Using FEMU for identifying plastic material behavior of heavy gauge steel

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VForm-xSteels

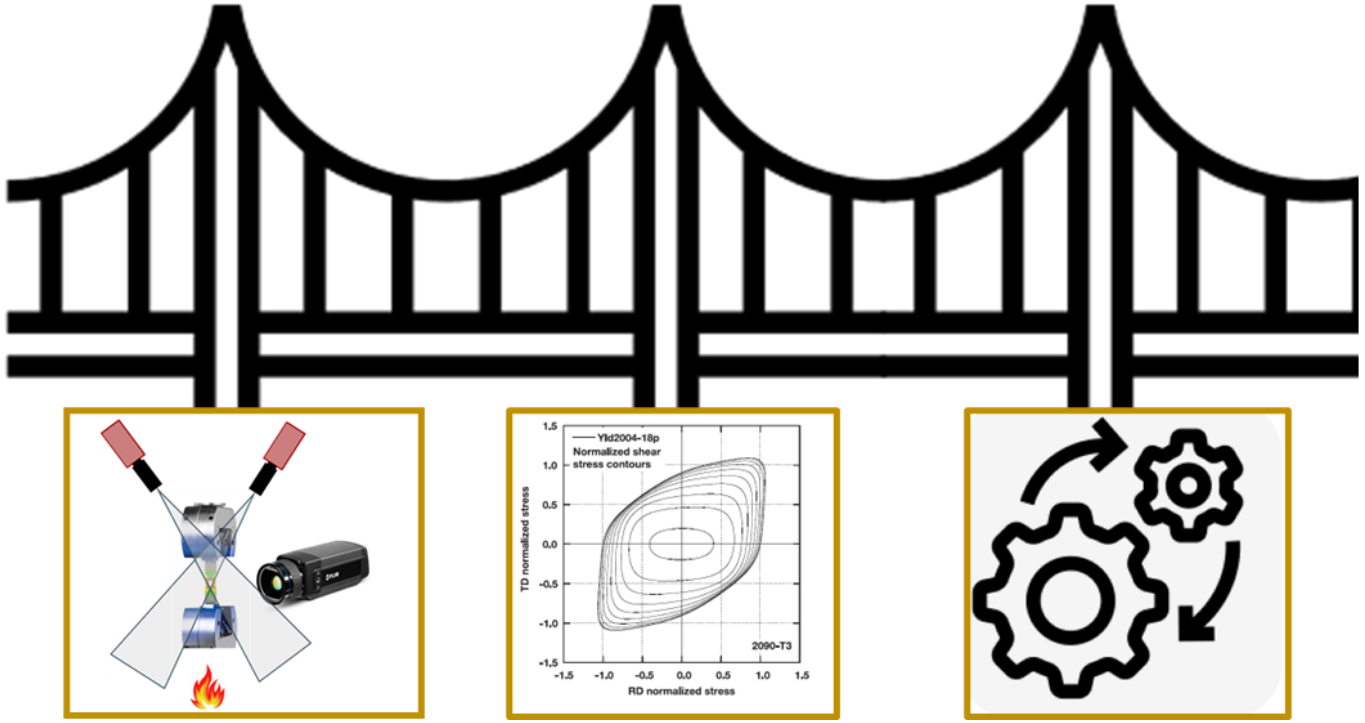
This project has received funding from the Research Fund for Coal and Steel under grant agreement No 888153

Material Twin Bridge*

MT1.0 facilitates understanding material behavior

MT1.0

Real Material Behavior



Virtual Material Behavior

Experimental Mechanics

Material Modelling

Calibration Methods

** After an idea of prof. M. Halilovič*

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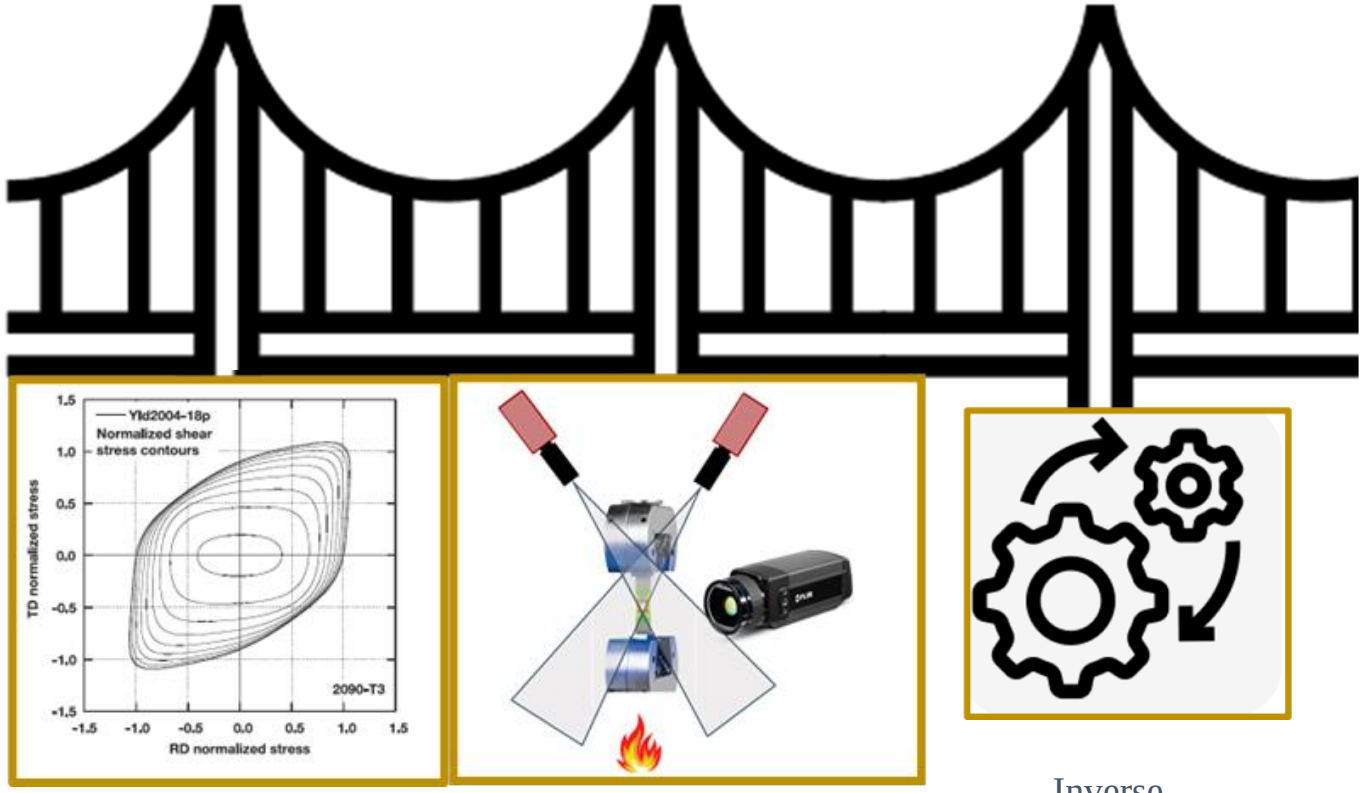
Material Twin Bridge

MT2.0 facilitates crossing the material twin bridge faster/better

MT2.0

Real Material Behavior



Virtual Material Behavior

Material Modelling

Experimental Mechanics

Inverse Methods

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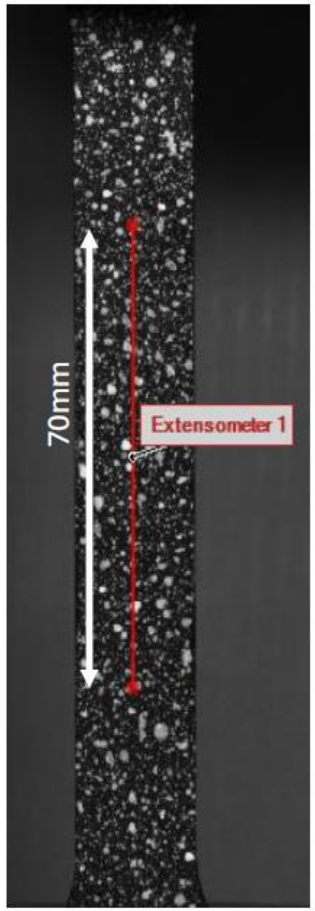
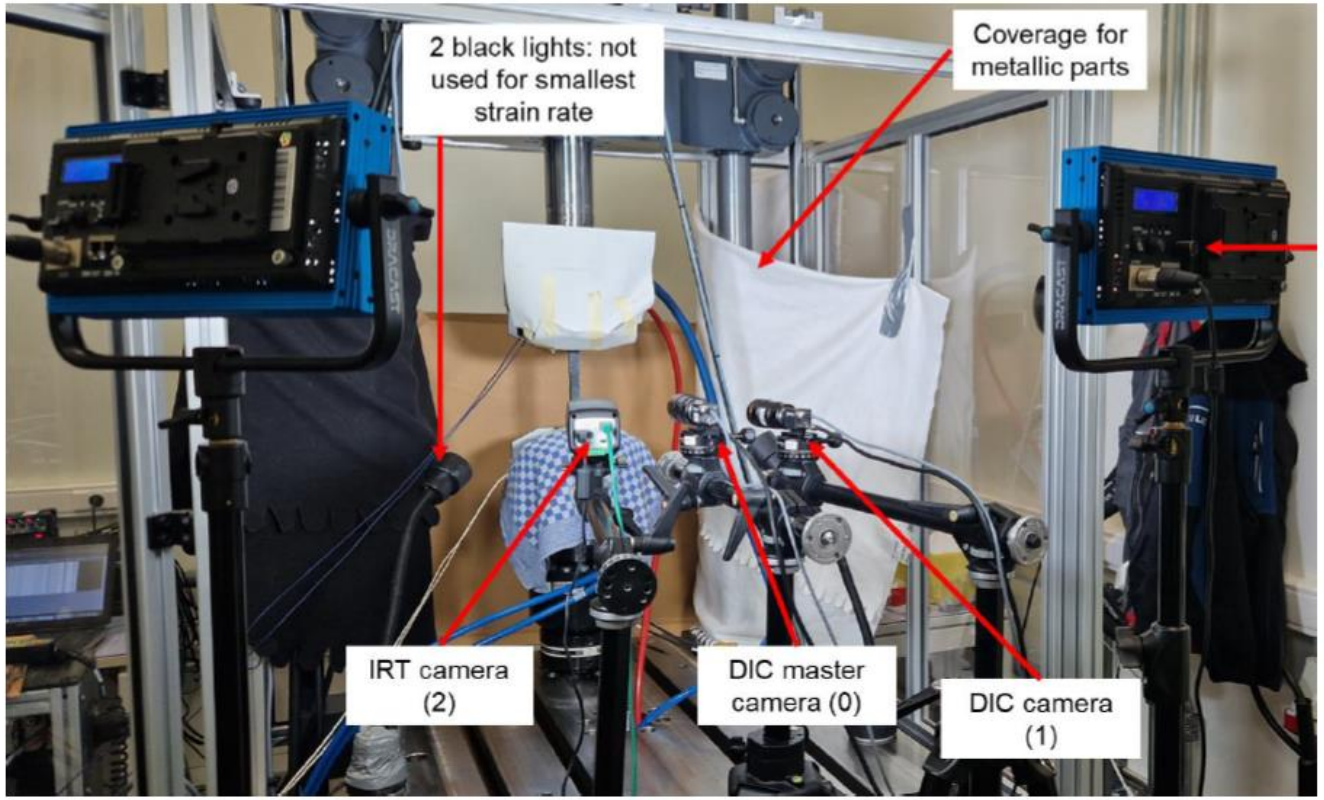
Material Phenomenology: MT1.0

MT1.0



Tensile testing using combined IRT-DIC



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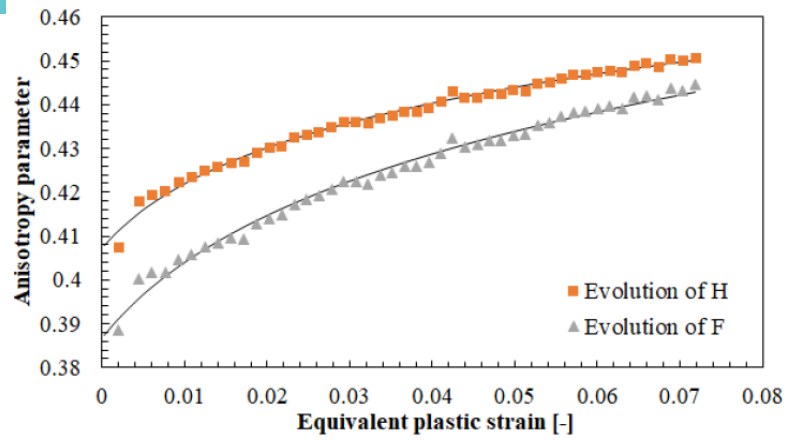
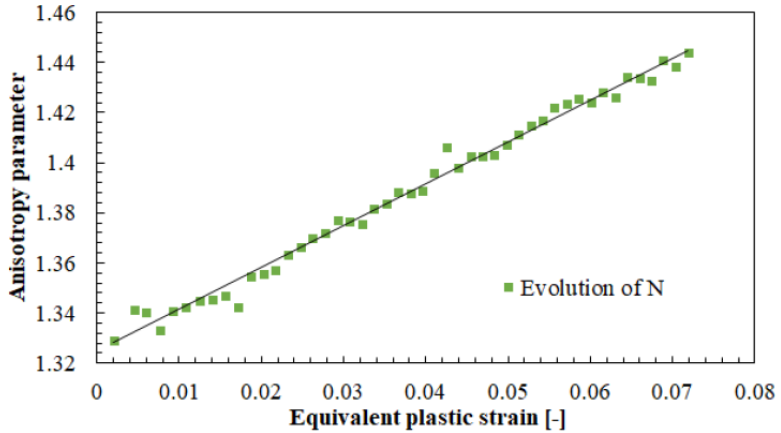
Material Phenomenology: MT1.0

