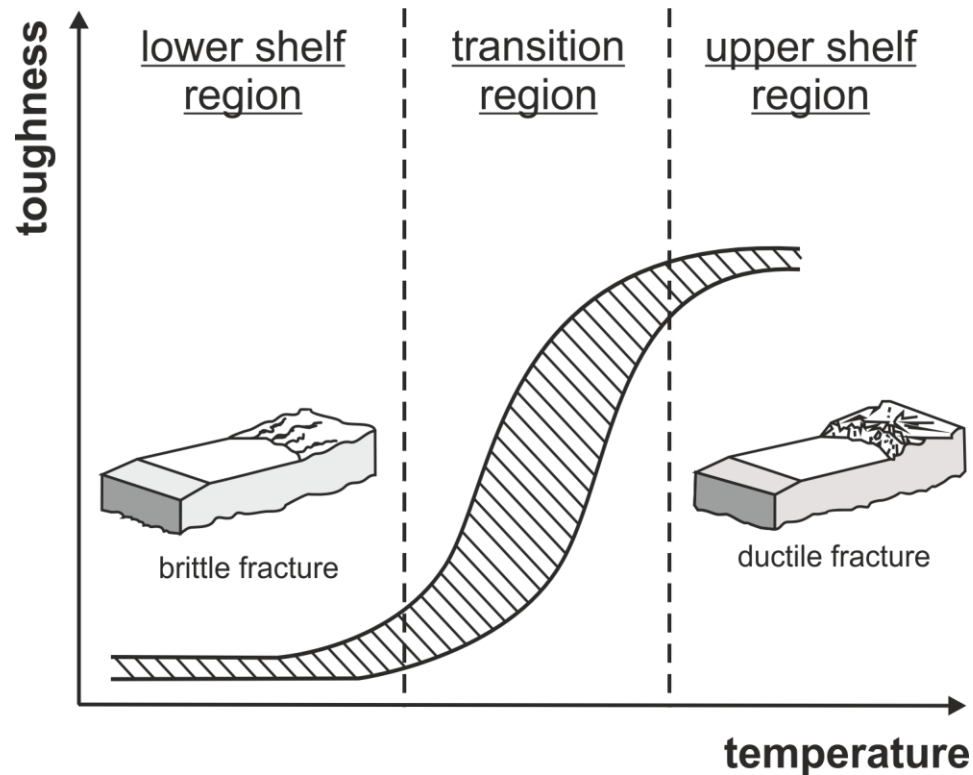


Material characteristics

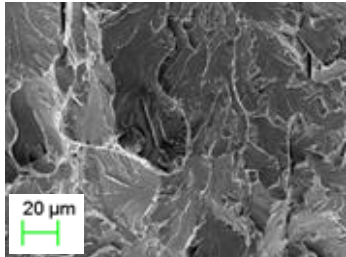
Ductility and toughness requirements for plastic design with regard to high strength steel

Temperature dependency

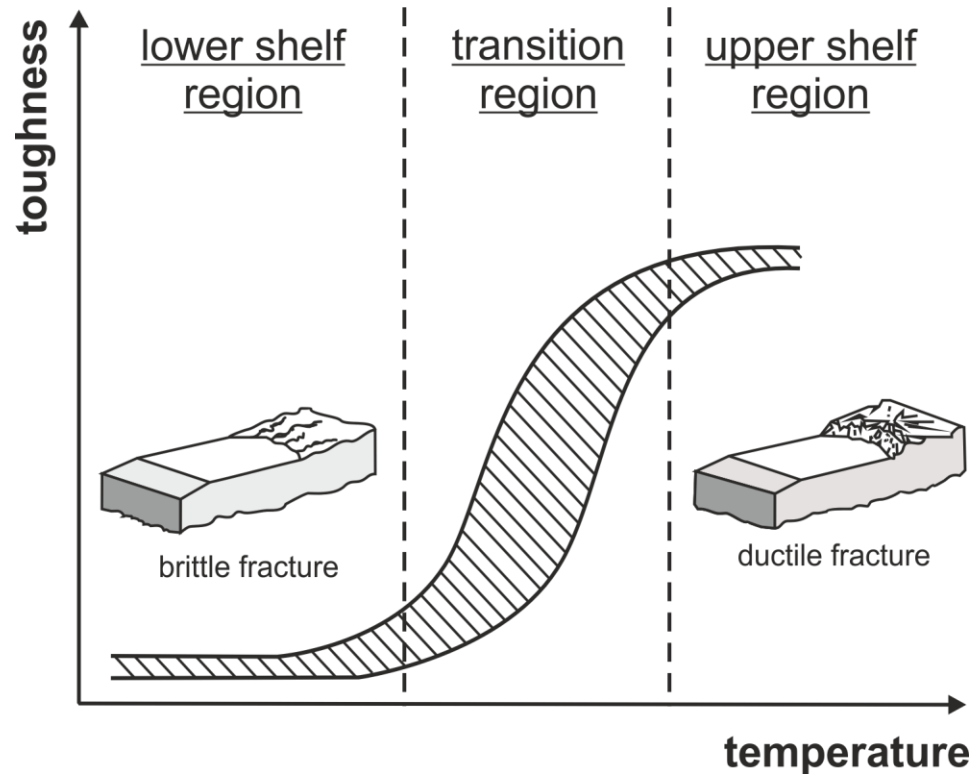
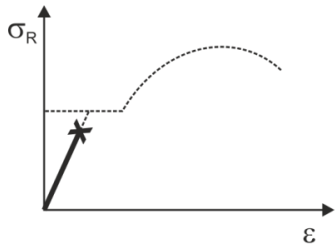


Temperature dependency

material behaviour

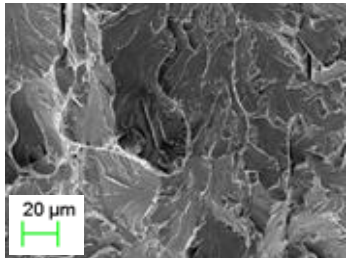


component behaviour

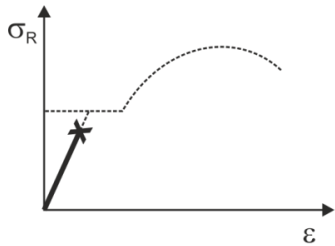


Temperature dependency

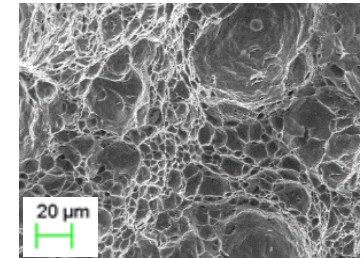
material behaviour



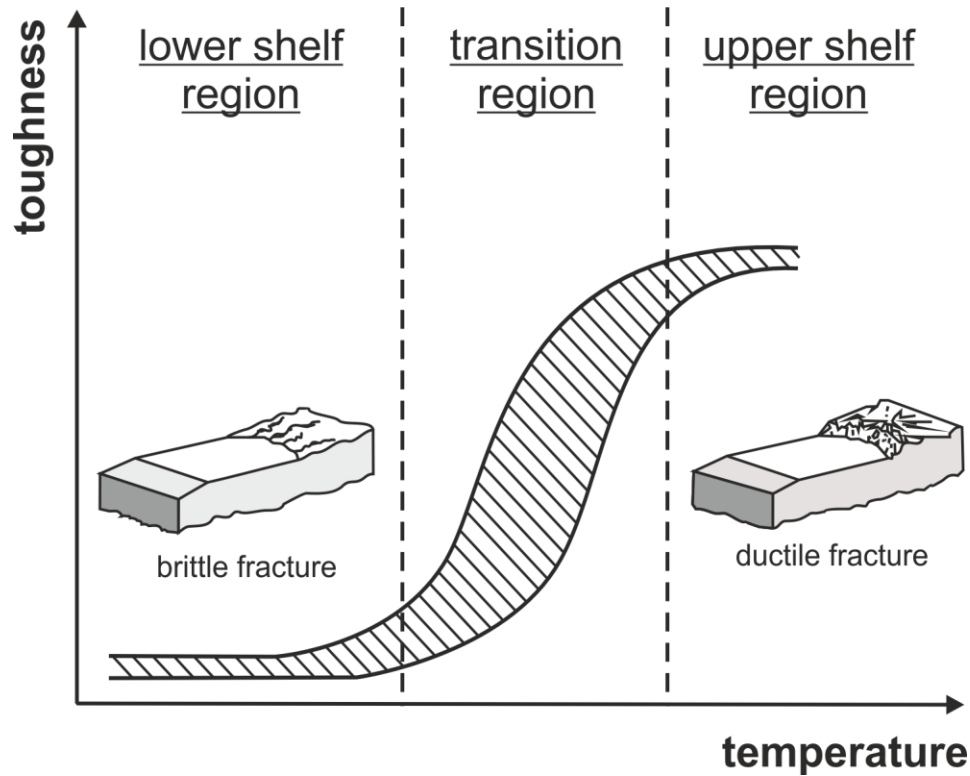
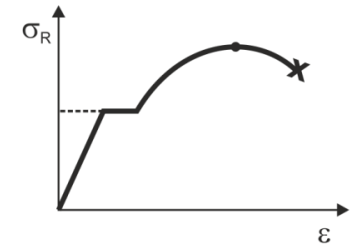
component behaviour



material behaviour

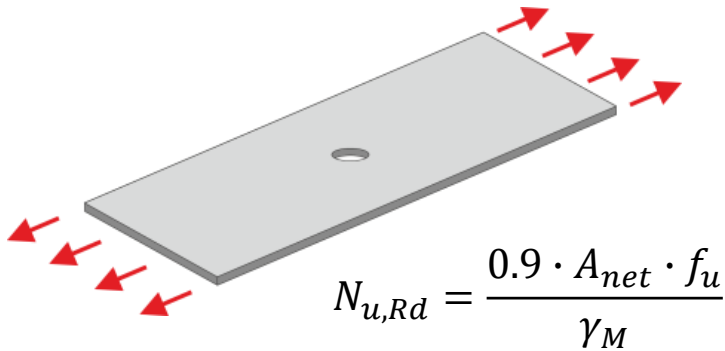


component behaviour

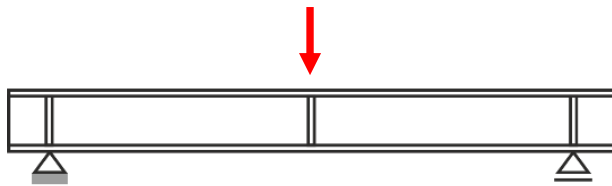


Plastic component behaviour

Tension:



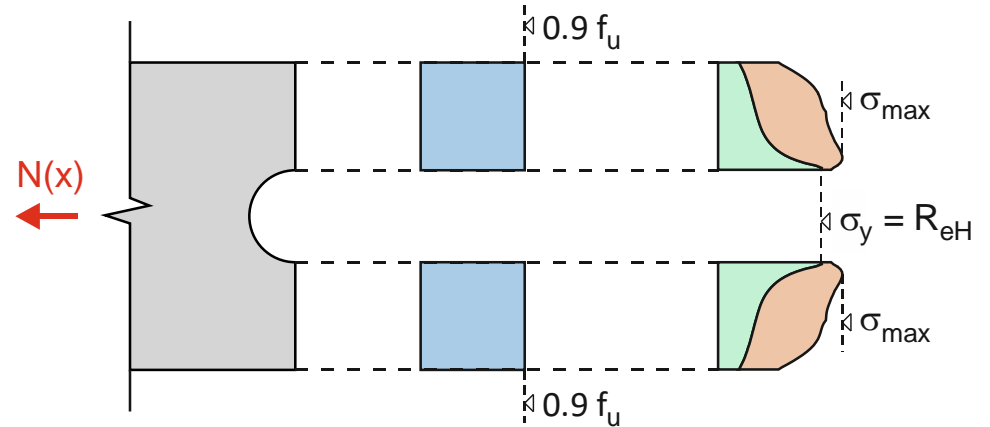
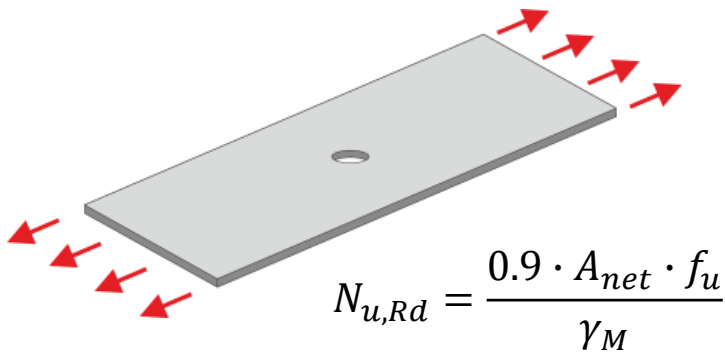
Bending:



