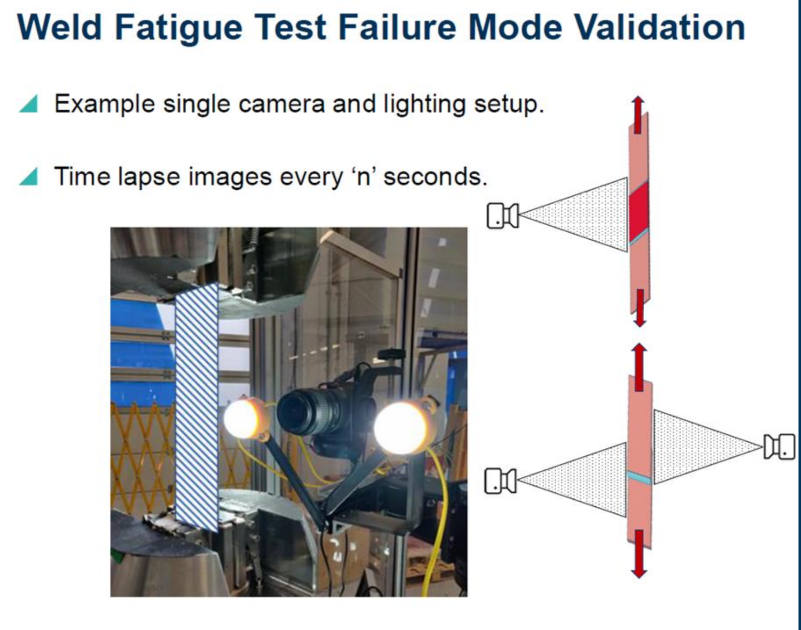
Virtual Seminar Series – Tuesday 2, 9, 16 November



Thin Sheet Welded Joint Fatigue Testing, Failure Mode Validation and Failure Criteria

Presented by Mr. Rob Plaskitt
Prenscia (HBK)

Tuesday, November 2, 2021

Thin Sheet Welded Joint Fatigue Testing, Failure Mode Validation and Failure Criteria

Abstract

Fatigue assessment of a welded joint using the structural stress approach requires stress-life (SN) fatigue curves derived from fatigue test specimens of representative weld geometry and manufacture. To obtain these SN curves requires fatigue test specimens that are designed and modelled by finite element analysis to cause the desired weld failure mode by a single axis fatigue test. Example failure modes for spot welds include cracks growing through the sheet or the spot weld nugget, and for seam welds cracks growing from the weld toe or weld root.

This presentation shows representative fatigue test specimens for thin sheet spot and seam welded joints and how different camera systems are used to obtain images and videos to validate the failure mode. Consequent fatigue tests are conducted at constant load cycles to plot applied load against the number of cycles to failure, with appropriate failure criteria, for characterisation into SN curves.

About the presenter, Mr. Rob Plaskitt, Prenscia (HBK)

Rob Plaskitt is an application engineer for Prenscia with a degree in Mechanical Engineering (Loughborough) and a masters in Structural Integrity (Sheffield). He has over 30 years of experience working as an engineer at Prenscia (formerly nCode) in areas of automotive, aerospace, defence and power generation. He has applied nCode software and technology in these industries from CAE concept design through full-scale testing, fleet monitoring, structural durability and vibration qualification.

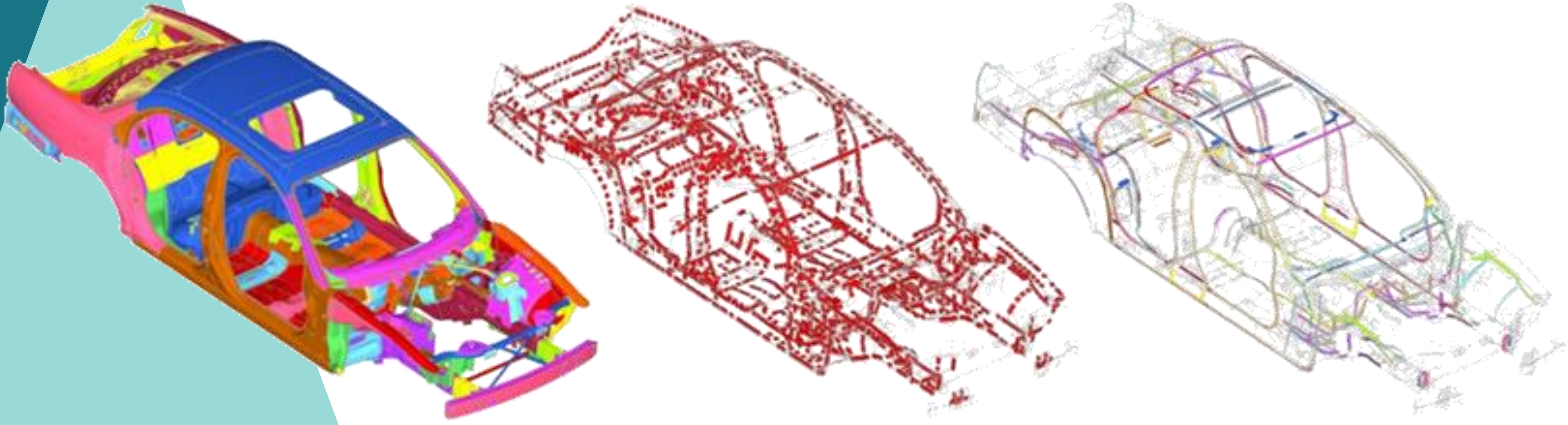
Rob has supported the Prenscia Advanced Materials Characterisation & Testing (AMCT) facility with their development of image and video manipulation capabilities; to verify failure modes, automatically extract images for reports, and reduce long high-resolution videos of fatigue tests to reasonable file size for ease of review.

Thin Sheet Welded Joint Fatigue Testing, Failure Mode Validation and Failure Criteria

Presenter: Rob Plaskitt

Thin Sheet Welded Joint Fatigue Testing, Failure Mode Validation and Failure Criteria

- Why do we need this?
  - … many structures have complex geometry with many welded joints
  - … electric vehicles and general vehicle “light-weighting” are motivating this
  - … automotive body, battery modules - joints with different geometry and materials



Agenda

1. Introduction
2. Weld Fatigue Test Specimens
   (lap seam weld)
3. Failure Mode Validation
4. Camera and Video Challenges
5. Weld Fatigue Test Specimens
   (spot weld coach peel, box section fillet seam weld)
6. Reporting and Characterisation
7. Questions

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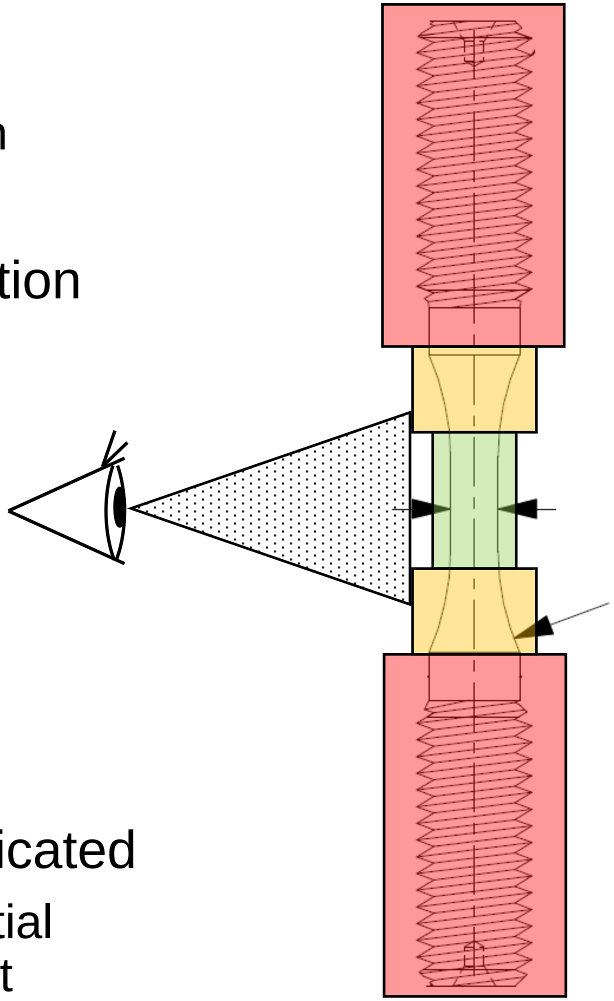
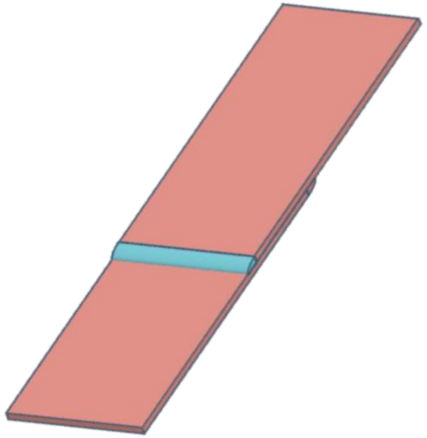
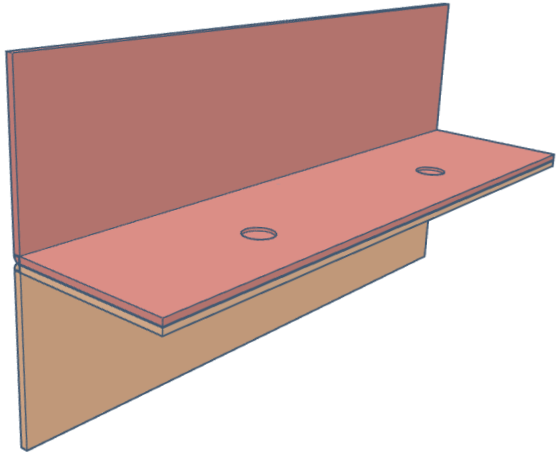
Introduction: Verify Failure Mode

