Assessing the Quality of Bonded Joints

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Outline

- Bonded Joint Quality Assessment
- Shockwave Method of Bond Strength Measurement
- Laser Bond Inspection (LBI) Development
- Laser Bond Inspection Device Application

Bondline Quality Issues

Joint strength is dependent on:

- **Quality/chemistry of the adhesive and adherends**
- **Surface preparation of the adherends**
- **Application of the adhesive**
- **Cleanliness of the operation**
- **Time and temperature control**
- **Handling/pressure application**

Failure to control all elements above runs the risk of a weak joint.

Bondline Quality Issues

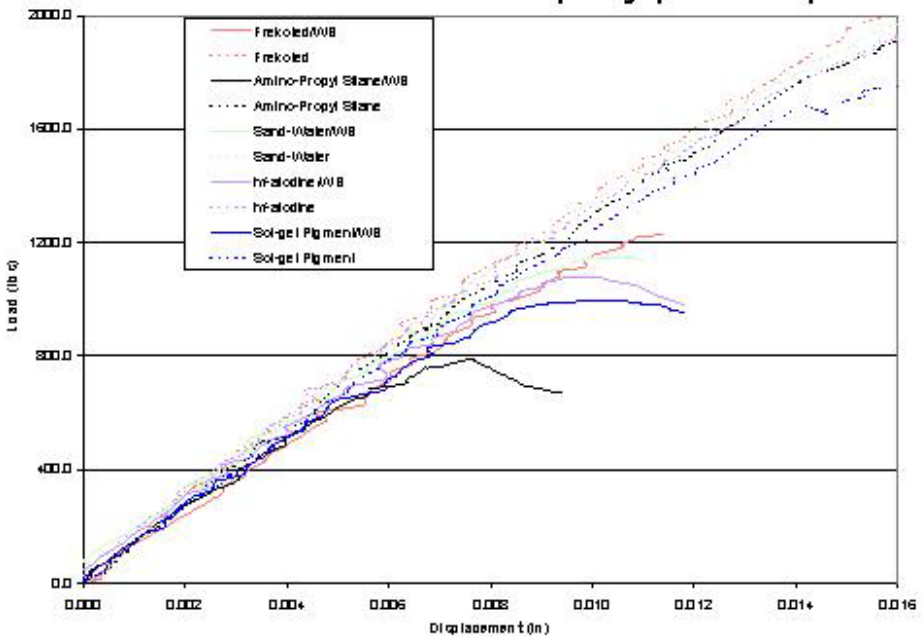
Joint strength is dependent on:

- **Quality/chemistry of the adhesive and adherends**
- **Surface preparation of the adherends**
- **Application of the adhesive**
- **Cleanliness of the operation**
- **Time and temperature control**
- **Handling/pressure application**

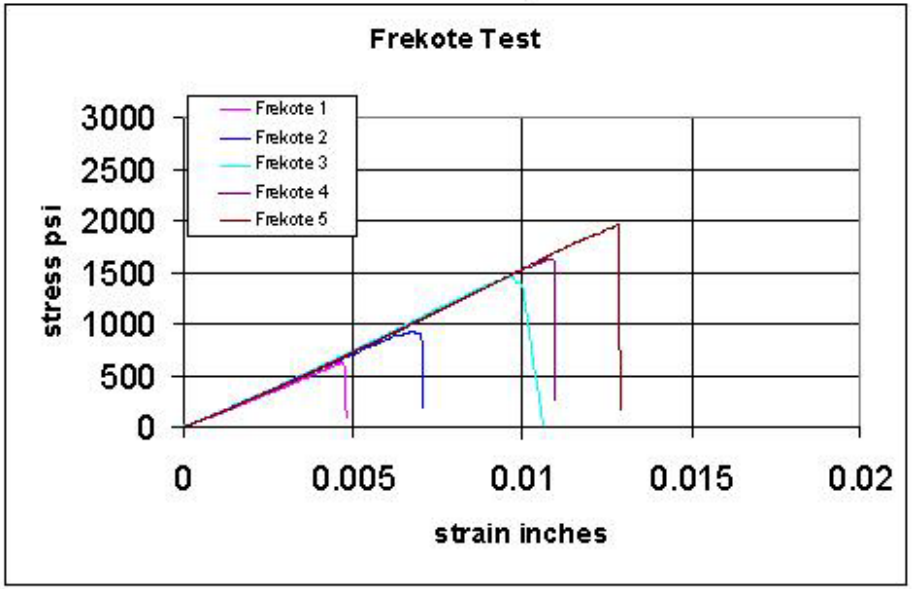
A nondestructive method to validate the bond strength after assembly and cure would be best.

Lap Shear Bondline Strength as a Function of Surface Preparation/Contamination

Film adhesive boron epoxy patch repair



Paste adhesive composite bonds



Bond strength variation does not significantly affect the elastic portion of the load displacement (stress vs strain) curve. Therefore strength of the bond will not be indicated by a nondestructive method.

Bondline Strength NDE Conclusion

Simple NDE is not able to measure bondline strength directly.

Bonds tested in this program do not show a significant variation in the elastic portion of the load vs displacement curve as a function of strength.

- NDE techniques can measure parameters or features such a void fraction, wave speed, bulk modulus, thickness, etc, - but not strength.

Mechanical proof testing is the only direct measurement joint strength.

But, low strain testing of bonds using shock waves could also be used as a localized proof test of the bondline.

Shockwave method of bond strength measurement

Bond Strength Measurement

- CAI studies with shock waves, have shown that stress waves (low strain) can generate a tensile load at the bond to measure the bond strength at a localized test zone.

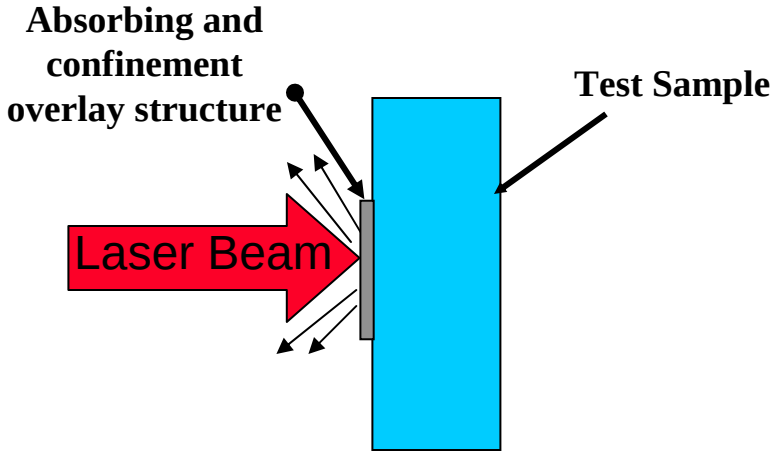
  - E-beam, mechanical impact and laser shock methods were tested.

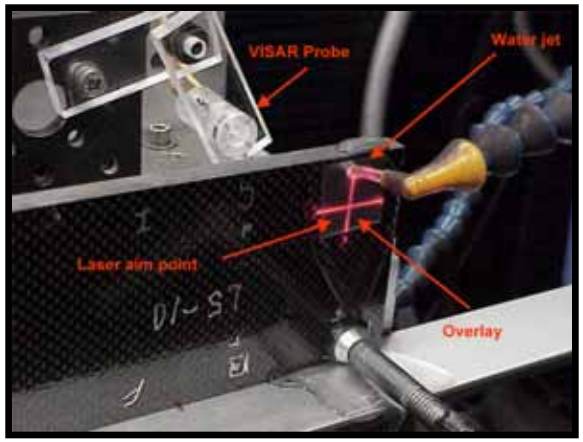
  - Test results show excellent sensitivity of the laser based dynamic strength measurement to variations in bond conditions including small changes in surface preparation, materials or contamination.

  - Apply as a process control tool.

  - Apply during manufacture or in-service as a weak bond detection system for product acceptance. (Localized proof test, nondestructive to strong bonds, destructive to weak bonds locally)

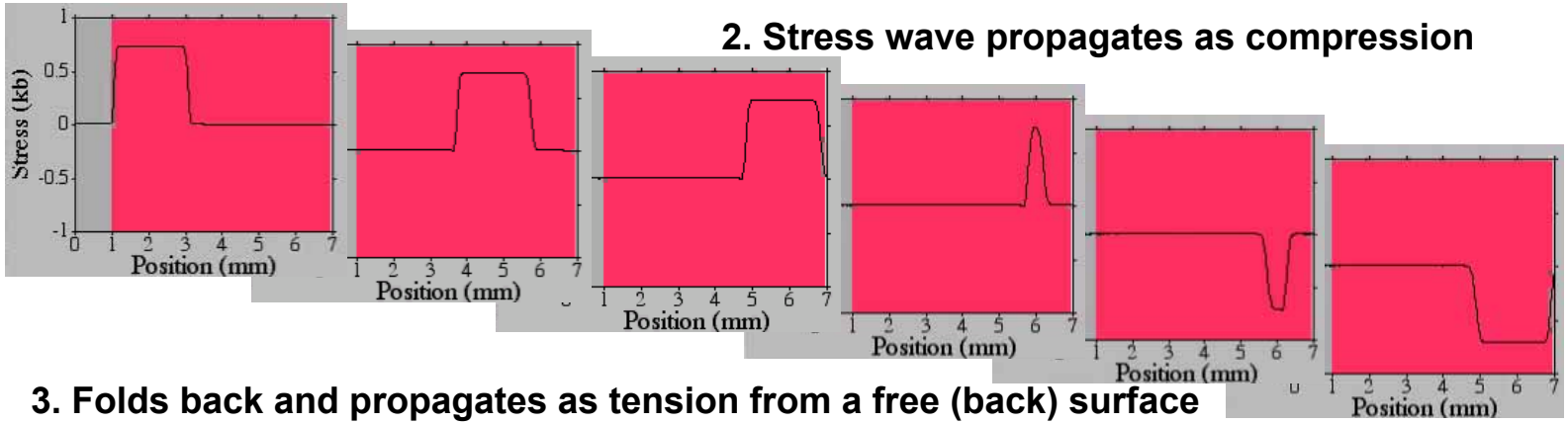
Pulsed Laser Method Injects Compressive Stress From One Surface





