A Tensile Setup for the IDNS Composite Composite Interlaminar Shear Test

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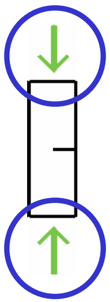
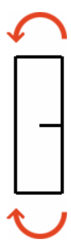
The IDNS concept

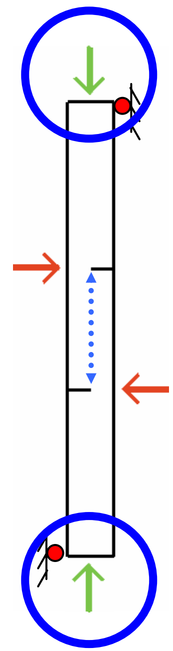
1 

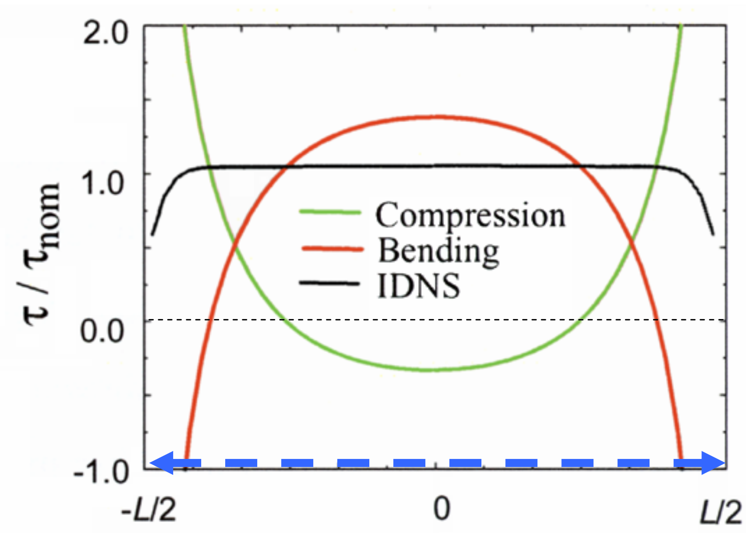
$$K_{\mathrm{I}}^{N} = \sigma^{N}\sqrt{\pi a}\, f^{N}$$

$$\sigma^{N} < 0$$

2 

$$K_{\mathrm{I}}^{M} = \sigma^{M}\sqrt{\pi a}\, f^{M}$$

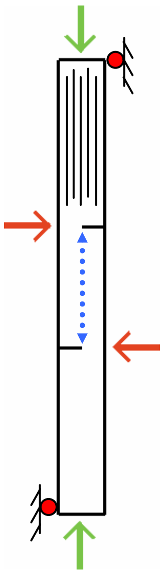




Proper combination when: $K_{\mathrm{I}}^{tot} = K_{\mathrm{I}}^{N} + K_{\mathrm{I}}^{M} = 0$

The IDNS Test

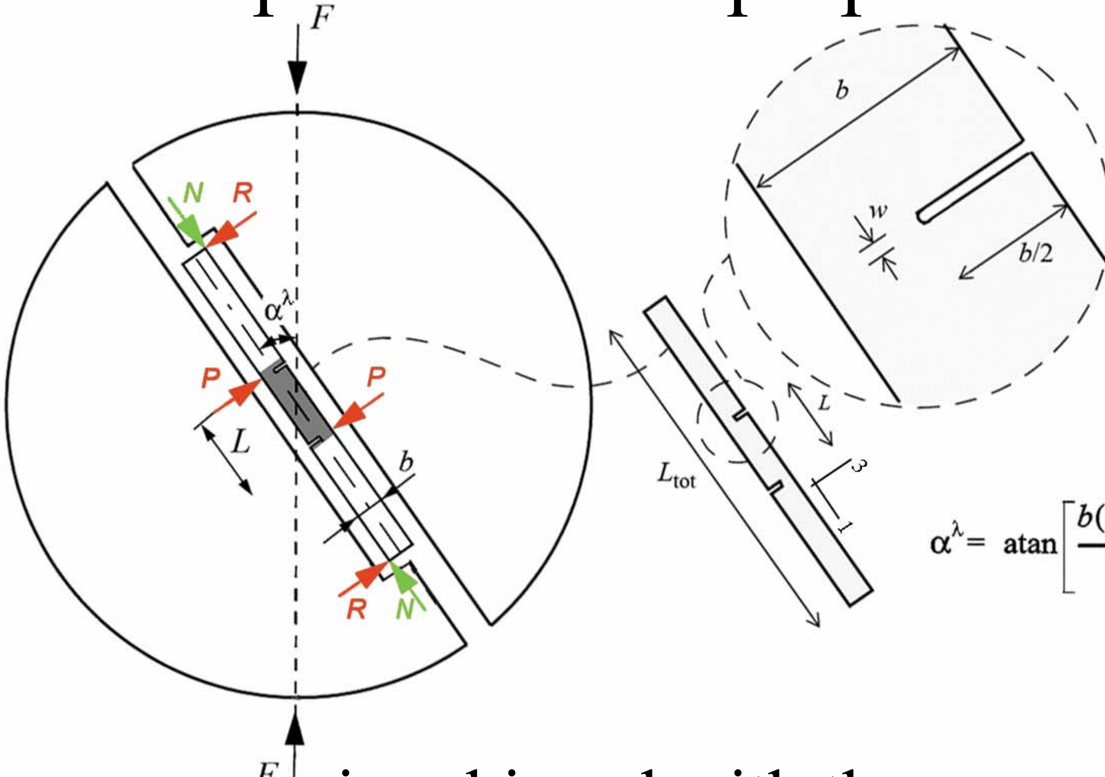
- Composites are built up of thin laminae
- Weak between layers: Testing important
- Relies on proper loading combination
- Proportional loading important



