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CO_2QUEST

Numerical modelling of brittle fracture in API X70 pipeline steel: A XFEM-based cohesive zone approach

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Outline

Introduction to Pipe Line Fracture
Experimental Set-up
Numerical Modelling
Conclusions

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Introduction to Pipe Line Fracture

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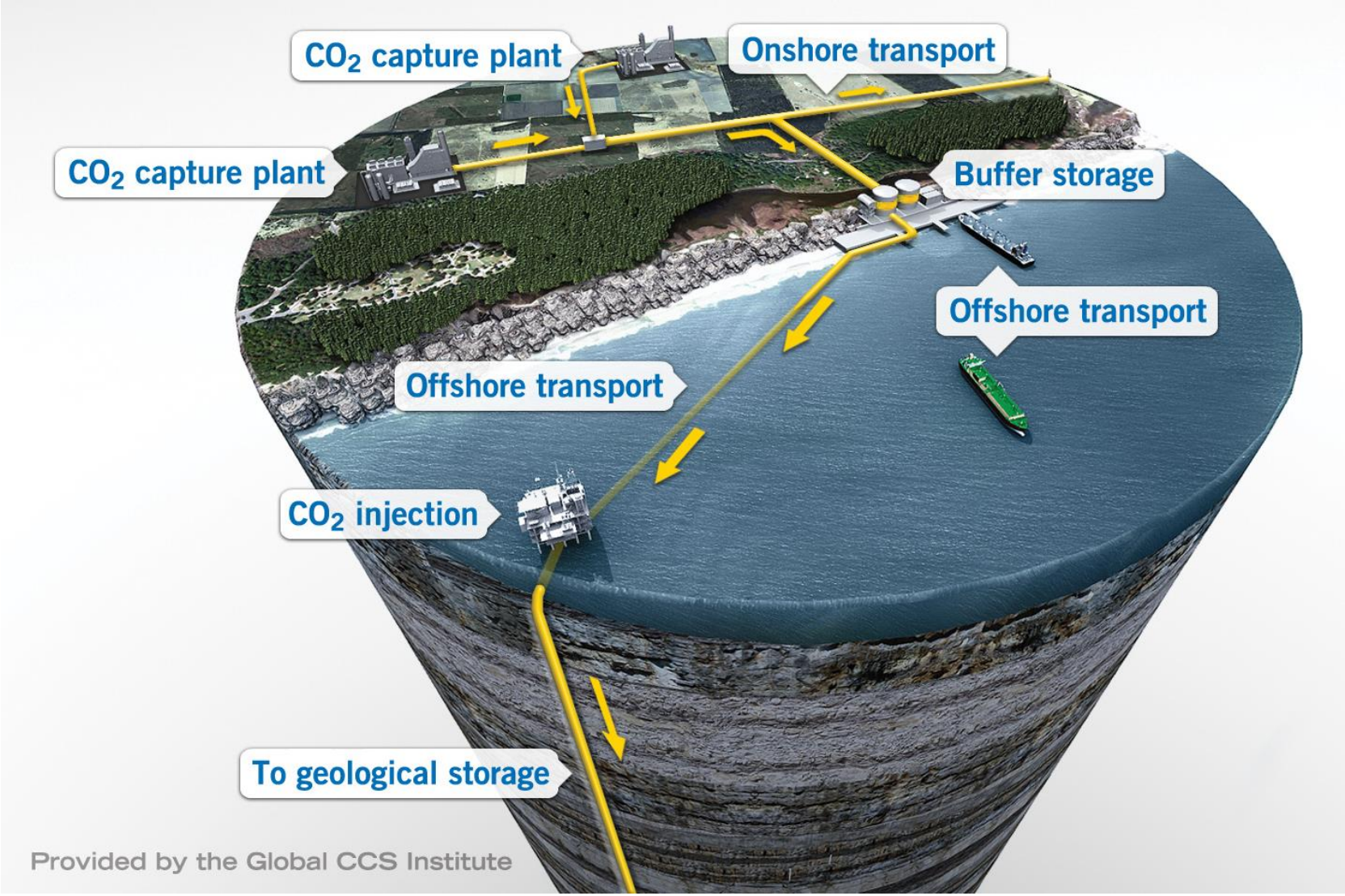
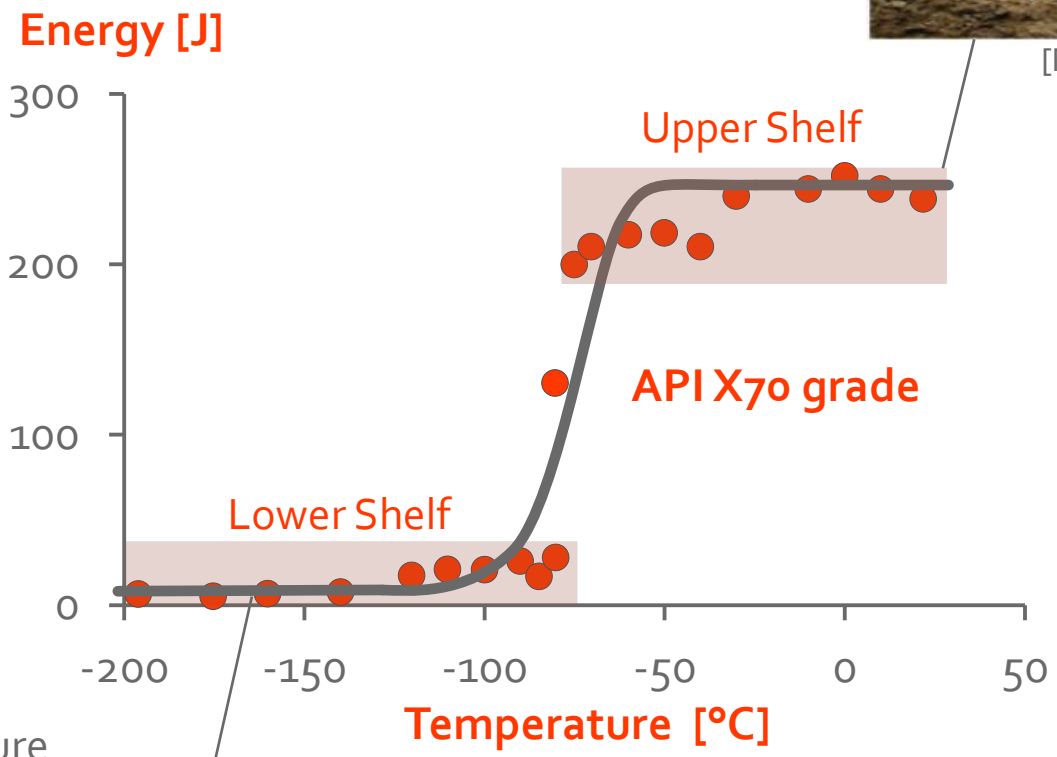
Introduction



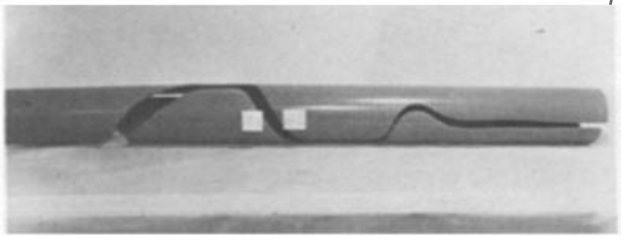
CO_2 Pipe Line Fracture

Ductile Fracture

[M. Bilio et al. 2009]

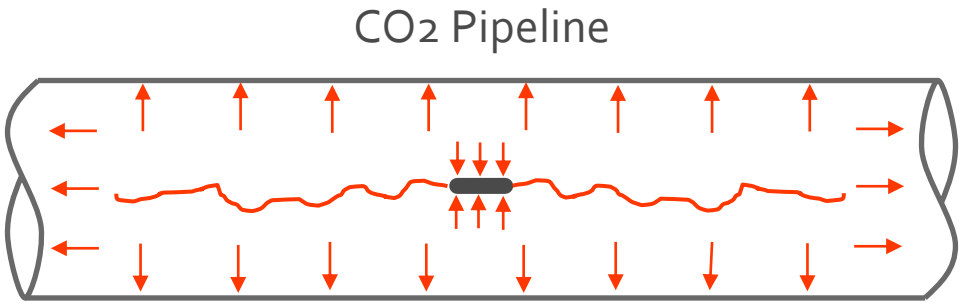


Brittle Fracture

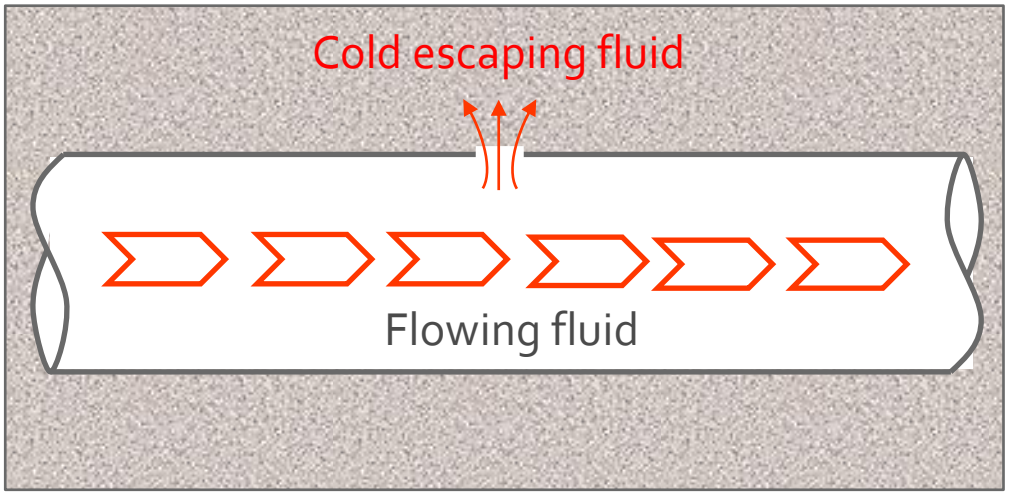


[M. Bilio et al. 2009]

