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On simulation of dynamic brittle fracture of CO_2 pipeline using coupled fluid–structure modelling approach

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- CCS is the third most important measure to limit the *global warming by 2°C* [IEA]
    - An important part of the CCS chain is the *transport of CO_2*

Taken from wiki.iploca.com

Outline

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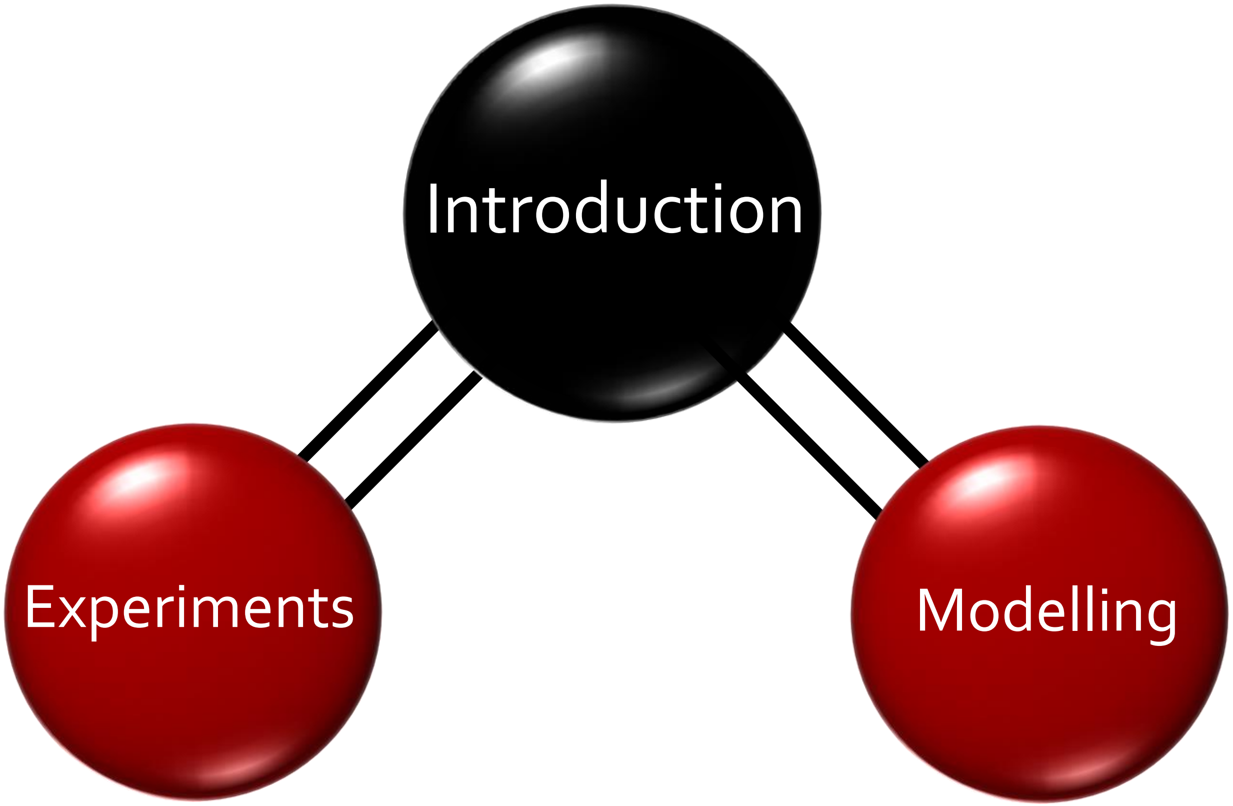

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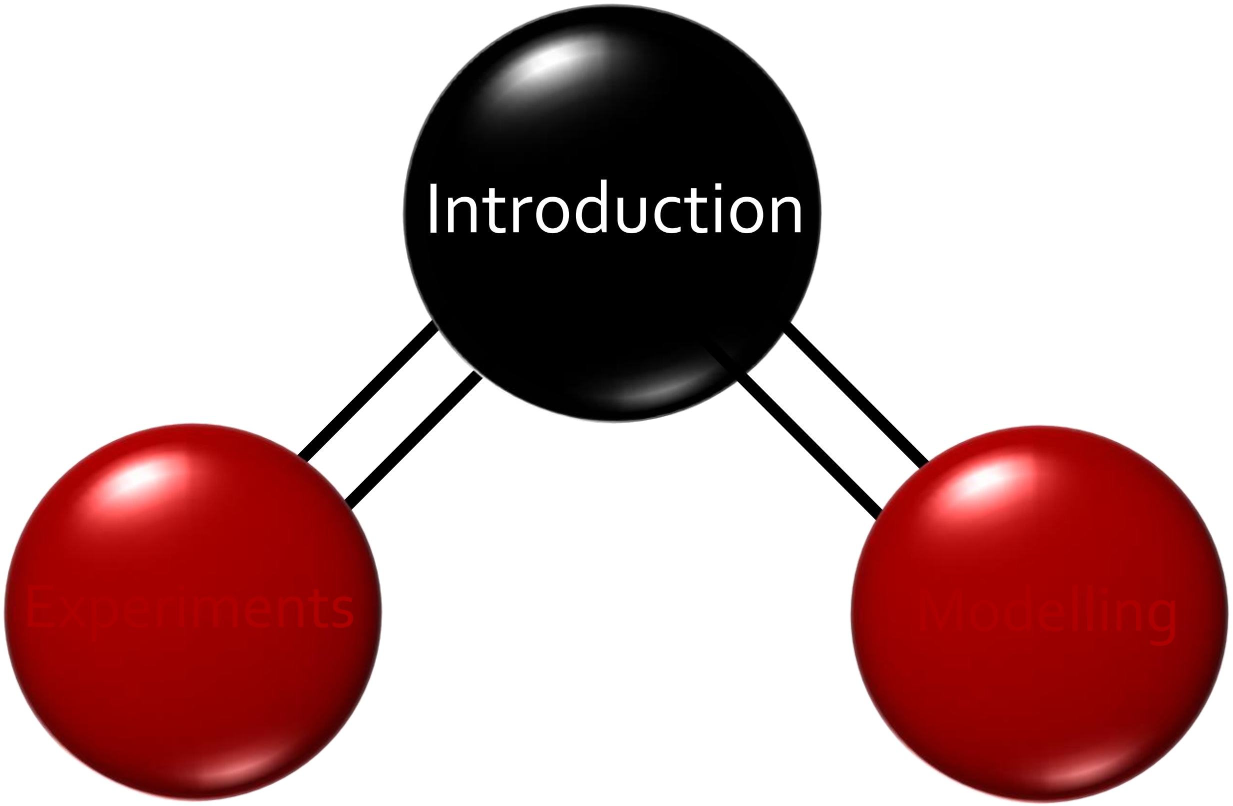

Introduction

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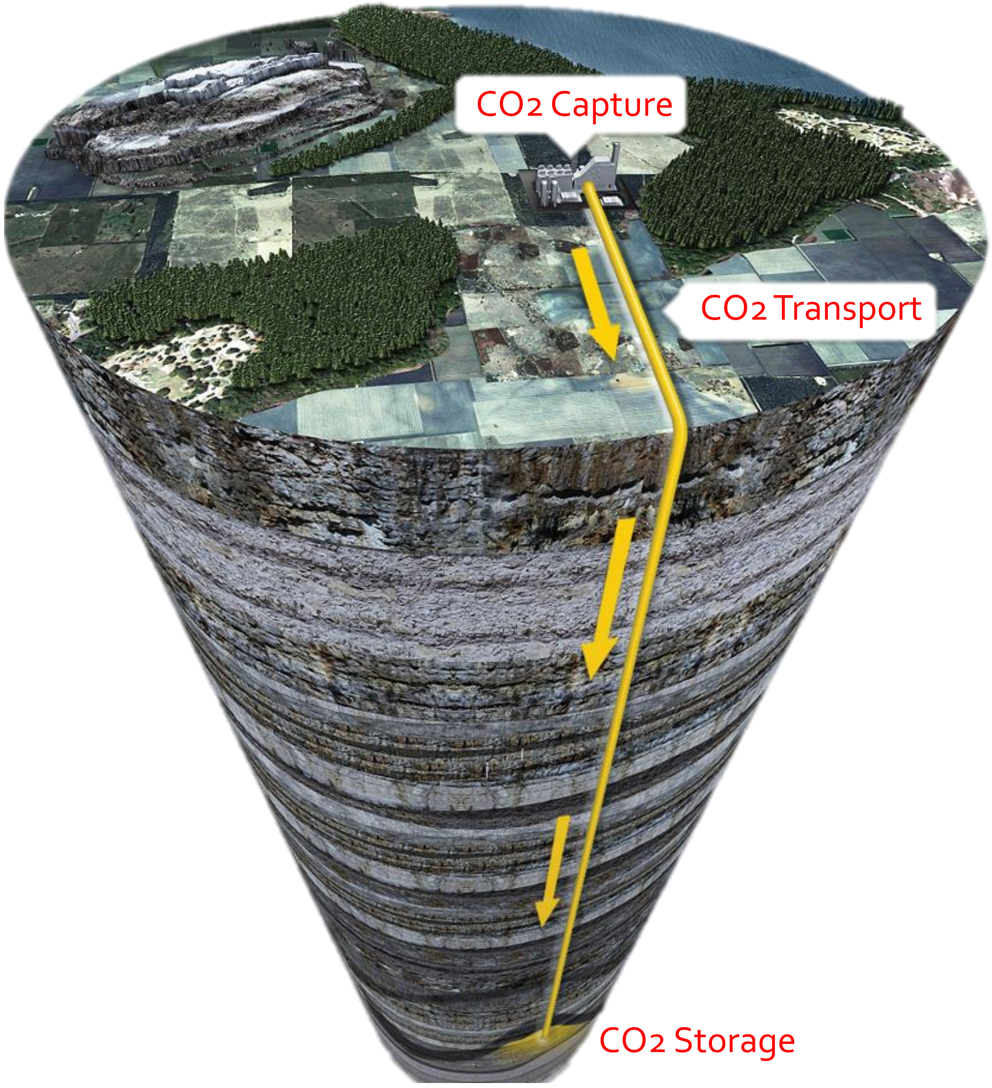

