Aalto University
School of Engineering

Simulating FCG of Multiple Cracks on Weld Toe

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Pasi Lindroth
M.Sc. (Tech.), Doctoral Candidate
Aalto University, Finland
pasi.lindroth@aalto.fi

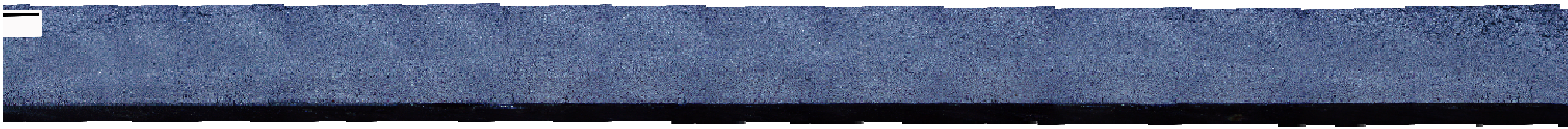
Grzegorz Glinka
Prof. University of Waterloo, Canada
Prof. Aalto University, Finland

Gary Marquis
Prof. Aalto University, Finland
Chairman - IIW Technical Management Board

Fatigue on Weld Toe

Multiple small cracks

Most of the cracks are difficult to see



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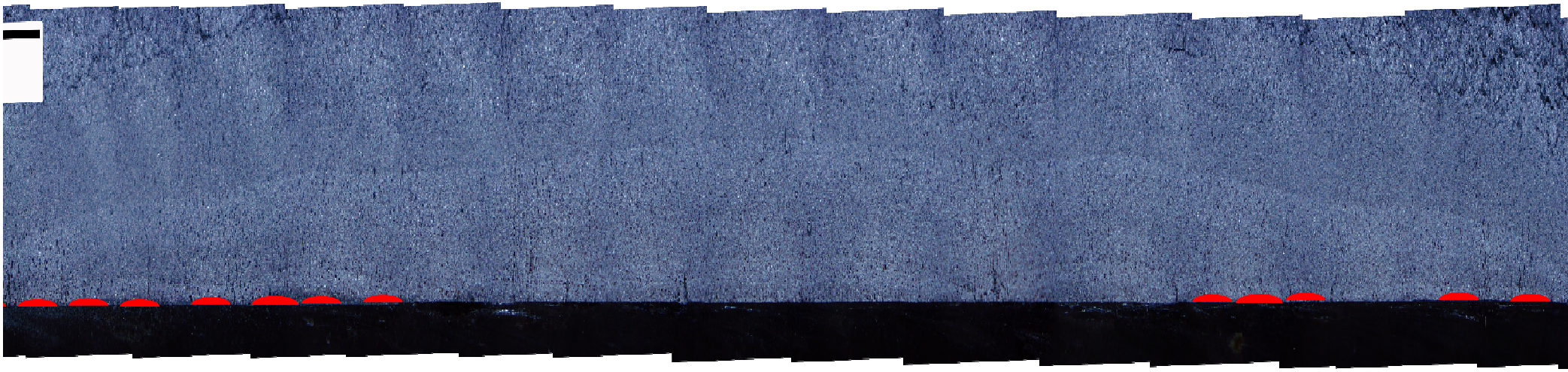

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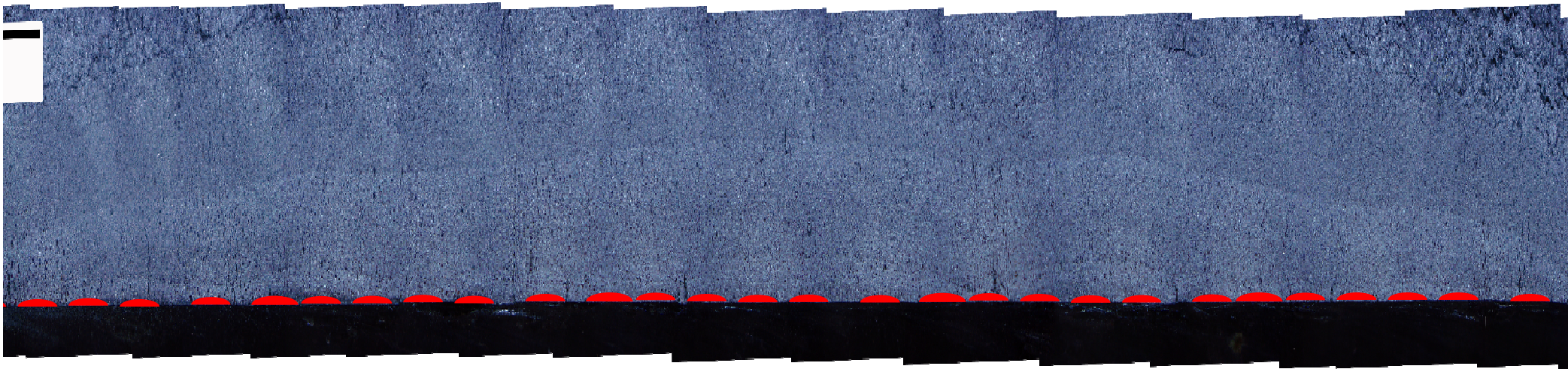
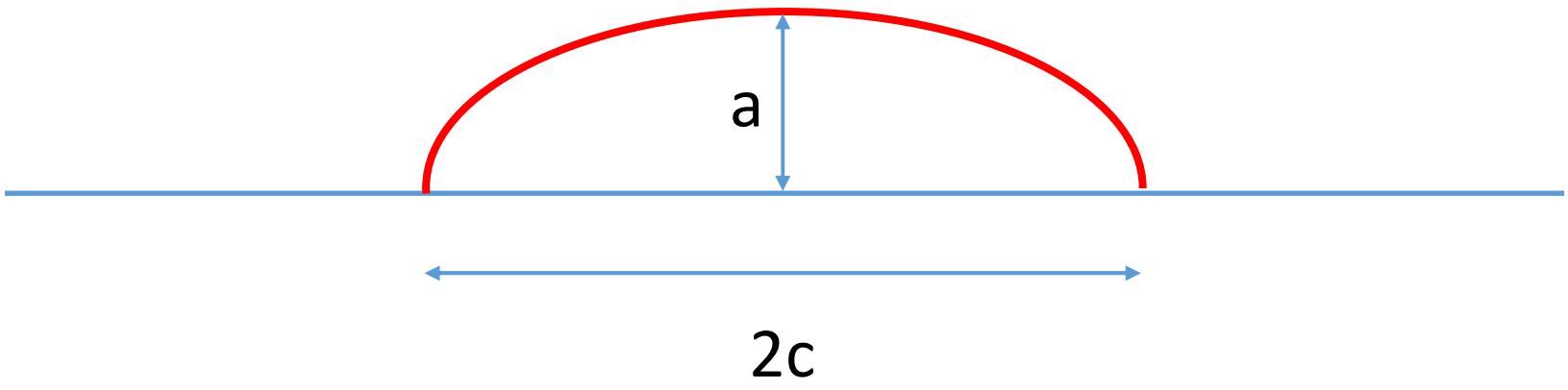


