N91-18194

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

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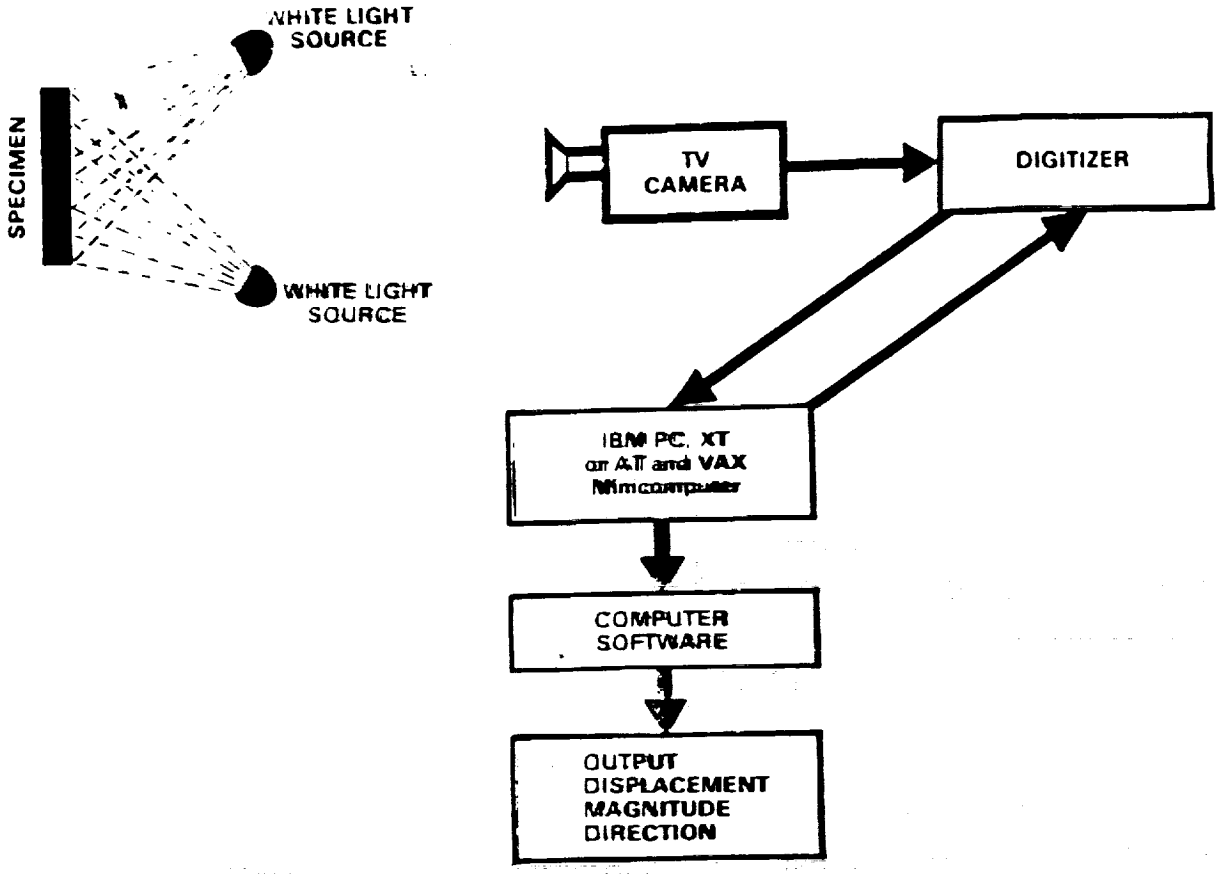

FIGURE 1. EXPERIMENTAL CONFIGURATION FOR IMAGE ACQUISITION AND IMAGE STORAGE.

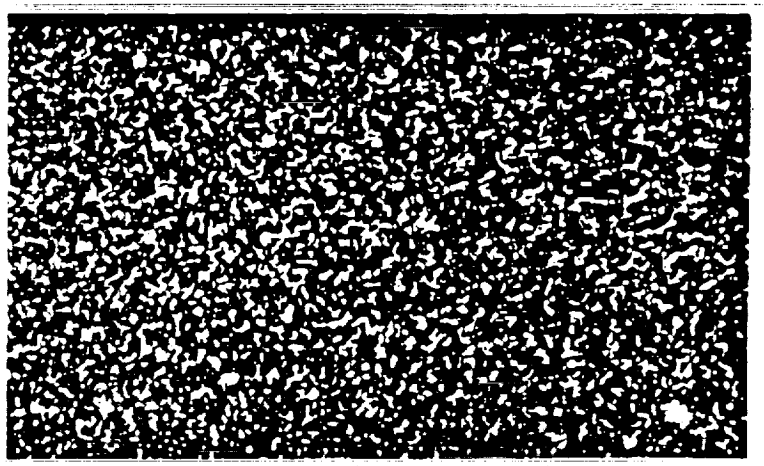

FIGURE 2. TYPICAL RANDOM SPECKLE PATTERN ON SURFACE OF SPECIMENS.

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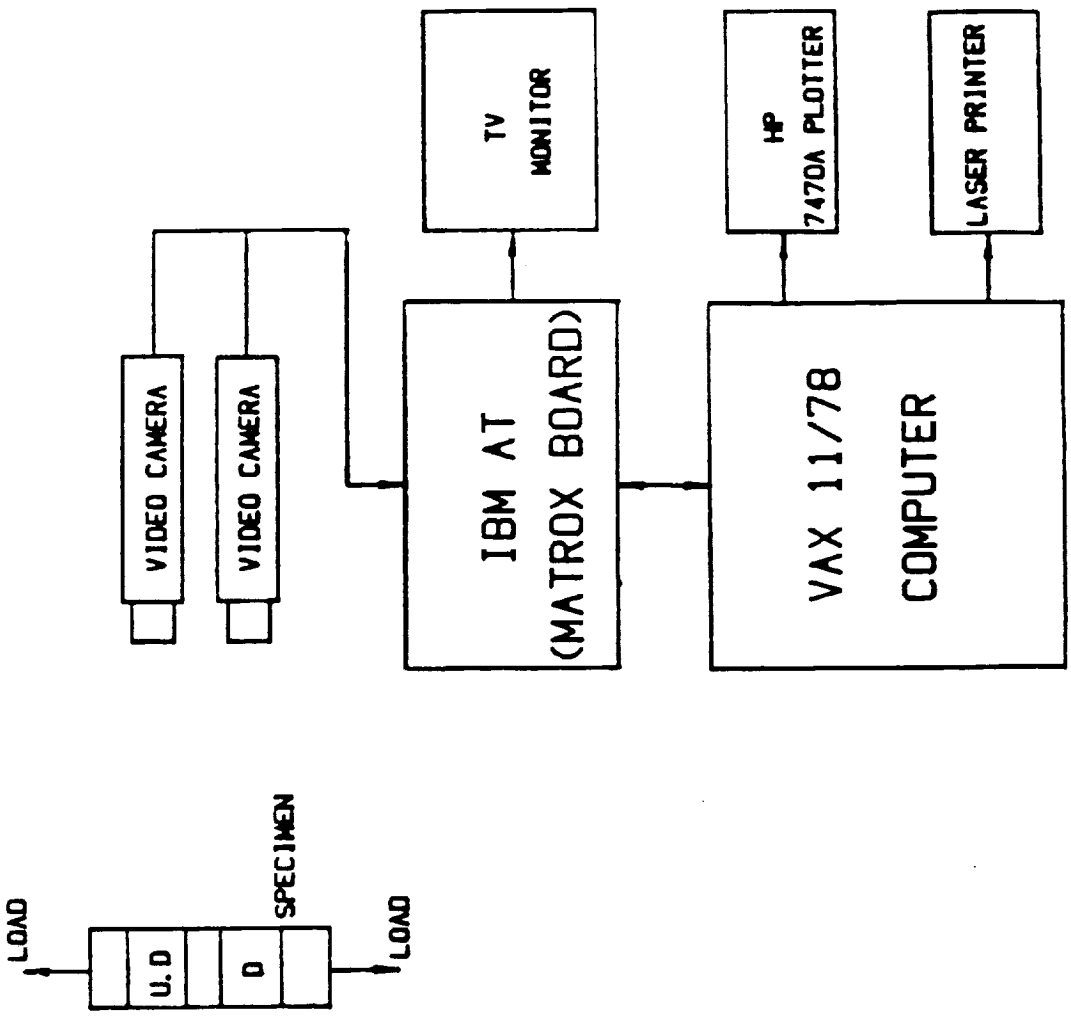