Shear test method for interlaminar shear properties

Inclined Double Notch Shear Test

- Proportional and proper loading of *N* and *P*



$$N = F \cdot \cos\alpha$$

$$P = F \cdot \frac{L_{tot}\sin\alpha - b\cos\alpha}{L_{tot} + L}$$

$$R = F \cdot \frac{L\sin\alpha + b\cos\alpha}{L_{tot} + L}$$

$$K_{\mathrm{I}}^{tot} = K_{\mathrm{I}}^{N} + K_{\mathrm{I}}^{M} = 0$$

=>

$$\alpha^{\lambda} = \operatorname{atan}\left[\frac{b(\lambda^{1/4}(2.639L + 0.639L_{tot}) - 0.115b)}{\lambda^{1/4}L(L_{tot} - L) - 0.115bL_{tot}}\right]$$

is achieved with the proper inclination angle, α^{λ}

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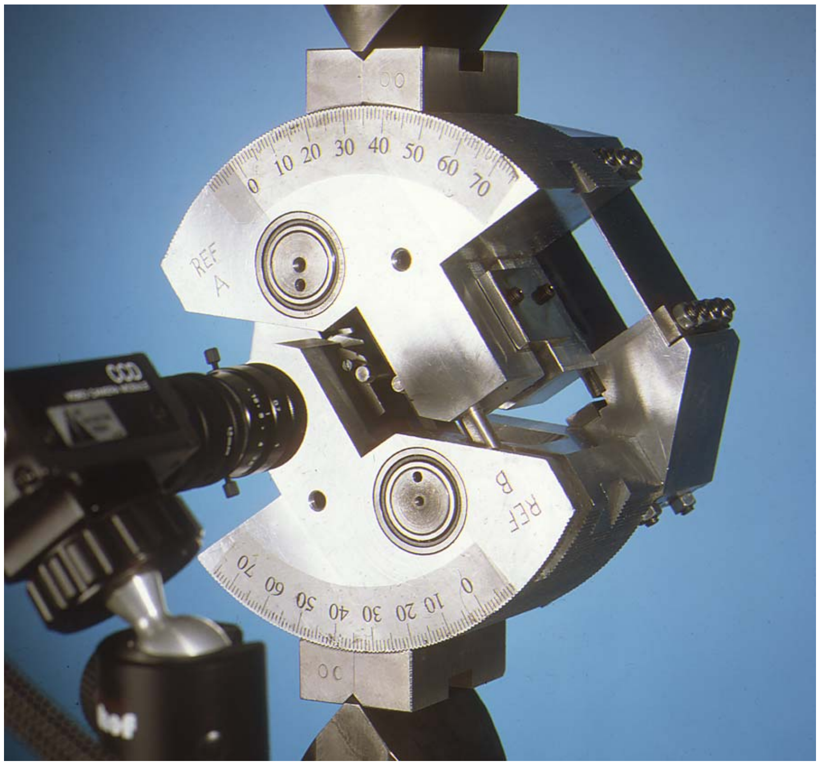
IDNS – Main features

- Uses DNC specimen (Double Notch Compression)
- DNC gives poor stress uniformity
- Superimpose bending moment M (opening)
- By holders and suport reactions (statically determined)
- M gives equally poor stress field (opposite sign)
- Characterized by mode I singularity (K_{I})
- Require $K_{\mathrm{I,tot}} = 0$ (proper loading combination)
- Proper proportion by correct holder inclination α
- Proportional loading is paramount (throughout test)

IDNS Fixture (old)



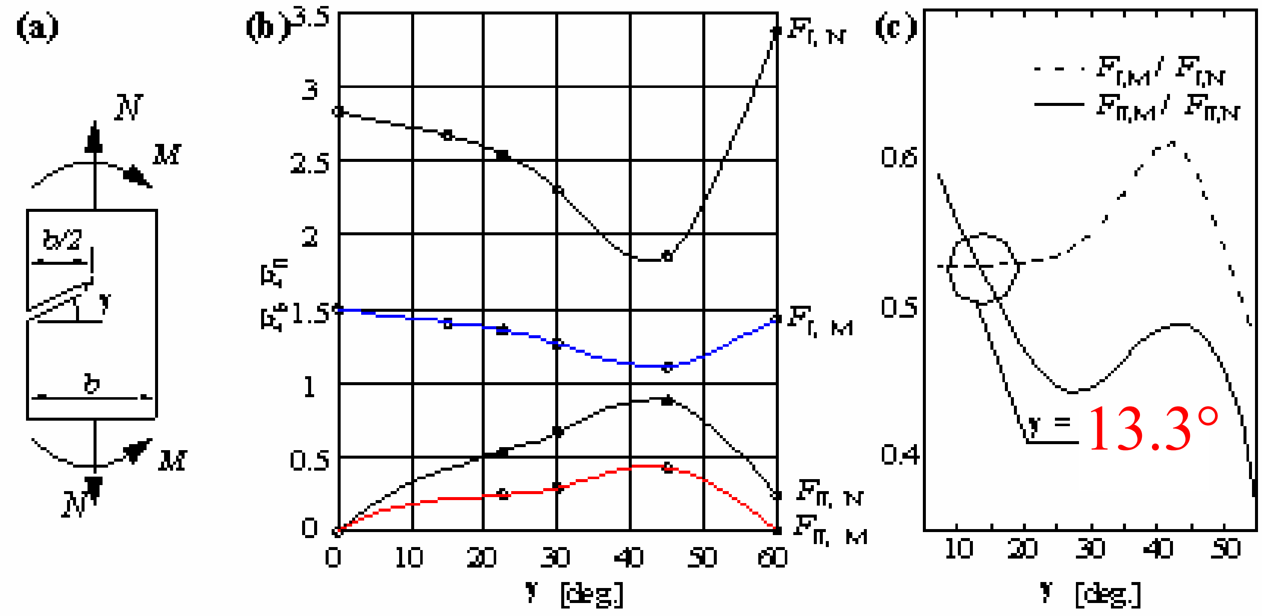
Issues:

