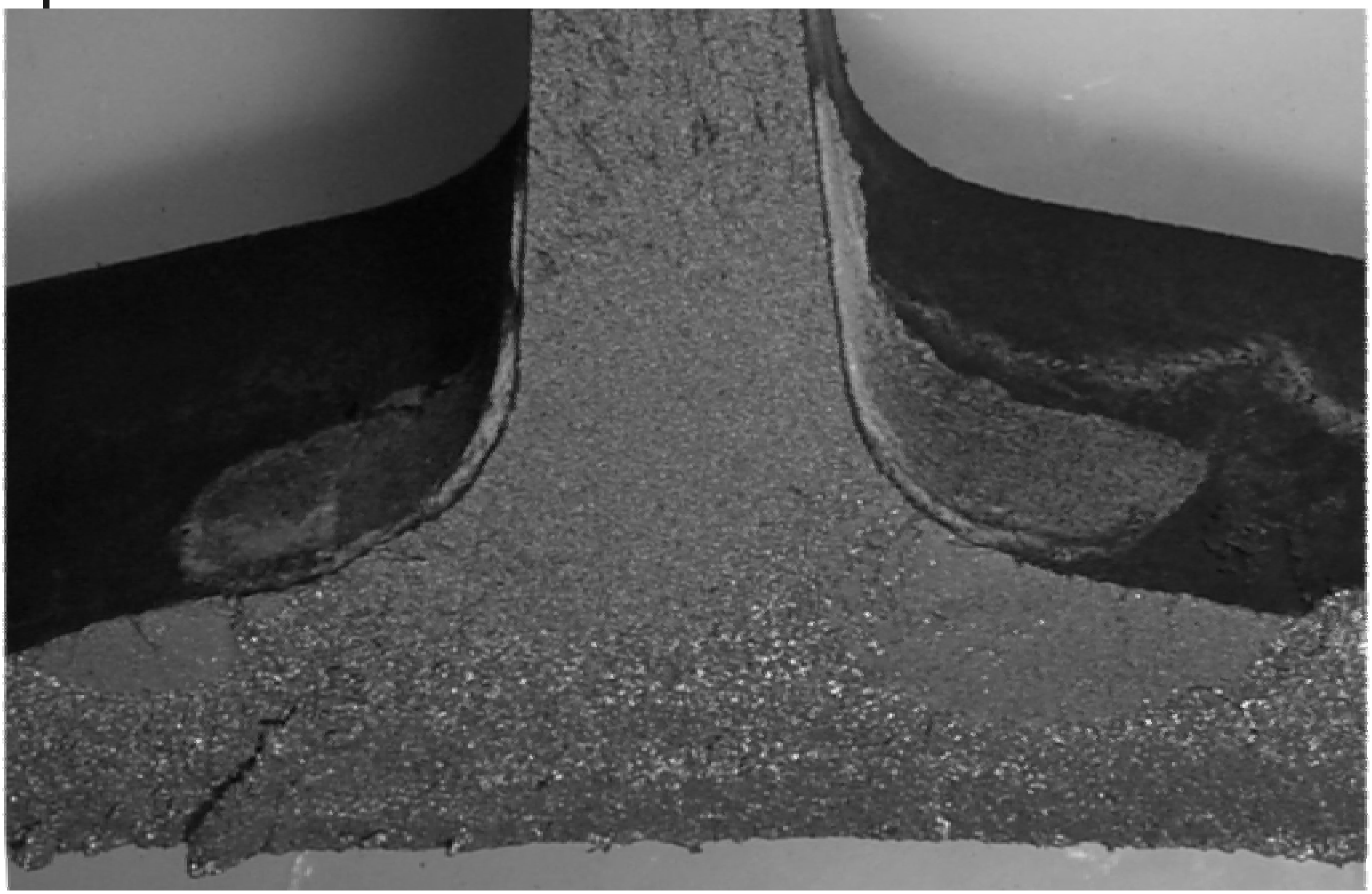
Standard 4-point bending test.