- Standard cylindrical fatigue test specimen
  - Is designed to cause failure in the gauge section
- Verify failure mode by post-test visual inspection
  - Failure in the gauge section
  - Failure in the radii
  - Failure in the threads
- Convert “load-life” to “stress-life”
  - Measured load divided by cross-sectional area
- Weld fatigue test specimens are more complicated
  - Harder to verify the failure mode, multiple potential locations, crack growth period is more significant
  - Harder to convert measured load to “stress” at the failure location







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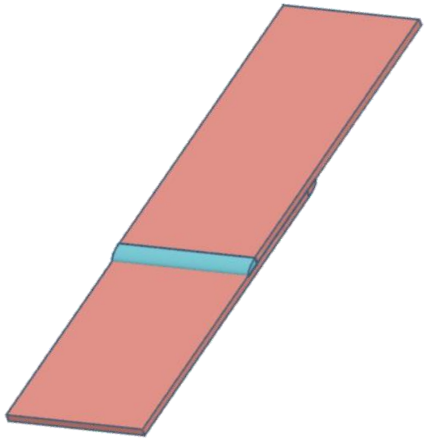
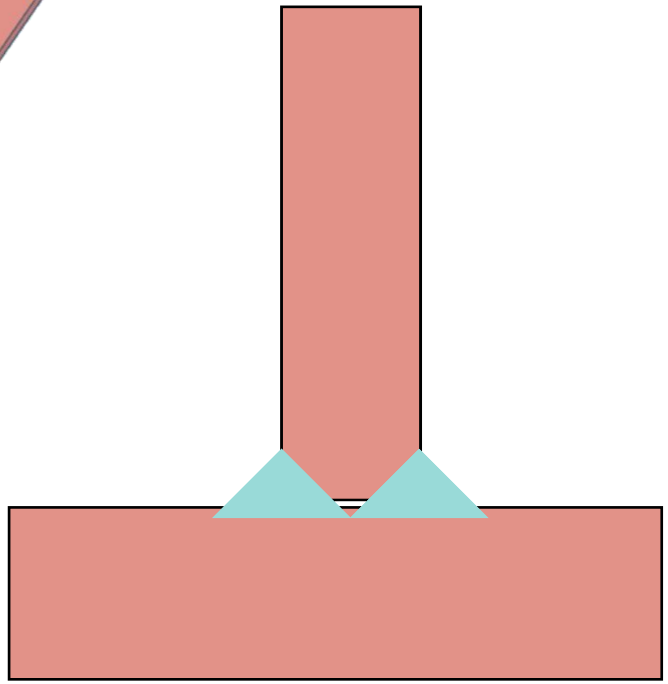
Introduction: “Thin Sheet” / “Thick Sheet”

- All examples shown are for “thin sheet” weld test specimens
  - about 1.0 - 3.0 mm sheet thickness
- Increasing sheet thickness, similar principles apply
  - the loads required get higher
  - bigger/stronger/stiffer test machine required
- Convert “load-life” to “stress-life”
  - requires finite element stress analysis
  - local stress “detailed” model to design failure mode
  - structural stress “simplified” model for fatigue analysis
- Necessary to verify expected failure mode





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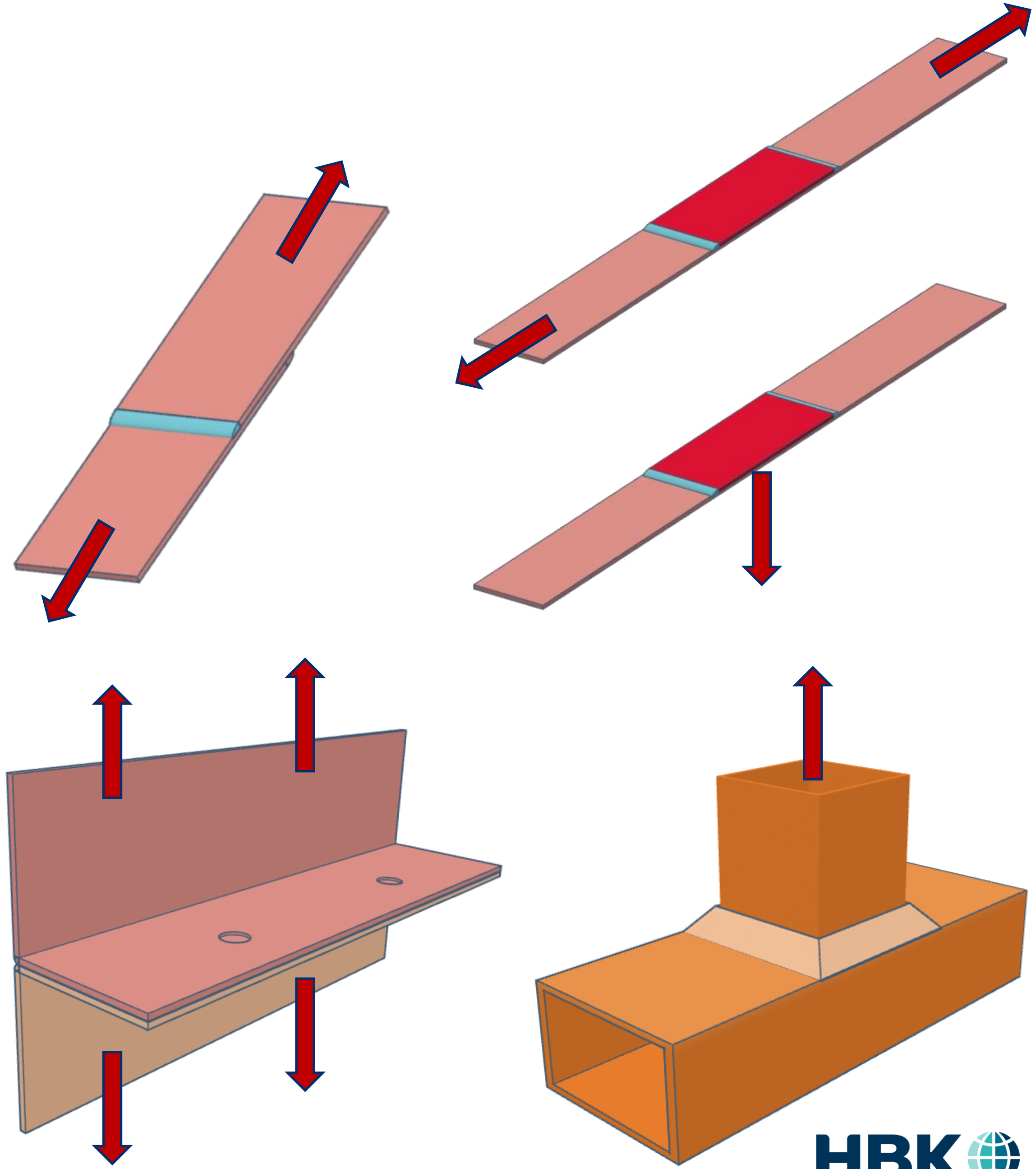
Weld Fatigue Test Specimens

- (1) Lap seam weld
- (2) Spot weld in coach peel
- (3) Box section fillet seam weld
- All fatigue test specimens are designed and modelled to represent their real-world application, and their desired failure mode :
  - joint geometry - size, thickness
  - joint material – manufacturing, treatment
  - weld condition – seam, spot, filler, arc, laser
  - loading & stress state – membrane, bending



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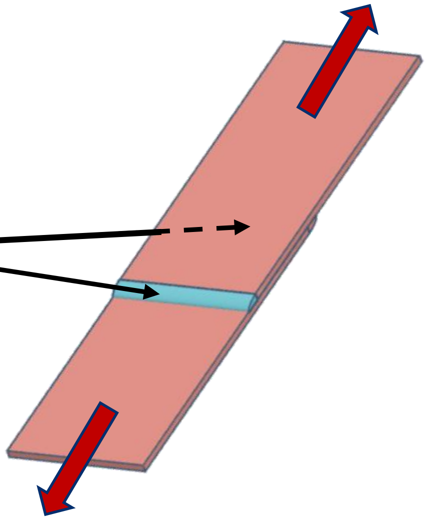
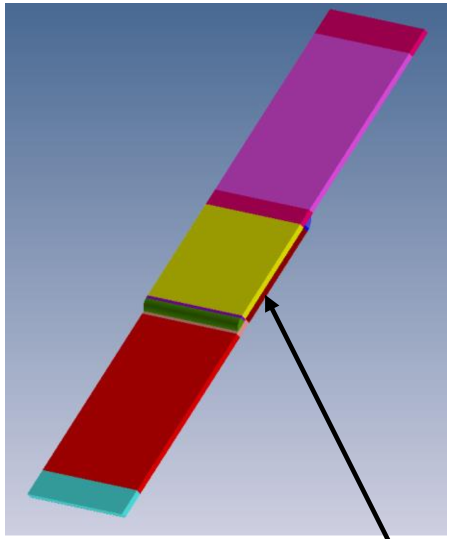
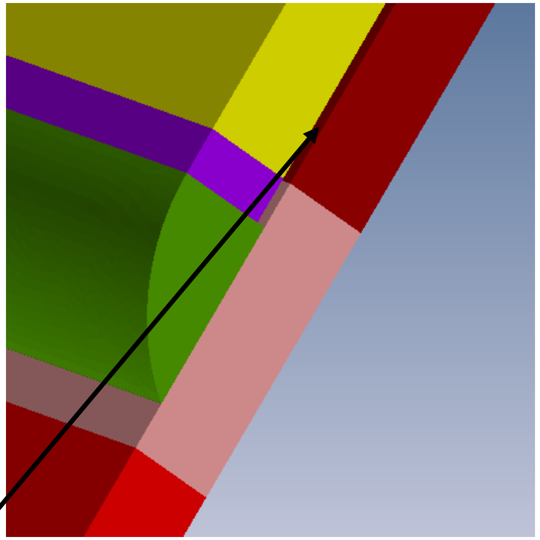
Weld Fatigue Test Specimens