- Compressive setup
- Instability phenomenon
- Specimen deformation
- Adjustment of $\alpha < \alpha_{calc}$
- K_{I} cancelled, but $K_{\mathrm{II}} = ?$
- Transverse stresses?
- What notch distance?

Simultaneous Cancellation of K_I and K_II

Mode I: $$K_\mathrm{I} = \sigma^N \sqrt{\pi a} F_{\mathrm{I},N} + \sigma^M \sqrt{\pi a} F_{\mathrm{I},M}$$

Mode II: $$K_\mathrm{II} = \sigma^N \sqrt{\pi a} F_{\mathrm{II},N} + \sigma^M \sqrt{\pi a} F_{\mathrm{II},M}$$



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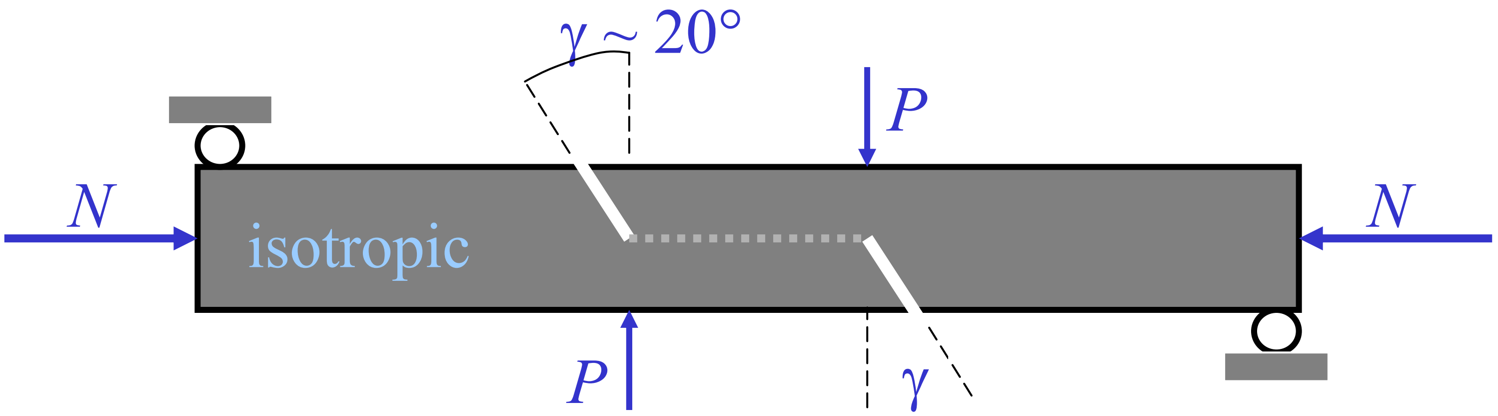
Cancelling K_I and K_II in an IDNS specimen

$\gamma = 13.3°$ (for pure loading conditions), but here:

- Two nearby notches
- Loading points (P) in vicinity
- Numerically, $\gamma \sim 20°$ gives low K_I and K_II,
- For an **isotropic** specimen!

