ISPR 2017 TU WIEN, Sept 2017

Department of Mechanical Engineering

Structural Integrity of Complex Components by Means of the Strain Energy Density Approach

F. Berto and Jan Torgersen

Prof Filippo Berto

Chair of Mechanics and Materials

Professor of Fatigue Design

Norwegian University of Science and Technology

TECHNISCHE UNIVERSITÄT WIEN

ISPR 2017

13-15 September 2017, Vienna

Üretim Araştırmaları Derneği

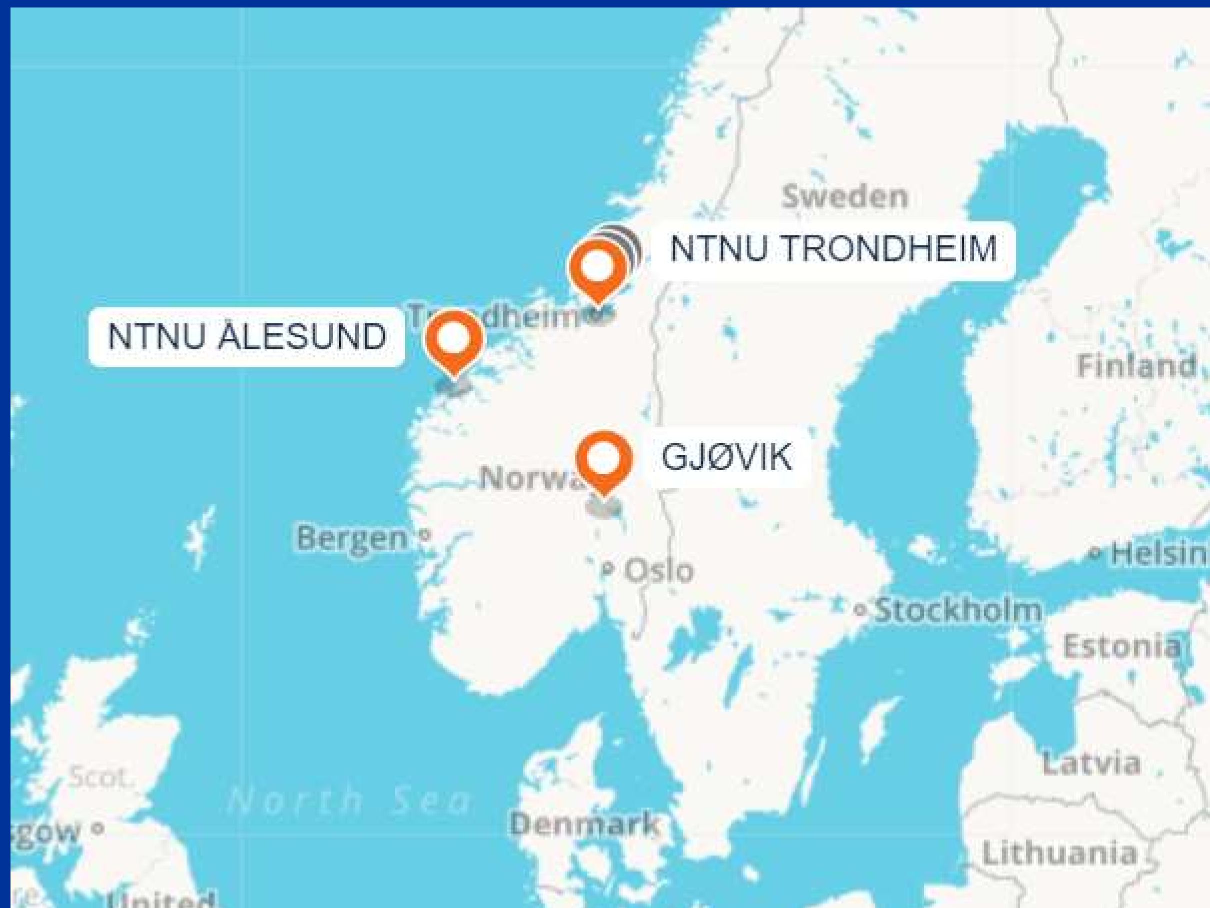
Outline of Presentation

Department of Mechanical Engineering

- Introduction
- Objectives
- Theoretical Background
- Testing
- SED applied for fatigue assessment
- Ongoing projects

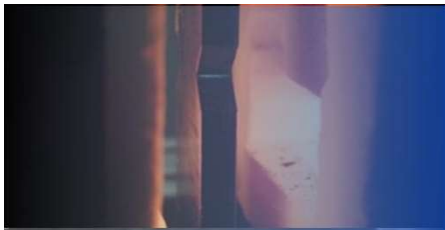
NTNU

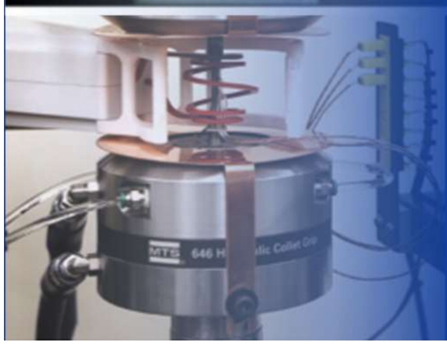
Department of Mechanical Engineering



NTNU

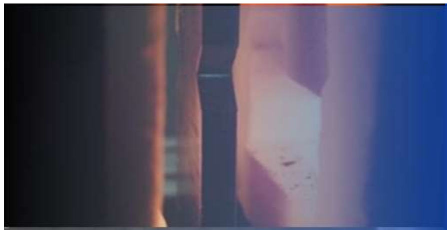
Department of Mechanical Engineering

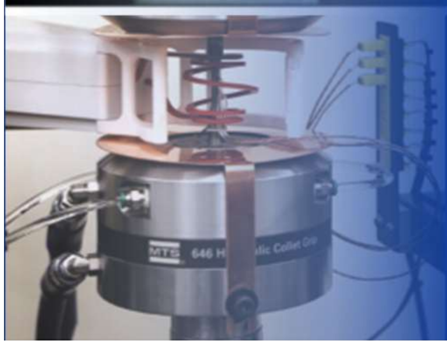
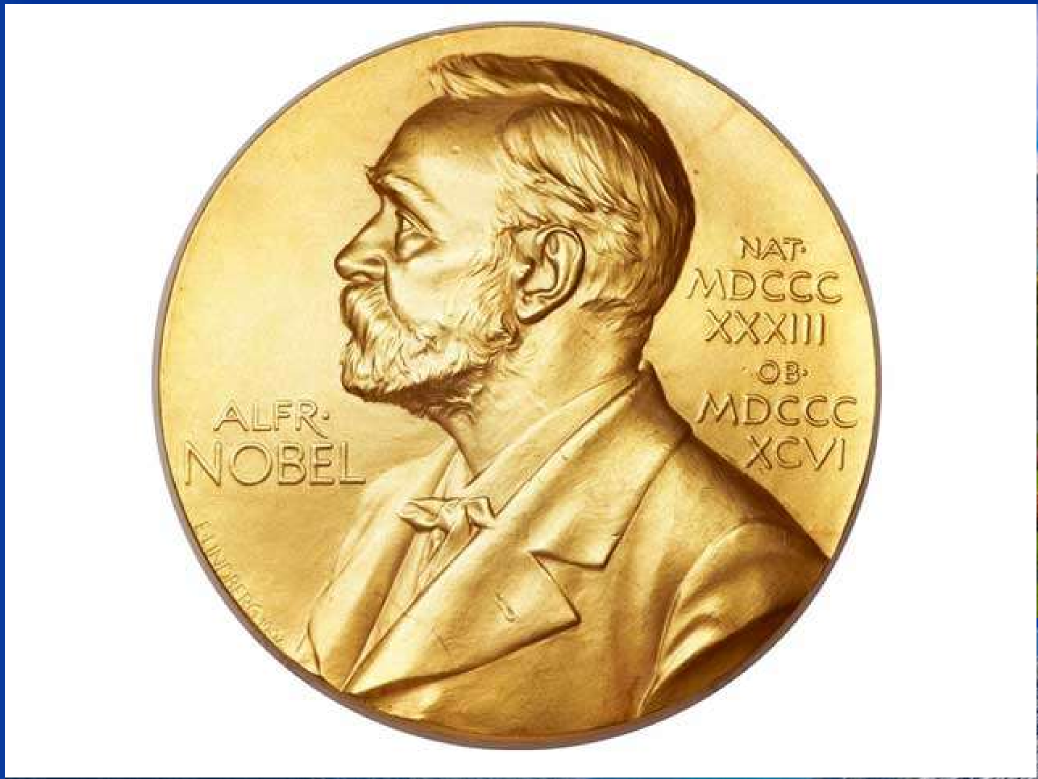



30000 students
40 faculties
Nobel prize award 2014

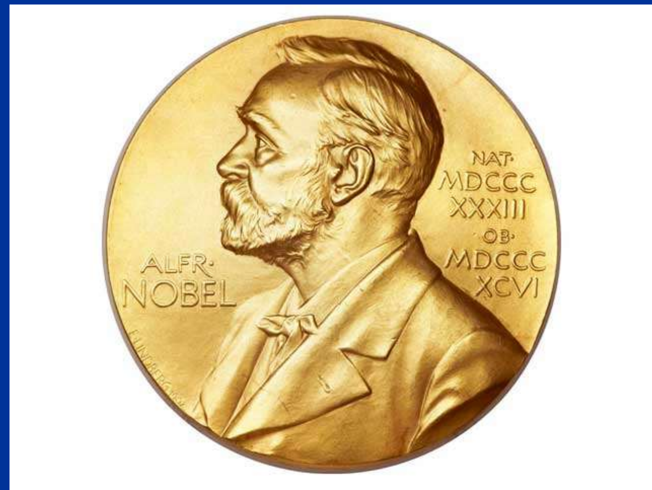
Department of Mechanical Engineering



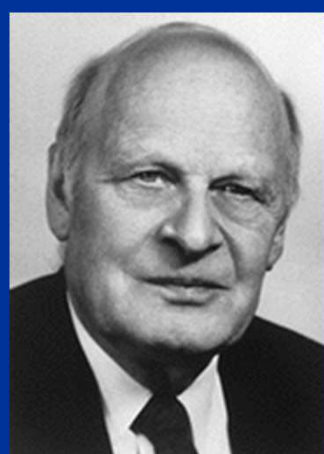




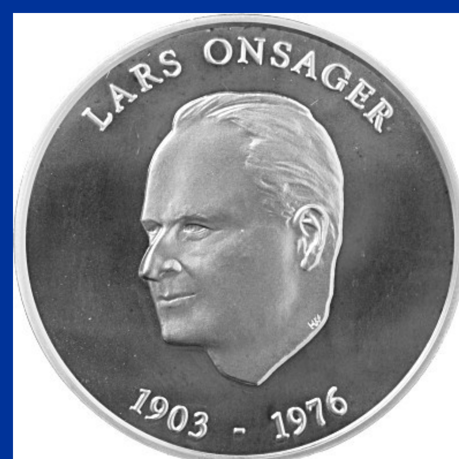


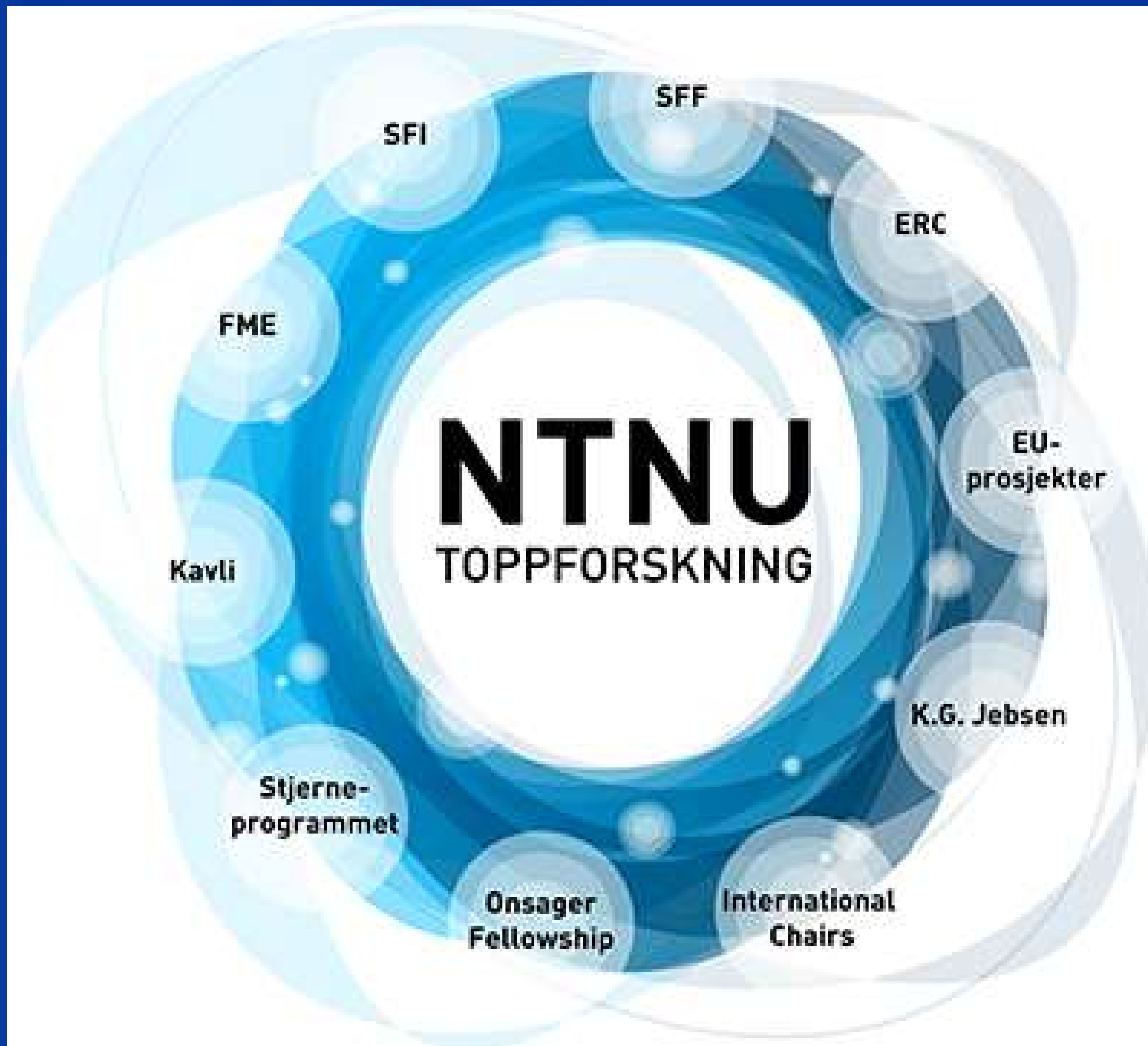
30000 students
40 faculties
Nobel prize award 2014



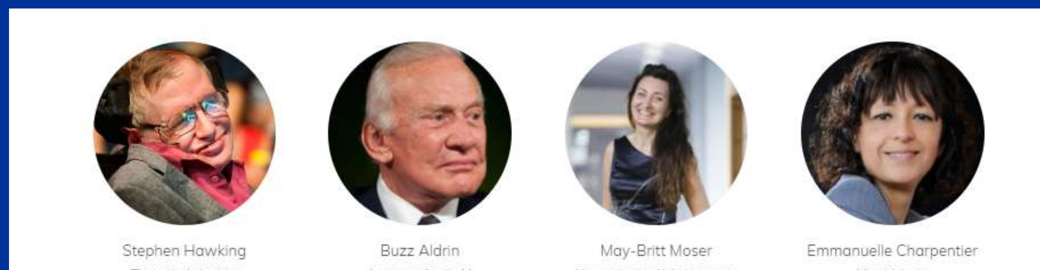
- 1968 Lars Onsager, Chemistry (graduate engineer from Norwegian Institute of Technology, NTH, in 1925)
- 1973 Ivar Giaever, Physics (graduate engineer from Norwegian Institute of Technology, NTH, in 1952)
- 2014 Edvard Moser, Medicine or Physiology (professor of neuroscience, NTNU)
- 2014 May-Britt Moser, Medicine or Physiology (professor of neuroscience, NTNU)
- 2014 John O'Keefe, Medicine or Physiology [31] (visiting researcher, NTNU 2015–)

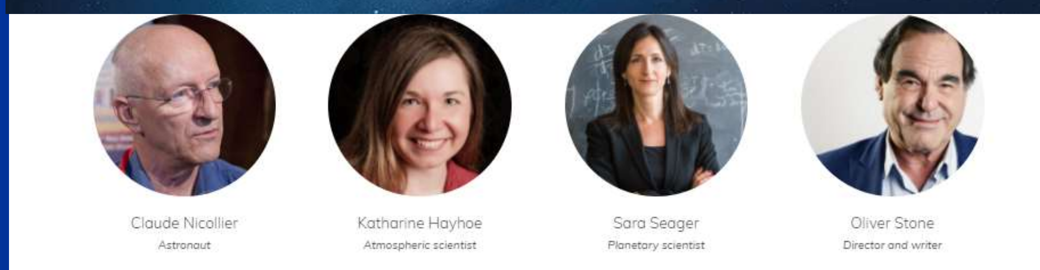





NTNU
TOPPFORSKNING
SFF
SFI
ERC
FME
EU-
prosjekter
Kavli
K.G. Jebsen
Stjerne-
programmet
Onsager
Fellowship
International
Chairs

NTNU
Department of Mechanical Engineering





Structural Mechanics and Materials Research Group

NTNU
Department of Mechanical Engineering

Staff in my group:
3 Academics
2 Research Fellows
~ 10 PhD students
Supported by workshop and admin staff

Research Directions:
Fatigue of metallic and non metallic materials
Solid and Fracture Mechanics
Structural Integrity of welding under fatigue loadings
Material Science
Full scale testing
Structural Health Monitoring

Structural Mechanics and Materials Research Group

Department of Mechanical Engineering

Facilities:

Welding facilities

Mechanical testing capabilities (more than 80 MEuro)

NanoLab

Lazzarin fatigue Lab (15 MEuro)

Collaboration:

Collaborative work with Norwegian, Australian, European, Canadian and South Korean Universities and Research Centres

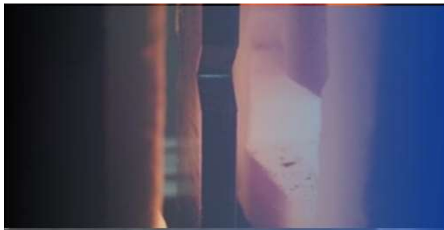
Department of Mechanical Engineering





NTNU

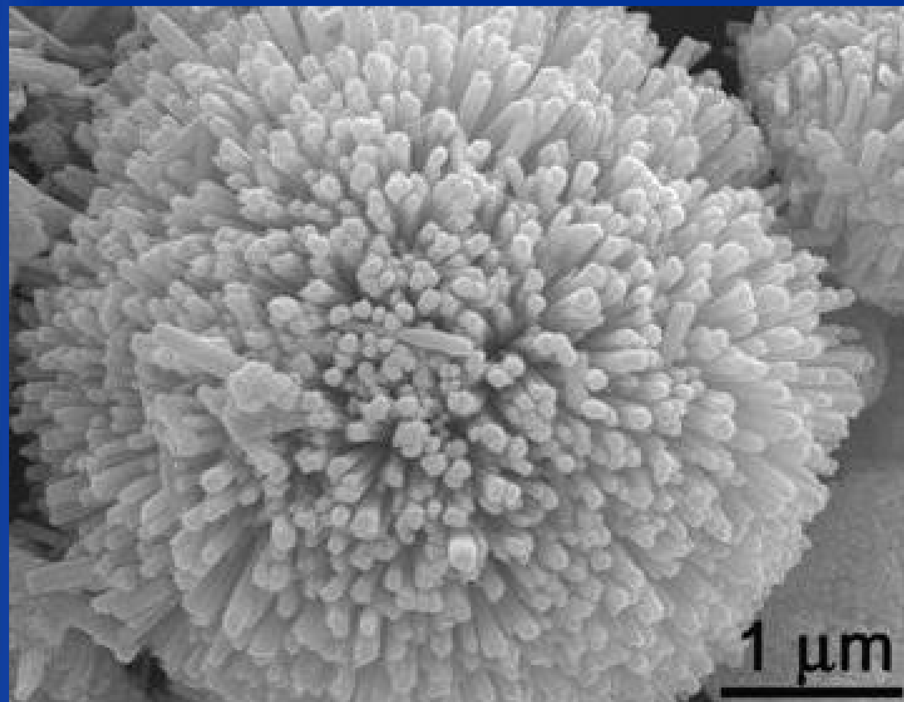
Department of Mechanical Engineering

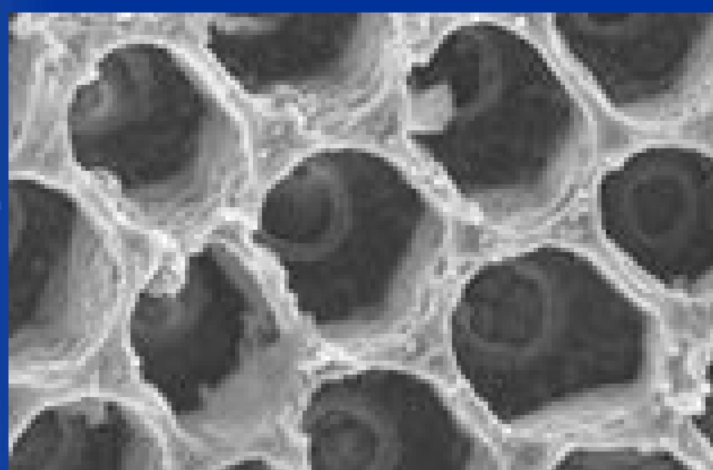


3/01/2018

NTNU

Department of Mechanical Engineering





OBJECTIVES

Department of Mechanical Engineering

The present work investigates the multiaxial fatigue strength of sharp V-notched components made of titanium grade 5 alloy (Ti-6Al-4V).