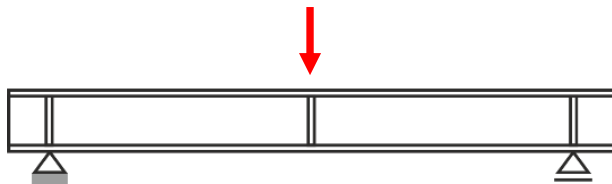
$$M_{pl,Rd} = \frac{W_{pl} \cdot f_y}{\gamma_M}$$

Plastic component behaviour

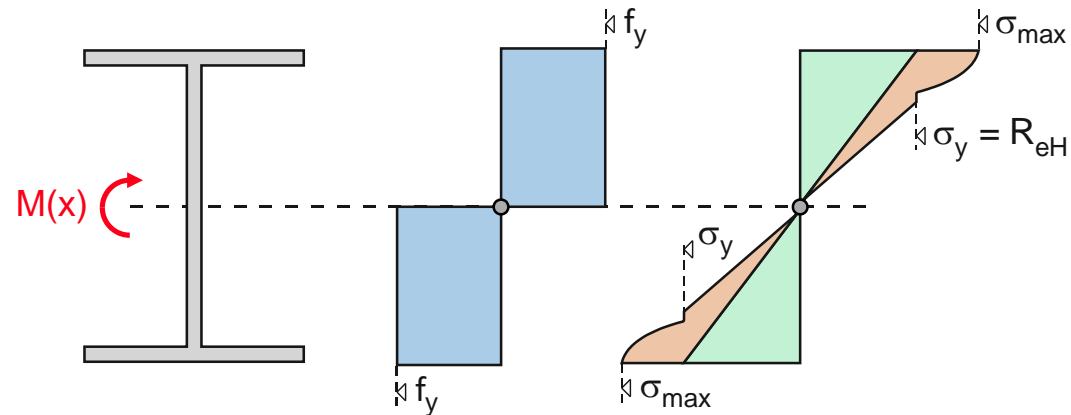
Tension:



Bending:



$$M_{pl,Rd} = \frac{W_{pl} \cdot f_y}{\gamma_M}$$

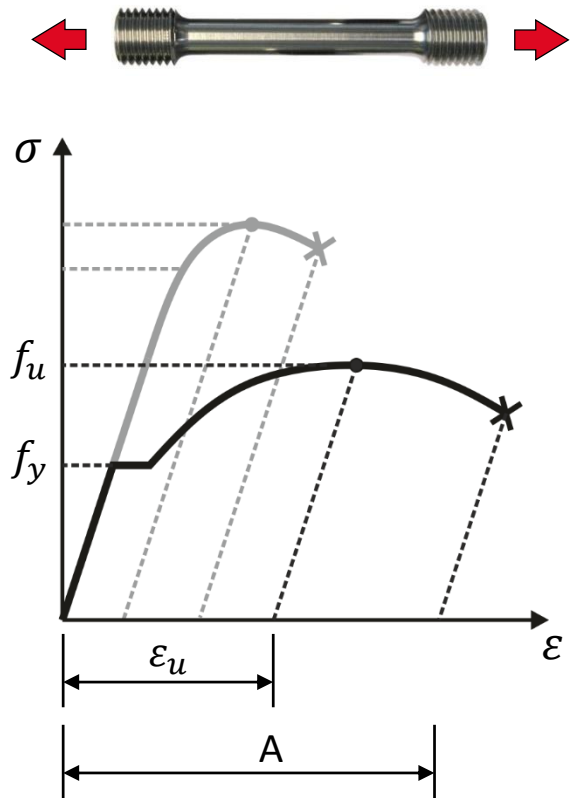


Current situation acc. EC3

Ductility requirements acc. to EUROCODE 3

	≤ S460 (EN 1993-1-1)	≤ S700 (EN 1993-1-12)
f_u/f_y	≥ 1.10	≥ 1.05
A	≥ 15 %	≥ 10 %
ϵ_u	≥ 15 f_y/E	≥ 15 f_y/E

- ❑ Requirements were **empirically determined** and have no direct mechanical background
- ❑ Requirements are more **difficult to meet with increasing strength**

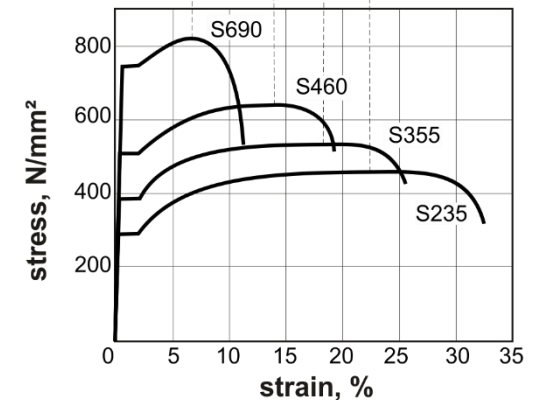
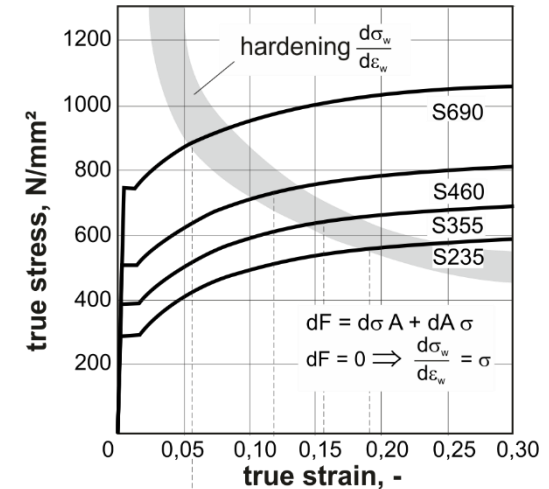


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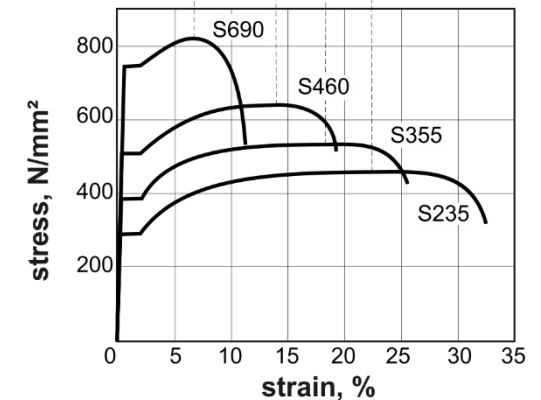
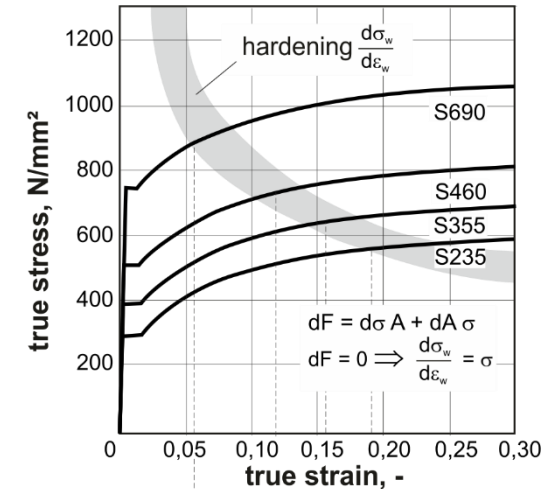
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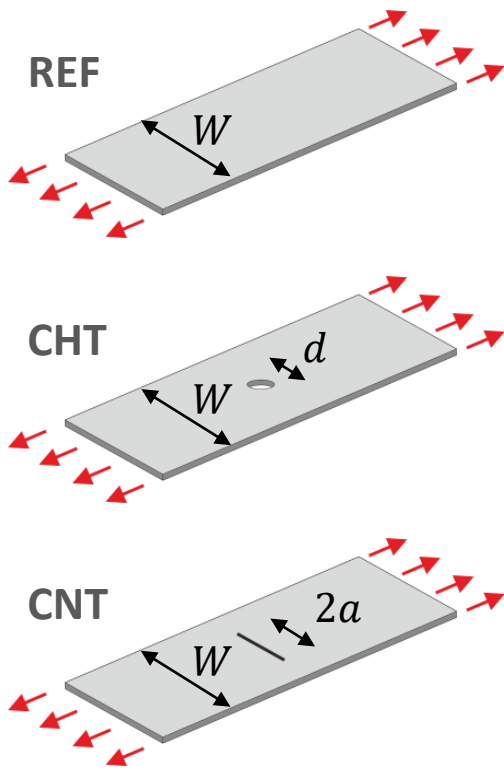
- ❑ Requirements were **empirically determined** and have no direct mechanical background
- ❑ Requirements are more **difficult to meet with increasing strength**

ϵ_u is not part of the *European Standards for Structural Steel Product* (e.g. EN 10025) or the *3.1 Material Certificate*

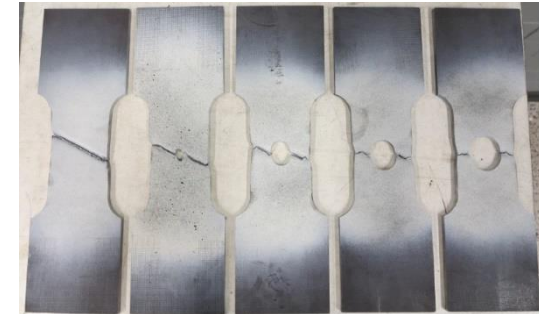
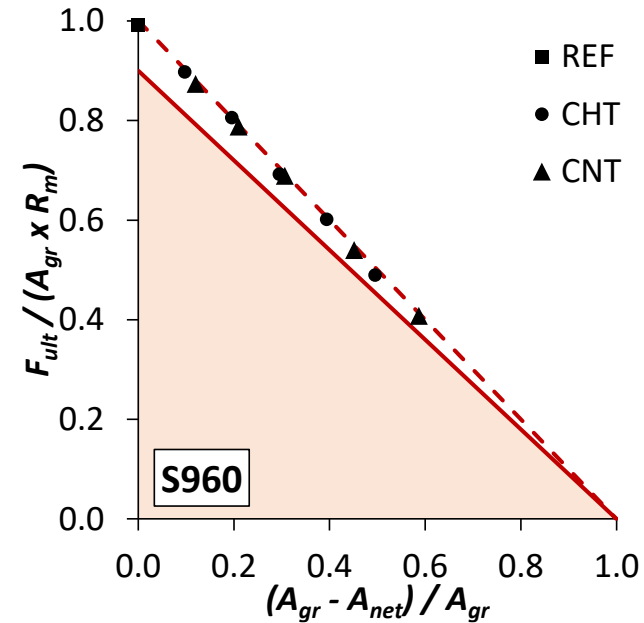
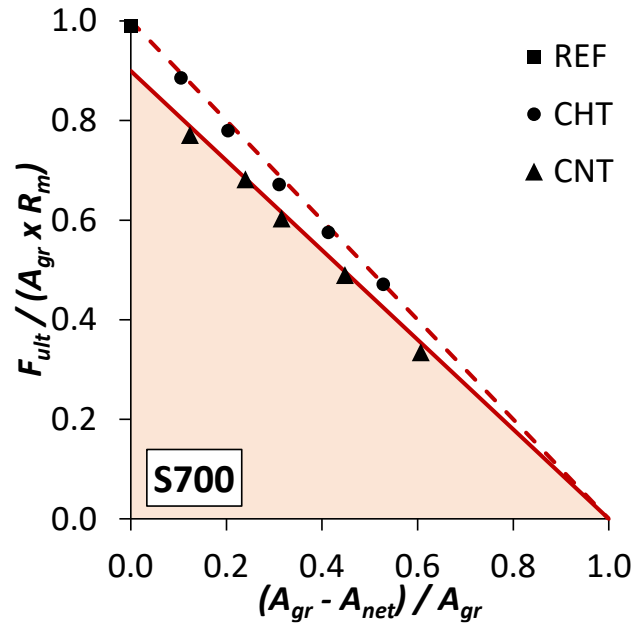