1. Laser produces pressure pulse in surface overlay structure

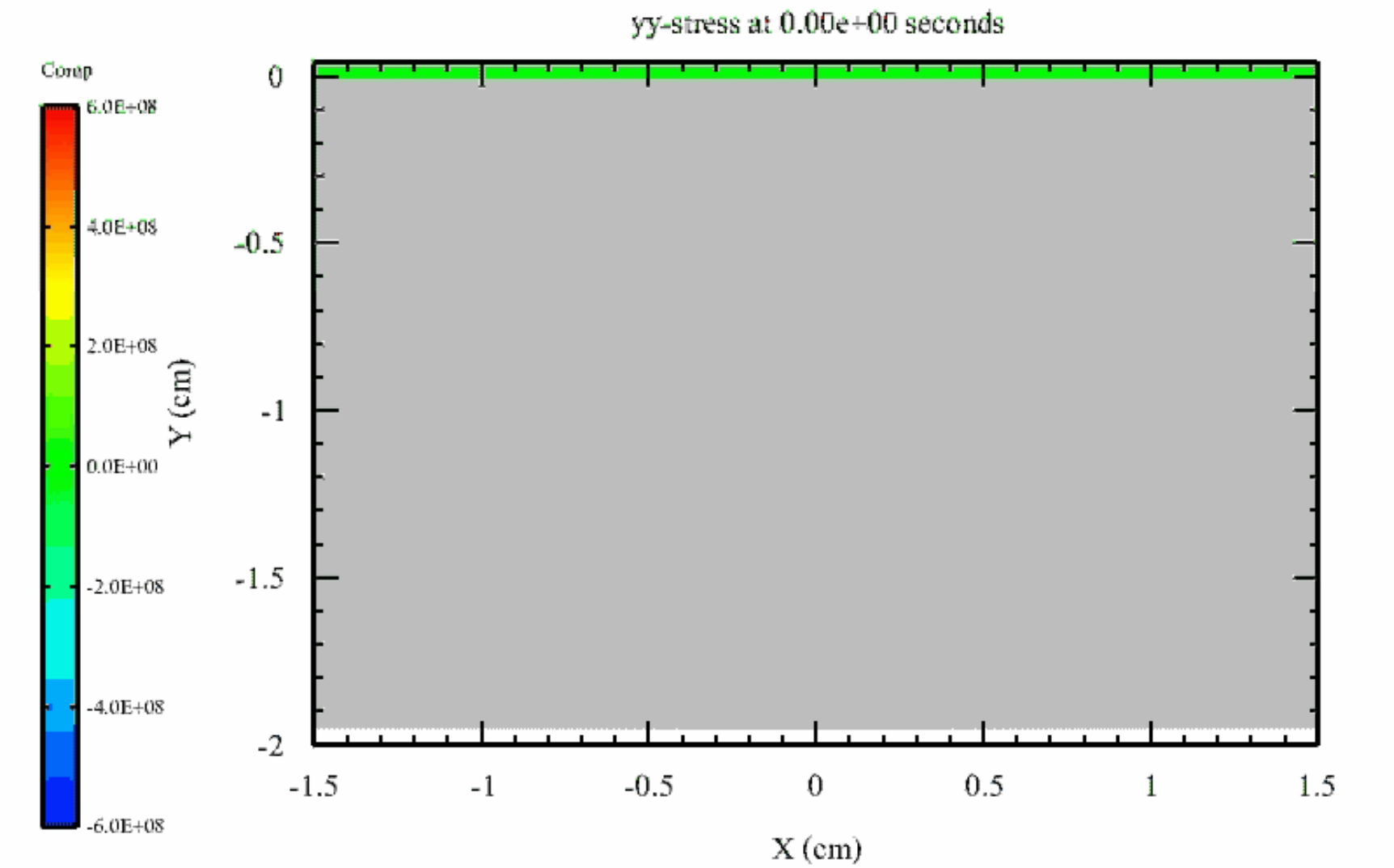
2. Stress wave propagates as compression



3. Folds back and propagates as tension from a free (back) surface

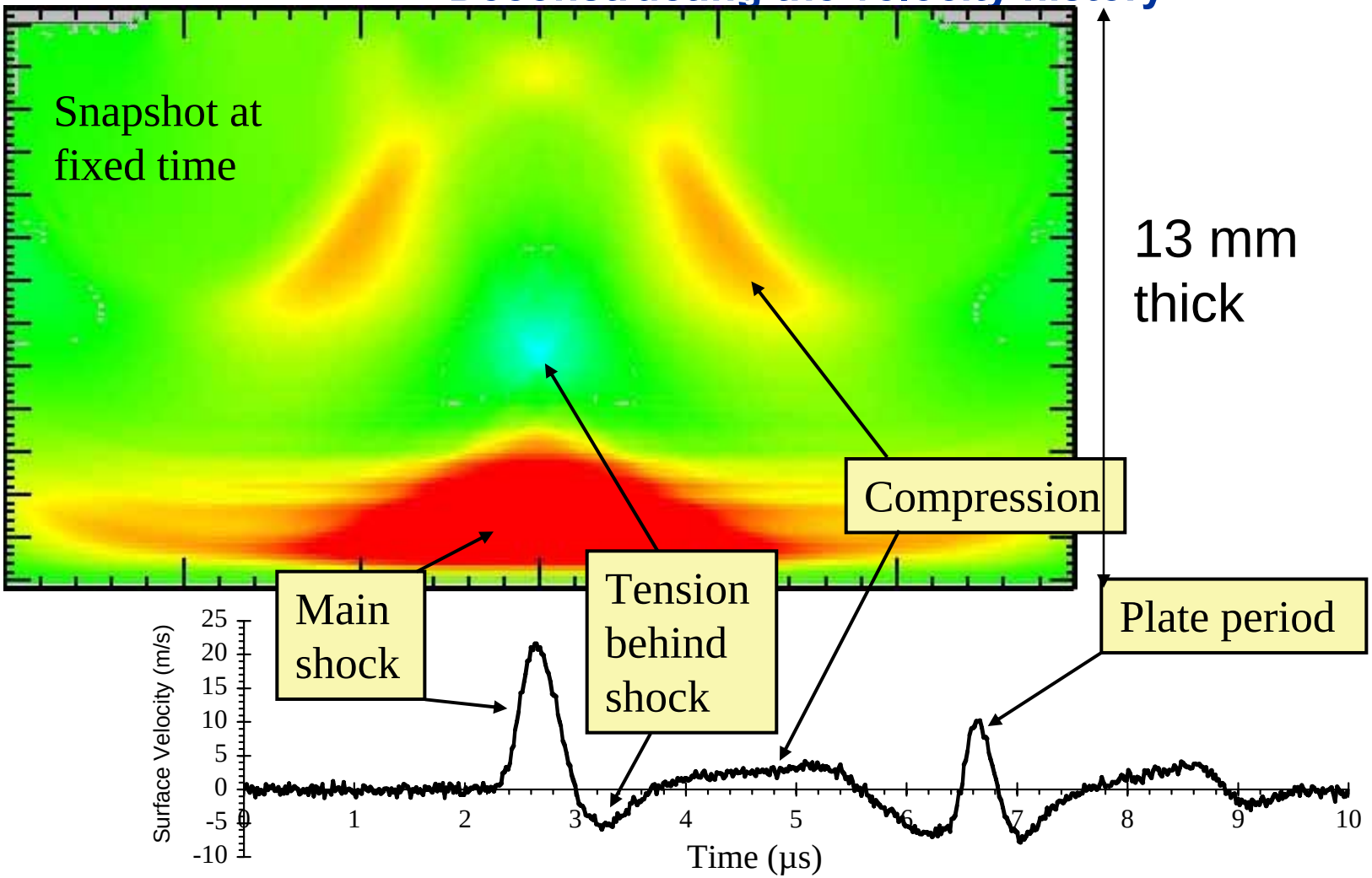
- Requires a high peak power, short pulse laser (i.e. 50 J in 100 to 300 ns)
- With a large diameter (1 cm +) beam

CTH Hydrodynamic 2D Code
Simulation of 19 mm Al Thick Specimen



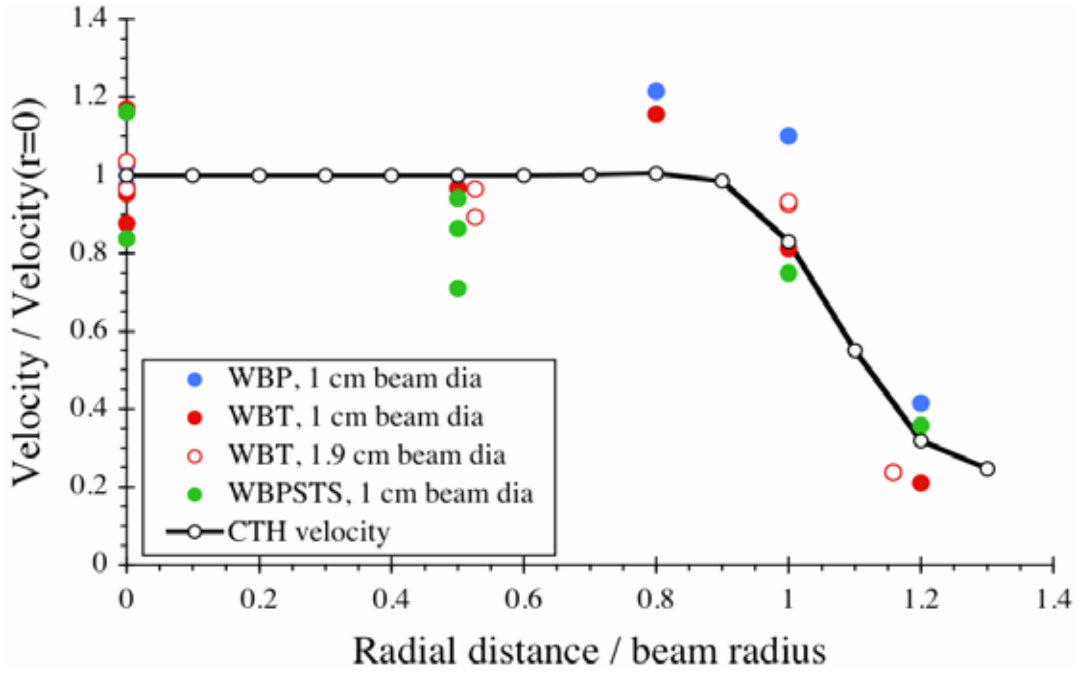
CTH Hydrodynamic 2D Code Simulation of Al Specimen