Axi-symmetric notched specimens have been tested under combined tension and torsion fatigue loadings, both proportional and non-proportional, taking into account different nominal load ratios (R = -1 and R=0) and biaxiality ratios ($\lambda=\tau/\sigma=2$ and 0.6). All tested samples have a notch root radius about equal to 0.1 mm, a notch depth of 6 mm and an opening angle of 90 degrees.

Altogether, more than 250 fatigue results (19 S-N curves) are examined, first on the basis of nominal stress amplitudes referred to the net area and secondly by means of the strain energy density averaged (Lazzarin and Zambardi, 2001) over a control volume embracing the V-notch tip.

Department of Mechanical Engineering

Strain Energy Density

NTNU
Department of Mechanical Engineering

Beltrami E (1885) Sulle condizioni di resistenza dei corpi elastici, Rend. R. Ist. Lombardo di Scienze, Lettere e Arti, 18, 704 (in Italian)

Gillemot L (1965) Brittle fracture of welded materials. Commonwealth Welding Conference C.7.353-358.

Gillemot L (1976) Criterion of crack initiation and spreading, Engng Fract Mech 8 239-253.

Gillemot L, Czoboly E and Havas I (1985) Fracture mechanics applications of absorbed specific fracture energy: Notch and unnotched specimens Theor Appl Fract Mech 4 39-45

Sih GC (1974) Strain-energy-density factor applied to mixed mode crack problems.Int J Fract 10 305-321.

Sih GC (1991) Mechanics of Fracture Initiation and Propagation: Surface and volume energy density applied as failure criterion, Kluwer Academic Publisher, Dordrecht

Sih GC, Tang XS (2005) Scaling of volume energy density function reflecting damage by singularities at macro-, meso- and microscopic level. Theor Appl Fract Mech 43 211–231.

Sih GC (2007) Multiscaling in molecular and continuum mechanics: interaction of time and size from macro to nano. Dordrecht: Springer.

Sih G.C. (2011) Pseudo global energy released locally by crack extension involving multiscale reliability

Theoretical and Applied Fracture Mechanics 55 (2011) 52–59

Ellyin F., Kujawski D (1989) Generalization of notch analysis and its extension to cyclic loading. Engineering Fracture Mechanics 32 819-826

Ellyin F (1997) Fatigue Damage, Crack Growth and Life Prediction, Chapman & Hall, London

Glinka G (1985) Energy density approach to calculation of inelastic strain-stress near notches and cracks Engng Fract Mech 22 485-508.

Gdoutos EE (1990) Fracture Mechanics Criteria and Applications, Dodrecht: Kluwer Academic Publishers; 1990.

Park J, Nelson D (2000) Evaluation of an energy-based approach and a critical plane approach for predicting constant amplitude multiaxial fatigue life. Int J Fatigue 22 23-39.

VARIATION OF THE STRAIN ENERGY DENSITY AT THE NOTCH TIP FOR BLUNT NOTCHES

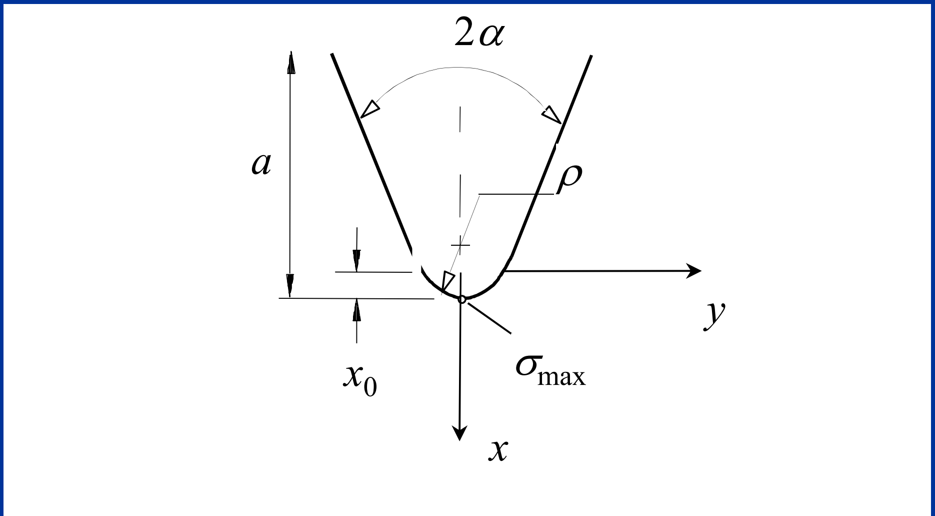
NTNU
Department of Mechanical Engineering

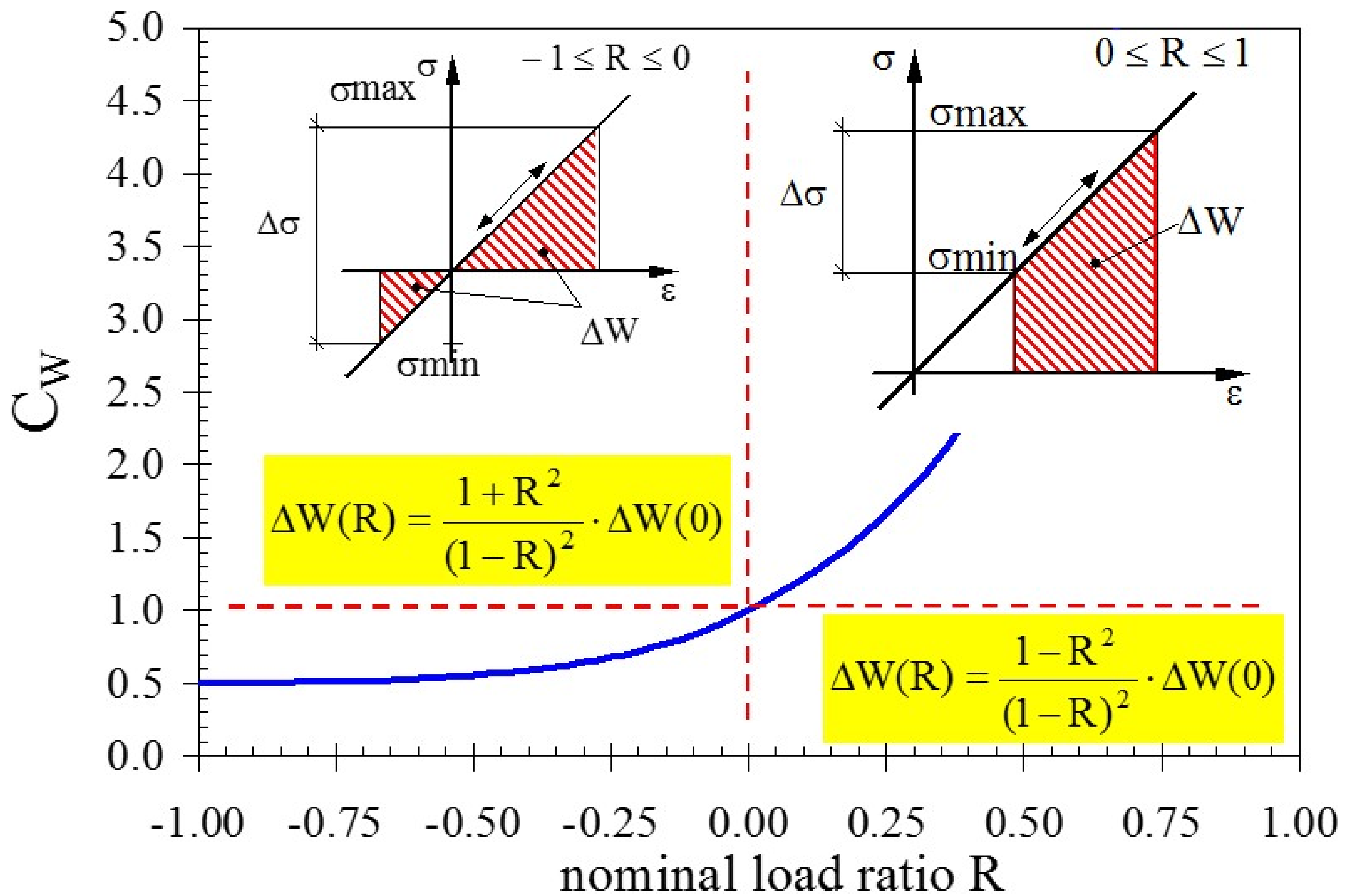
$$W^{(e)} = \frac{1}{2E}\left[\sigma_{rr}^{\ 2} + \sigma_{\theta\theta}^{\ 2} + \sigma_{zz}^{\ 2} - 2\nu\left(\sigma_{rr}\sigma_{\theta\theta} + \sigma_{rr}\sigma_{zz} + \sigma_{\theta\theta}\sigma_{zz}\right) + 2(1+\nu)\left(\sigma_{r\theta}^{\ 2} + \sigma_{rz}^{\ 2} + \sigma_{\theta z}^{\ 2}\right)\right]$$

$$\Delta W_t = c_w \cdot \frac{1}{2\cdot E} \cdot \left(\Delta\sigma_{p,el}^2 + 2\cdot(1+\nu)\cdot \Delta\tau_{p,el}^2\right)$$

$$\Delta W_t = c_w \cdot \frac{1}{2\cdot E} \cdot \left(k_{t\,net,ax}^2 \cdot \Delta\sigma_{net}^2 + 2\cdot(1+\nu)\cdot k_{t\,net,tors}^2 \cdot \Delta\tau_{net}^2\right)$$

$$c_w(R) = \begin{cases} \dfrac{1+R^2}{(1-R)^2} & \text{if} \quad -1 \le R < 0 \\ 1 & \text{if} \quad R = 0 \\ \dfrac{1-R^2}{(1-R)^2} & \text{if} \quad 0 < R \le 1 \end{cases}$$




C_W
nominal load ratio R
$-1 \le R \le 0$
$0 \le R \le 1$
σmax
σmin
Δσ
ΔW
σ
ε
$\Delta W(R) = \frac{1+R^2}{(1-R)^2} \cdot \Delta W(0)$
$\Delta W(R) = \frac{1-R^2}{(1-R)^2} \cdot \Delta W(0)$
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-1.00
-0.75
-0.50
-0.25
0.00
0.25
0.50
0.75
1.00

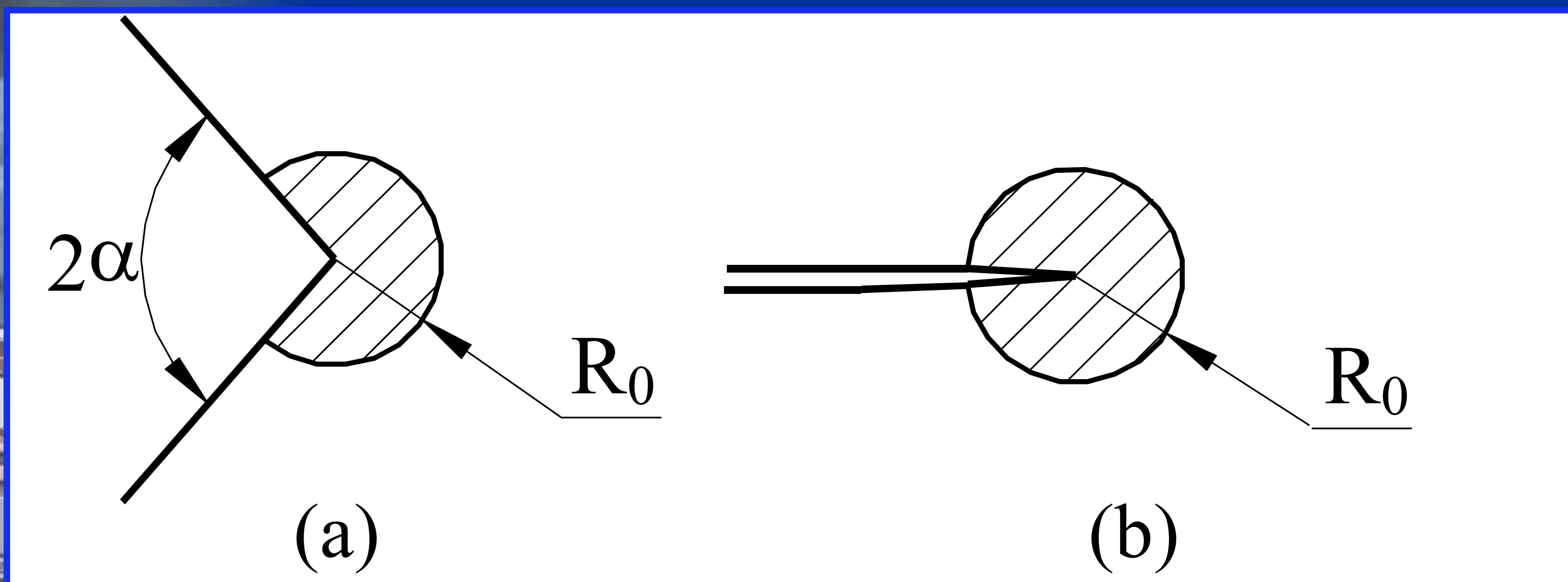
Analytical background

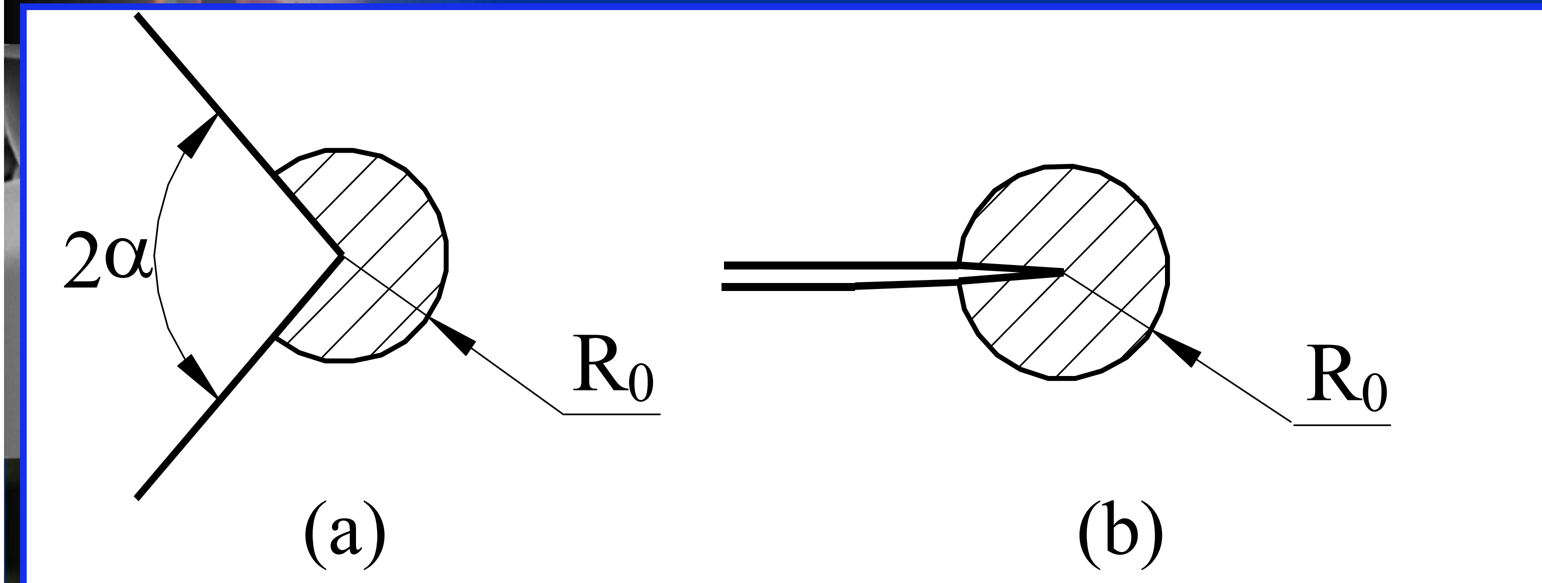
NTNU
Department of Mechanical Engineering

$$W(r,\theta) = W_1(r,\theta) + W_2(r,\theta) + W_{12}(r,\theta)$$

$$W_1(r,\theta) = \frac{1}{2E} r^{2(\lambda_1-1)} \cdot \left(K_1^N\right)^2 \left[\tilde{\sigma}_{\theta\theta}^{(1)^2} + \tilde{\sigma}_{rr}^{(1)^2} + \tilde{\sigma}_{zz}^{(1)^2} - 2\nu\left(\tilde{\sigma}_{\theta\theta}^{(1)}\tilde{\sigma}_{rr}^{(1)} + \tilde{\sigma}_{\theta\theta}^{(1)}\tilde{\sigma}_{zz}^{(1)} + \tilde{\sigma}_{rr}^{(1)}\tilde{\sigma}_{zz}^{(1)}\right) + 2(1+\nu)\tilde{\sigma}_{r\theta}^{(1)^2} \right]$$

$$W_2(r,\theta) = \frac{1}{2E} r^{2(\lambda_2-1)} \cdot \left(K_2^N\right)^2 \left[\tilde{\sigma}_{\theta\theta}^{(2)^2} + \tilde{\sigma}_{rr}^{(2)^2} + \tilde{\sigma}_{zz}^{(2)^2} - 2\nu\left(\tilde{\sigma}_{\theta\theta}^{(2)}\tilde{\sigma}_{rr}^{(2)} + \tilde{\sigma}_{\theta\theta}^{(2)}\tilde{\sigma}_{zz}^{(2)} + \tilde{\sigma}_{rr}^{(2)}\tilde{\sigma}_{zz}^{(2)}\right) + 2(1+\nu)\tilde{\sigma}_{r\theta}^{(2)^2} \right]$$





$$\Delta\overline{W} = \frac{e_1}{E}\left[\frac{\Delta K_1}{R_0^{1-\lambda_1}}\right]^2 + \frac{e_2}{E}\left[\frac{\Delta K_2}{R_0^{1-\lambda_2}}\right]^2$$

