A Tensile Setup for the IDNS Composite Composite Interlaminar Shear Test

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The IDNS concept

1. $K_I^N = \sigma^N \sqrt{\pi a} f^N$
   $\sigma^N < 0$

2. $K_I^M = \sigma^M \sqrt{\pi a} f^M$

Proper combination when: $K_I^{tot} = K_I^N + K_I^M = 0$
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 $P$

is achieved with the proper inclination angle, $\alpha^\lambda$

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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 support reactions (statically determined)
- $M$ gives equally poor stress field (opposite sign)
- Characterized by mode I singularity ($K_I$)
- Require $K_{I,tot} = 0$ (proper loading combination)
- Proper proportion by correct holder inclination $\alpha$
- Proportional loading is paramount (throughout test)
IDNS Fixture (old) Issues:

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

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

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

13.3°
Cancelling $K_I$ and $K_{II}$ in an IDNS specimen

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

- Two nearby notches
- Loading points ($P$) in vicinity
- Numerically, $\gamma \sim 20^\circ$ 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)

\begin{align*}
\gamma_{ortho} &= \tan^{-1}\left(\frac{\gamma_{iso}}{\frac{1}{4\sqrt{\lambda}}}\right)
\end{align*}

\[ E_x = 140 \text{ GPa} \]
\[ E_z = 10 \text{ GPa} \]
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 $\alpha$
- Tilted notches minimize $K_I$ and $K_{II}$
- What notch distance?
\[ N = F \cdot \cos \alpha \]

\[ P = F \cdot \frac{(L_{\text{tot}} + 2l_i) \sin \alpha + b \cos \alpha}{L_{\text{tot}} + l_p + 2l_i} \]

\[ R = F \cdot \frac{l_p \sin \alpha - b \cos \alpha}{L_{\text{tot}} + l_p + 2l_i} \]

\[ M = -F \cdot \frac{(L_{\text{tot}} + 2l_i - L) l_p \sin \alpha + (L + l_p) b \cos \alpha}{2(L_{\text{tot}} + l_p + 2l_i)} \]

\[ \sigma^N = \frac{N}{b W} \quad \sigma^M = \frac{6M}{W b^2} \]

\[ K_I^N = \sigma^N \sqrt{\pi a f_x^N} \quad K_I^M = \sigma^M \sqrt{\pi a f_x^M} \quad K_I^N + K_I^M = 0 \]

\[ \alpha_K = \arctan \left( \frac{b (f^N(l_p + L_{\text{tot}} + 2l_i) - 3f^M(L + l_p))}{3f^M l_p (L_{\text{tot}} - L + 2l_i)} \right) \]
Numerical (FE-) shear stress fields

DNC (ASTM)

IDNS (old)

Tensile IDNS ($\gamma = 40^\circ$)

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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 ($\gamma = 20^\circ$ and $60^\circ$ )

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Conclusions

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