Heat Treatments
Hot Isostatic Pressing
Materials Testing
Metallurgical Coatings

Engineering Critical Assessment (ECA)

Materialdagen 2004, Stavanger 27. Oktober
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ECA Reeled Pipe - Contents

- Capabilities and Experience BMT
- Failure by Fracture
- Basic Fracture Mechanics
- ECA and SENT-Testing
- BMT-Procedure
- Opportunities and Challenges
  - Norwegian Export "Article"
  - Added Value or Added Cost
- Concluding Remarks

Fracture Mechanics Capabilities

Specific to the Oil and Gas industry

- Bodycote Daventry and Sandnes Laboratories have worked on twenty separate projects using SENT geometry fracture mechanics to evaluate fracture toughness of welds
- In the past two years we have now tested in the region of 300 samples
- Sizes ranging from 8mm B x B to 72mm by 36mm 2B x W at temperatures from –30 to 150°C
- In addition comes testing for aero-space and nuclear industry

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Fracture Mechanics

FRACTURE MECHANICS APPROVALS

UKAS Accreditation

K_{1C}
J_{1C}
J_R
CTOD
Dynamic CTOD

BS 7448:Part 1:1991
BS 7448:Part 2:1997
BS EN ISO 12737:1999
ASTM B645-98
ASTM E399-90(1997)
ASTM E1820-01
ASTM E813-89
ASTM 1737-96
BS 6729:1987(1993)

R-Curve
Instability

ASTM E740-88(1995)
BS 7448:Part 4:1997
ASTM E561-98
ASTM E1290-99

UKAS TESTING
0658
GROUP

Documented In-House Methods
(SENT Geometry JResistance curve procedures)

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Failure by Fracture

Liberty Ship which failed in dock in 1941.

The engineering approach to fracture design dates from the 1940s when many unexpected brittle fractures in ships occurred.
The concepts had been developed earlier.

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Developments of Fracture Safe Criteria

- Griffith’s (1920’s) energy considerations in glass, overseen for 30 years (before Irwing developed model for metal)
- Charpy-tests for transition temperature
- Linear Elastic Fracture Mechanics (LEFM)
- Elastic-Plastic Fracture Mechanics (EPFM)
- Development of more explicit energy based methods J-integral and R-curves with powerful analytic/computer base tools

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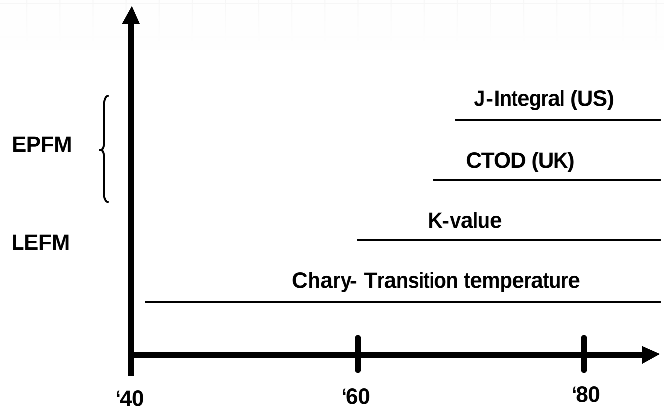
Developments of Fracture Safe Criteria (II)



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BODYCOTE MATERIALS TESTING

Basic Fracture Mechanics

- LEFM
- J-integral
- Crack Resistance

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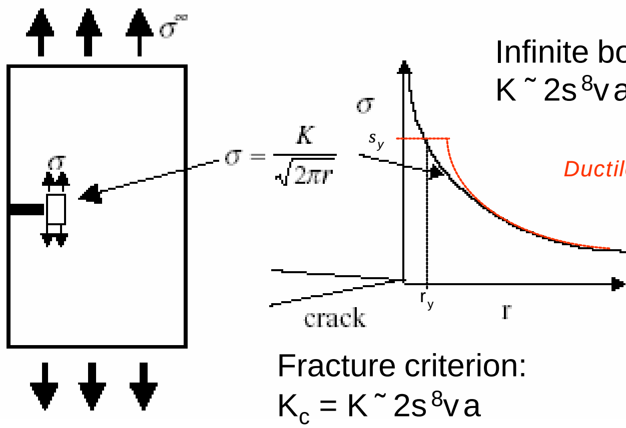
LEFM: K-factor
- Stress Field ahead of Sharp Crack



Infinite body:
K ˜ 2s^{8}va

Fracture criterion:
K_c = K ˜ 2s^{8}va

Anderson, 1995

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Effect of Specimen Dimensions