Global CCS Institute

Objectives

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- Material selection for safe *CO_2* transportation
- Developing ductile and ***brittle fracture*** models
- ***Coupling fluid/structure fracture model*** for predicting ductile and ***brittle fracture behaviour***
- Effects of different stream impurities on brittle fracture behaviour of CO2 pipeline

Brittle Fracture

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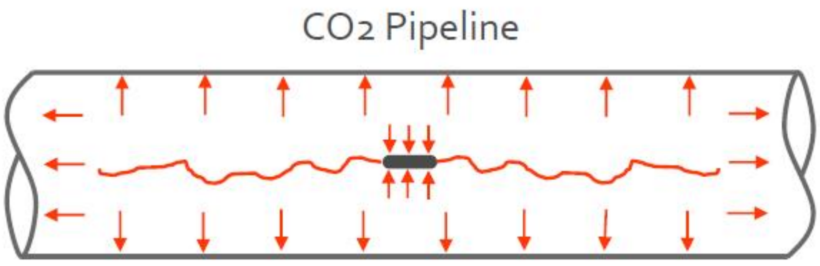
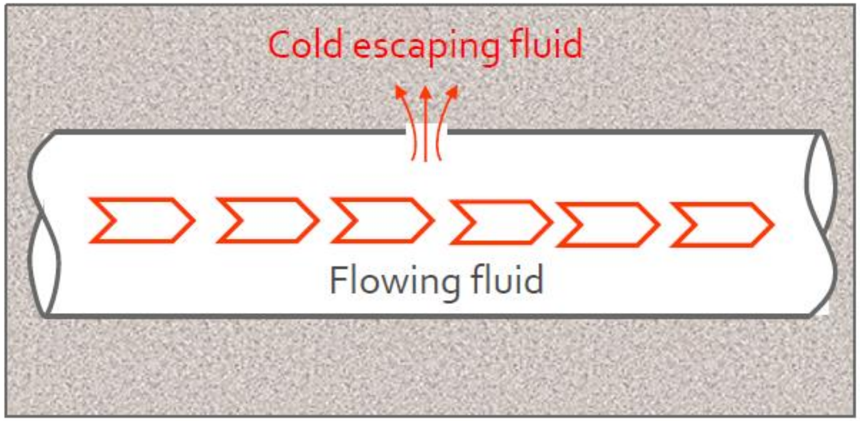


Localized pressure



Thermal stresses

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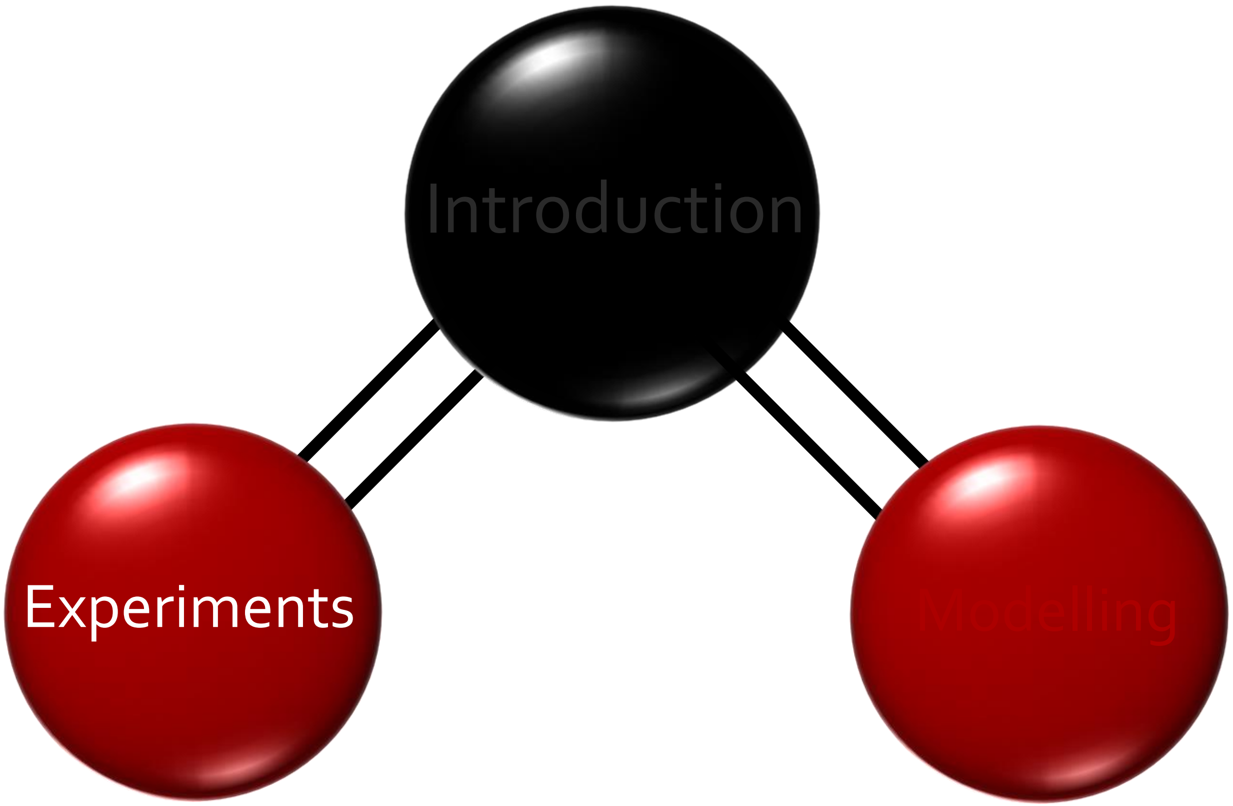