Current Method

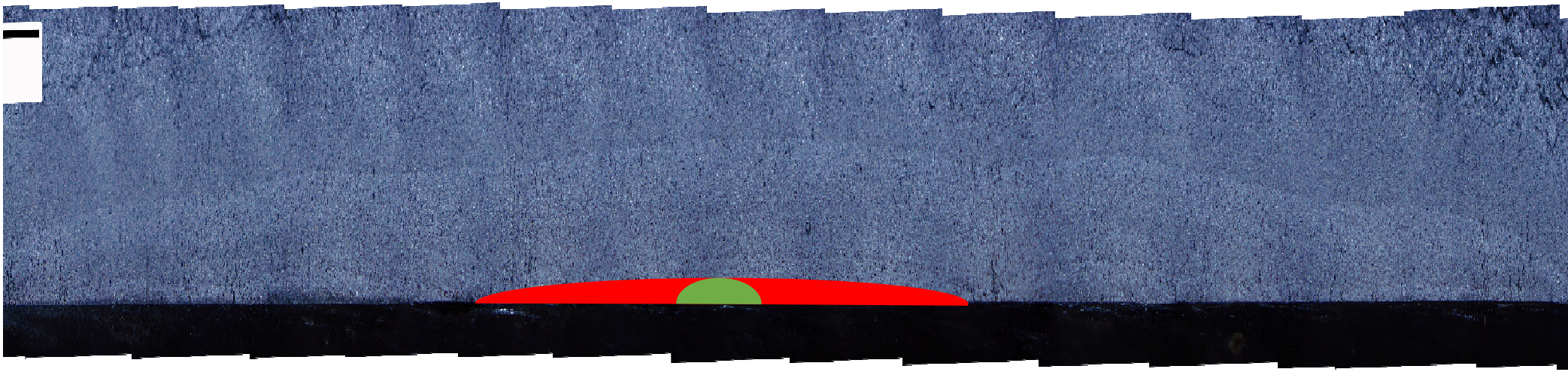
- Crack initianion based on strain life
  - Initial crack size and shape unclear.
  - a0 = 0.1 – 0.7 mm

- Fatigue crack growth
  - Edge crack or a single semi-elliptical crack

Semi-Elliptical Crack – Aspect Ratio a/c



Crack Initiation by Using Strain-Life

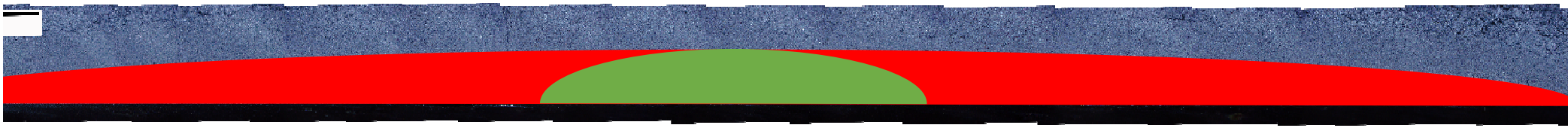


initial crack based on strain-life, a = 0.5 mm, a/c = 0.2

largest real crack, a = 0.5 mm, a/c = 0.033

Crack Growth After Strain-Life Inititation

racks on weld toe coalesce forming one large crack.
ingle crack methods predicts much smaller crack.



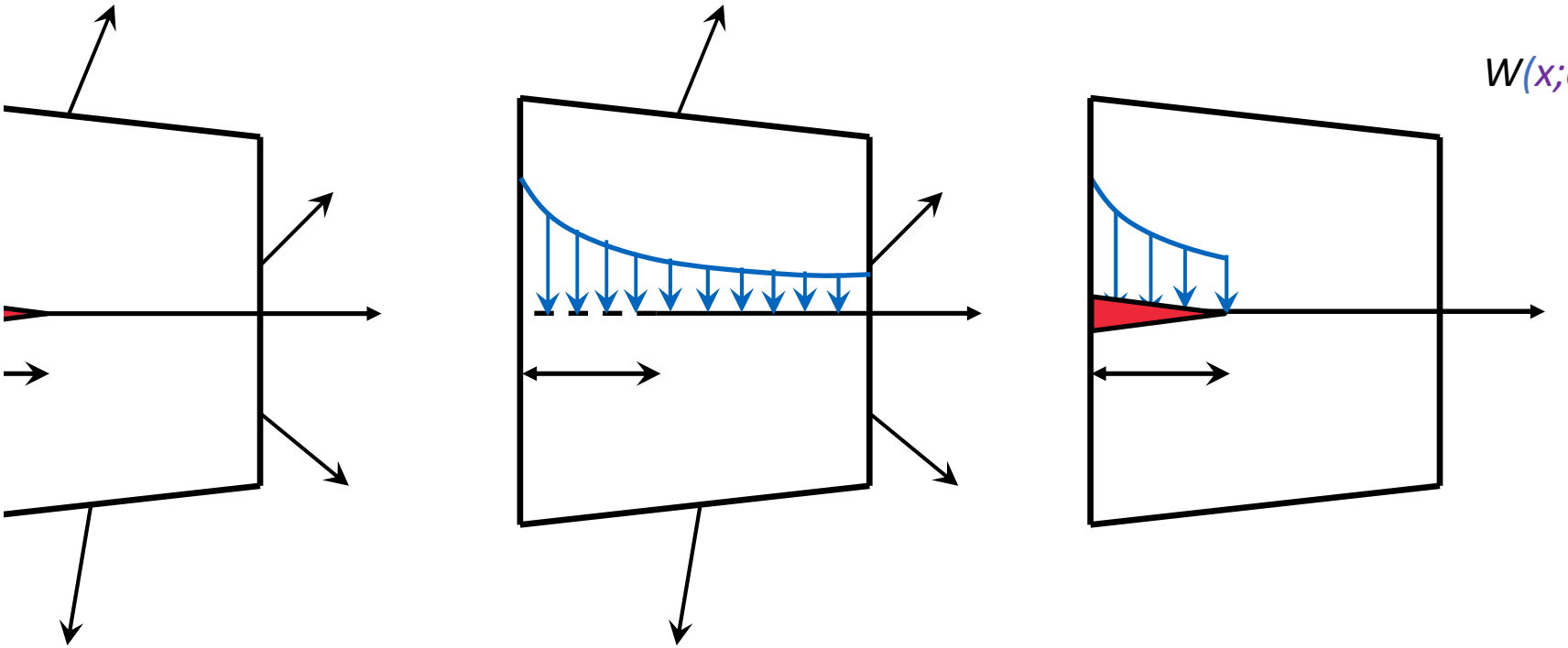
simulated crack growth upto a = 2.9 mm, a/c = 0.56