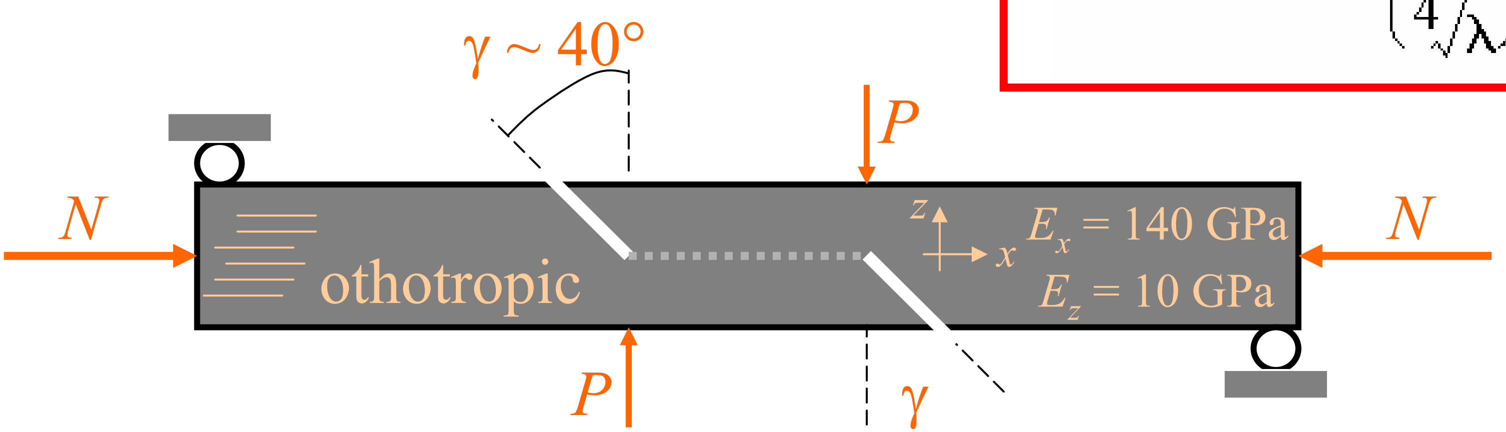


Cancelling K_{I} and K_{II} in Composite Specimen

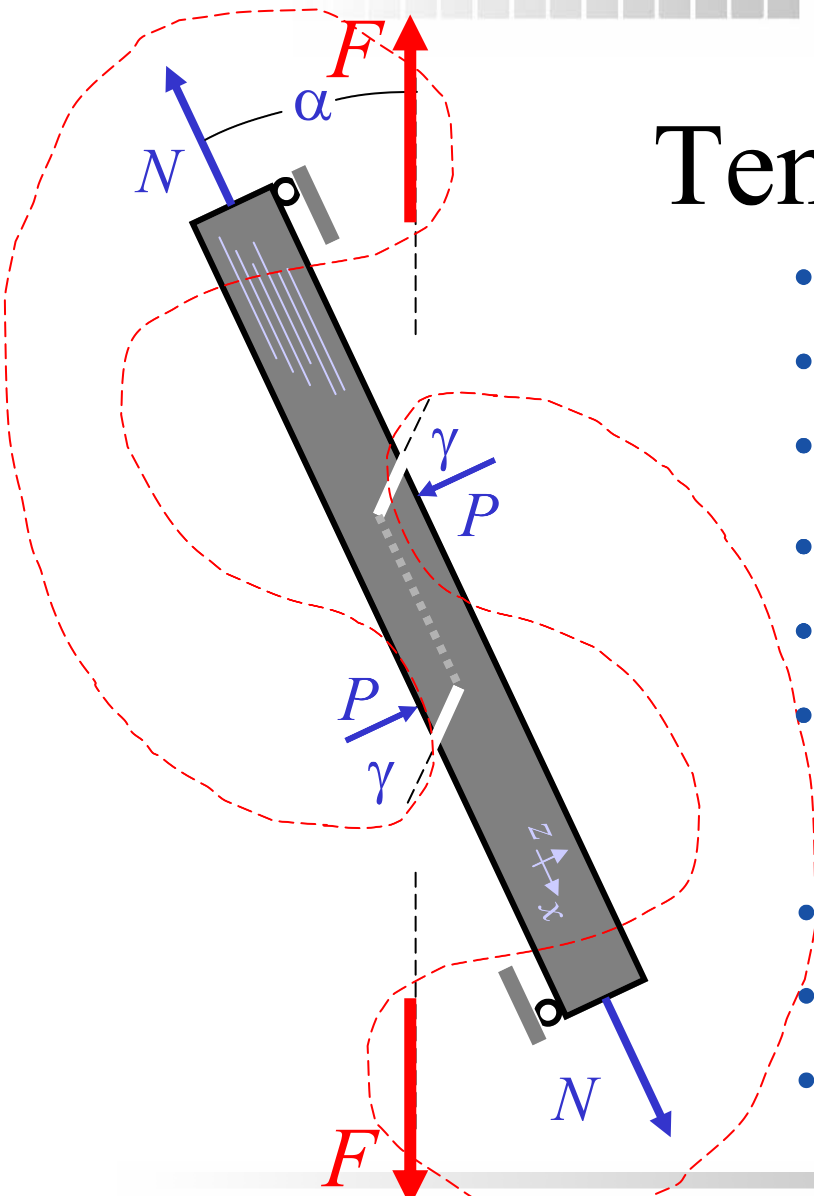
Composites - Orthotropic materials:

- Similar stress fields are achieved in rescaled geometry
- Rescaling lengthwise by $1/\lambda^{1/4}$,
- where $\lambda = E_z/E_x$ (= 1/14 here)

$$\boxed{\gamma_{\mathrm{orto}} = \operatorname{atan}\left(\frac{\gamma_{\mathrm{iso}}}{\sqrt[4]{\lambda}}\right)}$$