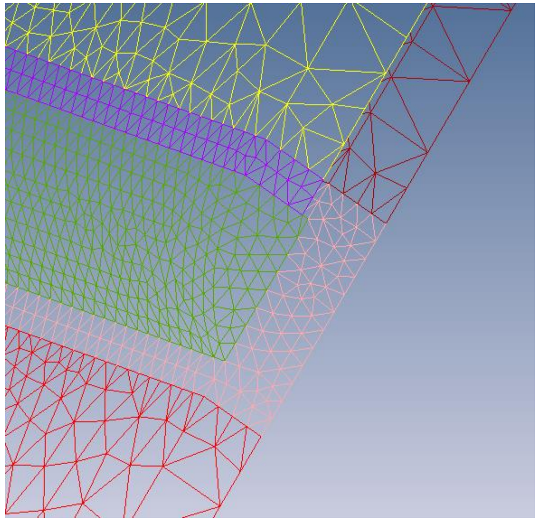
- (1) Lap seam weld



2 weld beads



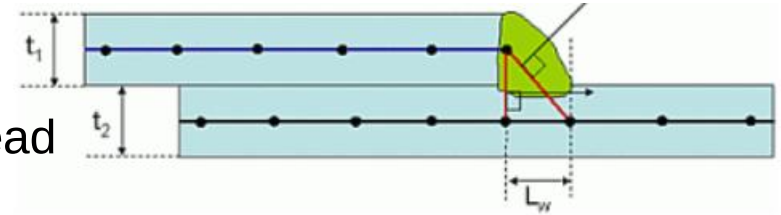




Solid model, with
“gap” between sheets

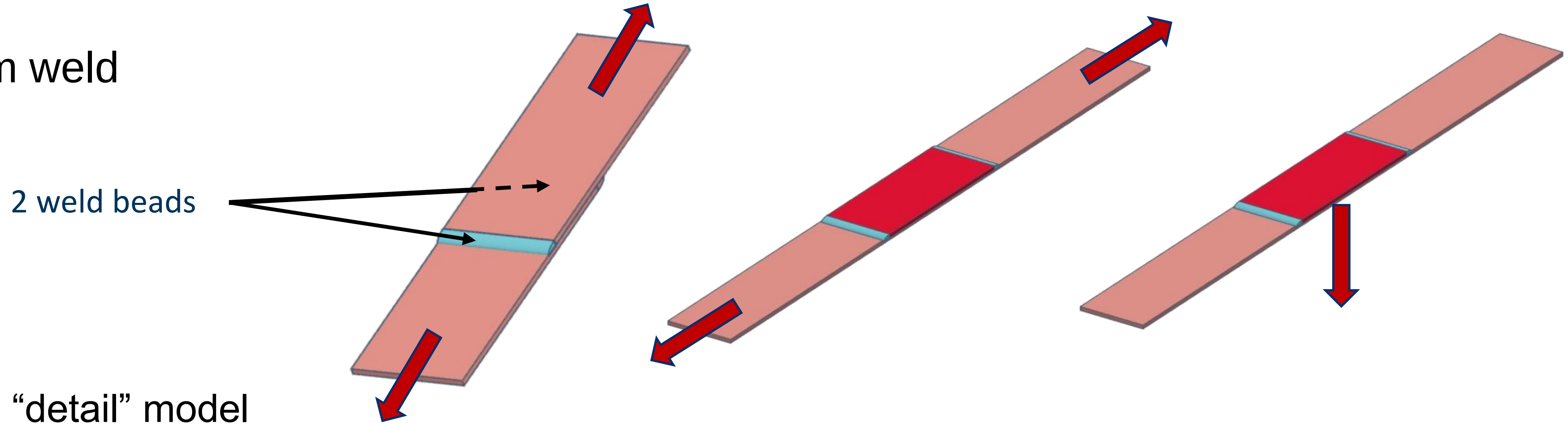
- Local stress “detailed” model
- Solid elements, with “gap” between sheets
- Fine mesh to connect weld beads to sheets
- Parametric model – thickness, width, length, weld bead, gap, etc

- Structural stress “simplified” model
- Shell elements
- Coarse mesh, 1 element for the weld bead

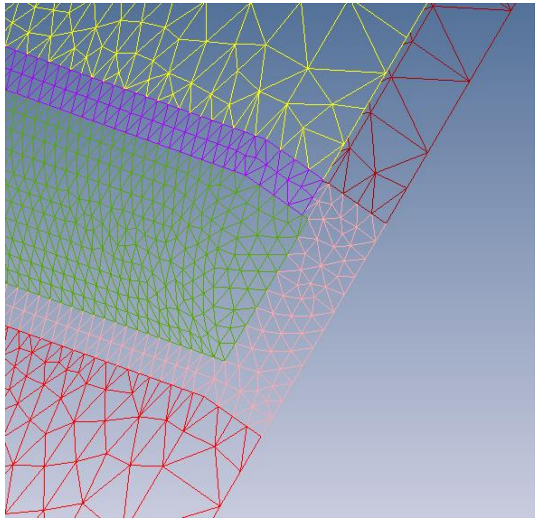


Weld Fatigue Test Specimens

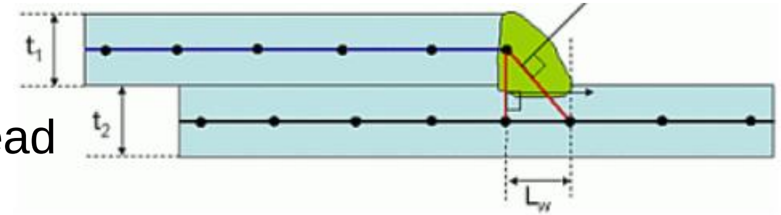
- (1) Lap seam weld



  - Local stress “detail” model
  - Solid elements, with “gap” between sheets
  - Fine mesh to connect weld beads to sheets
  - Parametric model – thickness, width, length, weld bead, gap, etc



  - Structural stress “simplified” model
  - Shell elements
  - Coarse mesh, 1 element for the weld bead



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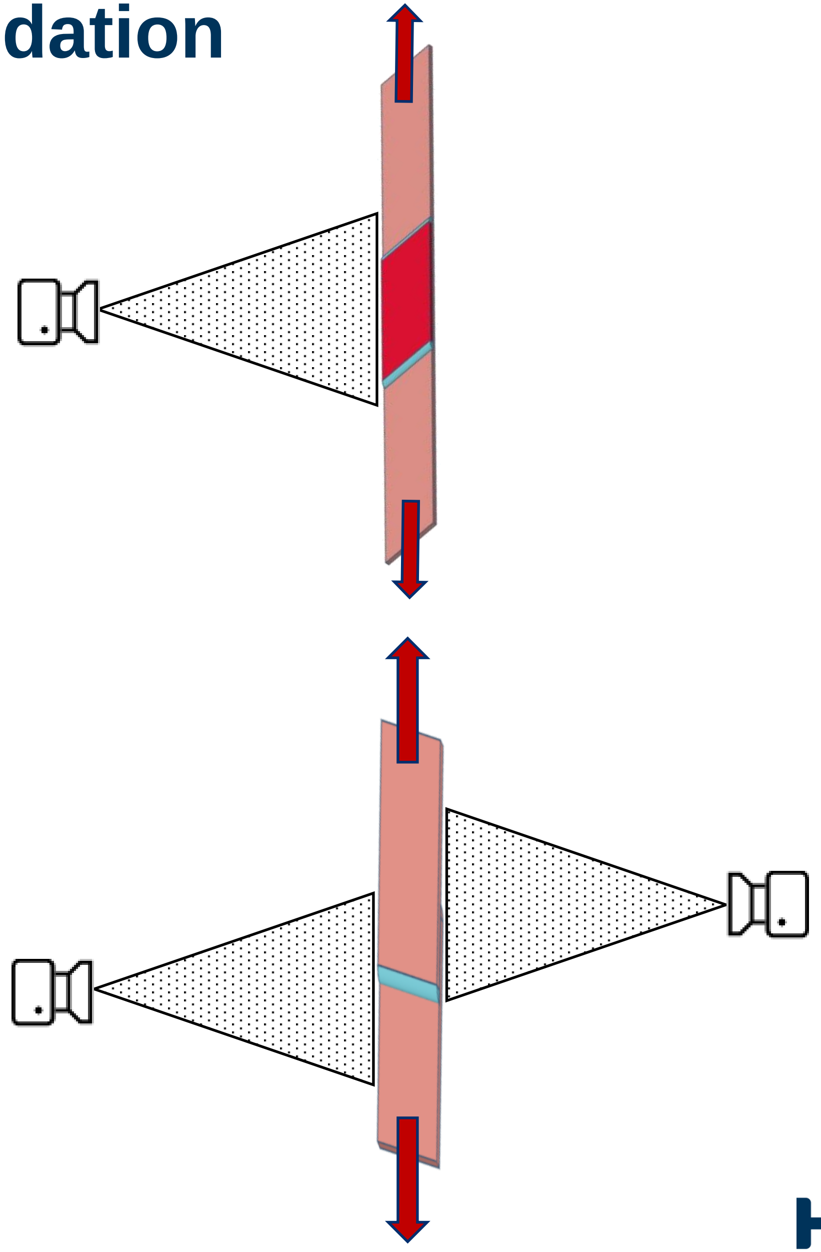
Weld Fatigue Test Failure Mode Validation

- Test machine records displacement, load, cumulative cycles and cycles to failure.
  - machine stops at separation
- Failure criterion?
  - separation, visible crack, stiffness drop
- Camera systems required to record the failure for post-test inspection and validate the failure mode.
- Test specimen symmetry means cracks can start at a symmetrically “opposite” location.
- 1 or 2 cameras - depending on weld configuration.