Brittle Fracture



Localized pressure



Thermal stresses

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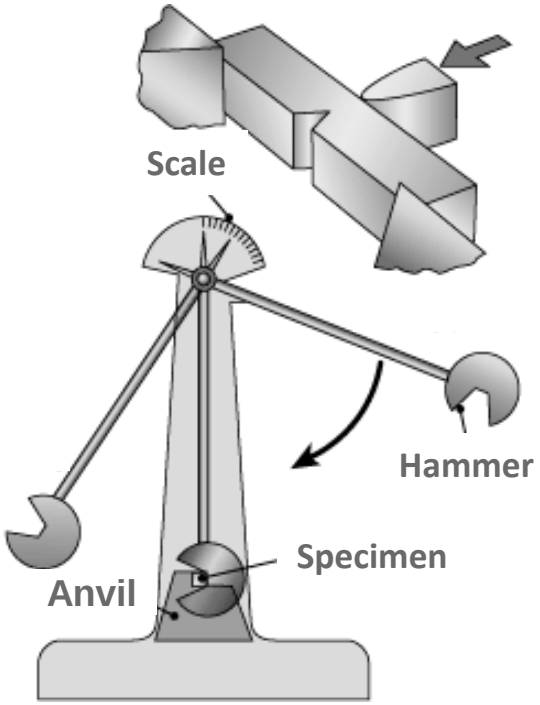
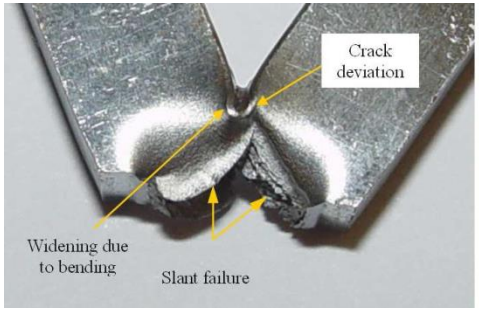
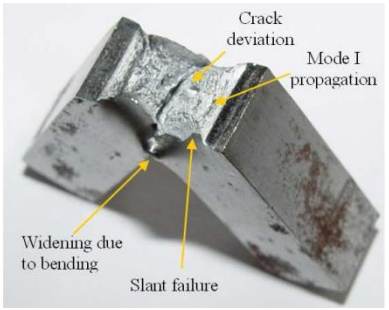
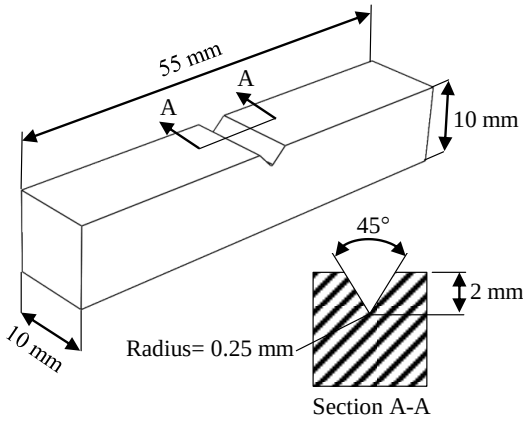
Charpy V-Notch (CVN) Impact Test Set-up

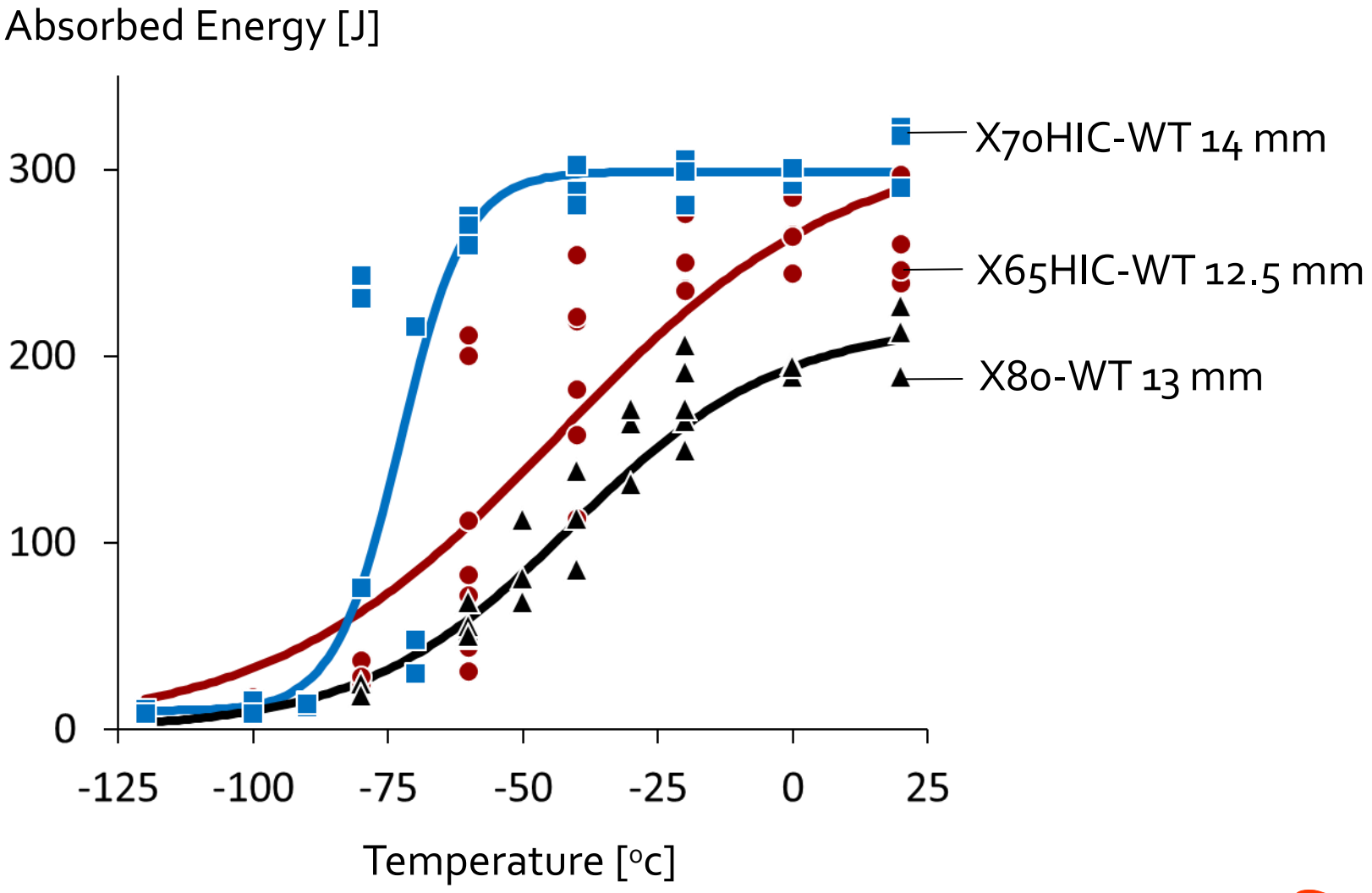




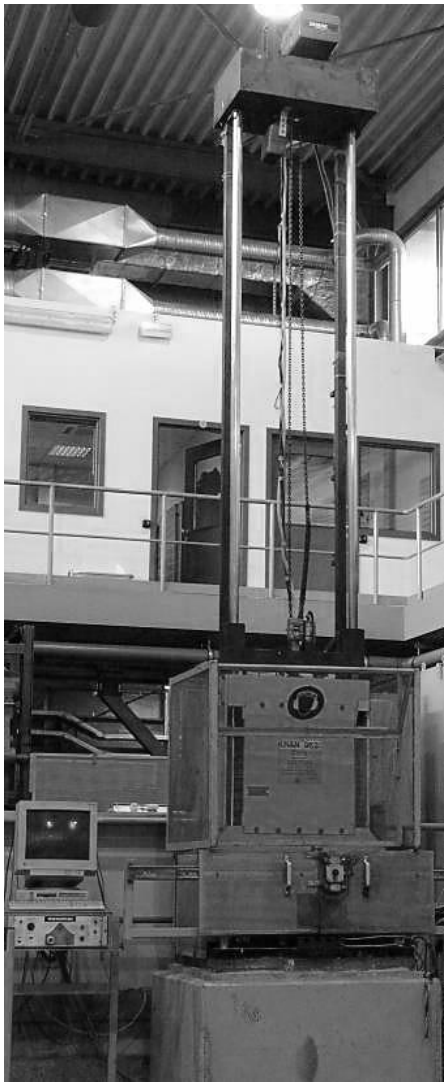




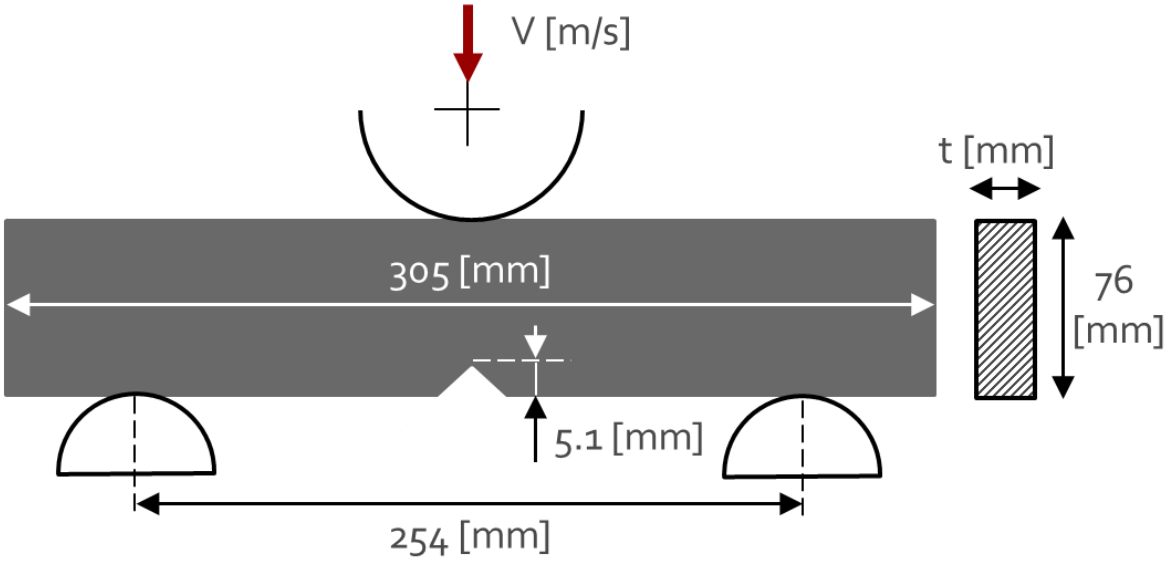
CVN Results


Absorbed Energy [J]
300
200
100
0
-125
-100
-75
-50
-25
0
25
Temperature [°c]
X70HIC-WT 14 mm
X65HIC-WT 12.5 mm
X80-WT 13 mm