R_0: control volume radius

$$e_1 = -5.373\cdot 10^{-6}\,(2\alpha)^2 + 6.151\cdot 10^{-4}\,(2\alpha) + 0.1330$$

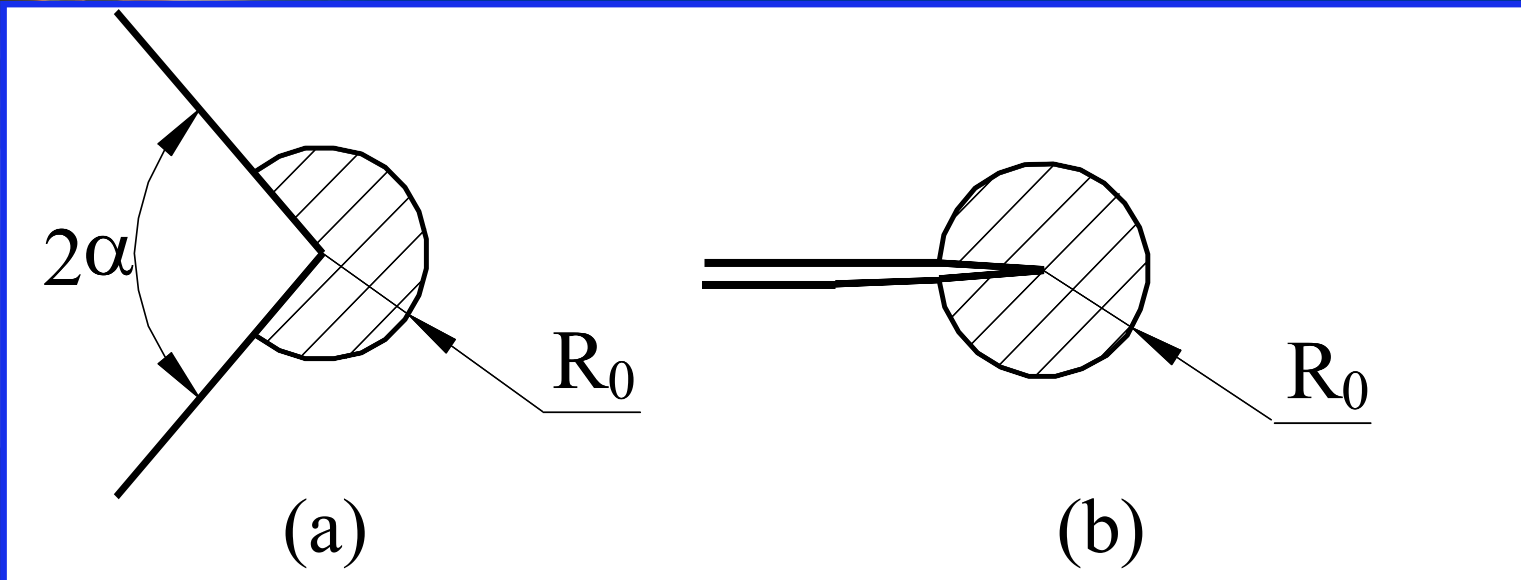
$$e_2 = 4.809\cdot 10^{-6}\,(2\alpha)^2 - 2.346\cdot 10^{-3}\,(2\alpha) + 0.3400$$

$e_{1,2}$: shape functions, which depend on the notch angle and Poisson's ratio

NTNU
Department of Mechanical Engineering

$$\Delta\overline{W} = c_w \left\{ \frac{e_1}{E}\left[\frac{\Delta K_1}{R_0^{1-\lambda_1}}\right]^2 + \frac{e_2}{E}\left[\frac{\Delta K_2}{R_0^{1-\lambda_2}}\right]^2 + \frac{e_3}{E}\left[\frac{\Delta K_3}{R_0^{1-\lambda_3}}\right]^2 \right\}$$

					Plane strain		Axis-sym.
2α [rad]	γ [rad]	λ_1	λ_2	λ_3	e_1	e_2	e_3
0	π	0.5000	0.5000	0.5000	0.13449	0.34139	0.41380
$\pi/12$	$23\pi/24$	0.5002	0.5453	0.5217	0.13996	0.30588	0.39659
$\pi/6$	$11\pi/12$	0.5014	0.5982	0.5455	0.14485	0.27297	0.37929
$\pi/3$	$5\pi/6$	0.5122	0.7309	0.6000	0.15038	0.21530	0.34484
$\pi/2$	$3\pi/4$	0.5445	0.9085	0.6667	0.14623	0.16793	0.31034
$2\pi/3$	$2\pi/3$	0.6157	1.1489	0.7500	0.12964	0.12922	0.27587
$3\pi/4$	$5\pi/8$	0.6736	1.3021	0.8000	0.11721	0.11250	0.25863



$$SED = c_W \times \Delta\overline{W} = \frac{1}{E}\left[e_1 \times \frac{\Delta K_1^{\ 2}}{R_1^{\ 2(1-\lambda_1)}} + e_3 \times \frac{\Delta K_3^{\ 2}}{R_3^{\ 2(1-\lambda_3)}} \right]$$

$$R_1 = \left(\sqrt{2\, e_1} \times \frac{\Delta K_{1A}}{\Delta\sigma_{1A}} \right)^{\frac{1}{1-\lambda_1}}$$

$$R_3 = \left(\sqrt{\frac{e_3}{1+\nu}} \times \frac{\Delta K_{3A}}{\Delta\tau_{3A}} \right)^{\frac{1}{1-\lambda_3}}$$

NTNU
Department of Mechanical Engineering

Advantages

- Permits consideration of the scale effect
- Permits consideration of the contribution of different Modes
- Permits consideration of the cycle nominal load ratio
- Overcomes the complex problem tied to the different NSIF units of measure in the case of crack initiation at the toe ($2\alpha=135°$) or root ($2\alpha=0°$)
- SED can be evaluated with coarse meshes
- It directly takes into account the T-stress
- It directly includes three-dimensional effects
- Direct link with other local approaches (NSIFs, PS method, critical distances)
- Not specific coefficient to be set up

Tests

NTNU
Department of Mechanical Engineering

Analysis of the bi-axial fatigue behaviour of notched specimens in Ti6Al4V (Gr. 5) alloy under combined tensile and torsion loading, both in-phase and out-of-phase, with particular reference to the evaluation of HCF

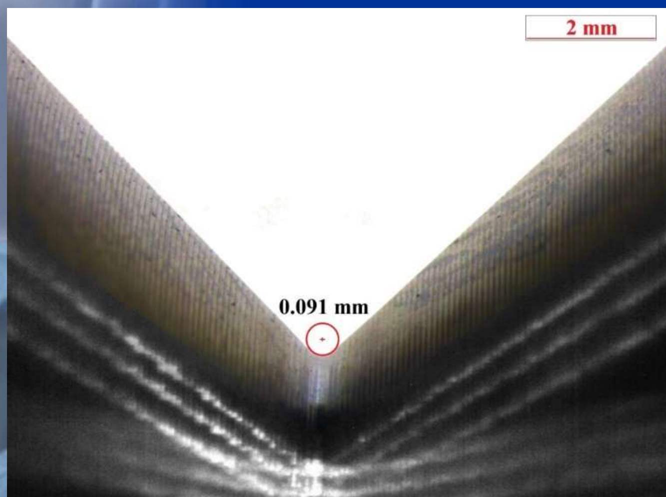
Application of an energy-based approach to summarise the fatigue data in presence of severe notches

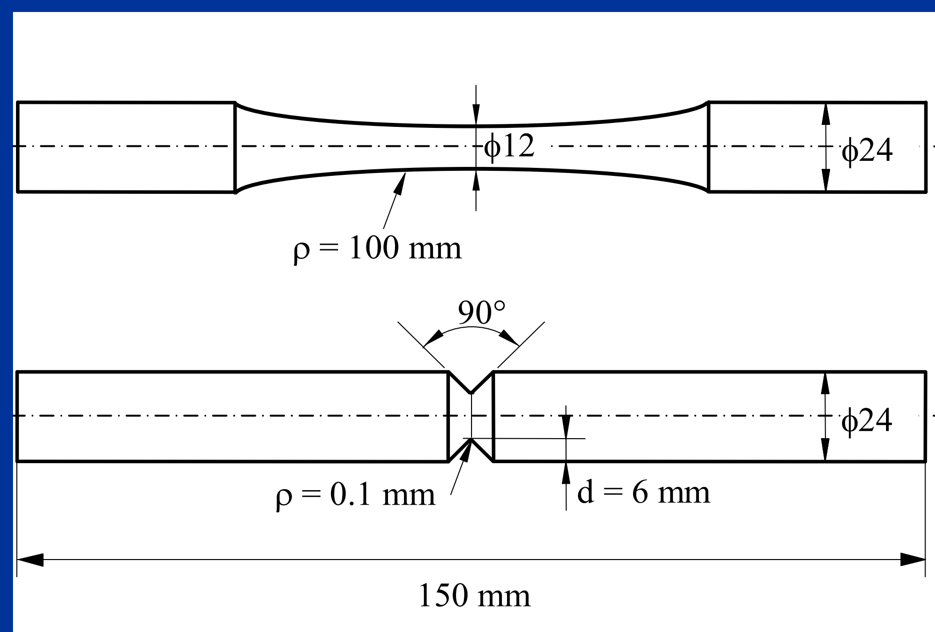
- **Tensile fatigue tests on notched specimens (R=-1 and R=0 f=5-20 Hz)**
- **Torsional fatigue tests on notched specimens (R=-1 and R=0, f=5-20 Hz)**
- **Combined tensile-torsional fatigue tests on notched specimens**
- **Analysis of the influence of load ratio on the multiaxial fatigue behaviour (R=0 and R=-1, f=5-20 Hz)**
- **Analysis of the influence of biaxiality ratio on the multiaxial fatigue behaviour (λ=0.6 and 2 , f=5-20 Hz)**
- **Analysis of the influence of the phase angle on the multiaxial fatigue behaviour (Φ=0 and Φ=90°, f=5-20 Hz)**