Fig. 4.5 Image processing set-up

C-2

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Fig. 2.3 Local motion and Distortion of a subset image

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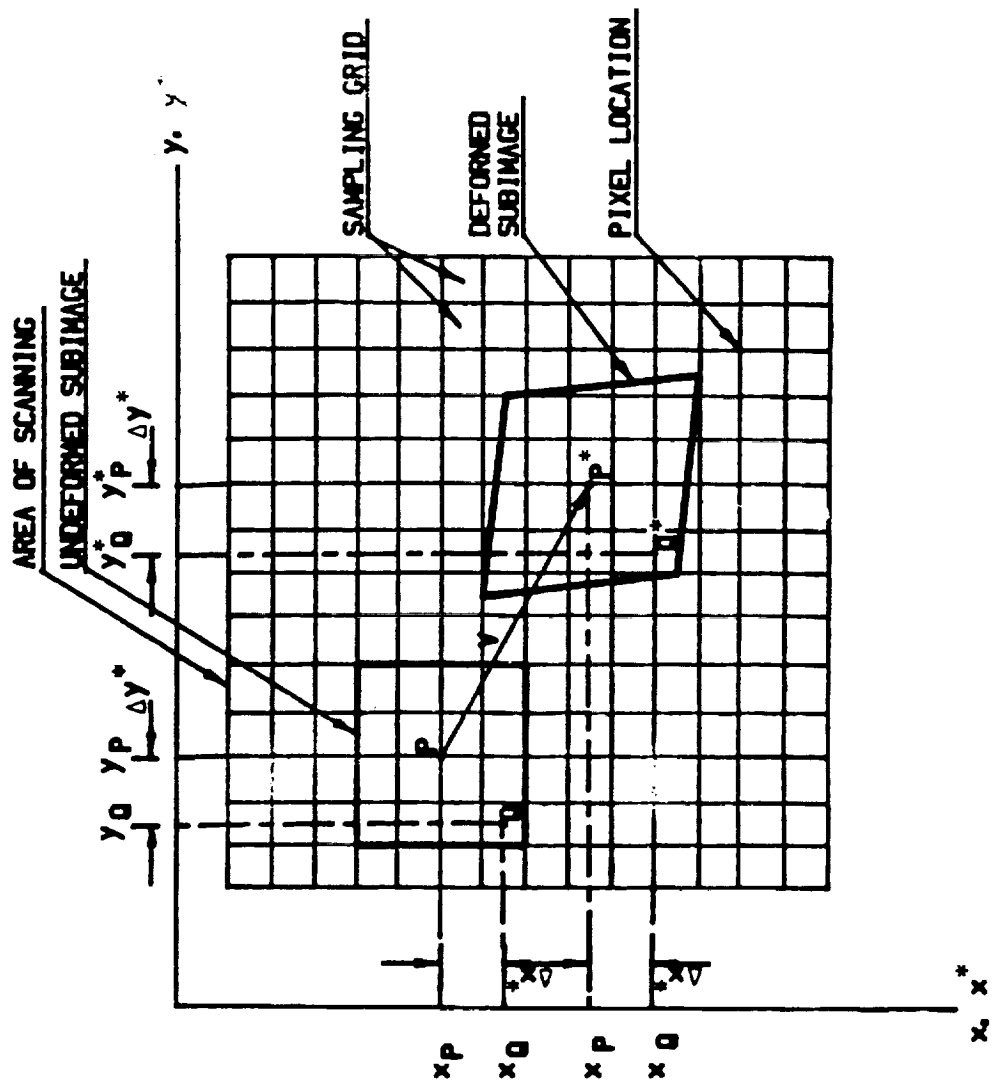

Fig. 2.4 Deformation of a subimage in a sampling grid

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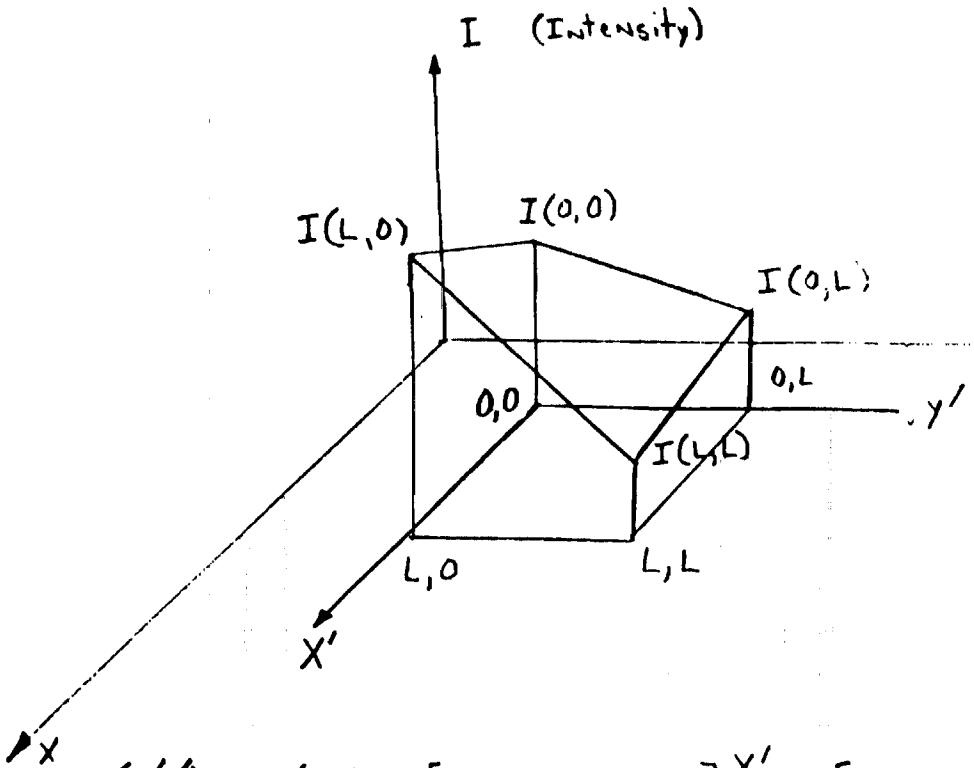
Bilinear Interpolation