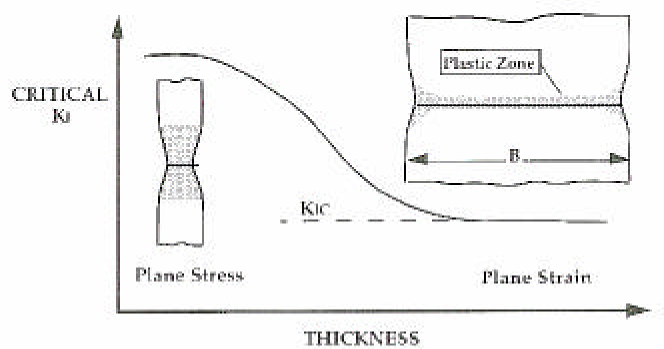

FIGURE 2.43 Effect of specimen thickness on Mode I fracture toughness.

Validity for LEFM: a,B,(W-a) $\geq$ 2.5 $(K_I/s_{ys})^2$

Anderson, 1995

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Comparison for Elastic Conditions

- J(-integral)$=K^2/E'$
- CTOD$=K^2/2s_fE'$

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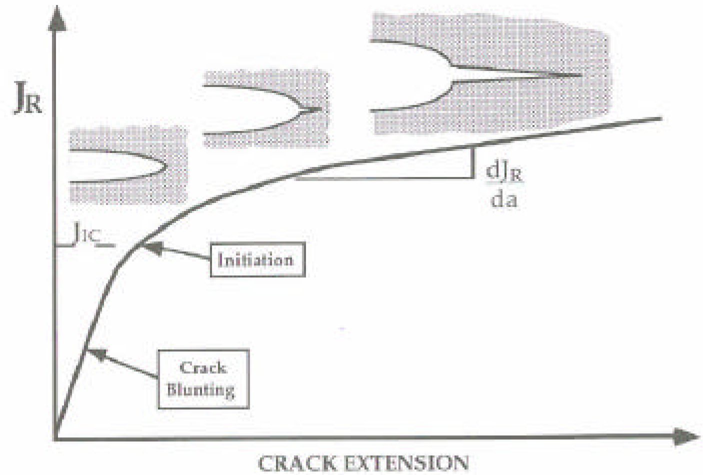
J-integral Evaluation

- Determine crack extension energy in load and/or displacement control
- Determine crack growth resistance for the material

<u>Engineering Critical Assessment:</u>

- Find conditions for stable/unstable crack growth

J_R - Crack Growth Resistance Curve



Anderson, 1995

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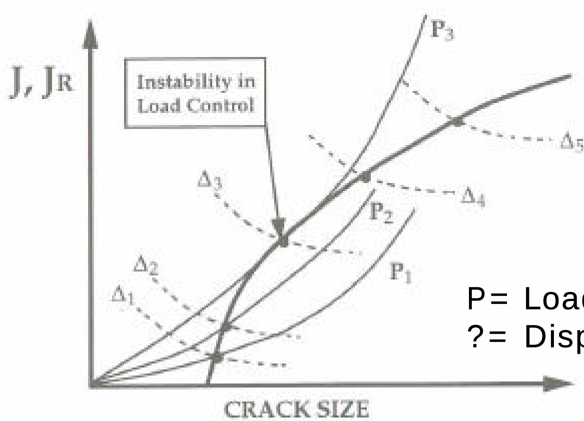
Resistance Versus Driving Force



P= Load Control
?= Displacement Control

Anderson, 1995

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ECA and SENT-testing

- Benefits
- Procedure
- Equipment
- Results and Evaluation
- Assessment

BODYCOTE MATERIALS TESTING

Basis for Method Development (BMT)

- JIP Project guideline for ECA of pipeline installation methods with cyclic plastic strains (DNV, Sintef and TWI)
- DNV-OS-F101 Submarine pipeline systems
- BS 7910 Guide on methods for assessing the acceptability of flaws in fusion welded structures (supersedes PD 6493:1991 which is withdrawn)
- In-house long and strong history of fracture mechanical testing and analysis

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Method Benefits

- Allows utilization of plastic capacity of modern pipeline materials in design
- Provides a flaw acceptance procedure for situations with large cyclic plastic strains
- May demonstrate that the pipeline system has adequate resistance against crack extension by tearing and unstable fracture during installation
- Provides information about the defect size after installation which is needed for assessing possible fatigue crack growth and unstable fracture during operation

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Main Procedural Steps during ECA Projects