Inconsistencies of current rules

RFCS-Project RUOSTE – Rules on high strength steels

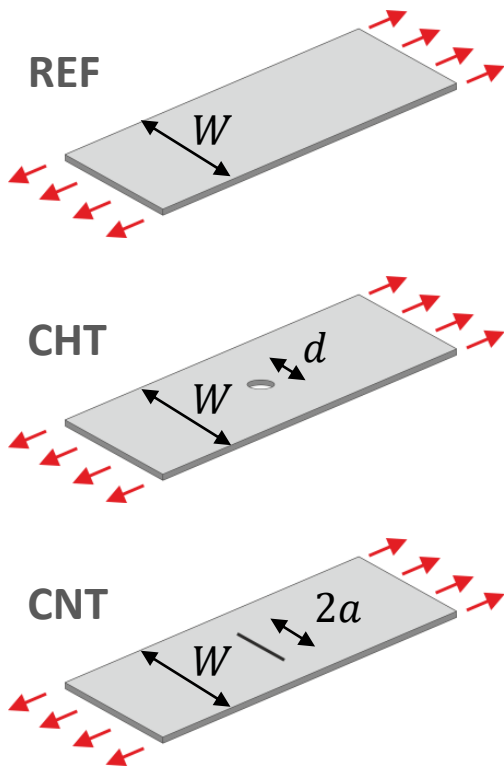


$$N_{u,Rd} = \frac{0.9 \cdot A_{net} \cdot f_u}{\gamma_{M12}}$$

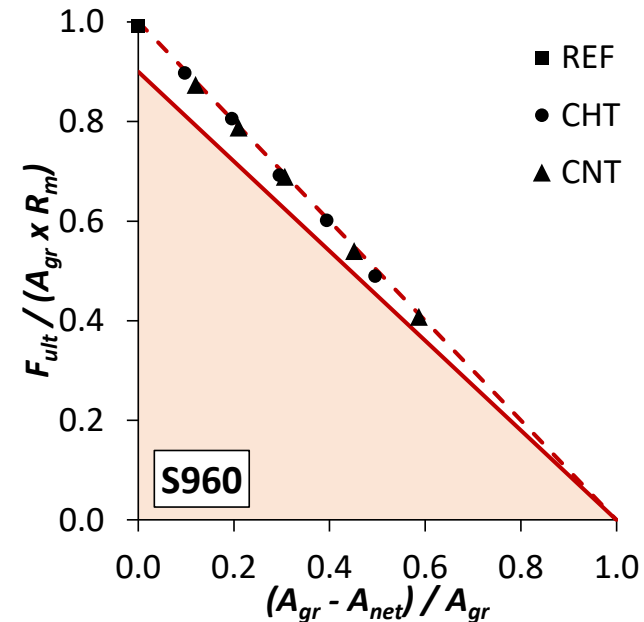
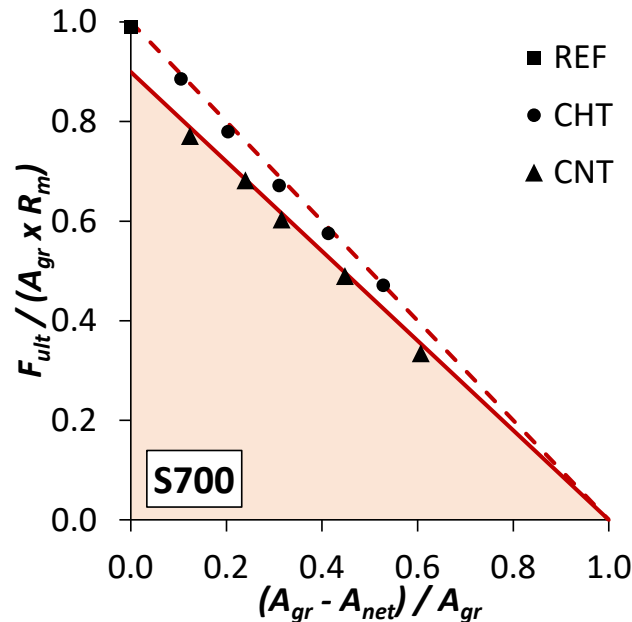


Inconsistencies of current rules

RFCS-Project RUOSTE – Rules on high strength steels



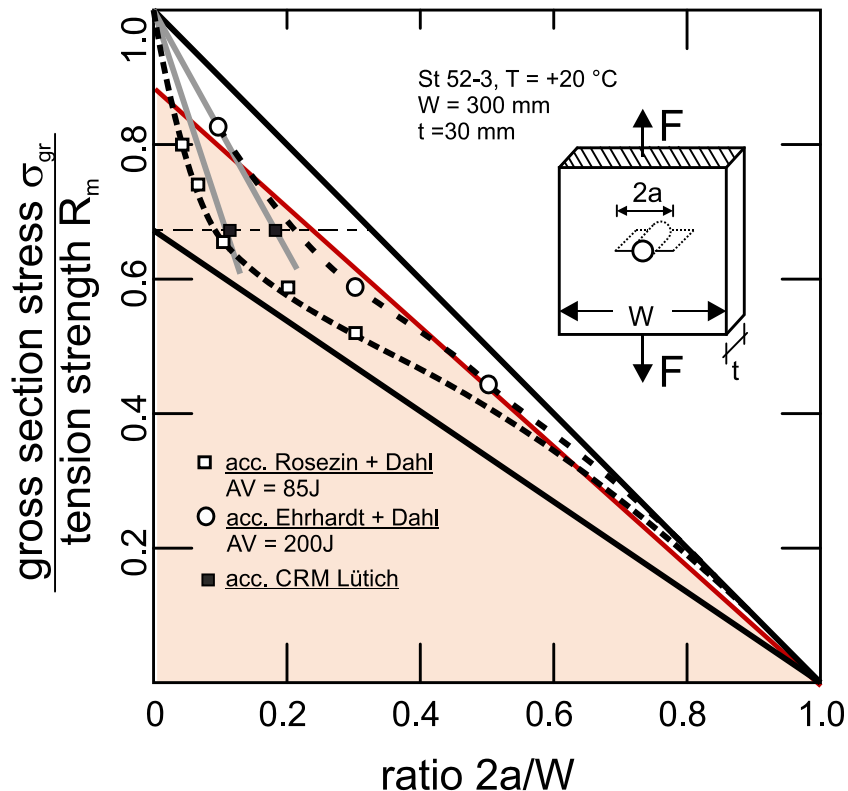
$$N_{u,Rd} = \frac{0.9 \cdot A_{net} \cdot f_u}{\gamma_{M12}}$$



	R_{eH} [N/mm ²]	R_m [N/mm ²]	R_m / R_{eH} [-]	A_u [%]
S700	753	843	1.12 (>1.05) ✓	9.3 (>5.4) ✓
S960	1018	1053	1.03 (>1.05) ✗	5.3 (>7.5) ✗

Inconsistencies of current rules

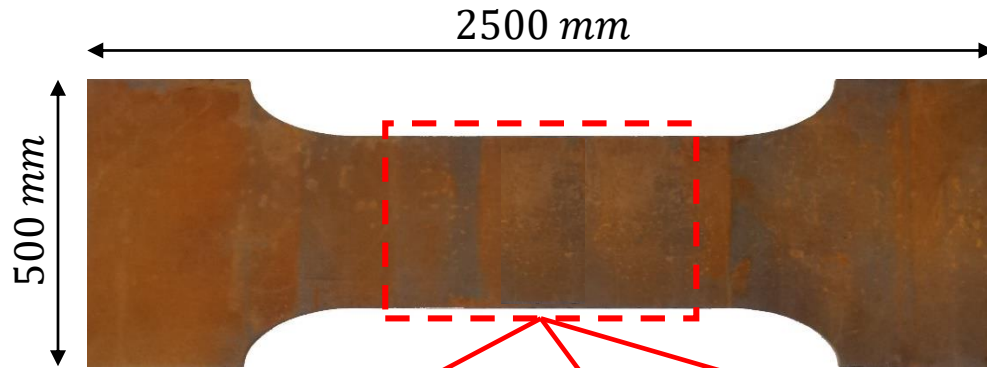
JRC Scientific and Technical Report – Commentary and worked examples to EN 1993-1-10



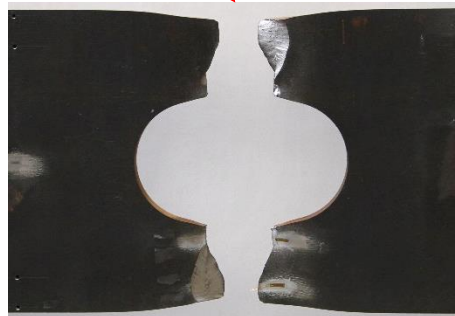
- Strong influence of upper-shelf toughness properties
- Individual analysis of strength and toughness properties experimentally
- Application of a combined experimental-numerical method based on damage mechanics

Further experimental tests

FOSTA/AiF-Project BESTA – Derivation of new, optimized strength criteria

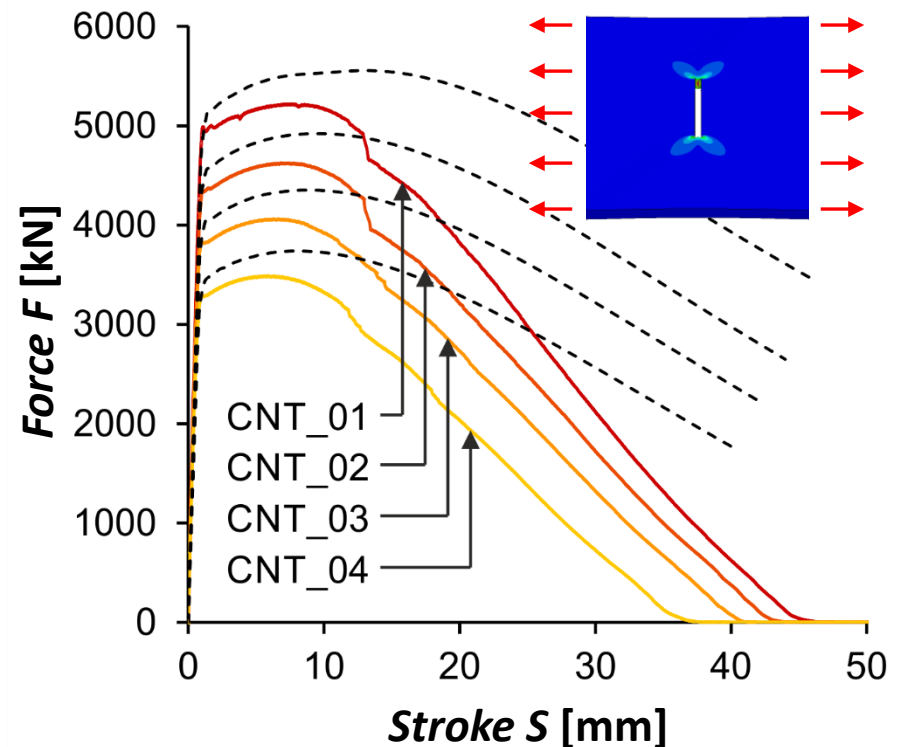
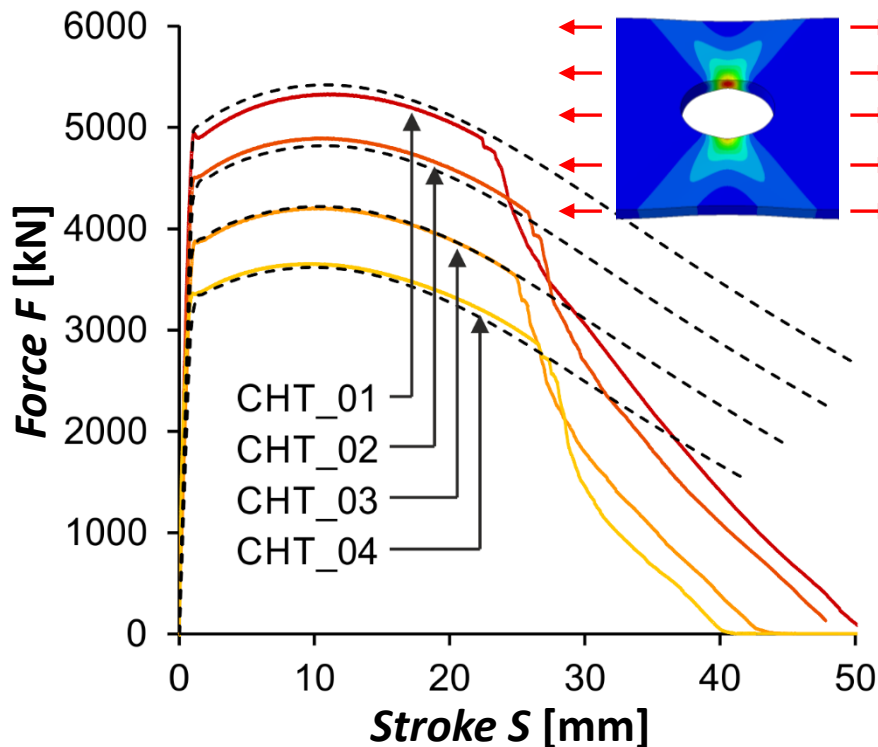