Deconstructing the velocity history



Important Points about LBI

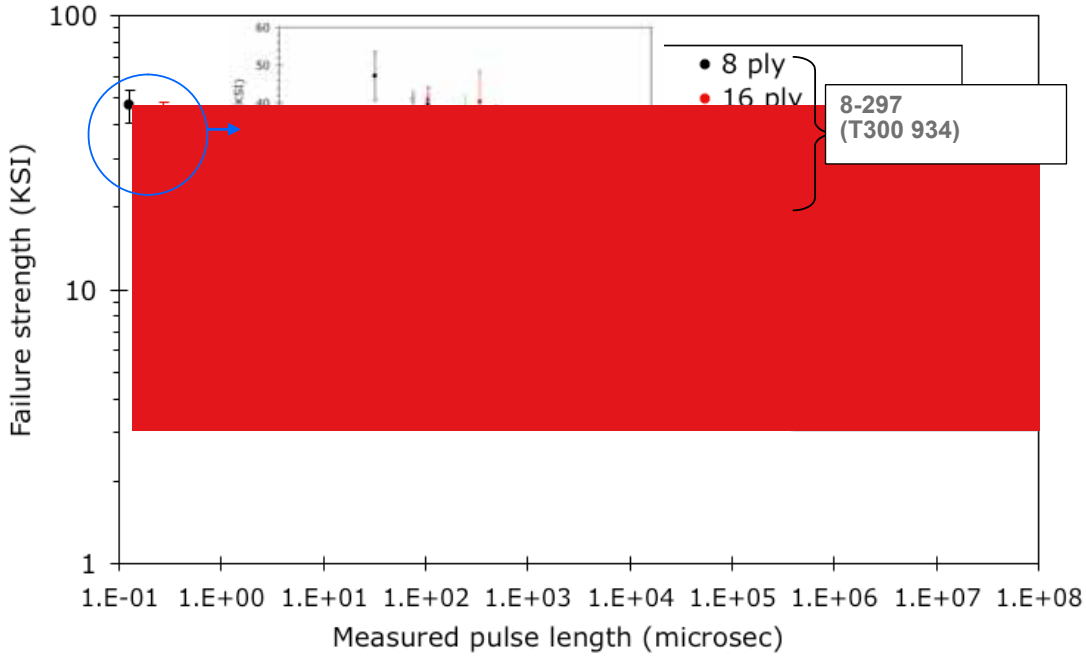
- Test zone is localized to the beam diameter.



- Beam size and pulse width make a difference on peak stress
  Diameter ≥ the object thickness evens the stress distribution, but it is not essential for testing.

Important Points about LBI

•**Pulse width – this is a dynamic test and dynamic strength is greater than static strength.**



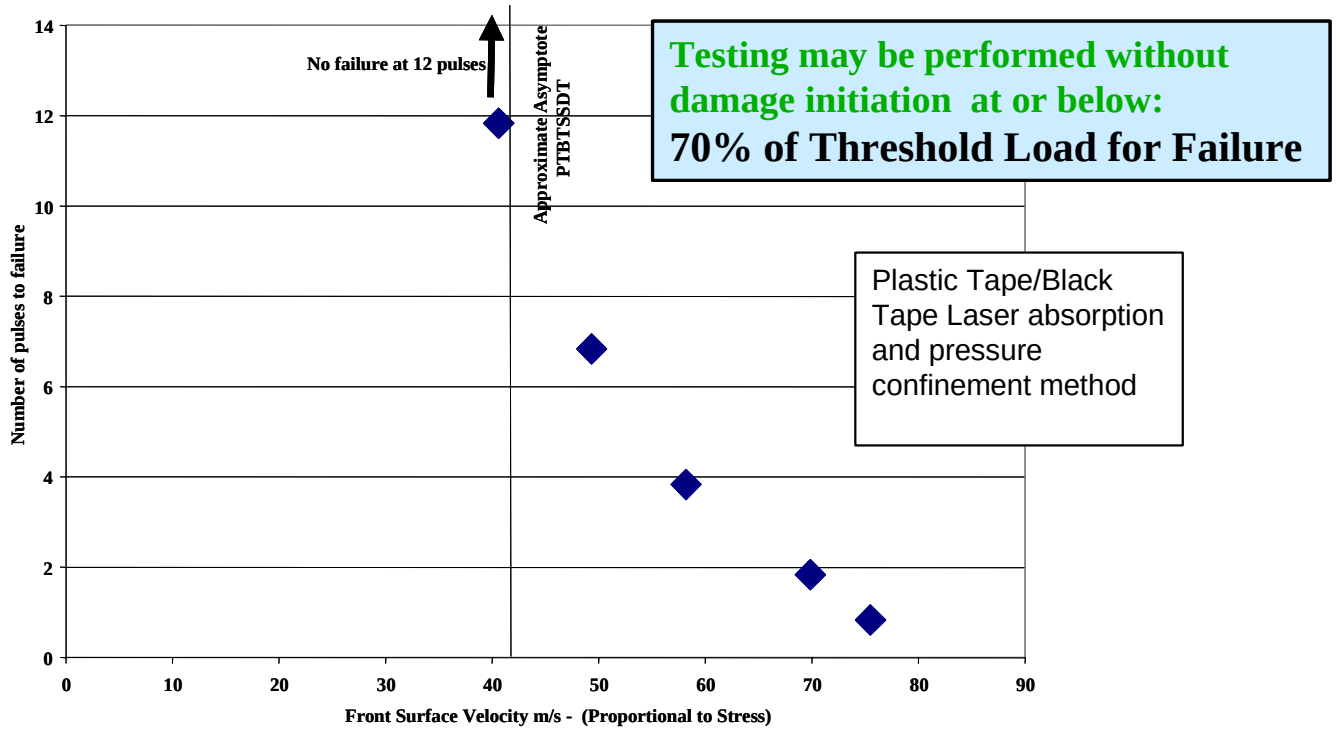
Important Points about LBI

- **Need a free back surface – there may be a thickness limitations due to beam attenuation.**

23 mm thick sample – 16 mm skin with 7 mm stringer flange

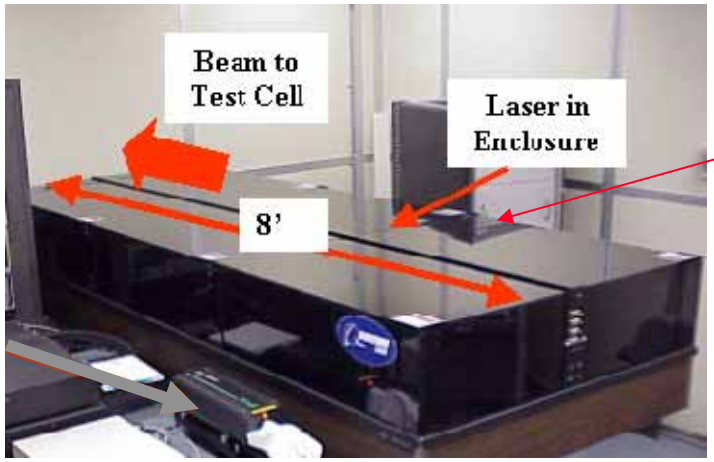
Important Points about LBI

- There is a fatigue type of effect
  - test at <70% of failure load.