real crack growth upto a = 2.9 mm, a/c = 0.065

Multi-Crack Approach

- Multiple semi-elliptical initial cracks.
- Stress intensity factor calculations using weight function method.
- Total life approach.
  - No separated initiation and crack growth.
- Crack growth incremenet based on UniGrow model.
- Crack coalescence.

Weight Function

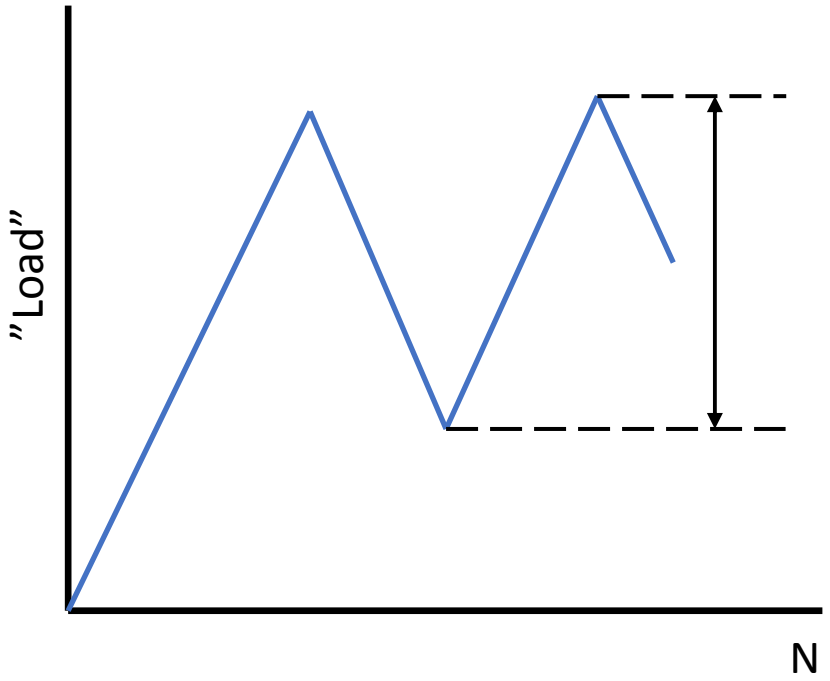


$\sigma(x)$ = stress field of unc

$W(x;a)$ = weight functio
specific crack g

Crack Growth Rate

UniGrow model, Glinka et al.