1. Develop input data specification
2. Testing and engineering calculations
   - SENT-tsting
   - Calculations (Crackwise and other tools)
3. Assessment of output data
4. Acceptable defect sizes
   -FAD
5. Verification testing
   -Segment testing
6. Final acceptable defect sizes

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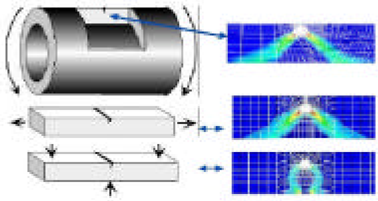
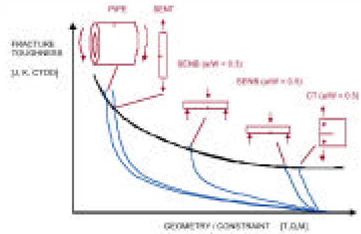
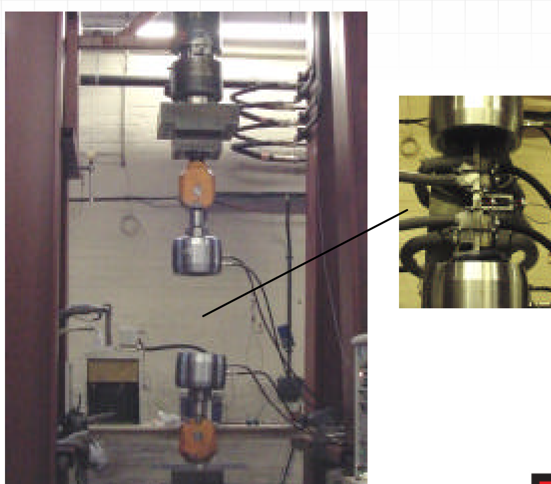
Simulation of Conditions in Pipes



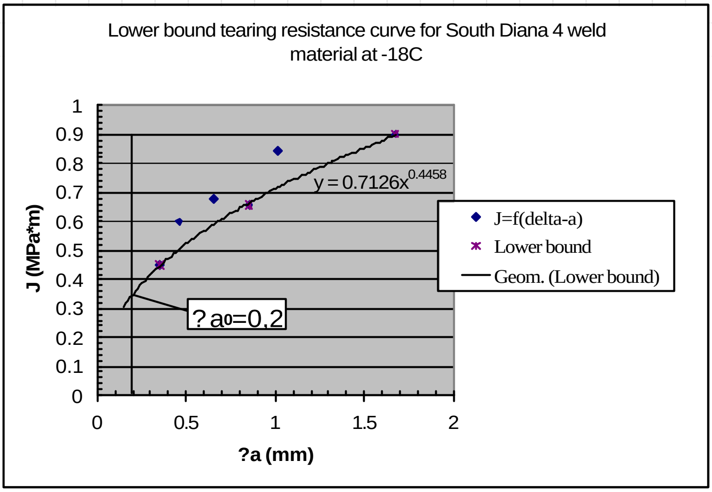


B. Nyhus

SENT Testing



Fracture resistance testing



Fracture Mechanics

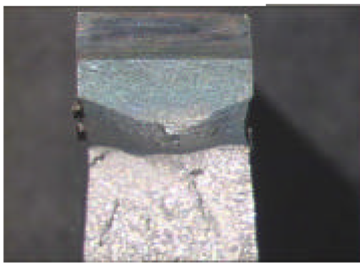
Weld Overmatching – Bulk Yielding

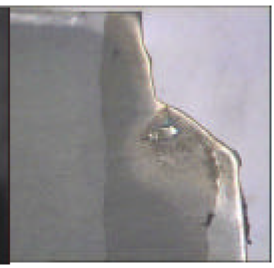
- For reeling situations it is essential that the weld is “overmatched” to the parent material
- Equally relevant to carbon steel or clad pipe welds
- An ECA often models the worst case, even matching, but we test a random level of overmatching
- Weld centre line testing of heavy wall thickness pipes most likely resulting in bulk yielding of parent metal instead of notch tearing

Fracture Mechanics

Weld Overmatching – Out of plane tearing in welds

- The tearing path tends to move to the path of least resistance i.e. normally the parent material
- JR curve based on in plane crack and tearing lengths, but tearing path actually greater





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Fracture Mechanics

Weld Overmatching – Mismatched tearing on fusion line

- Differential tearing due to local flow stress mismatch

- Effect gets worse as tearing length increases and plastic zone increasingly distorts