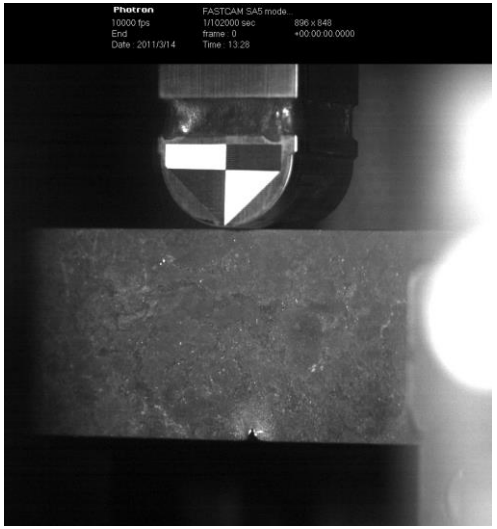
Drop Weight Tear Test (DWTT) Set-up



DWTT Set-up

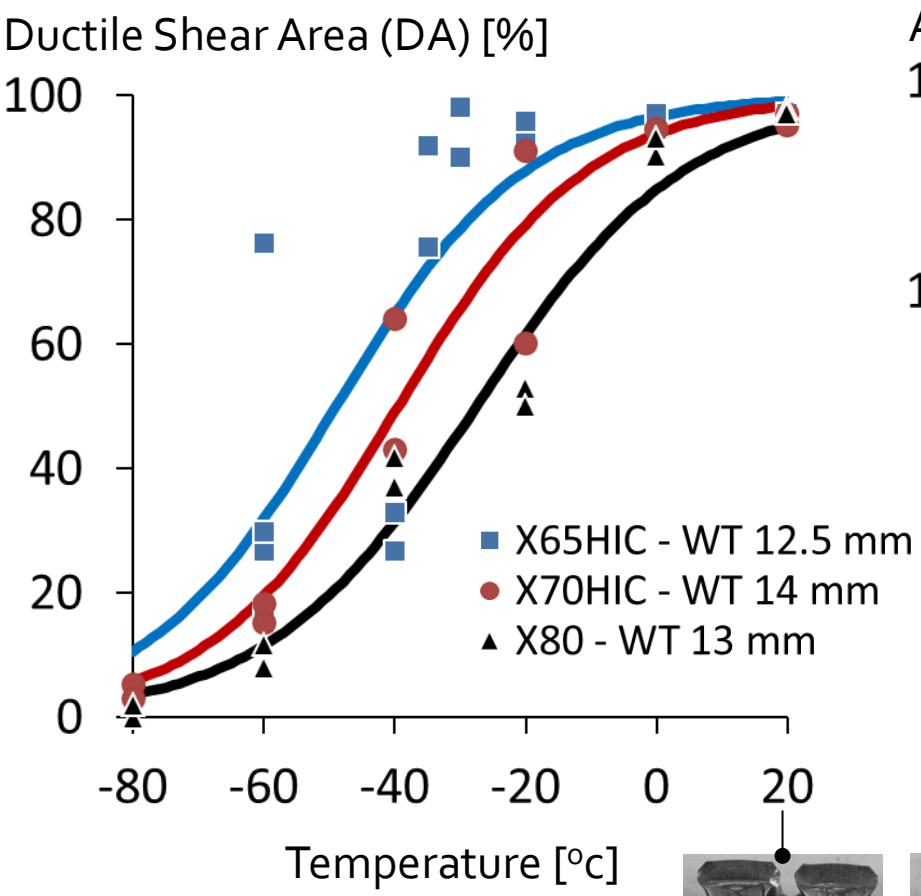


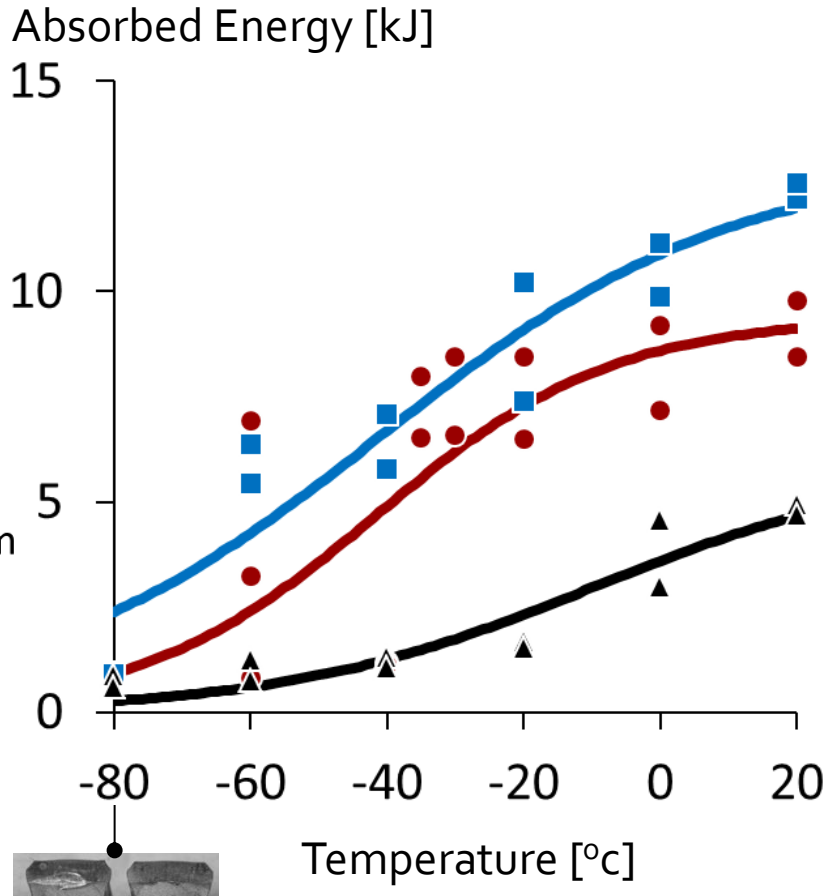
T= 20 °C



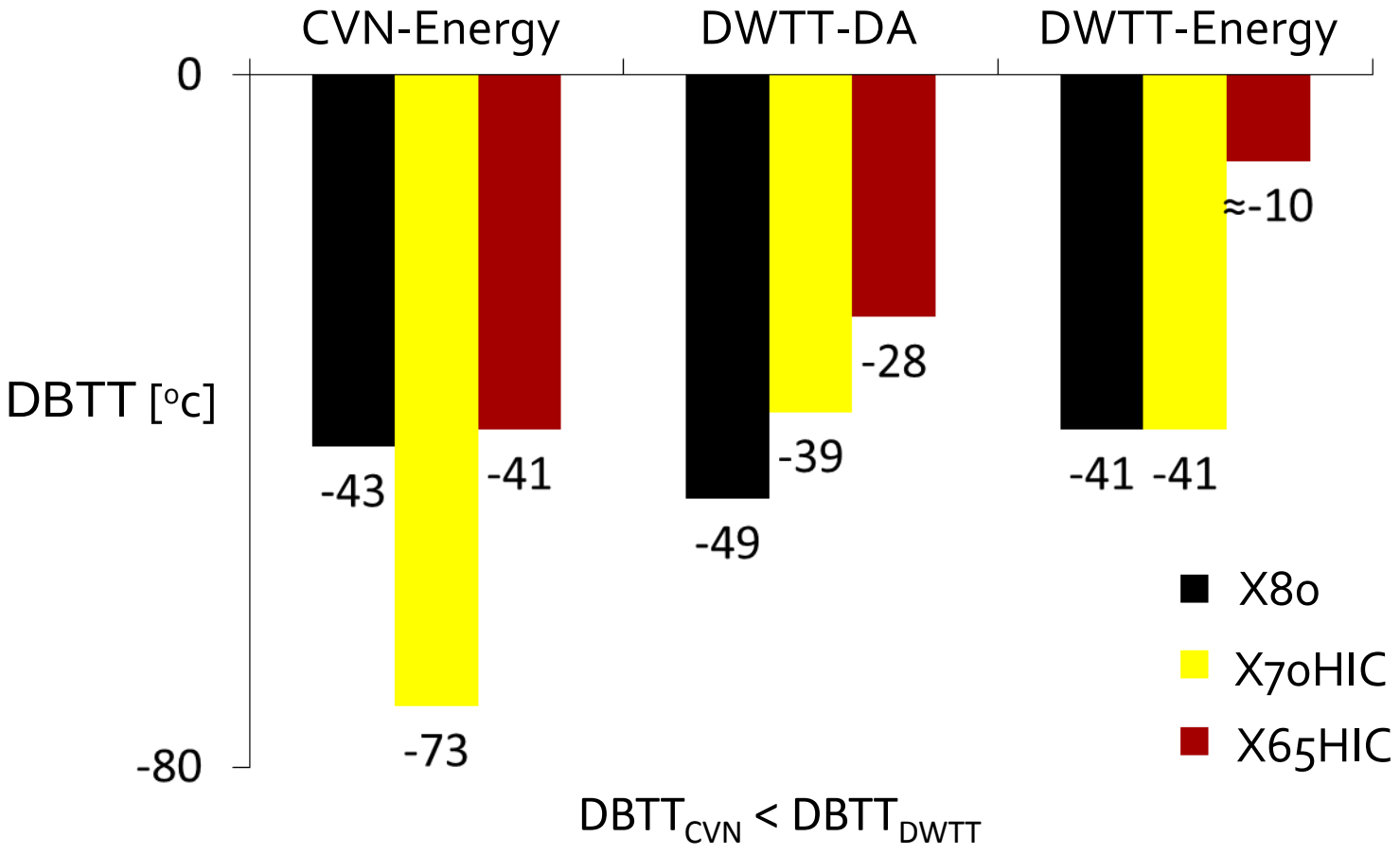
T= -65 °C

DWTT Results



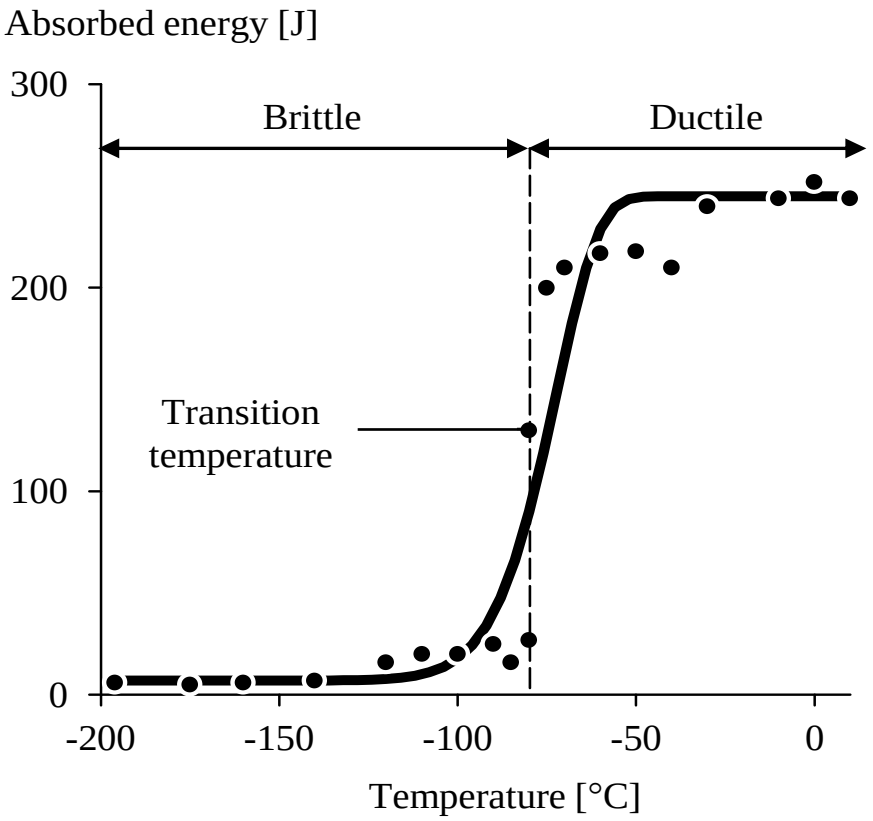


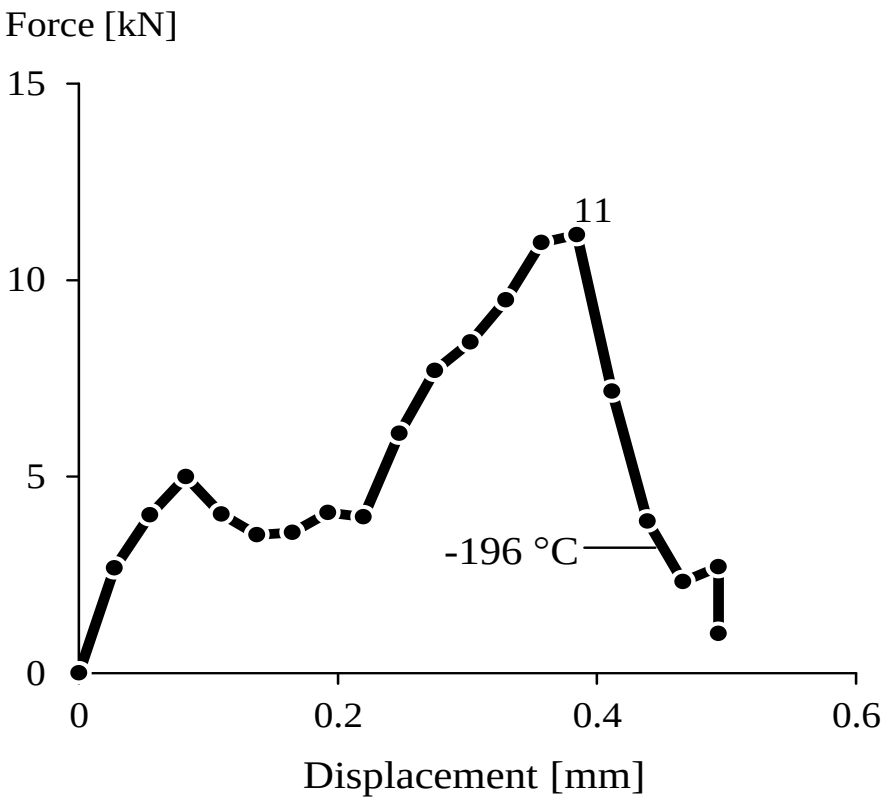
CVN VS DWTT



X70MS (HIC) offers the best combination of strength, low temperature toughness and resistance to (accidental) H_2S exposure

Charpy V-Notch (CVN) Impact Results