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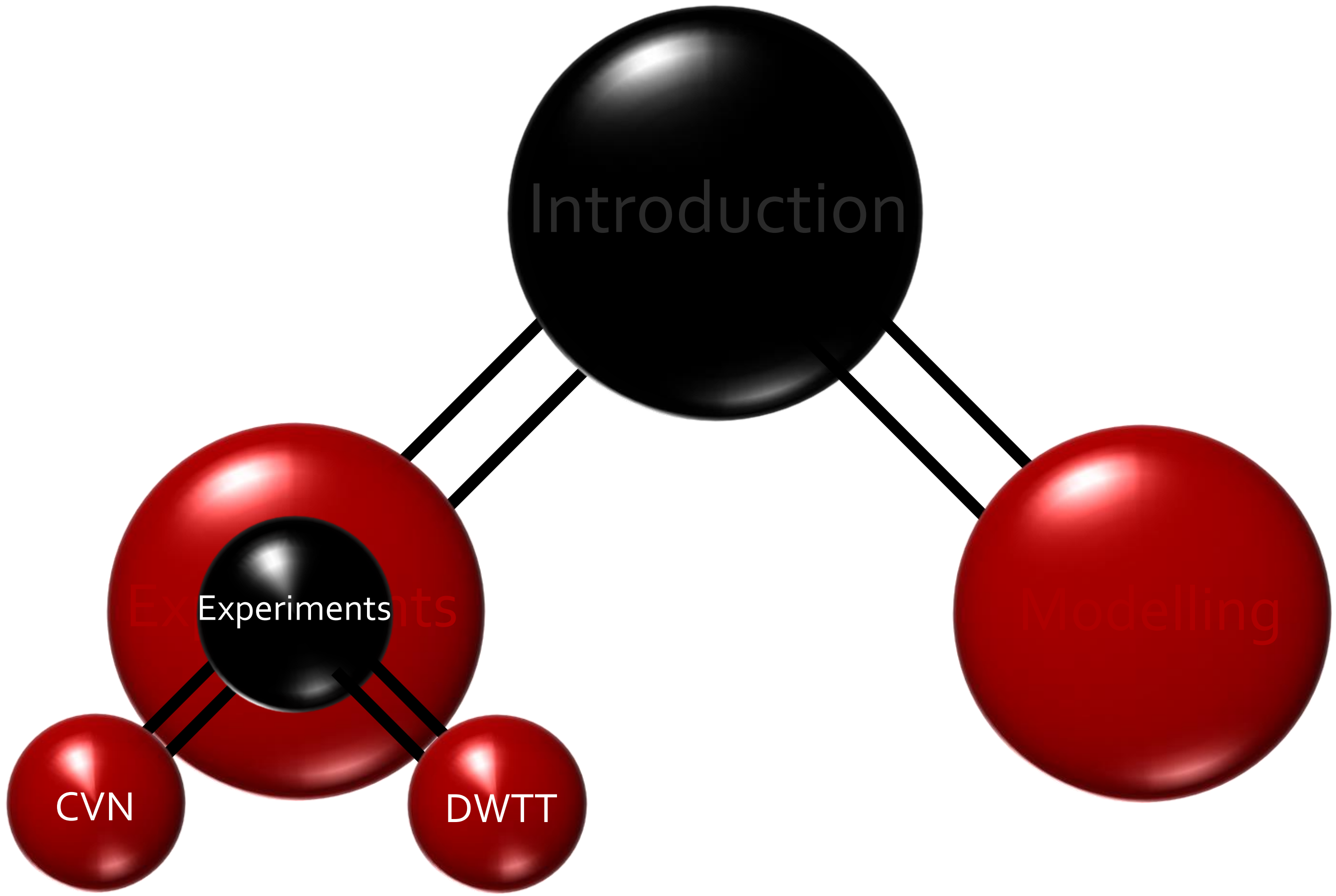

Charpy V-Notch (CVN)

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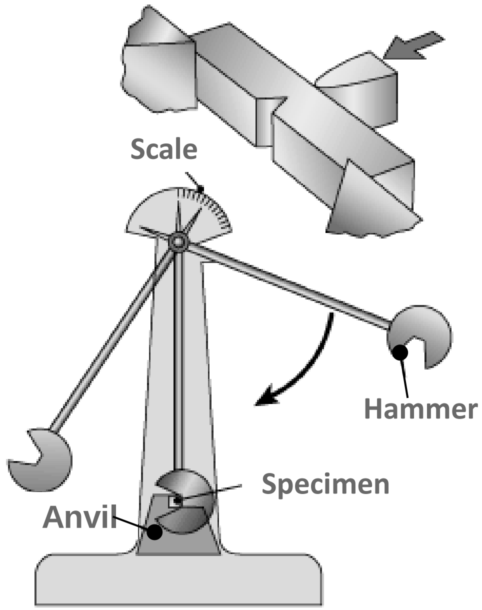

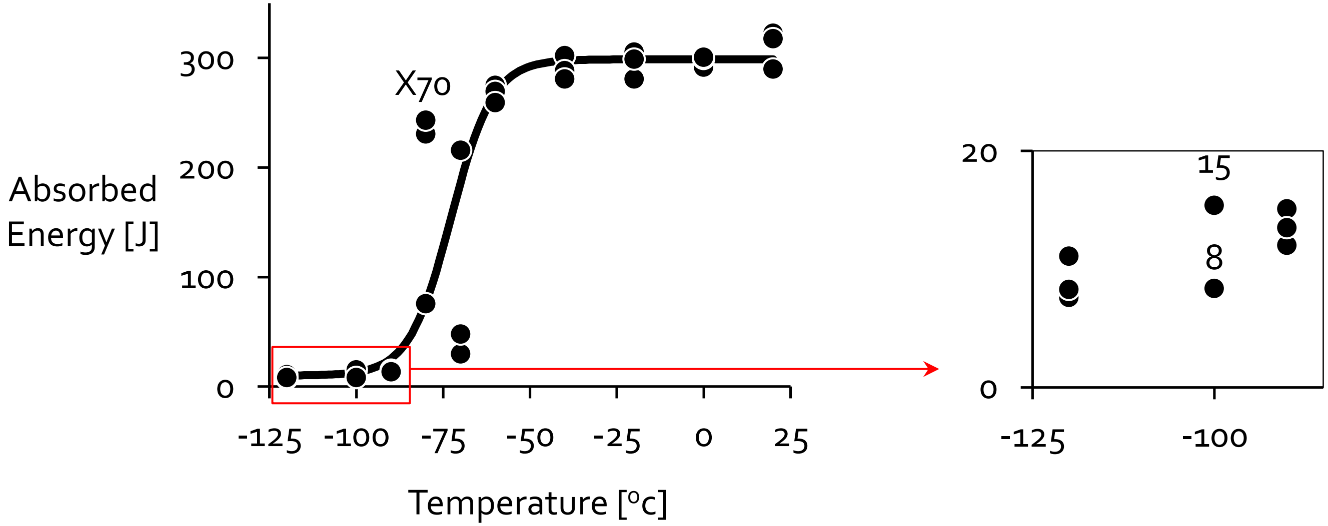

Drop Weight Tear Test (DWTT)

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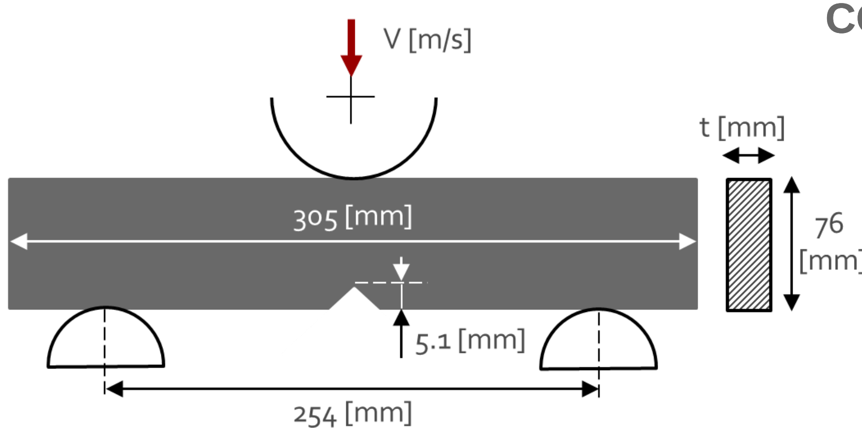
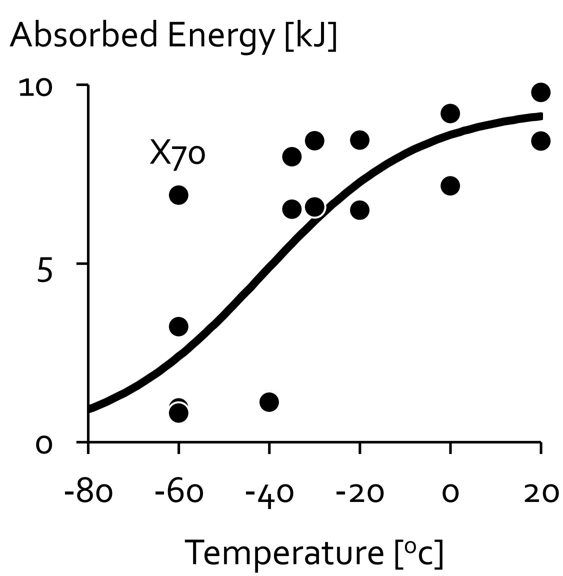
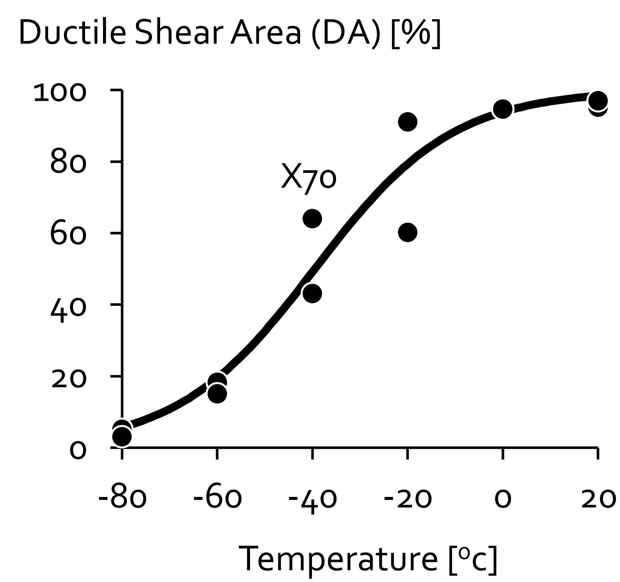
DWTT Set-up