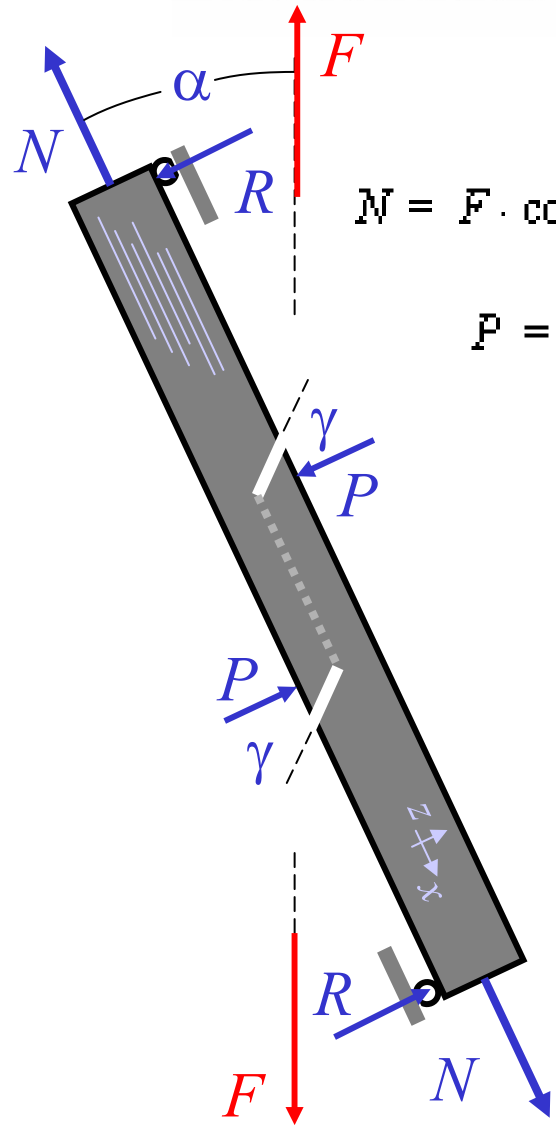
Tensile IDNS Setup



- Tensile nominal loading (*N*)
- No instability phenomenon
- Less specimen deformation
- Proportional loading (*N* and *P*)
- Through specimen holders
- External load (*F*)

- Simple calculation of α
- Tilted notches minimize K_I and K_{II}
- What notch distance?

Proper α?



$$N = F \cdot \cos\alpha$$

$$P = F \cdot \frac{(L_{tot} + 2l_l)\sin\alpha + b\cos\alpha}{L_{tot} + l_p + 2l_l} \qquad R = F \cdot \frac{l_p \sin\alpha - b\cos\alpha}{L_{tot} + l_p + 2l_l}$$

$$M = -F \cdot \frac{(L_{tot} + 2l_l - L)\, l_p \sin\alpha + (L + l_p)\, b\cos\alpha}{2(L_{tot} + l_p + 2l_l)} \longrightarrow$$

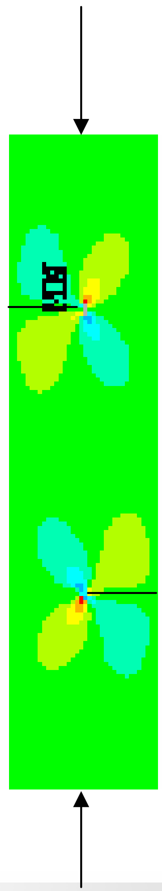
$$\sigma^N = \frac{N}{bW} \qquad \sigma^M = \frac{6M}{Wb^2} \longrightarrow$$

$$K_I^N = \sigma^N \sqrt{\pi a} f_*^N \qquad K_I^M = \sigma^M \sqrt{\pi a} f_*^M \longrightarrow K_I^N + K_I^M = 0$$

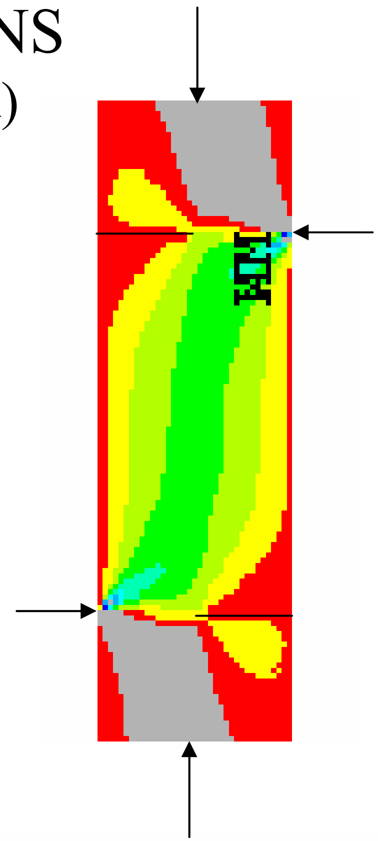
$$\boxed{\alpha_K = \operatorname{atan}\left(\frac{b\,(f^N(l_p + L_{tot} + 2l_l) - 3f^M(L + l_p))}{3f^M l_p (L_{tot} - L + 2l_l)}\right)}$$

Numerical (FE-) shear stress fields

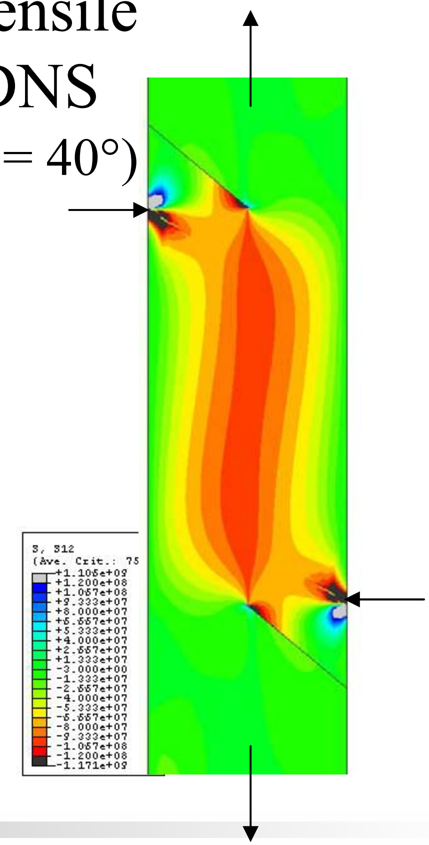
DNC
(ASTM)