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Fracture Mechanics

Microstructural Validation – fusion line samples

- In normal pipeline SENB Geometry CTOD tests the pre-crack tip is to be within 0.5mm of the fusion line (DNV-OS-101)
- Based on plastic zone size, if you are within this distance then the CTOD value obtained is representative of the fracture toughness of the fusion line

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Fracture Mechanics

Microstructural Validation – fusion line samples

- In JR Curve analysis – what does it mean
- J-value is a composite of all the structures sampled by the tearing path, and we cannot control the direction of the tearing path
- Microstructural validation still proves that the the initial fatigue crack tip placement is adequate
- There is however more to be learned about the relative fracture toughness of the material by studying the direction of the tearing path

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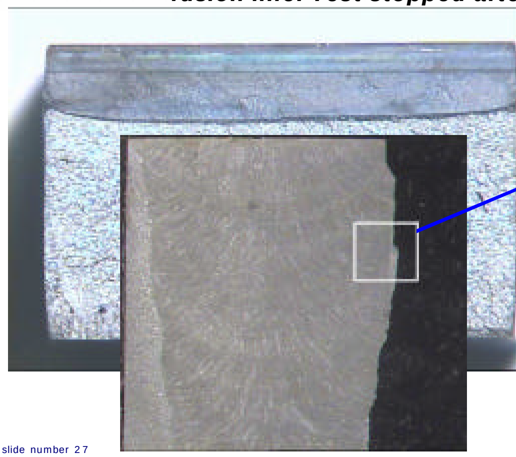
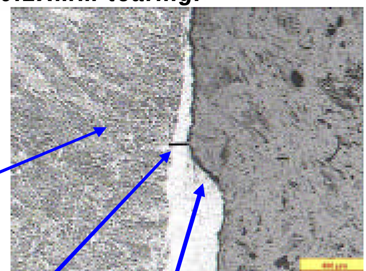
Fracture Mechanics

VALIDATION OF SURFACE NOTCHED FUSION LINE SAMPLES

Section of Fusion Line specimen showing tip of pre-crack is 0.X mm from fusion line. Test stopped after >0.2Xmm tearing.





Precrack tip 0.X mm from fusion line

Tearing path away from fusion line

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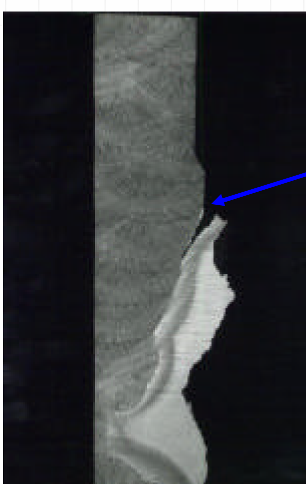
Fracture Mechanics

VALIDATION OF SURFACE NOTCHED FUSION LINE SAMPLES



The tearing path on this sample highlights that the weakest tearing path is the fusion line

Fatigue crack tip

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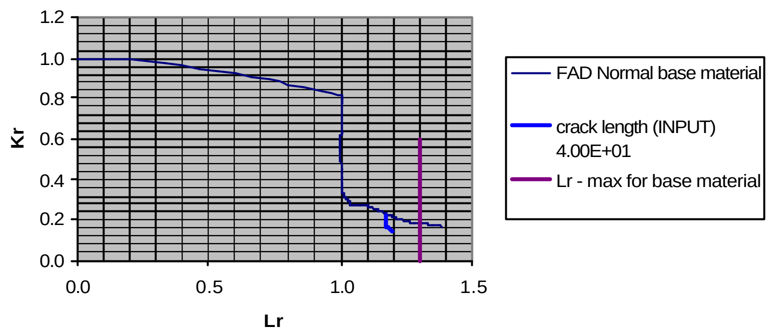
Corresponding FAD (typical)

Assessment of FL/HAZ defects based on normal base material
MEAN VED 20C *(no tearing)*



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Opportunities and Challenges

- Norwegian Export “Article”
- Added Value or Added Cost?

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Challenges

- Challenge in material testing to measure load, displacement and crack extension correctly and with correct mode
- Reduce number of samples
- Is both Installation and Operation needed?
- Segment testing is expensive and does it give relecant information
- “Shallow notced” CTOD preffered method in other areas of the world
- Ensure open competition and customer trust

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Concluding Remarks

- Lean ECA to be developed for reduced cost
- Open documentation on the method; DnV RP?
- ECA should facilitate and ensure “quantum” leap in technology deployment
- ECA should be a design tool more than “workman ship” control

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