- S355J2+N, S500M, S690QL & S960QL
 - 20 – 40mm thickness
 - REF, CHT & CNT Geometry
- ➔ 46 wide-plate tension tests



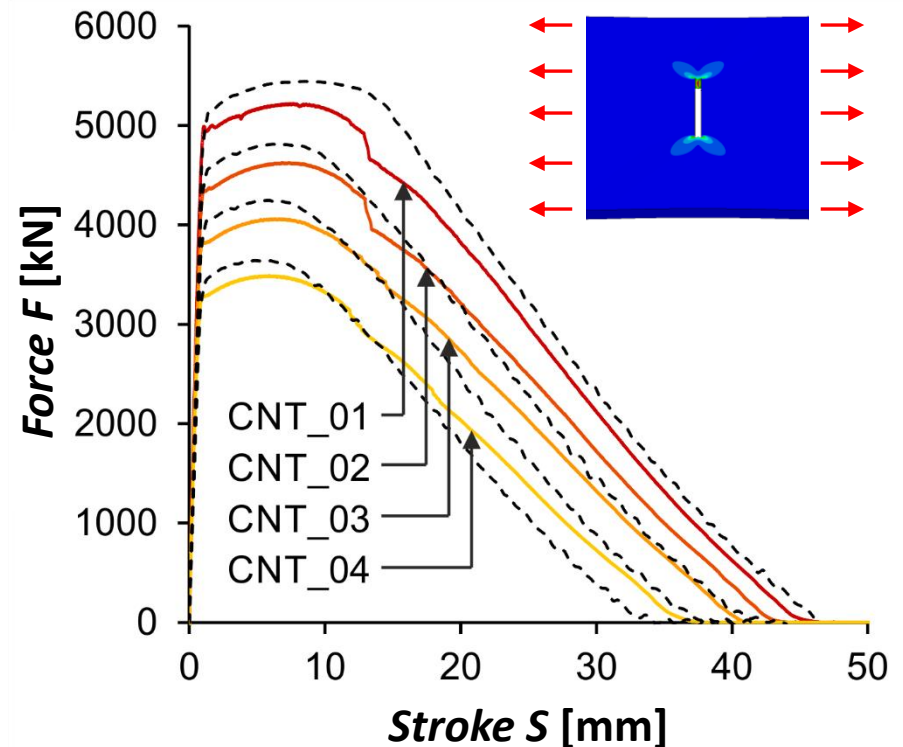
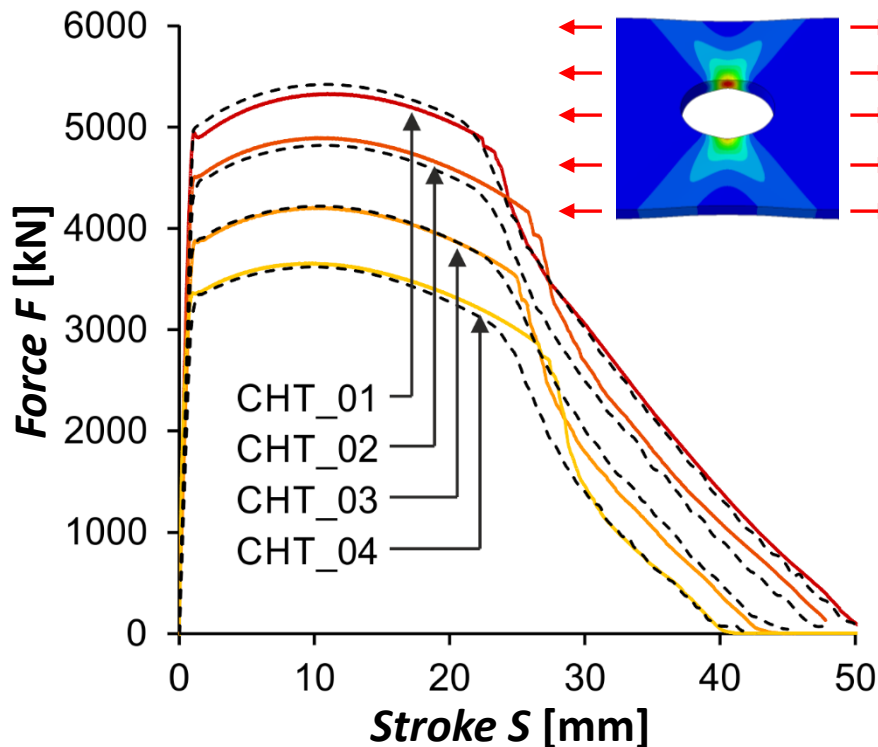
Numerical simulation

FOSTA/AiF-Project BESTA – Derivation of new, optimized strength criteria



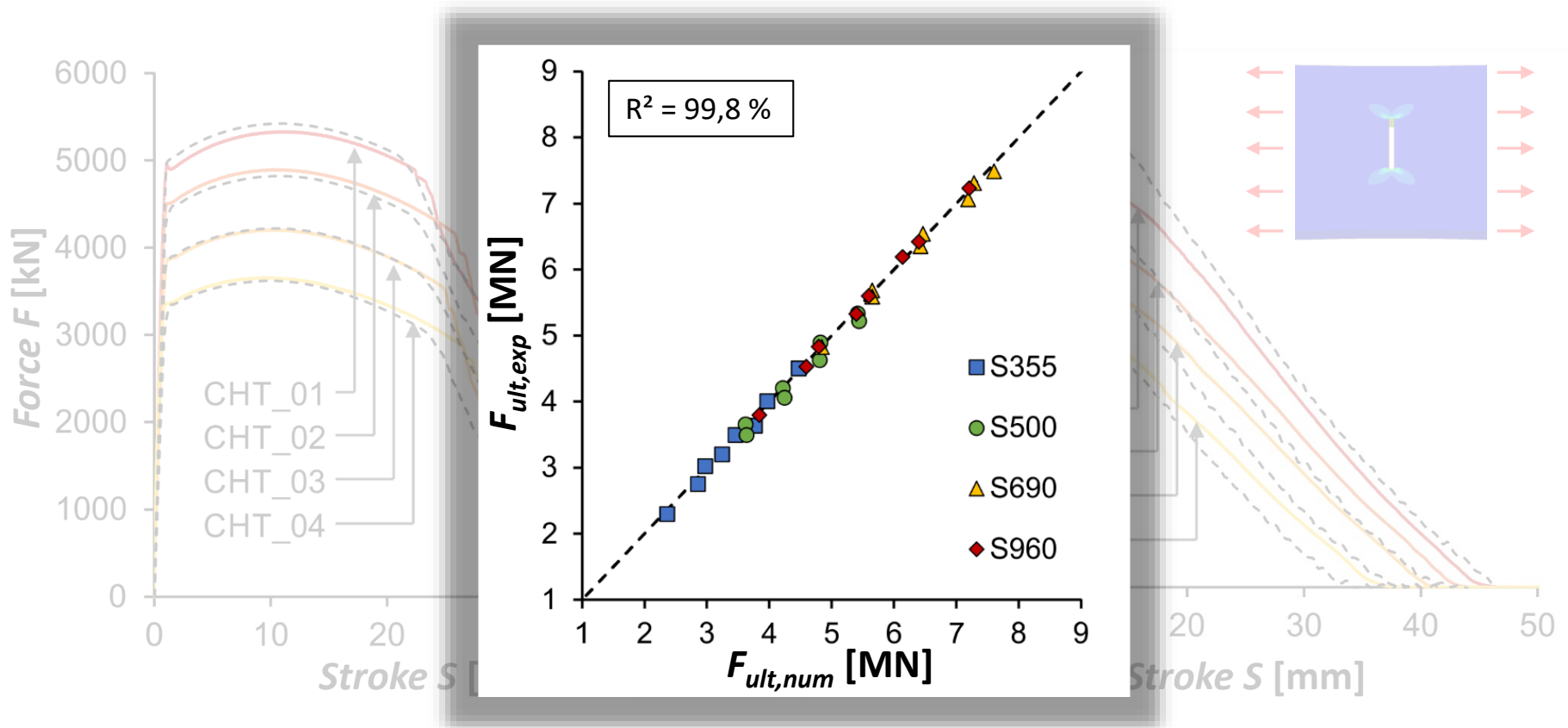
Numerical simulation

FOSTA/AiF-Project BESTA – Derivation of new, optimized strength criteria



Numerical simulation

FOSTA/AiF-Project BESTA – Derivation of new, optimized strength criteria



Material database

Database with ca. 300 data sets

- Steel grades S235 - S960
- Thickness $t = 4\text{mm} - 80\text{mm}$
- Delivery conditions:
 - non-alloy
 - normalized
 - thermomechanical rolled
 - quenched and tempered
- Data:
 - R_{eH}
 - R_m
 - A_u
 - A_L