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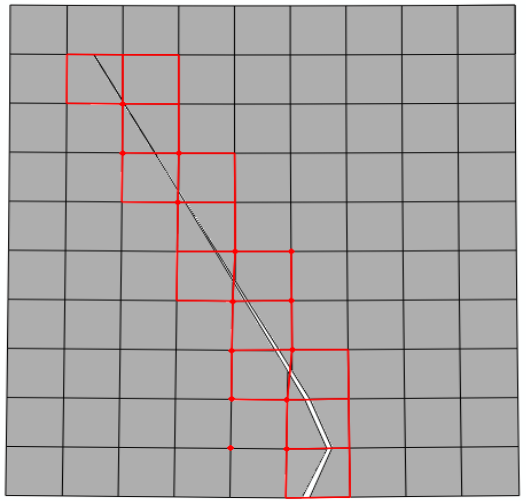
Brittle Fracture Model

eXtened Finite Element Method (XFEM)

Moës, Nicolas;
Dolbow, John;
Belytschko, Ted
(1999)



S_A= All nodes
S_H= Nodes cut by the crack
S_c= Nodes surrounding the crack tip

Heaviside enrichment function

$$u^h(x) = \sum_{I \in S_A} N_I(x) u_I + \sum_{J \in S_H} N_J(x) H(x) q_J^0$$

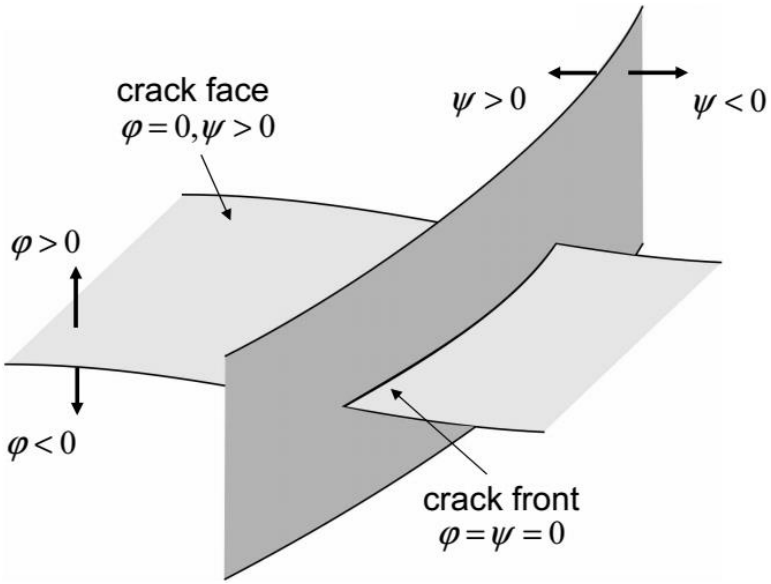
u_I Nodal DOF for conventional shape functions N_I