x', y' → local co-ordinates

L → Subset size

$$I(x',y') = I(0,0) + [I(L,0) - I(0,0)]\frac{x'}{L} + [I(0,L) - I(0,0)]\frac{y'}{L}$$
$$+ [I(L,L) + I(0,0) - I(L,0) - I(0,L)]\, x'y'/L^2$$

$$C\left(u,\ v,\ \frac{\partial u}{\partial x},\ \frac{\partial u}{\partial y},\ \frac{\partial v}{\partial x},\ \frac{\partial v}{\partial y}\right)$$

$$\frac{\int_{\Delta M^*} f(x,y)\ f^*(x+\xi,y+\eta)\ dA}{\left[\int_{\Delta M} |f(x,y)|^2 dA \int_{\Delta M^*} |f^*(x+\xi,y+\eta)|^2 dA\right]^{1/2}} \qquad (2.13)$$

$$\xi = u + \frac{\partial u}{\partial x}\Delta x + \frac{\partial u}{\partial y}\Delta y$$

$$\eta = v + \frac{\partial v}{\partial x}\Delta x + \frac{\partial v}{\partial y}\Delta y$$

(pixels)

$$\epsilon_{xx} = \frac{\partial u}{\partial x} = \frac{u(200,100) - u(160,100)}{40 \text{ pixels}}$$

$$\epsilon_{yy} = \frac{\partial v}{\partial y} = \frac{\Delta v}{\Delta y}$$

etc.

Use Strains as Indicator of Damage
Use Control Load

Concept: Measure strains, generate Tsai-Hill failure map

$$F_I = A\,\varepsilon_1^2 + B\,\varepsilon_2^2 + C\,\varepsilon_1\,\varepsilon_2 + D\,\gamma_{12}^2$$

where

$$A = \frac{Q_{11}^2}{X^2} + \frac{Q_{12}^2}{Y^2} - \frac{Q_{11}\,Q_{12}}{X\,Y}$$

$$B = \frac{Q_{12}^2}{X^2} + \frac{Q_{22}^2}{Y^2} - \frac{Q_{11}\,Q_{22}}{X\,Y}$$

$$C = \frac{2\,Q_{11}Q_{12}}{X^2} + \frac{2\,Q_{12}Q_{22}}{Y^2} - \frac{Q_{11}\,Q_{22} + Q_{12}^2}{X\,Y}$$

$$D = \frac{Q_{66}^2}{S^2}$$

$$Q_{11} = \frac{E_1}{1 - \nu_{12}\,\nu_{21}}$$

$$Q_{12} = \frac{\nu_{12}\,E_2}{1 - \nu_{12}\,\nu_{21}}$$

$$Q_{22} = \frac{E_2}{1 - \nu_{12}\,\nu_{21}}$$

$$Q_{66} = G_{12}$$

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

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

where

$$\xi_2 = \frac{R}{R + a_0}$$

a_0 is material parameter
a_0 ~ 0.15 for 1002 Gl-Ep
Scotchply

Notch

$$K_q = \sigma_0 \sqrt{\pi a_0 \xi_4}$$

where

$$\xi_4 = \frac{C}{2C + a_0}$$

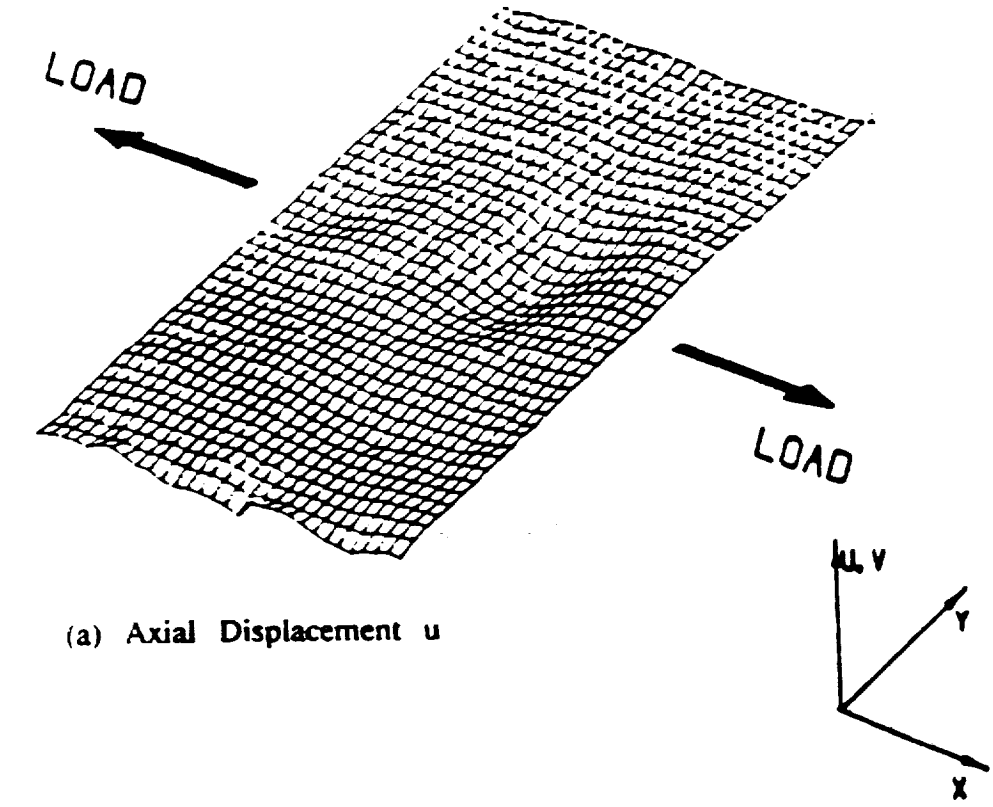
C is 1/2 notch length

1 ~ 256 pixels ⟶ 40 pixels ~ 0.156 in
IN.

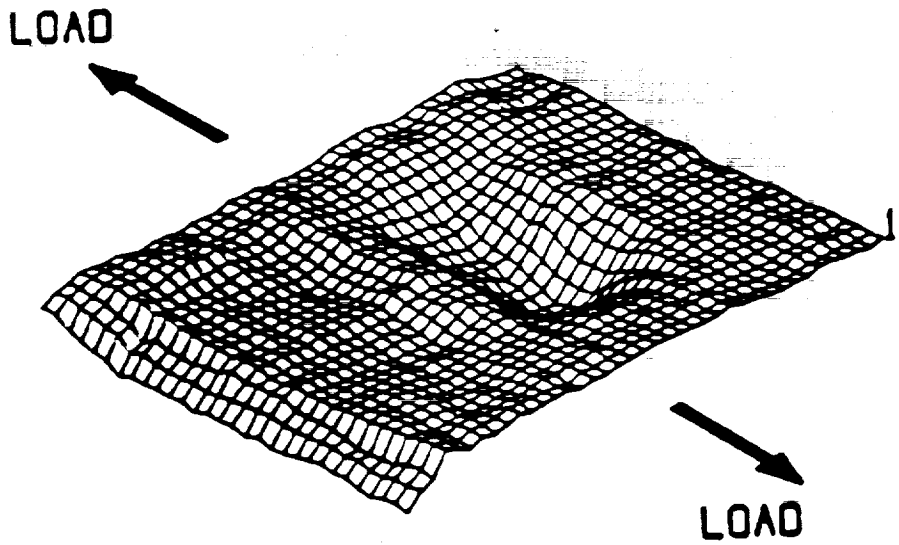
So critical distance is appropriate.
However, damage is generally complex stress-strain state!