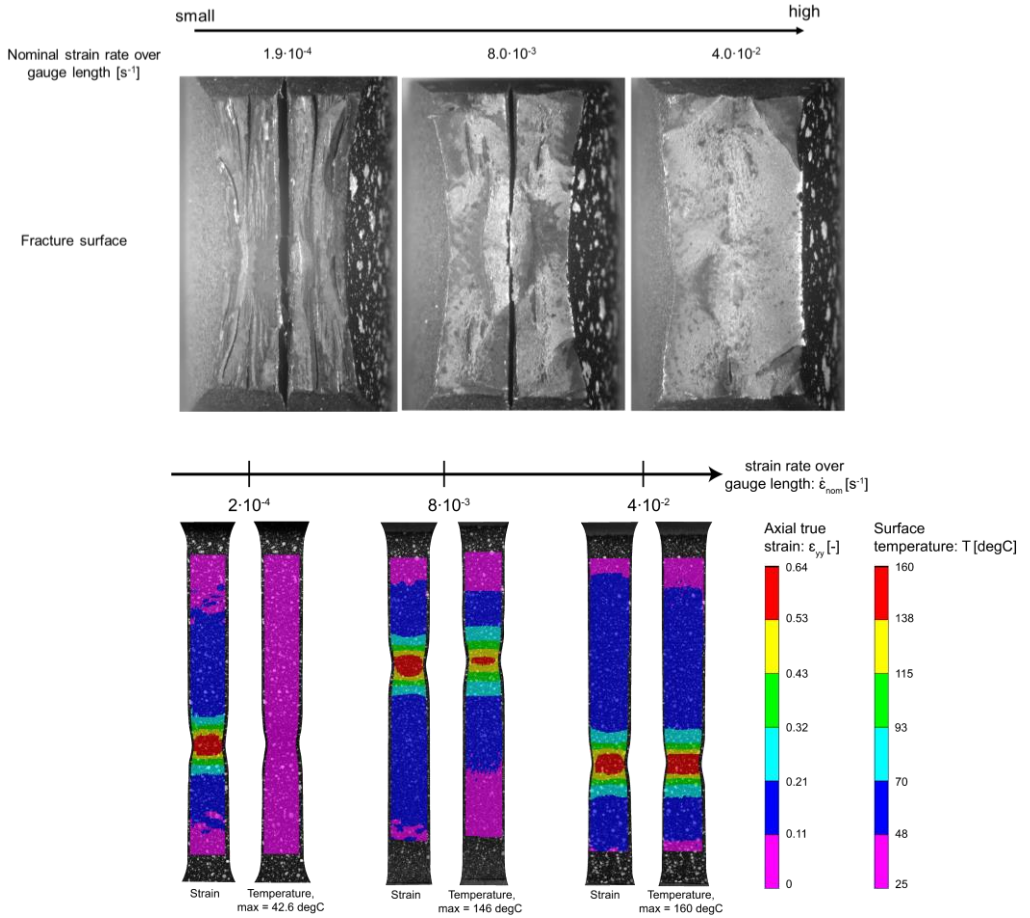
MT1.0

Evolution of anisotropy parameters





Onset of damage in relation to strain rate and temperature



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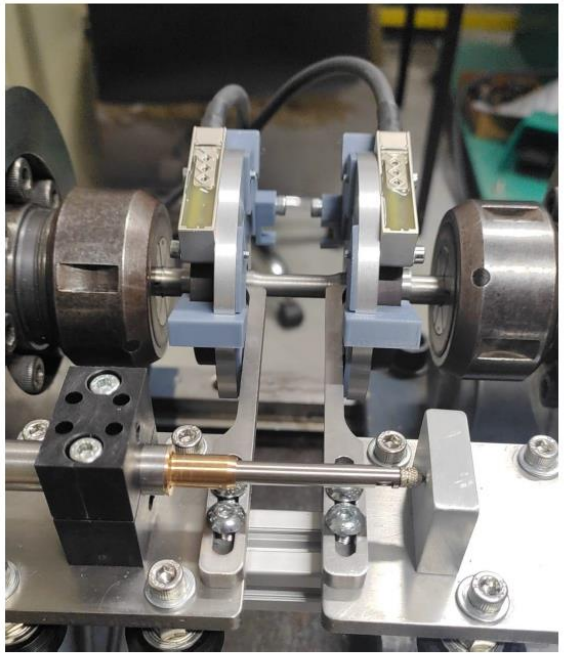
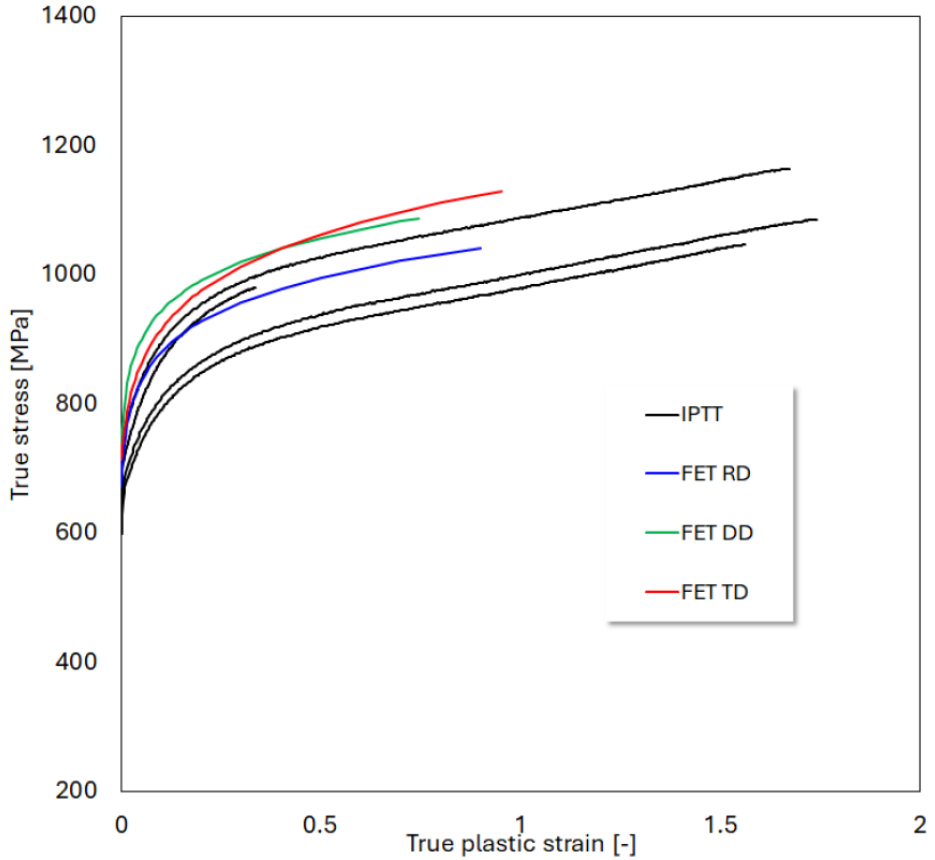
Material Phenomenology

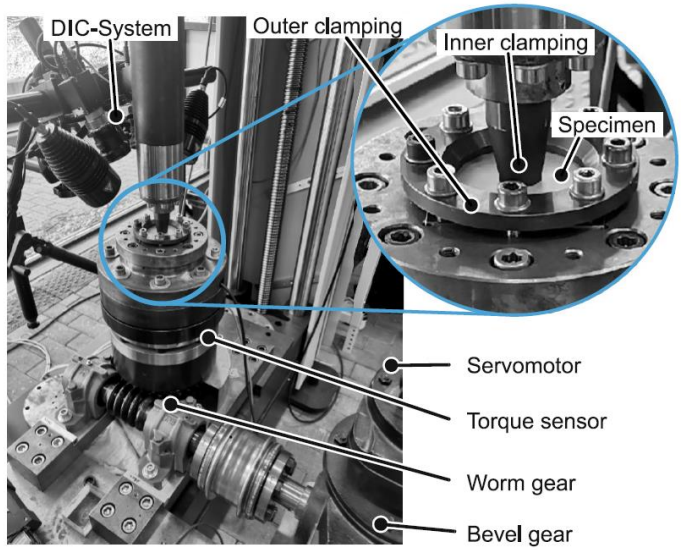
MT1.0

More advanced experiments enabling to probe a specific material response



Free-End Torsion Test (FET)





The in-plane torsion test (IPPT)

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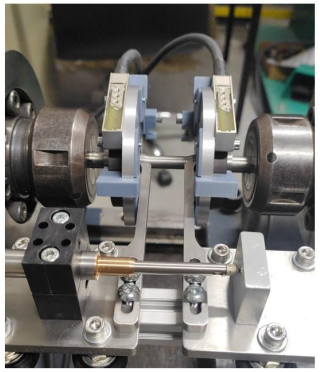
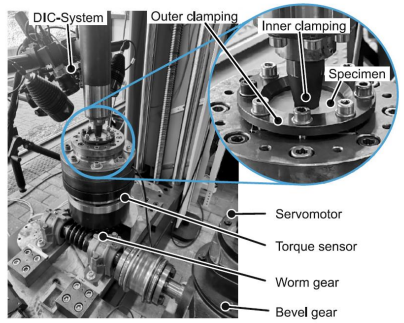
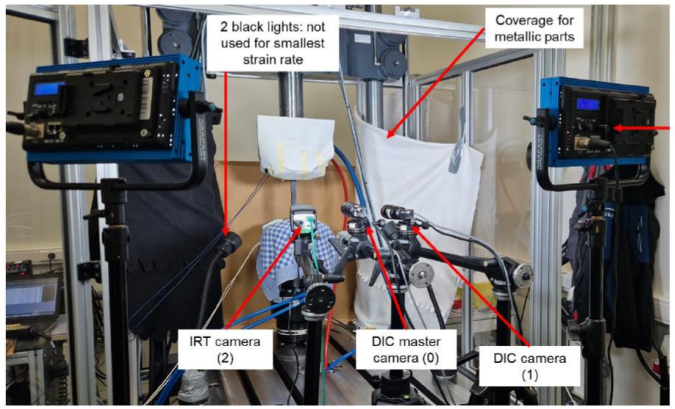
Material Twin Bridge

MT1.0

blueprint of material behavior





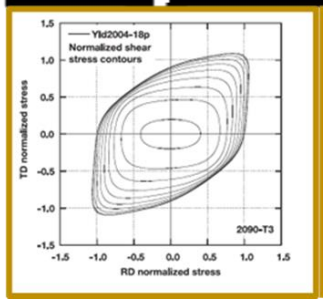


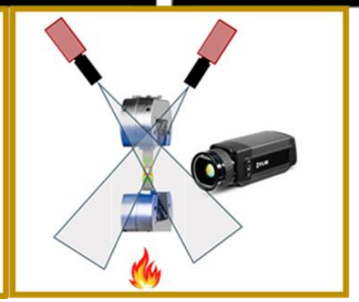
MT2.0

crossing the material twin bridge faster/better (for a specific material response in relation to an application)