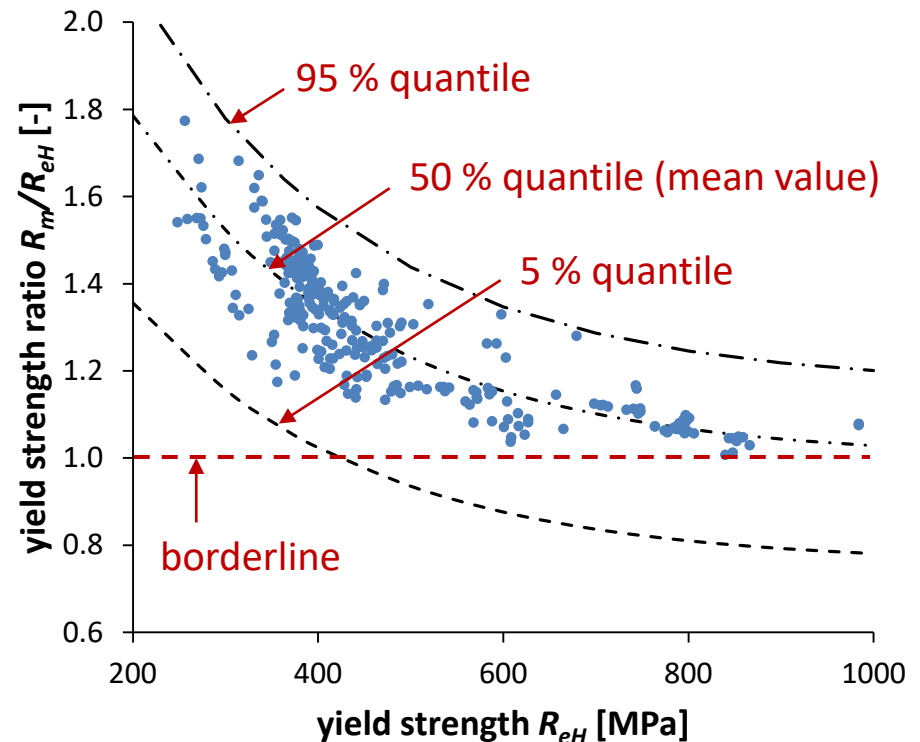
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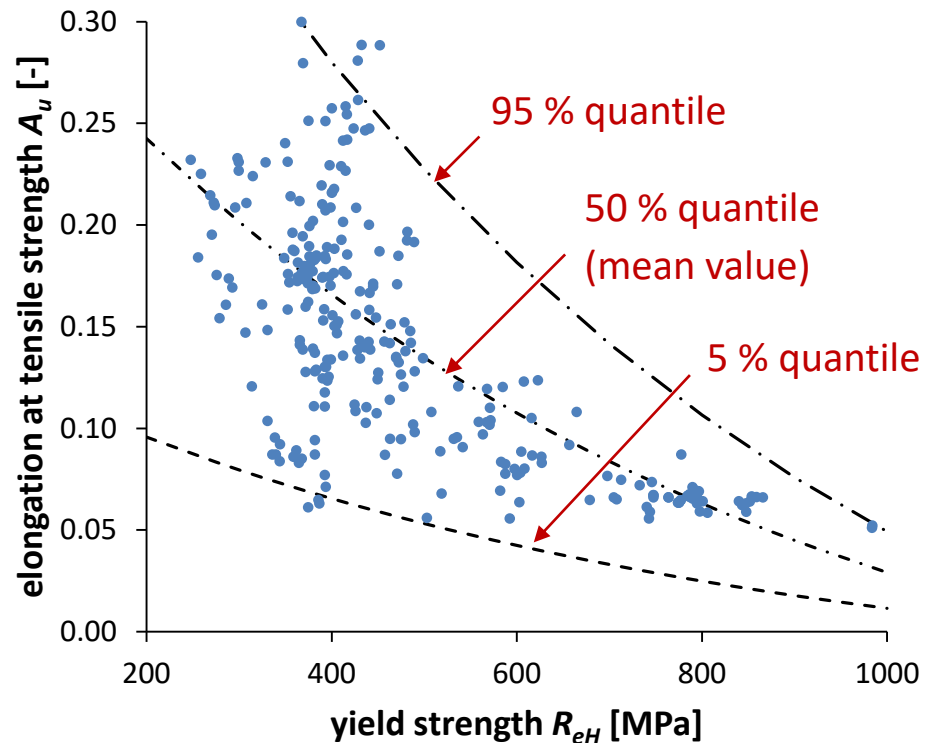
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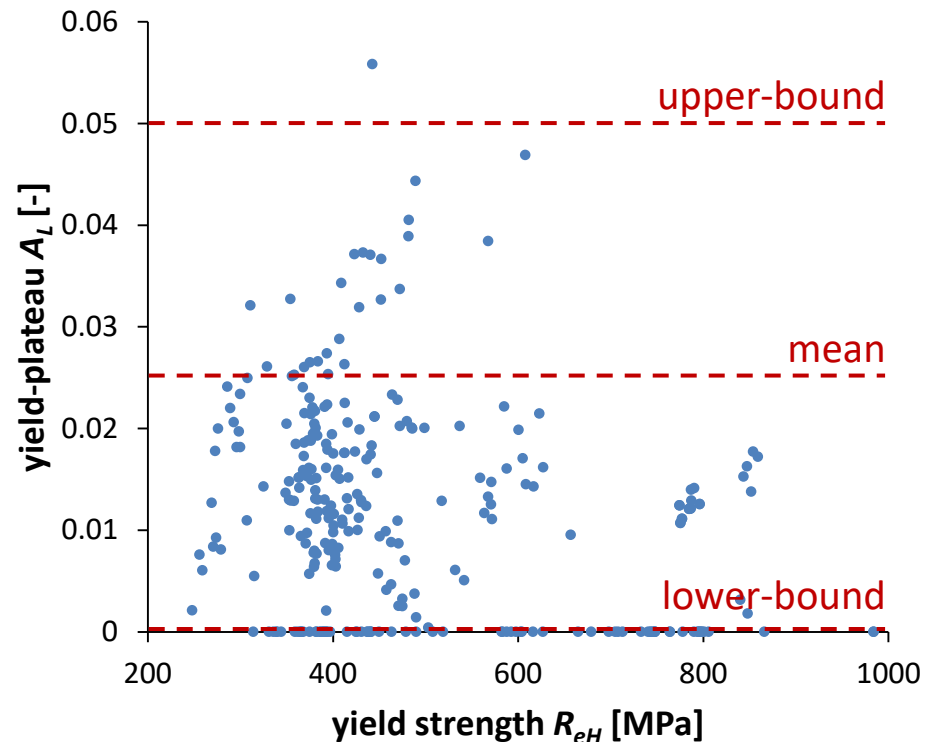
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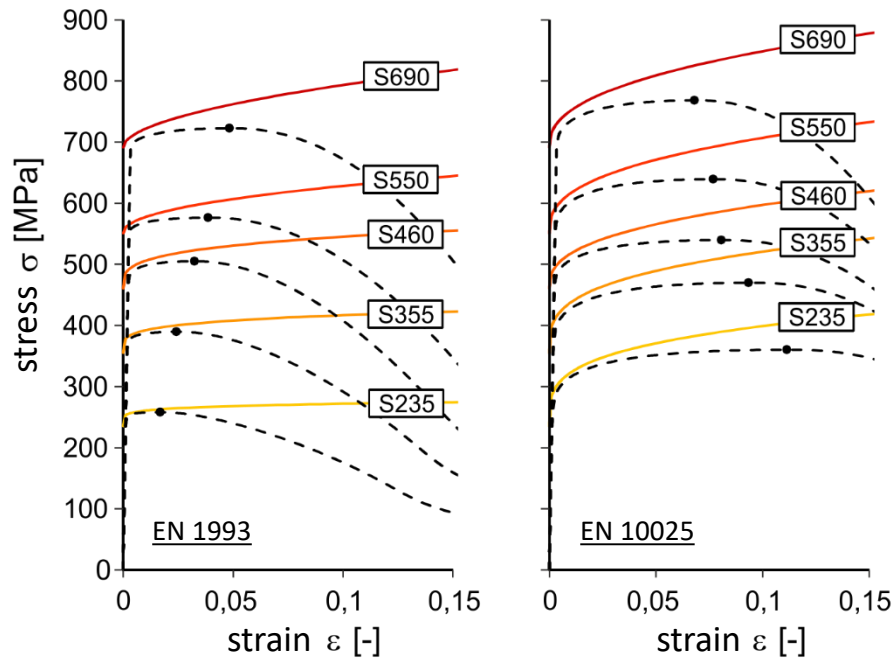
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- R_m
- A_u
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Parametric material properties

Strength properties

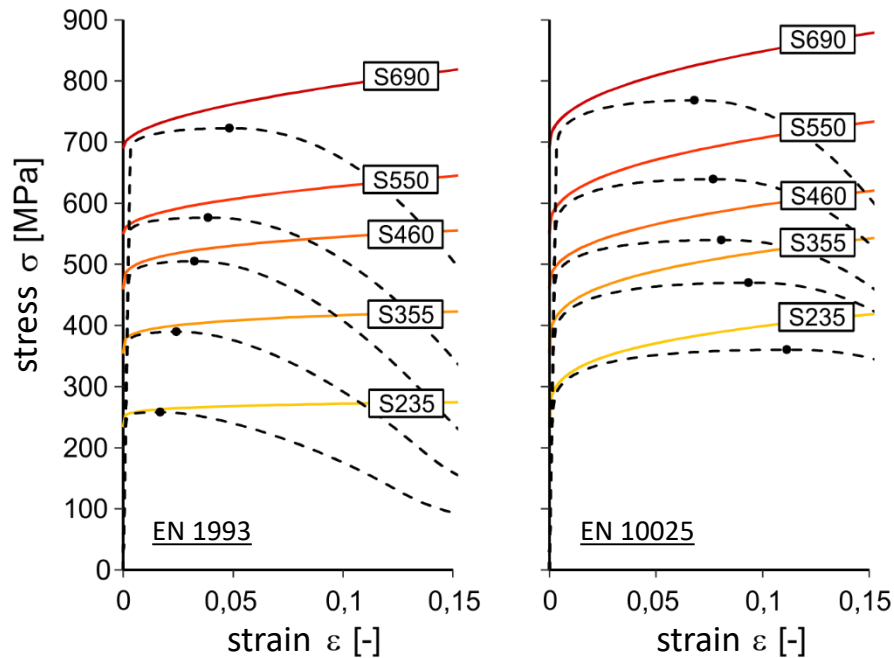
Parametric true stress-strain curves:



Parametric material properties

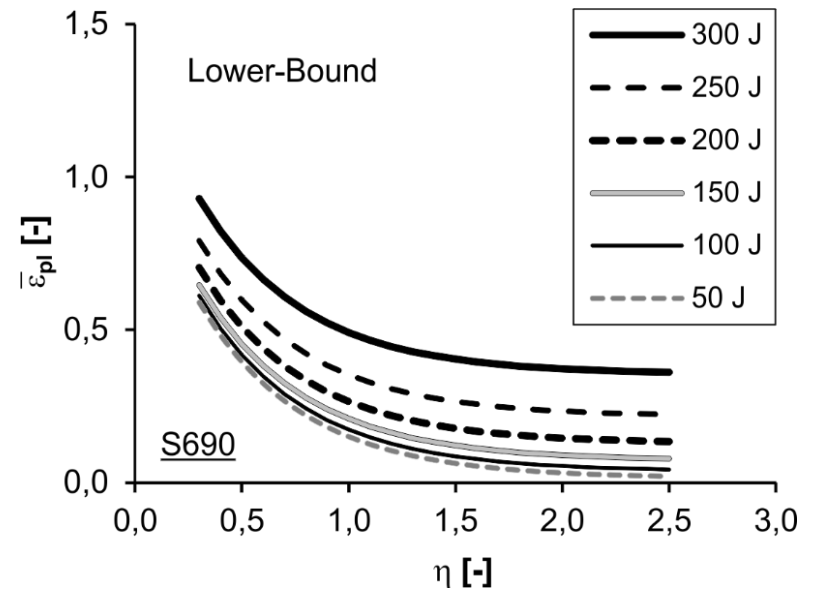
Strength properties

Parametric true stress-strain curves:

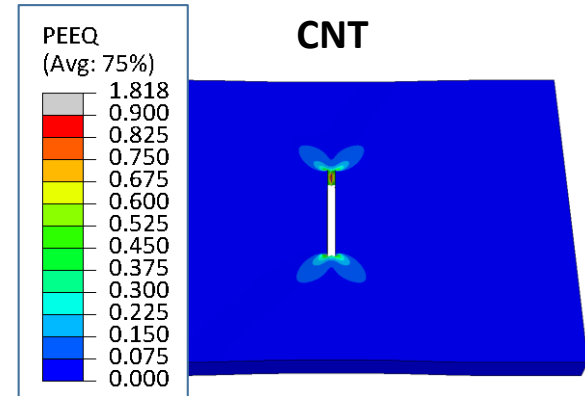
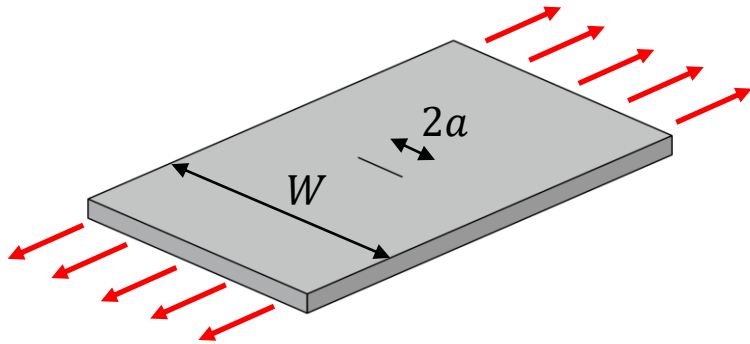


Upper-shelf toughness

Parametric damage curves:

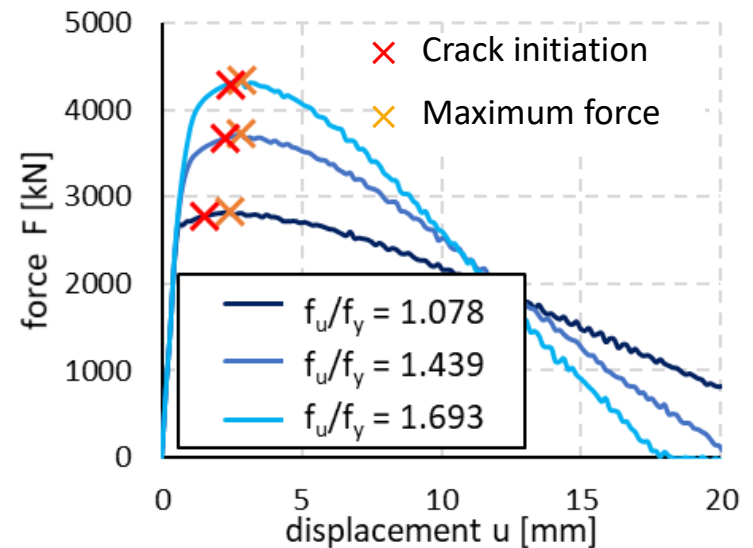


Numerical parametric study

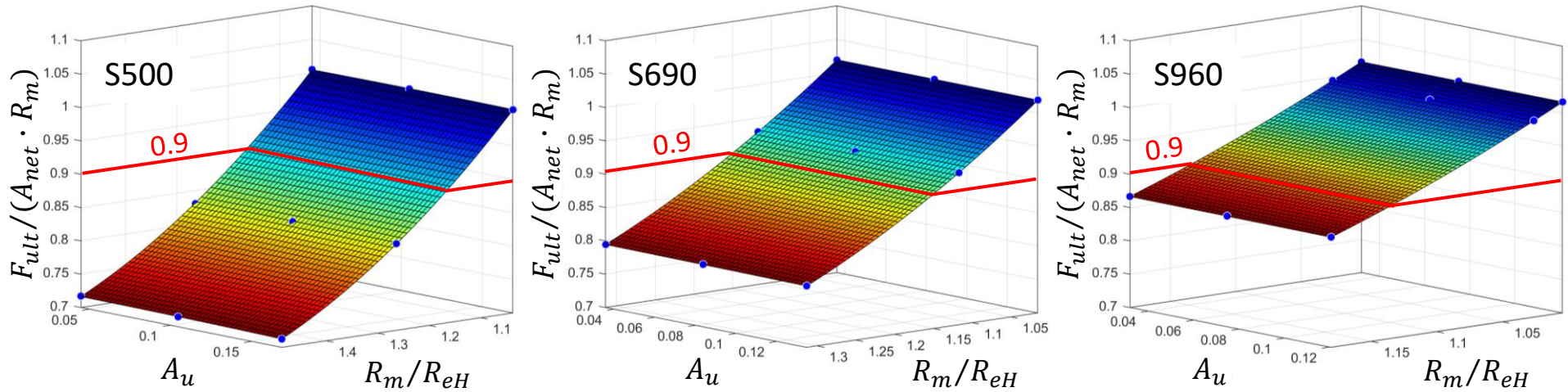


Variation of:

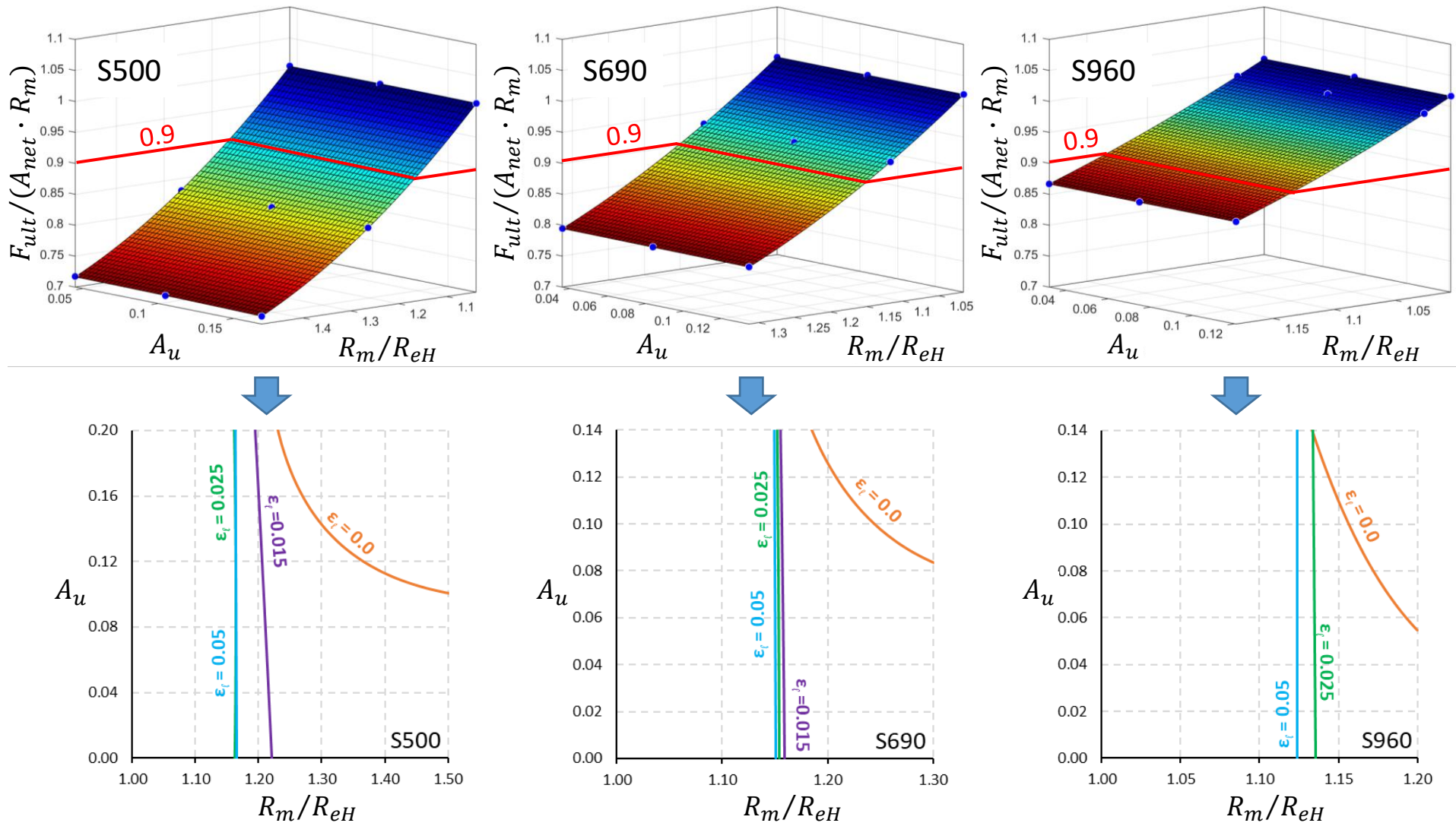
- geometry → net-section ratio
- strength → true σ - ϵ -curves
- toughness → damage curves