Test Case: Cross-Ply Gl-Epoxy Scotchply Coupons

Damage: Inclusion
Slit Fibers
Impact Damage



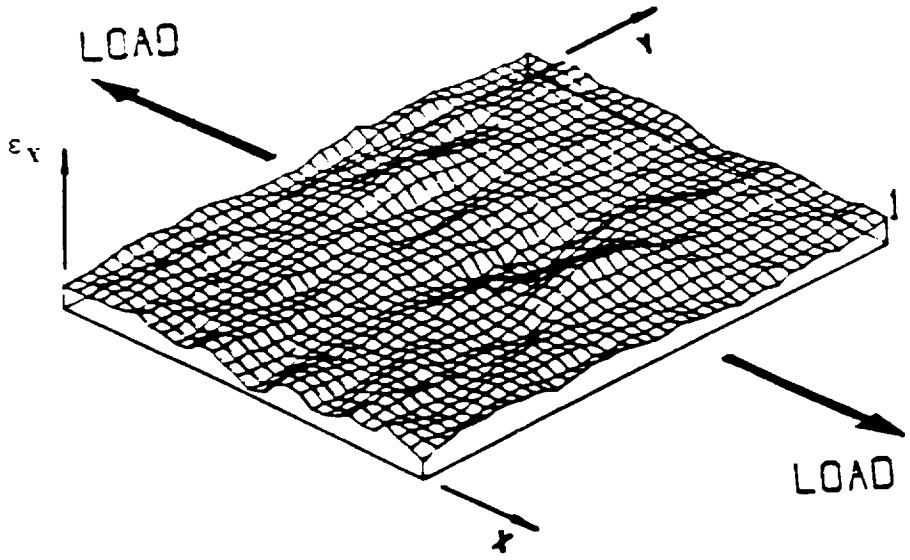
(a) Axial Displacement u



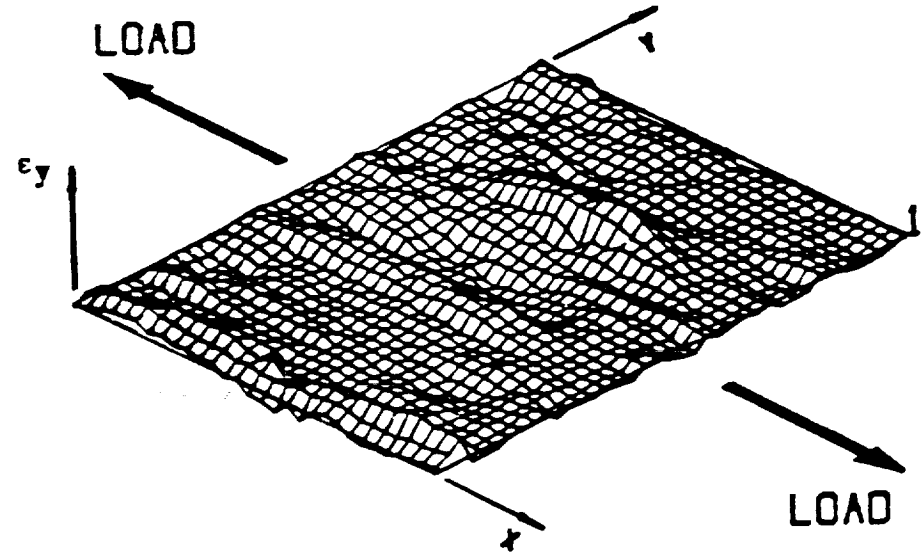
(b) Transverse Displacement v

FIGURE 6. DISPLACEMENTS FOR MYLAR INCLUSION.

$[0, 90_4, Q]^{\circ}$ $\epsilon_x = 0.33\%$



(a) Axial Strain ε_x



(b) Transverse Strain ε_y

FIGURE 7. STRAINS FOR MYLAR INCLUSION.

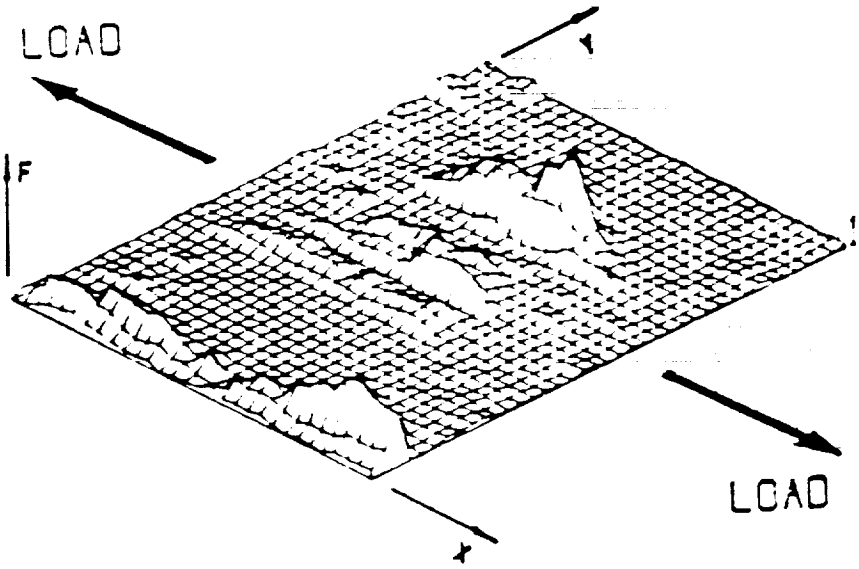
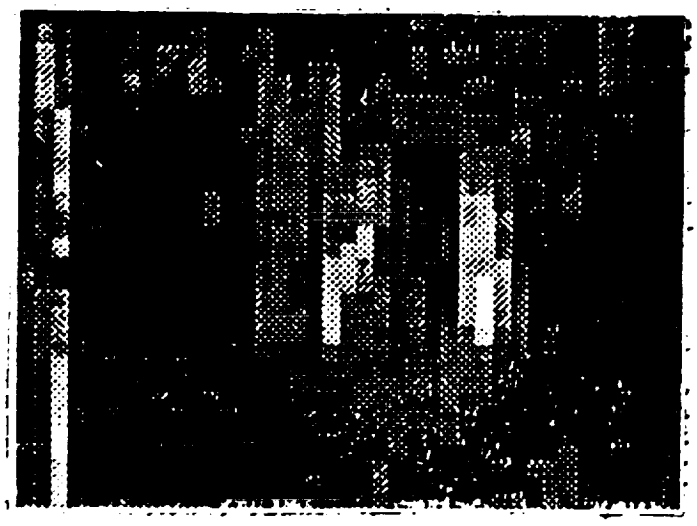


FIGURE 8. FAILURE FUNCTION (F) FOR MYLAR INCLUSION.