Real Material Behavior

Virtual Material Behavior





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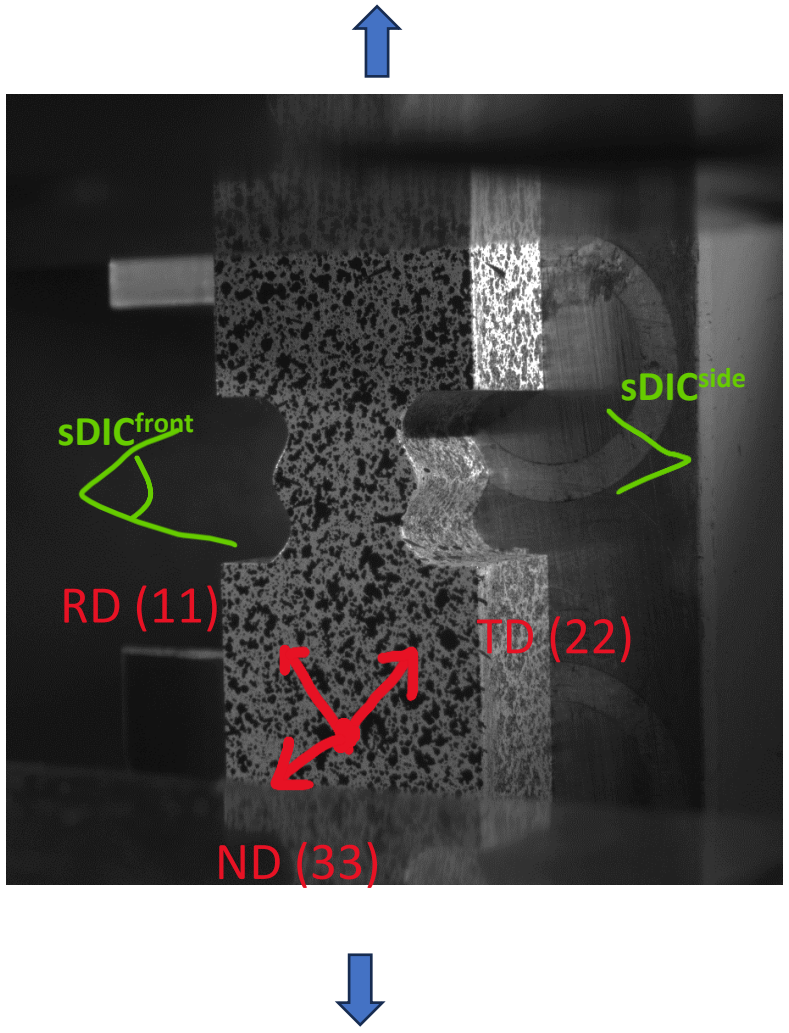
Material Phenomenology: anisotropic yielding



Material S700MC, nominal thickness 12 mm

Known: average strain hardening behavior in RD

Unknown: 5 anisotropy parameters of 3D Hill48 ($G + H = 1$)

$$\sigma_{eq}^2 = F(\sigma_{22} - \sigma_{33})^2 + G(\sigma_{33} - \sigma_{11})^2 + H(\sigma_{11} - \sigma_{22})^2 + 2L\sigma_{23}^2 + 2M\sigma_{31}^2 + 2N\sigma_{12}^2$$

FEMU: Strain-based cost function

$$C(\boldsymbol{p}) = C(\boldsymbol{p})^{Front} + C(\boldsymbol{p})^{side}$$

$$C(\boldsymbol{p})^{side} = \sum_{i=1}^{m}\sum_{j=1}^{n_i} \delta \left[\left(\frac{\epsilon_{yy,ij}^{exp} - \epsilon_{yy,ij}^{num}}{\epsilon_{yy,RMS,i}^{exp}} \right)^2 + \left(\frac{\epsilon_{zz,ij}^{exp} - \epsilon_{zz,ij}^{num}}{\epsilon_{zz,RMS,i}^{exp}} \right)^2 + \left(\frac{\epsilon_{yz,ij}^{exp} - \epsilon_{yz,ij}^{num}}{\epsilon_{yz,RMS,i}^{exp}} \right)^2 \right]$$

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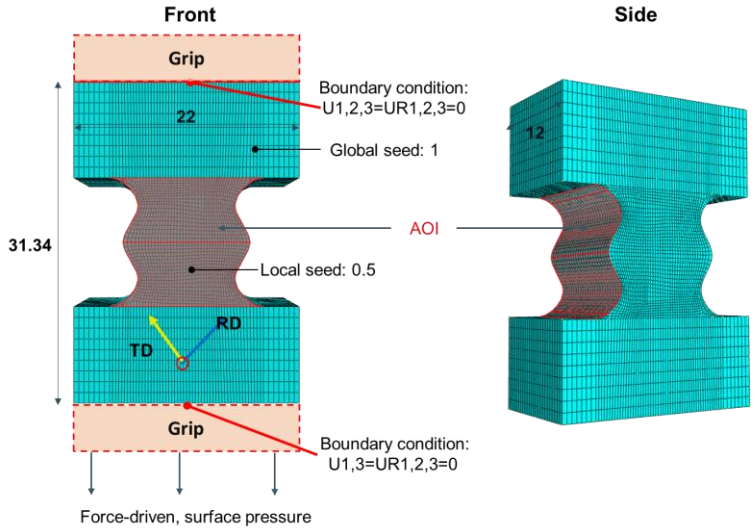
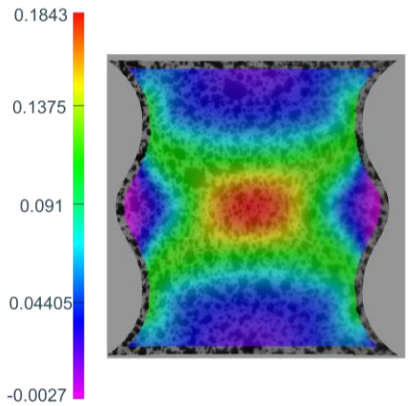
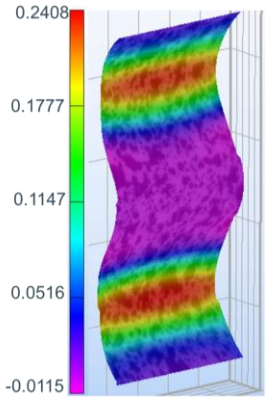
MT2.0: Specimen design

Shape optimization: maximizing strain heterogeneity



ε^{Mises}



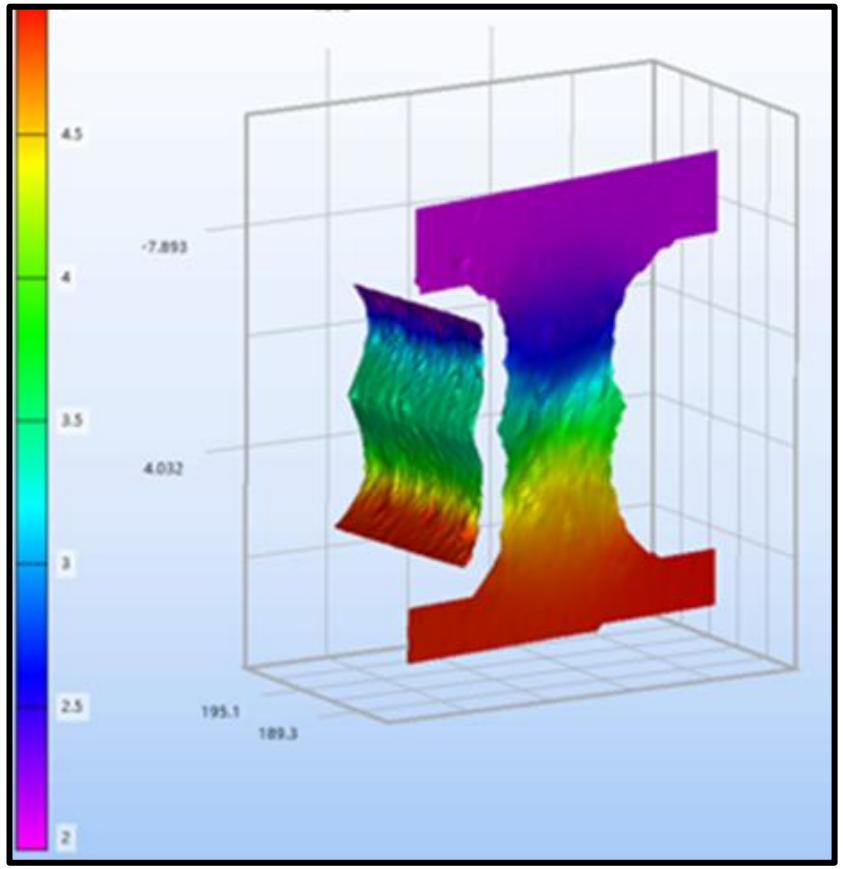


Stereo DIC front

Stereo DIC side

DVT

Stereo DIC front + Stereo DIC side



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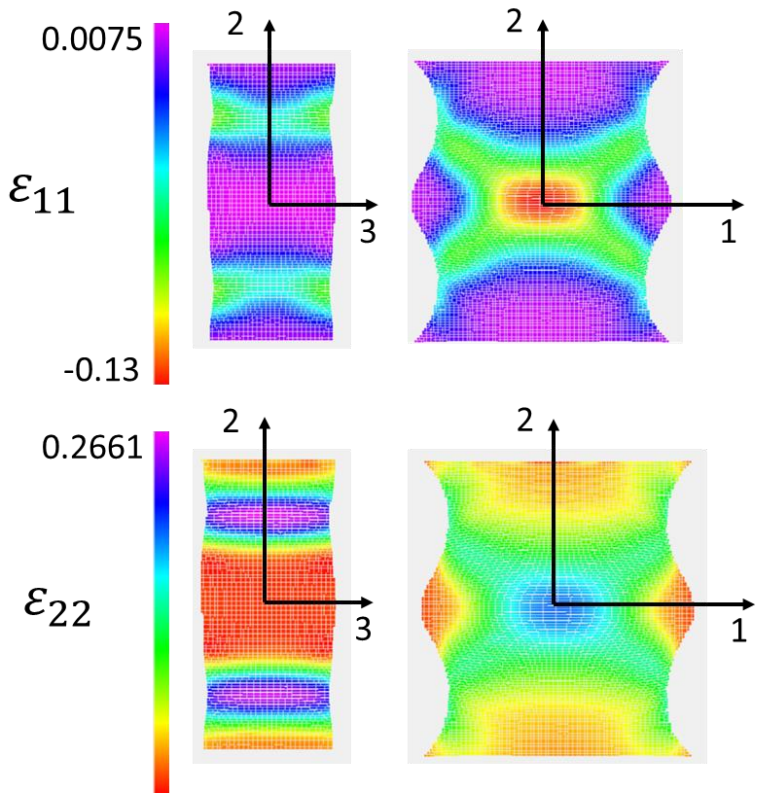
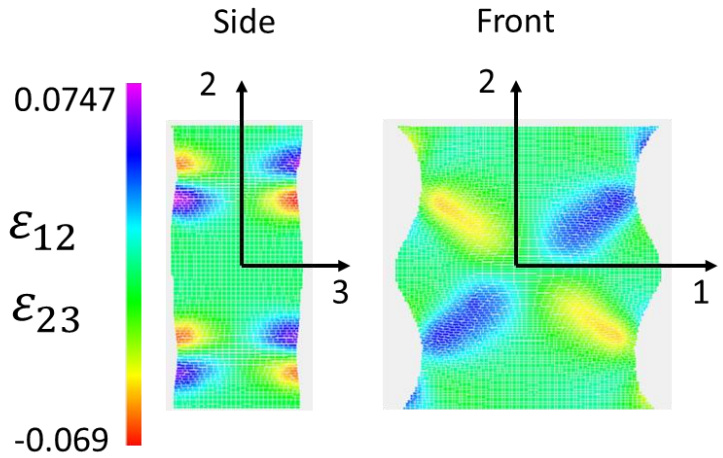
MT2.0: Specimen design

Shape optimization: maximizing strain heterogeneity





- Computationally heavy for thick specimens.
- Identifiability cannot be guaranteed.
- Material orientation should be a design variable.
- Spatial convergence of the measurement method ?