IDNS
(old)



Tensile
IDNS
($\gamma = 40°$)



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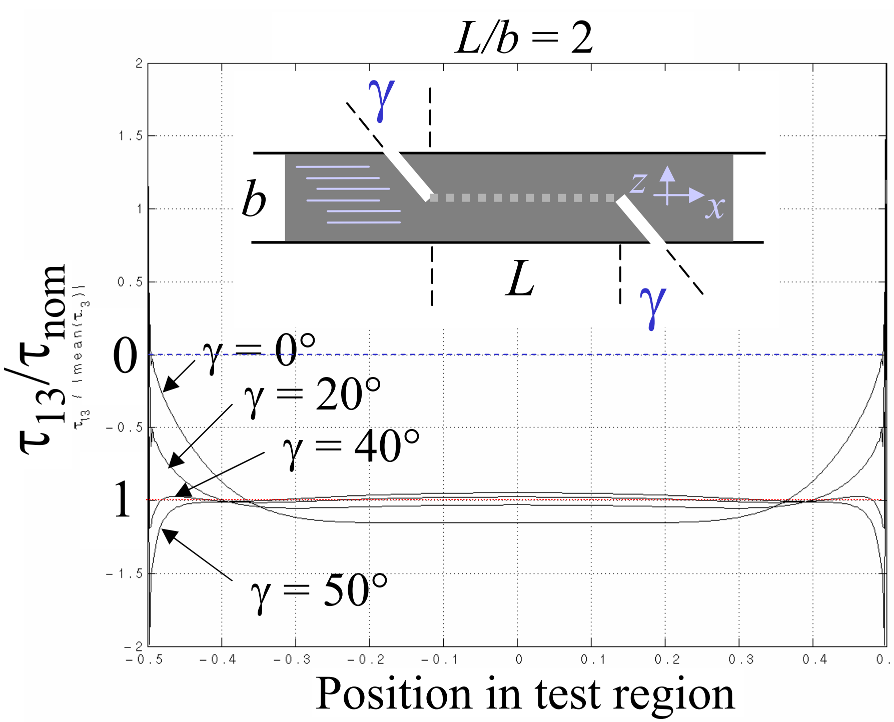
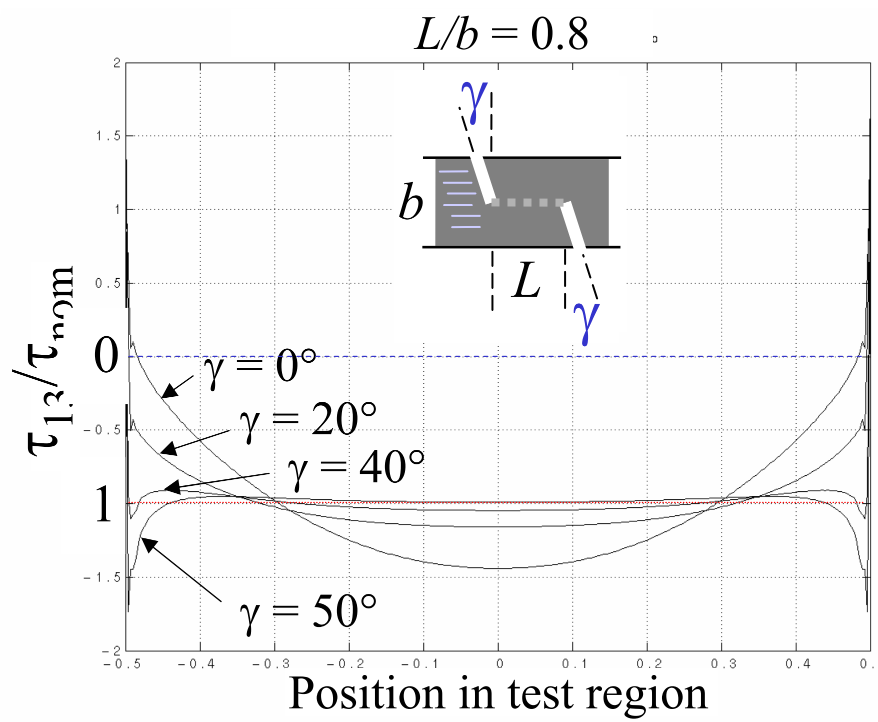
Numerical (FE-) shear stress profiles