NTNU
Department of Mechanical Engineering

MATERIAL: Ti6Al4V

E= 110 GPa, σ_{uts} = 995 MPa, σ_y = 880 MPa

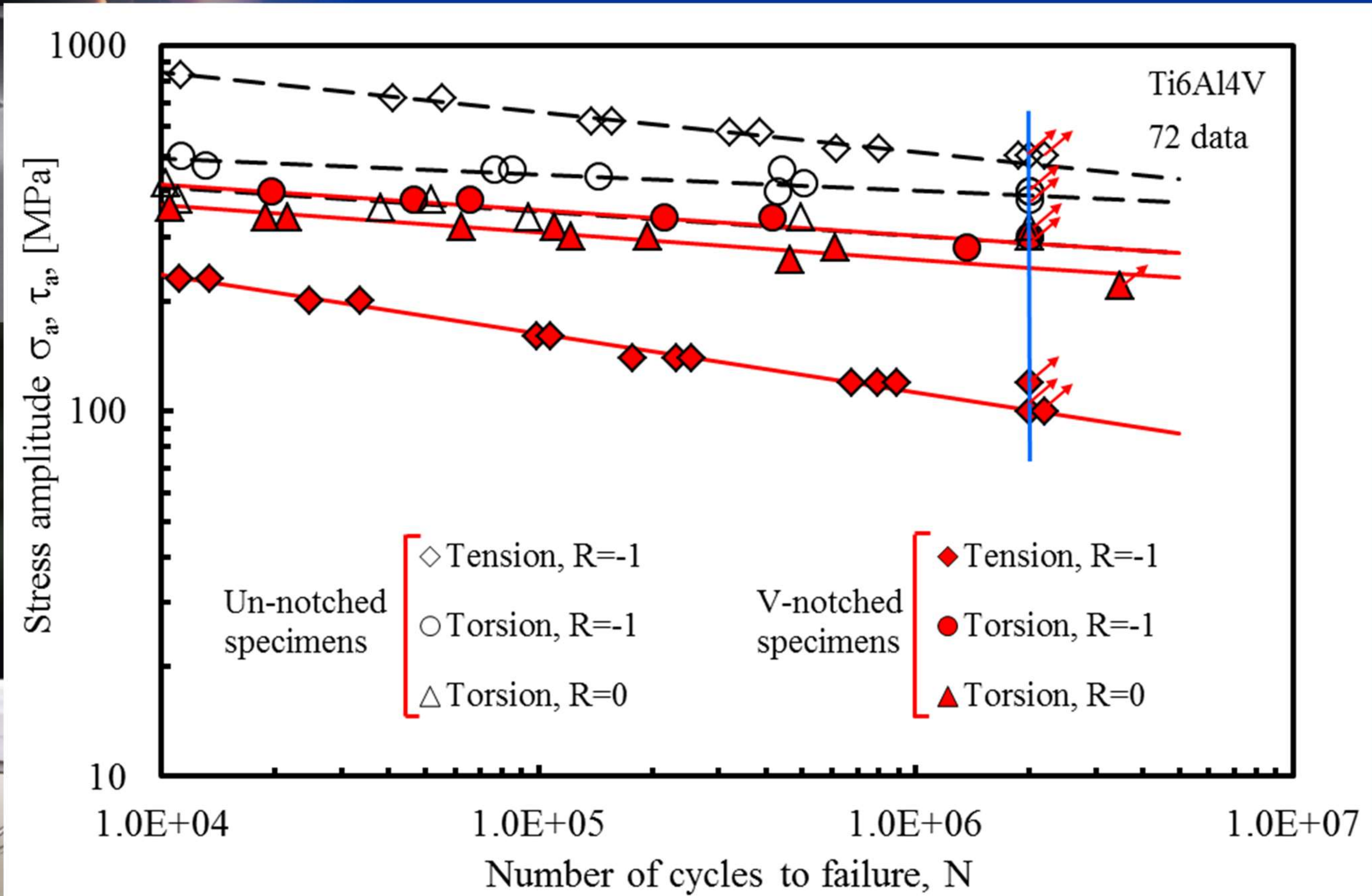




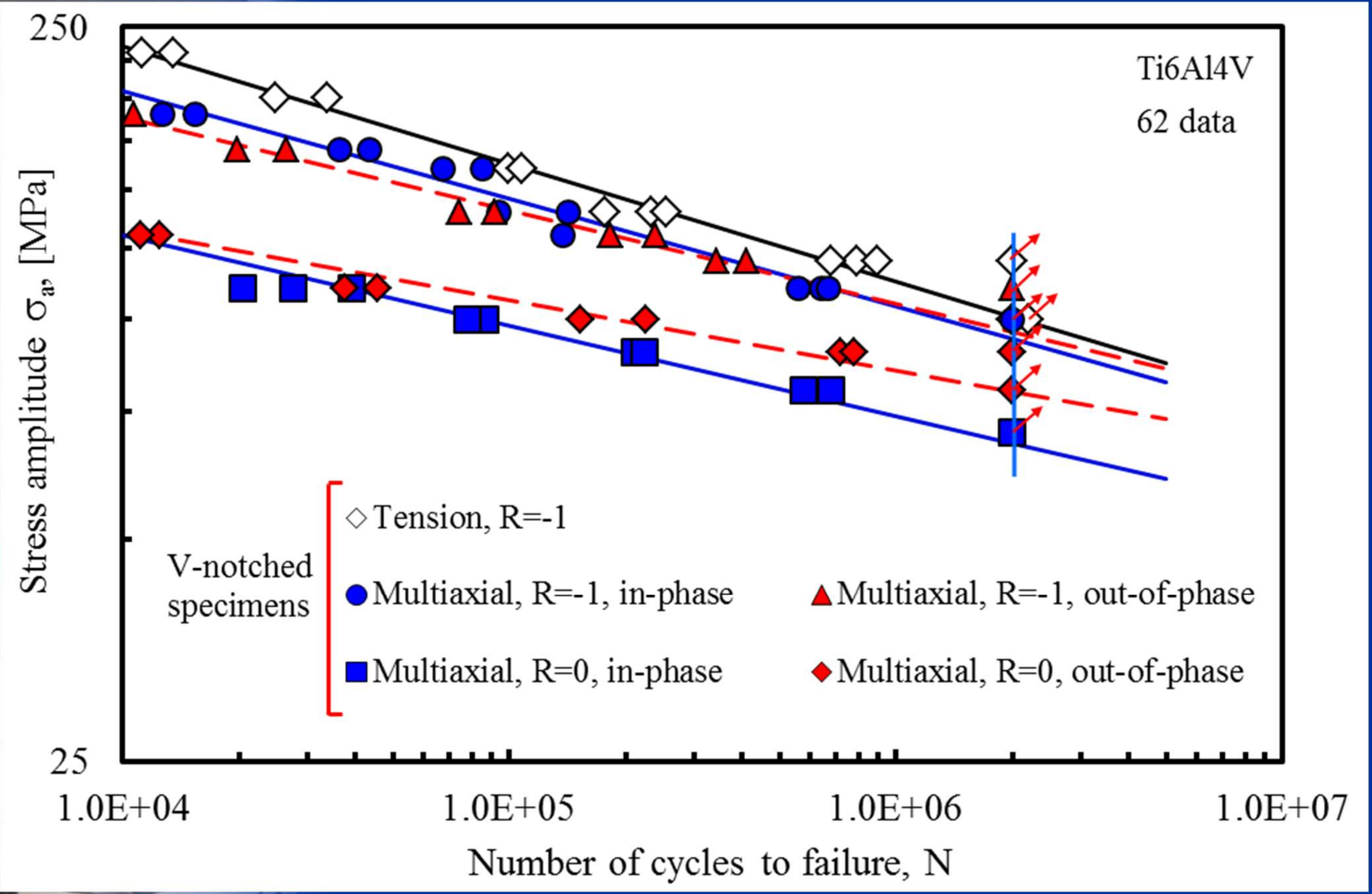
Unnotched specimens

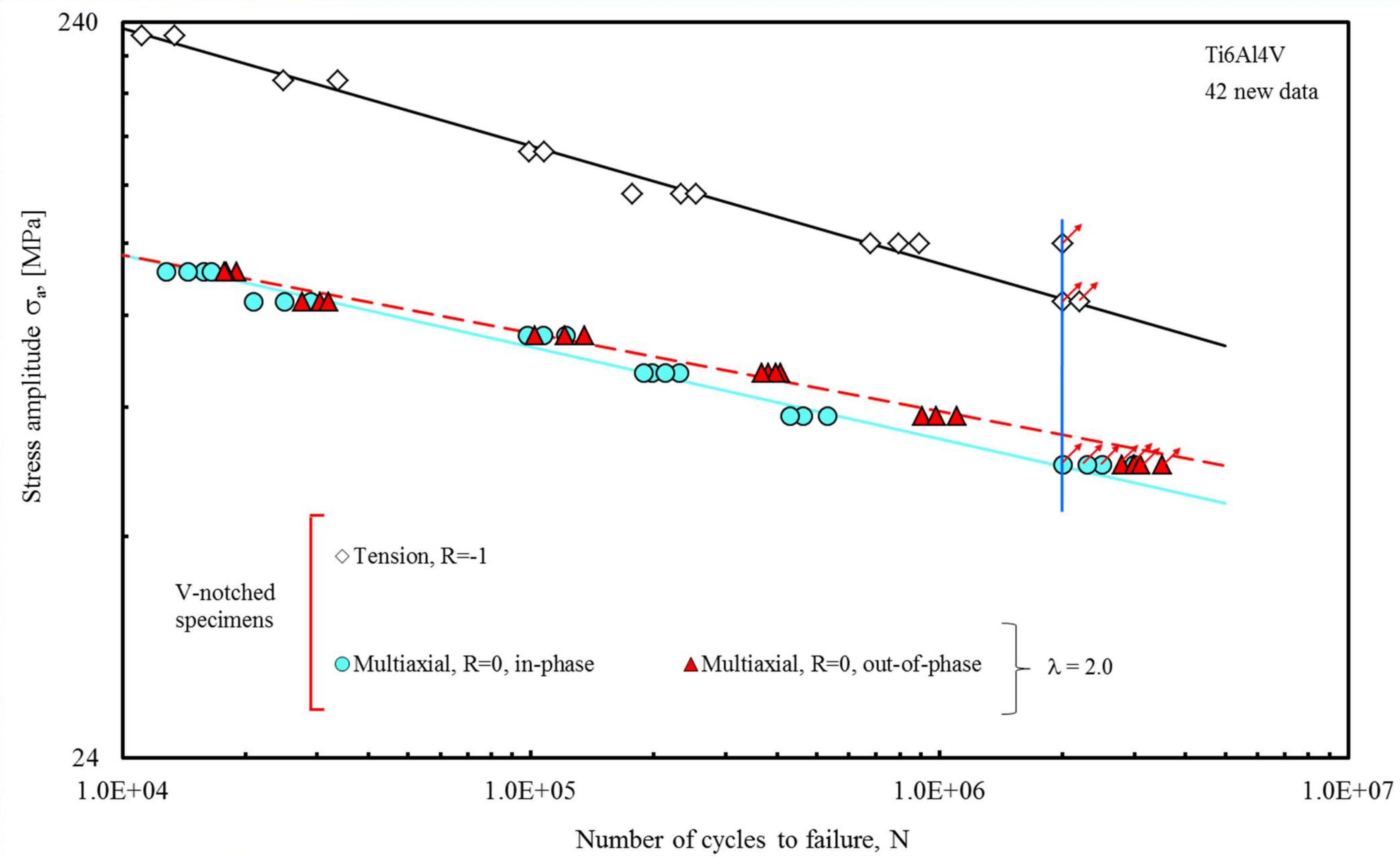
Notched specimens with ρ < 0.1 mm

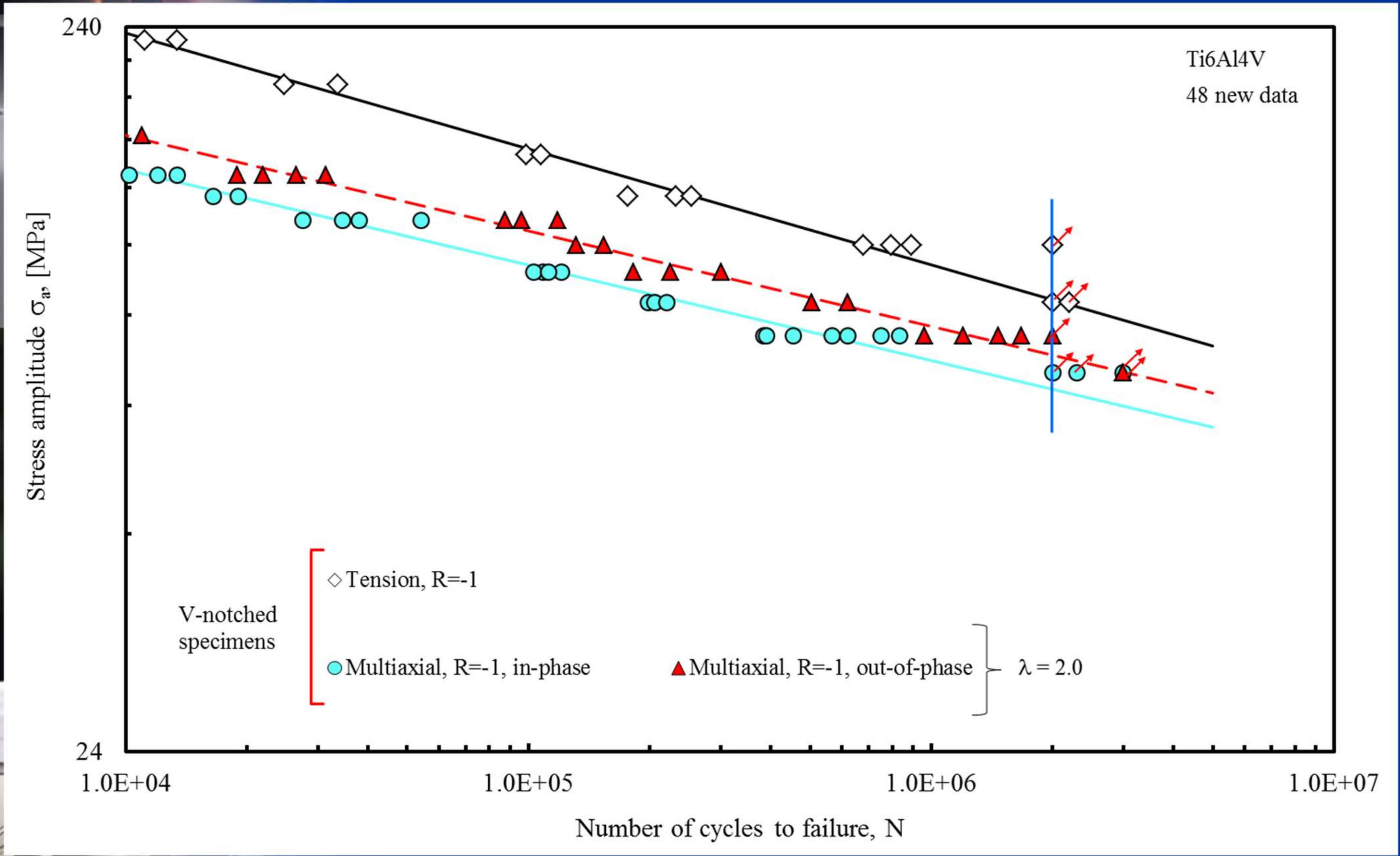
Department of Mechanical Engineering



NTNU
Department of Mechanical Engineering

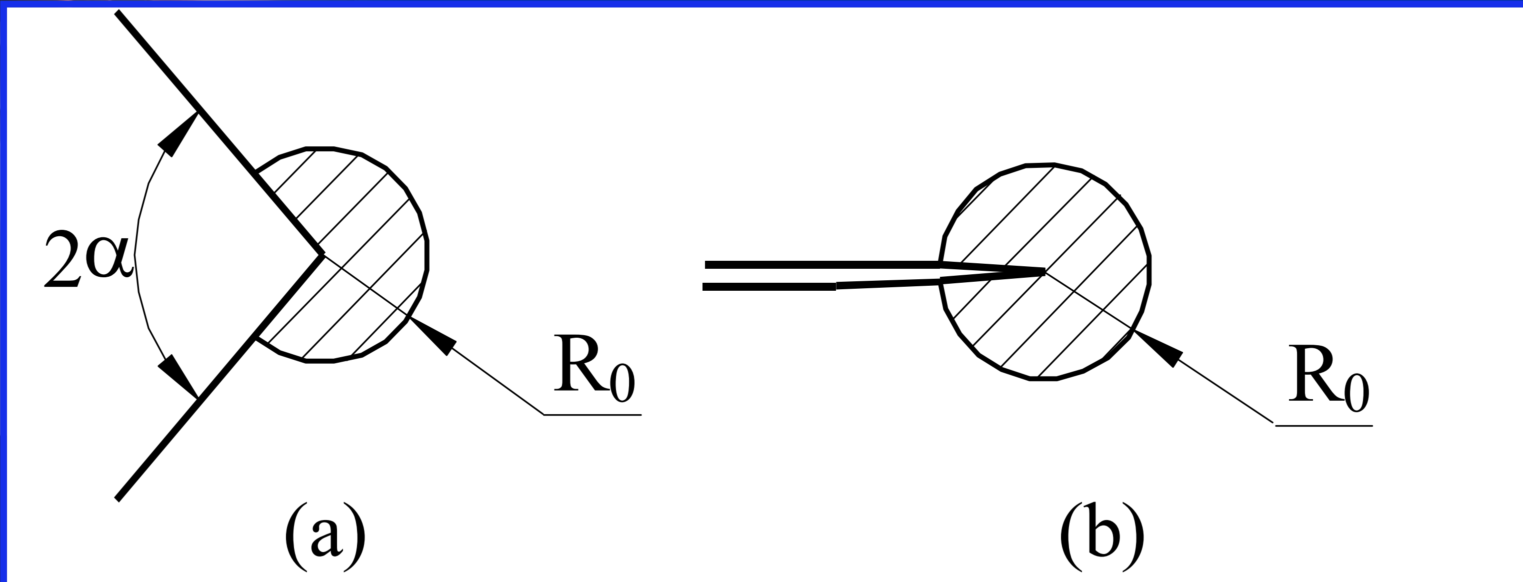



240
24
Stress amplitude σa, [MPa]
1.0E+04
1.0E+05
1.0E+06
1.0E+07
Number of cycles to failure, N
Ti6Al4V
42 new data
V-notched specimens
Tension, R=-1
Multiaxial, R=0, in-phase
Multiaxial, R=0, out-of-phase
λ = 2.0



240
24
Ti6Al4V
48 new data
Stress amplitude σa, [MPa]
V-notched specimens
Tension, R=-1
Multiaxial, R=-1, in-phase
Multiaxial, R=-1, out-of-phase
λ = 2.0
1.0E+04
1.0E+05
1.0E+06
1.0E+07
Number of cycles to failure, N

NTNU
Department of Mechanical Engineering



$$SED = c_W \times \Delta\overline{W} = \frac{1}{E}\left[e_1 \times \frac{\Delta K_1^{\ 2}}{R_1^{2(1-\lambda_1)}} + e_3 \times \frac{\Delta K_3^{\ 2}}{R_3^{2(1-\lambda_3)}}\right]$$

$$R_1 = \left(\sqrt{2\,e_1} \times \frac{\Delta K_{1A}}{\Delta\sigma_{1A}}\right)^{\frac{1}{1-\lambda_1}}$$

$$R_3 = \left(\sqrt{\frac{e_3}{1+\nu}} \times \frac{\Delta K_{3A}}{\Delta\tau_{3A}}\right)^{\frac{1}{1-\lambda_3}}$$

NTNU
Department of Mechanical Engineering

- Plain (unnotched specimens): Beltrami's expressions

Pure tension

$$\Delta\overline{W} = c_w \frac{\Delta\sigma_{nom}^2}{2E}$$

Pure Torsion

$$\Delta\overline{W} = c_w(1+\nu)\frac{\Delta\tau_{nom}^2}{E}$$

- V-notched specimens: SED in a control volume

$$\Delta\overline{W} = \frac{c_w}{E}\left[e_1 \cdot \frac{\Delta K_1^2}{R_1^{2(1-\lambda_1)}} + e_3 \cdot \frac{\Delta K_3^2}{R_3^{2(1-\lambda_3)}}\right]$$

NTNU
Department of Mechanical Engineering

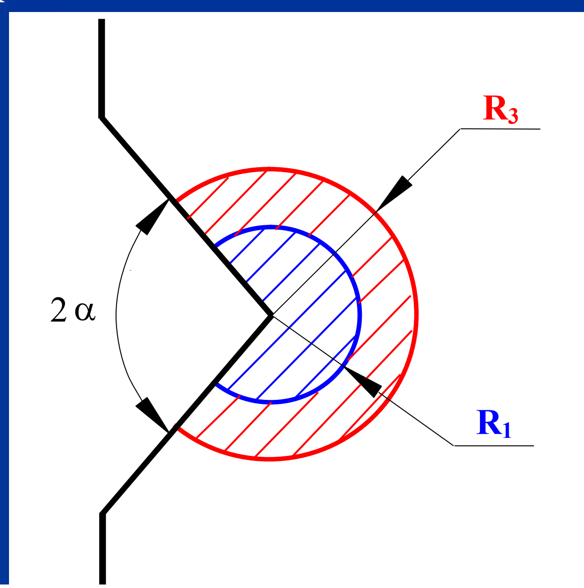
$$R_1 = \left(\sqrt{2\,e_1} \times \frac{\Delta K_{1A}}{\Delta \sigma_{1A}} \right)^{\frac{1}{1-\lambda_1}} \qquad R_3 = \left(\sqrt{\frac{e_3}{1+\nu}} \times \frac{\Delta K_{3A}}{\Delta \tau_{3A}} \right)^{\frac{1}{1-\lambda_3}}$$

For mode 1 loading:

$\Delta K_{1A} = 452\ \mathrm{MPa \cdot mm^{0.455}}$; $\Delta \sigma_{1A} = 950\ \mathrm{MPa}$

For mode 3 loading:

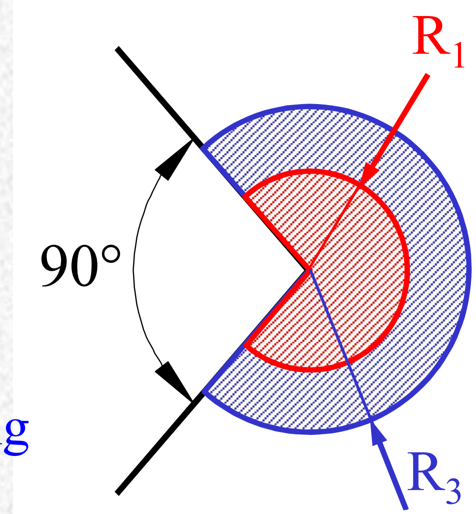
$\Delta K_{3A} = 1216\ \mathrm{MPa \cdot mm^{0.333}}$; $\Delta \tau_{3A} = 776\ \mathrm{MPa}$



$R_1 = 0.051$ mm
$R_3 = 0.837$ mm

STRAIN ENERGY DENSITY AT THE NOTCH TIP
MODE 1 + MODE 3

- ΔK_1 and ΔK_3 are the NSIFs range under Mode I and Mode III:



$$\Delta \mathbf{K_1} = k_1 d^{1-\lambda_1} \Delta\sigma_{nom} = 2.260\, \Delta\sigma_{nom} \quad (\text{MPa mm}^{0.445})$$

$$\Delta \mathbf{K_3} = k_3 d^{1-\lambda_3} \Delta\tau_{nom} = 2.096\, \Delta\tau_{nom} \quad (\text{MPa mm}^{0.333})$$

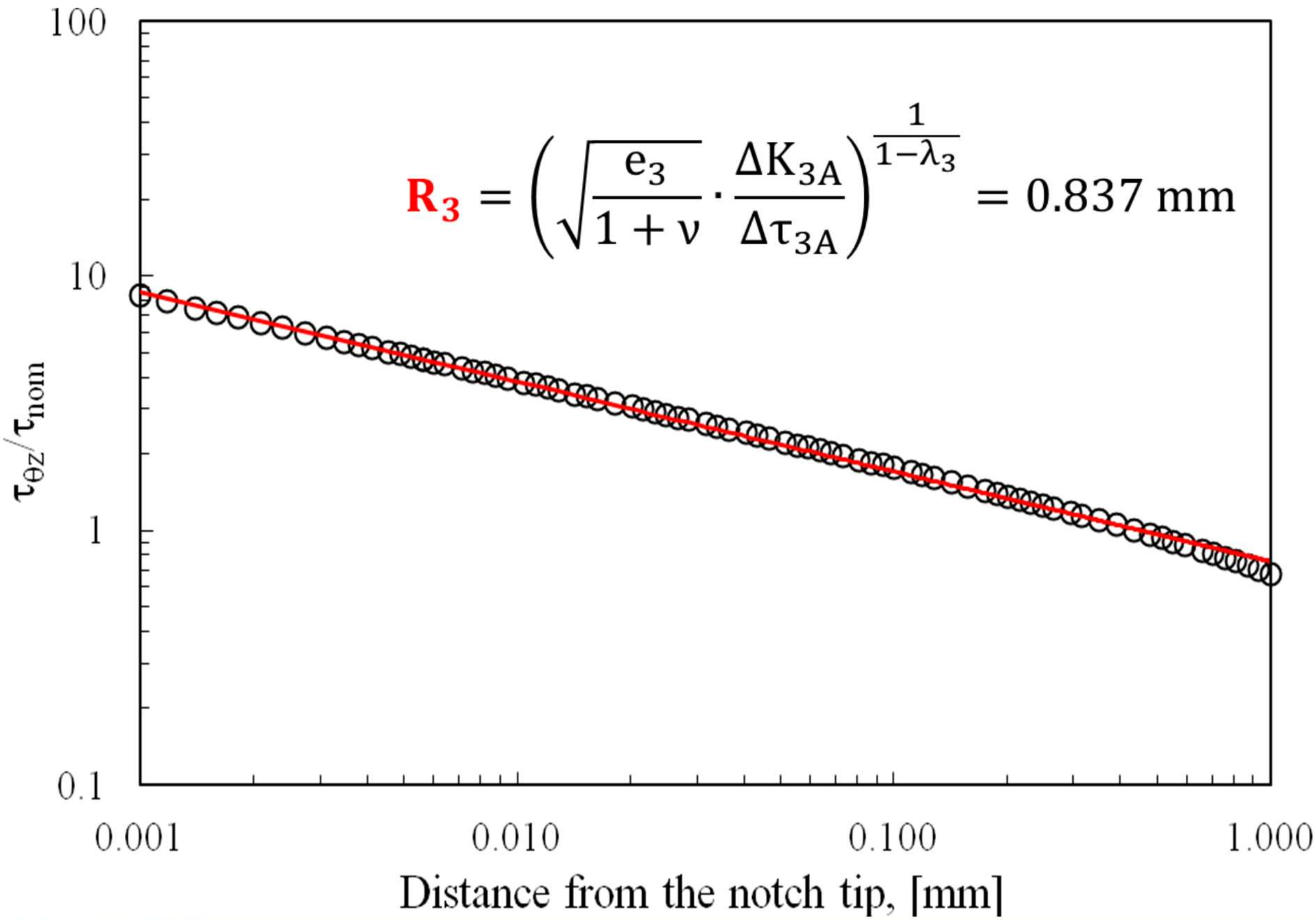
- $e_1 = 0.146$ and $e_3 = 0.310$ depend on the notch opening angle and Poisson's ratio;