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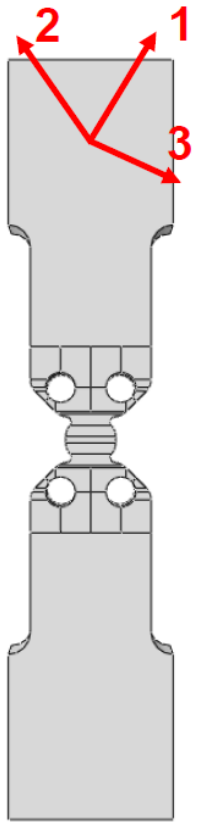
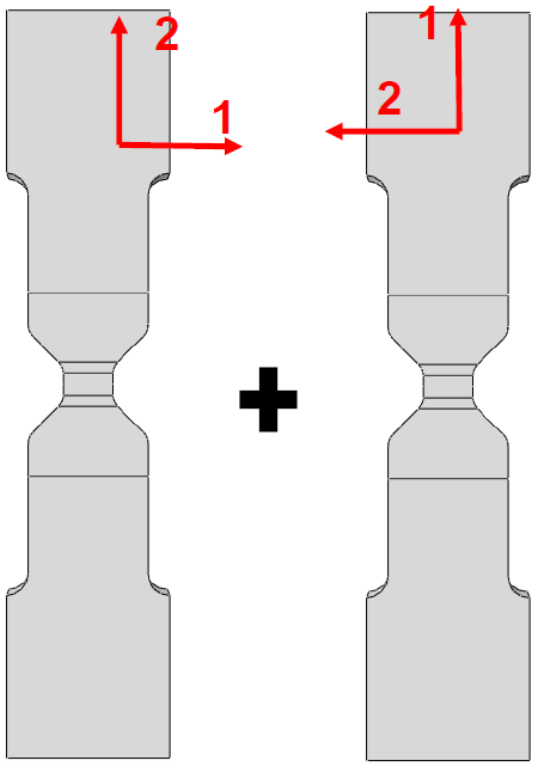
MT2.0: Specimen design

Identifiability analysis: maximizing parameter (set) identifiability



Single complex specimen approach



Two-specimen approach

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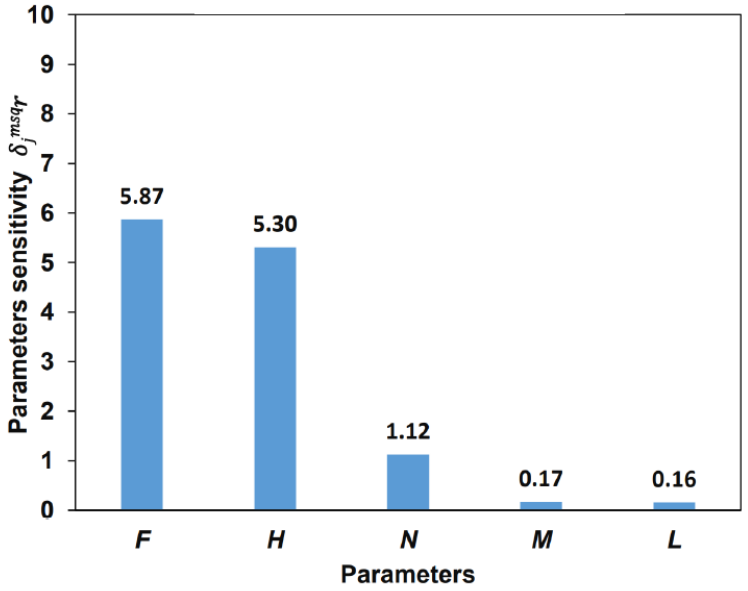
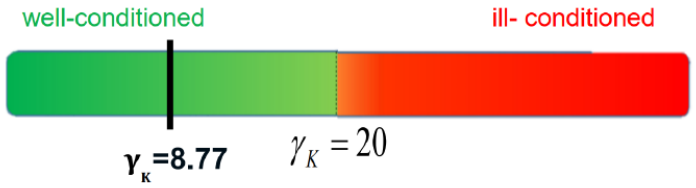
MT2.0: Specimen design

Identifiability analysis: maximizing parameter identifiability

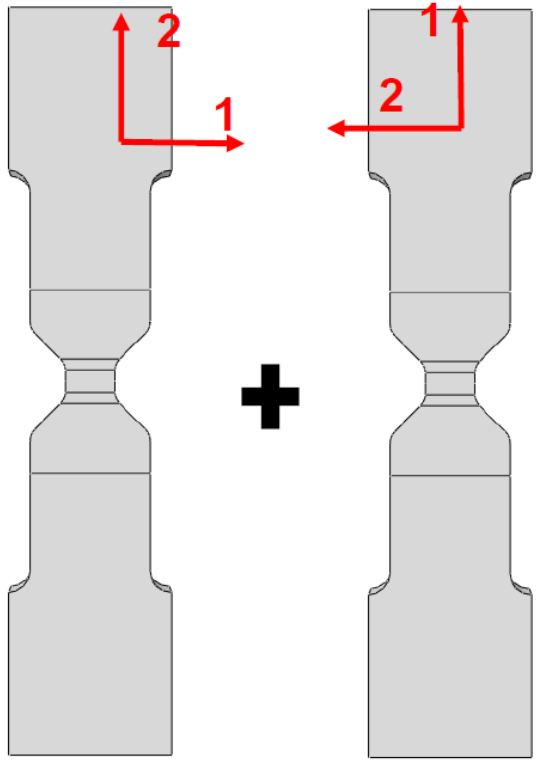
Sensitivity Strength



Collinearity index



Identifiability analysis



Two-specimen approach

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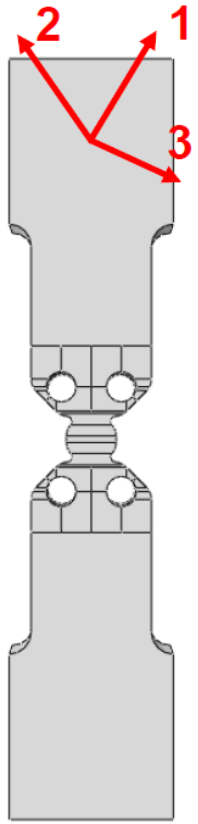
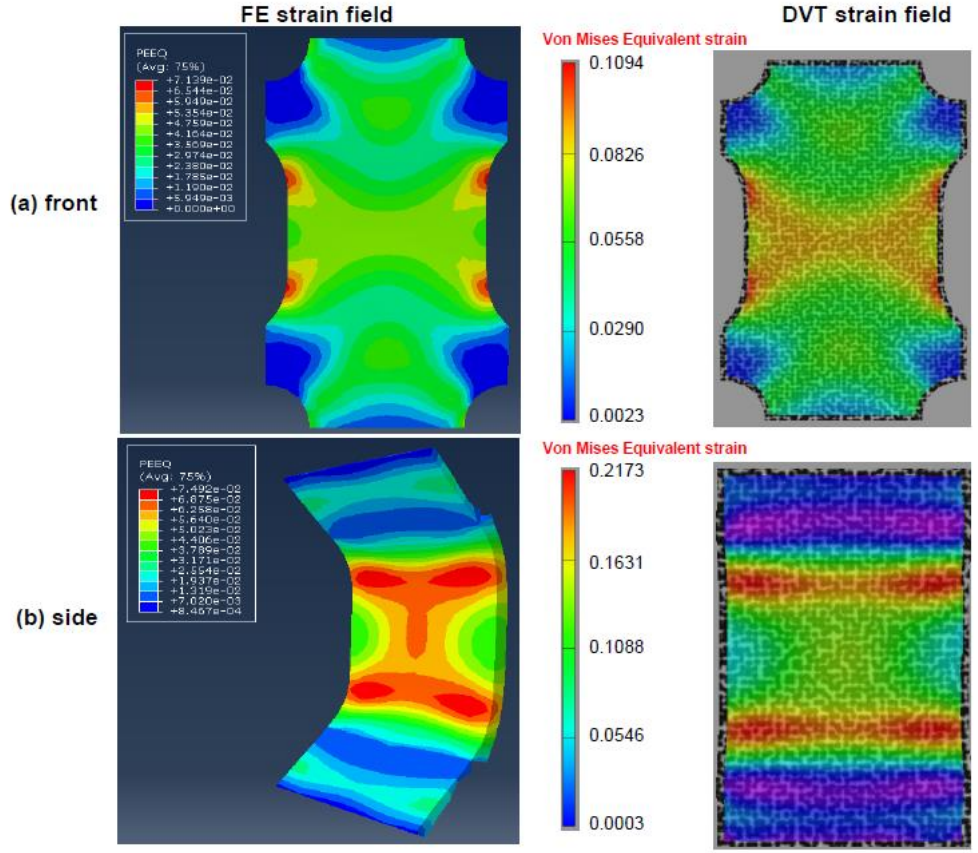
MT2.0: Specimen design - DVT

Digital Virtual Twin to evaluate FEMU





Single complex specimen approach

Metrological aspects

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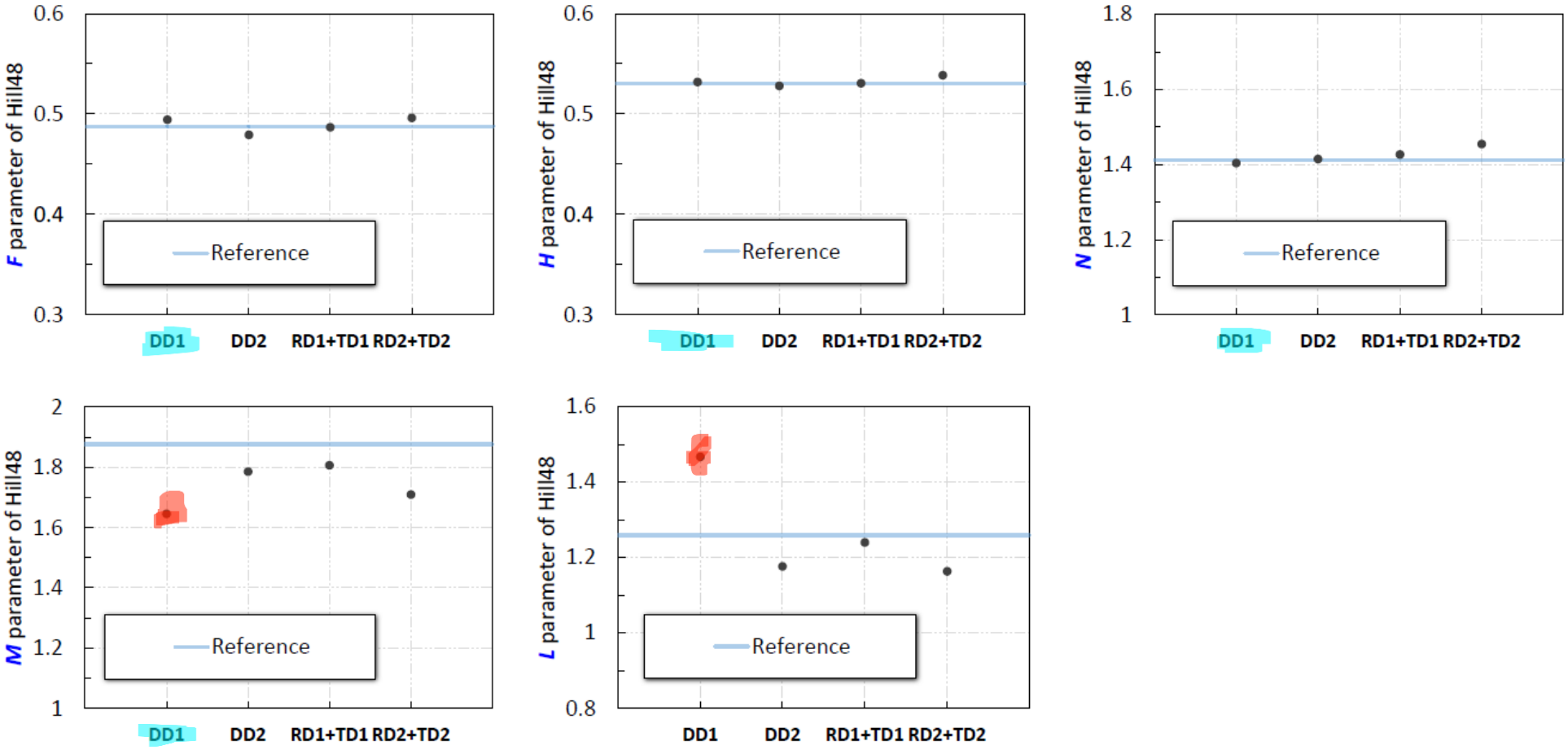
MT2.0: Specimen Design - DVT