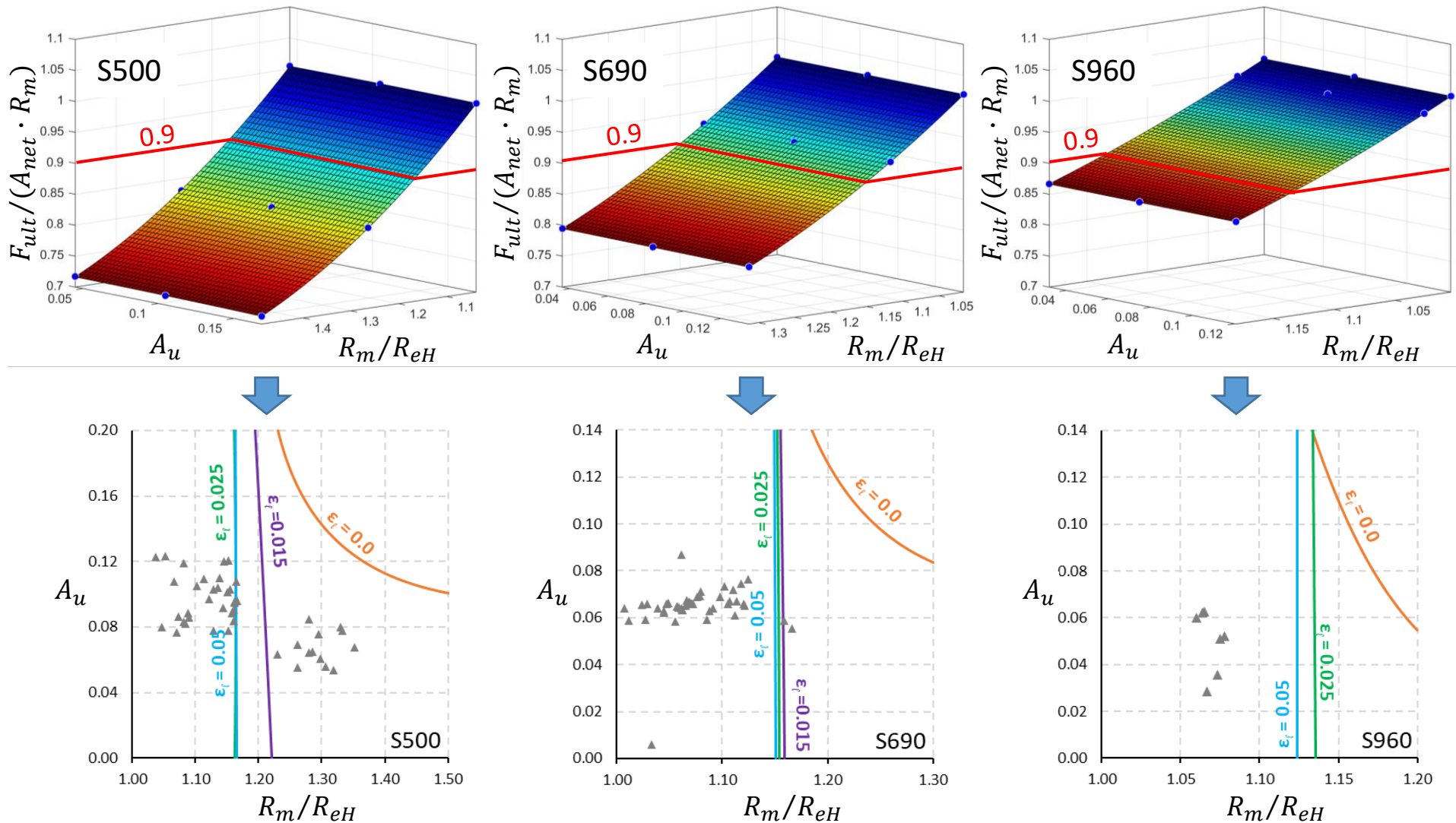
Numerical parametric study



Numerical parametric study

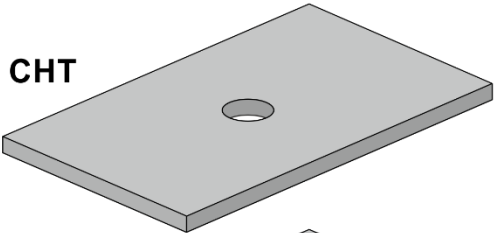


Numerical parametric study

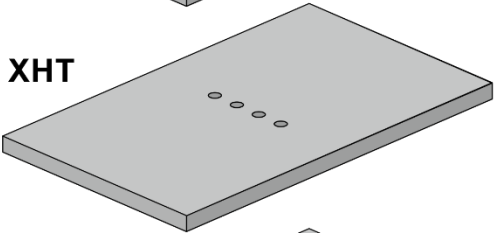


Deviating geometries

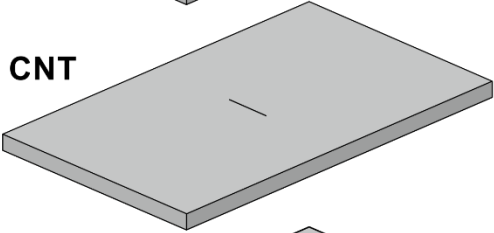
CHT



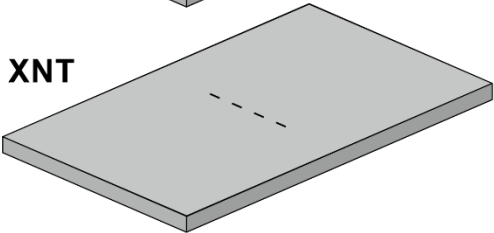
XHT



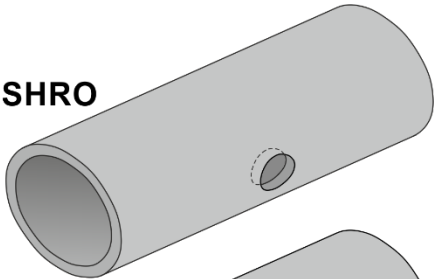
CNT



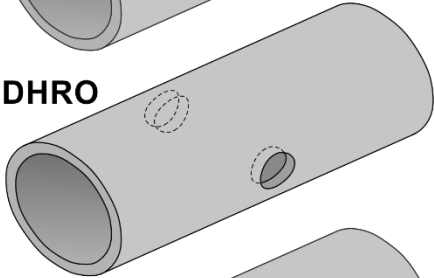
XNT



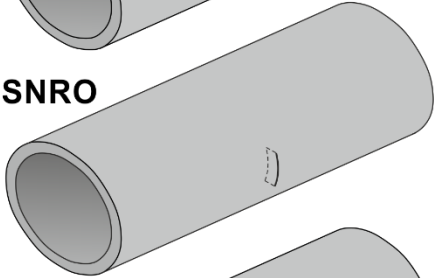
SHRO



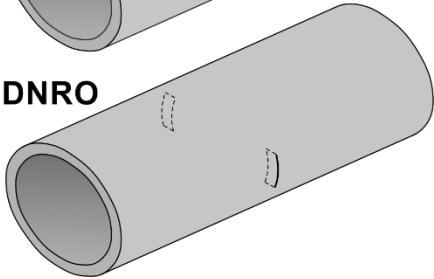
DHRO



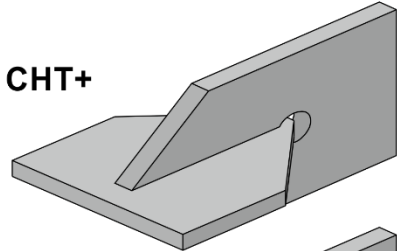
SNRO



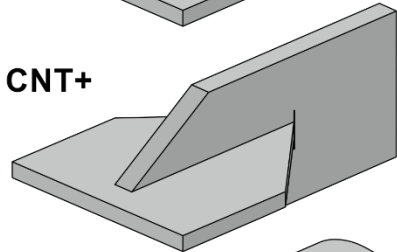
DNRO



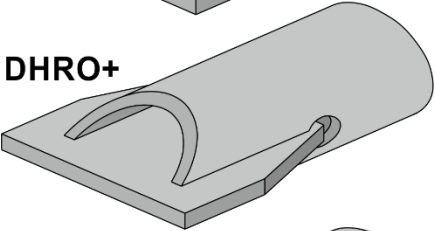
CHT+



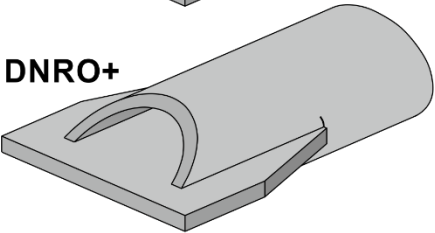
CNT+



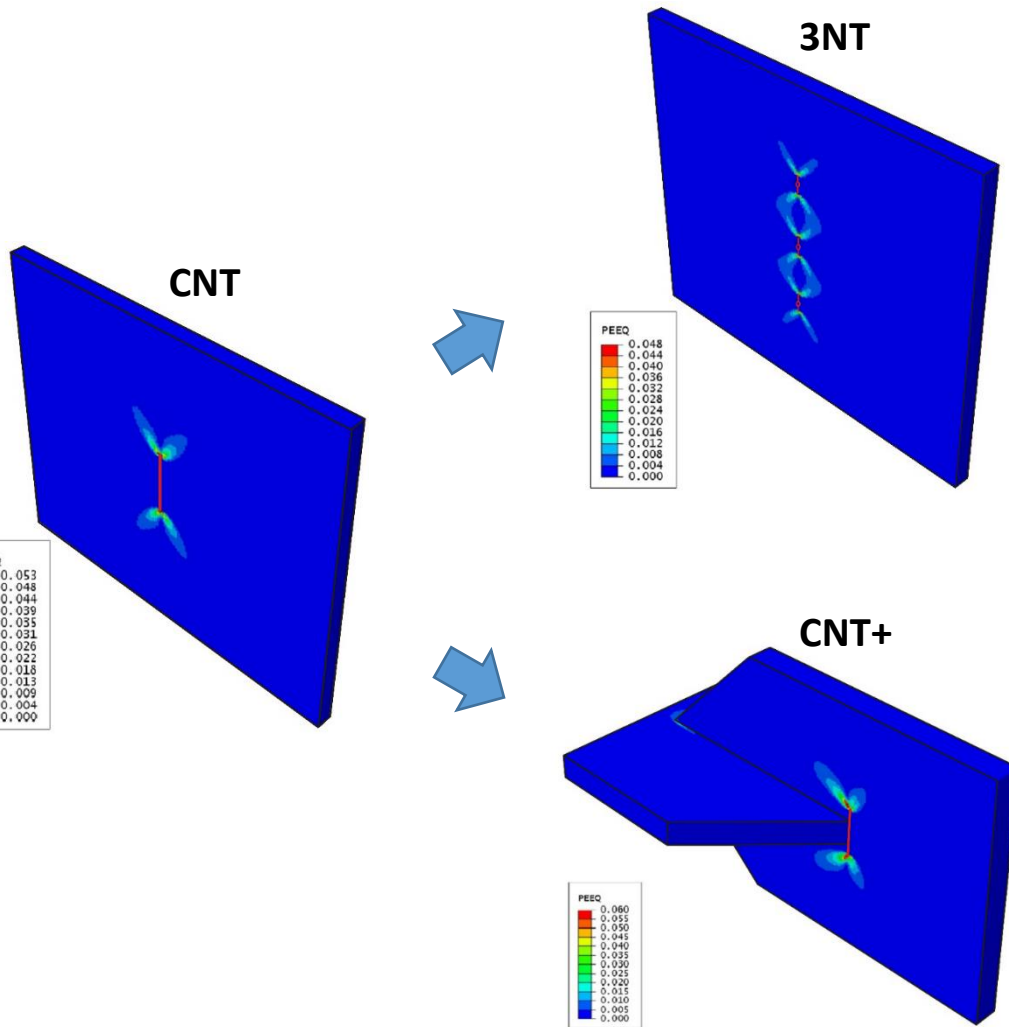
DHRO+



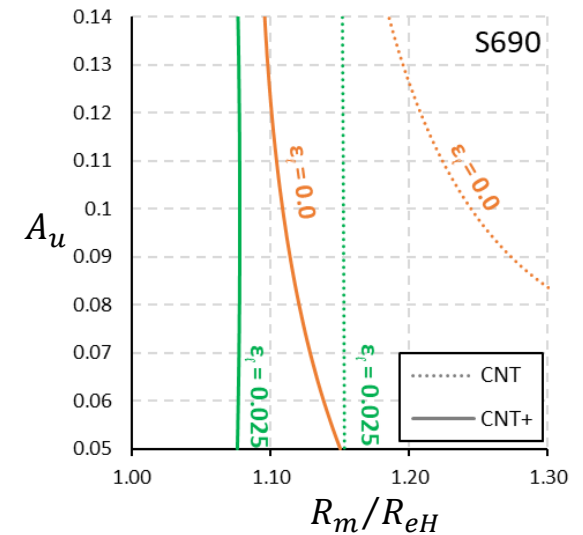
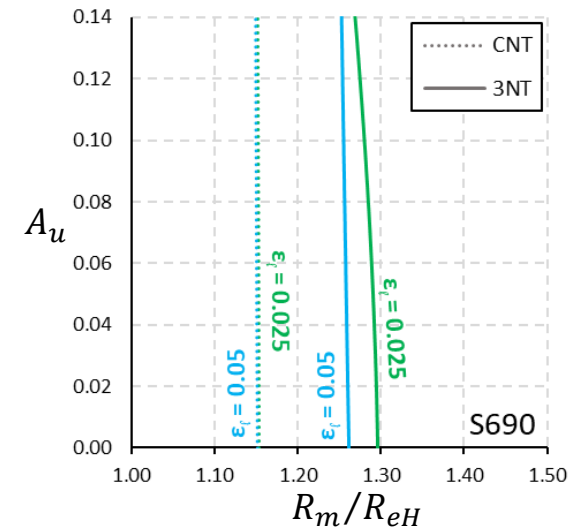
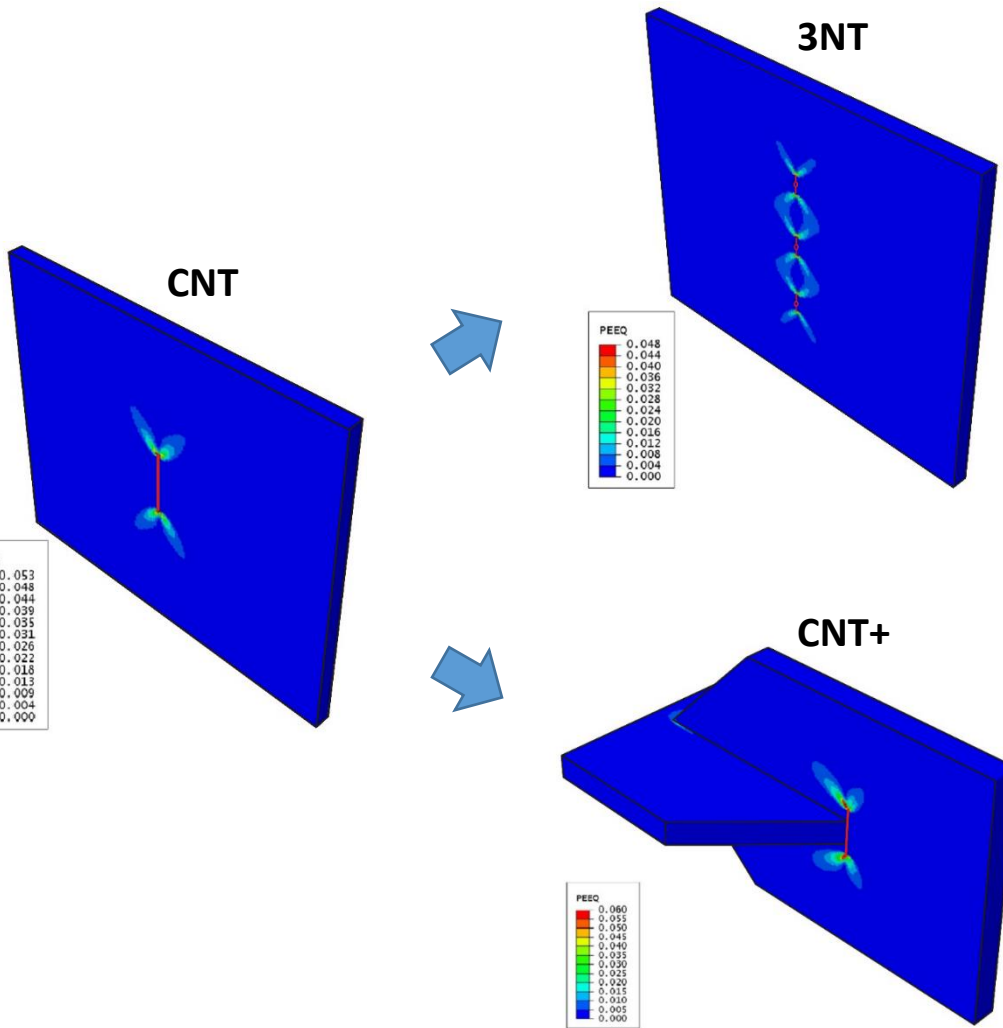
DNRO+