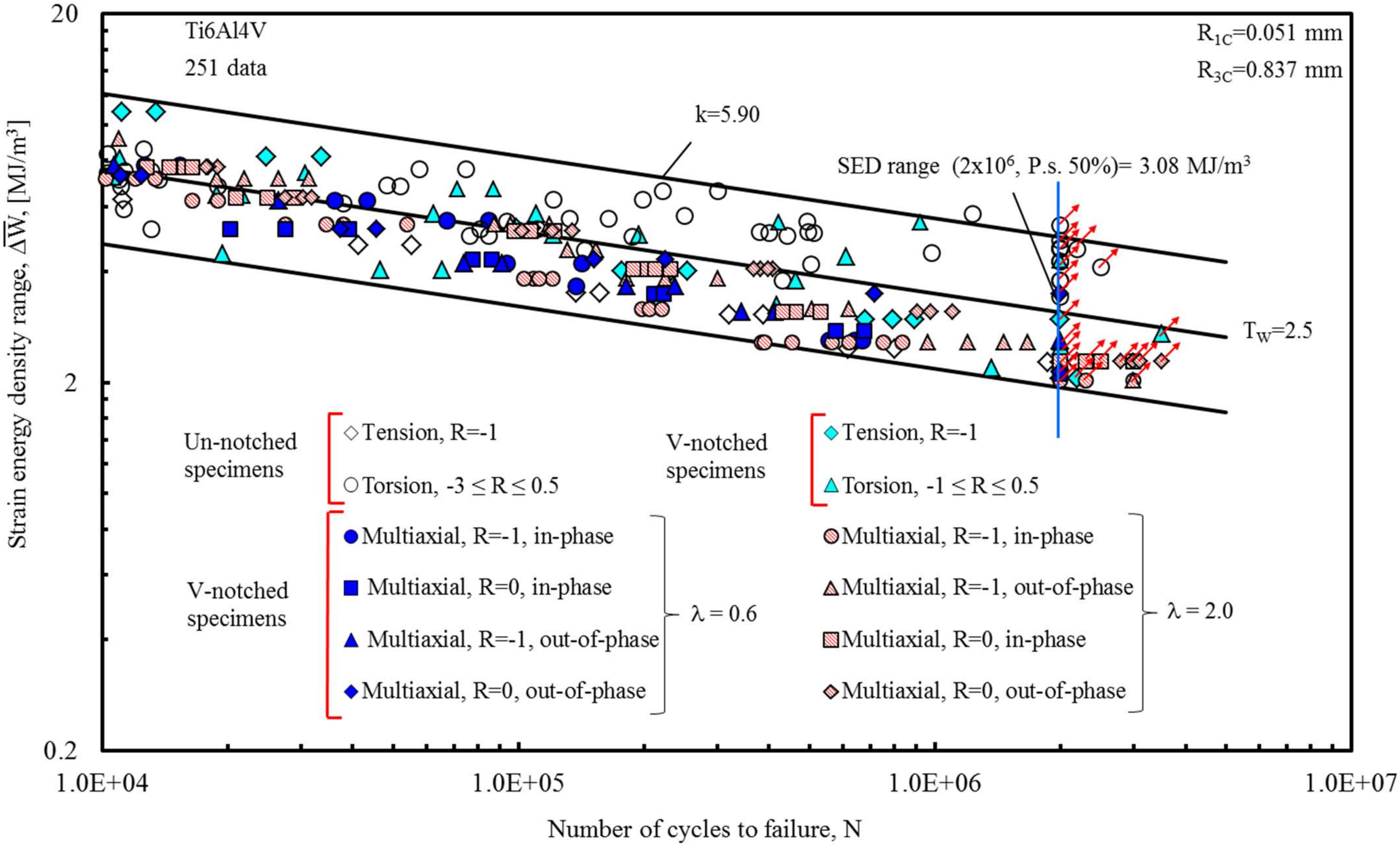
- The control radii depend on the fatigue strength of unnotched specimens and on the stress range of the NSIFs values:

$$\mathbf{R_1} = \left(\sqrt{2e_1} \cdot \frac{\Delta K_{1A}}{\Delta\sigma_{1A}}\right)^{\frac{1}{1-\lambda_1}} = 0.051\text{ mm} \quad \mathbf{R_3} = \left(\sqrt{\frac{e_3}{1+\nu}} \cdot \frac{\Delta K_{3A}}{\Delta\tau_{3A}}\right)^{\frac{1}{1-\lambda_3}} = 0.837\text{ mm}$$

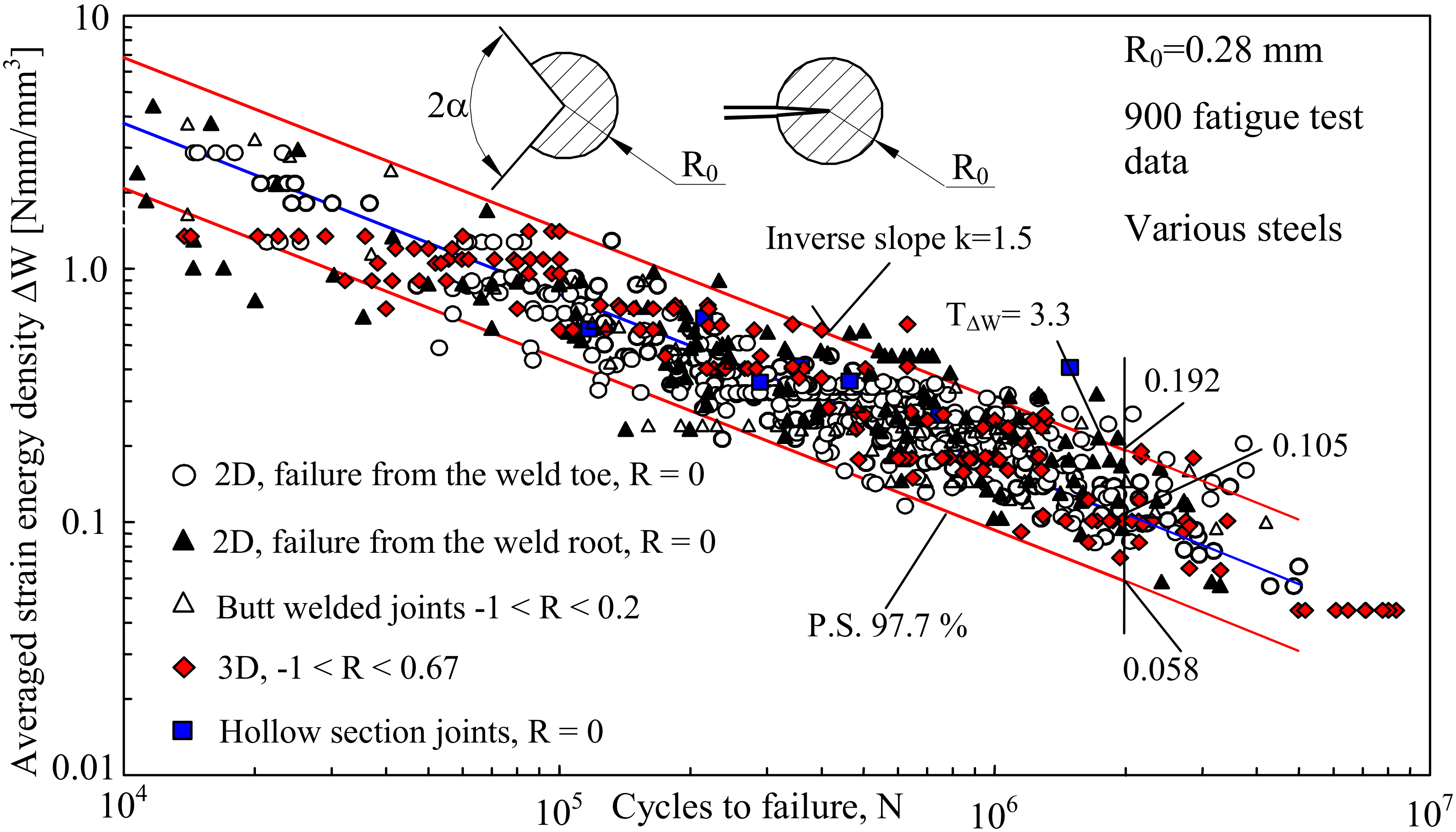
NTNU

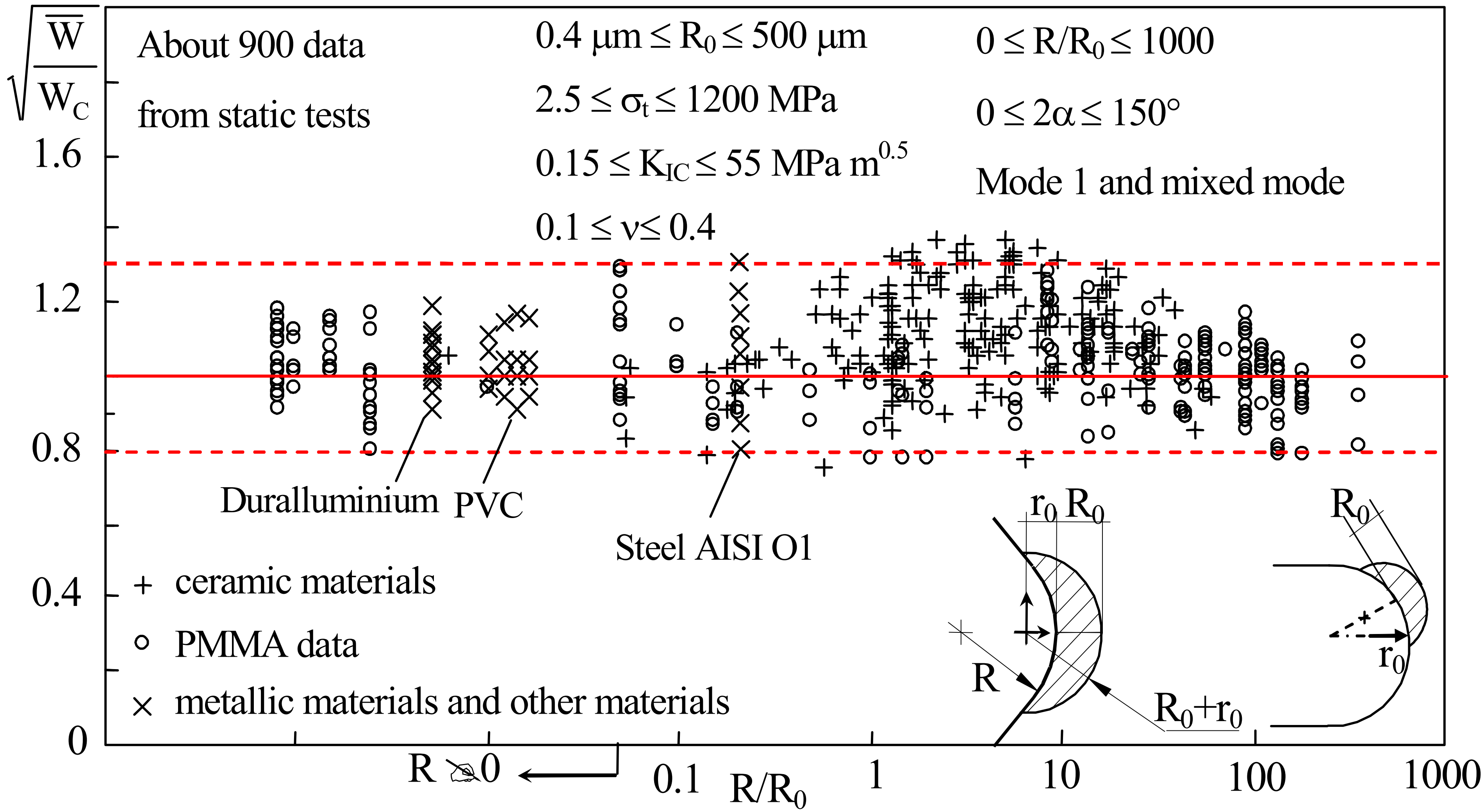
Department of Mechanical Engineering





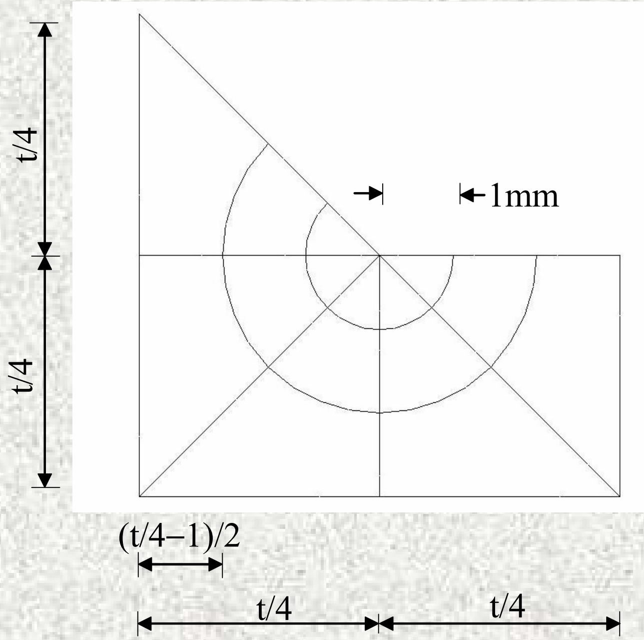
Ti6Al4V
251 data
R1C=0.051 mm
R3C=0.837 mm
k=5.90
SED range (2x10^6, P.s. 50%)= 3.08 MJ/m^3
TW=2.5
Strain energy density range, ΔW, [MJ/m^3]
Number of cycles to failure, N
20
2
0.2
1.0E+04
1.0E+05
1.0E+06
1.0E+07
Un-notched specimens
Tension, R=-1
Torsion, -3 ≤ R ≤ 0.5
V-notched specimens
Tension, R=-1
Torsion, -1 ≤ R ≤ 0.5
V-notched specimens
Multiaxial, R=-1, in-phase
Multiaxial, R=0, in-phase
Multiaxial, R=-1, out-of-phase
Multiaxial, R=0, out-of-phase
λ = 0.6
Multiaxial, R=-1, in-phase
Multiaxial, R=-1, out-of-phase
Multiaxial, R=0, in-phase
Multiaxial, R=0, out-of-phase
λ = 2.0

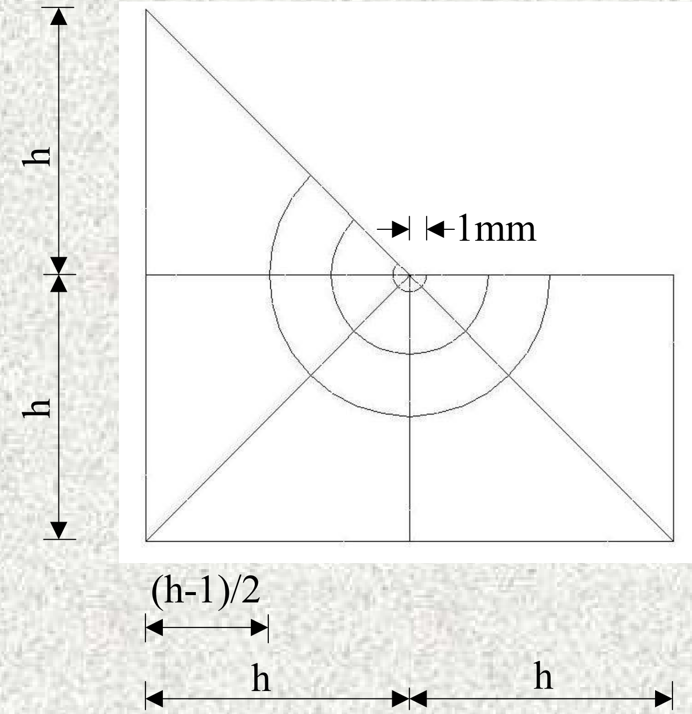

10
1.0
0.1
0.01
Averaged strain energy density ΔW [Nmm/mm3]
10^4
10^5
Cycles to failure, N
10^6
10^7
2α
R_0
R_0
R_0=0.28 mm
900 fatigue test data
Various steels
Inverse slope k=1.5
$T_{\Delta W}$= 3.3
0.192
0.105
0.058
P.S. 97.7 %
2D, failure from the weld toe, R = 0
2D, failure from the weld root, R = 0
Butt welded joints -1 < R < 0.2
3D, -1 < R < 0.67
Hollow section joints, R = 0

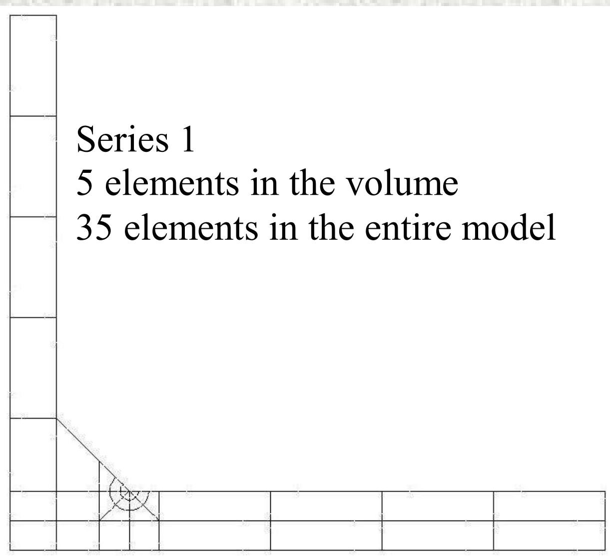

$\sqrt{\frac{\overline{W}}{W_C}}$
About 900 data
from static tests
$0.4\ \mu m \leq R_0 \leq 500\ \mu m$
$2.5 \leq \sigma_t \leq 1200$ MPa
$0.15 \leq K_{IC} \leq 55$ MPa m$^{0.5}$
$0.1 \leq \nu \leq 0.4$
$0 \leq R/R_0 \leq 1000$
$0 \leq 2\alpha \leq 150°$
Mode 1 and mixed mode
1.6
1.2
0.8
0.4
0
Duralluminium
PVC
Steel AISI O1
+ ceramic materials
○ PMMA data
× metallic materials and other materials
r_0 R_0
R
R_0+r_0
R_0
r_0
R → 0
0.1
R/R_0
1
10
100
1000