Digital Virtual Twin



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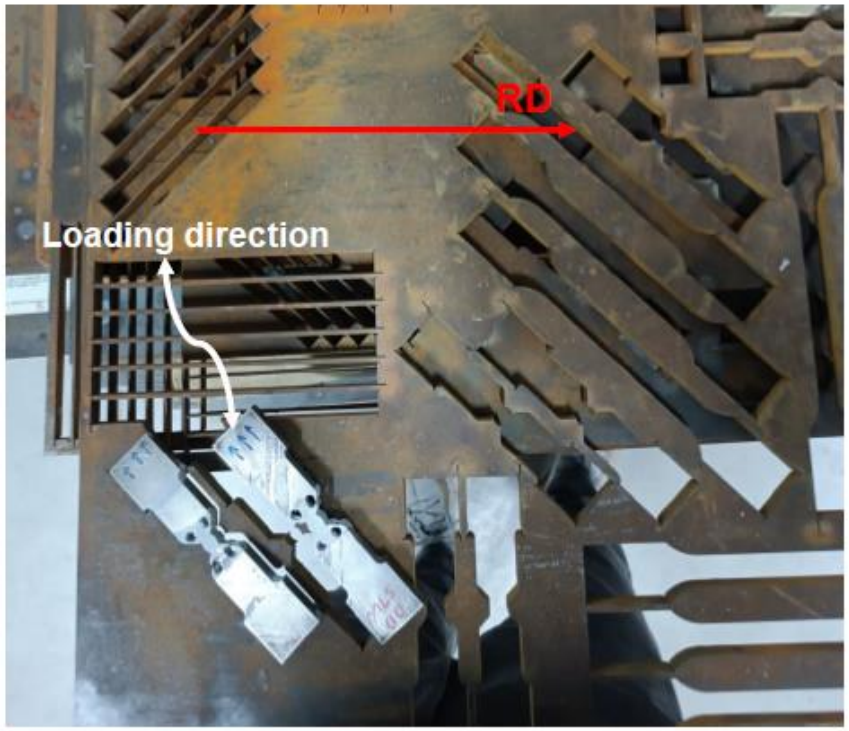
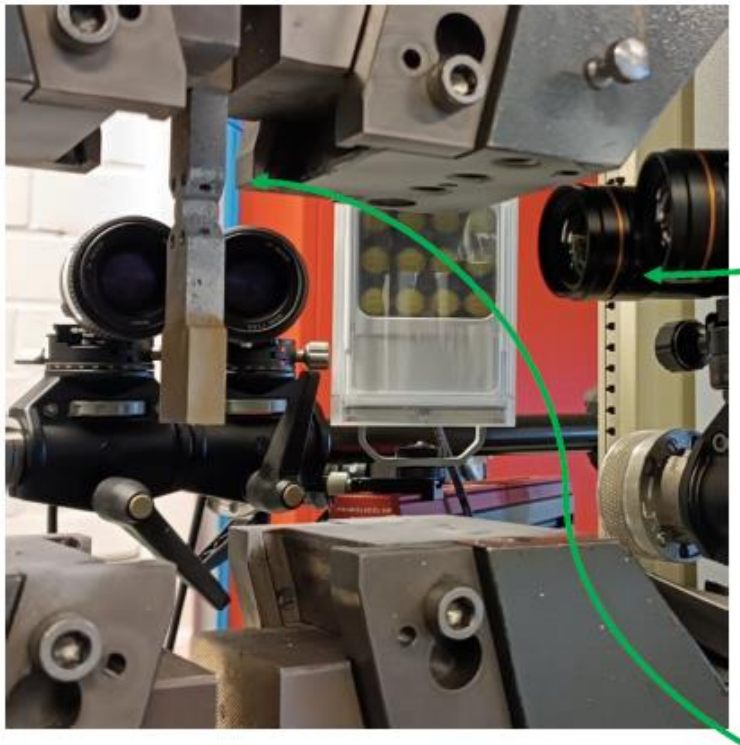
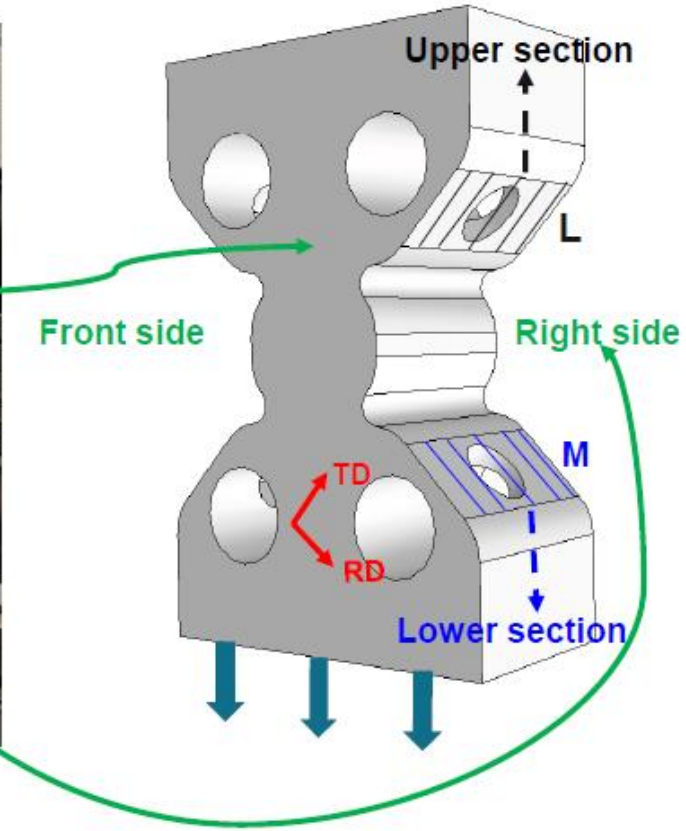
MT2.0: Experimental validation







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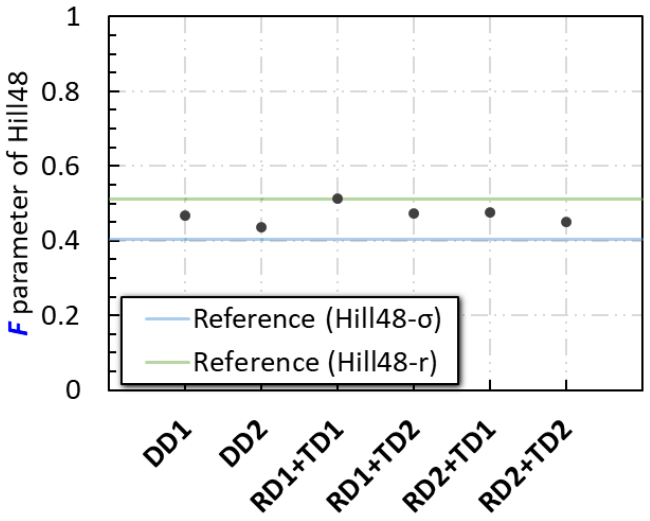
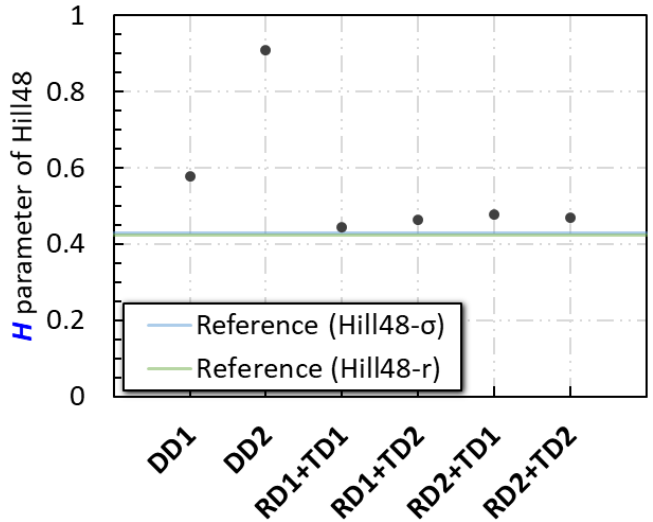
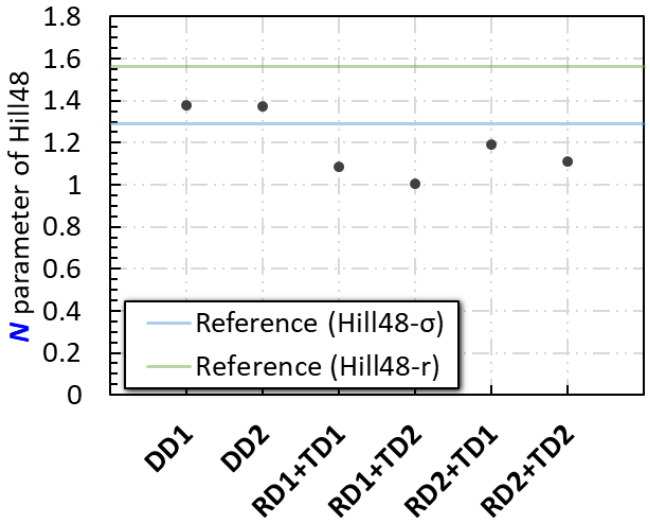
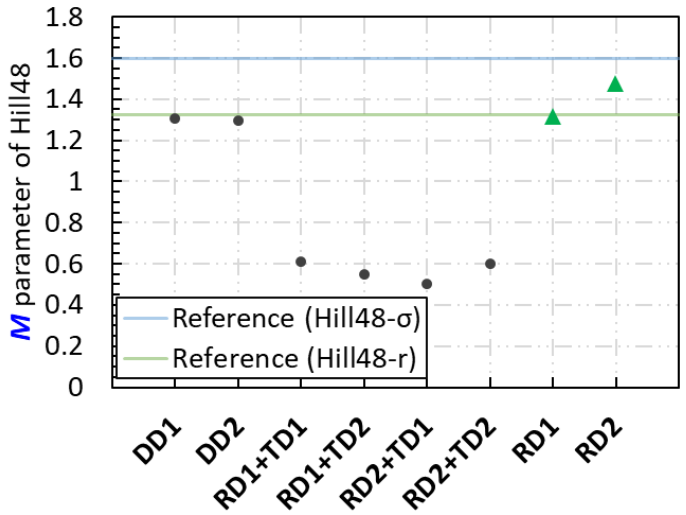
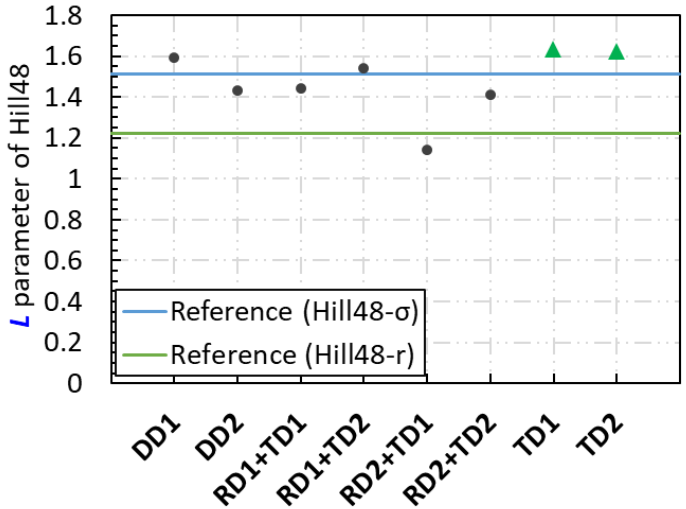
MT2.0: Experimental validation – “Reference” data











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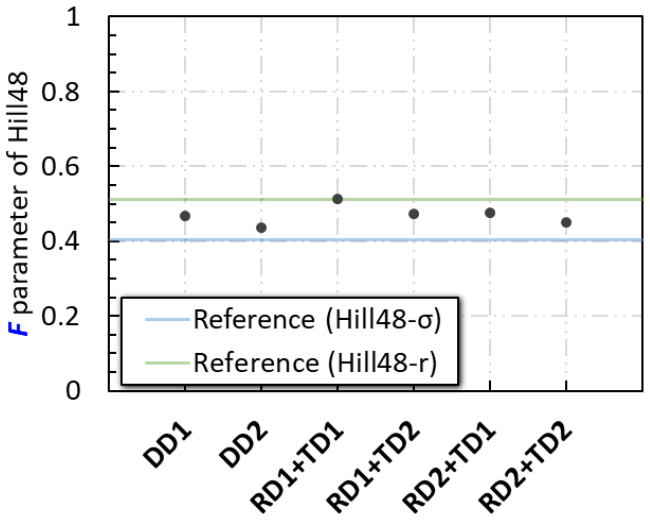