E 9. GREY LEVEL FAILURE FUNCTION (F) FOR MYLAR INCLUSI
BLACK TO WHITE SIGNIFIES INCREASING VALUES OF F.

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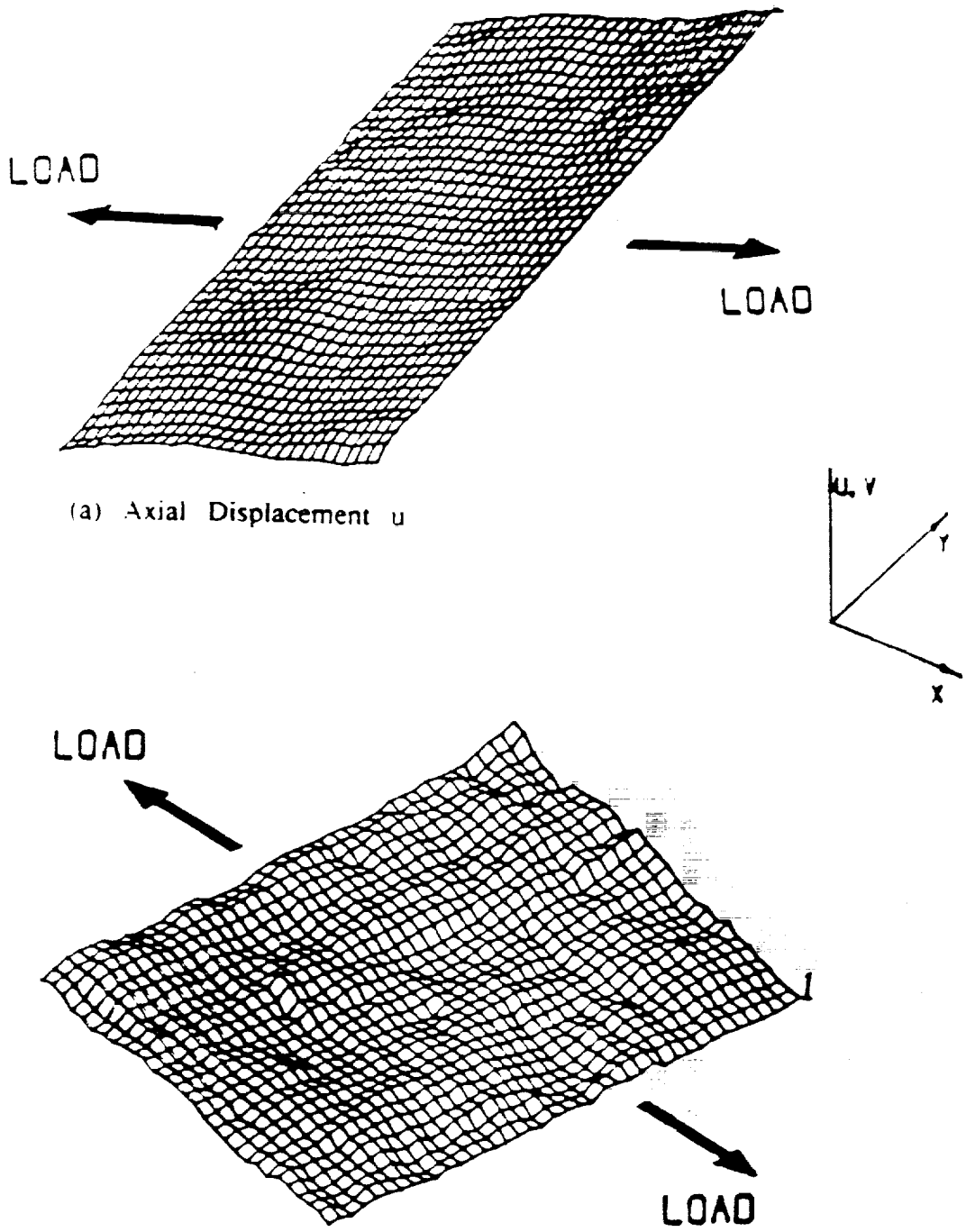
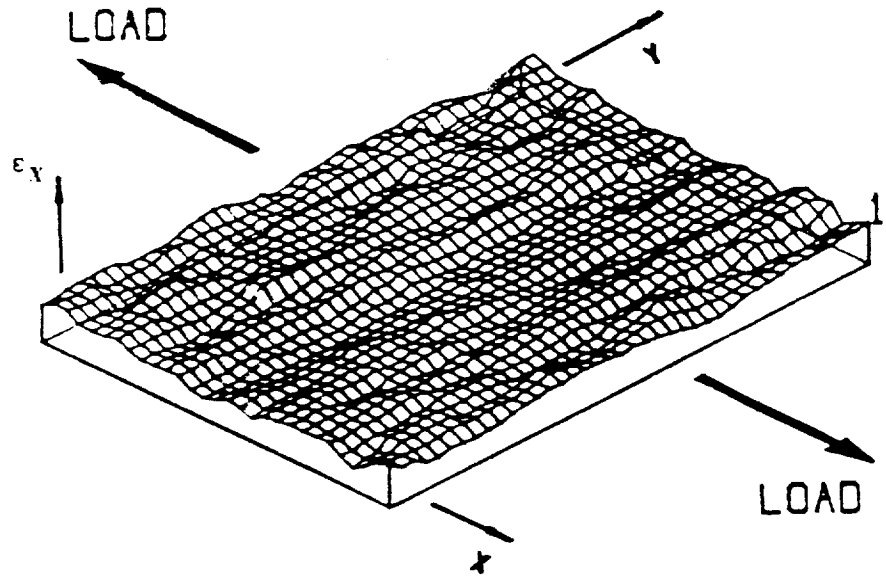


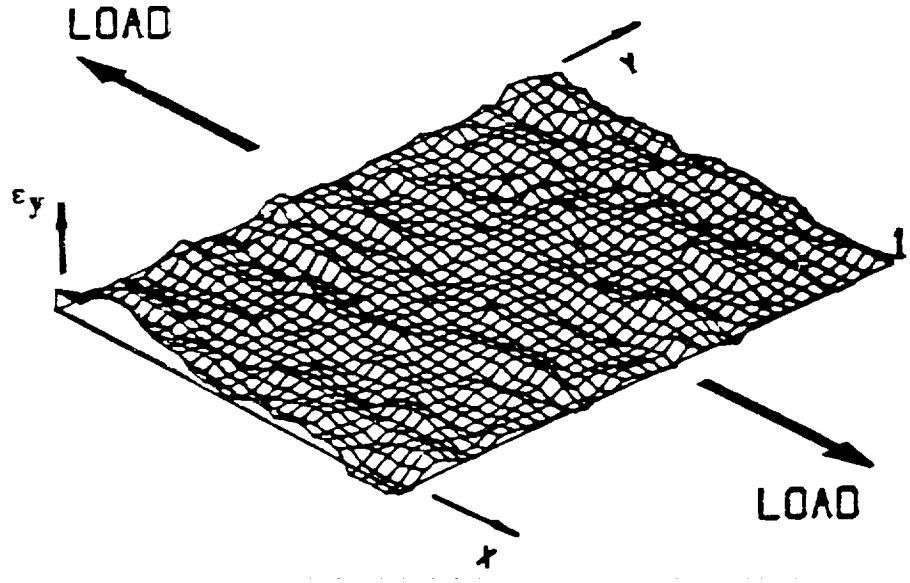
(a) Axial Displacement u

(b) Transverse Displacement v

FIGURE 11. DISPLACEMENTS AWAY FROM THE INCLUSION.