Coarse mesh

NTNU
Department of Mechanical Engineering



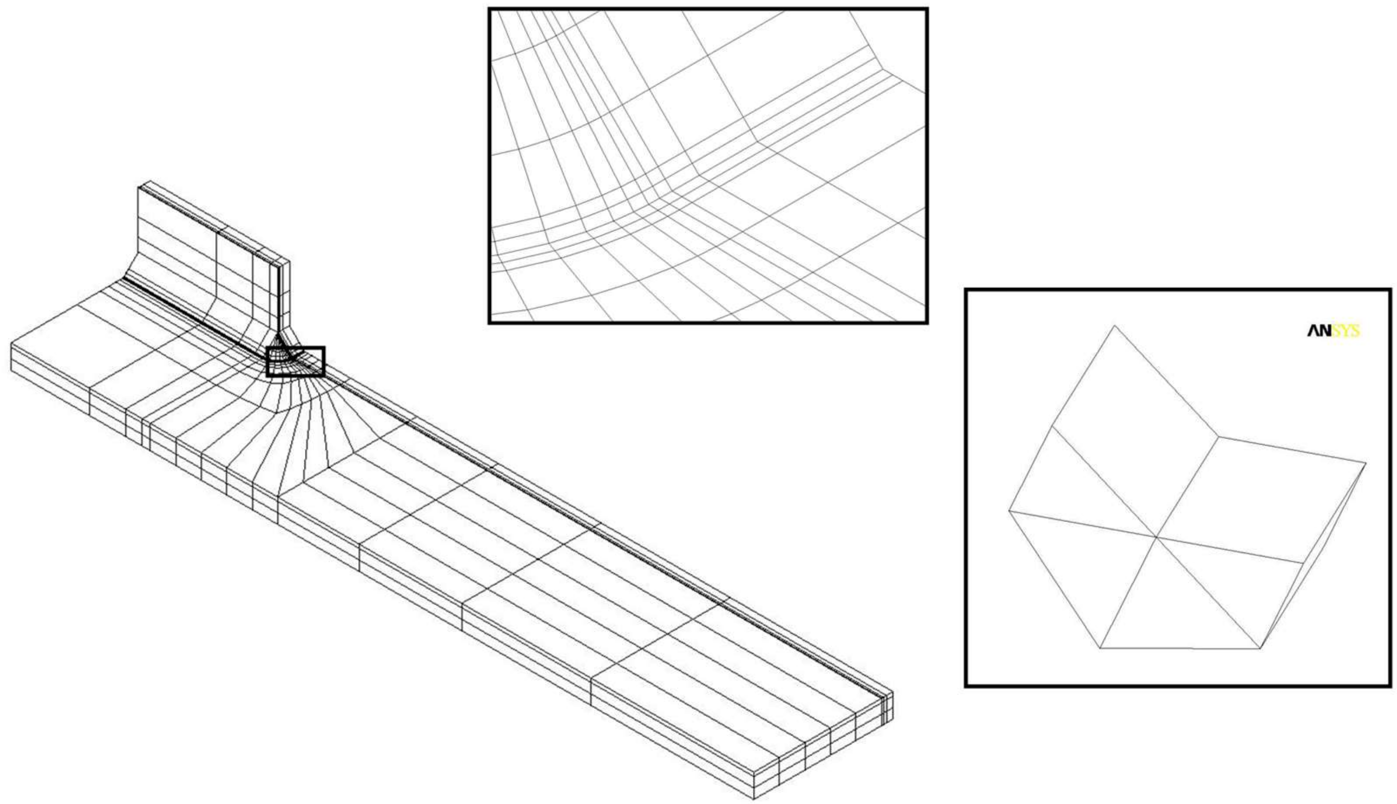


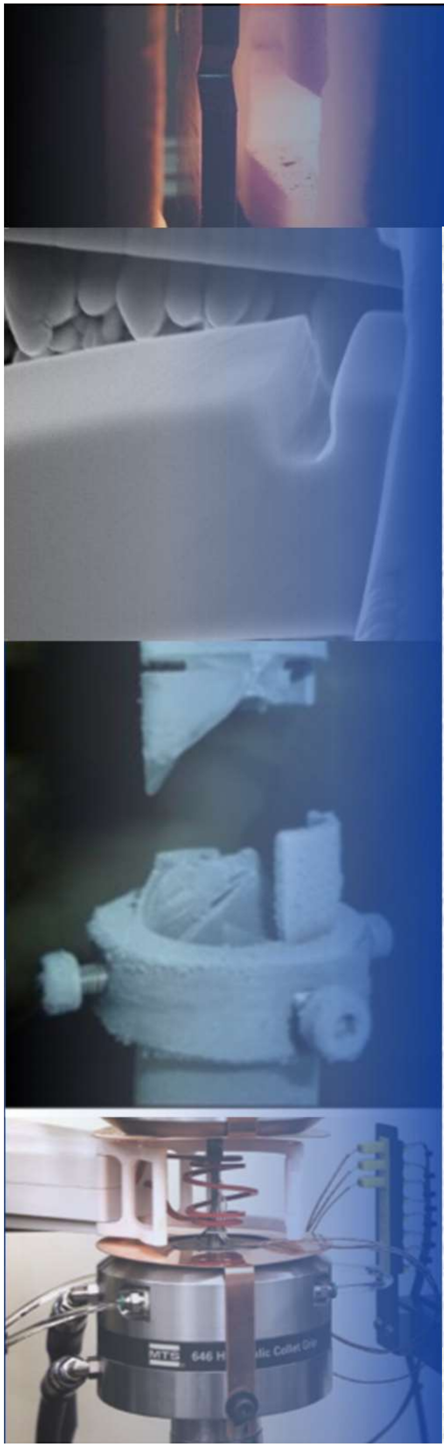


Coarse mesh

NTNU

Department of Mechanical Engineering

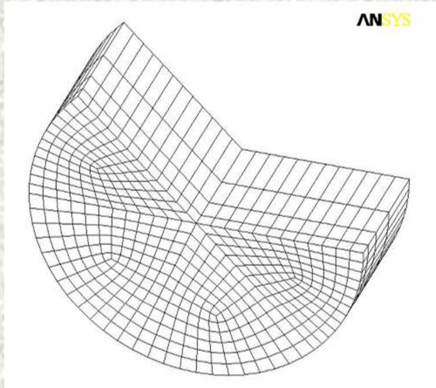




Coarse mesh

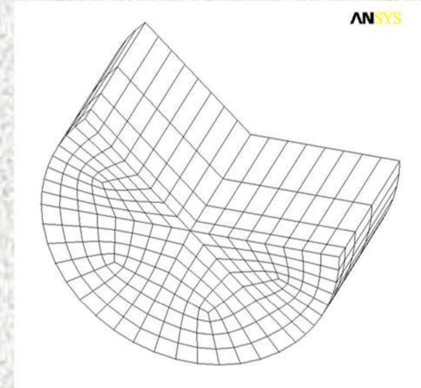
NTNU
Department of Mechanical Engineering

Mesh 1



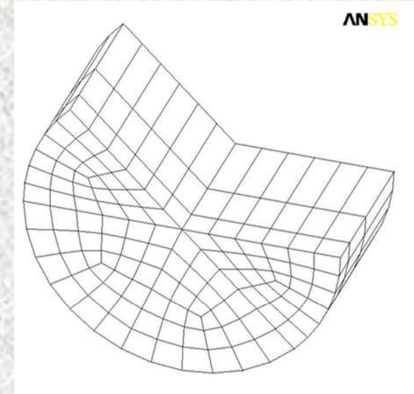
1969 elements

Mesh 2



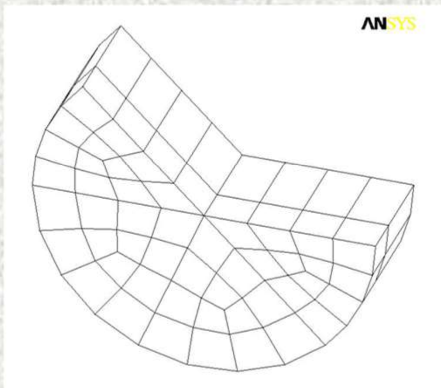
768 elements

Mesh 3



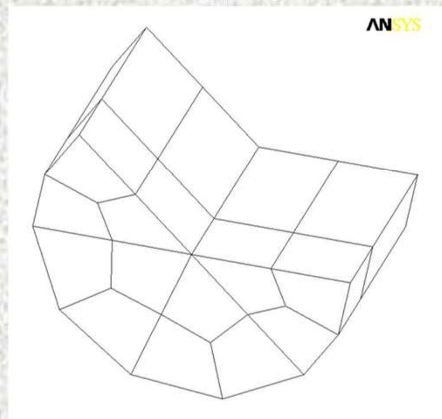
324 elements

Mesh 4



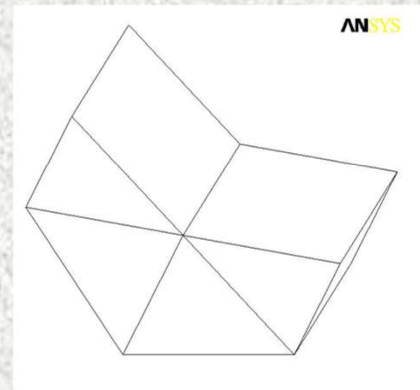
96 elements

Mesh 5



24 elements

Mesh 6



4 elements

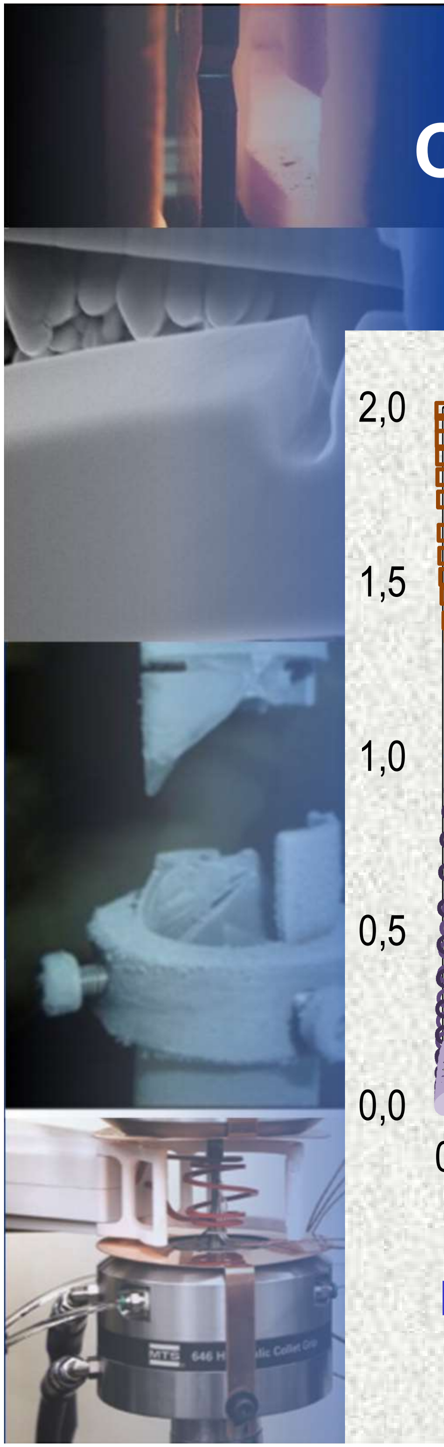
Coarse mesh

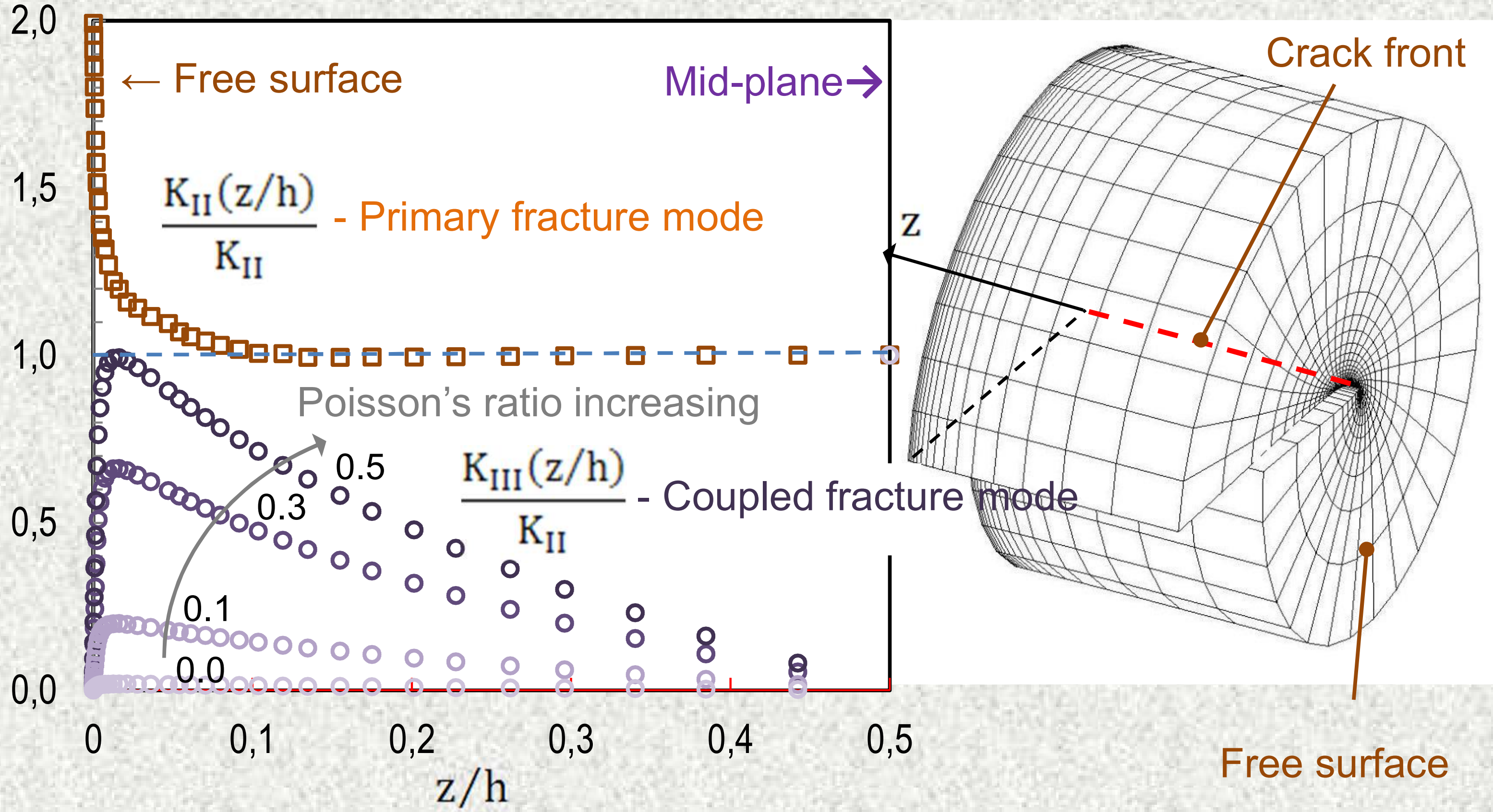
NTNU
Department of Mechanical Engineering

3D models	Number of FE in the volume	Degrees of freedom (complete model)	$\overline{W}$ Nmm/mm^3	K_1 [MPa mm$^{0.326}$]	Δ%
1	1696	$8.6 \cdot 10^5$	0.07937	373.5	0
2	768	$4.6 \cdot 10^5$	0.07903	372.7	0.21
3	324	$2.5 \cdot 10^5$	0.07896	372.5	0.26
4	96	$1.7 \cdot 10^5$	0.07895	372.5	0.26
5	24	$4.5 \cdot 10^4$	0.07790	370.0	0.93
6	4	$1.1 \cdot 10^4$	0.07594	365.3	2.18

Coupled Fracture Modes

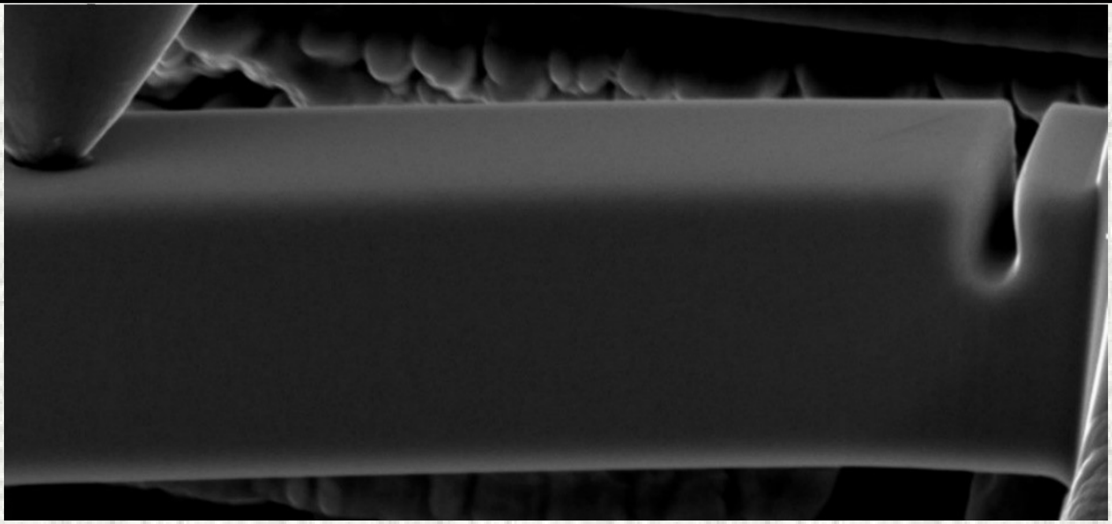
Department of Mechanical Engineering

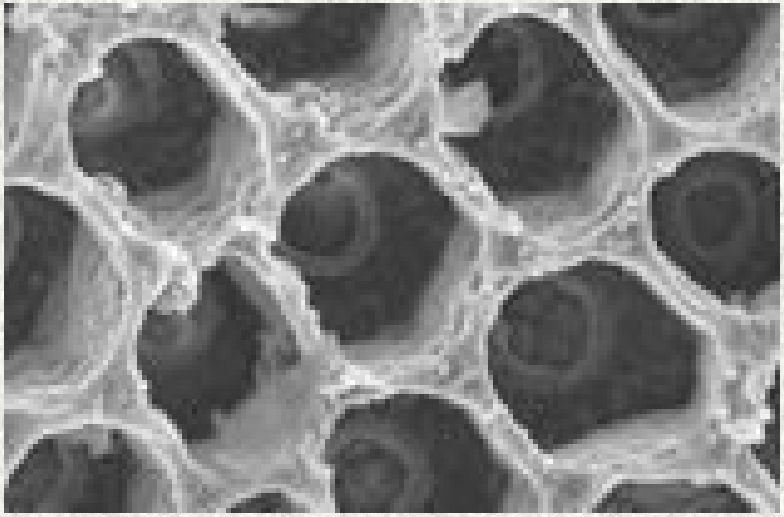




Mechanism of generation of coupled mode: Poisson's Effect

Nanoscale (1)





Nanoscale (2)

Department of Mechanical Engineering

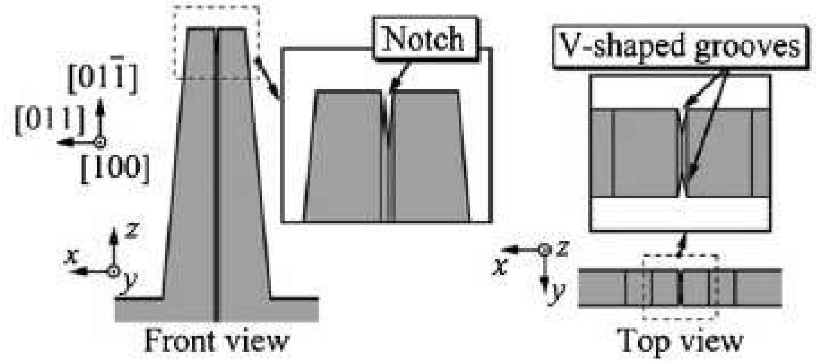


Fig. 1 Si specimen with notch.