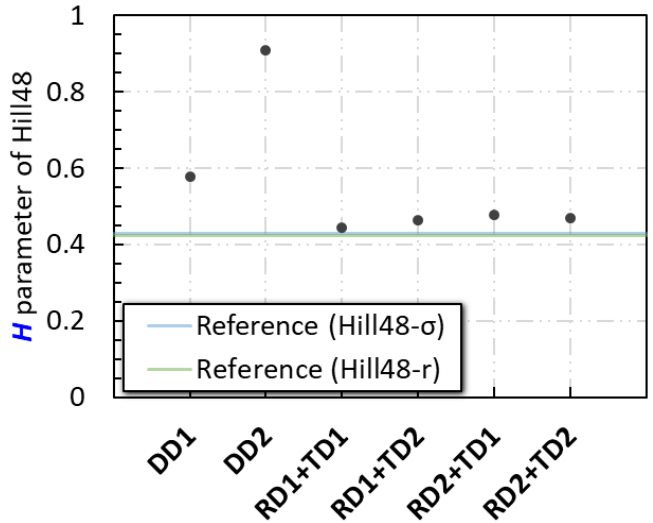

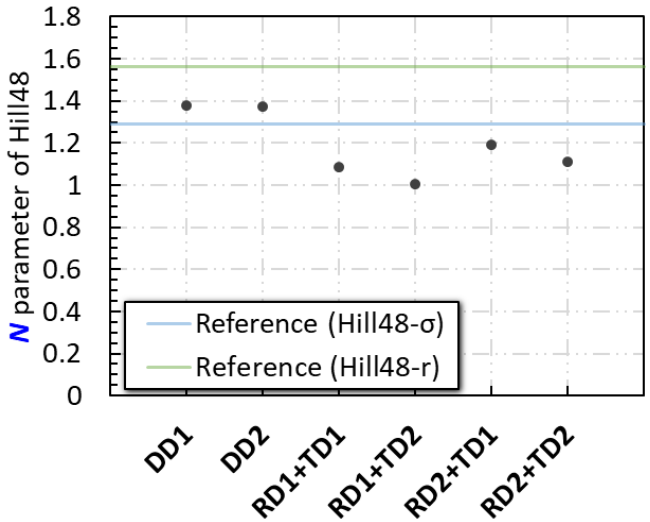

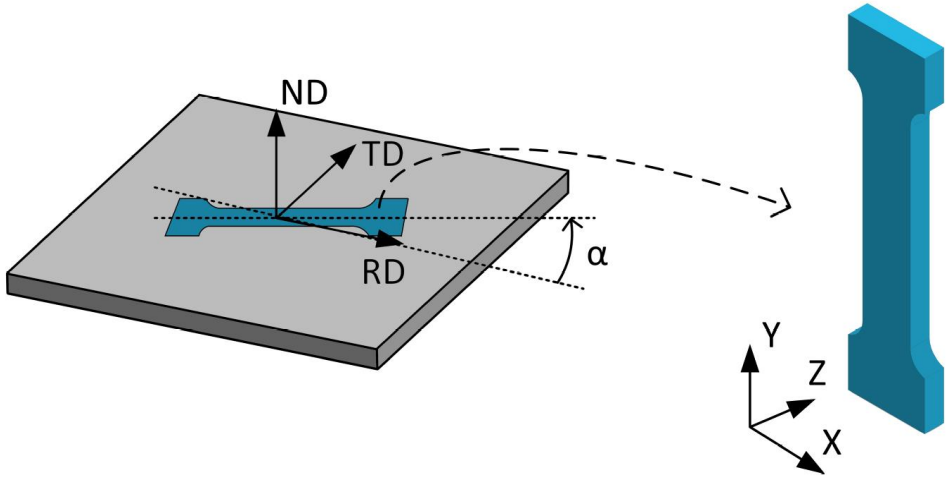

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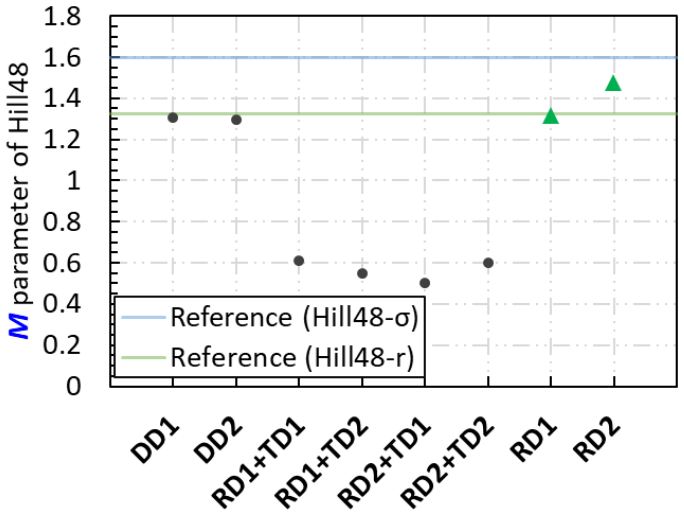
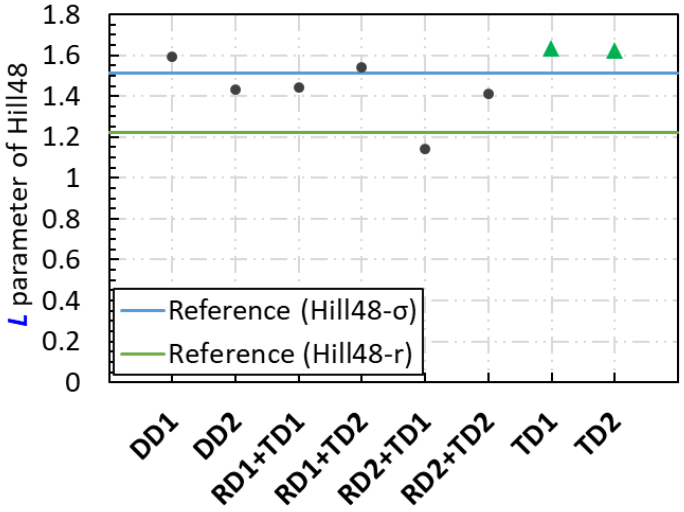
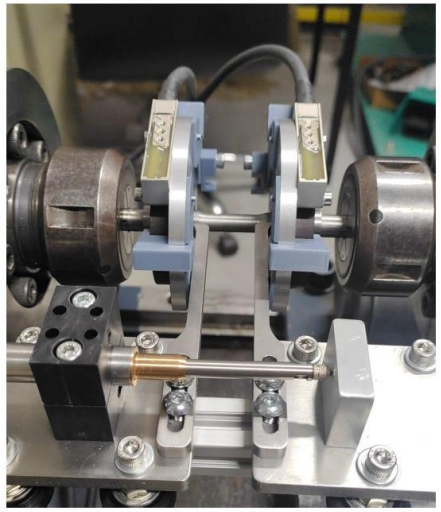
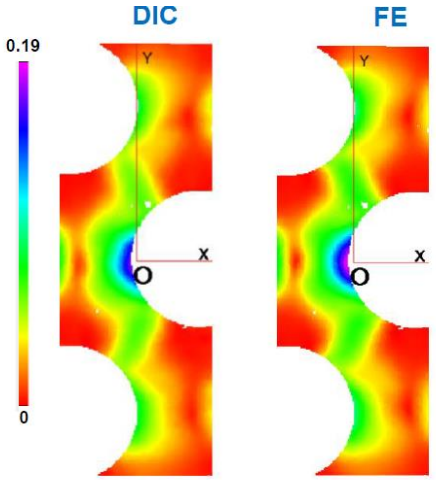
MT2.0: Experimental validation – “Reference” data





MT2.0





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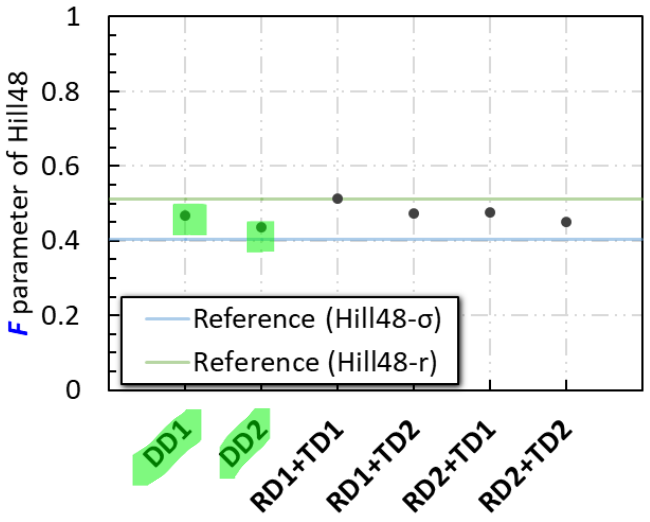
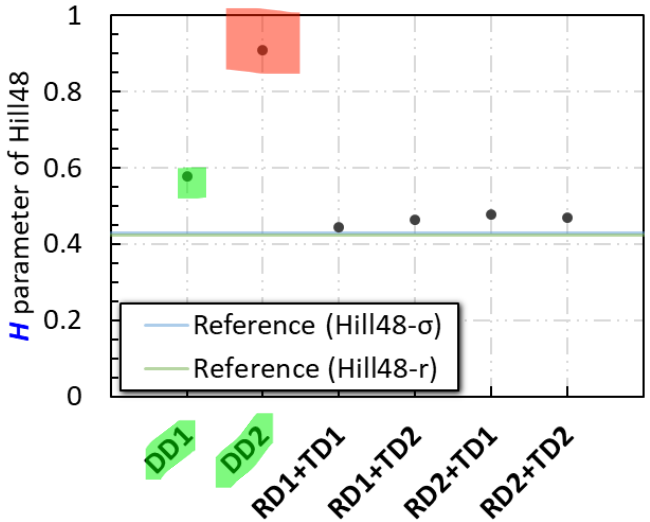
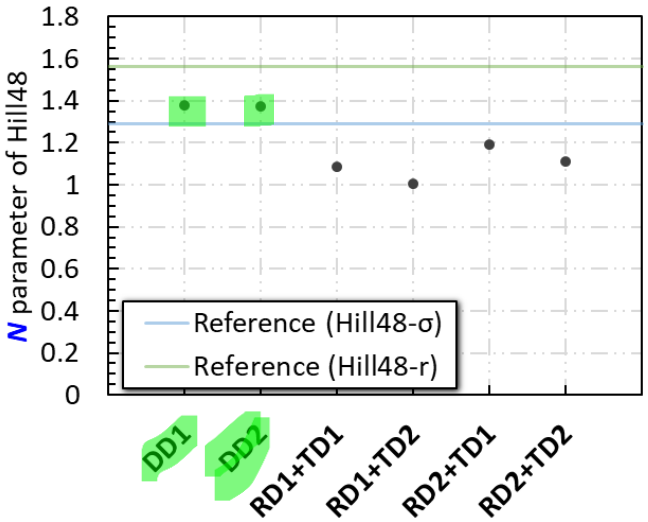
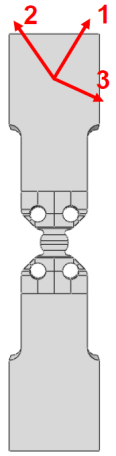
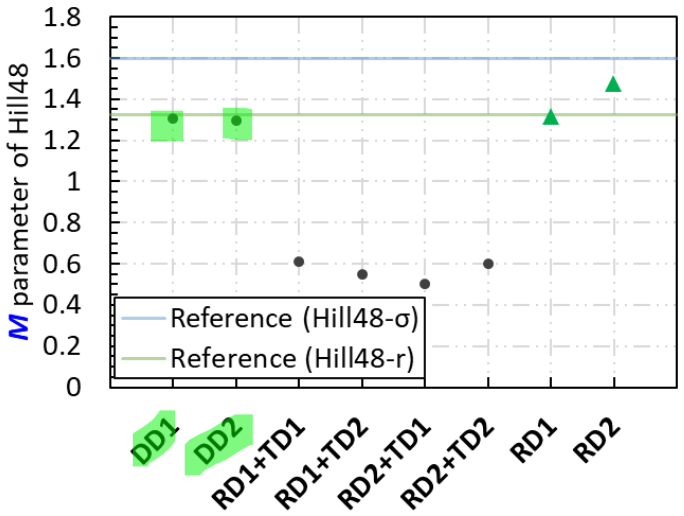
MT2.0: Experimental validation – Robustness