(a) Axial Strain ε_x



(b) Transverse Strain ε_y

FIGURE 12. STRAINS AWAY FROM THE INCLUSION.

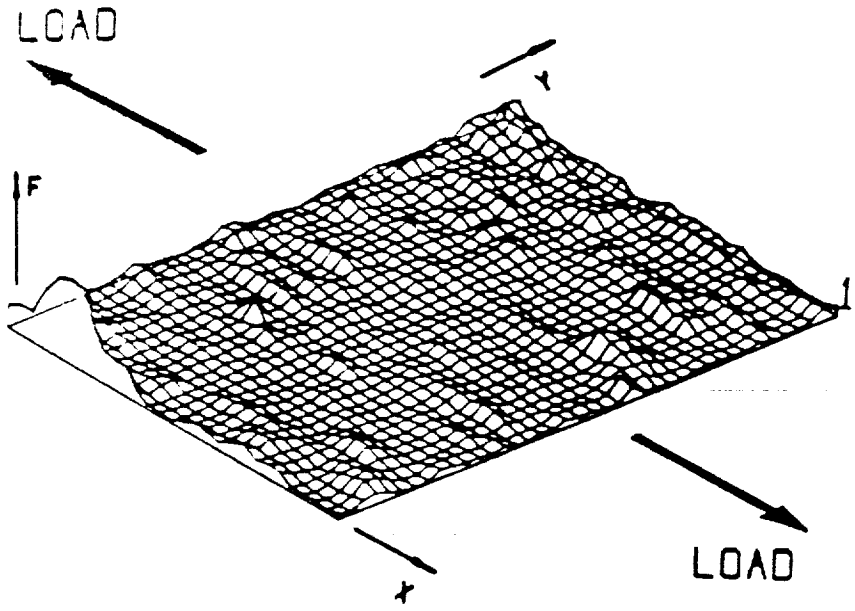


FIGURE 13. FAILURE FUNCTION (F) FIELDS AWAY FROM THE INCLUSION.

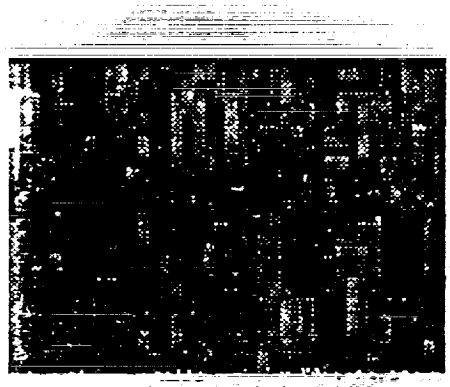
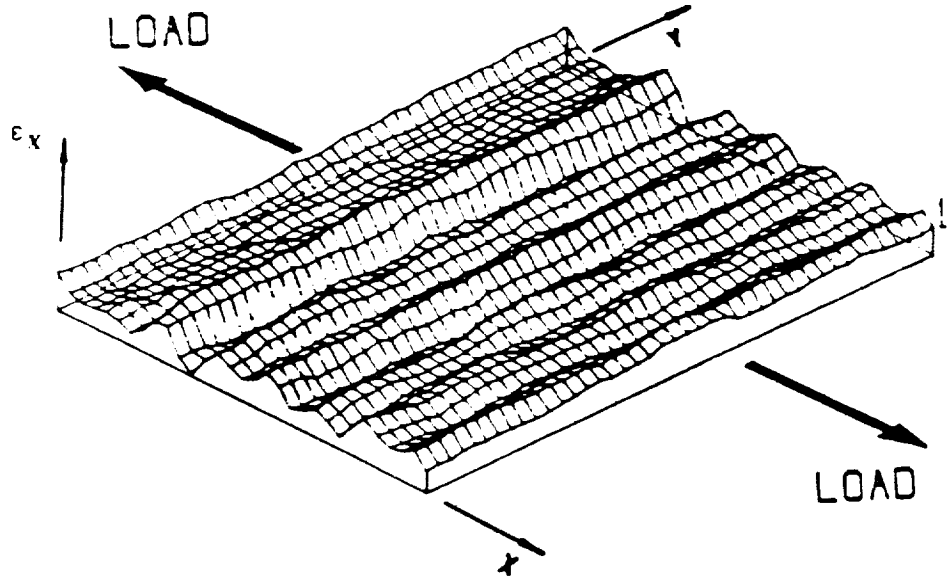
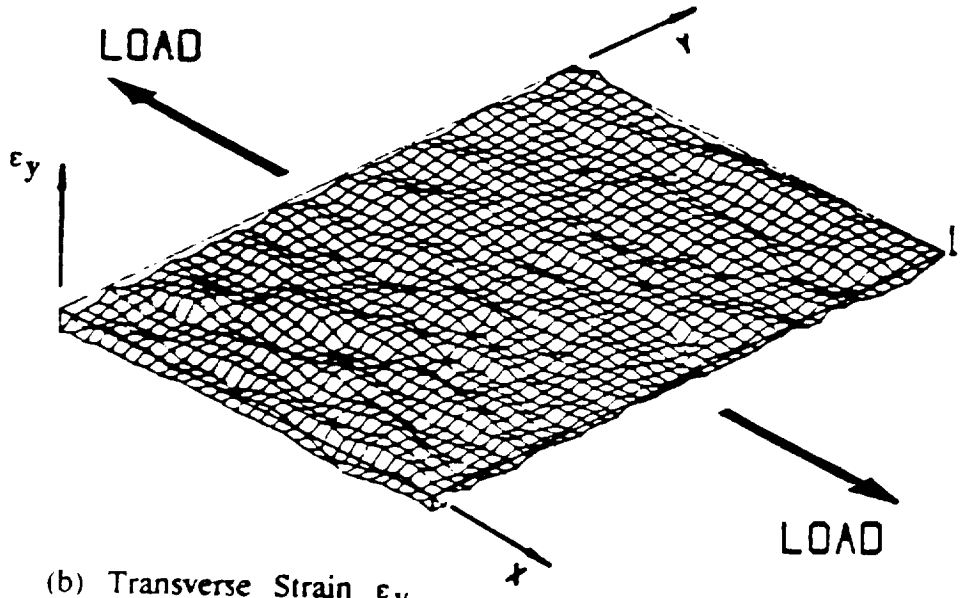


FIGURE 14. GREY SCALED FAILURE FUNCTION FIELD AWAY FROM THE INCLUSION.



(a) Axial Strain ε_x



(b) Transverse Strain ε_y

FIGURE 16. STRAINS FOR SPECIMEN WITH SLIT THROUGH BACK 0° PLY.