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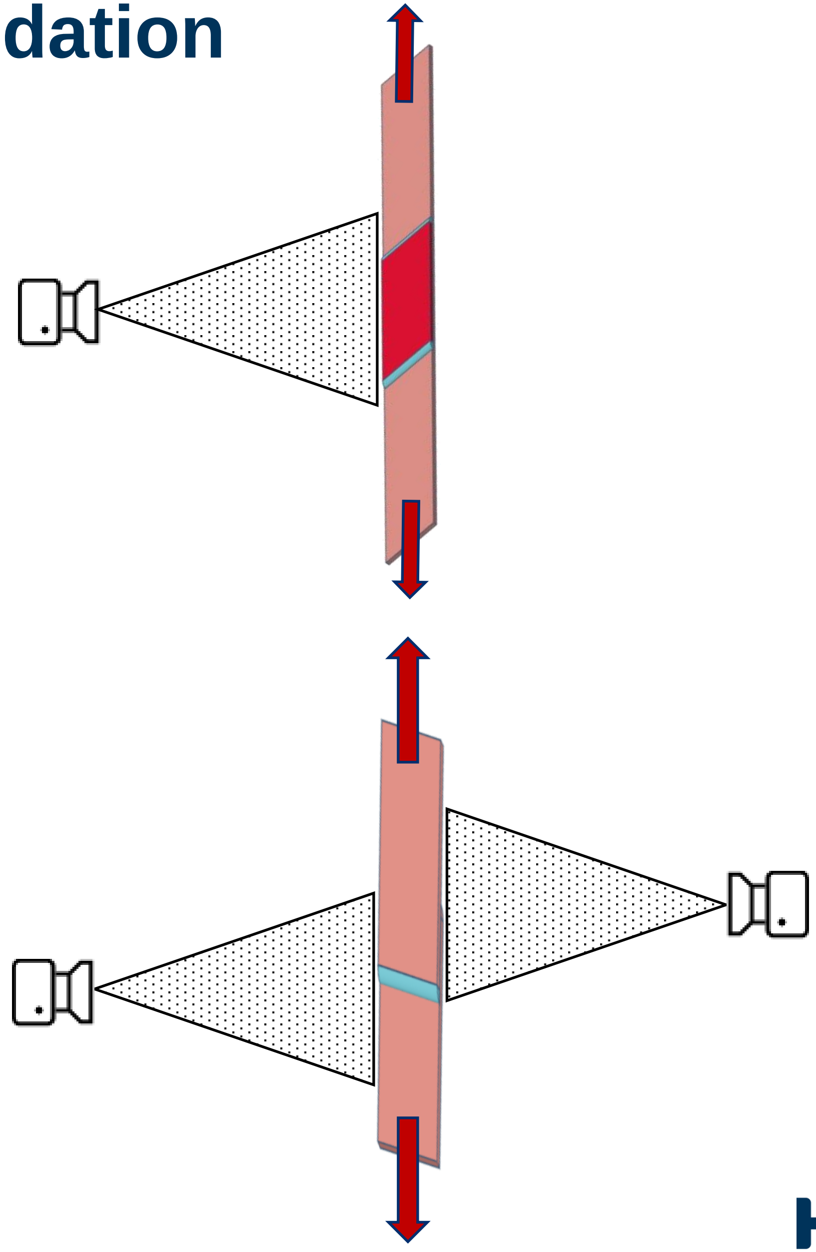
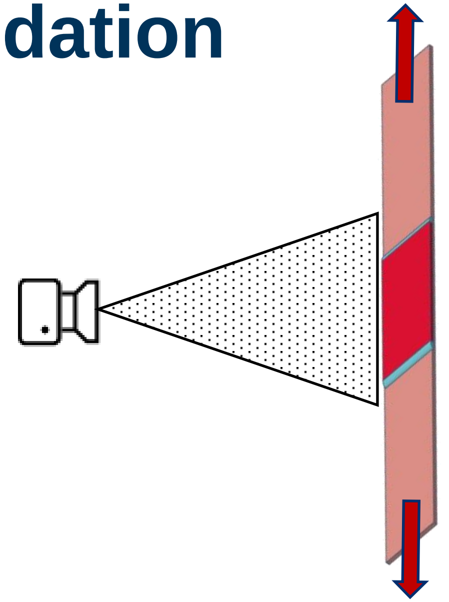
Weld Fatigue Test Failure Mode Validation

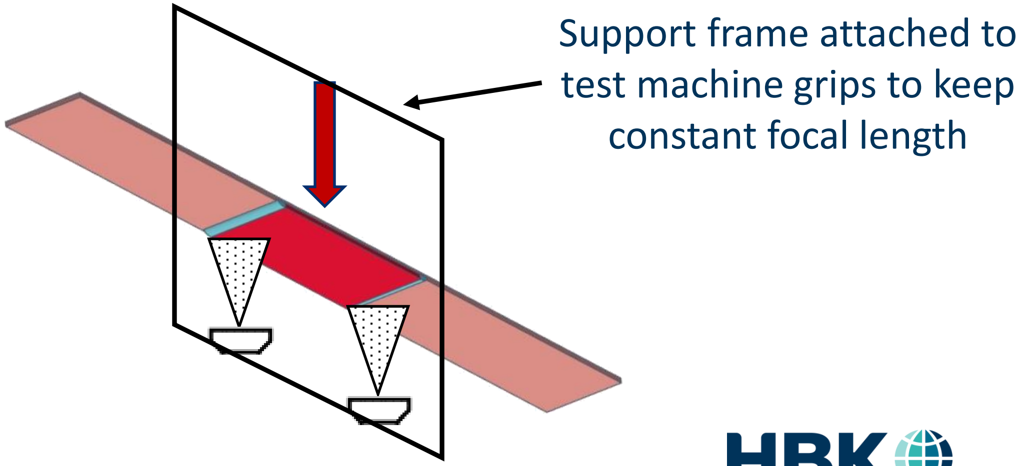
- Example single camera and lighting setup.
- Time lapse images every ‘n’ seconds.



Weld Fatigue Test Failure Mode Validation



- It is important to have a well-lit and in-focus weld image for crack identification.
- Tensile tests have a big advantage
  - the focal length between the lens and the weld is constant.
- 3-point bend tests are more complicated
  - relatively large deflections
  - with a fixed camera the focal length changes
- The cameras must be:
  - light weight to move with the test specimen (and not affect the load).
  - small to fit within the limited test machine space.



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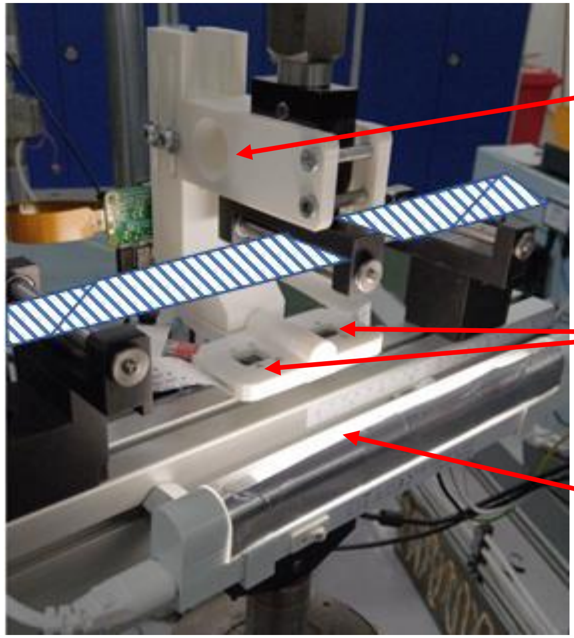
Weld Fatigue Test Failure Mode Validation

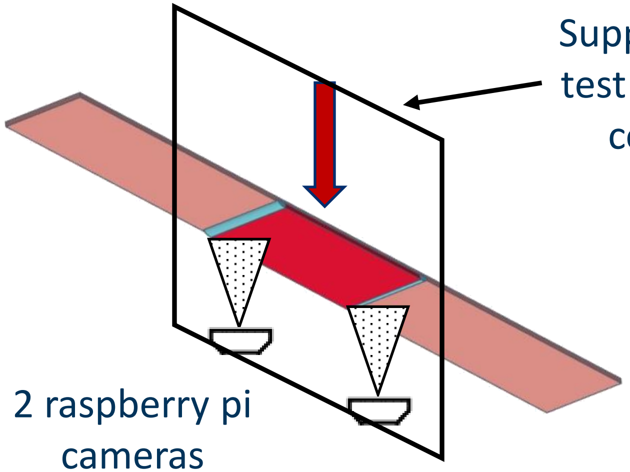
- It is important to have a well-lit and in-focus weld image for crack identification.

- Tensile tests have a big advantage
  - … the focal length between the lens and the weld is constant.

- 3-point bend tests are more complicated
  - … the focal length changes as the test specimen bends.

- The cameras must be:
  - light weight to move with the test specimen (and not affect the load).
  - small to fit within the limited test machine space.





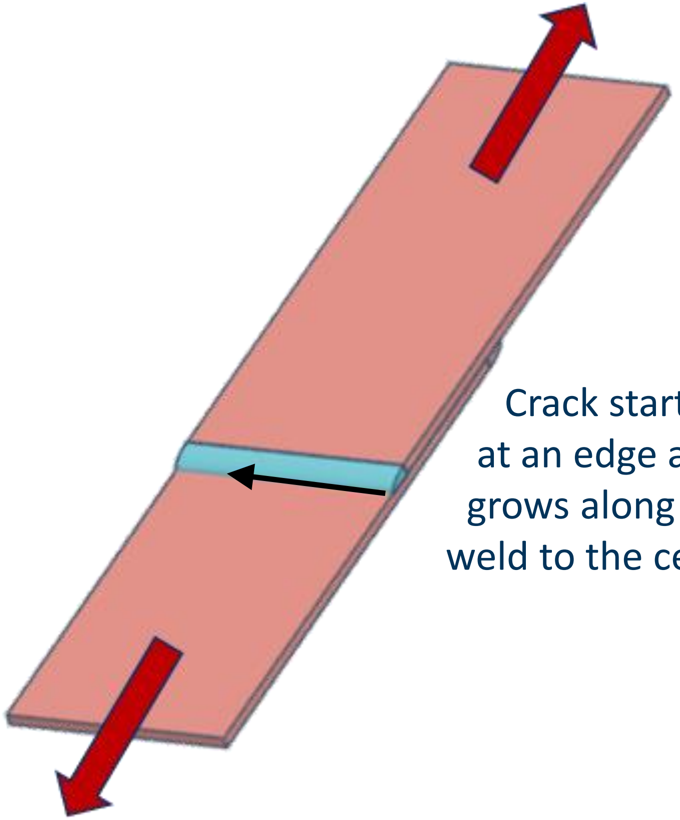
Weld Fatigue Test Failure Mode Validation

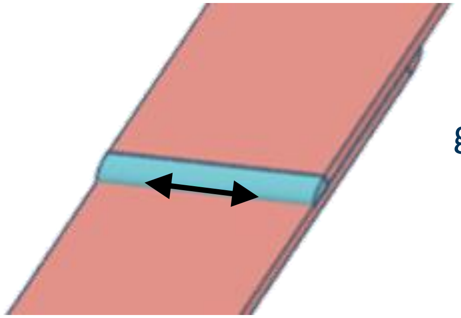
- After testing, review the failed test specimen and the test video.
  - Is cracking observed before separation failure?
  - Is the initial crack in the expected location?
  - Does the crack grow in the expected direction?
  - Is failure caused by the expected failure mode?

