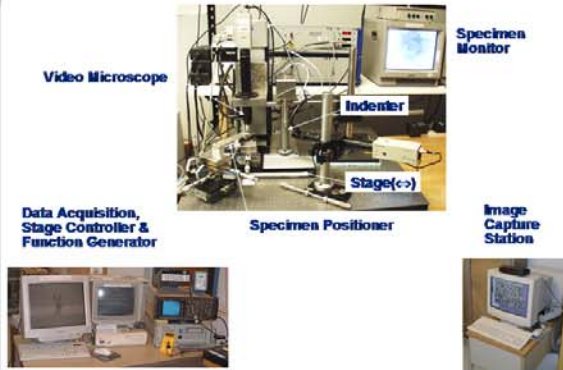


THE INTERPHASE CHARACTERIZATION PROCESS USING THE DYNAMIC INTERPHASE LOADING APPARATUS

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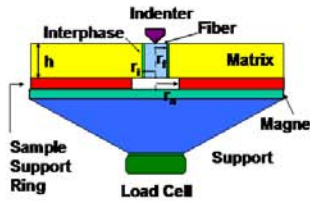
DYNAMIC INTERPHASE LOADING APPARATUS



ACKNOWLEDGEMENTS

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LOAD CELL ASSEMBLY

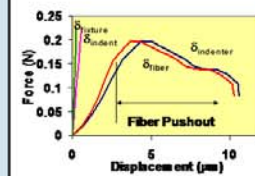


Typical Dimensions

- Sample thickness, $h \approx 100 \mu\text{m}$
- Fiber radius, $r_f = 4 \mu\text{m}$
- Annulus radius, $r_a = 17 \mu\text{m}$
- Displacement Rates
 - 100 – 50,000 $\mu\text{m}/\text{sec}$
- Measured Response
 - Force, displacement vs. rate
 - Calculated Interphase Properties vs. Rate
 - Strength
 - Debonding & Transitional Energy
 - Frictional Sliding Energy
 - Interphase Shear Stress/Strain

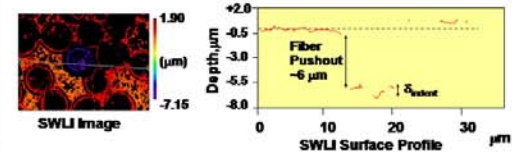
• The diamond tip is attached to the piezo actuator. The fast displacement capability of the piezo is used to load the interphase under high loading rates.

TYPICAL RESULTS

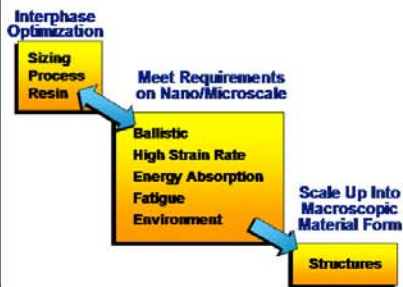


- δ_{indenter} – Transducer Displacement Sensor Output
- δ_{fixture} – Fixture Compliance
- δ_{indent} – Indent Depth
- δ_{fiber} – Actual Displacement of Fiber

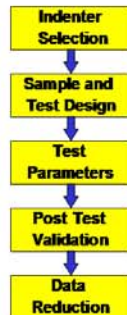
$$\delta_{\text{fiber}} = \delta_{\text{indenter}} - \delta_{\text{fixture}} - \delta_{\text{indent}}$$



VISION FOR INTERPHASE DESIGN

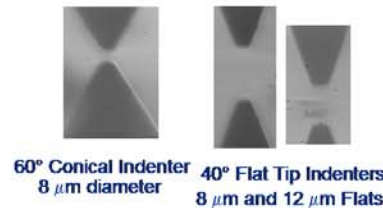


INTERPHASE CHARACTERIZATION PROCESS



INDENTER SELECTION

- $r_{\text{indenter}} < r_{\text{fiber}}$
- Minimize Contact Stresses
- Maximize Pushout

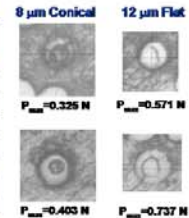


INDENTER SELECTION

• Use selected indenter to determine maximum load (P_{crack}) prior to fiber cracking

Maximum Pushout

Fiber Dia.	12 μm 40° Flat	8 μm 60° Conical
15	4.1	9.0
16	5.5	9.9
17	6.9	10.7
18	8.2	11.6
19	11.0	12.5
20	12.4	13.3
21	13.7	14.2