$\epsilon_x = 0,47\%$ $[0_2 90_3 0_2]$

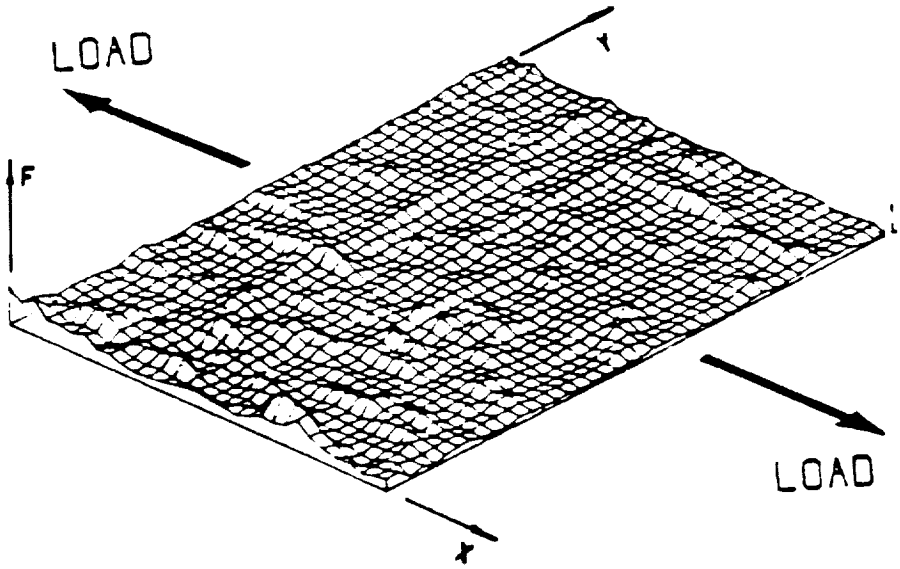


FIGURE 17. FAILURE FUNCTION (F) FOR SPECIMEN WITH SLIT THROUGH BACK 0° PLY.

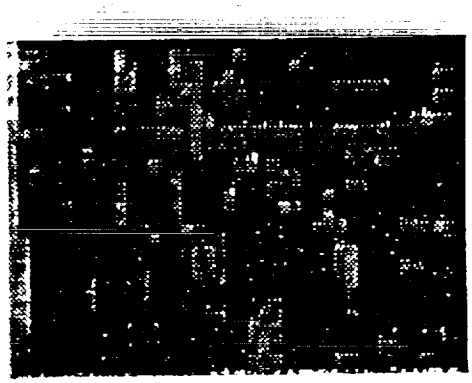


FIGURE 18. GREY LEVEL PRESENTATION OF FAILURE FUNCTION FOR SPECIMEN WITH SLIT THROUGH BACK 0° PLY.

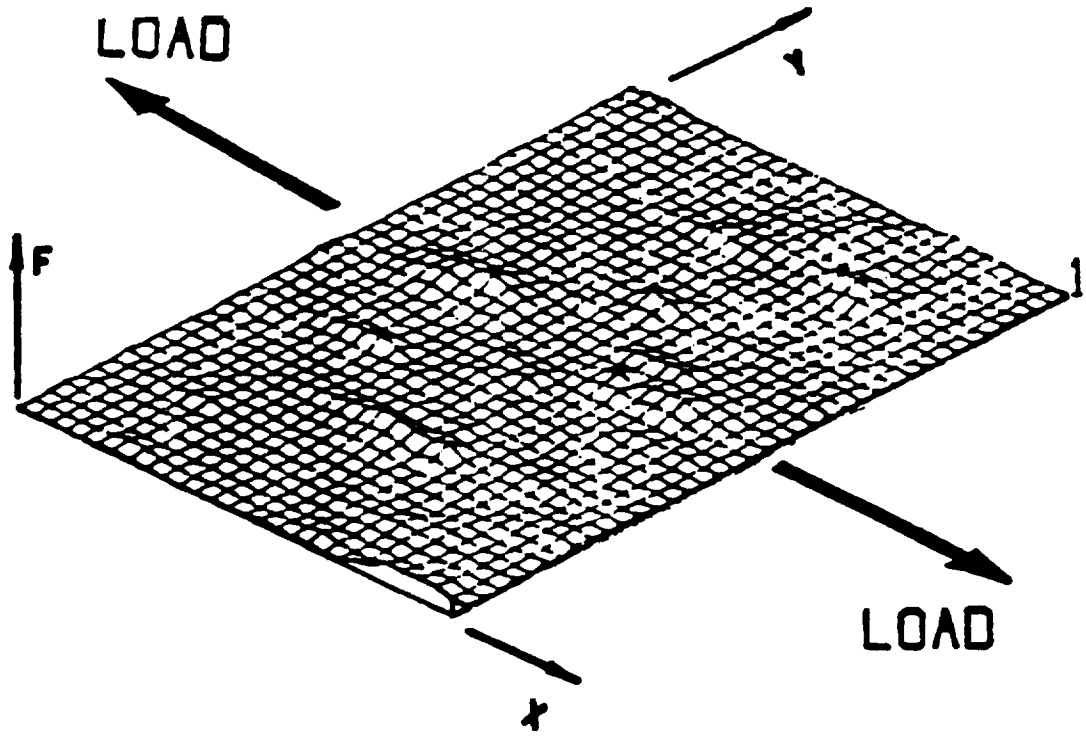


FIGURE 21. FAILURE FUNCTION (F) AT IMPACT DAMAGED ZONE.