- If “no” to any, investigate and understand why.

- If “yes” to all, continue with next test specimen.

- Failure mode validation by video is advised for new test specimen designs, new test setups, new test groups, but is not a requirement for every test,
  - or, is an optional extra for report purposes.





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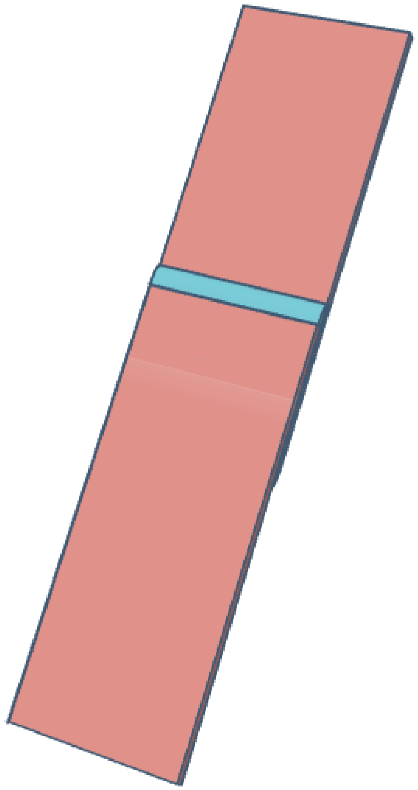
Video #1

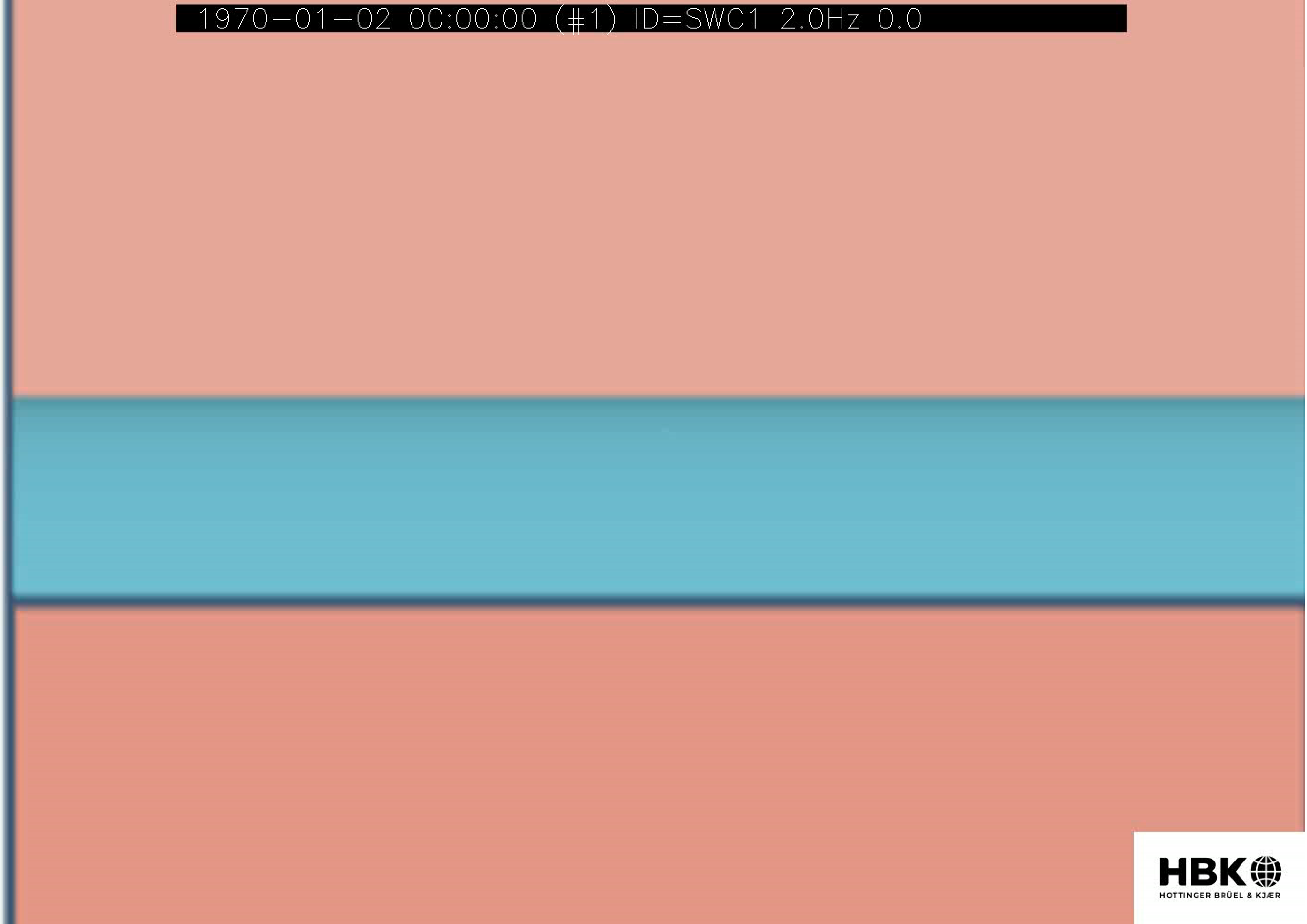
Representative example.

Seam weld.

Centre-crack.

All images.





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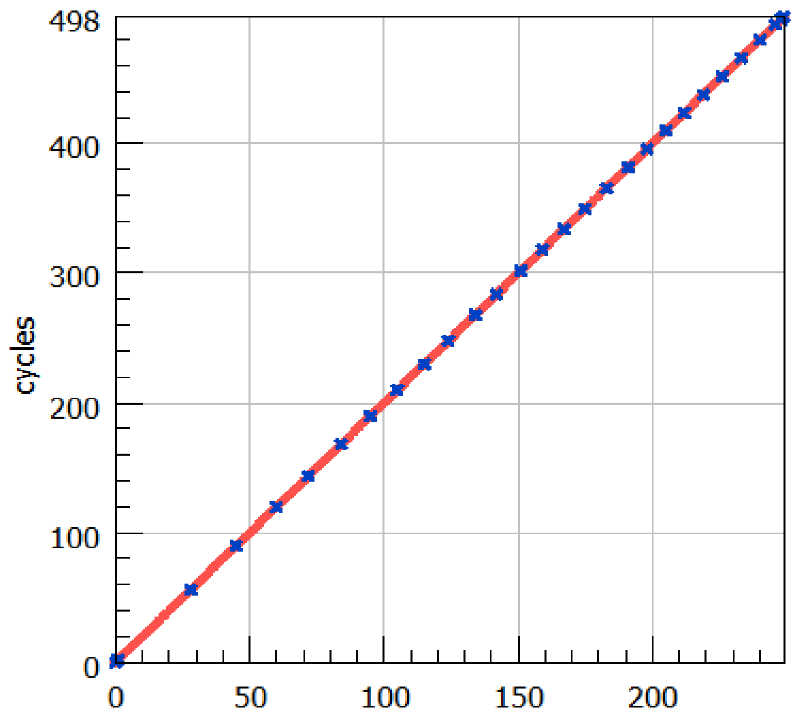
Camera and Video Challenges

- Cameras acquire large quantity of image data quickly:
  - fatigue tests have long duration
  - high resolution cameras create very large files
  - 1000s of still images or direct to video
  - MBytes per image/frame becomes GBytes per video



- Videos are easier and quicker to review to:
  - correlate the failure modes
  - verify crack start location and growth direction

- Reduce video size for email & presentation:
  - non-linear image sampling
  - start and end groups
  - reduce resolution
  - crop to region of interest
  - add audit information – date, time, image/frame number, specimen number, test frequency, cumulative cycles