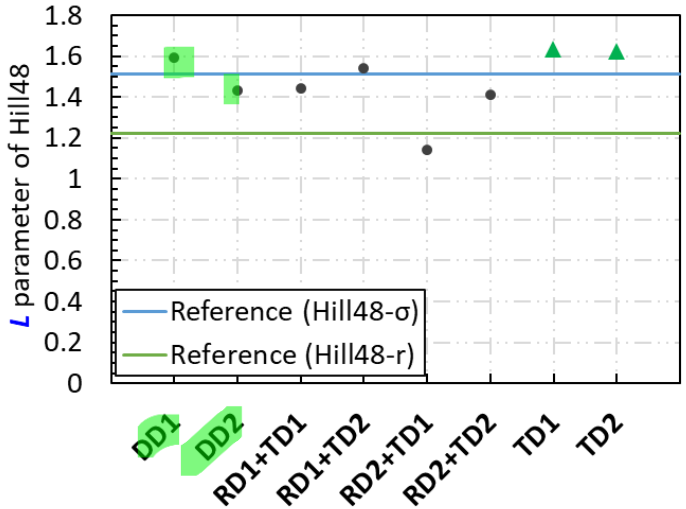












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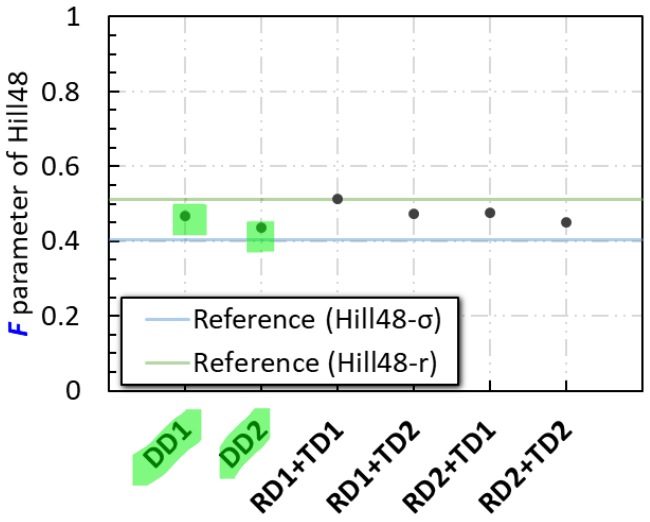
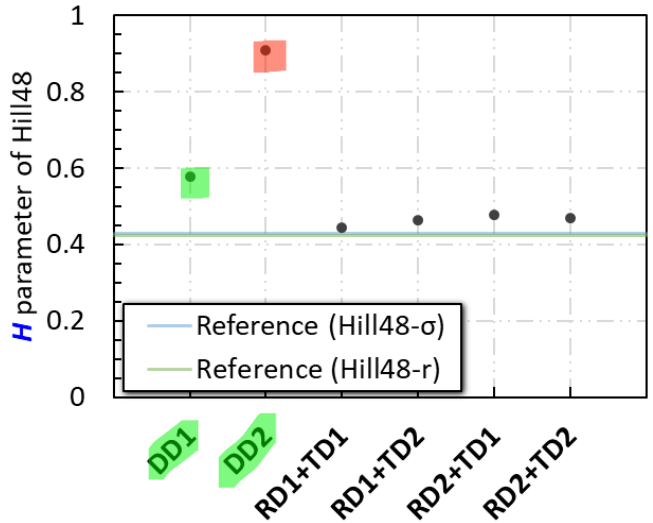
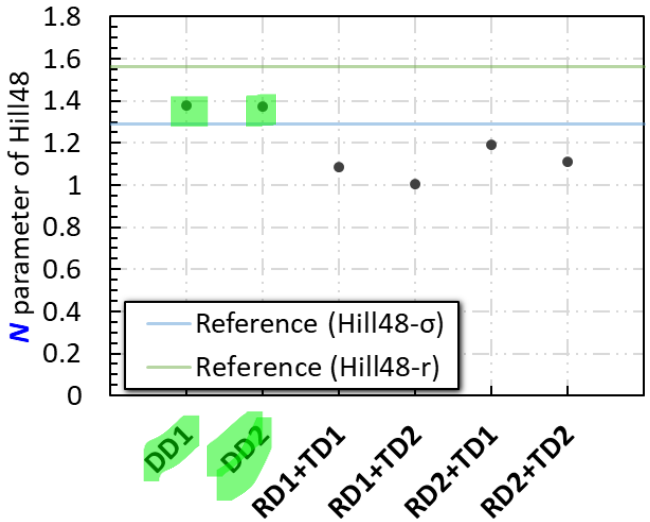
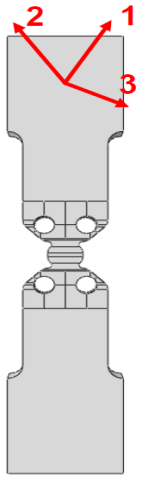
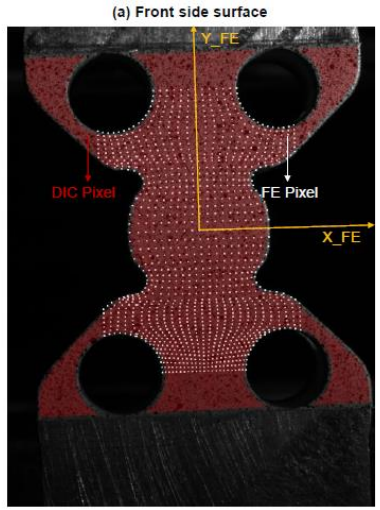
MT2.0: Experimental validation – Robustness

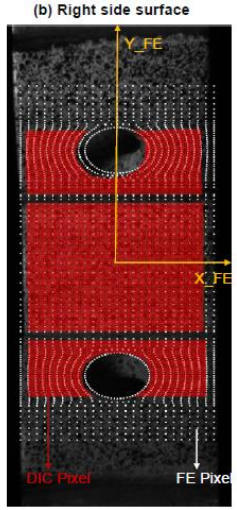


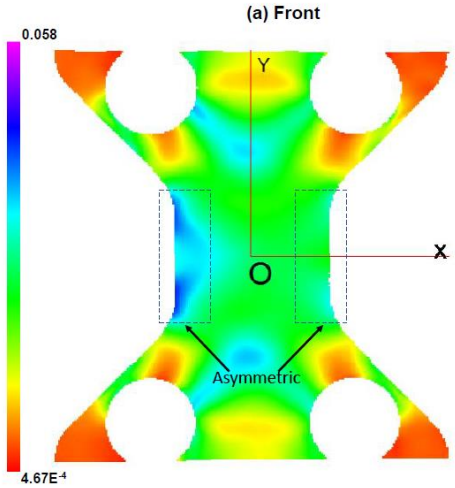


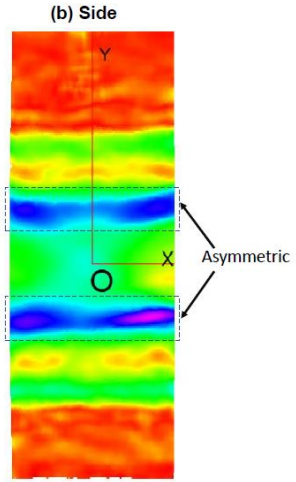












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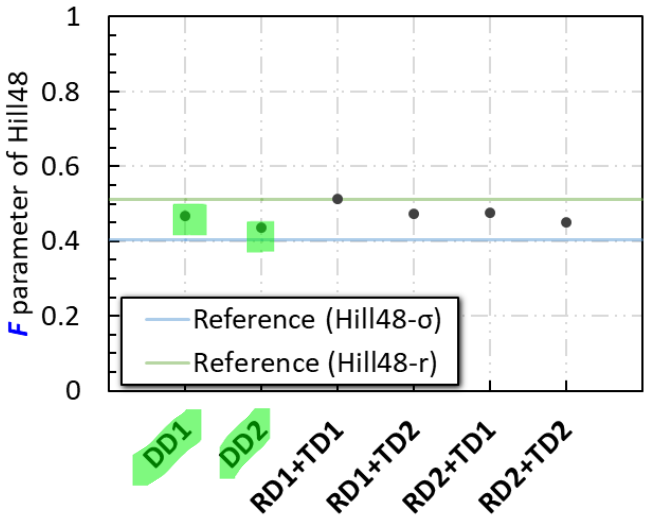
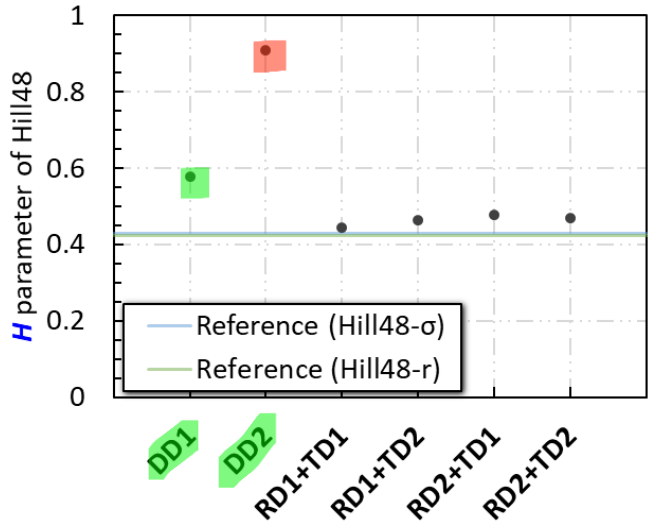
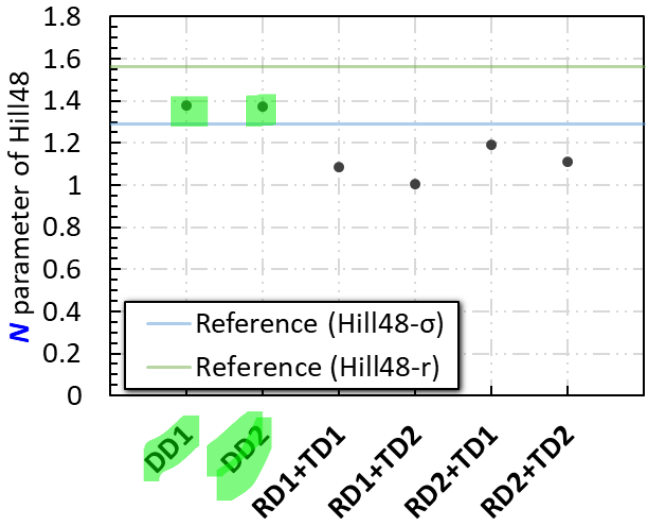
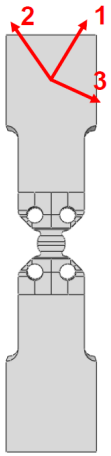
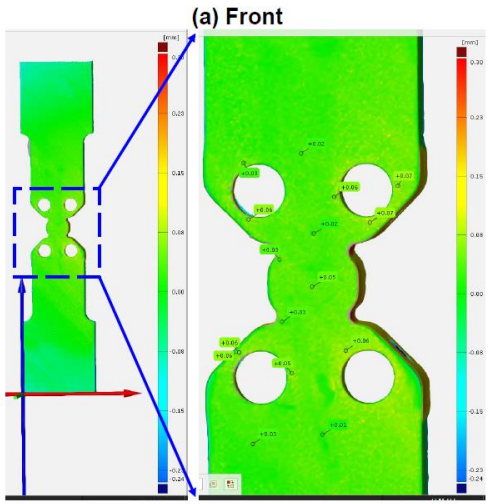
MT2.0: Experimental validation – Robustness

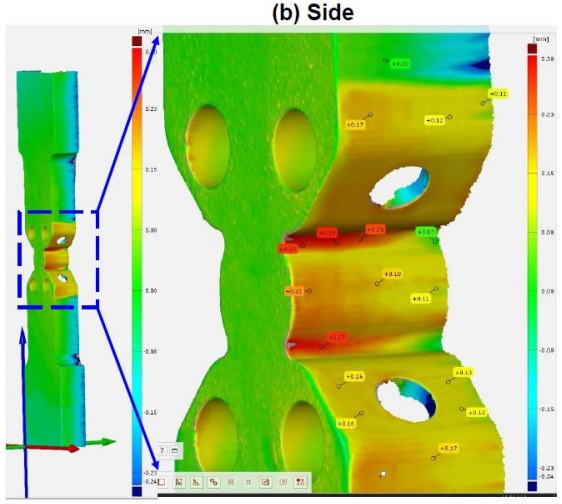












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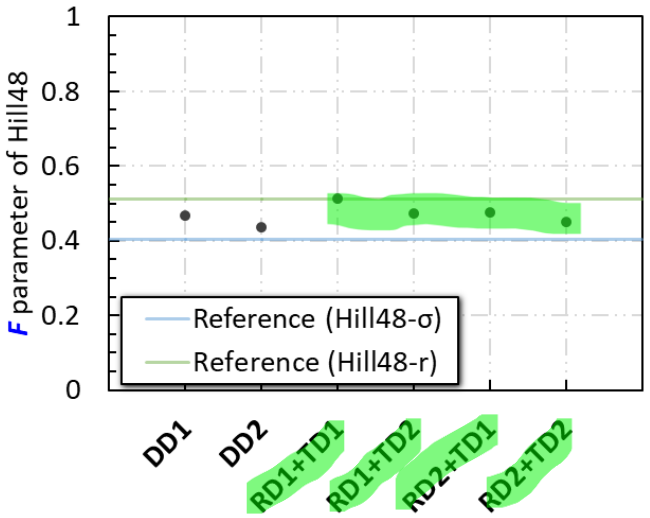
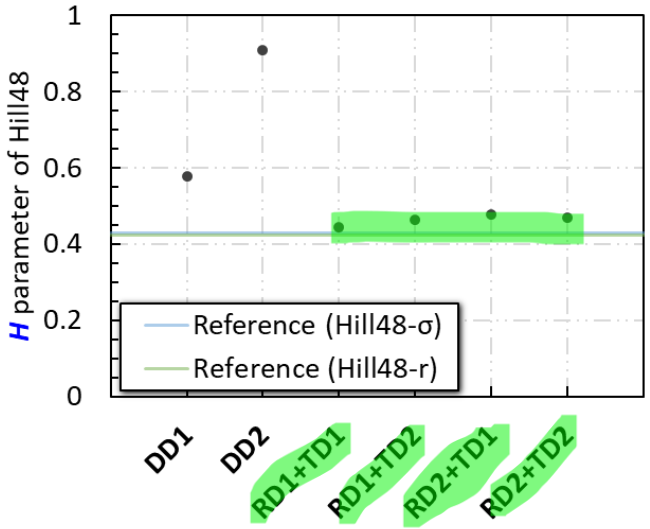
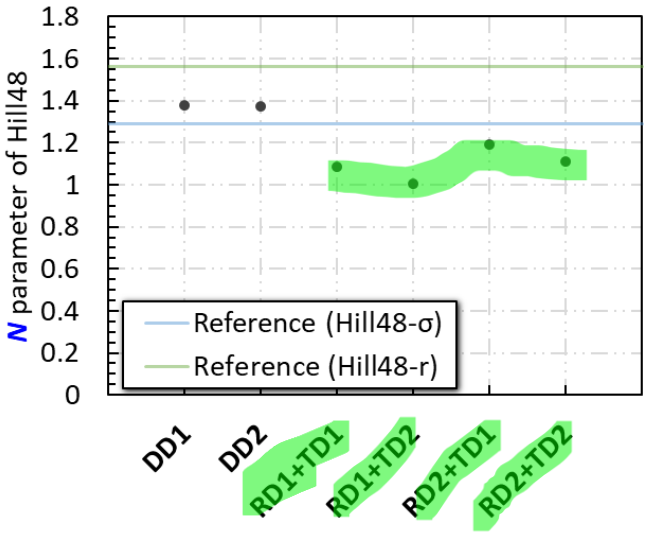
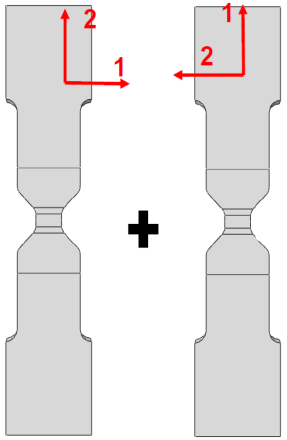
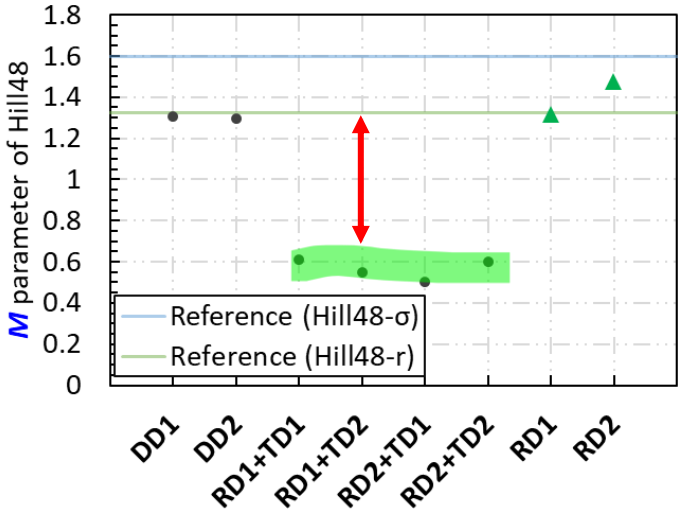
MT2.0: Experimental validation – Material model error