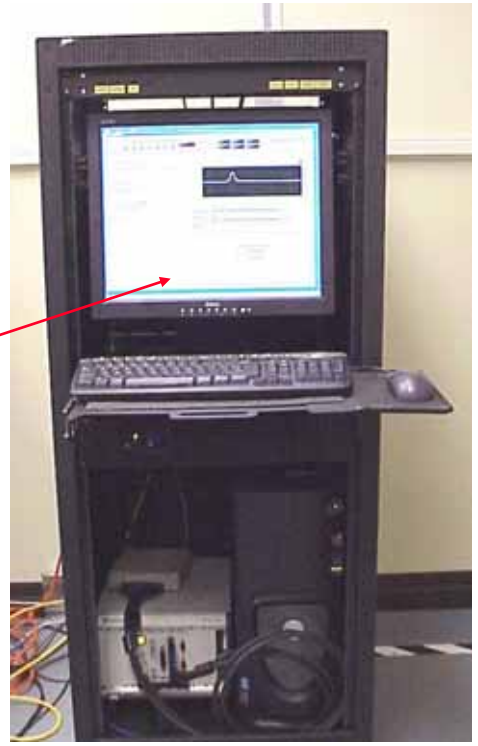
Laser Bond Inspection (LBI) Development

Laser Bond Inspection Laboratory Equipment

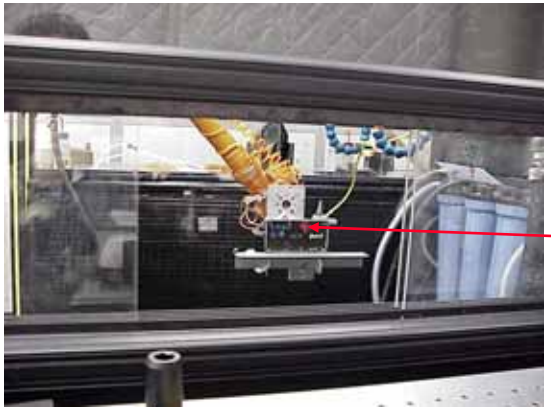


Pulsed Laser
- 1054 nm wavelength
- 100-300 ns pulse width
- energy up to 45 J

Laser Pulse Control and Data Acquisition & Reduction



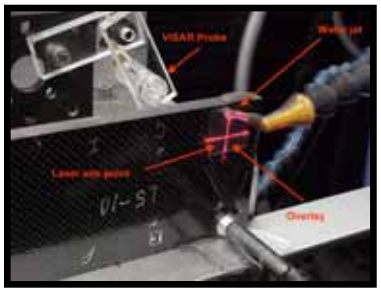
Optical Table

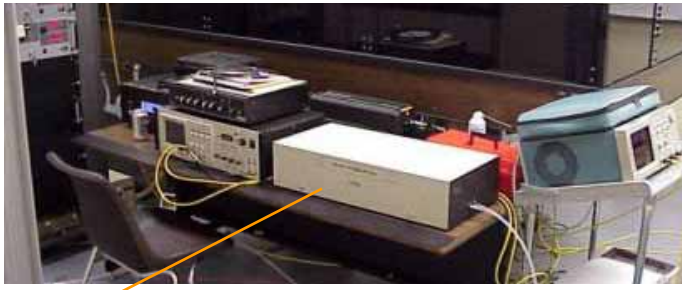


Laser Beam aimed at Test Object

Boeing Laser at LSP Technologies in Dublin, OH
Experiments performed by Craig Walters

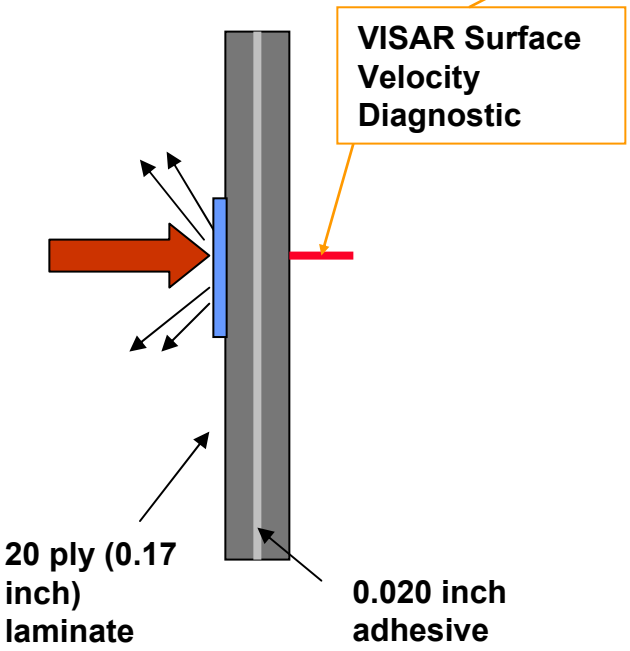
Velocity Measurement Calibrates Stress and Indicates Delamination

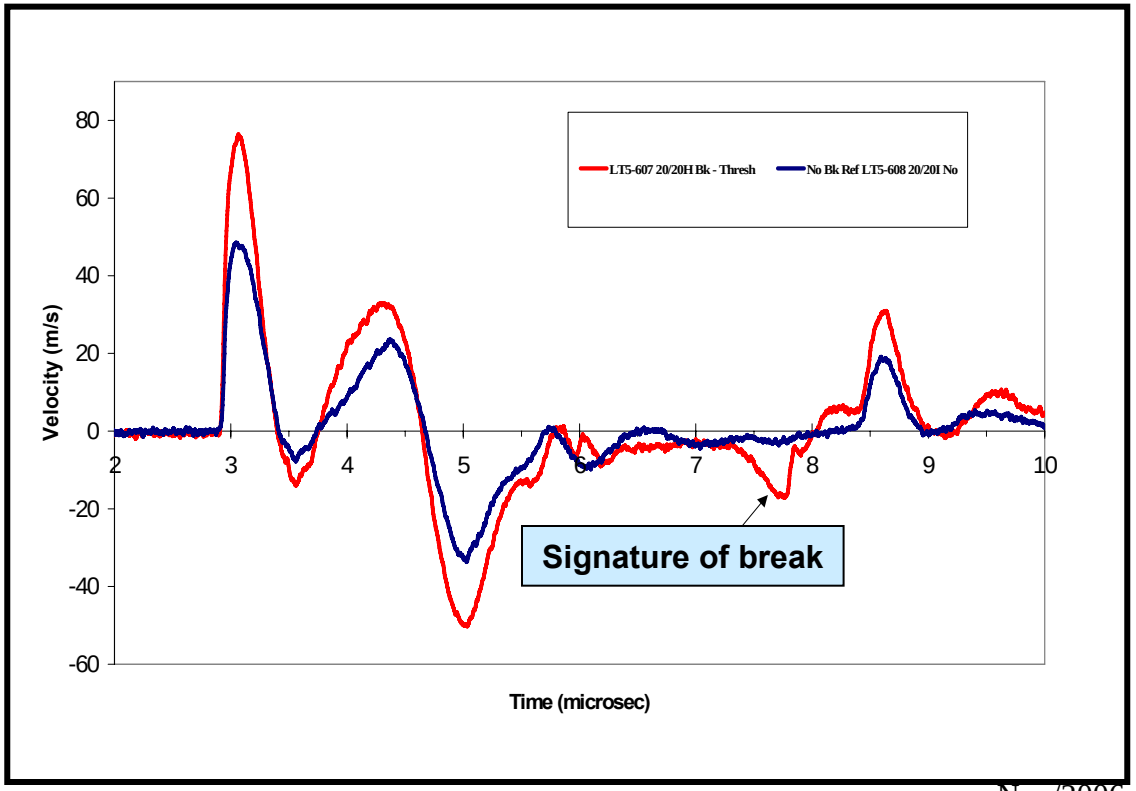




Bond failure is also detected by post test Ultrasonic NDI

Laser pulse tests





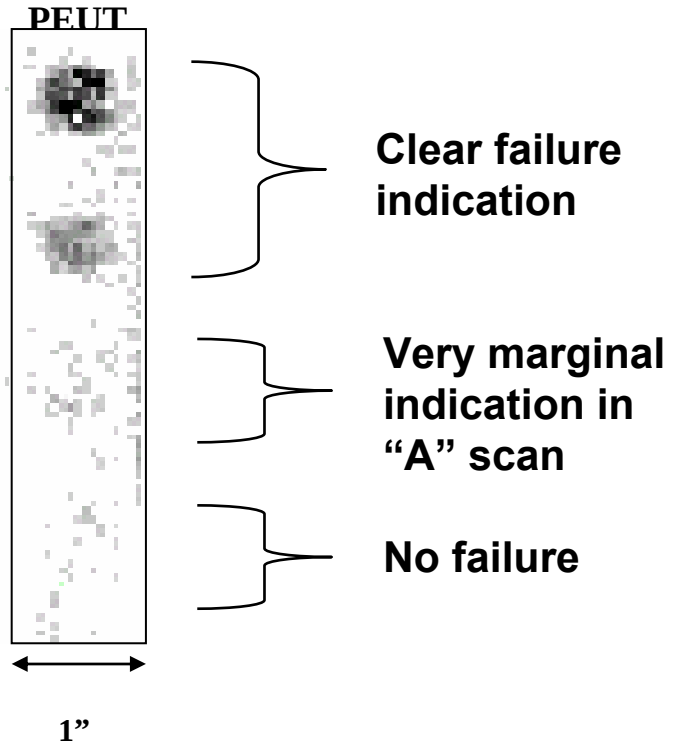
Ultrasound Measurement Indicates Post Test Condition

8-256 CN-16 As –tooled DCB specimen

1,179 ng/cm²

Red – LBID Detected Failure Fluence (J/cm2)

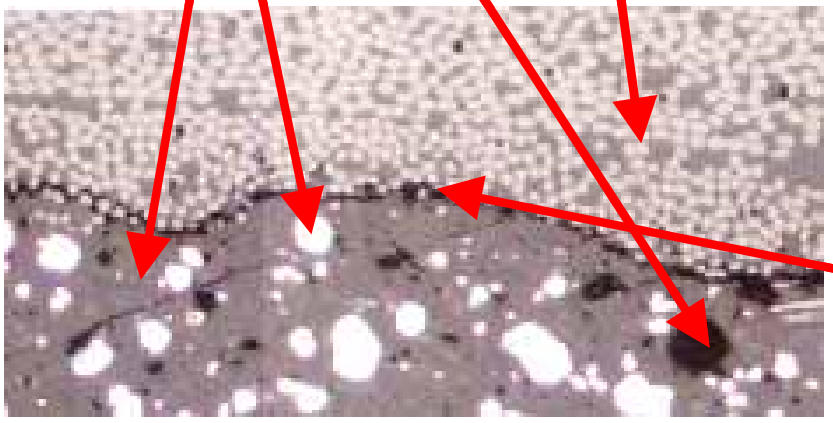
Black – no LBID indication



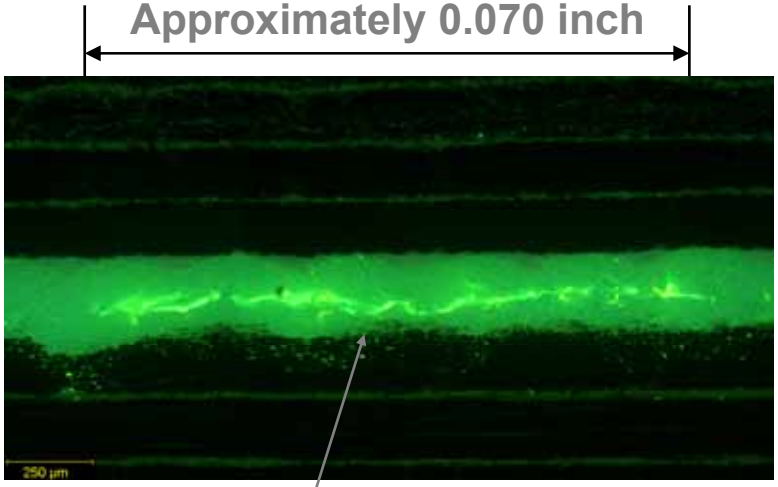
Laser Pulse Energy for Bond Failure in Weak and Strong Paste Adhesive