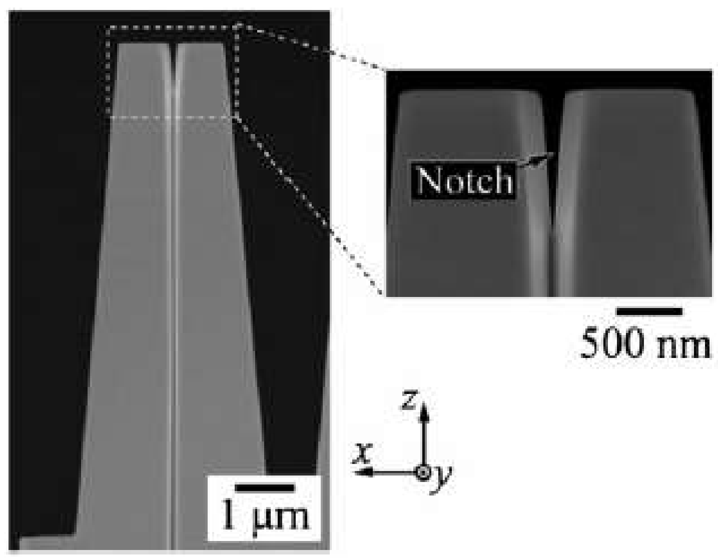
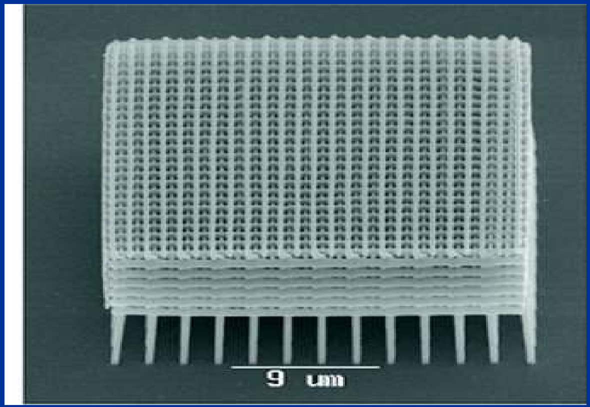
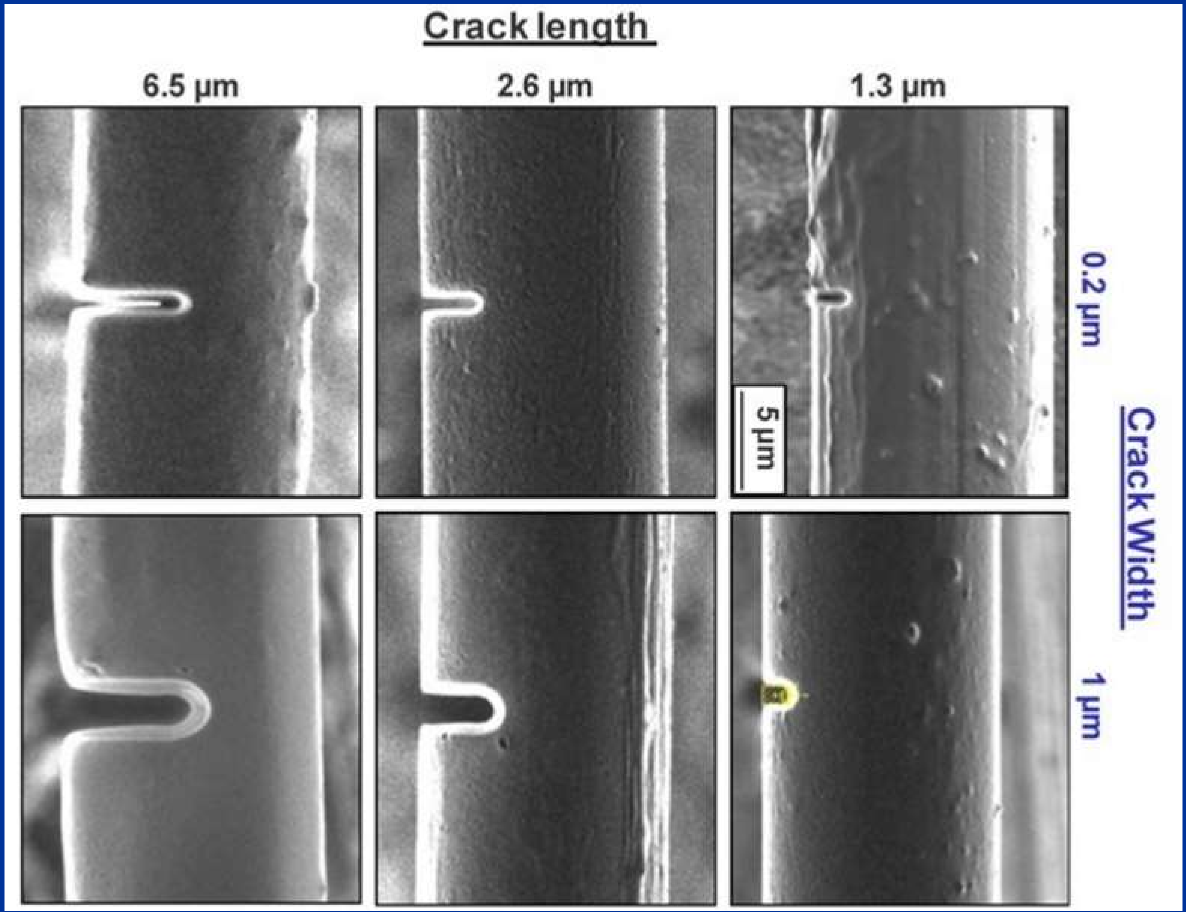


Fig. 2 Scanning electron microscopy image of the specimen with notch.



Department of Mechanical Engineering

Microscale



Intermediate scale

NTNU
Department of Mechanical Engineering

Additive Materials

NTNU
Department of Mechanical Engineering

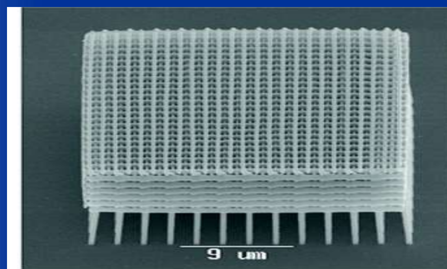
Additive Manufacturing (AM) materials under fatigue loading from full scale to nano level.

Examination of the state-of-the-art shows that fatigue assessment and quality assurance of additively manufactured components cannot be performed accurately due to a lack of bespoke methodologies allowing the specific microstructural features as well as the specific mechanical/cracking behaviour of additively manufactured materials to be modelled effectively.

Additive Materials

NTNU
Department of Mechanical Engineering

Topological complexity



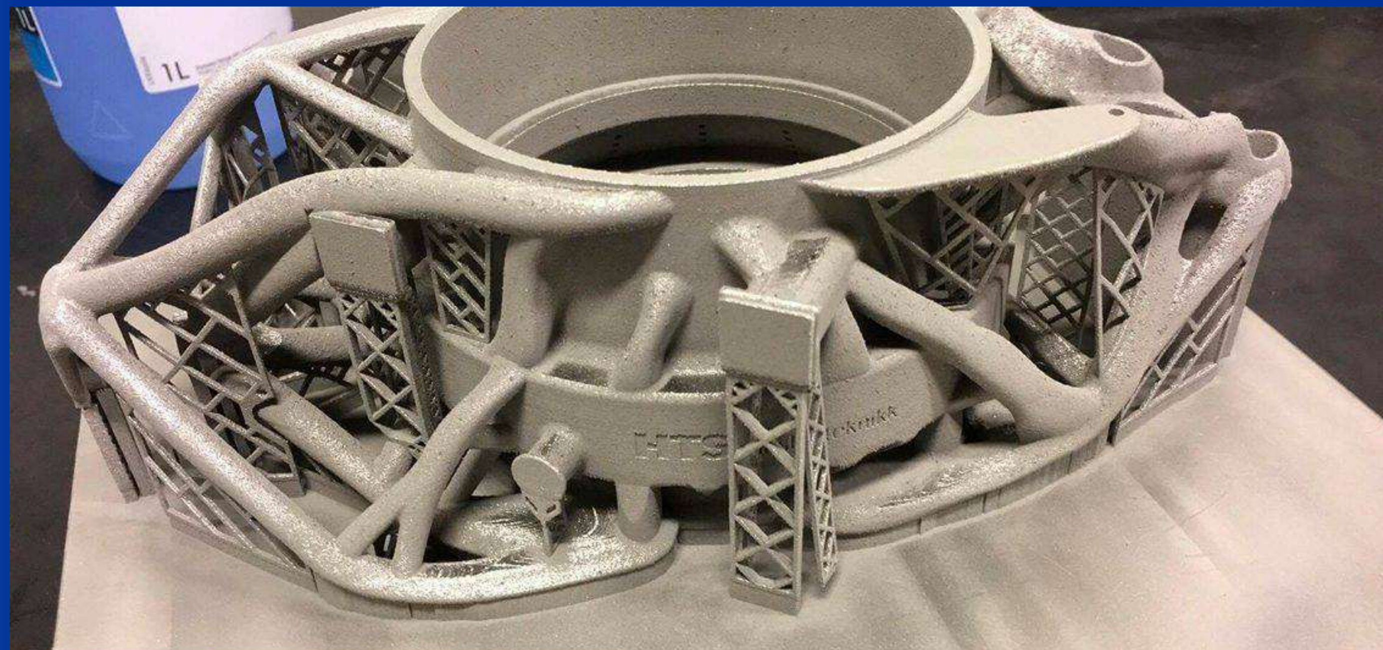
Material/Hierarchical complexity

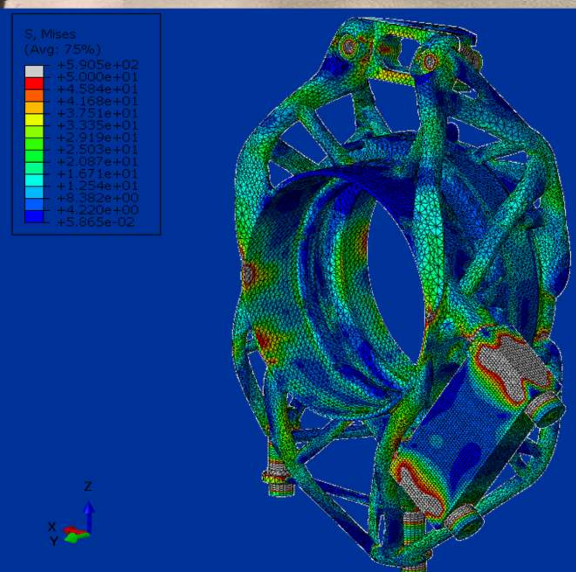
Functional complexity

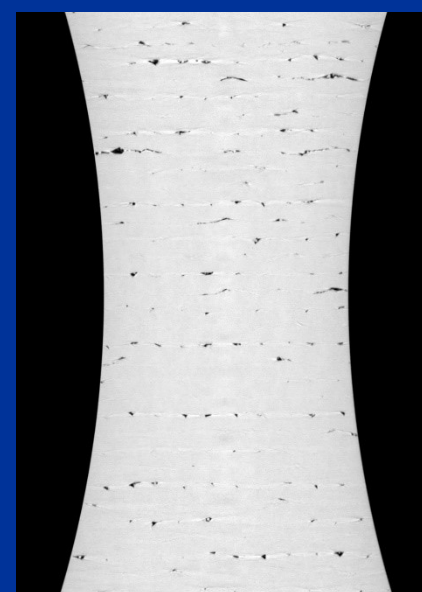
Quality assurance

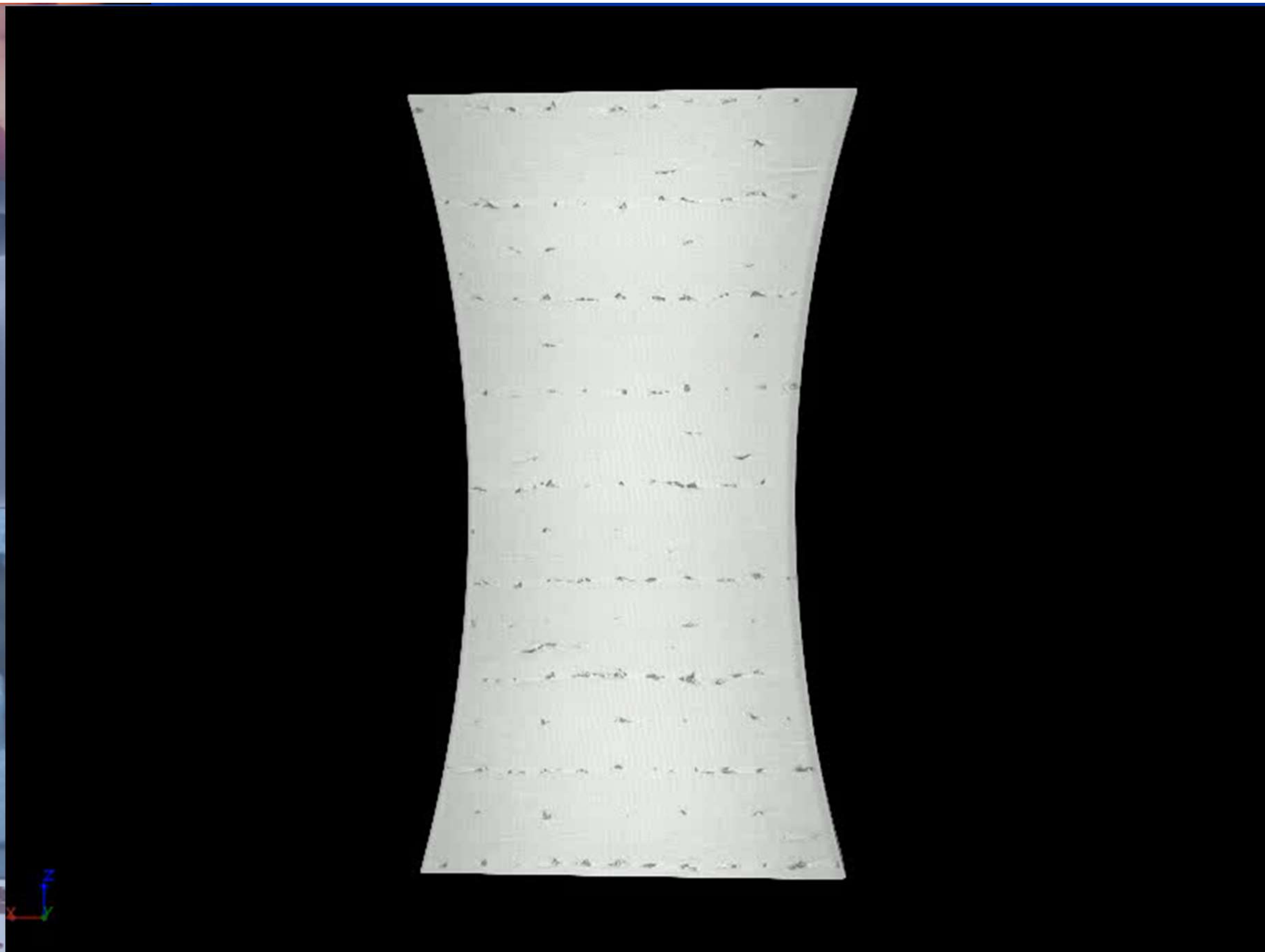
Additive Materials
Interactions btw notches and defects

NTNU
Department of Mechanical Engineering



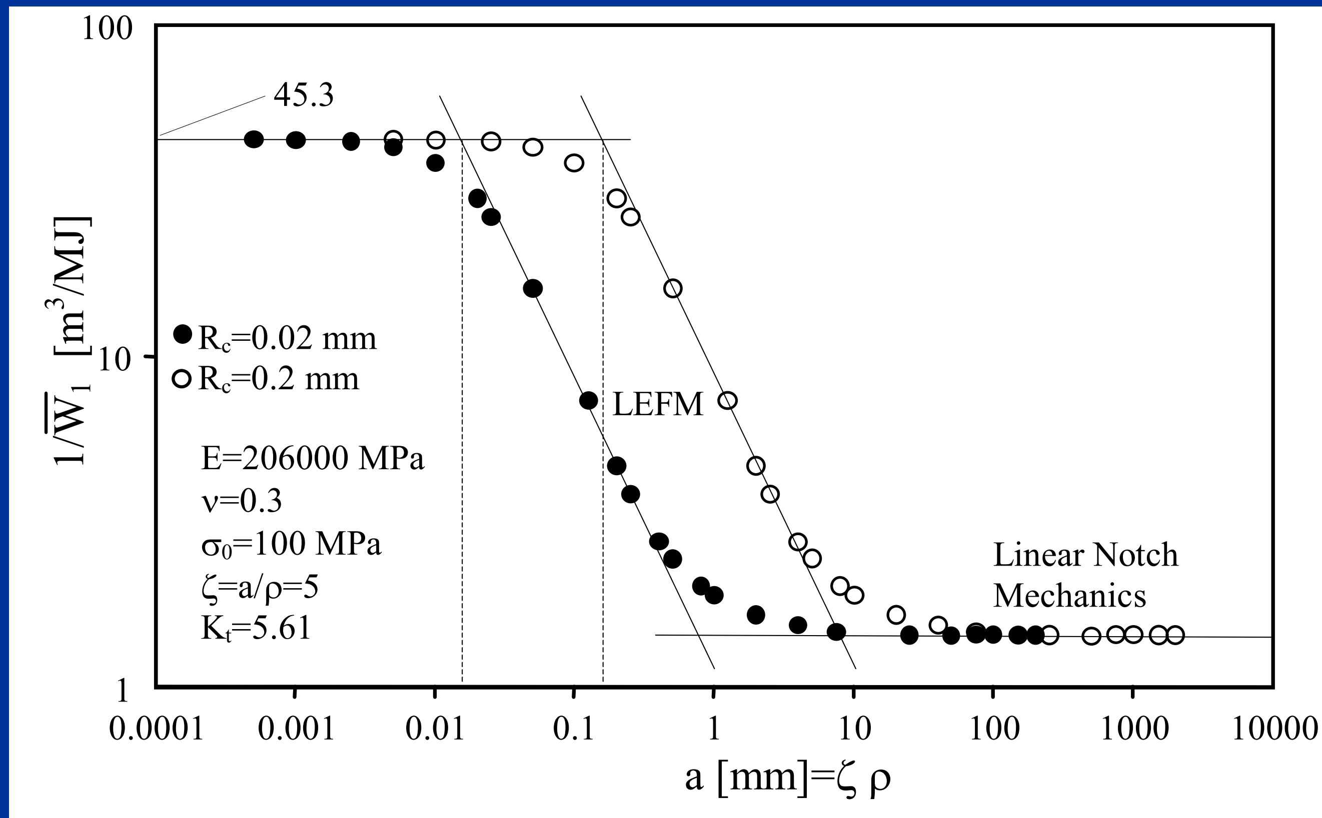






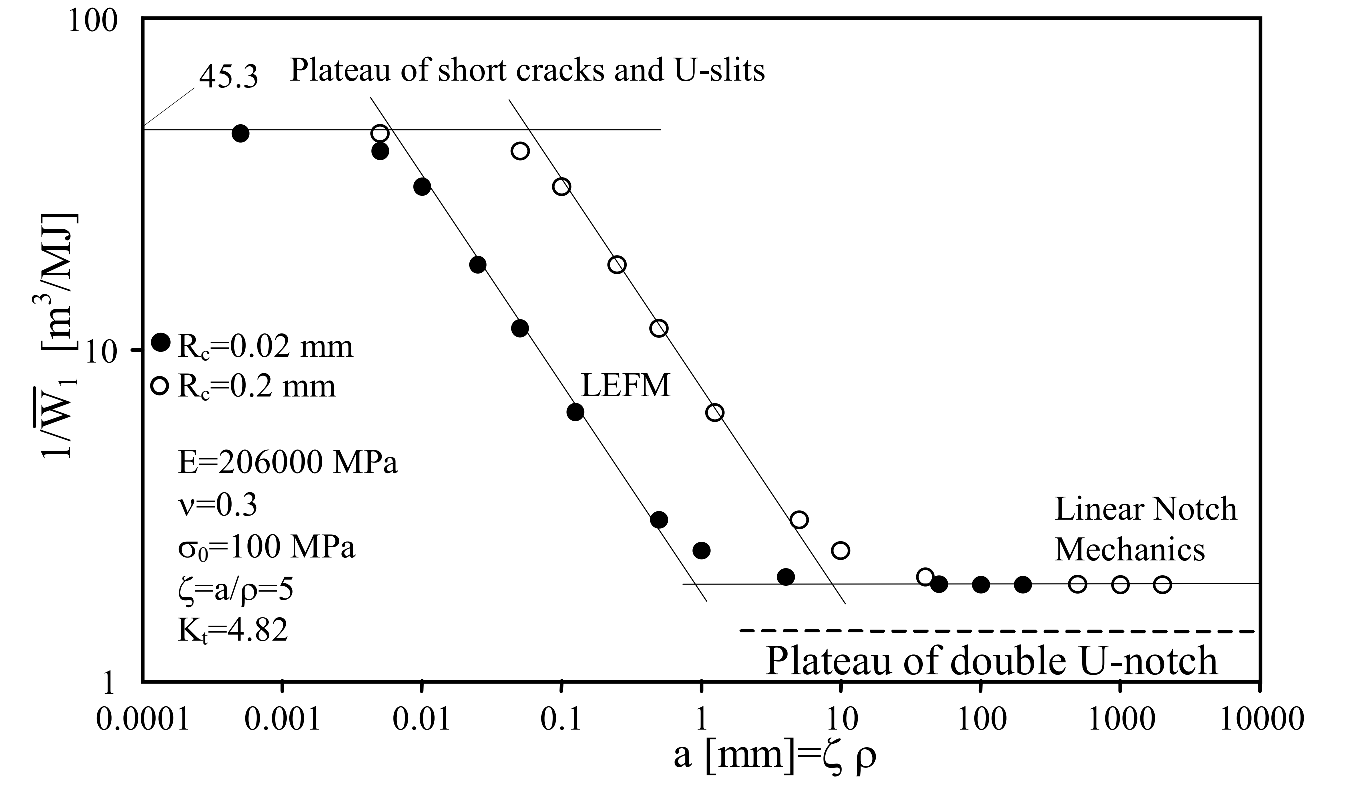
Additive Materials
Interactions btw notches and defects