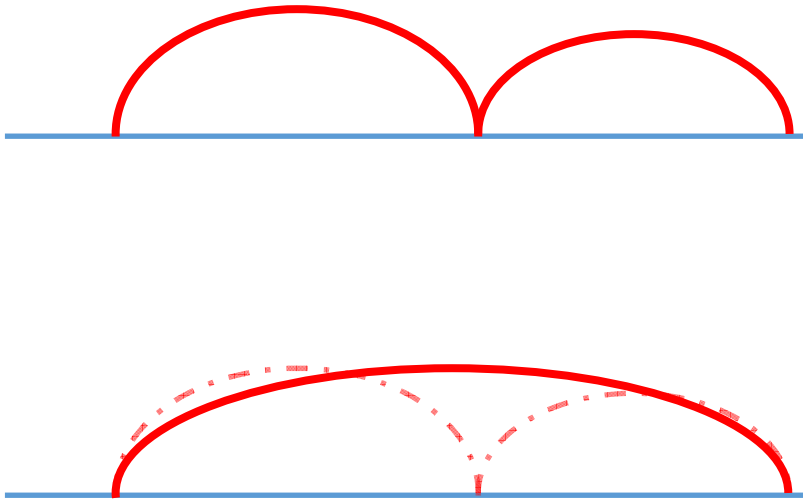


K_r = Local residual stress field around the crack tip

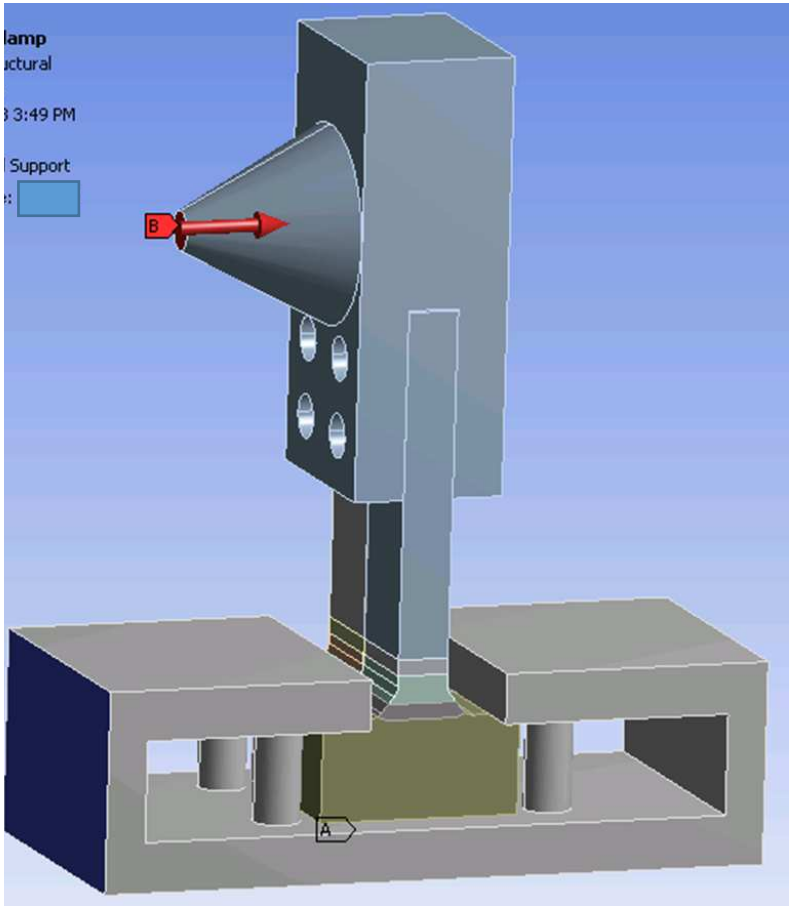
Coalescence

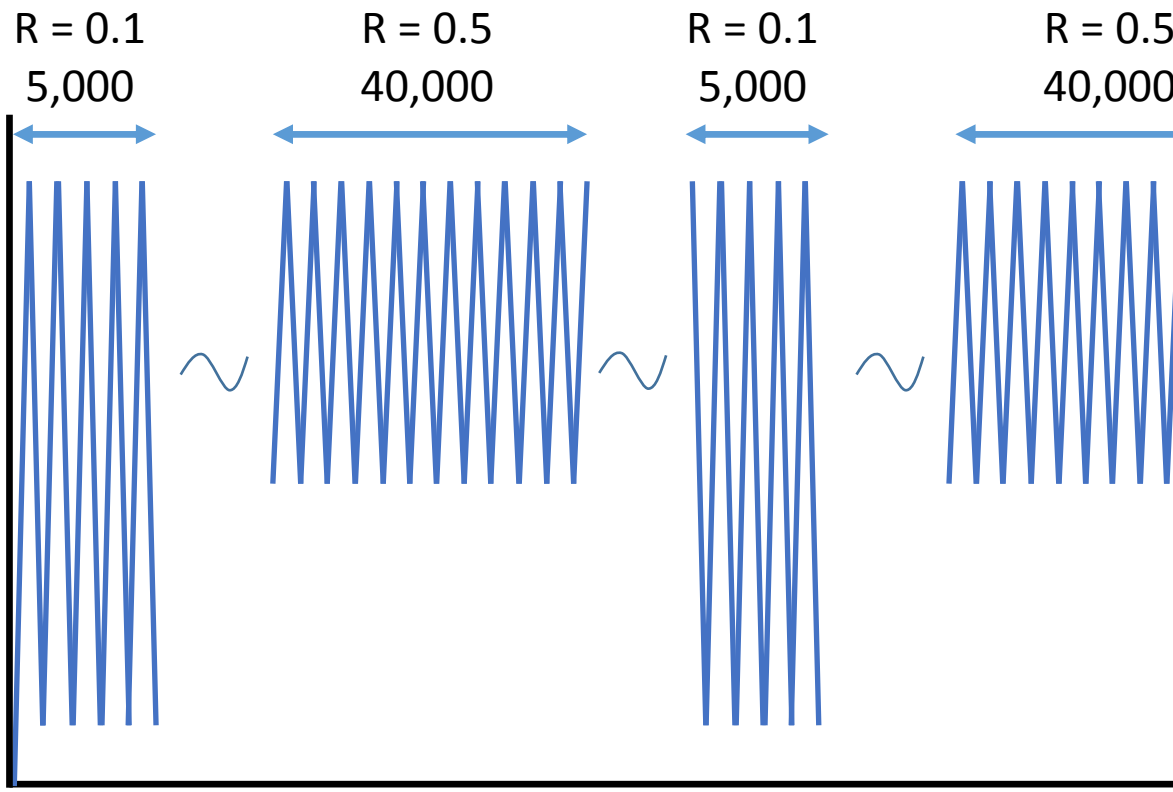
ollided cracks are replaced by one semi-lliptical crack.

lo interaction between cracks before oalescence.