Modified Weld Specimen #28



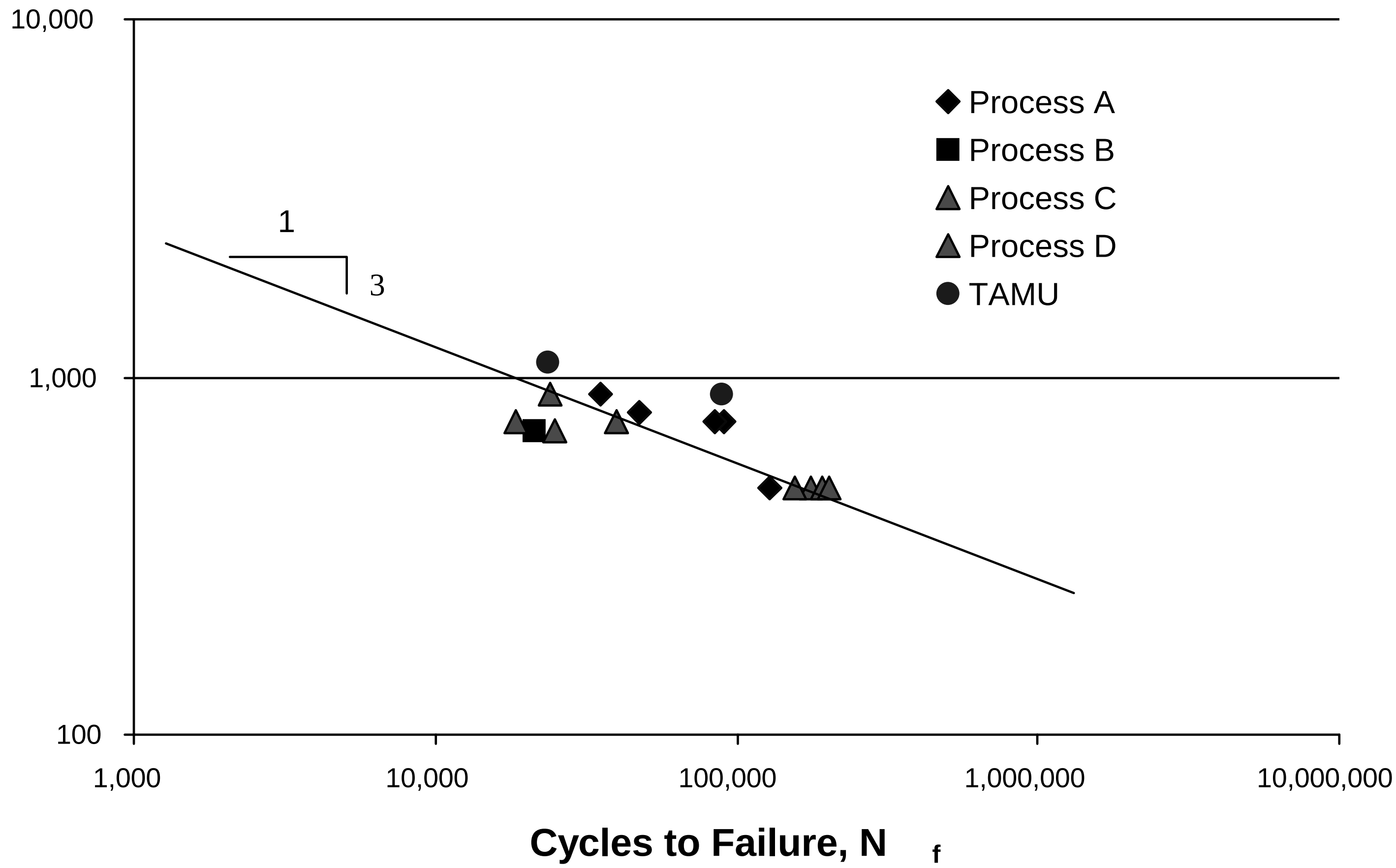
Limit of fatigue crack growth

Effect of modifications

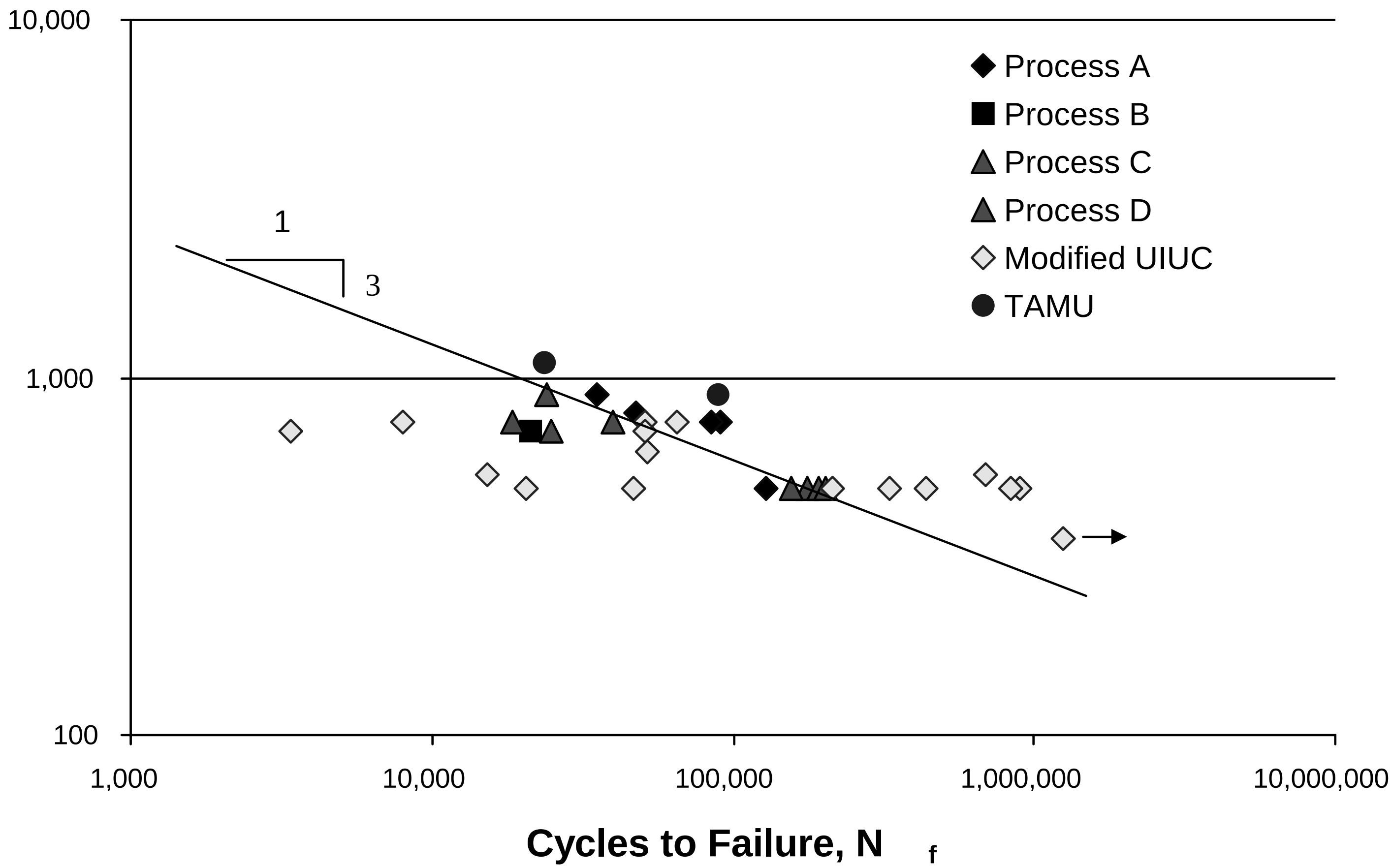


Cold lap formation beyond sealing paste

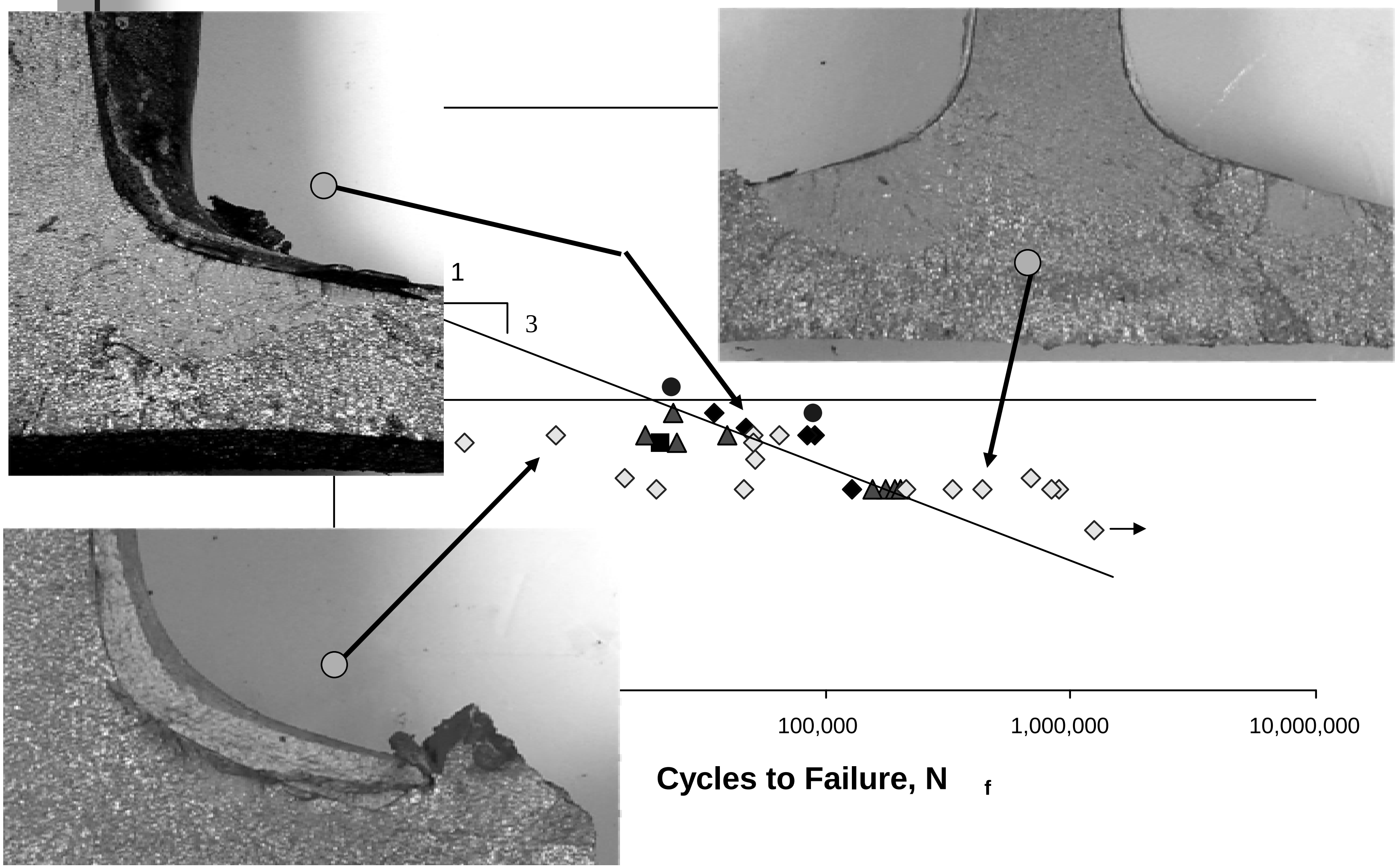
Standard weldments



UIUC experimental welds



UIUC experimental welds



Summary - Head failures

- Head failures caused by internal defects notably porosity and high concentration areas of porosity.
- Thermal conditions during solidification may cause one weldment to be good and another to be bad?

Summary - Web-base failures

- Web and base failures aggravated by severe external geometry and cold laps.
- Thermal conditions during solidification play a role in web-base fatigue problems?
- Fatigue life can be increased by modifications of external weld geometry.