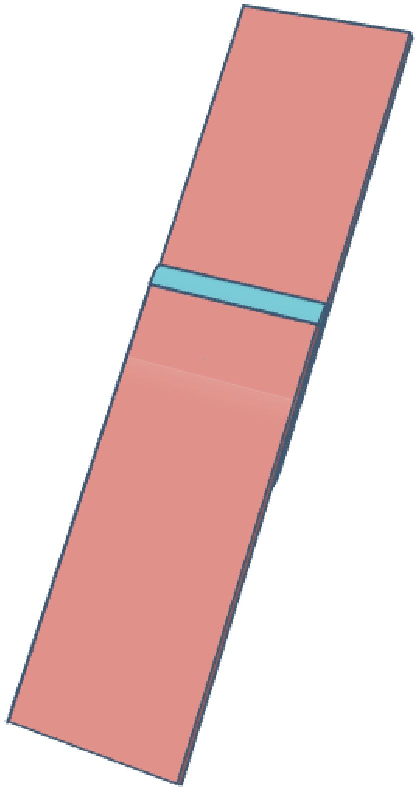
Video #2

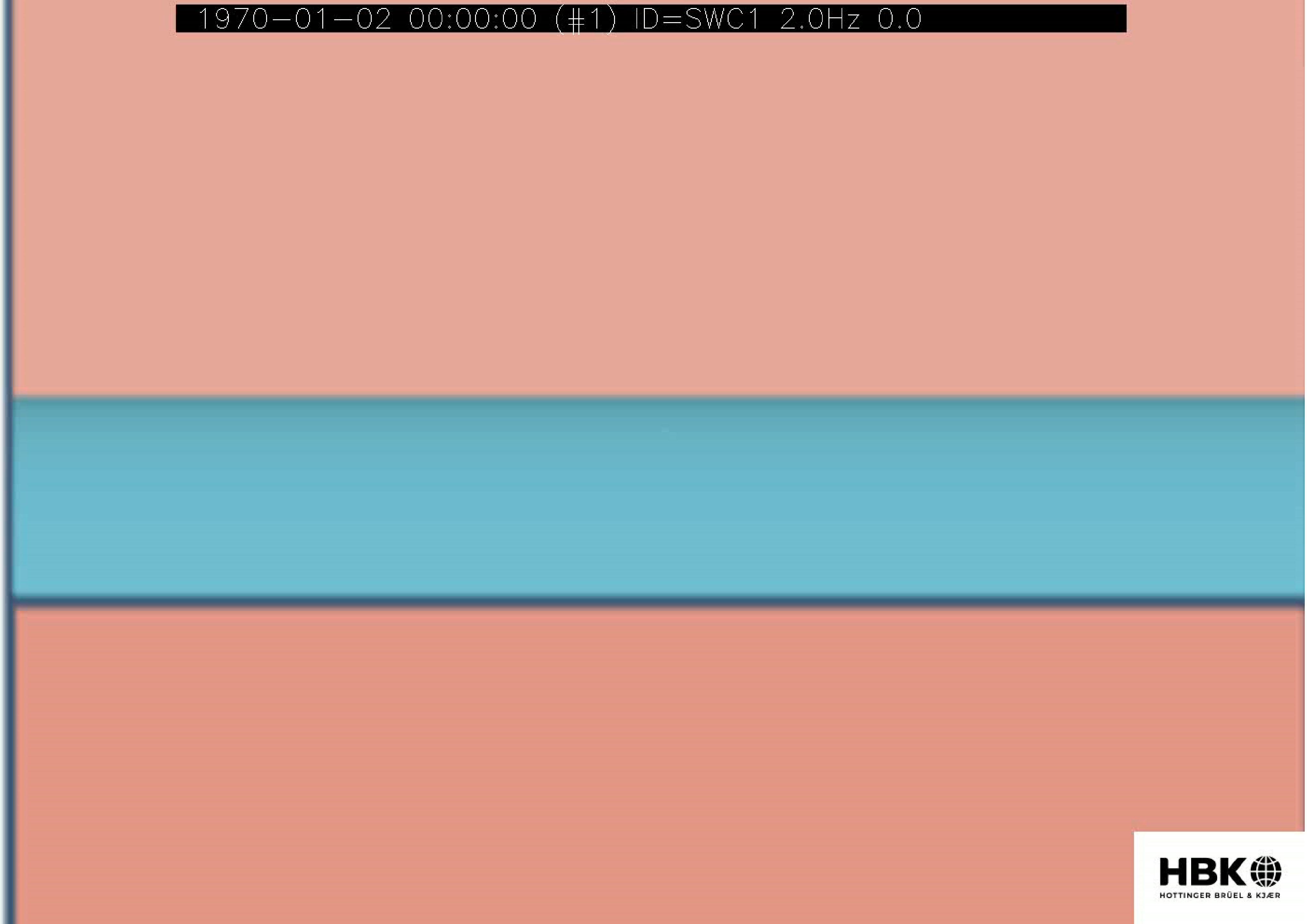
Representative example.

Seam weld.

Centre-crack.

Filtered images.





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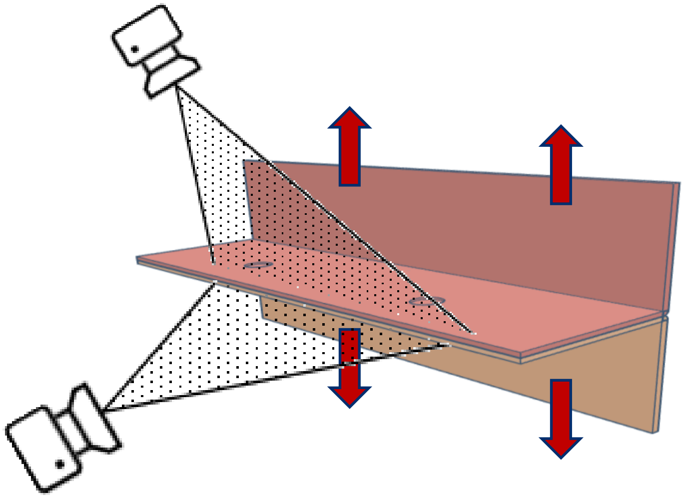
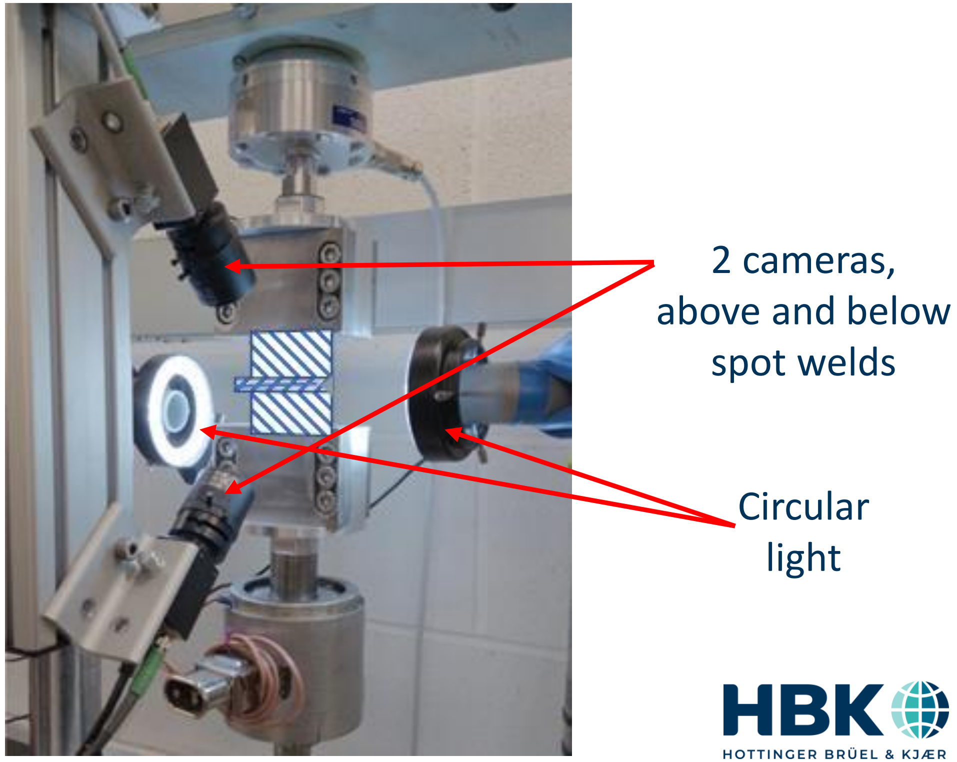
Weld Fatigue Test Specimens

- (2) Spot weld in coach peel
  - Design test specimen
  - Local stress “detail” model
  - Structural stress “simplified” model



- Test specimen symmetry means cracks can start at a symmetrically “opposite” location.
- 2 cameras are required
  - above and below the spot welds
- Example double camera and lighting setup
- Video camera records whole test duration



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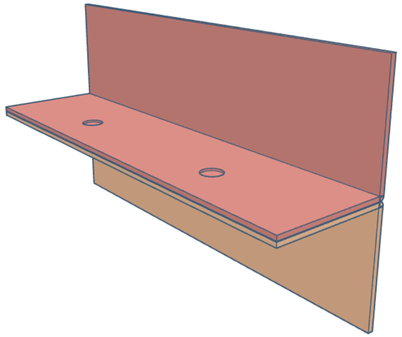
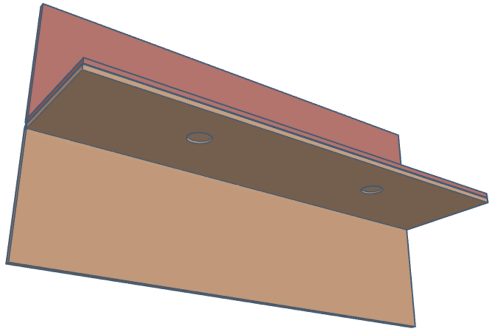
Video #3