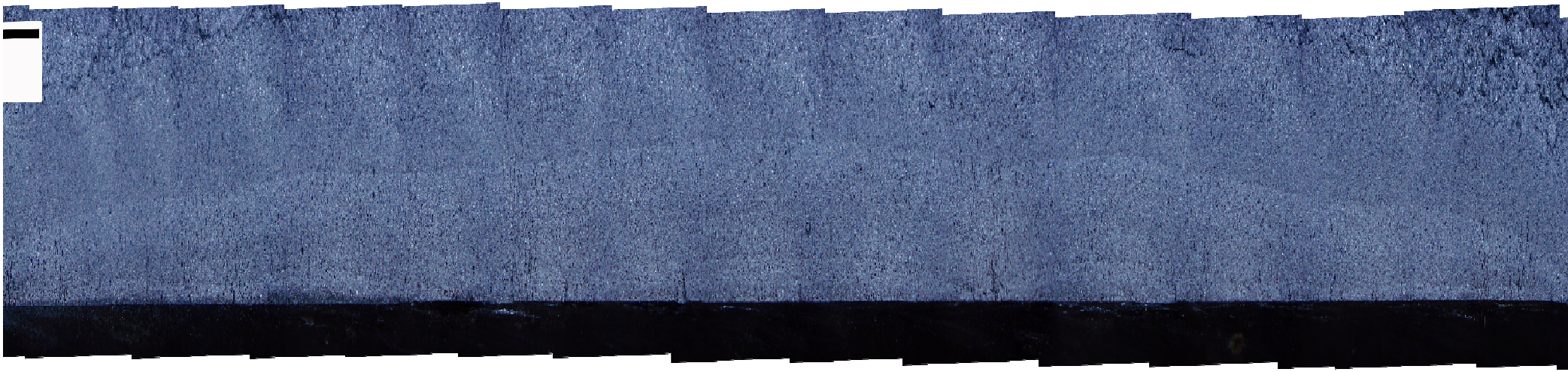
Experiment – Welded T-joint



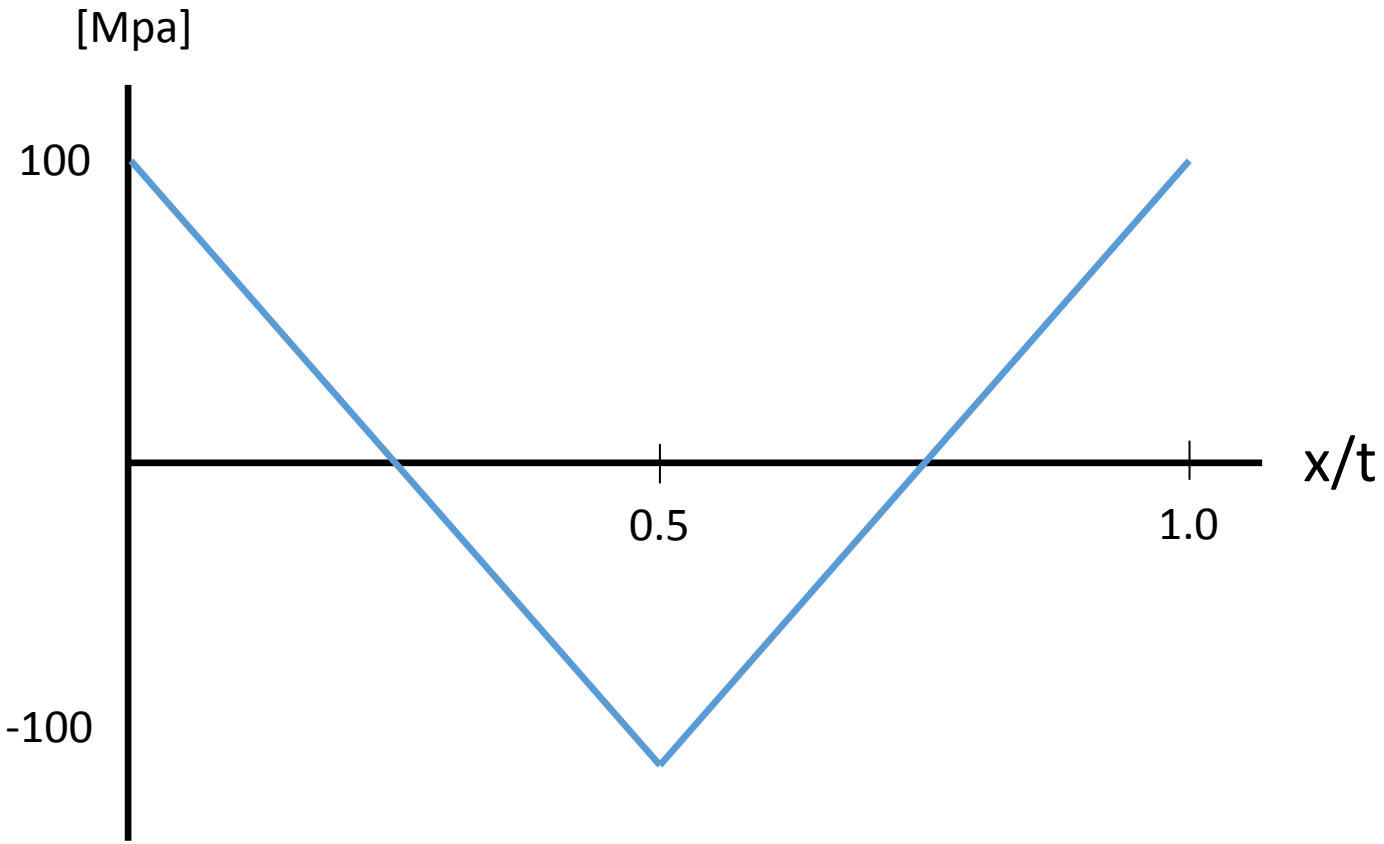


Experiment – Welded T-joint

Failed after 138,421 cycles.
Failed during 7th block (R = 0.1)



Residual Stress Field



Estimating Initial Cracks

- Smallest visible cracks are a = 0.14 mm & c = 1.2 mm after 50,000 cycles.
  - Very wide crack.
  - What is the initial crack that leads to this?
- Fatigue crack growth simulations were performed in order to find correct initi crack.
  - No any realistic crack were found.
  - Small cracks does not grow fast enough along the surface.
- Results indicates that multiple smaller cracks are needed to form the smallest cracks we can see.

Estimating Initial Cracks

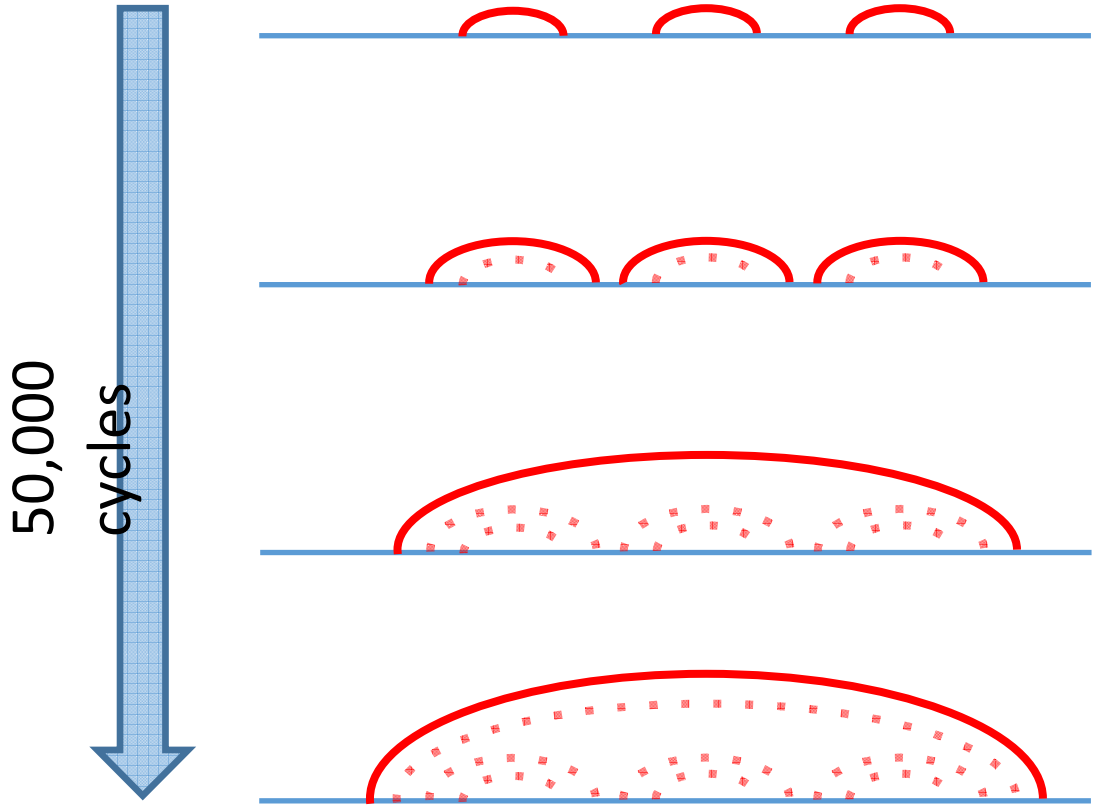
everal very small initial cracks.