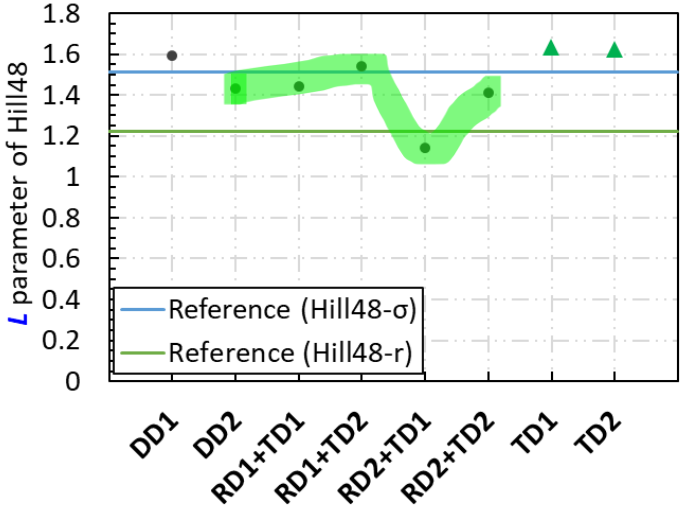












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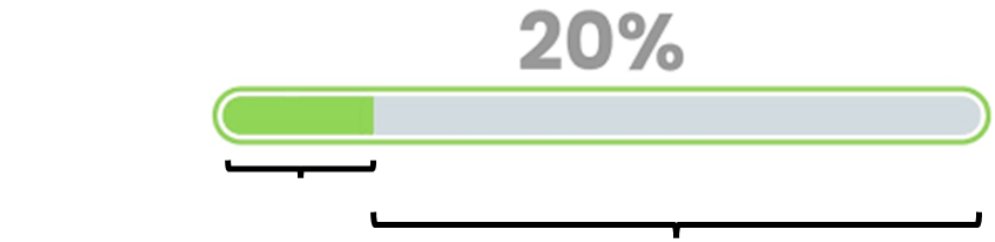
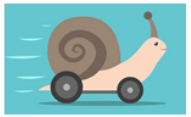
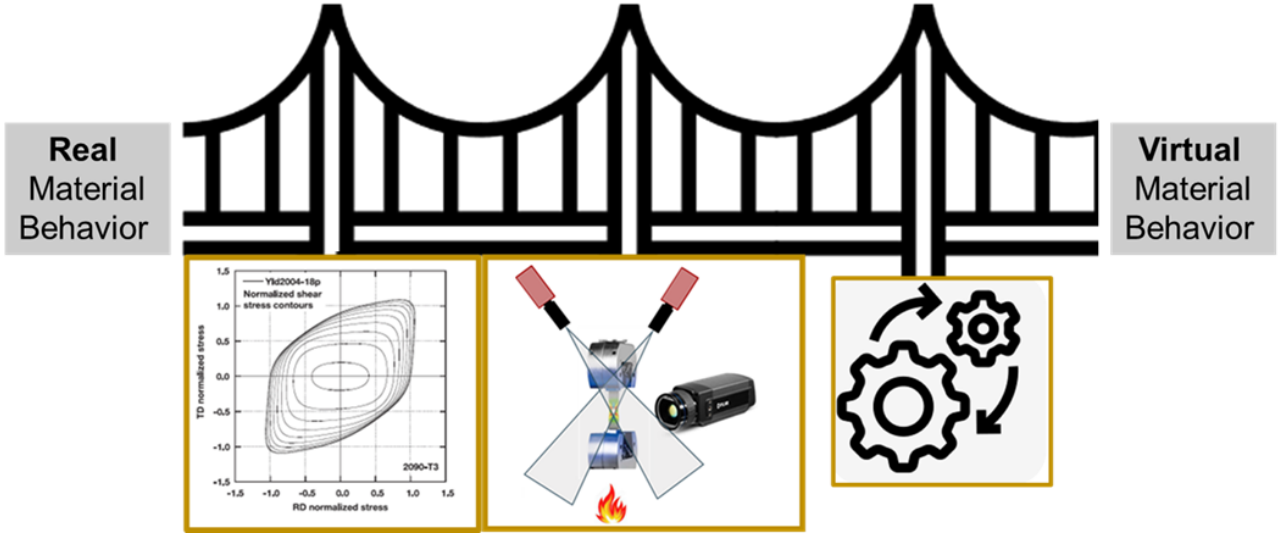
Conclusions MT2.0 for heavy gauge steel





MT2.0

crossing the material twin bridge faster/better



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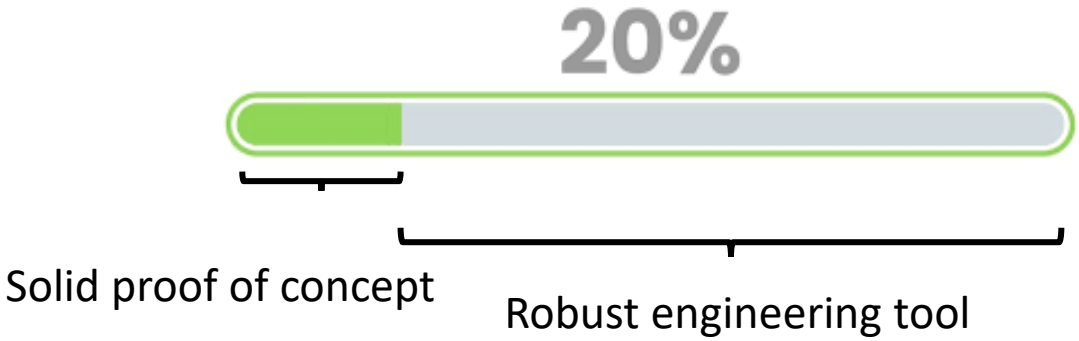
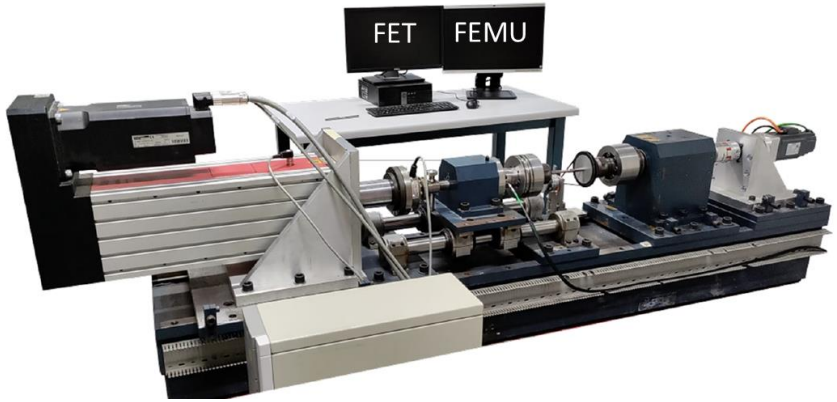
Conclusions MT2.0 for heavy gauge steel



- Simplicity of the specimen is key[1]: rather two simple specimens than one very complex.
- An automated design strategy[2] is still lacking for thick heavy gauge steel.
- Material model selection[3] is an open question, there are options[4] but therefore FEMU methods need to be accelerated.
- DVT is crucial tool (extension to IRT is under way[5]).
- Integrated MT2.0 solutions are required to gain industrial relevance[6].



[1] *PhD Yi Zhang*
[2] *PhD Mafalda* Gonçalves
[3] *PhD Mariana Conde*
[4] *PhD Amar Peshave*
[5] *PhD Alessandro Lambrughi*

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- Thank you !

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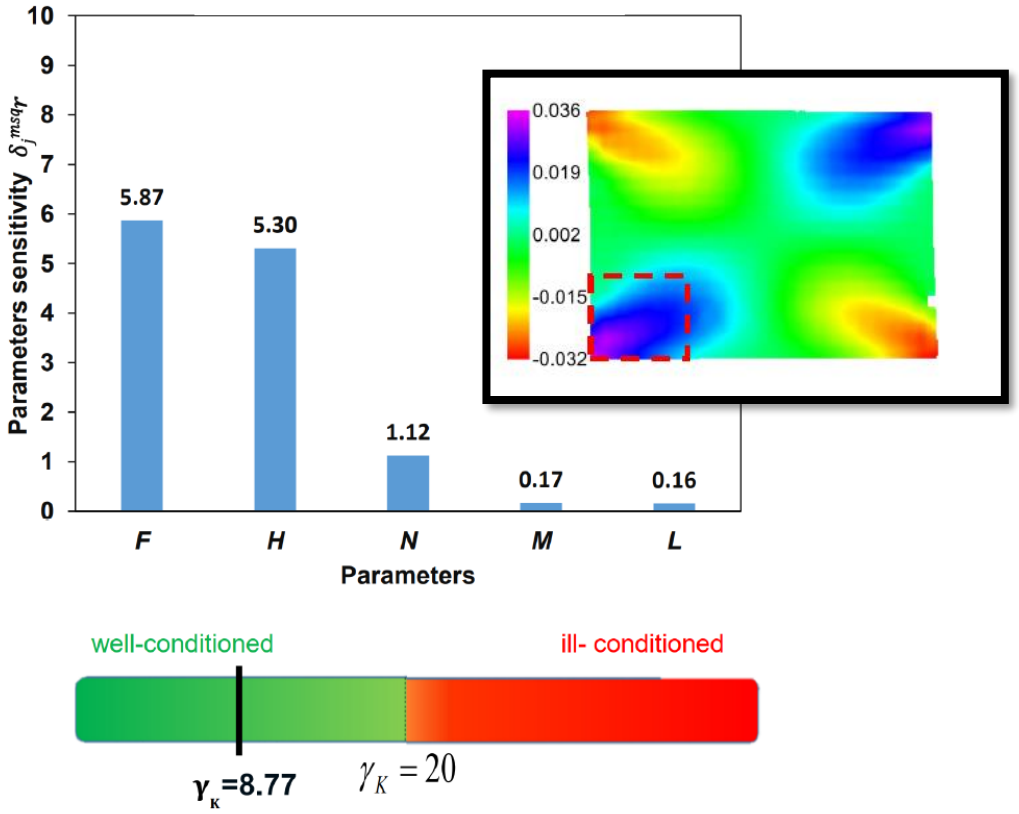
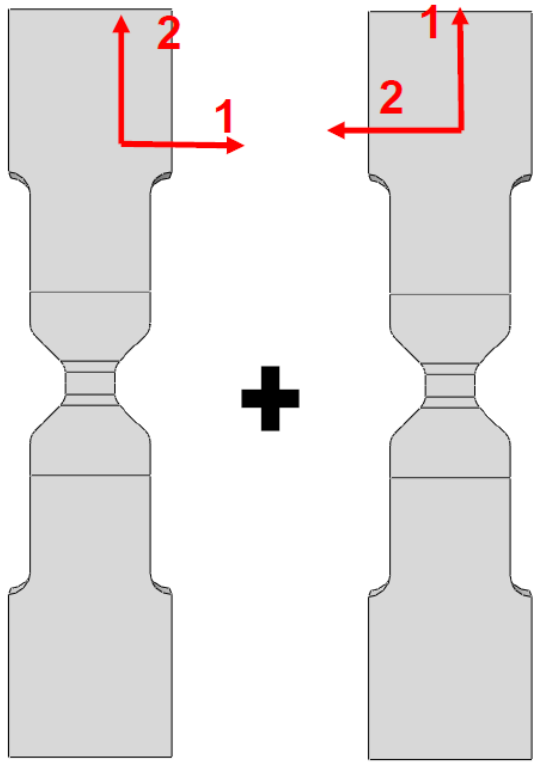
MT2.0: Specimen design

Identifiability analysis: maximizing parameter identifiability



Identifiability analysis



Two-specimen approach

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