Fractography

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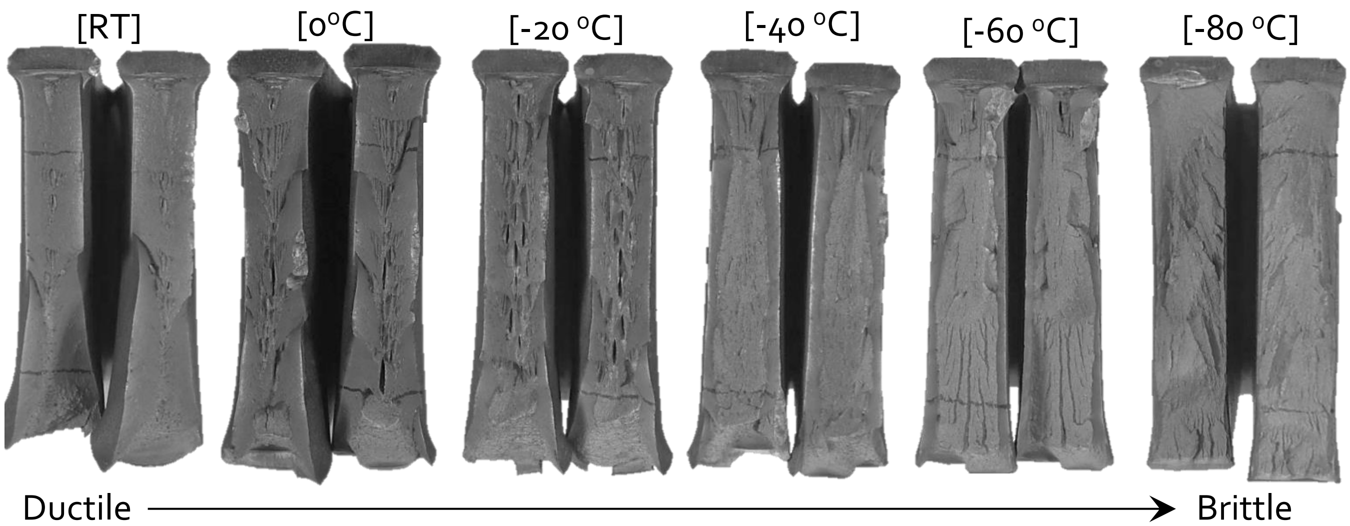

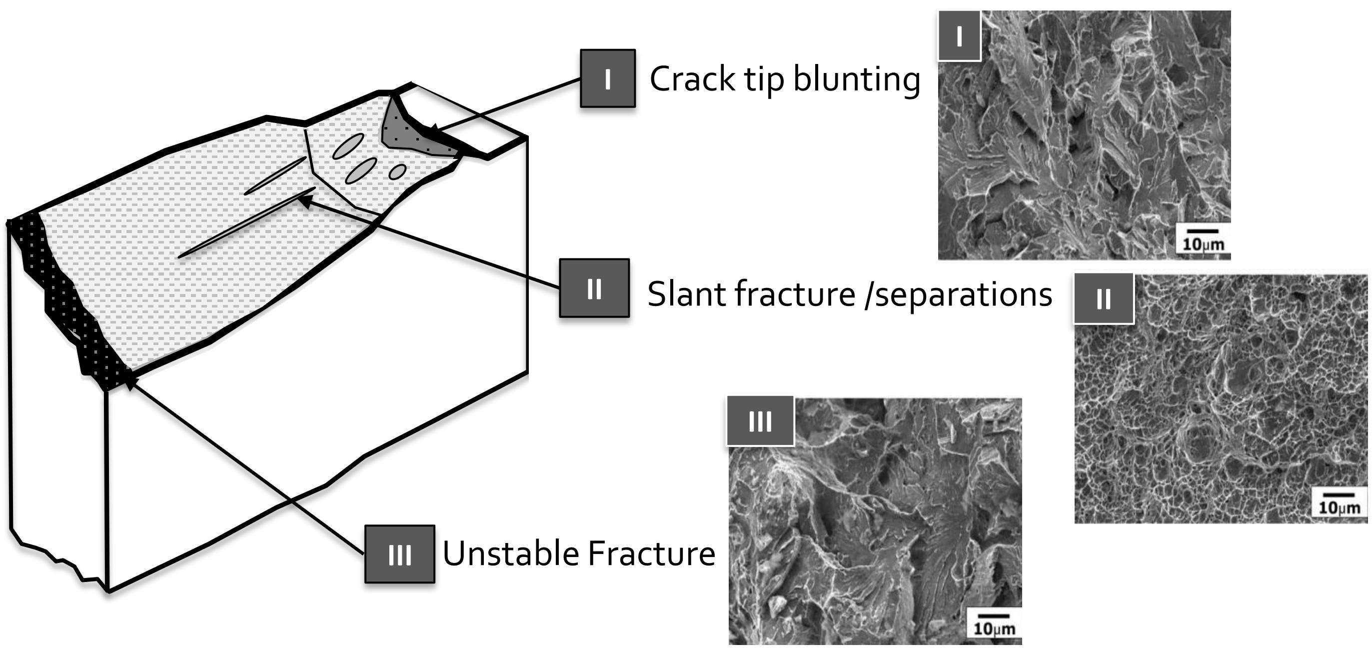

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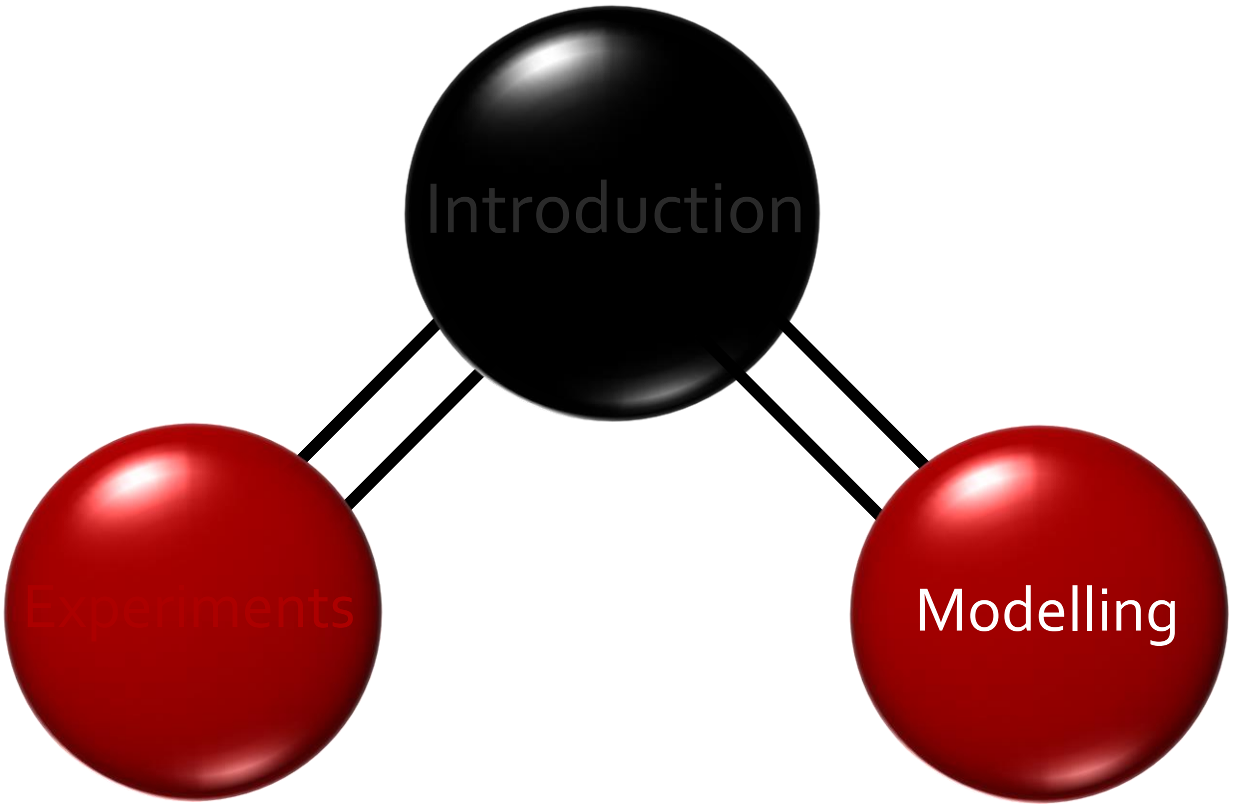