Weak EA 9394 Paste Adhesive Mix LT4-11D Weak

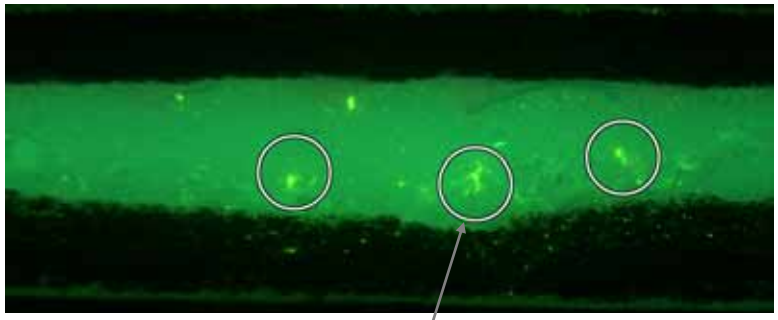
Strong EA 9394 Paste Adhesive Mix LT4-4B Standard



Micrograph of Film Bond LBID Inspection



Micrograph of LBI damage
- Hot film bond
- Full strength
- Easily detected by post test NDI
- Below rejectable defect size

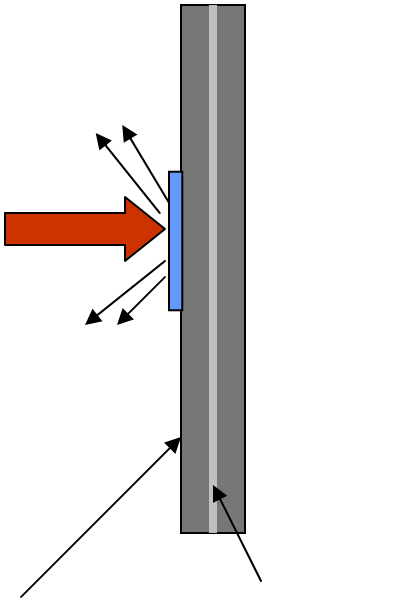


Micrograph of LBI damage
- Hot film bond
- Full strength
- At detection limit of post test NDI