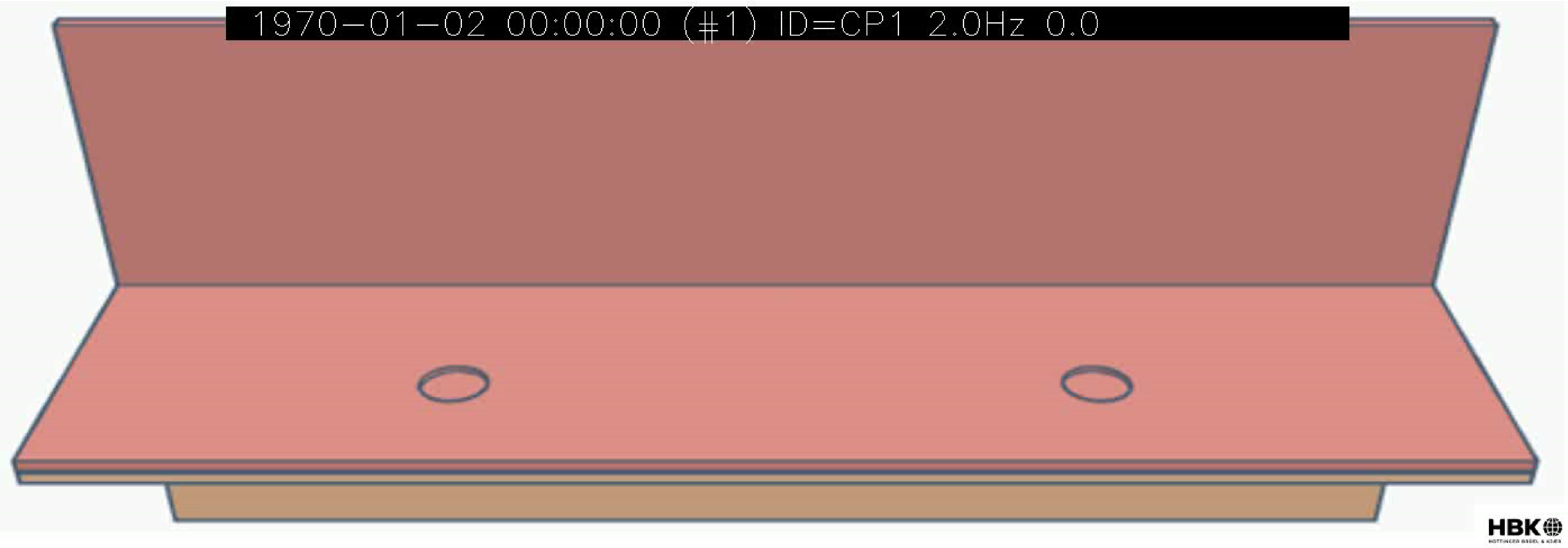
Representative example.

Spot weld coach peel

Filtered images

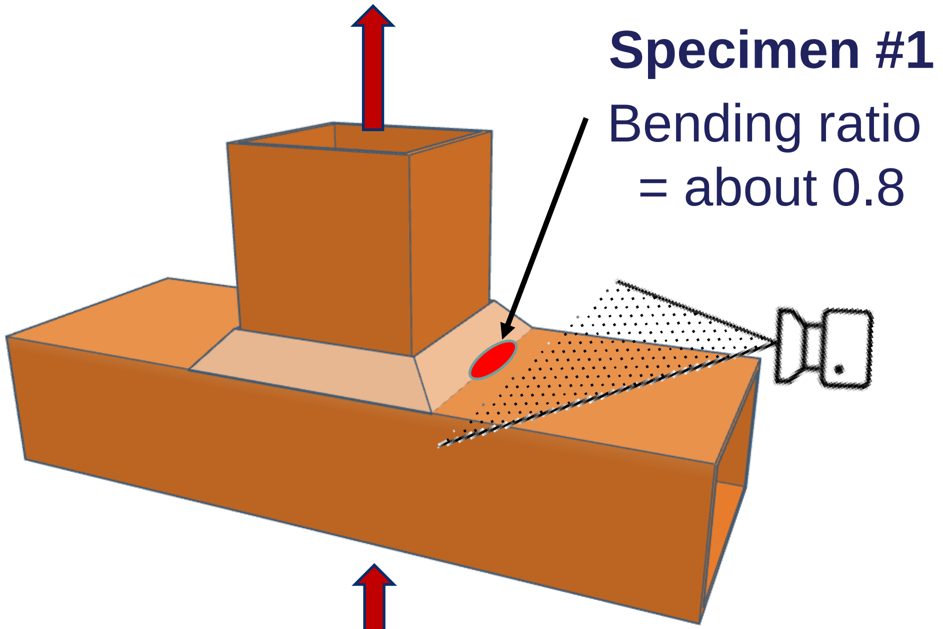


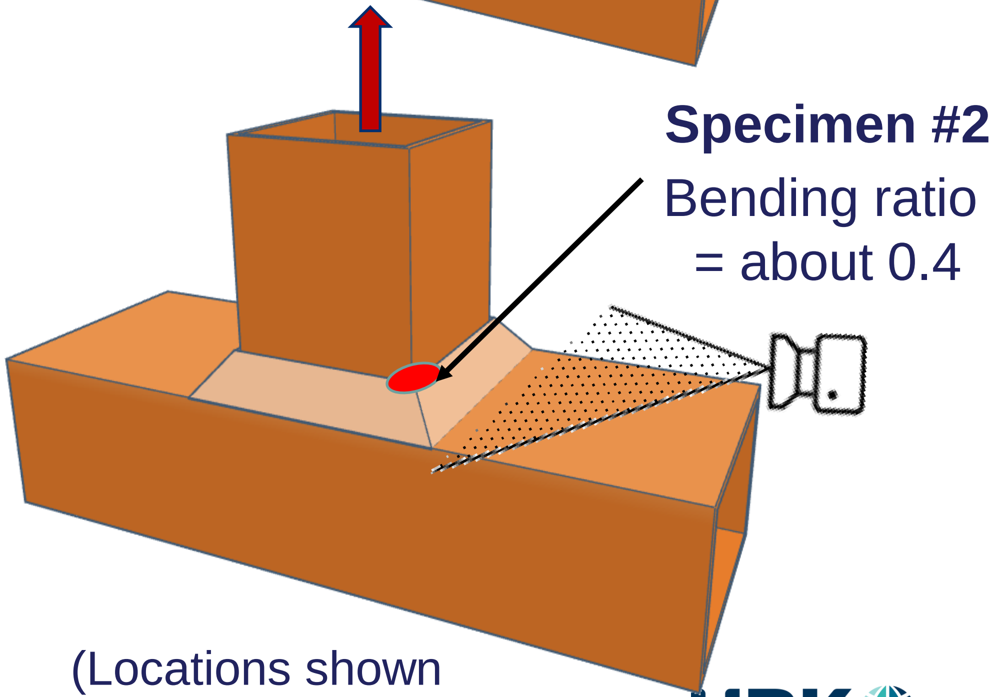




Weld Fatigue Test Specimens

- (3) Box section fillet seam weld
  - Design test specimen, local and structural stress models
- 2 fatigue test specimens, similar but slightly different
  - use plate thickness to control bending ratio
- Designed to give the desired failure mode
  - crack start location (usually at a weld toe)
  - crack growth direction
    (usually along the weld, or into the weld or plate)
- Designed to give stress state bending ratios to be “far enough apart” to be separated during characterisation
  - do not need to be 0 (pure membrane) or 1 (pure bending)
- Usually only 1 camera is required





(Locations shown
are schematic)

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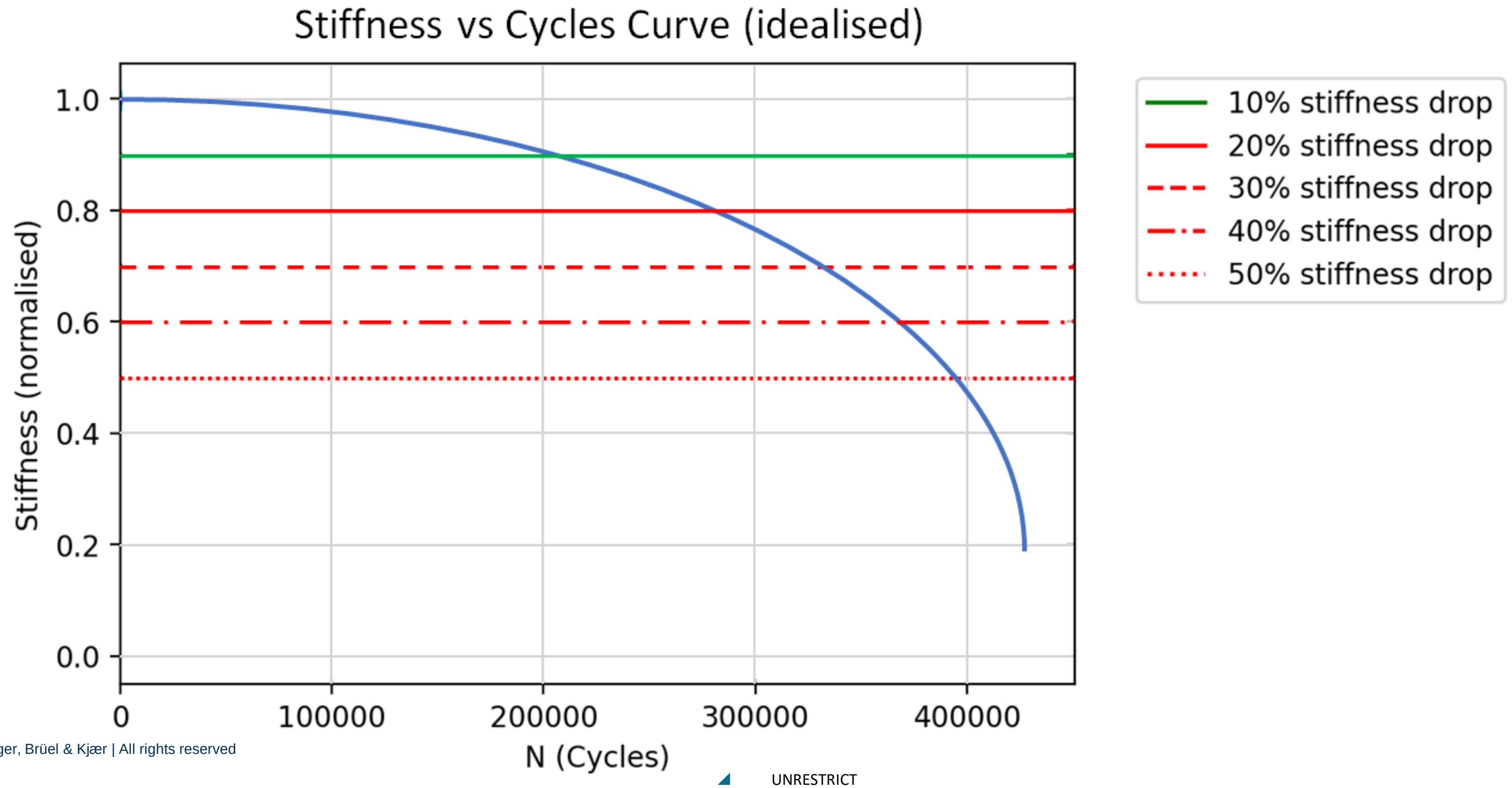
Weld Fatigue Test Reporting – Test Measurements