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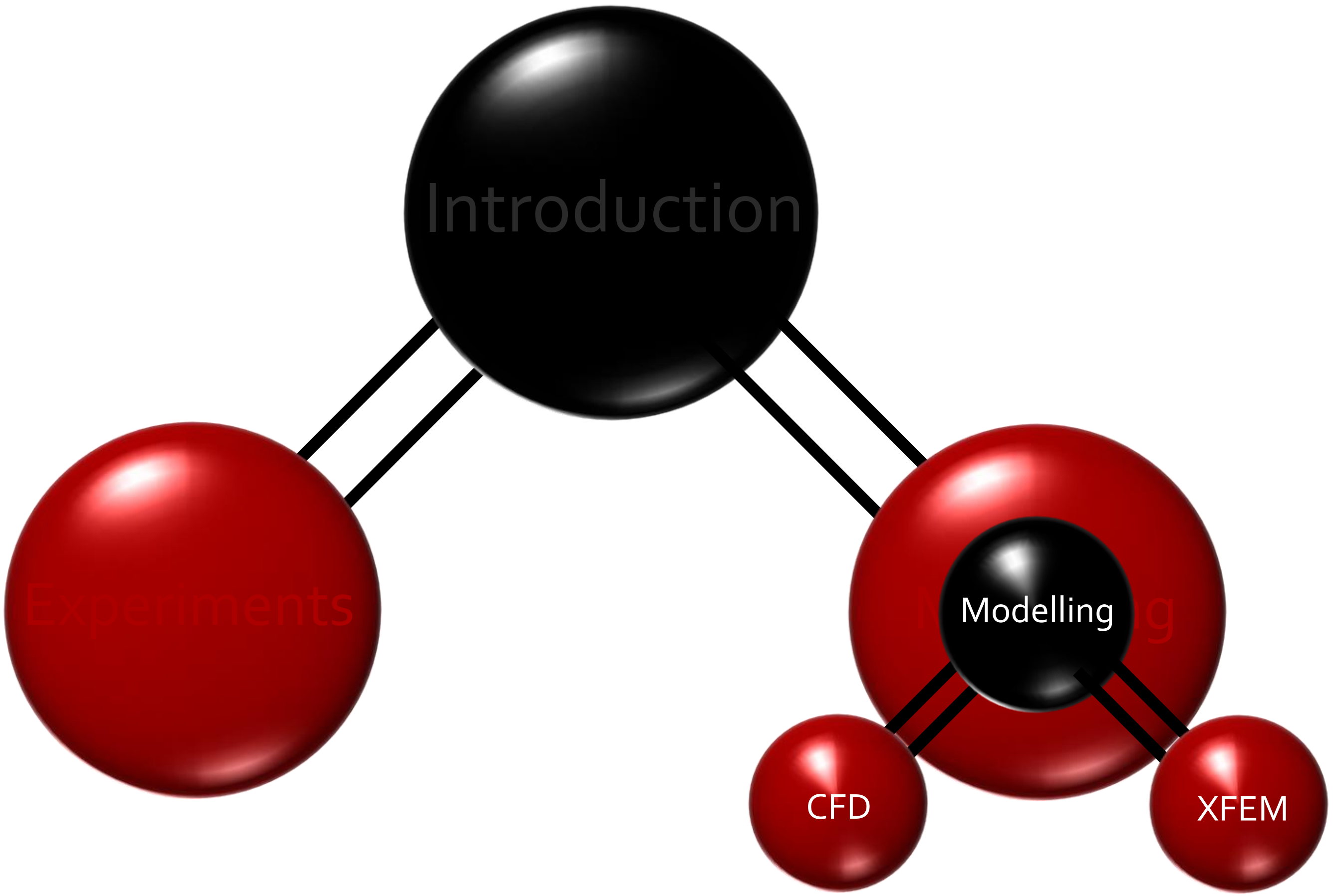

Pipeline flow model (CFD)

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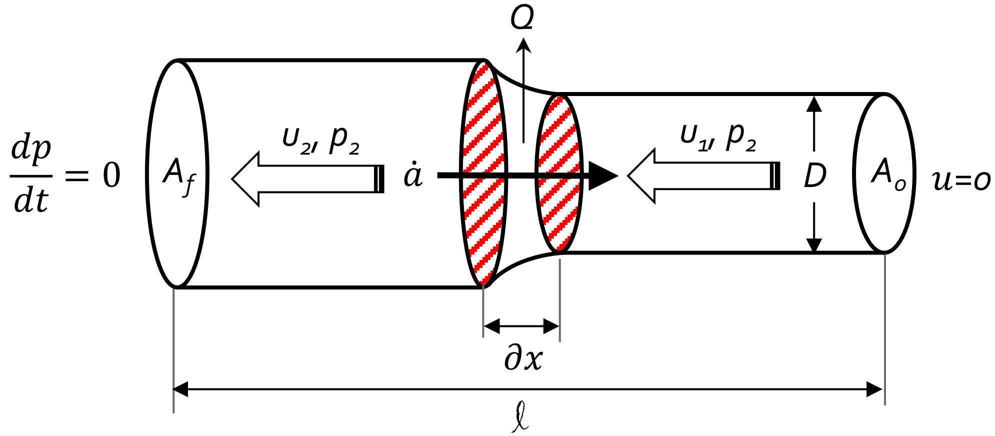
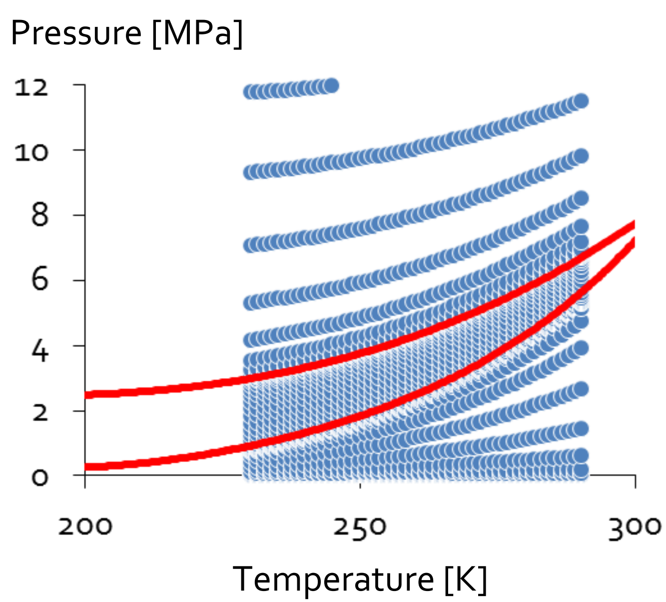
$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} = \mathbf{S}$$

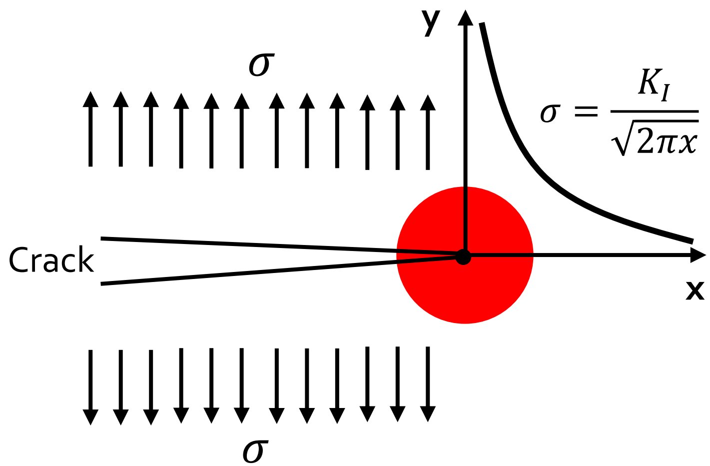
$$\begin{cases} \dfrac{\partial \rho A}{\partial t} + \dfrac{\partial \rho u A}{\partial x} = 0 \\ \dfrac{\partial \rho u A}{\partial t} + \dfrac{\partial \rho A u^2 + PA}{\partial x} = P\dfrac{\partial A}{\partial x} \\ \dfrac{\partial \rho E A}{\partial t} + \dfrac{\partial \rho u H A}{\partial x} = 0 \\ \dfrac{\partial A}{\partial t} + \dot{a}\dfrac{\partial A}{\partial x} = 0 \end{cases}$$