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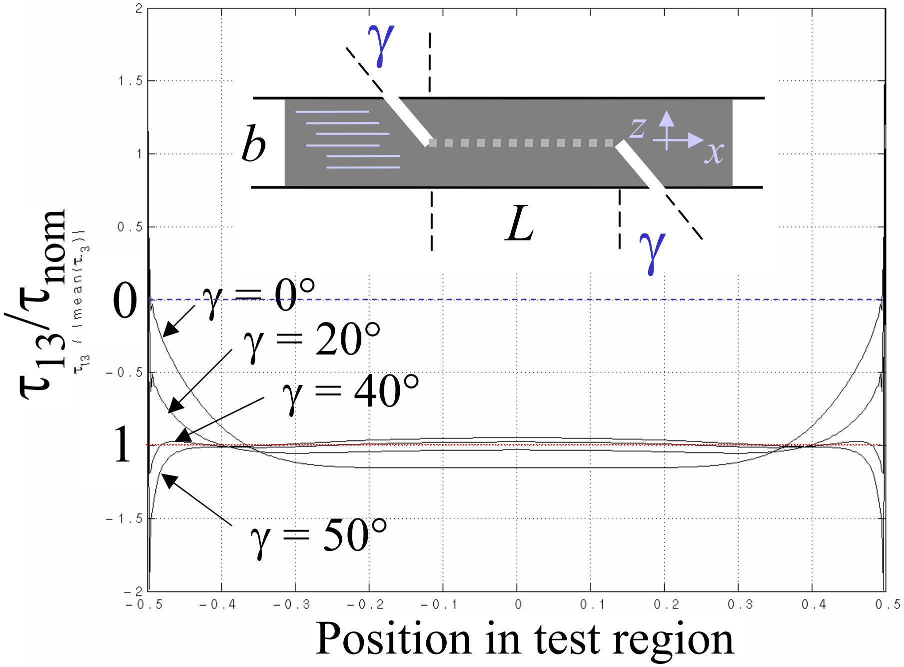
Numerical (FE-) stress profiles

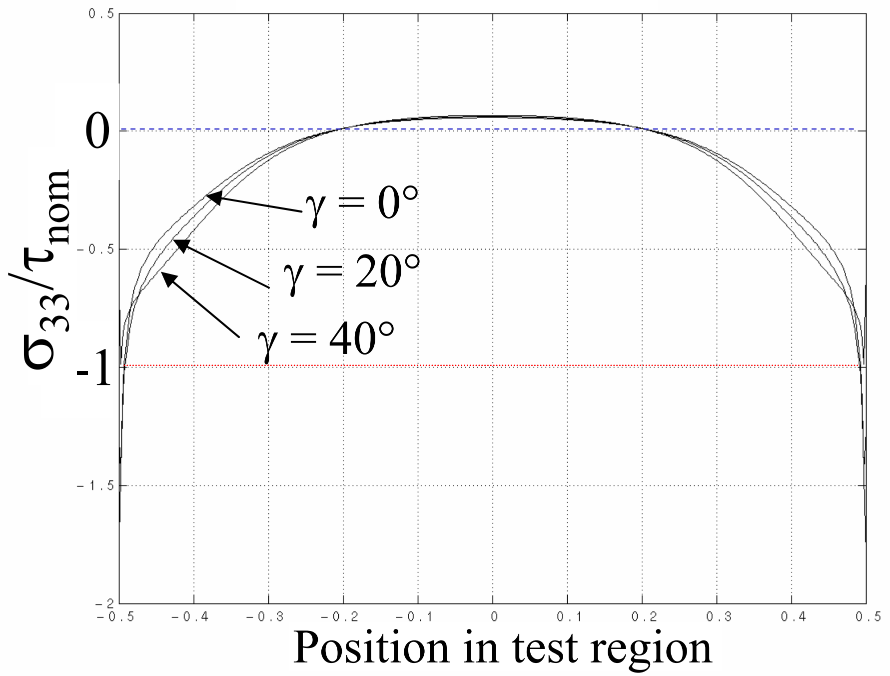
Shear stress (nominal)

$L/b = 2$



Transverse stress

$L/b = 2$



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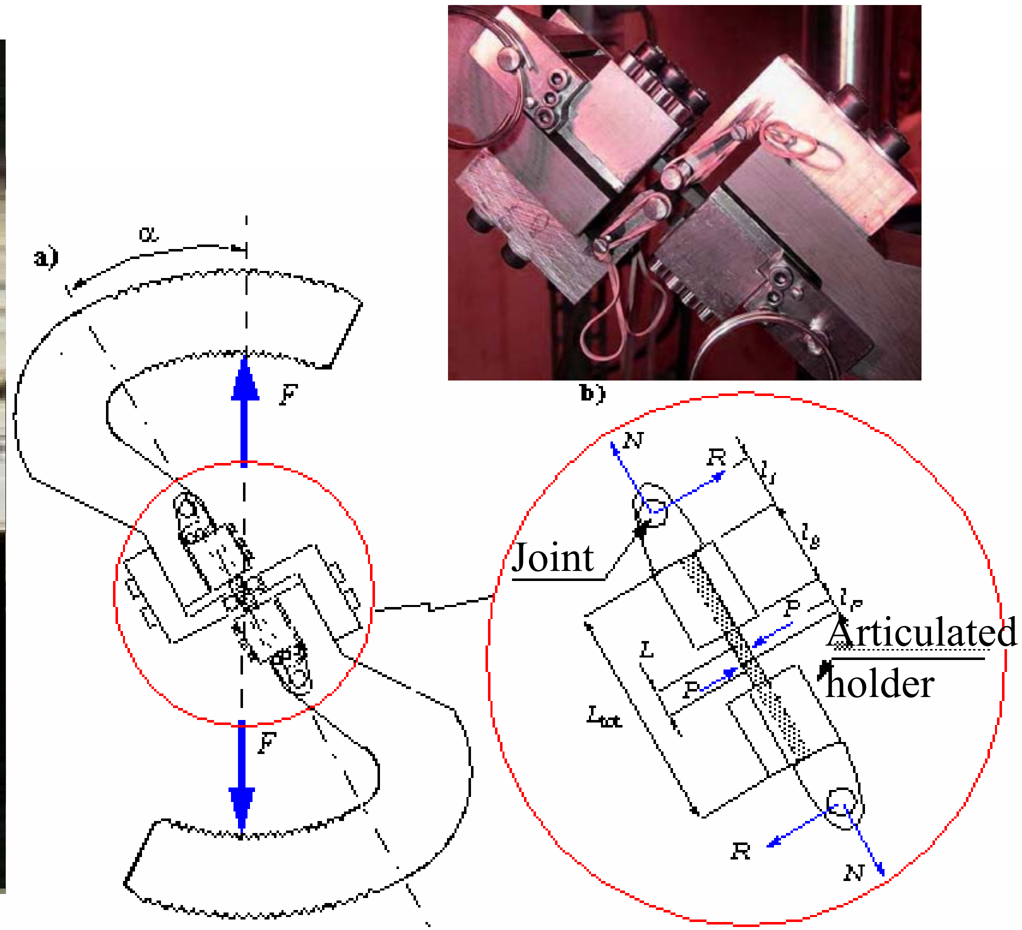
Tensile IDNS Fixture