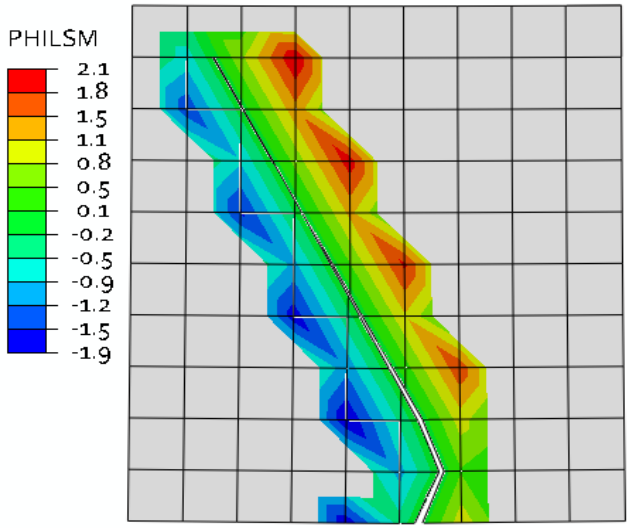
Basic XFEM Concepts

Level Set Method

The level set Φ= o represents the crack face

The intersection of level sets Φ= o and Ψ = o denotes the crack front

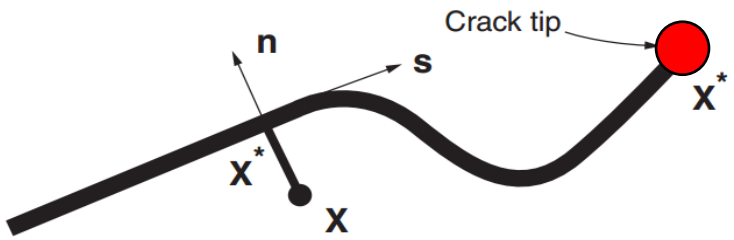




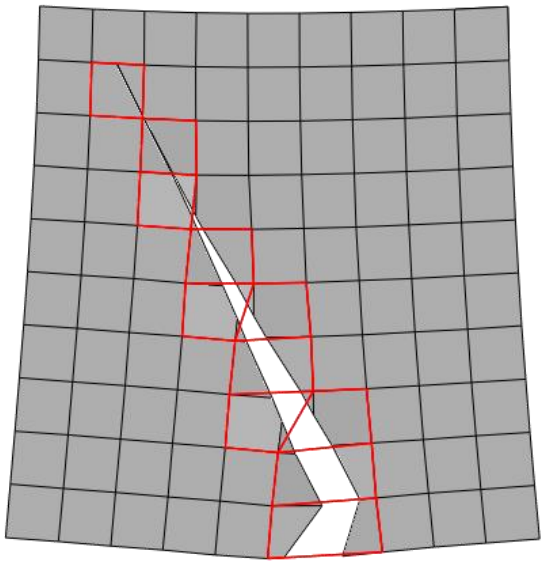
Basic XFEM Concepts

Heaviside function

Accounts for displacement jump across crack



$$H(x) = \begin{cases} 1 & for, (x - x^*)n \geq 0 \\ -1 & else, \end{cases}$$

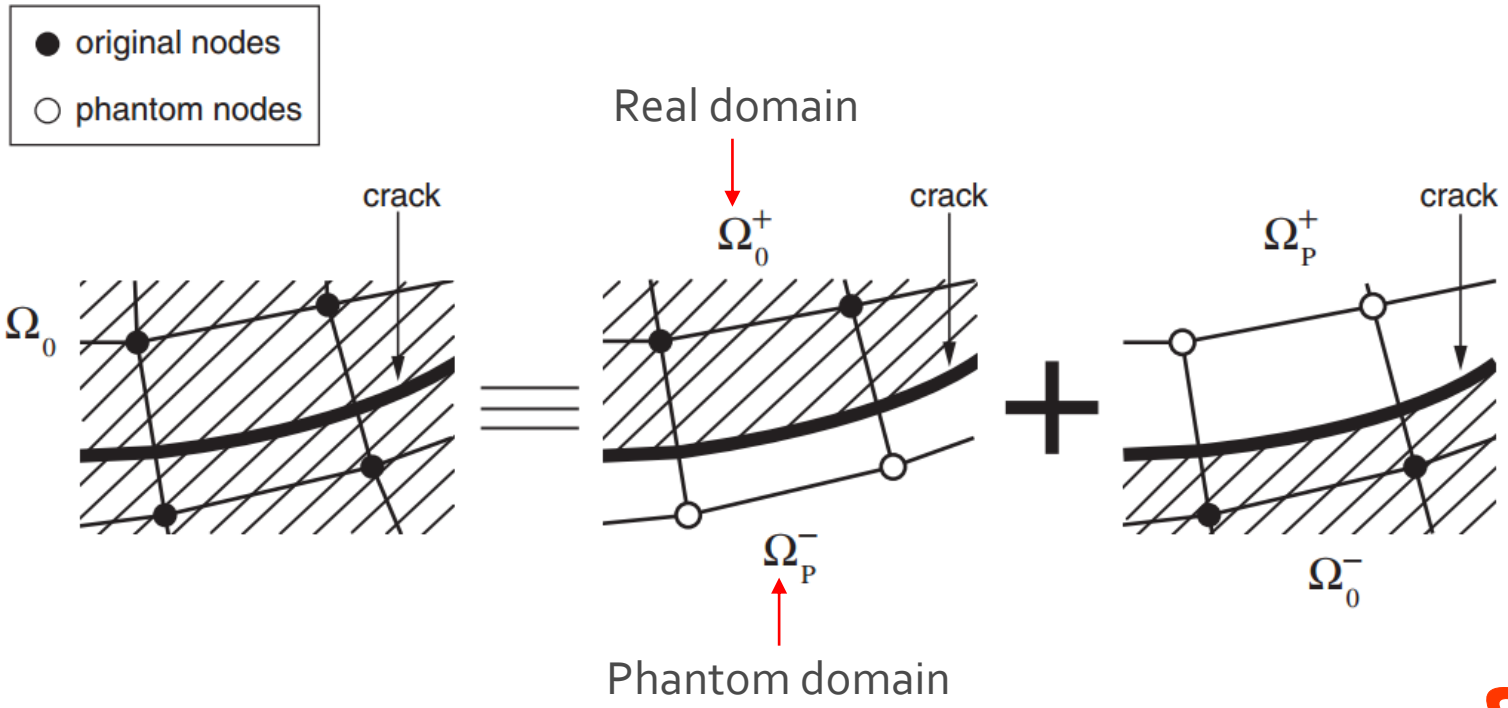


Basic XFEM Concepts

Phantom node approach (propagating cracks)

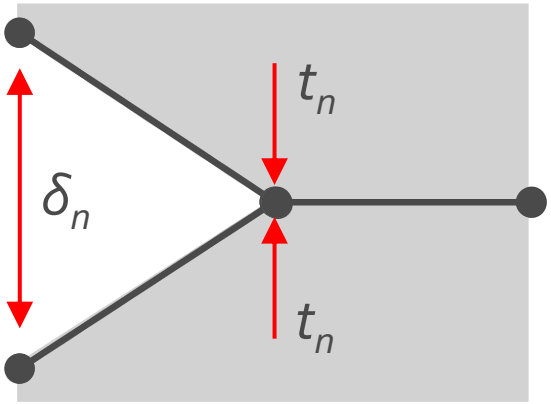
Belytschko *et al.* (2006)

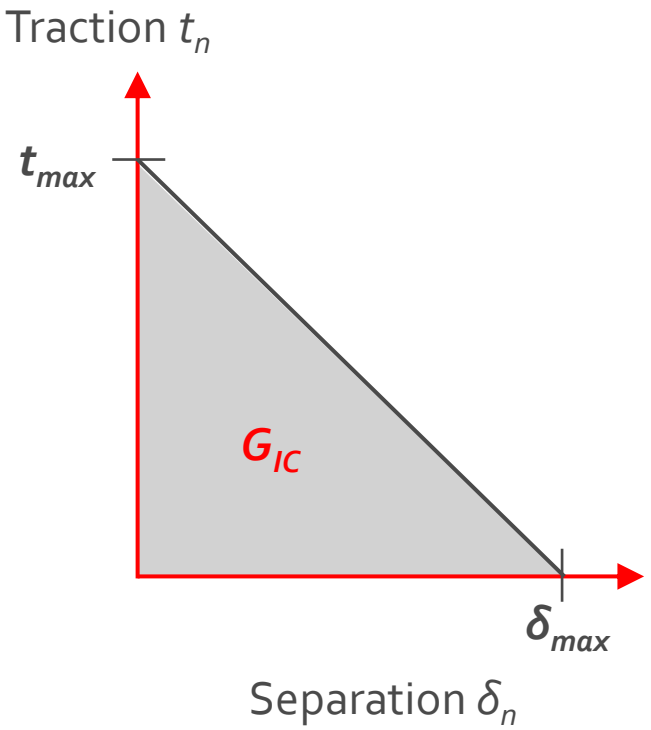
Discontinuous element with Heaviside enrichment is treated as a single element with ***real*** and ***phantom nodes*** that gets split into two parts



XFEM-Based CZM approach

Cohesive Zone Model (CZM)