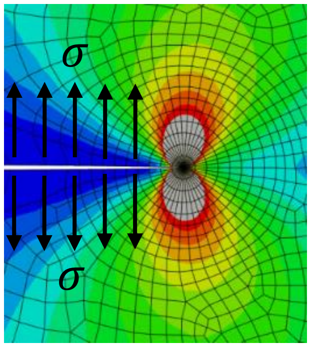
$$E = e + \frac{1}{2}u^2$$



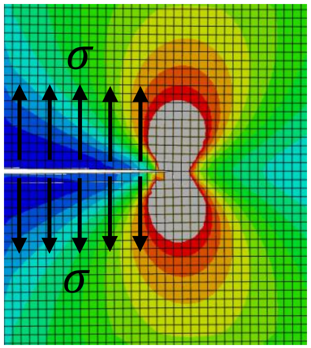


Fracture propagation model (XFEM)





FEM



XFEM

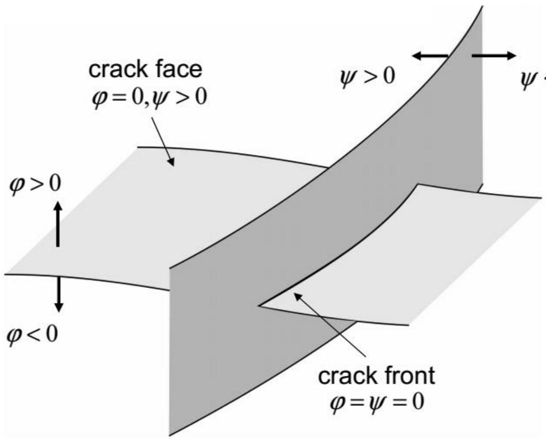
Heaviside enrichment function

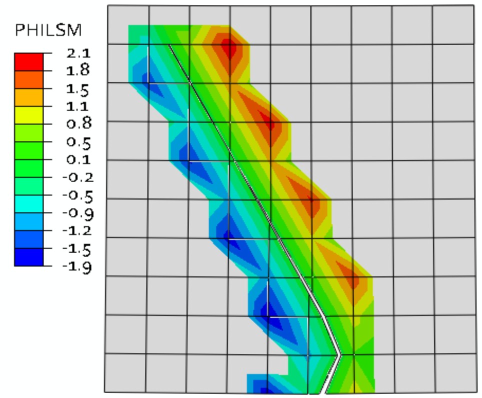
$$u^h(x) = \sum_{I \in S_A} N_I(x) u_I + \sum_{J \in S_H} N_J(x) H(x) q_J^0 + \sum_{K \in S_c} \sum_{\alpha=1}^{4} N_K(x) F_\alpha(x) q_K^\alpha$$

FEM

Crack tip enrichment function

XFEM-based cohesive segment



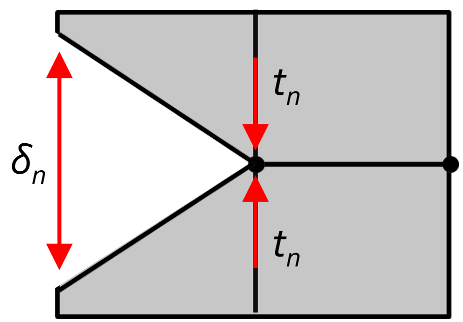


- Crack initiation

$$f = \left\{ \frac{\langle \sigma_{max} \rangle}{T_{max}} \right\}$$

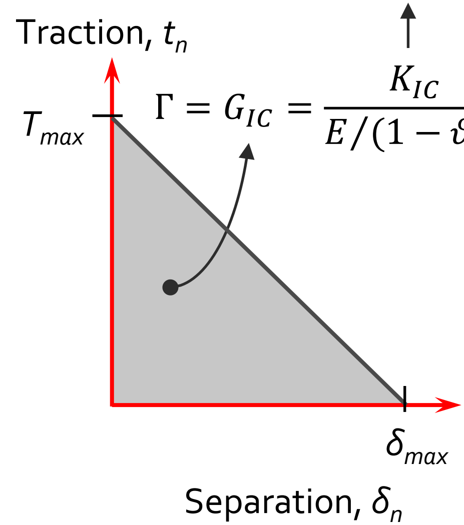
- Crack Propagation

$$D = \int_0^{\delta_{max}} \frac{T_{max}}{\Gamma} d\delta$$



$$K_{IC} = 6.67(CV)^{\frac{3}{4}}$$

$$\Gamma = G_{IC} = \frac{K_{IC}}{E/(1-\vartheta^2)}$$



CVN model

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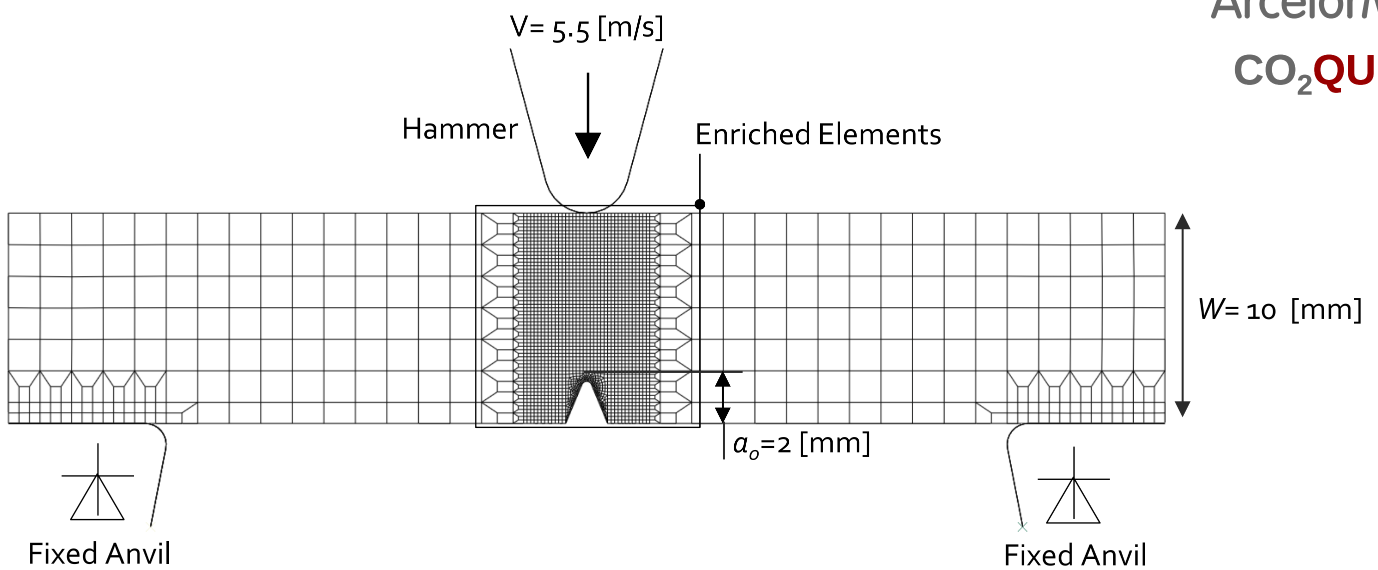
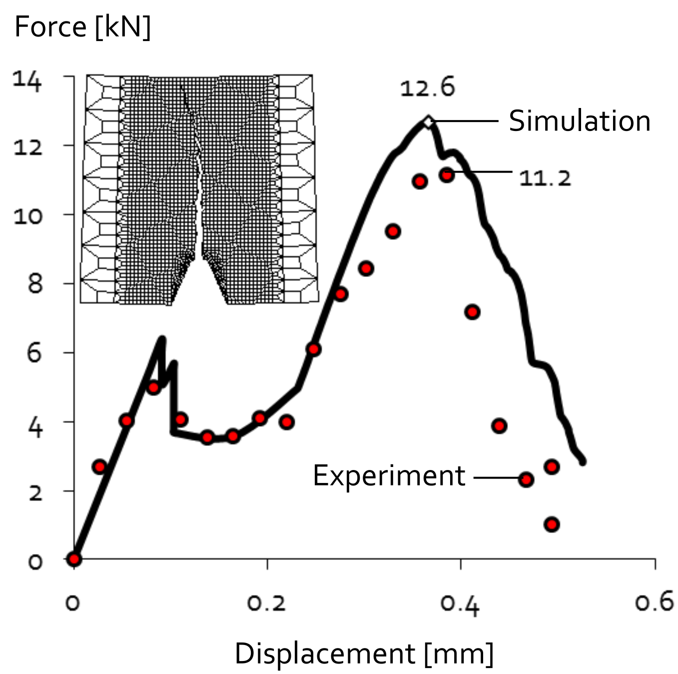
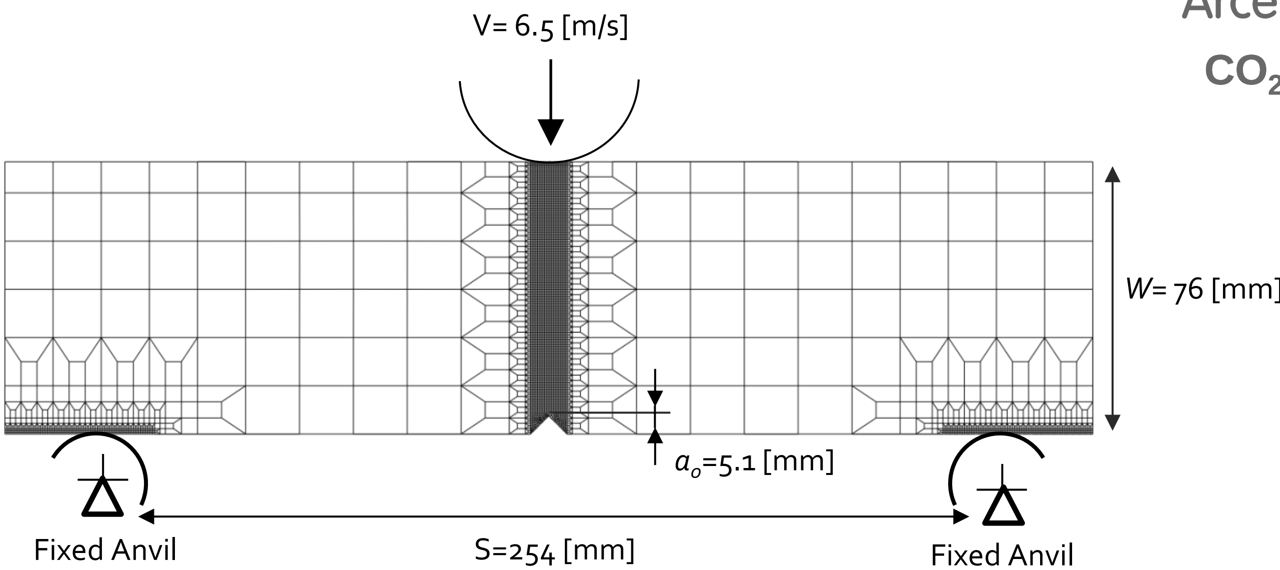
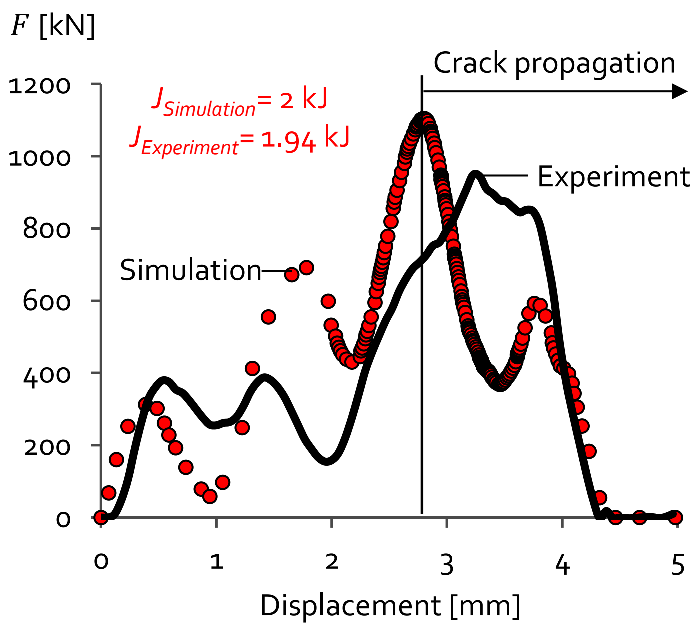