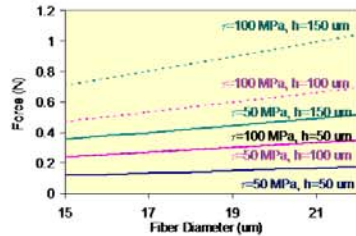


$P_{\text{crack}} = 0.3 \text{ N}$ $P_{\text{crack}} = 0.6 \text{ N}$

SAMPLE AND TEST DESIGN

Sample Thickness and Support Radius

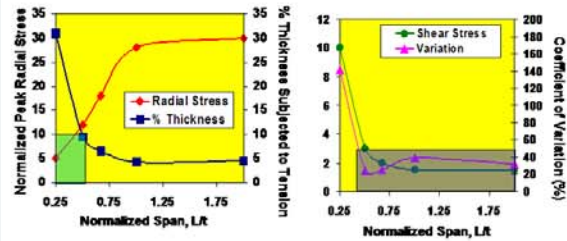
- Minimize radial stresses
- Uniform shear stress
- $P_{max} < P_{crack}$



$$\text{Pushout Force} = \text{Average Shear Strength} \cdot \pi \cdot \text{thickness} \cdot \text{fiber diameter}$$

INTERPHASE SHEAR AND RADIAL STRESSES

For glass fiber reinforced vinyl ester system



- ♦ Optimum Span Length criteria - less than 10% of specimen thickness under radial tension and a uniform shear stress along the interface.

Optimum Lt 0.45-0.55
For t = 150 μm
L = 65-85 μm

TEST PARAMETERS

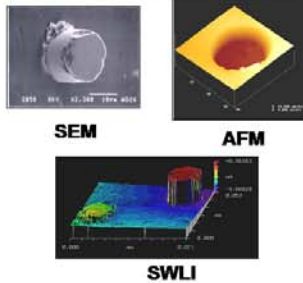
- Input signal parameters- maximum displacement, time, shape
- Sample collection parameters - sample rate, number of samples

Examples of Input Signals



POST TEST VALIDATION

- ♦ Techniques used to characterize pushouts
 - ♦ Atomic Force (AFM)
 - ♦ Scanning Electron Microscopy (SEM)
 - ♦ Scanning White Light Interferometry (SWLI)



DATA REDUCTION

Shear Strain & Modulus

$$\gamma_i = \frac{w \left(\frac{F/w}{2\pi h G_m} \ln \frac{r}{r_m} - 1 \right)}{r \ln \frac{r}{r_f}}$$

$$G_i = \frac{(F/w) a \coth(ah) \ln \frac{r}{r_f} (1 + B_1)}{2\pi}$$

where

$$B_1 = \frac{G_i}{G_m} \frac{\ln \frac{r_m}{r_f}}{\ln \frac{r}{r_f}}$$

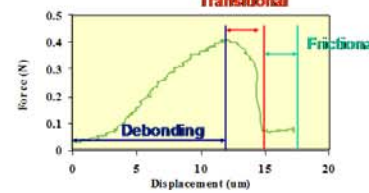
$$a^2 = \frac{2G_i}{E_f \eta^2 \ln \frac{r}{r_f} (1 + B_1)}$$

Average Shear Strength

$$\tau_{max} = \frac{F_u}{2\pi h r_f}$$

DATA REDUCTION

Specific Absorbed Energies



$$E_{a,deb} = \frac{\int_{\delta_f=0}^{\delta_f,deb} F d\delta_f}{A_1}$$

$$E_{a,tr} = \frac{\int_{\delta_f,deb}^{\delta_f,tr} F d\delta_f}{A_1}$$

$$E_{a,func} = \frac{\int_{\delta_f,tr}^{\delta_f,func} F d\delta_f}{A_1}$$

$$A_1 = 2\pi r_f h$$

CONCLUSIONS

- ♦ Development of interphase characterization process including the DILA apparatus and data reduction scheme allows one to determine the interphase modulus, strength, and energy absorbing properties over a wide range of loading rates.
- ♦ Indenter geometry has a large effect on contact stresses with a flat tip generating lower stresses than a conical tip.
- ♦ Need to test isolated fibers for interphase strength measurements to avoid stress concentrations of nearest neighbors
- ♦ Initial fatigue study confirmed feasibility of performing cyclic loading with the DILA.