Paste Adhesive Mixing Discriminated

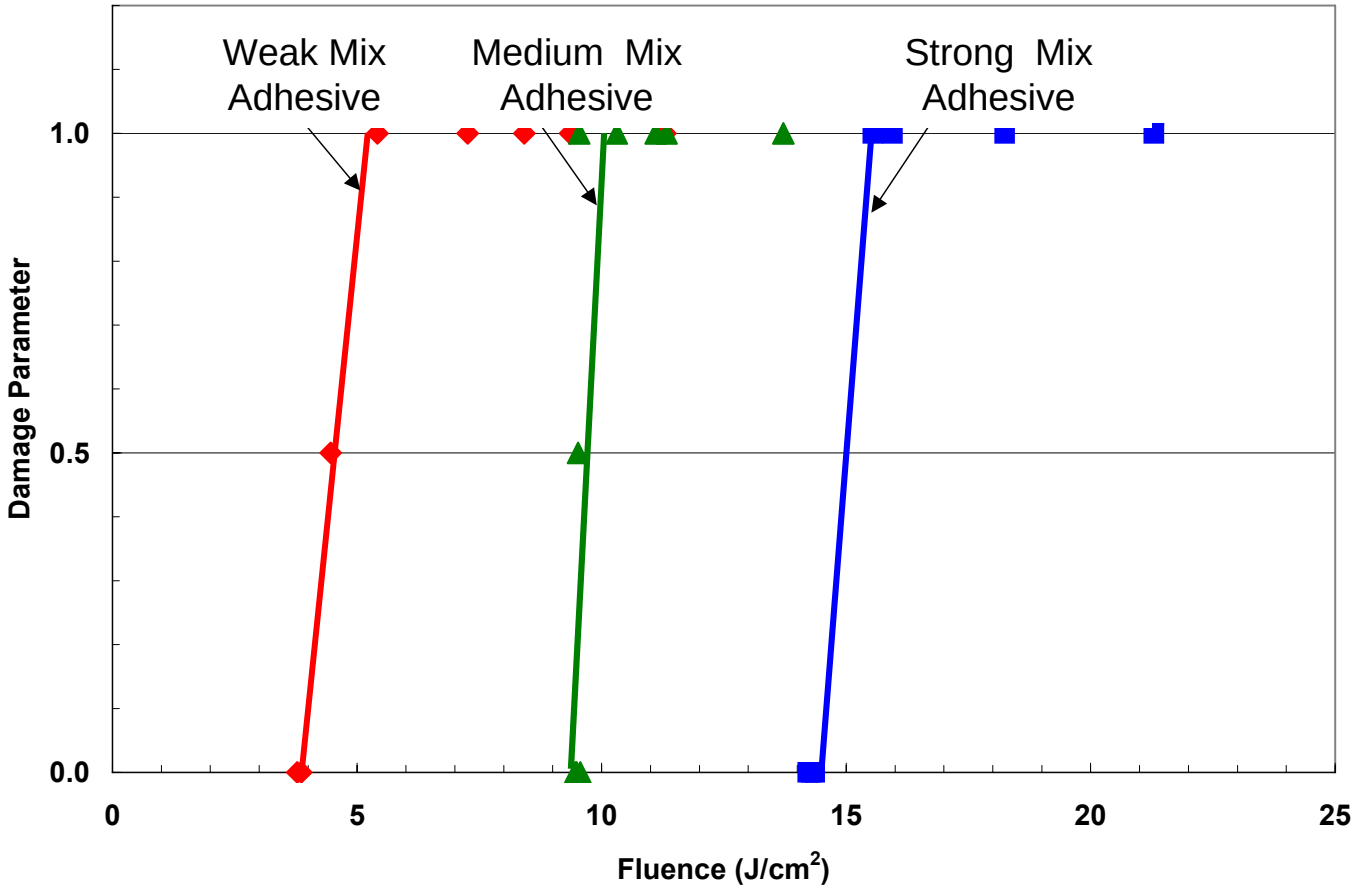
Paste Bonded Samples

Laser pulse tests



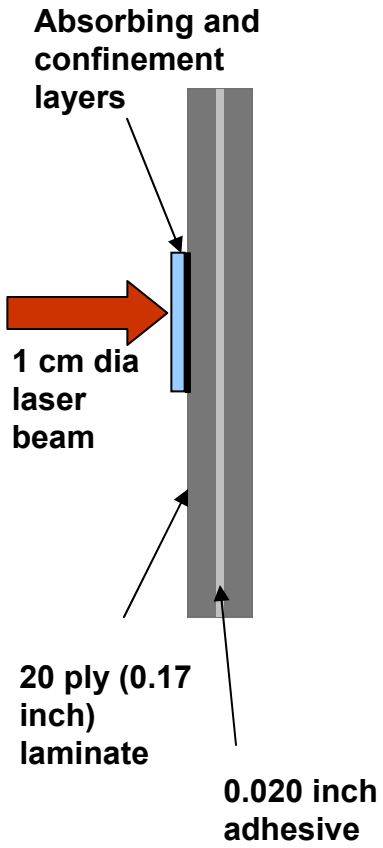
20 ply (0.17 inch) laminate

0.020 inch adhesive

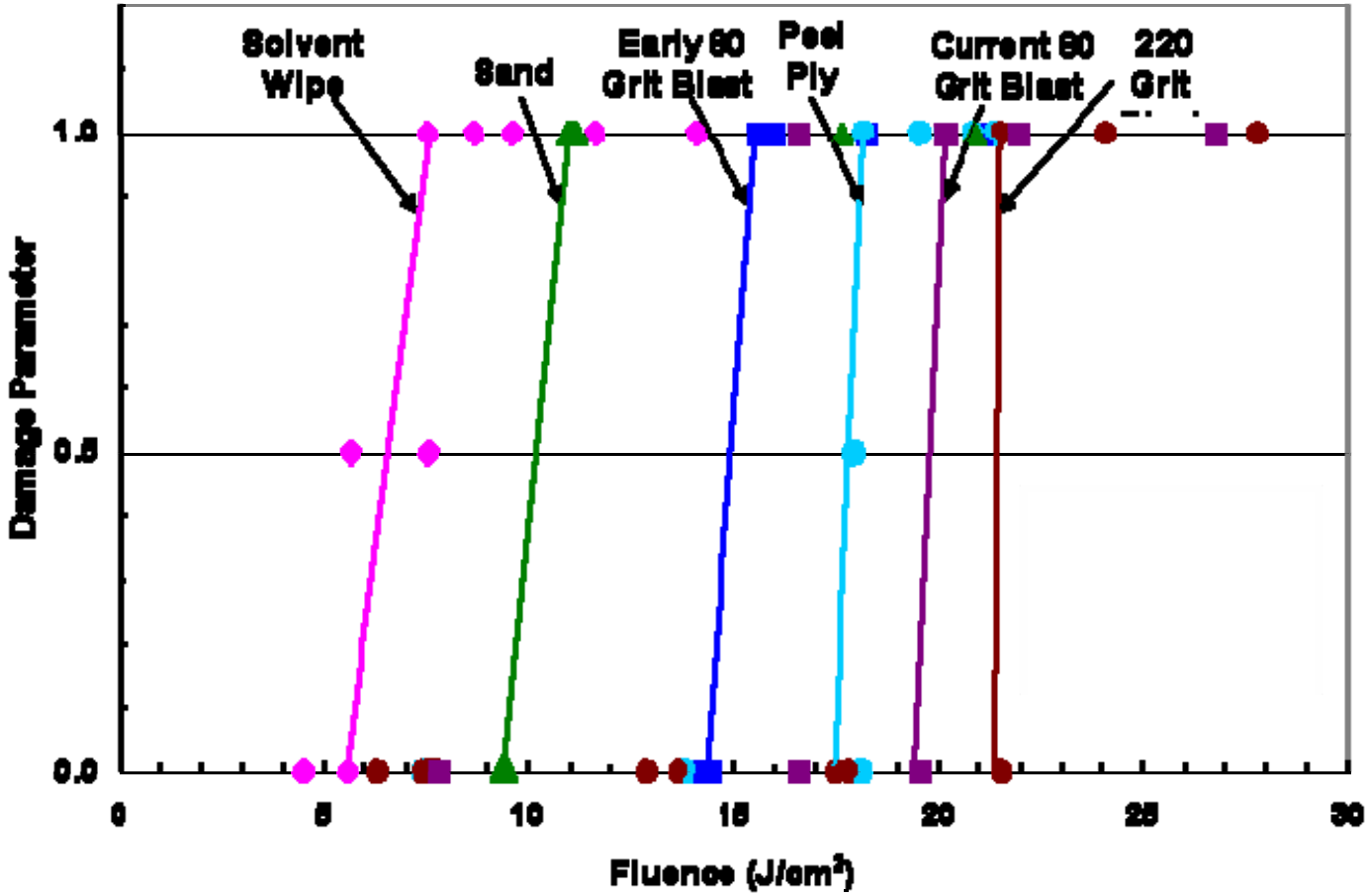


Surface Preparations Easily Discriminated

Laser pulse tests

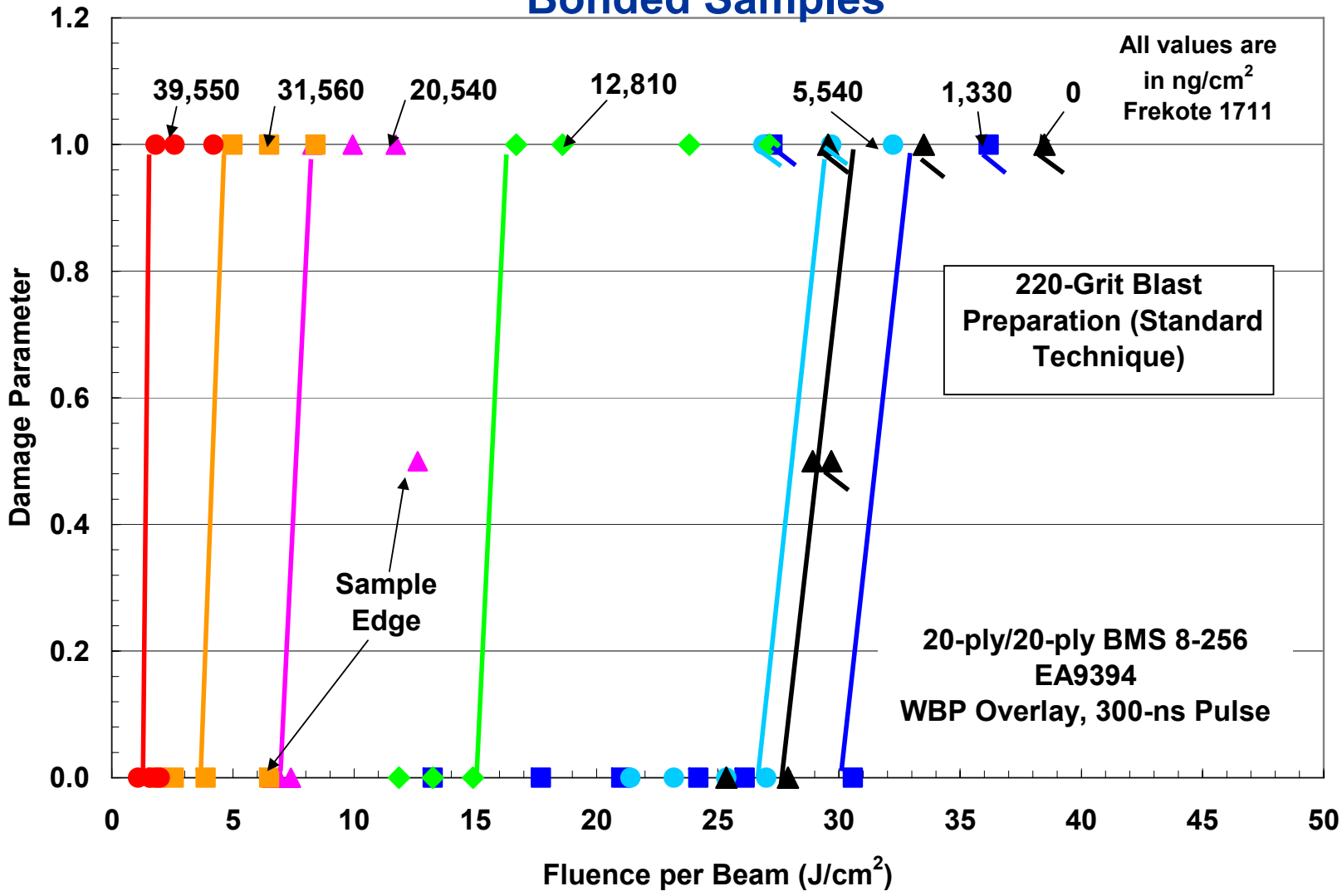


Paste Bonded Samples



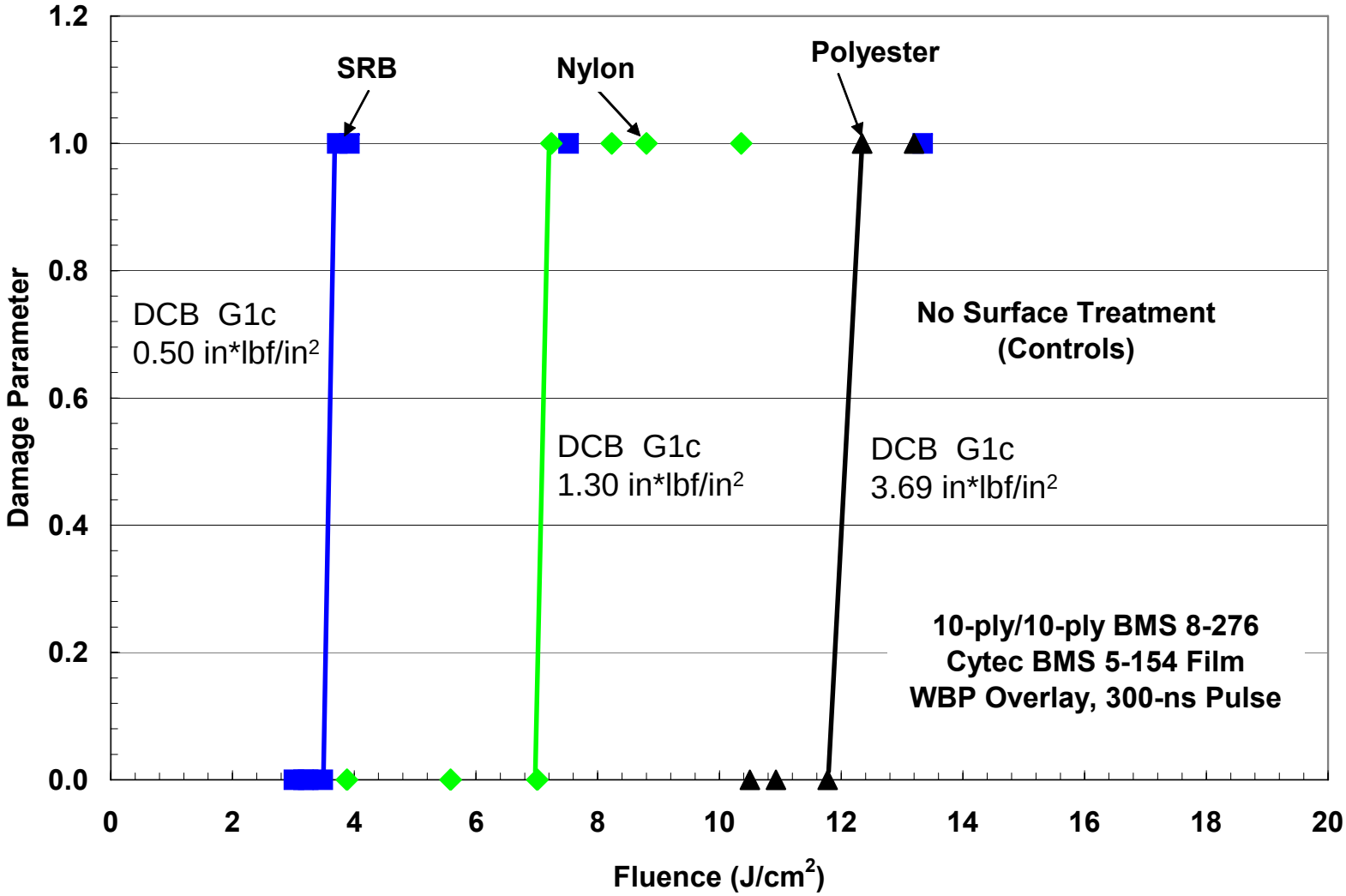
Surface Contamination Effects Readily Detected