DWTT model



V= 6.5 [m/s]
W= 76 [mm]
a_o=5.1 [mm]
Fixed Anvil
S=254 [mm]
Fixed Anvil



F [kN]
1200
1000
800
600
400
200
0
0
1
2
3
4
5
Displacement [mm]
J_Simulation= 2 kJ
J_Experiment= 1.94 kJ
Crack propagation
Experiment
Simulation

Crack speed

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$$K_{ID} = \frac{E\delta_{CMOD}}{\beta\sqrt{a\alpha}} \times \frac{C_1(\alpha)}{C_2(\alpha)}$$

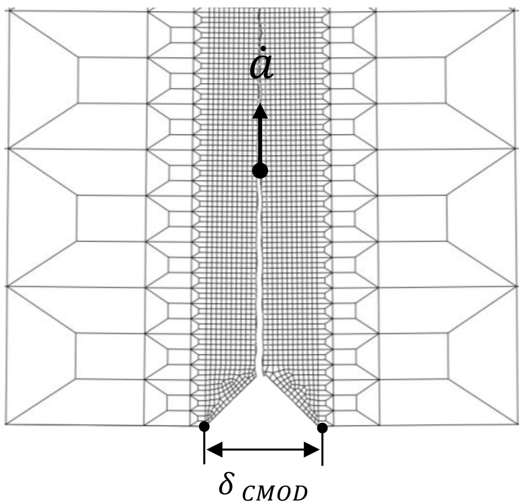
Nishioka and Atluri (1982)

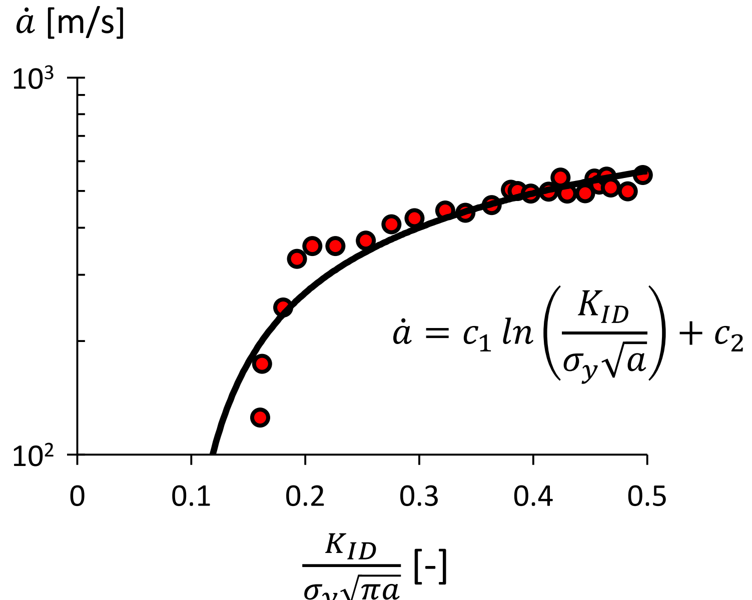
$\alpha = a/W$

$\beta = S/W$

$$C_1(\alpha) = \frac{\sqrt{\alpha}}{\sqrt[2]{(1-\alpha)^3}(1+3\alpha)}(1.9 + 0.41\alpha^2 - 0.17\alpha^3)$$

$$C_2(\alpha) = 0.76 - 2.28\alpha + 3.87\alpha^2 - 2.04\alpha^3 + (0.6/(1-\alpha)^2)$$