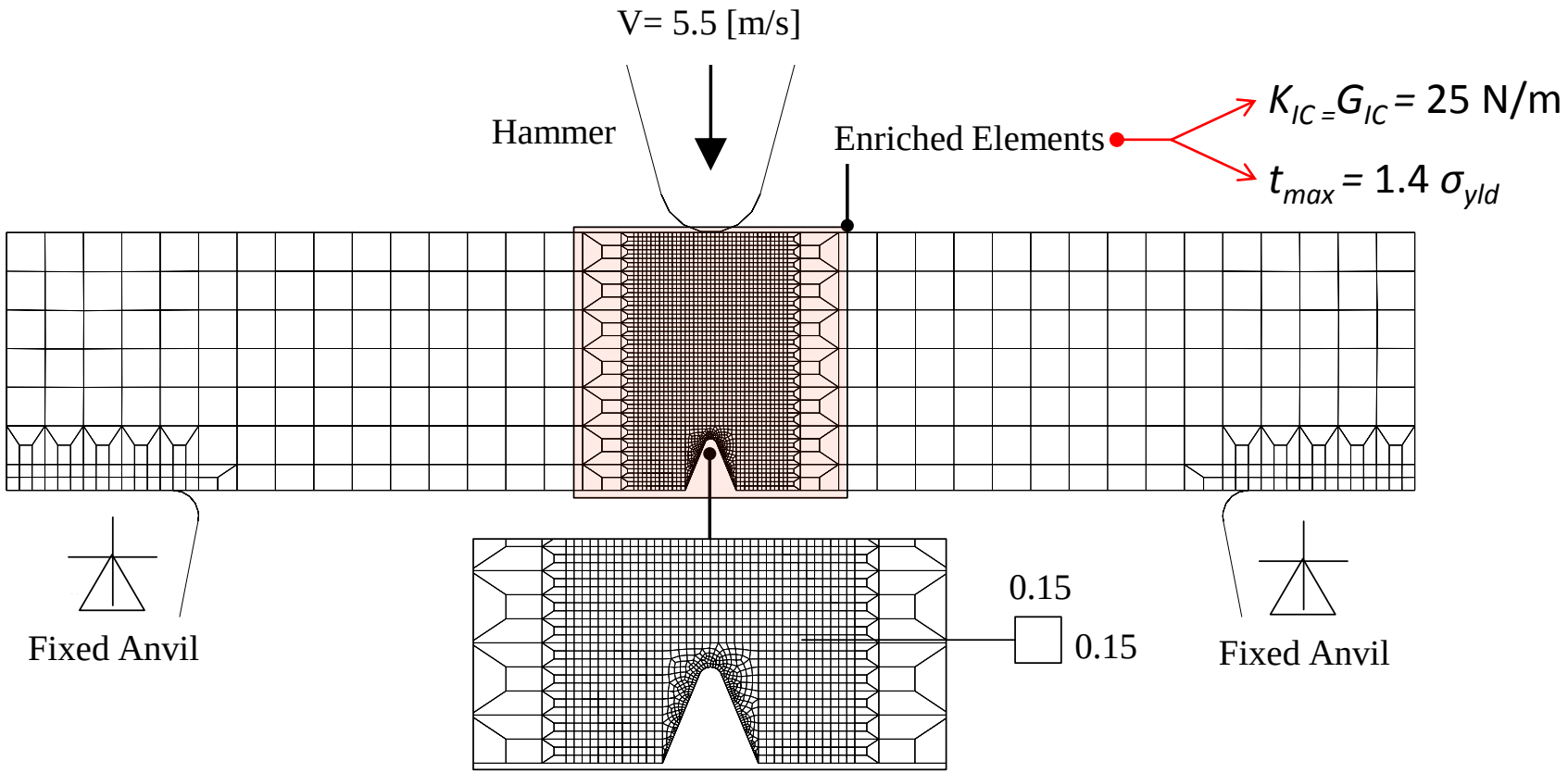
$$G_c = \int_0^{\delta_{max}} T(\delta)d\delta$$

G_{IC}

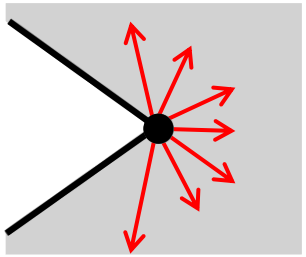
t_{max}

δ_{max}

CVN Brittle Fracture Model

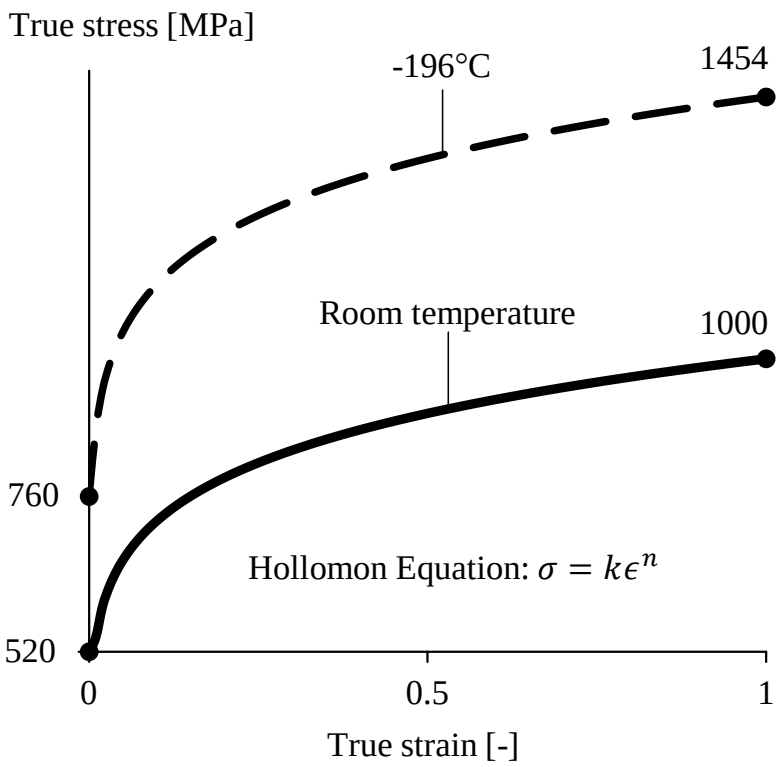


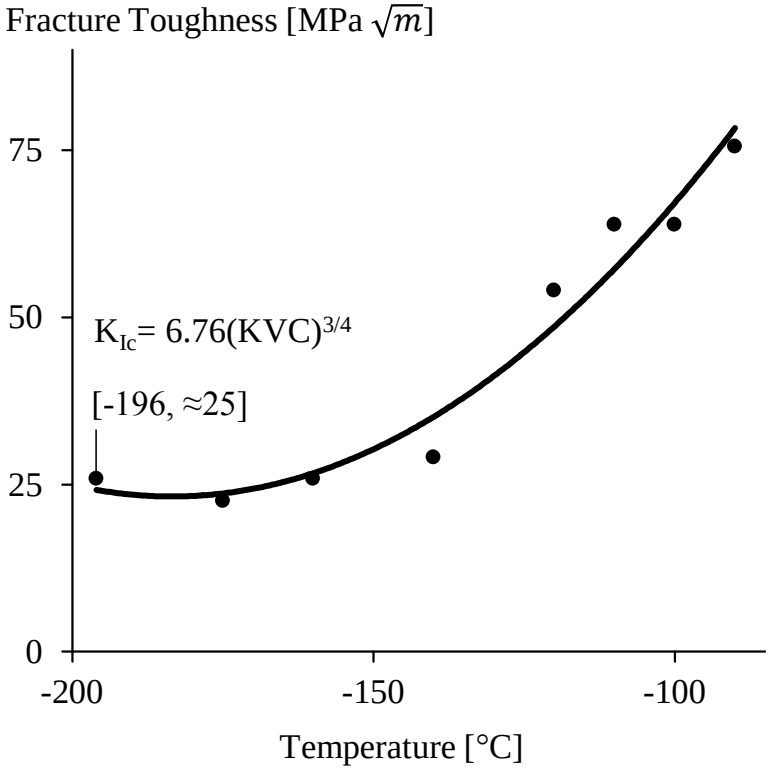
$$f = \left\langle \frac{\sigma_{max}}{\sigma^0_{max}} \right\rangle$$ *IF f= 1* → Crack initiates or an existing crack extendes