$[0°, 90°_3, 0°]$

$\epsilon_x = .267\%$

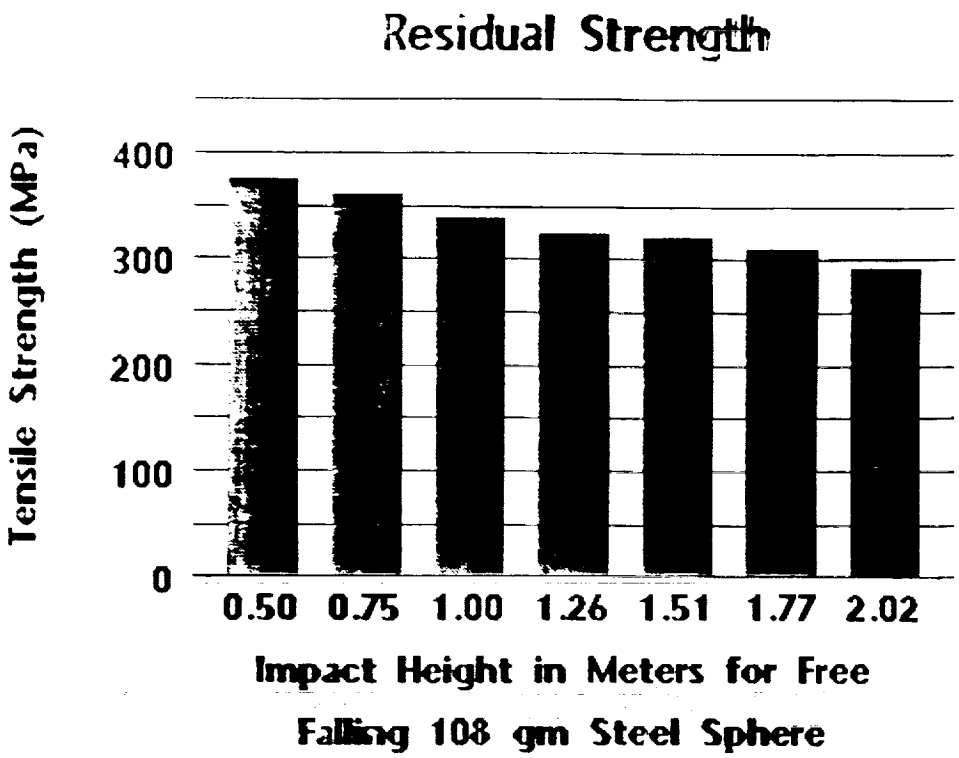


FIGURE 22. STRENGTH OF IMPACTED [0°, 90°$_3$, 0°] SPECIMENS

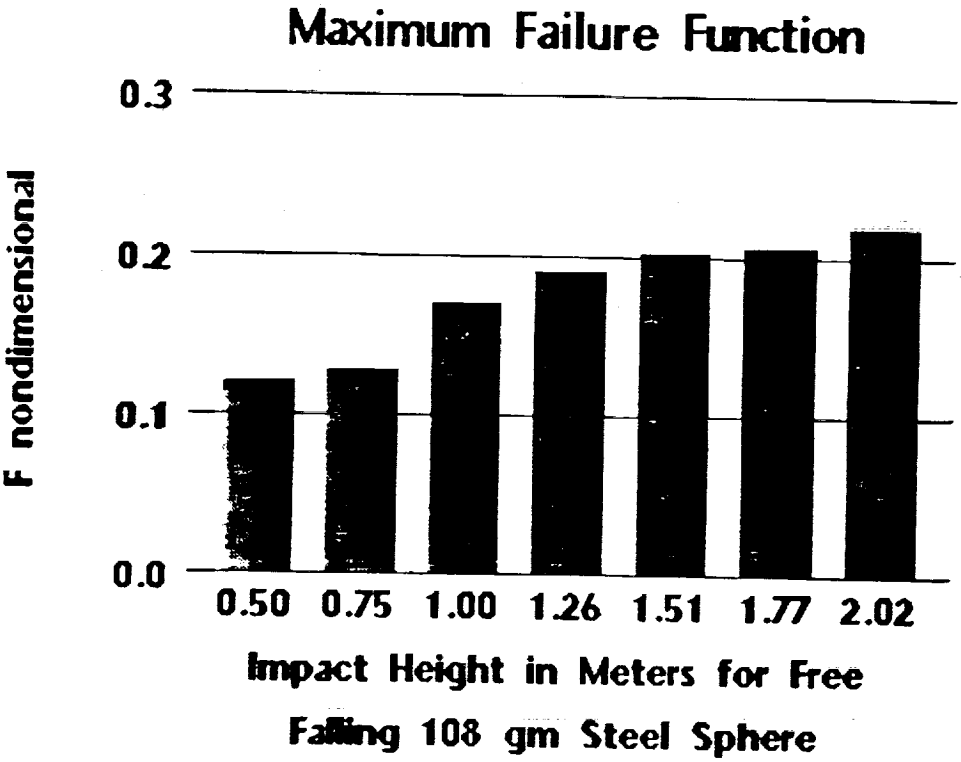
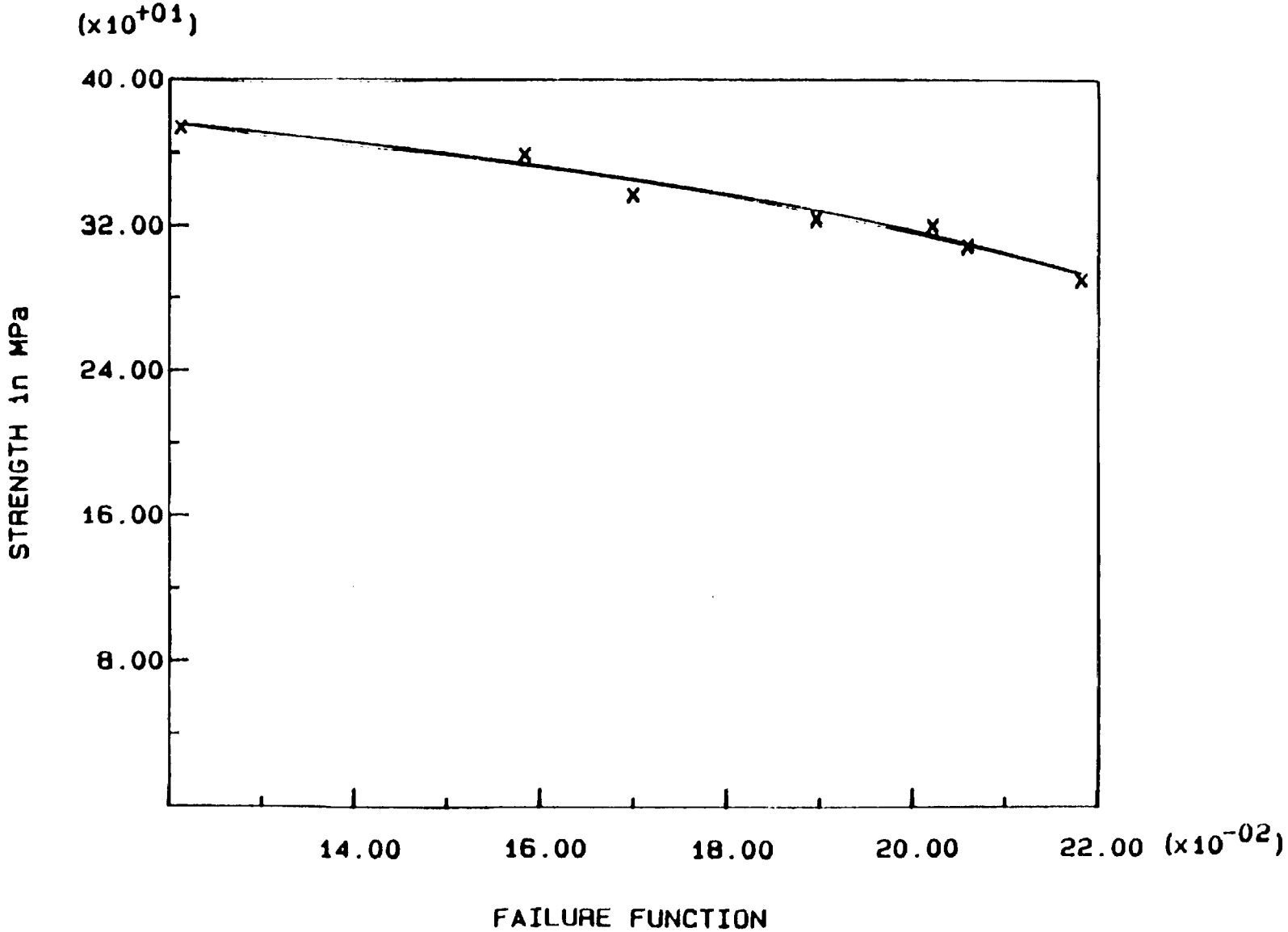


FIGURE 23. MAXIMUM FAILURE FUNCTION (F) FOR IMPACTED [0°, 90°$_3$, 0°] SPECIMENS.


(x10+01)
40.00
32.00
24.00
16.00
8.00
STRENGTH in MPa
14.00
16.00
18.00
20.00
22.00 (x10-02)
FAILURE FUNCTION

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