- ≈ 0.00005 – 0.00015 m

atigue crack growth.

- ≈ 50,000 cycles.

fter coalescene a wide crack is ormed.



Simulation – Initial Cracks

Weld toe is full of small surface flaws

Random size

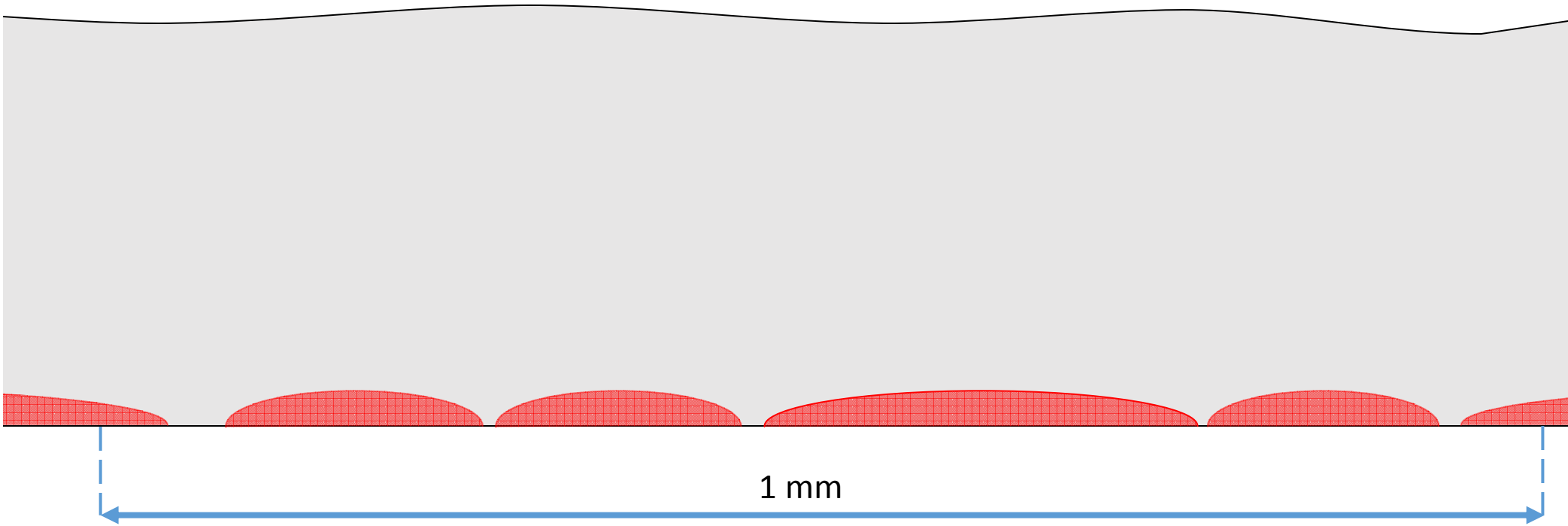
- a = 0.000049 mm (= ρ* material constant)
- $c \sim N(\mu,\sigma^2)$, $\mu = 2.5a$, $\mu/\sigma = 0.5$
- Average a/c = 0.4

Random distance between cracks

- $d \sim N(\mu,\sigma^2)$, $\mu = 0.33a$, $\mu/\sigma = 0.5$
- Distance is small because no interaction between cracks is modelled