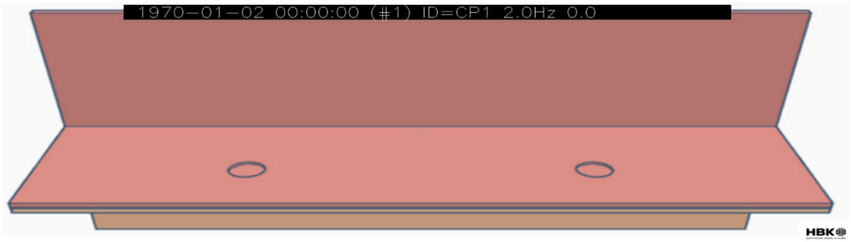
- Test measurements
  - load, displacement, cumulative cycles, separation cycles
- Measurement post processing
  - normalised stiffness vs cycles
  - identify cycles to % stiffness drop



Weld Fatigue Test Reporting – Test Images & Video

- Image and video post processing
  - reduce to reasonable size (~10MB)
  - crop to cracked region
  - non-linear filter
  - review and correlate the failure mode

- Images for report
  - start of test (first cycle)
  - first ‘by eye’ visible crack (from video)
  - % stiffness drop for characterisation
  - end of test (last cycle before separation)



=== Start of test ===
• 0.0 cycles
• 1970-01-02 00:00:00
• ImageID = 1
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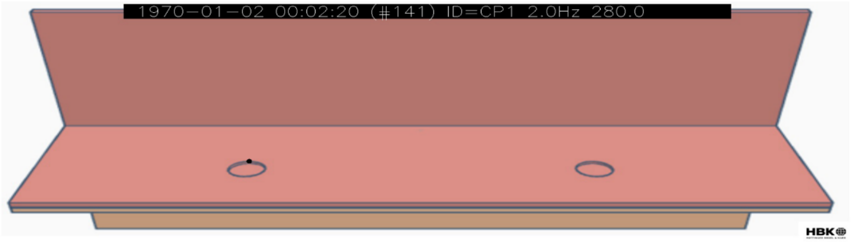

=== First visible crack ===
• 280.0 cycles
• 1970-01-02 00:02:20
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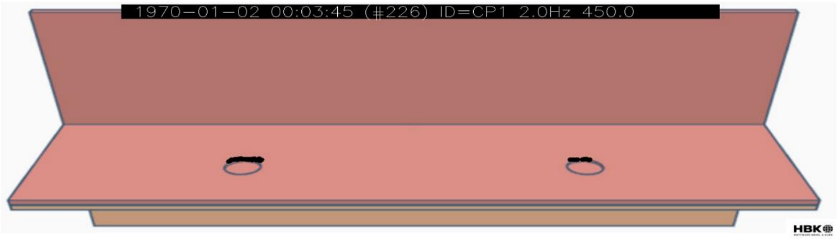

=== 20% stiffness drop ===
• 450.0 cycles
• 1970-01-02 00:03:45
• ImageID = 226
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=== Before test stopped ===
• 488.0 cycles
• 1970-01-02 00:04:04
• ImageID = 245
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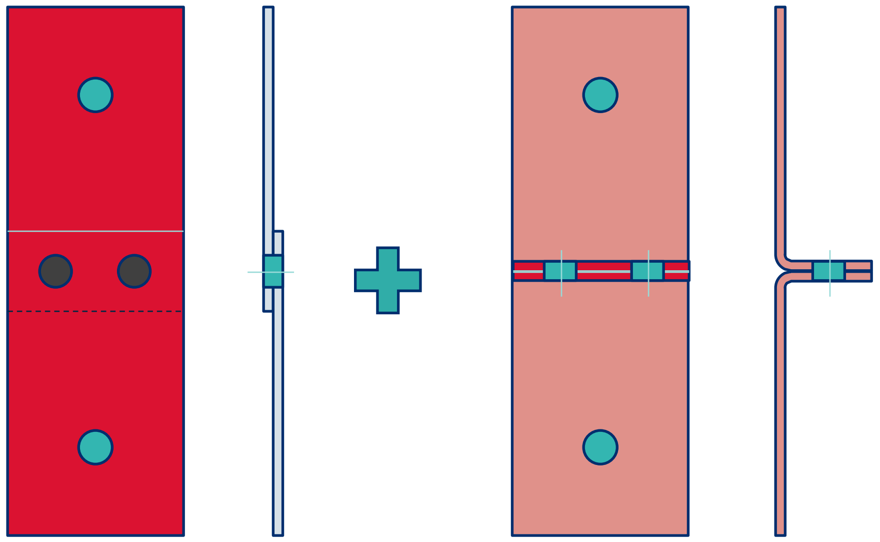
Session #5, Tuesday, 16 November,
Dr. Cristian Bagni
"Fatigue Characterisation of Welded Joints"

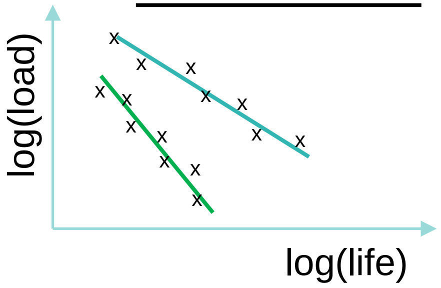
Weld Fatigue Test Characterisation



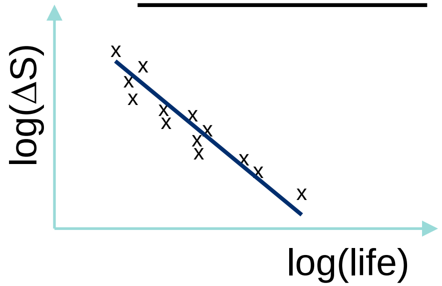
Lap shear test coupons
(predominantly membrane)

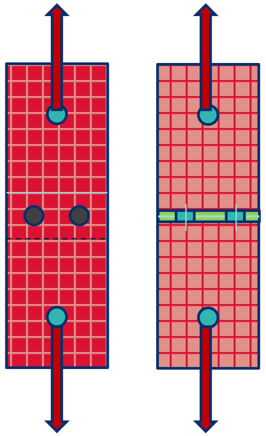
Coach peel test coupons
(predominantly bending)

Load-life curves



Stress-life curve





FEA analysis

Equations to calculate structural stresses in the sheet

$$\Delta S(\theta) = -\sigma(F_x)\cos\theta - \sigma(F_y)\sin\theta + \sigma(F_z) + \sigma(M_x)\sin\theta + \sigma(M_y)\cos\theta$$

$$\sigma(F_x) = d^{DEFXY} \cdot t^{TEFXY} \frac{F_x}{\pi d t}$$

$$\sigma(F_y) = d^{DEFXY} \cdot t^{TEFXY} \frac{F_y}{\pi d t}$$

$$\sigma(F_z) = SFFZ \cdot d^{DEFZ} \cdot t^{TEFZ} \frac{1.744 F_z}{t^2}$$

$$\sigma(M_x) = SFMXY \cdot d^{DEMXY} \cdot t^{TEMXY} \frac{1.872 M_x}{d t^2}$$

$$\sigma(M_Y) = SFMXY \cdot d^{DEMXY} \cdot t^{TEMXY} \frac{1.872 M_Y}{d t^2}$$

Optimizer

Component	Factor	Diameter Exponent	Thickness Exponent
FX, FY	SFFXY = 1.0	DEFXY = 0.0	TEFXY = 0.0
MX, MY	SFMXY = 0.6	DEMXY = 0.0	TEMXY = 0.5
FZ	SFFZ = 0.6	DEFZ = 0.0	TEFZ = 0.5

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Questions

Thank You

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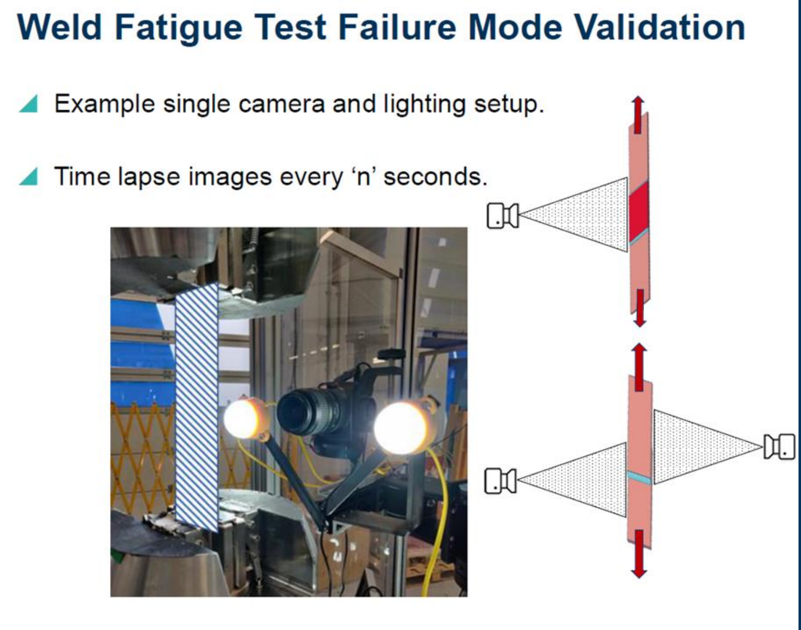
Q&A

- (no questions)

Virtual Seminar Series – Tuesday 2, 9, 16 November



Thin Sheet Welded Joint Fatigue Testing, Failure Mode Validation and Failure Criteria

Presented by Mr. Rob Plaskitt
Prenscia (HBK)

Tuesday, November 2, 2021