IMAGE CORRELATION NONDESTRUCTIVE EVALUATION
OF IMPACT DAMAGE IN A GLASS FIBER COMPOSITE

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Introduction to Digital Image Correlation
• Image Acquisition
• Speckle Generation
• Bilinear Interpolation
• Displacement and Strain Fields

Damage in Fiberous Composites
• Whitney and Neusimer Model
• Strains as an Indicator
• Failure Criteria as an Evaluation Tool

Damaged Coupons--Cross-Ply Scotchply Gl-Ep Laminate
• Inclusion
• Slit Fibers
• Impact Damage
  • Residual Strength
  • Failure Criteria Maximum Values

Conclusions
FIGURE 1. EXPERIMENTAL CONFIGURATION FOR IMAGE ACQUISITION AND IMAGE STORAGE.

FIGURE 2. TYPICAL RANDOM SPECKLE PATTERN ON SURFACE OF SPECIMENS.
Fig. 4.5 Image processing set-up
Fig. 2.3  Local motion and Distortion of a subset image
Fig. 2.4 Deformation of a subimage in a sampling grid
Bilinear Interpolation

\[ I(x',y') = I(0,0) + \left[ I(L,0) - I(0,0) \right] \frac{x'}{L} + \left[ I(0,L) - I(0,0) \right] \frac{y'}{L} \]

\[ + \left[ I(L,L) + I(0,0) - I(L,0) - I(0,L) \right] \frac{x'y'}{L^2} \]

\( x', y' \) local co-ordinates

\( L \) subset size
\[
C(u, v, \epsilon_x, \epsilon_y, \epsilon_x, \epsilon_y) = \frac{\int_{\Delta M^*} f(x, y) f^*(x+\epsilon, y+\eta) \, dA}{\left( \int_{\Delta M} |f(x, y)|^2 \, dA \int_{\Delta M^*} |f^*(x+\epsilon, y+\eta)|^2 \, dA \right)^{1/2}} \tag{2.13}
\]

\[
\epsilon = u + \frac{\epsilon_u}{\epsilon_x} \Delta x + \frac{\epsilon_u}{\epsilon_y} \Delta y
\]

\[
\eta = v + \frac{\epsilon_v}{\epsilon_x} \Delta x + \frac{\epsilon_v}{\epsilon_y} \Delta y
\]
\[ \varepsilon_{xx} = \frac{\partial u}{\partial x} = \frac{u(200,100) - u(160,100)}{40 \text{ pixels}} \]

\[ \varepsilon_{yy} = \frac{\partial v}{\partial y} = \frac{\Delta y}{\Delta y} \]

etc.
Use Strains as Indicator of Damage
Use Control Load

Concept: Measure strains, generate Tsai-Hill failure map

\[ F_1 = A \varepsilon_1^2 + B \varepsilon_2^2 + C \varepsilon_1 \varepsilon_2 + D \gamma_{12}^2 \]

where

\[ A = \frac{Q_{11}}{x^2} + \frac{Q_{12}}{y^2} - \frac{Q_{11} Q_{12}}{x y} \]

\[ B = \frac{Q_{12}}{x^2} + \frac{Q_{22}}{y^2} - \frac{Q_{11} Q_{22}}{x y} \]

\[ C = \frac{2 Q_{11} Q_{12}}{x^2} + \frac{2 Q_{12} Q_{22}}{y^2} - \frac{Q_{11} Q_{22} + Q_{12}^2}{x y} \]

\[ D = \frac{Q_{66}^2}{s^2} \]

\[ Q_{11} = \frac{E_1}{1 - \nu_{12} \nu_{21}} \]

\[ Q_{12} = \frac{\nu_{12} E_2}{1 - \nu_{12} \nu_{21}} \]

\[ Q_{22} = \frac{E_2}{1 - \nu_{12} \nu_{21}} \]

\[ Q_{66} = G_{12} \]
SUPPORTING RESEARCH

- Whitney and Nuismer model
  JCM, Vol. 8, July 1974

"failure occurs when the average stress over some distance, \( a_0 \), equals the unnotched laminate strength."

Hole

\[
\sigma_N = \sigma_0 \left[ \frac{2(1-\xi_2)}{2 - \xi_2^2 - \xi_2^4} \right]
\]

Notch

\[
\kappa_q = \sigma_0 \sqrt{\pi a_0 \xi_4}
\]

where

\[
\xi_2 = \frac{R}{R + a_0}
\]

and

\[
\xi_4 = \frac{C}{2C + a_0}
\]

\( a_0 \) is material parameter
\( a_0 = 0.15 \) for 1002 GI-Ep Scotchply

\( 1 - 256 \) pixels \( \rightarrow \) 40 pixels - 0.156 in

So critical distance is appropriate.
However, damage is generally complex stress-strain state!
Test Case: Cross-Ply GI-Epoxy Scotchply Coupons

Damage: Inclusion
    Slit Fibers
    Impact Damage
FIGURE 6. DISPLACEMENTS FOR MYLAR INCLUSION.
FIGURE 7. STRAINS FOR MYLAR INCLUSION.
FIGURE 8. FAILURE FUNCTION \((F)\) FOR MYLAR INCLUSION.
E 9. GREY LEVEL FAILURE FUNCTION (F) FOR MYLAR INCLUSI
BLACK TO WHITE SIGNIFIES INCREASING VALUES OF F.
FIGURE 11. DISPLACEMENTS AWAY FROM THE INCLUSION.
FIGURE 12. STRAINS AWAY FROM THE INCLUSION.
FIGURE 13. FAILURE FUNCTION ($F$) FIELDS AWAY FROM THE INCLUSION.

FIGURE 14. GREY SCALED FAILURE FUNCTION FIELD AWAY FROM THE INCLUSION.
FIGURE 16. STRAINS FOR SPECIMEN WITH SLIT THROUGH BACK 0° PLY.

\( \varepsilon_x = 0.4\% \)
FIGURE 17. FAILURE FUNCTION (F) FOR SPECIMEN WITH SLIT THROUGH BACK 0° PLY.

FIGURE 18. GREY LEVEL PRESENTATION OF FAILURE FUNCTION FOR SPECIMEN WITH SLIT THROUGH BACK 0° PLY.
FIGURE 21. FAILURE FUNCTION (F) AT IMPACT DAMAGED ZONE.

\[
[0^\circ, 90^\circ_3, 0^\circ]
\]

\(\varepsilon_x = 2.6\%\)
FIGURE 22. STRENGTH OF IMPACTED \([0^\circ, 90^\circ 3, 0^\circ]\) SPECIMENS

FIGURE 23. MAXIMUM FAILURE FUNCTION \((F)\) FOR IMPACTED \([0^\circ, 90^\circ 3, 0^\circ]\) SPECIMENS.
CONCLUSIONS

- IMAGE CORRELATION ACCURACY--0.03%

- STRAINS CAN BE PROCESSED THROUGH TSAI-HILL FAILURE CRITERIA TO QUANTIFY DAMAGE

- STATISTICAL DATA BASE MUST BE GENERATED TO EVALUATE CERTAINTY OF DAMAGE ESTIMATE

- SIZE EFFECTS NEED CONSIDERATION

- BETTER NUMERICAL TECHNIQUES NEEDED FOR PREVIOUS TWO GOALS