Coupled fluid/structure model

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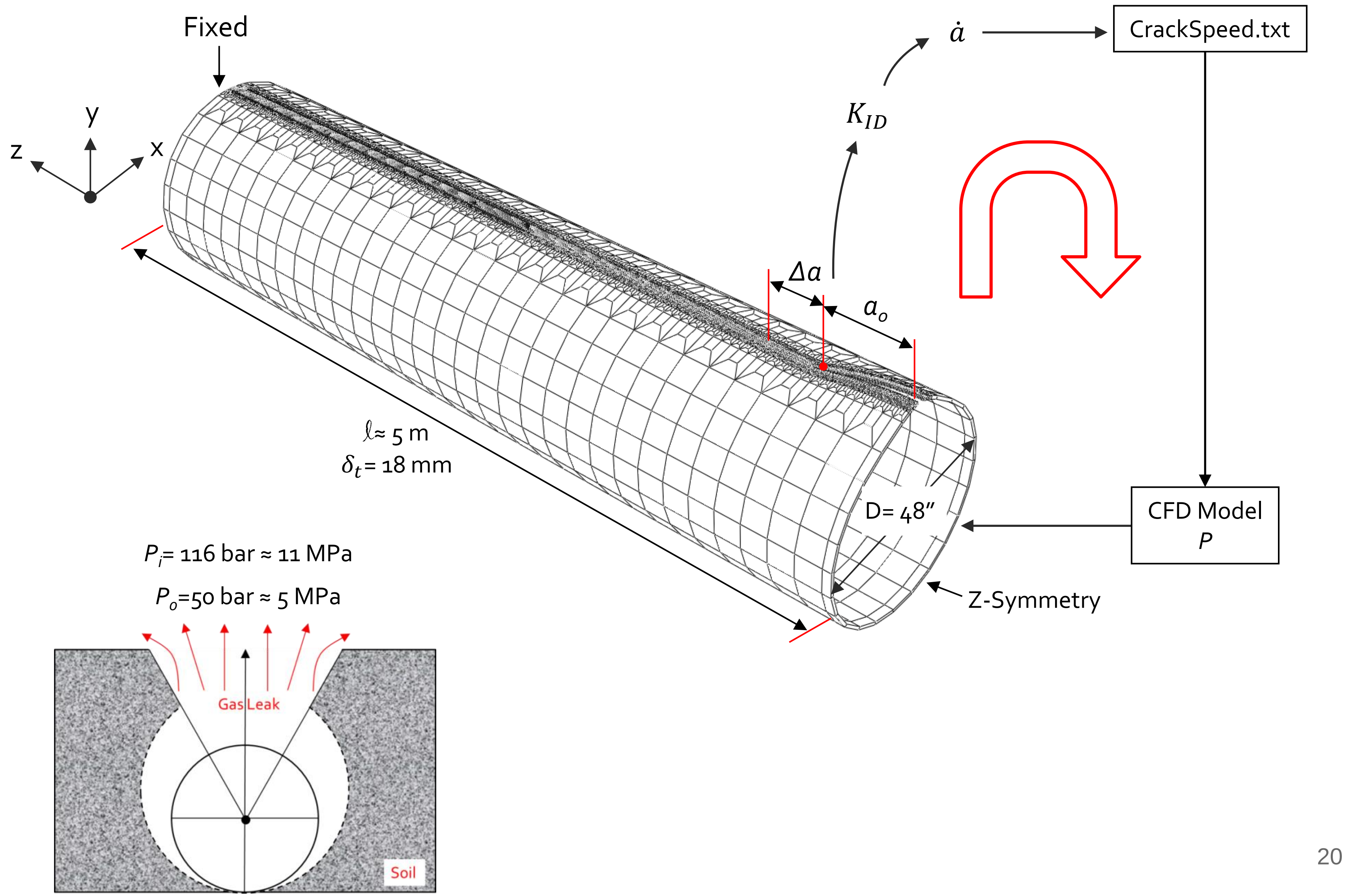
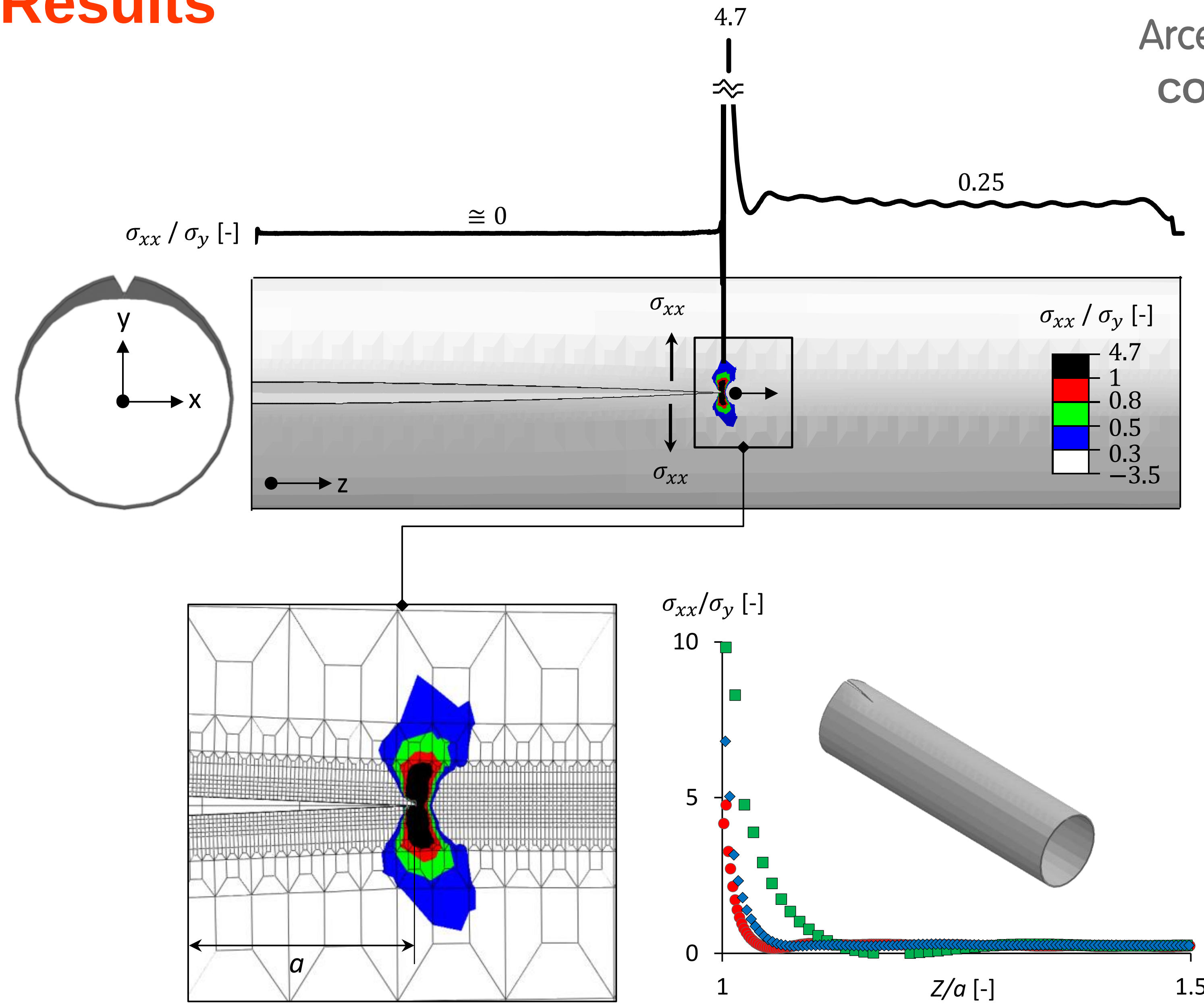


Results


4.7
0.25
≅ 0
σxx / σy [-]
y
x
z
σxx
σxx
σxx / σy [-]
4.7
1
0.8
0.5
0.3
−3.5
a
σxx/σy [-]
10
5
0
1
Z/a [-]
1.5

Verification

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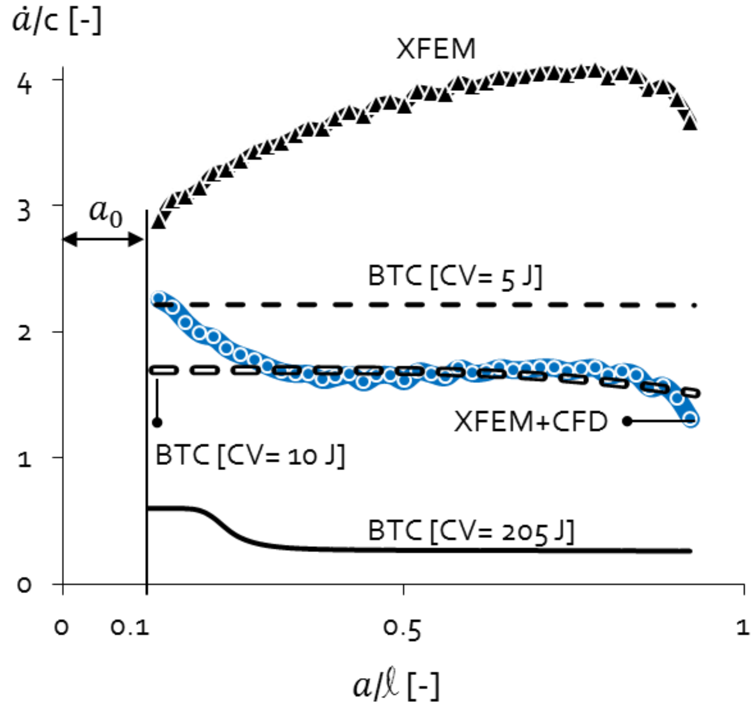
$$\dot{a} = 0.67 \frac{\sigma_f}{\sqrt{J_{DWTT}/A_p}} (P/P_a - 1)^{0.393}$$

Makino et al., 2001

$$P_a = 0.382 \frac{\delta_t}{D} \times \sigma_f \times cos^{-1}\left(exp\left(-\frac{3.81 \times 10^7}{\sqrt{D\delta_t}} \times \frac{J_{DWTT}/A_P}{{\sigma_f}^2}\right)\right)$$

$$J_{DWTT} = 3.29{\delta_t}^{1.5}\, {C_V}^{0.544}$$

$$\sigma_f = 0.5(\sigma_y + \sigma_u)$$



Acknowledgements and Disclaimer

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