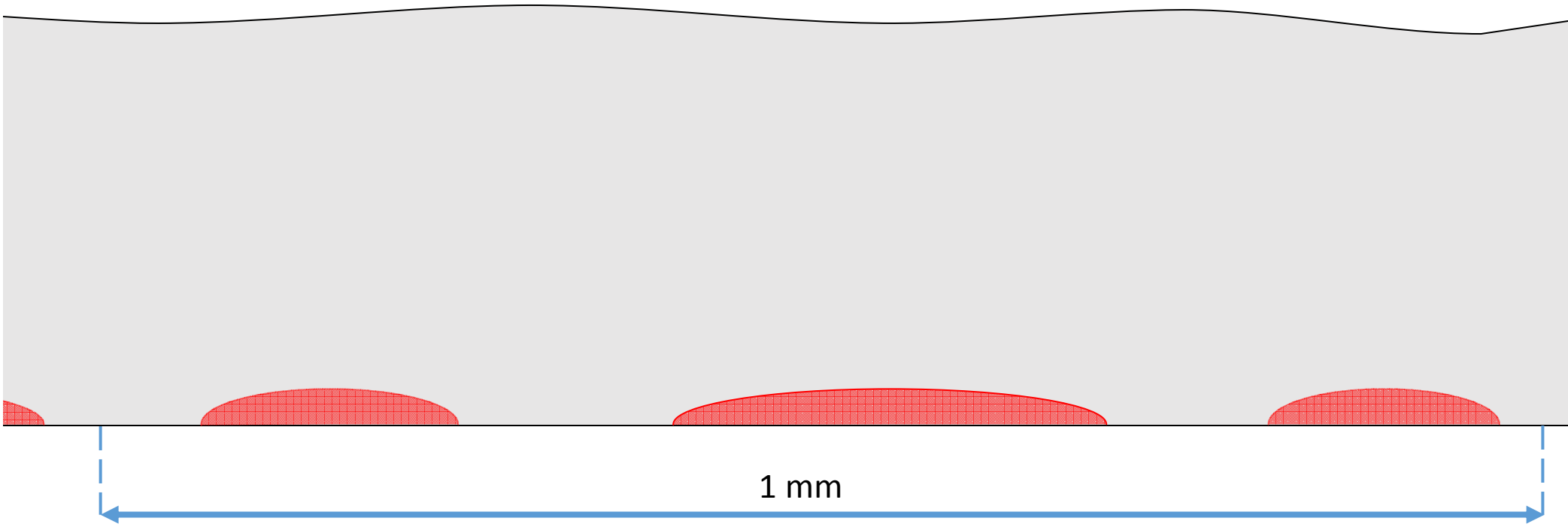
≈ 360 initial flaws along the weld toe

Simulation – Initial Cracks

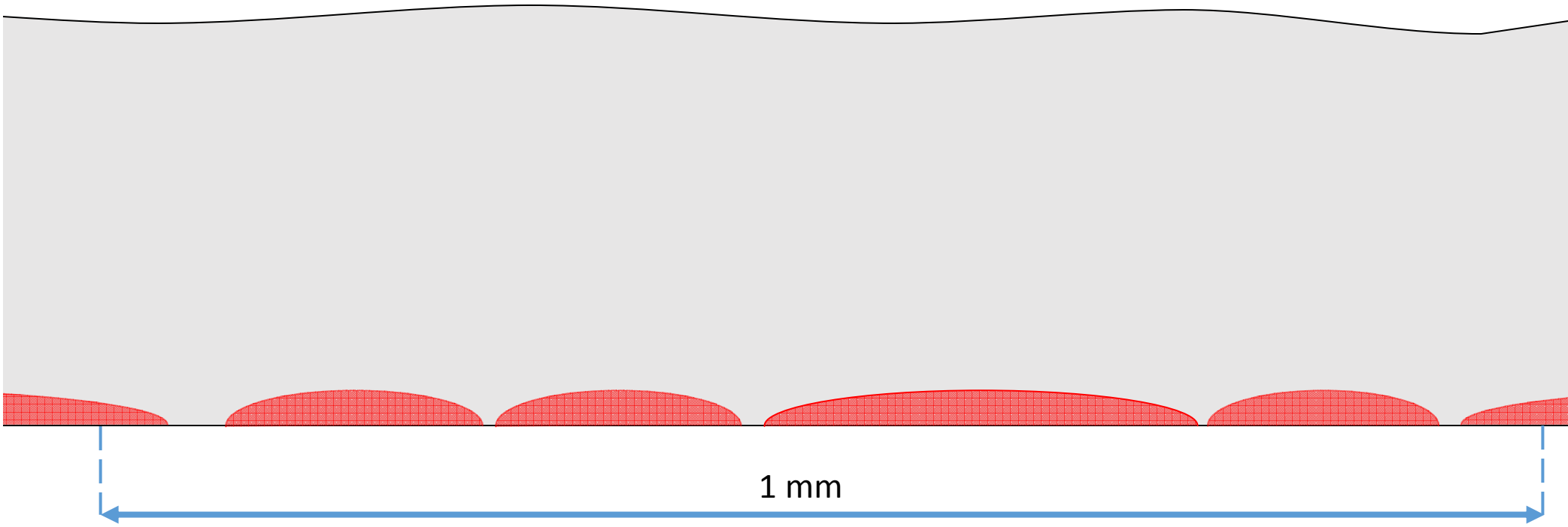


Simulation – Initial Cracks With Interaction

(assumption)