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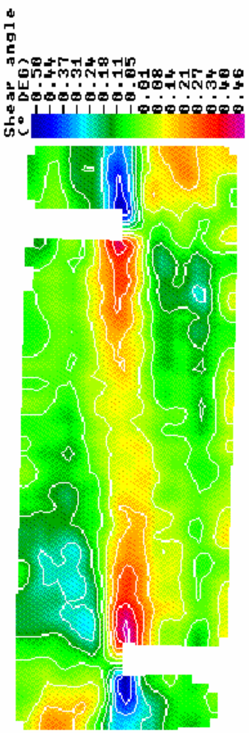
Experimental shear strain fields

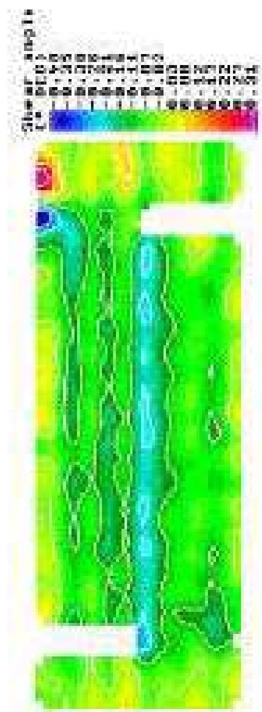
DNC

(ASTM standard)

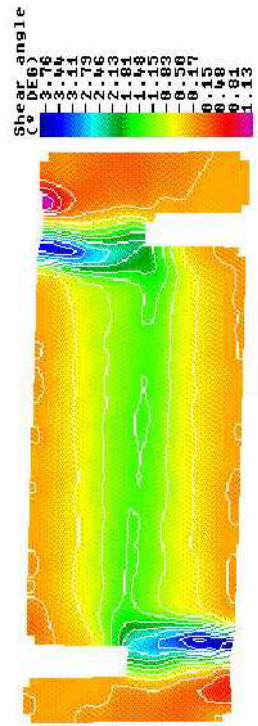


IDNS (compressive)

Low load

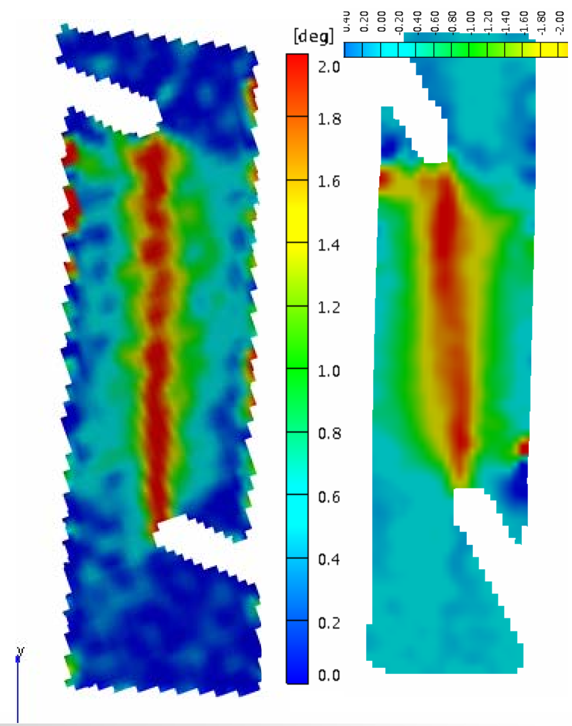


High load



Tensile IDNS

High loads (γ = 20° and 60°)



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Conclusions

- Tensile IDNS setup feasible (gripping)
- Less specimen deformation, no instability
- Adjustment of α simpler, according to eq.
- Lower α needed, more benign loading
- Tilted notches favorable, diminishes K_{II}
- Notch tilt $\gamma_{\mathrm{iso}} = 20°$, rescale by $(E_x/E_z)^{1/4}$
- Adjustment of α insensitive to γ

Conclusions (continued)

- Even more uniform shear stress distributions
- Particularly for the shortest notch distances
- (still, most uniform profiles for longer L/b)
- Lower levels of transverse stress
- Higher shear strengths than old IDNS
- Notch distance $L/b = 0.8$ optimal
- More difficult handling/gripping/adjusting