NTNU
Department of Mechanical Engineering

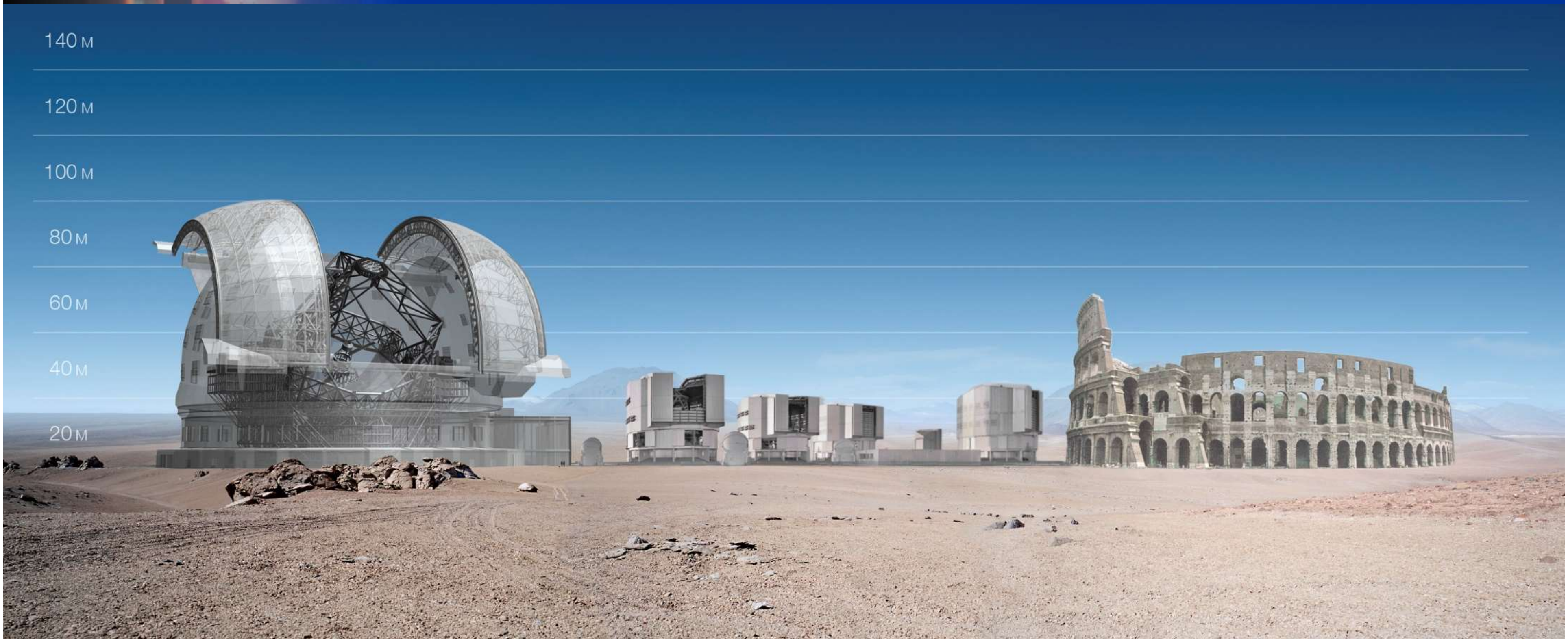


Additive Materials
Interactions btw notches and defects

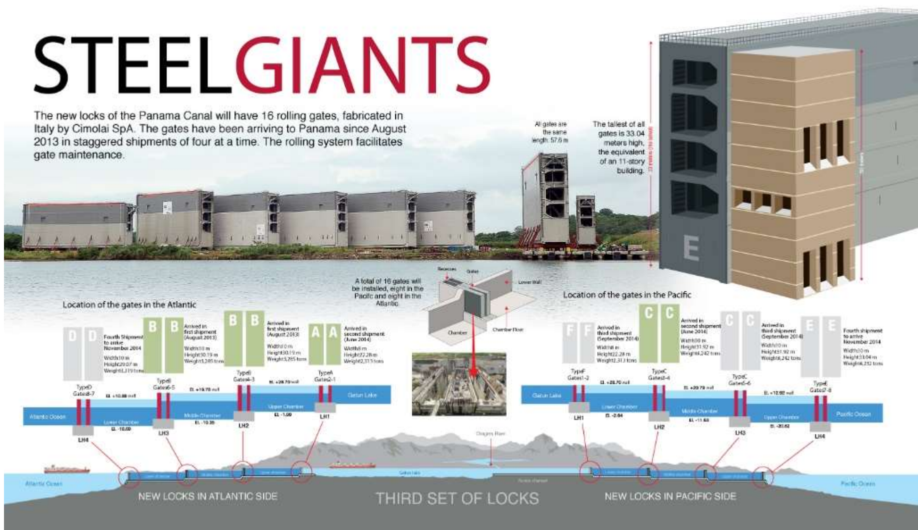
NTNU
Department of Mechanical Engineering



NTNU
Department of Mechanical Engineering



EUROPEAN-EXTREMELY LARGE TELESCOPE (E-ELT) 1.200.000 weldments, 1.500.000 notches

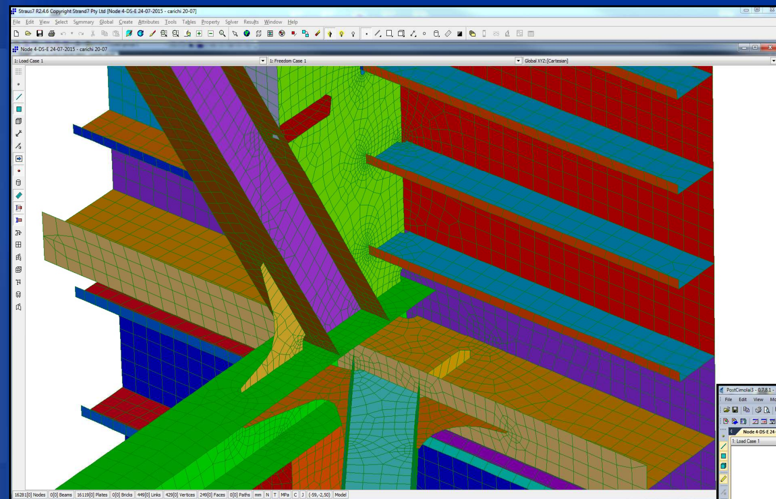


NTNU
Department of Mechanical Engineering

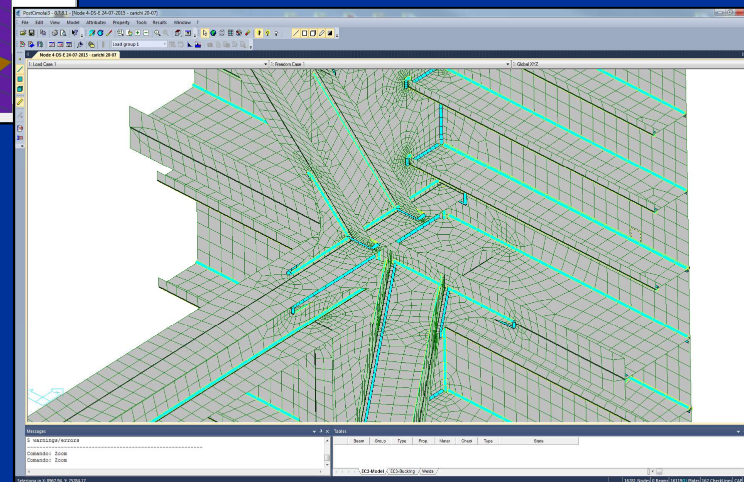
Very proud!!!! (design of the gates and of the ships for the transportation 10.000 Km by sea)
Cimolai has financed 5 PhD (500 KEuro) and employed 10 master students opening a research centre dedicated to advanced structural problems

AUTOMATIC FATIGUE CHECK OF WELDS AND NOTCHES

Department of Mechanical Engineering



Dedicated post-processor for massive fatigue check of weldings, notches and base material.

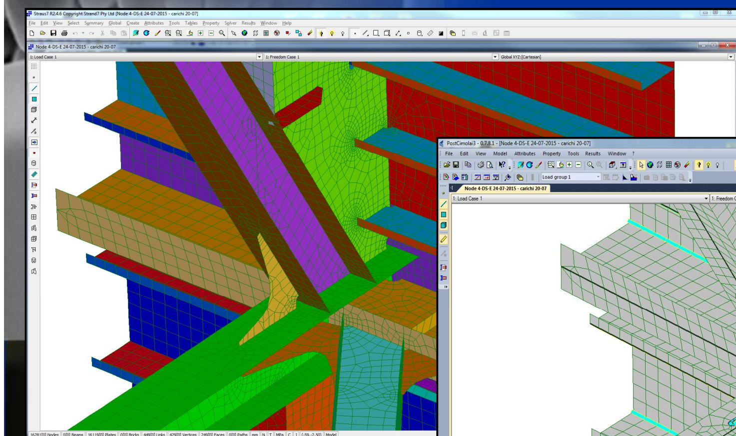


- **AUTOMATED APPROACHES:**
  - Nominal stress
  - Modified nominal stress
  - SED and N-SIF (shell element based)
  - Hot-Spot stress
- **IMPLEMENTED STANDARDS:**
  - Eurocode 3 - Design of steel structures: Fatigue
  - IIW - Recommendations for fatigue design of welded joints, Hobbacher
  - EN 13445 - DNV-GL (Hot Spot user defined)

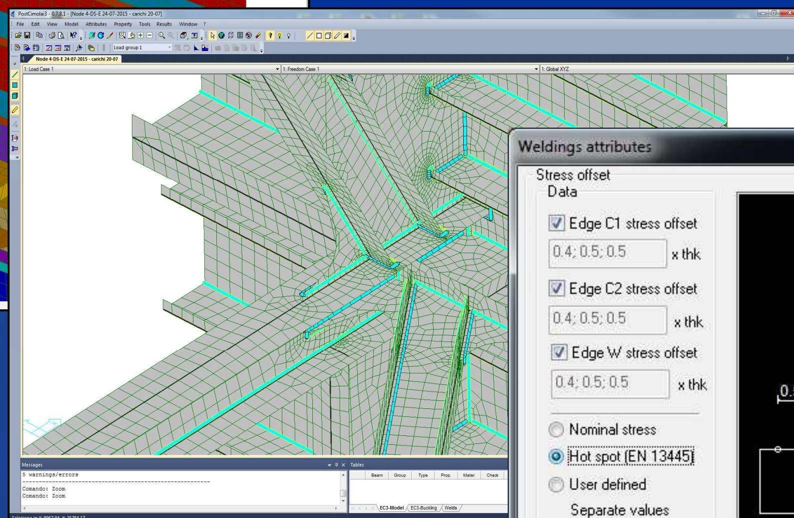
AUTOMATIC FATIGUE CHECK OF WELDS AND NOTCHES

Department of Mechanical Engineering

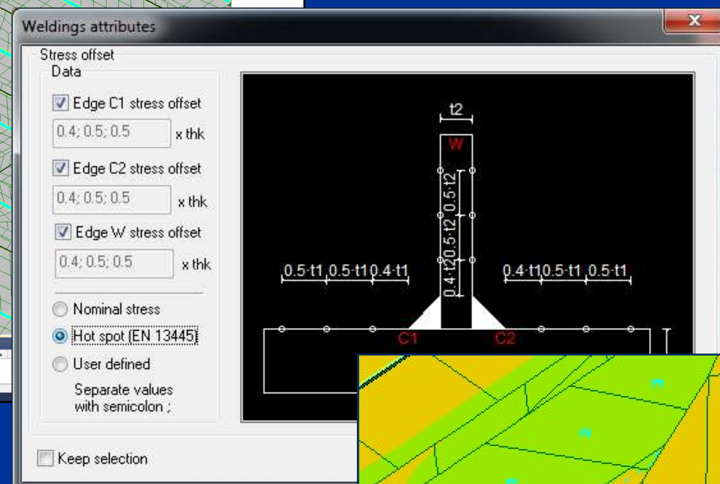
1. Definition of a shell finite element model

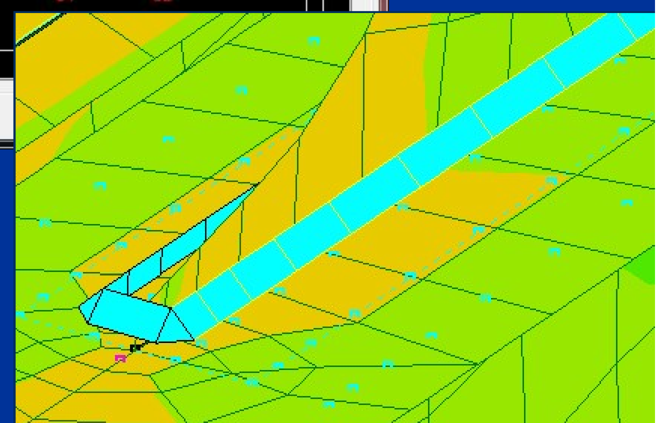


2. Automatic finding of check lines in the postprocessor



3. Set of offsets to stress reading



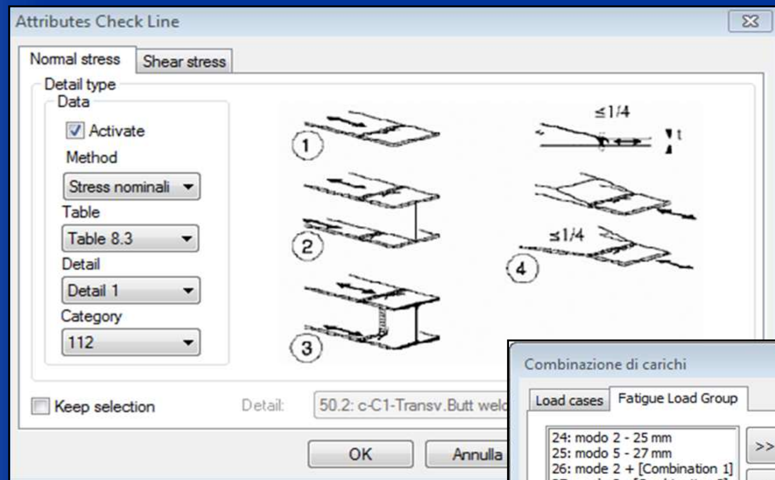


OFFSET STRESS READING:

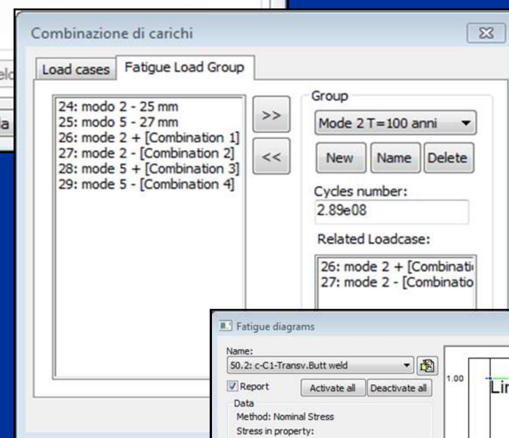
- ✓Nominal stress: default 1.5t (DVS 1612 and Hobbacher)
- ✓Hot-Spot stress: default 0.4t;0.5t;0.5t (EN 13445)
- ✓User defined (SED and other local approaches)

NTNU
Department of Mechanical Engineering

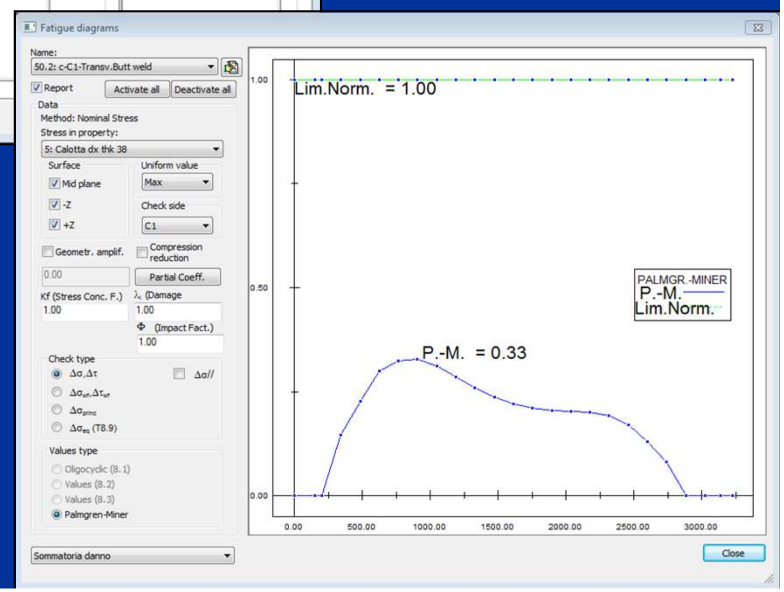
4. Set the fatigue class details



5. Load spectrum



6. Fatigue check



Additive Materials

Department of Mechanical Engineering

ESIS Technical committee 15 (Chief)
ESFRI HORIZON 2020 PROPOSAL (180 ME, 13 PARTNERS)

The fatigue behaviour of Ti6Al4V under multi-axial loading and in presence of notches was investigated

- **The nominal load ratio was found to have a great influence on the fatigue strength while the influence of the load phase angle seems to be limited**

- **The re-analysis of the fatigue data in terms of the strain energy density range at the notch tip allowed us to summarise all the multiaxial data on notched specimens in a single fatigue scatter band**

- **The proposed approach results therefore a very useful tool for the fatigue analysis of components subjected to multiaxial fatigue loading in the presence of severe notches**


You are also welcome
in Norway!!!

TU WIEN TECHNISCHE UNIVERSITÄT WIEN

ISPR 2017

13-15 September 2017, Vienna

Üretim Araştırmaları Derneği

Department of Mechanical Engineering

MANY THANKS
FOR THE KIND INVITATION

HONORED AND GRATEFUL TO BE HERE

it was better to meet you at least once
then never have met you

'My favorite things in life don't cost any money. It's really clear that the most precious resource we all have is time'