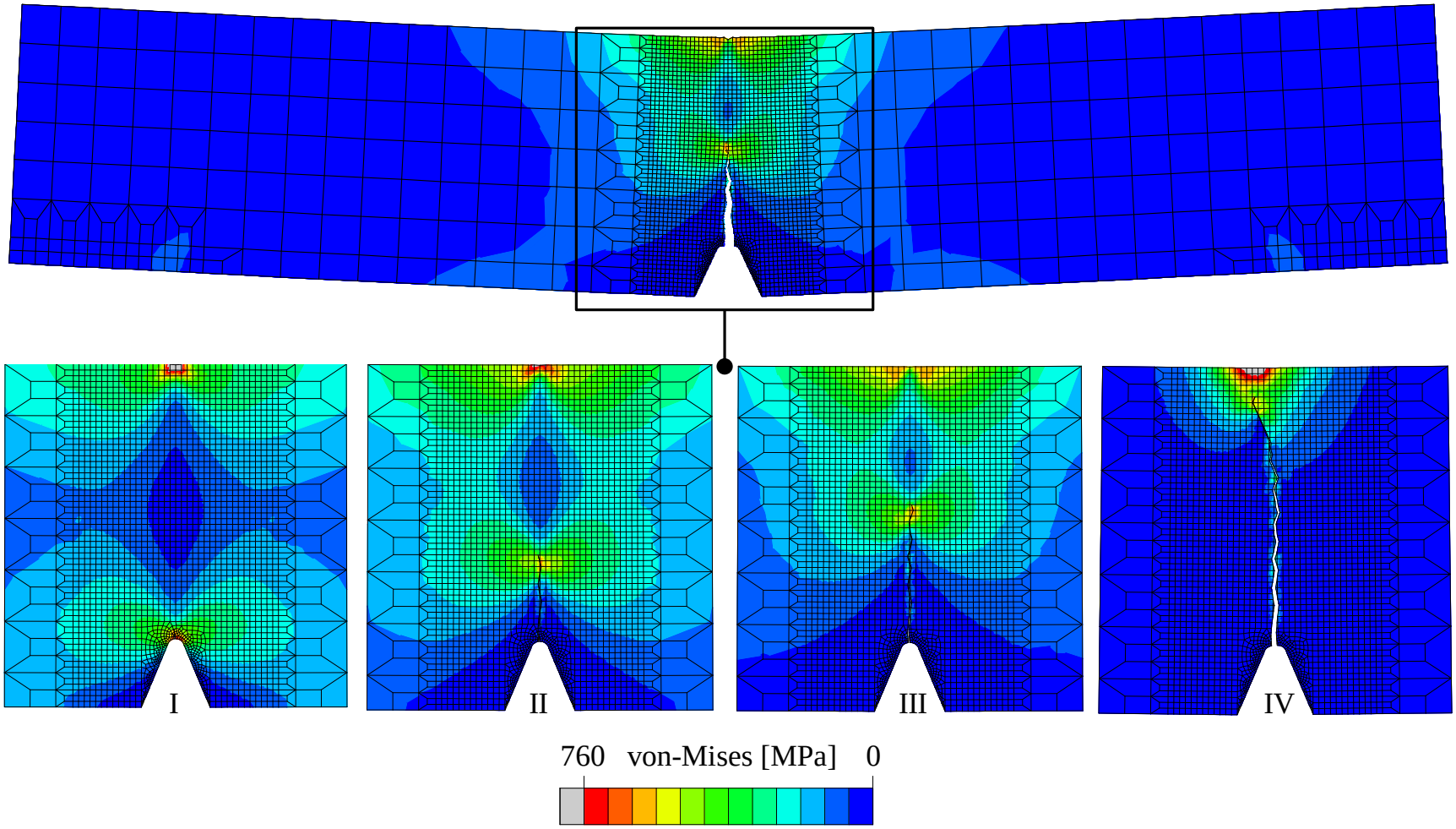
→ Crack propagation direction

Material Properties

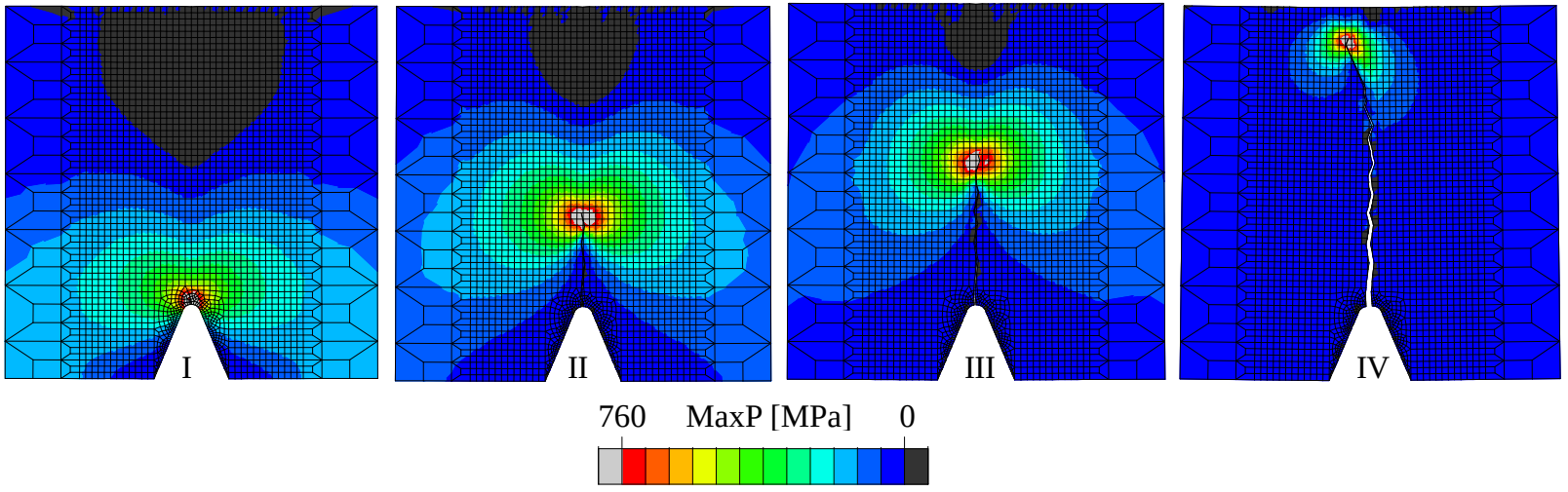


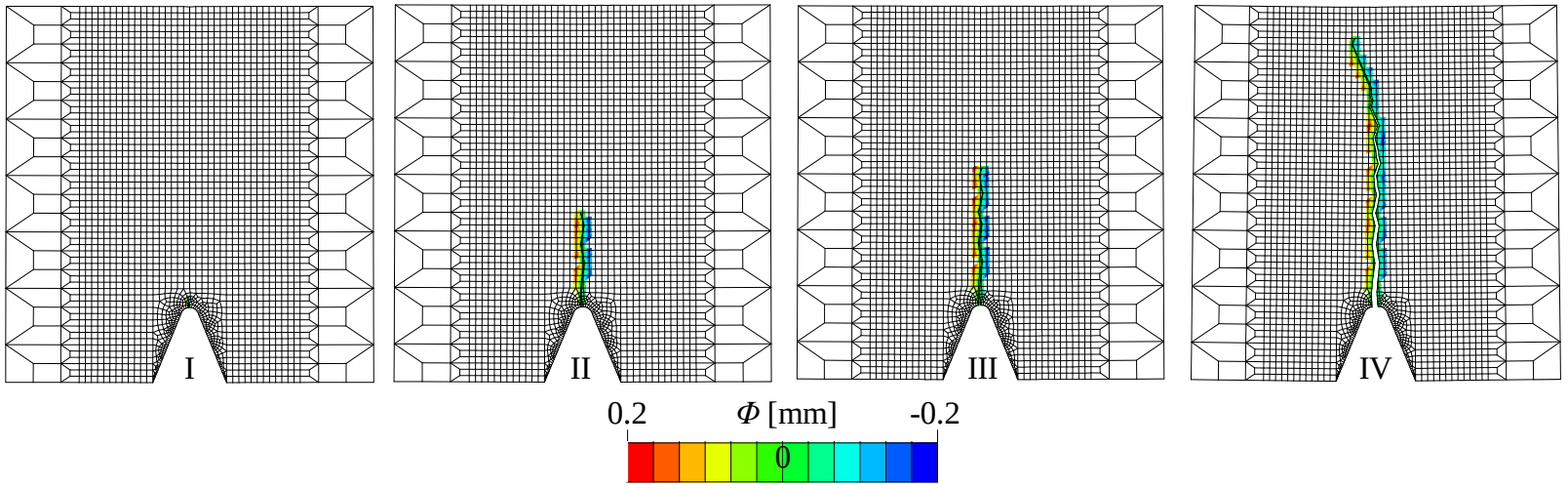


Numerical Model Results

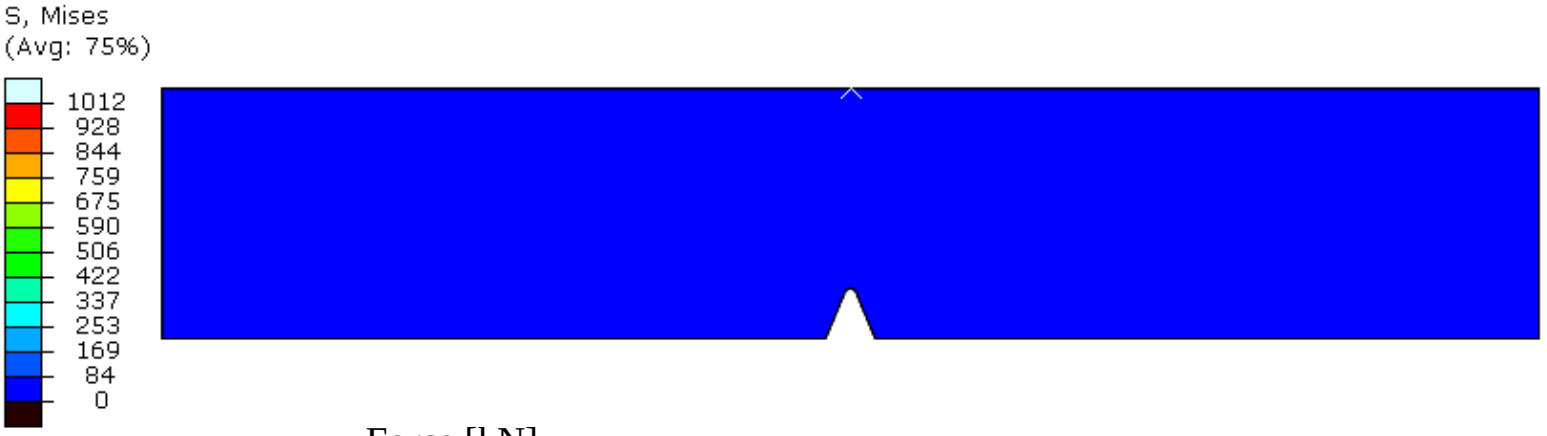


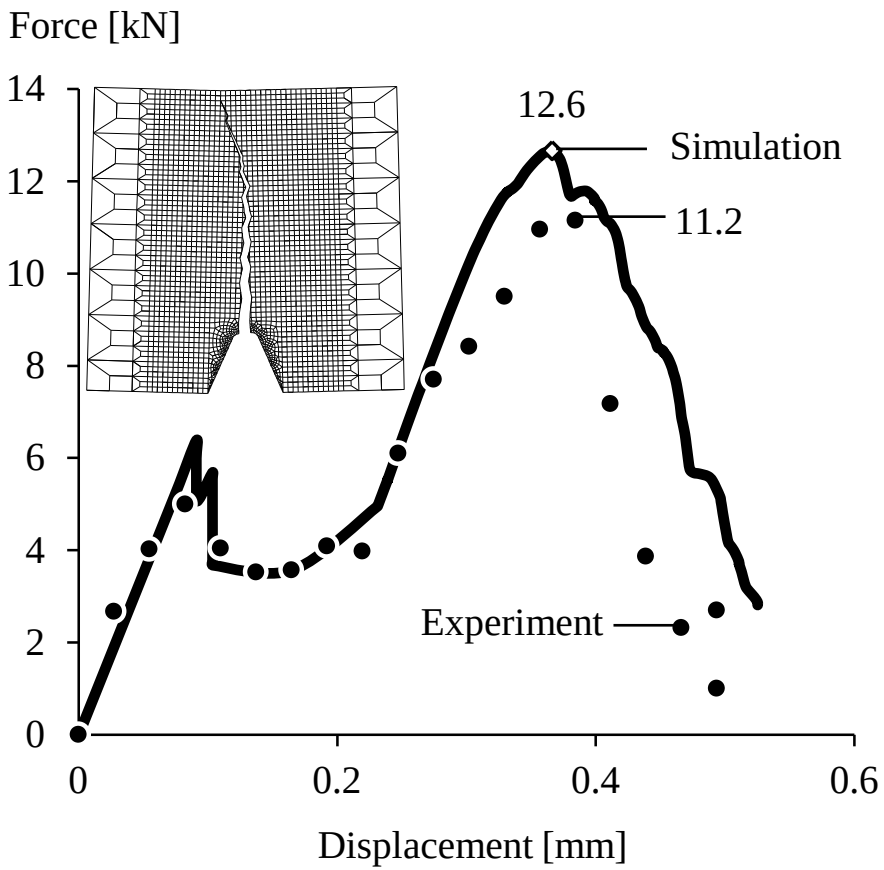
Numerical Model Results



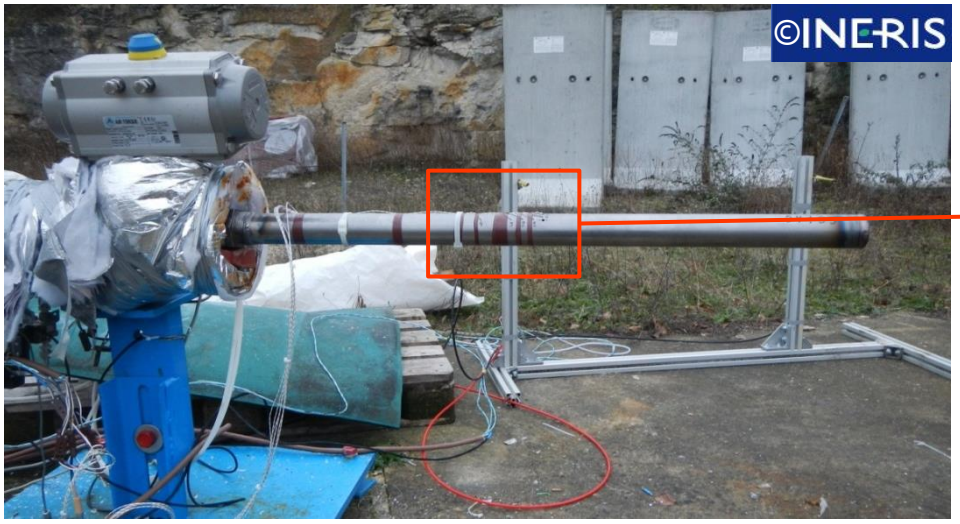


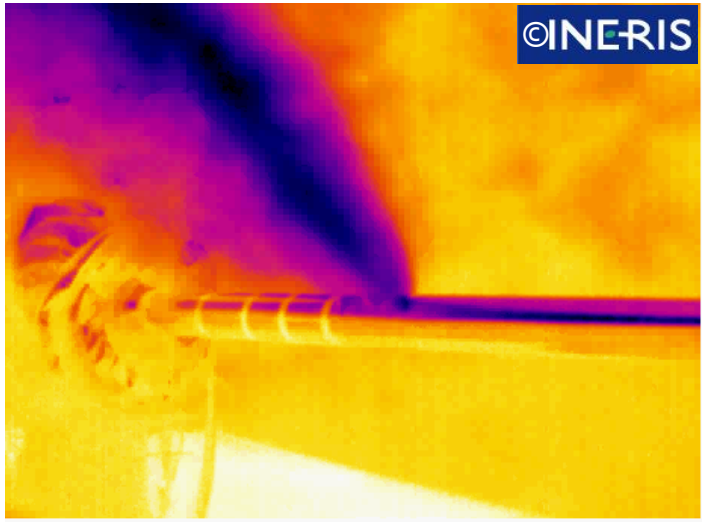
Numerical Model Validation



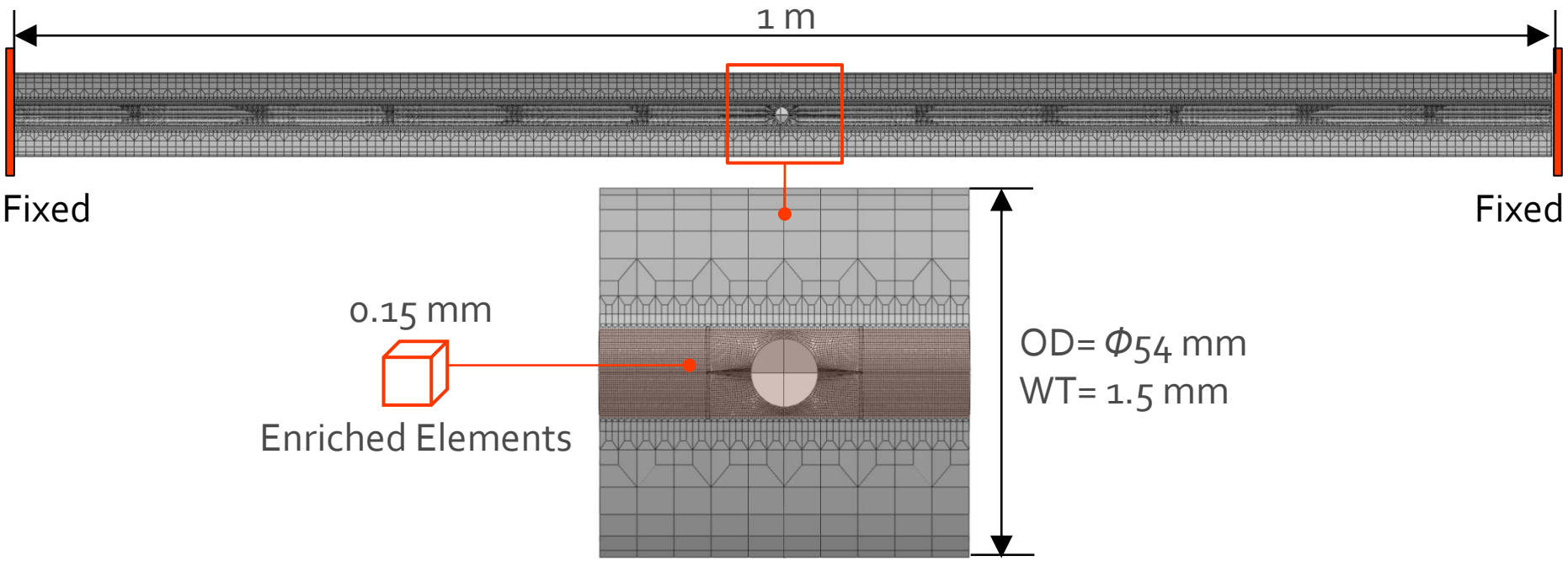


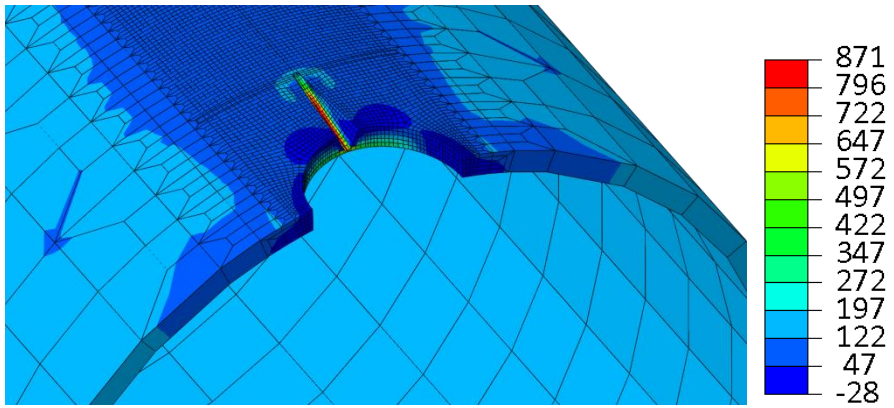
Small Scale Pipe Fracture Test



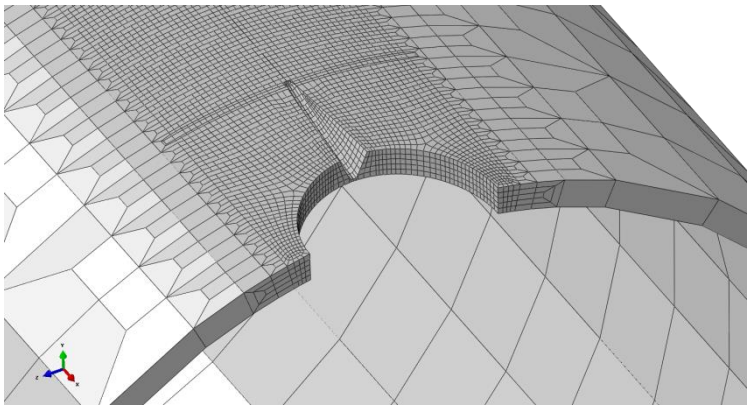


Small Scale Pipe Fracture Model





Maximum Principal Stress [MPa]



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Conclusions

- XFEM-based cohesive zone approach is a suitable methodology to model brittle fracture behaviour of API X70 pipeline steels
    - Due to strong discontinuity behaviour of XFEM crack propagation process the possibility of facing numerical convergence issues are high!

Acknowledgements and Disclaimer

The research leading to the results described in this presentation has received funding from the European Union 7th Framework Programme FP7-ENERGY-2012-1-2STAGE under grant agreement number 309102.


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25-50mm 0.001mm