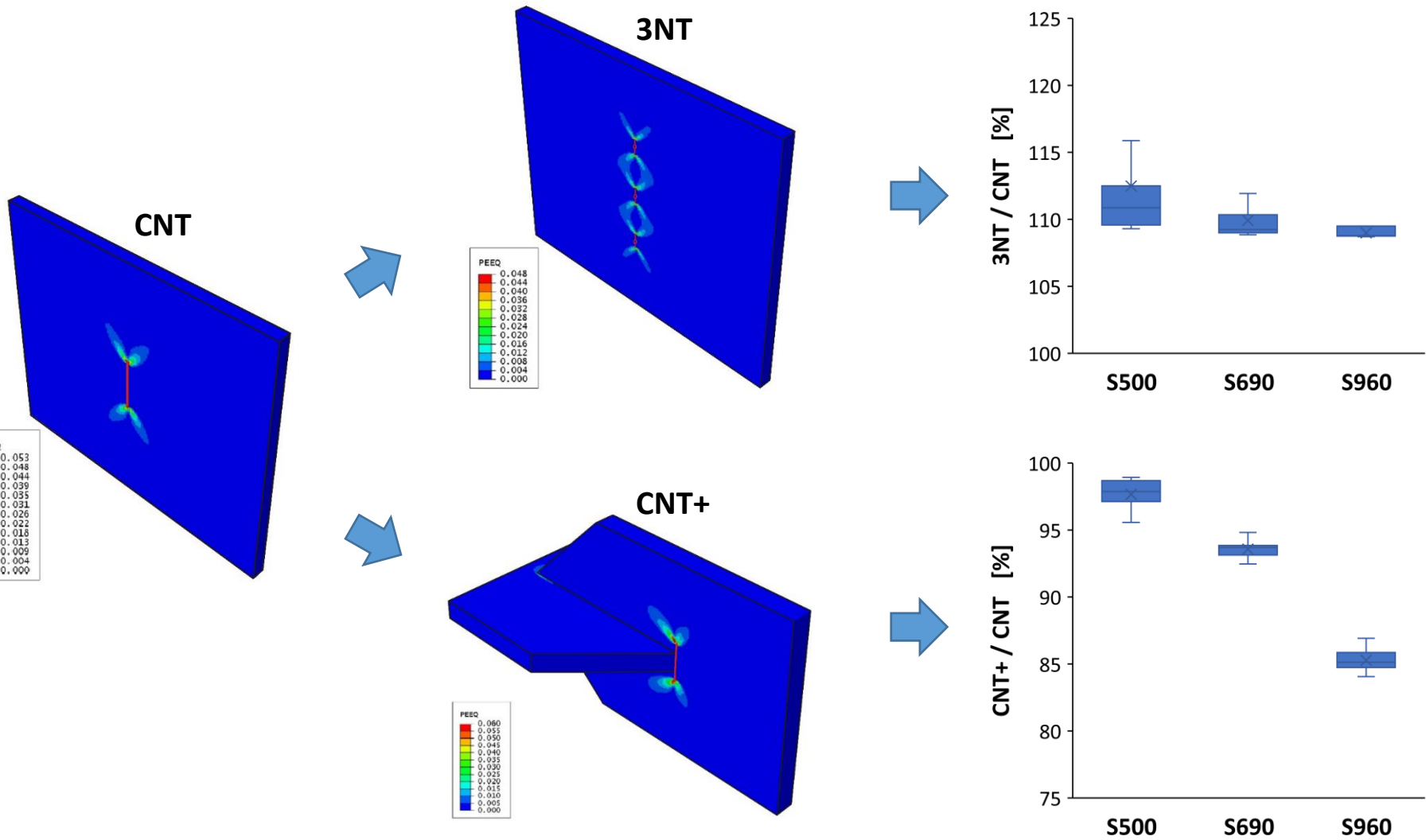
Deviating geometries



Deviating geometries



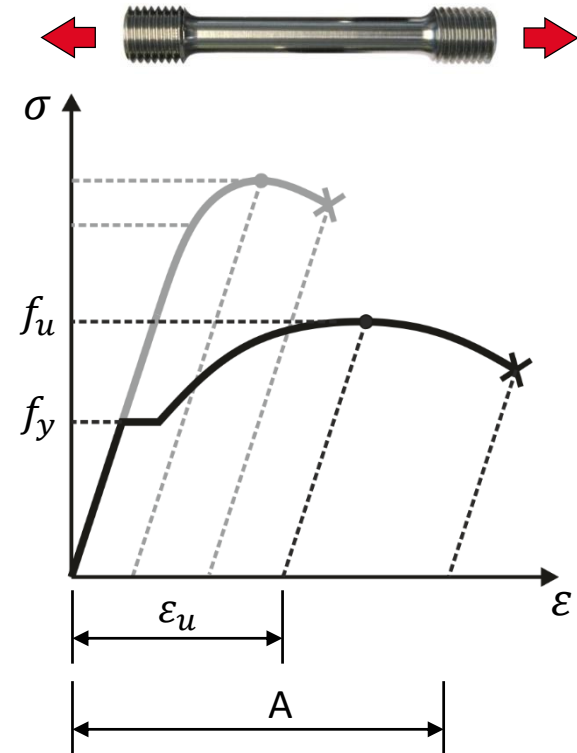
Deviating geometries



Conclusion & Outlook

Ductility requirements acc. to EC3 (1st Edition)

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Conclusion & Outlook

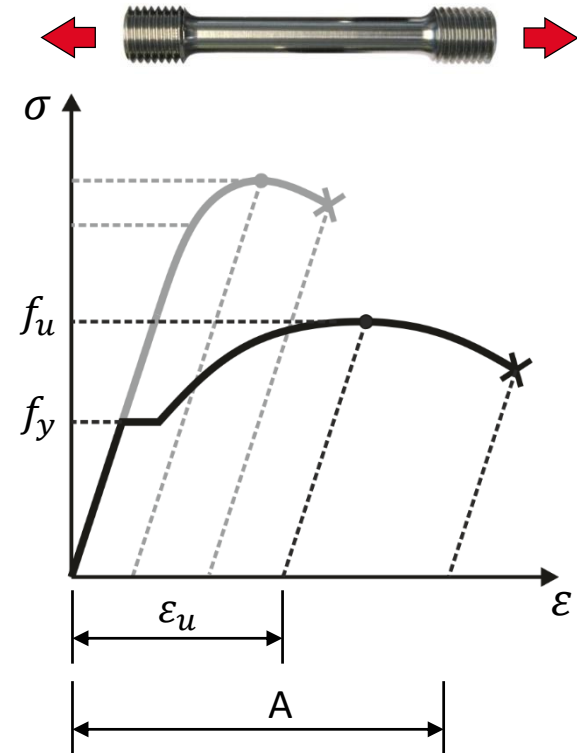
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Ductility requirements acc. to EC3 (2nd Edition)

	plastic global analysis	elastic global analysis
f_u/f_y	≥ 1.10	≥ 1.05
A	≥ 15 %	≥ 12 %



Conclusion & Outlook

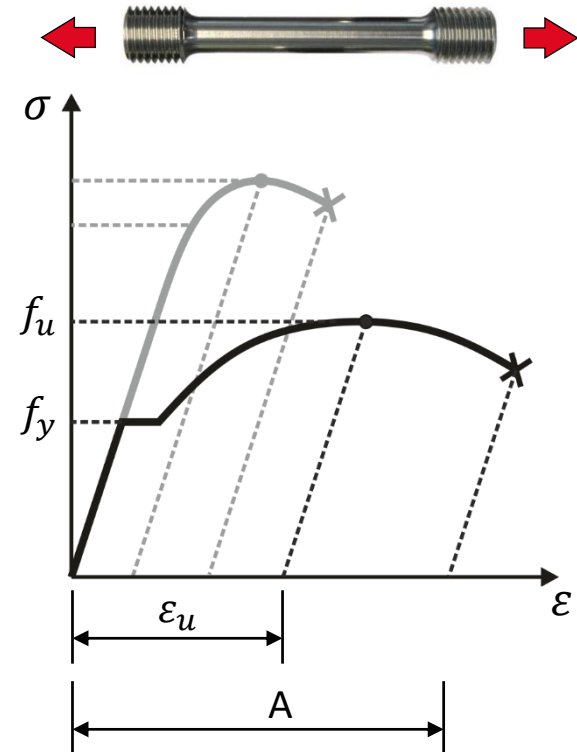
Ductility requirements acc. to EC3 (1st Edition)

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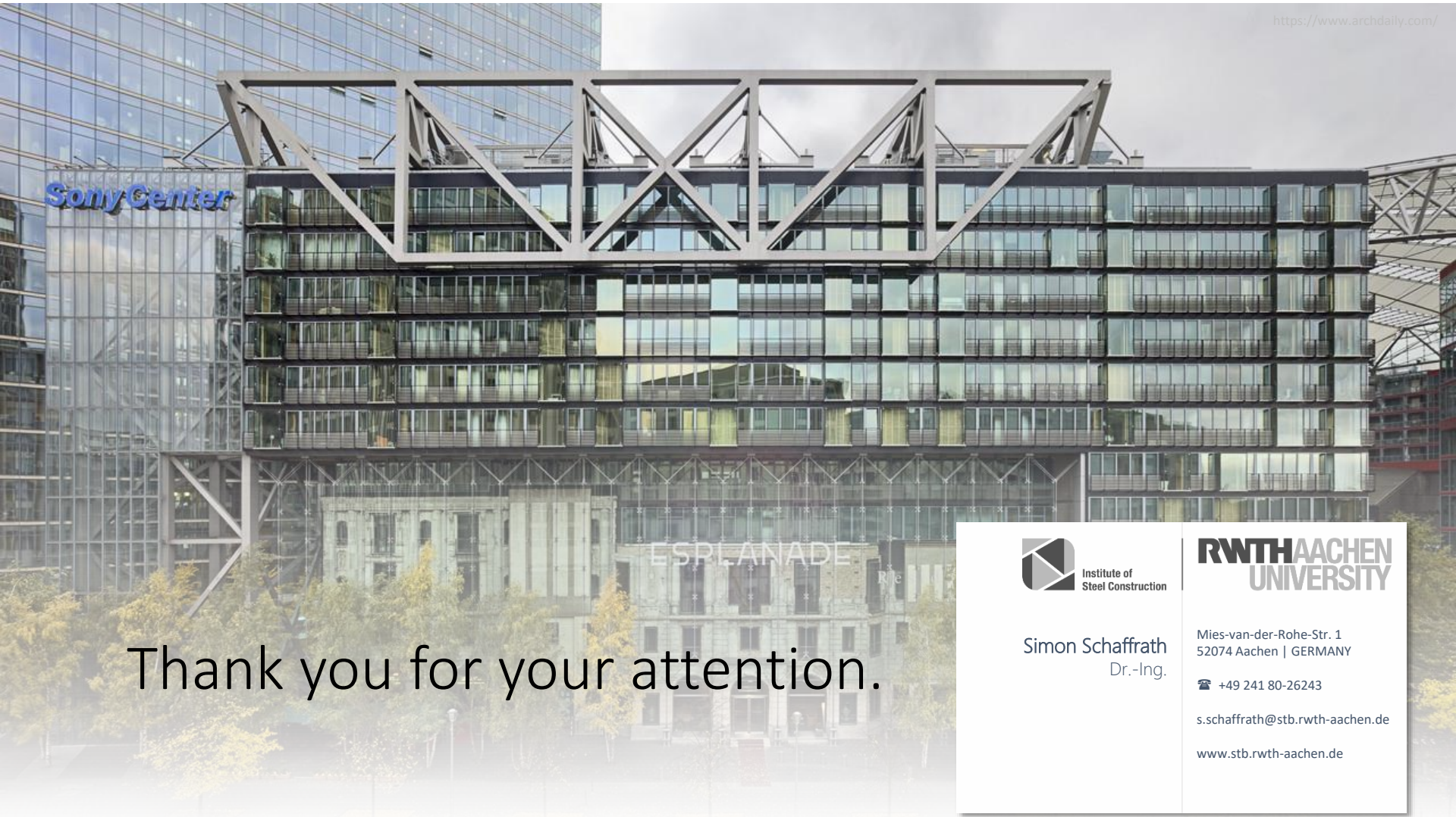
Ductility requirements acc. to EC3 (2nd Edition)

	plastic global analysis	elastic global analysis
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A	≥ 15 %	≥ 12 %



Upper-shelf toughness requirements acc. to EUROCODE 3 (2nd Edition)

- Part 1-10: “... AV_{US} of at least 100 J should be proven at room temperature.”



Thank you for your attention.



Institute of
Steel Construction

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Dr.-Ing.

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