Frekote 1711 Contamination of Grit Blasted and Paste Bonded Samples



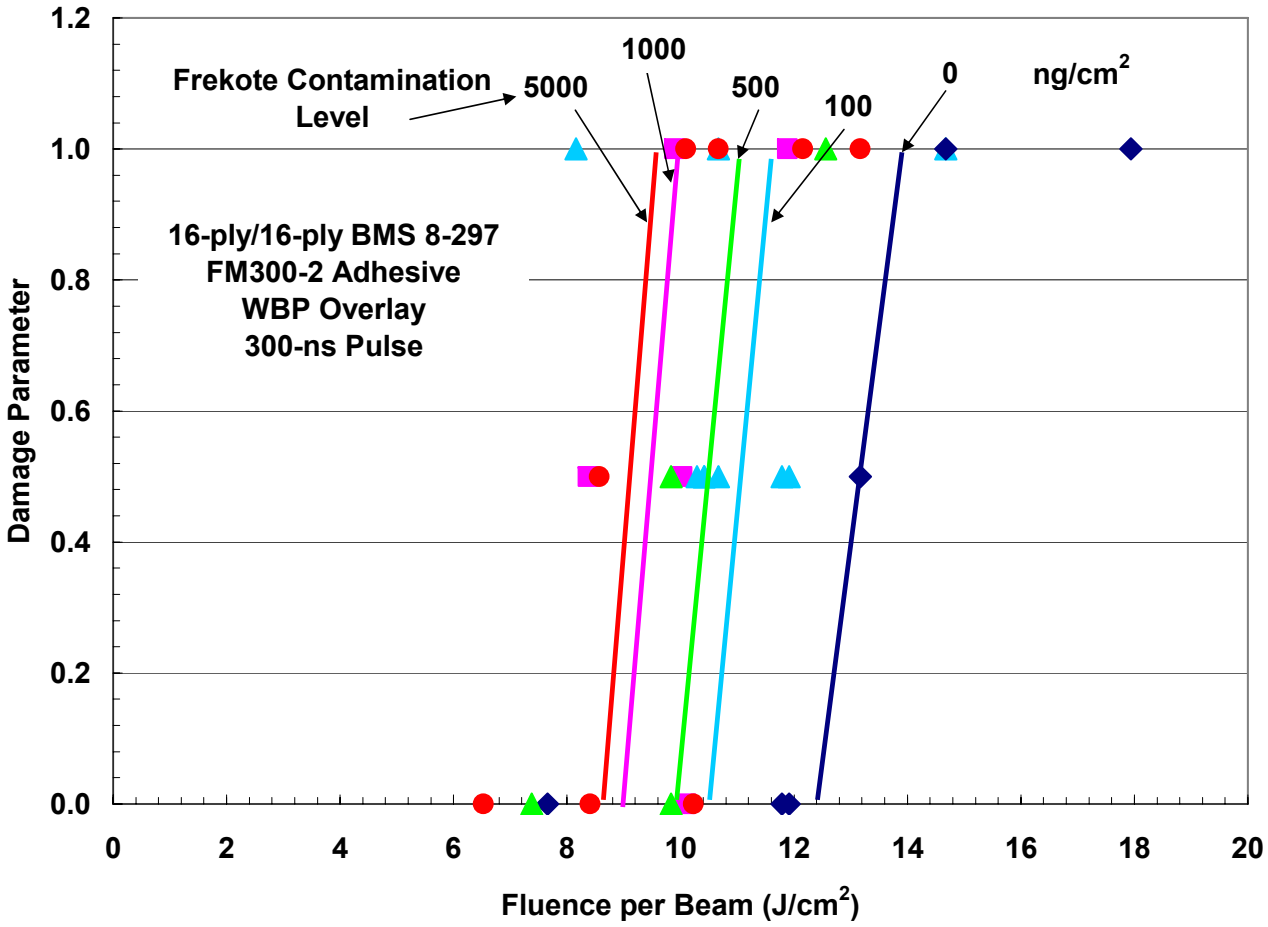
LBI Detection of Incorrect (weak) Peel Ply Surface Prep

Film Bonded Peel Ply Samples



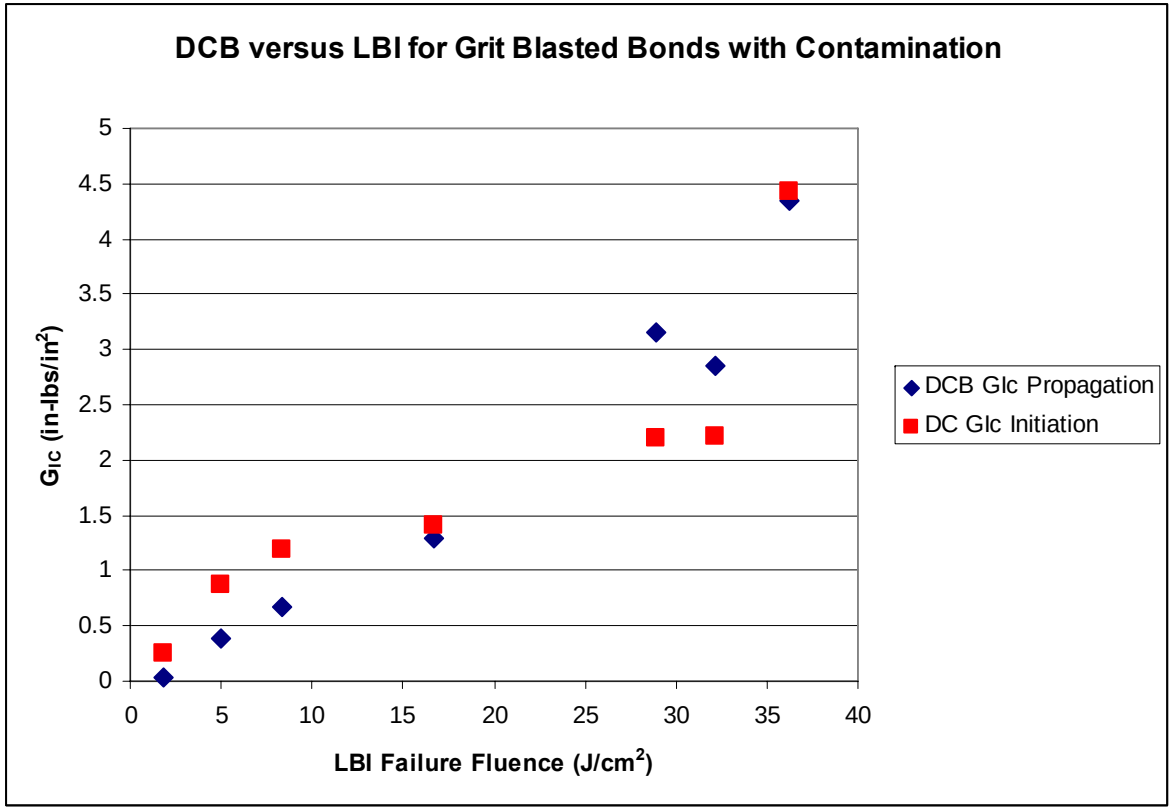
Surface Contamination Effects Readily Detected

Frekote 1711 Contamination of Film Bonded Peel Ply Samples



LBI and DCB results

- LBI can be used as a material test method – results agree with DCB tests, not dependent on edge effects like mechanical tests.



Laser Bond Inspection Device (LBID)

LBID

Components

- **Containment of laser beam for delivery and safety**
- **Process head for surface alignment and overlay**
- **Front surface velocity diagnostic technique**
- **Computer control system**