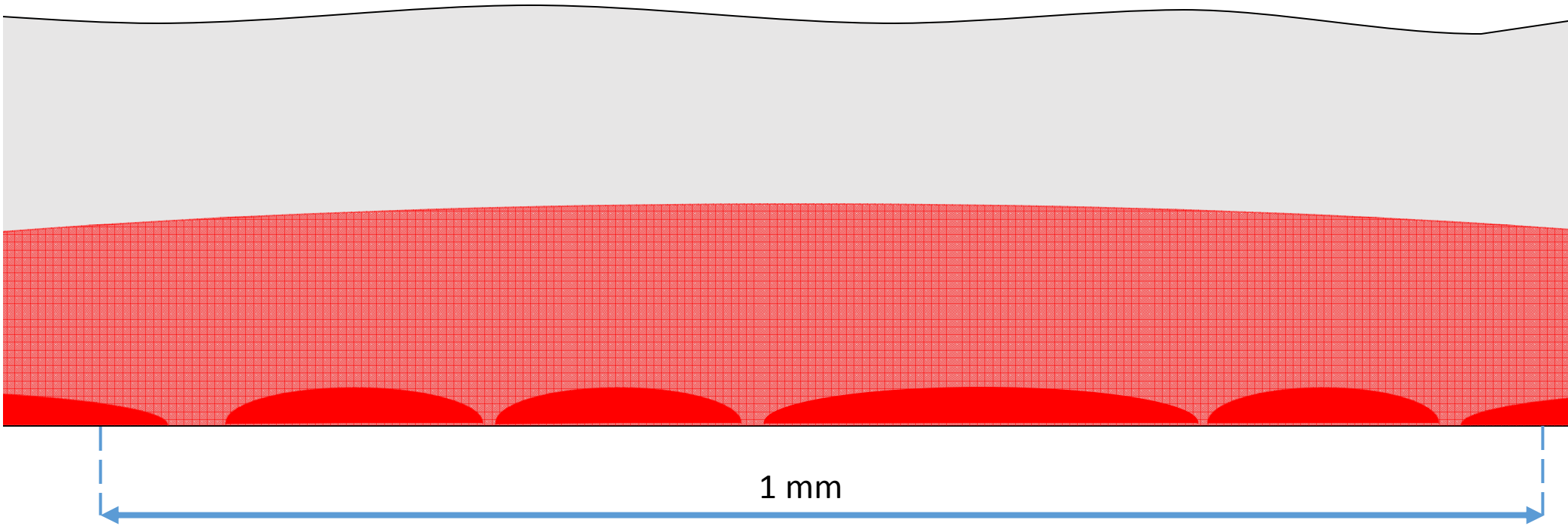
Simulation – Initial Cracks



Simulation – Crack Growth 50,000 cycles

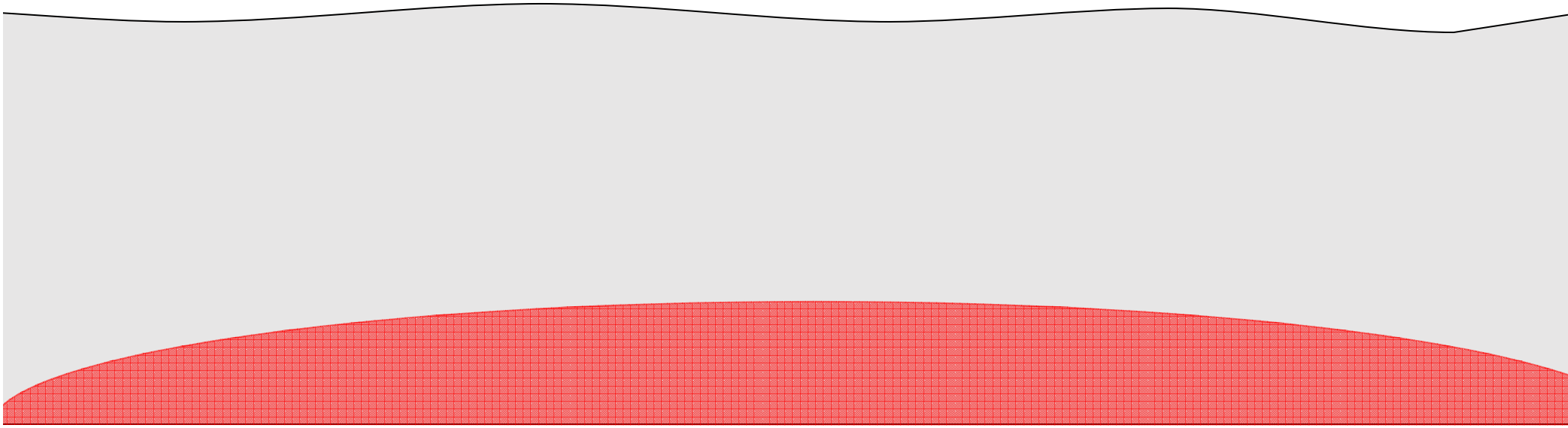
40 cracks
a/c = 0.05 ... 0.94

- Median a/c = 0.15 (excluding 20 cracks below threshold, a < 0.000
- a/c based on experiment ≈ 0.09 … 0.2



Simulation – Crack Growth

ntually only 1 crack exists.
y high stress intenstity
:or.



100 mm

Simulation – Fatigue Life Distribution

Average life: 85,503

Max life: 92,220

Min life: 78,261

Number of simulations: 97

Simulation – Effect of Residual Stress Field

- Exactly same initial cracks.
  - No scatter
- With residual: 90,465
- Without residual: 114,480

Conclusions

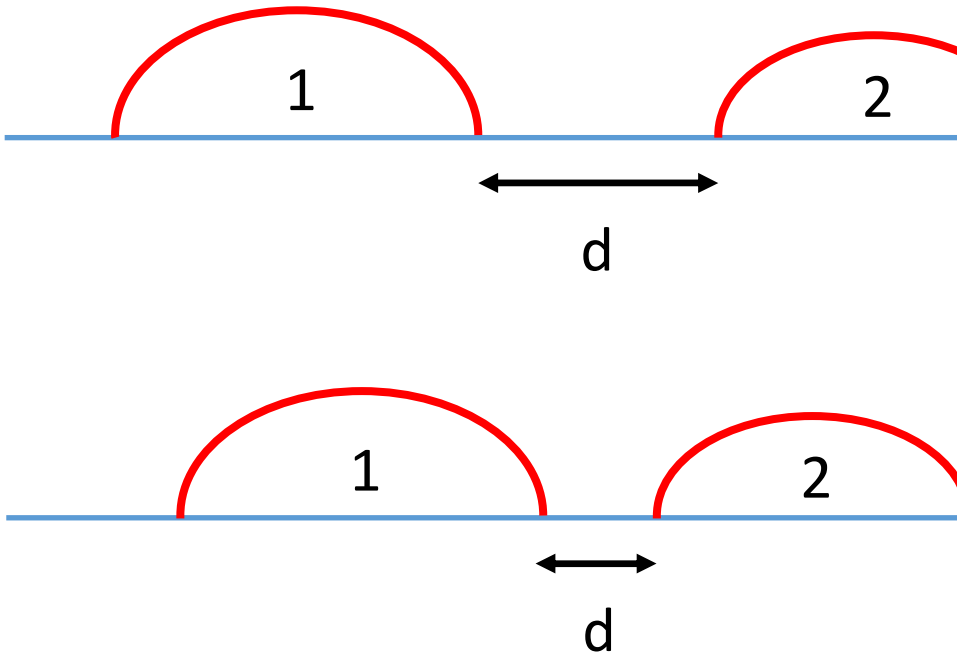
- Simulated fracture surface obtained by using multiple cracks corresponds to experimental results.
- Obtained total fatigue life is conservative.
- Interaction between cracks is needed.
- Cracks growth rate in depth direction is too high.

Open Questions – Interaction

What is interaction between two cracks

$K_{eff} = K \cdot f(a_1, c_1, a_2, c_2, d)$

Finite element analyzes needed to find f



Open Questions – High SIF values

SIF > 50 MPa $m^{0.5}$

Open Questions

- What is interaction between 2 surface cracks?
- Very high K-values are obtained after all cracks are coalesced. According the experiments, there are still thousands of fatigue crac growth cycles. Why specimen didn't fail earlier?
- What is residual stress distribution?
- What are the actual initial flaw distributions?