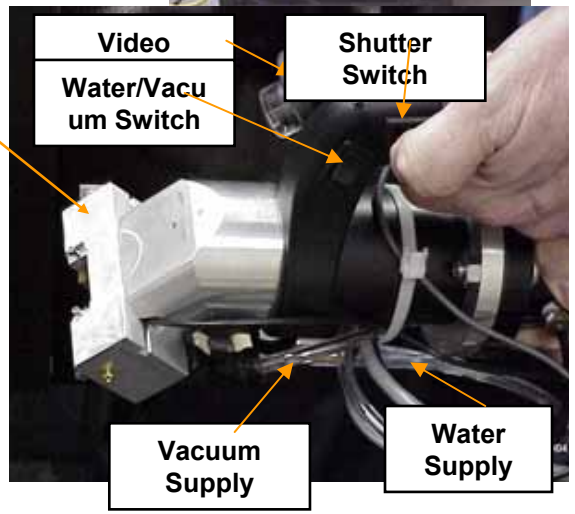
LBID Prototype

Pulsed Laser

- 1054 nm wavelength
- 100-300 ns pulse width
- energy up to 45 J

Laser Pulse Control and Data Acquisition & Reduction

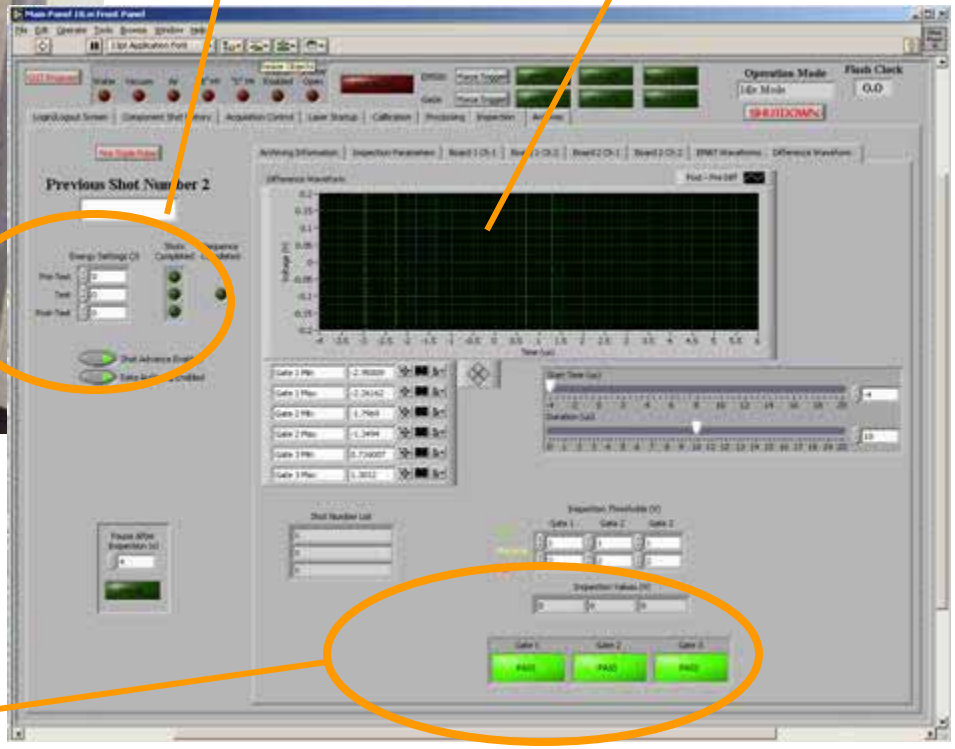
- **Articulating arm**
- **Angled process head permits corner access**
- **Laser beam fully enclosed to sample surface**
- **Operator protection requirements:**
  - **Gloves**
  - **Laser goggles**
- **Counter balance system**



Computer Control

Probe, Pulse, Probe Laser Control

EMAT Waveform Display Window

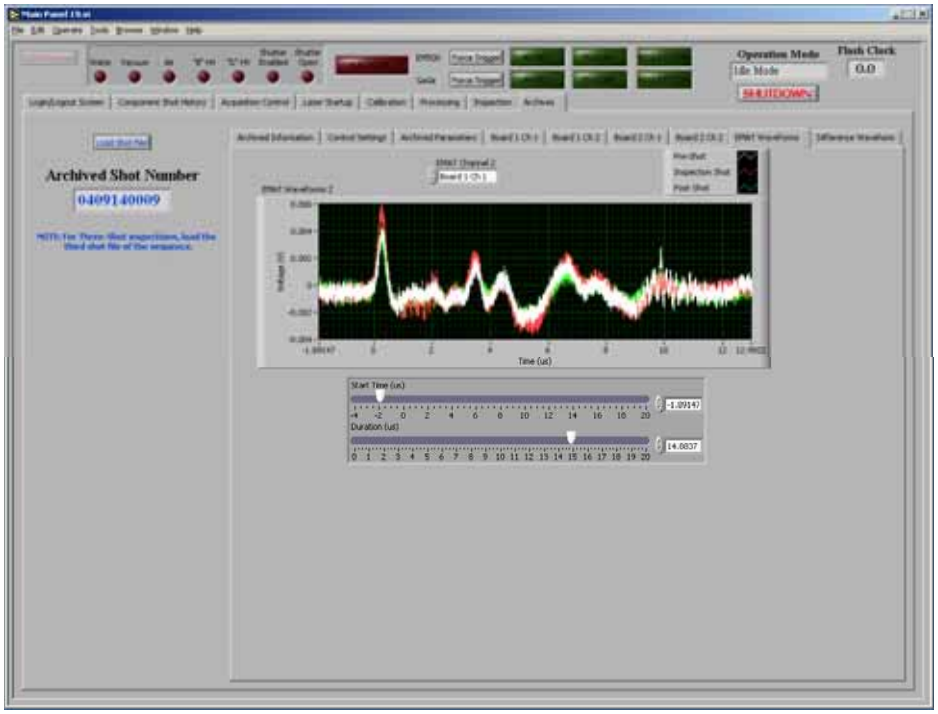


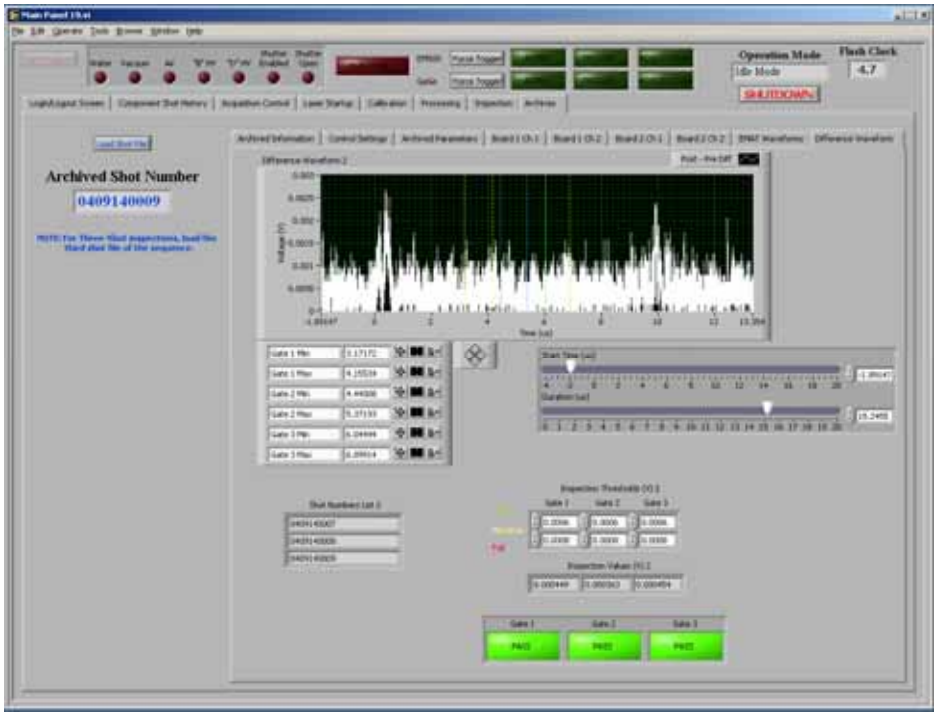
Automated Pass/Fail Diagnostic

Laser Bond Strength Test

Computer Control

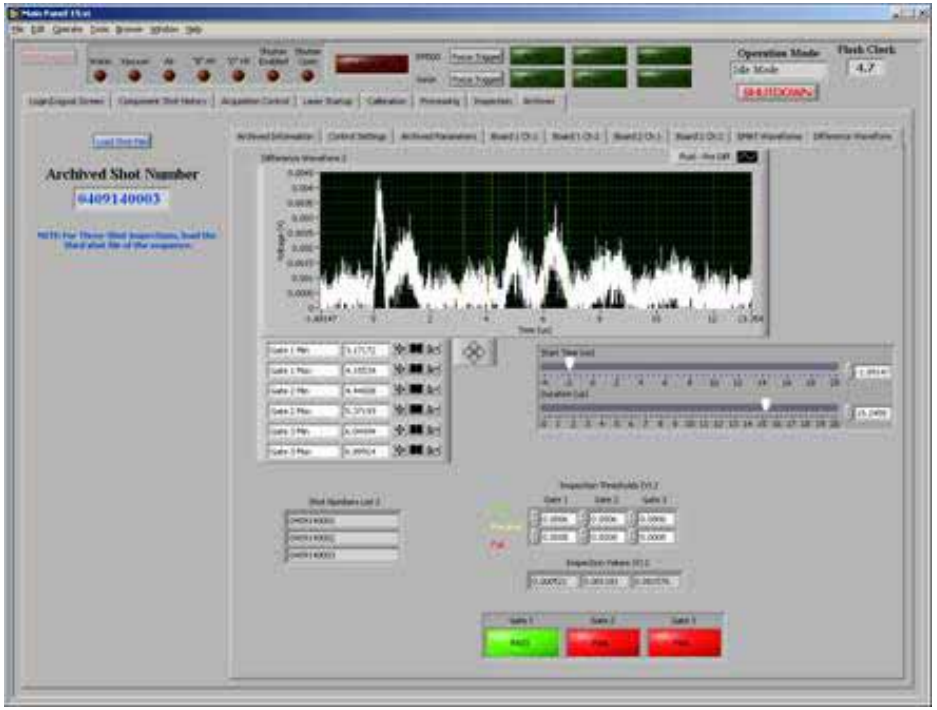
Bond OK





Computer Control

Bond Failed



Conclusions

- Short pulse, high power laser excitation can be used for measuring bond strength and has been able to identify variations in surface preparation, contamination and adhesive mixing.

- The approach can be used for:

  Bonding process development and control

  Nondestructive measure of minimum load carrying capability. (Test below failure level of good structure to detect kissing or weak bonds.)

On-going and Future Efforts

- **Funded USAF SBIR Programs for Laser Bond Inspection with LSP Technologies, Dublin, OH**
  - **Phase I "Development of a Compact Laser for Damage Detection and the Laser Bond Inspection"**
    - Program Status: Completed
  - **Phase II "Development of a Compact Laser for Damage Detection and the Laser Bond Inspection"**
    - Program Status: In progress
  - **Phase I "Advanced Laser Technology for Composite Bond Inspection"**
    - Program Status: Completed
  - **Phase II "Advanced Laser Technology for Composite Bond Inspection"**
    - Program Status: In progress

Contacts: www.lspt.com

Laser Bond Inspection

For further information contact

- **Richard Bossi at 206 544 5885**

Acknowledgements

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- **Mike Chapman, Robert Burns, Bill Shepherd, Kevin Housen and Ben Koltenbah – Boeing**
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