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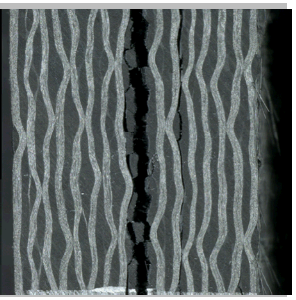

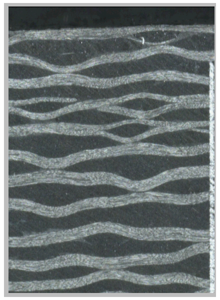

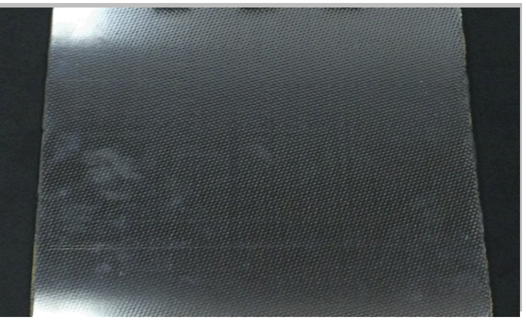

Bond Interface Evaluation of Solid Woven Carbon Fiber Composite onto Aluminum Alloys

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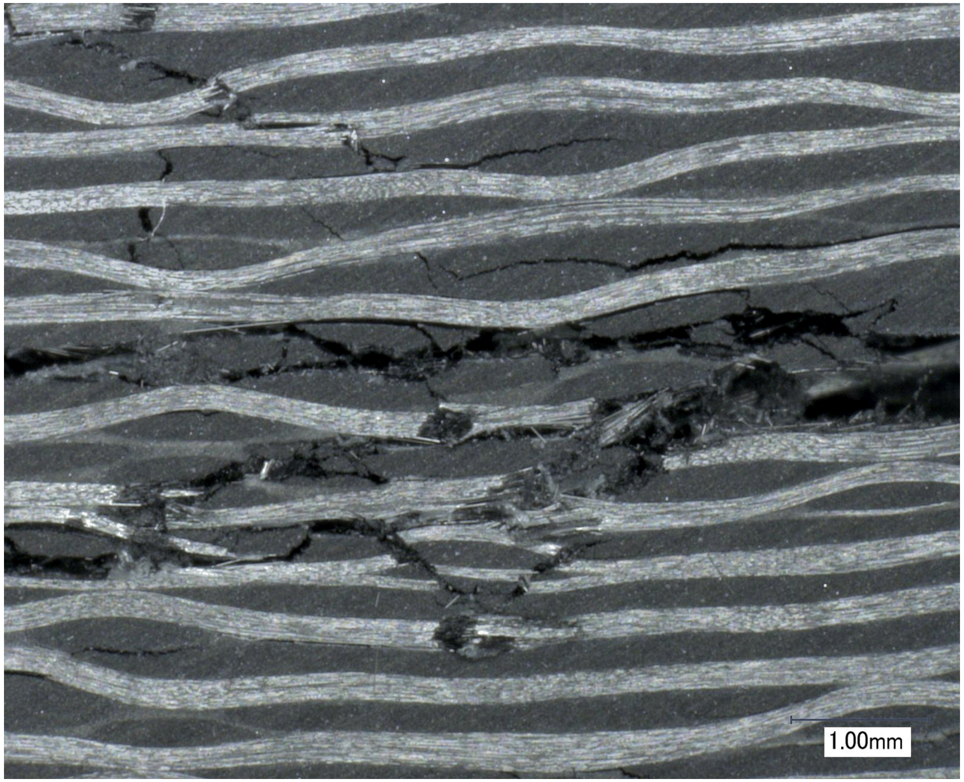
Composite Materials - Background

Fibrous composites are extremely strong in the fiber's longitudinal direction, however provide little support in transverse directions. Strength in the transverse direction is added by changing ply orientation.

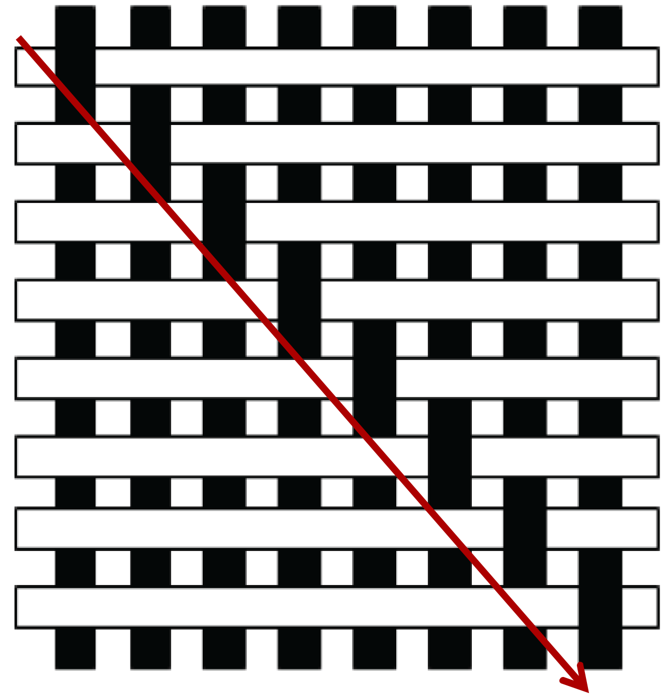
- For applications where more than one fiber orientation is required, a fabric combining 0 and 90 degrees fiber orientation is useful. Woven product are interlaced with warp 0°, and weft, 90° fibers in a regular pattern or weave style.
- The fabric's integrity is maintained by the mechanical interlocking of the fiber weave.



Solid Laminate Layup

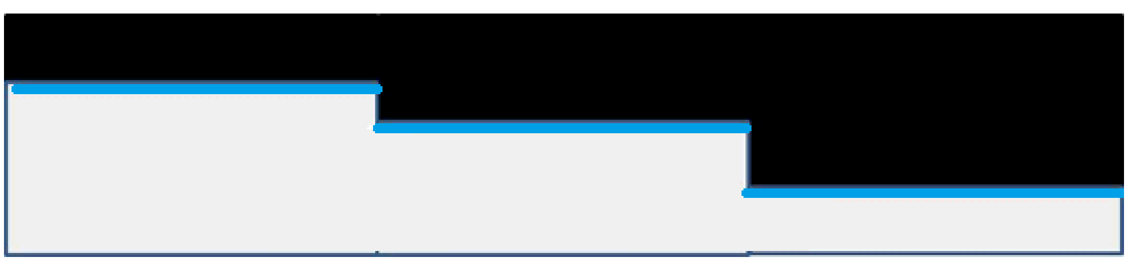
Specimens are constructed with carbon fiber reinforced plastic (CFRP) $[[0/90]_n]_s$ preimpregnated “prepreg” 8 harness-satin weave with UF3352 TCR™ Resin.

4 ply $[0/90]_2]_s$
8 ply $[0/90]_4]_s$
12 ply $[0/90]_6]_s$

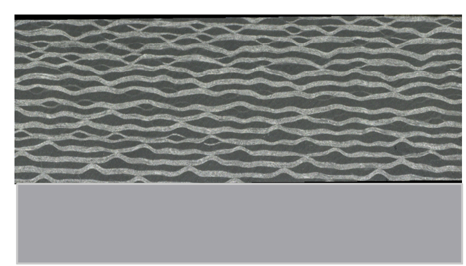


This weave is resistant to wrinkles and allows for tight radius layups.

Side view



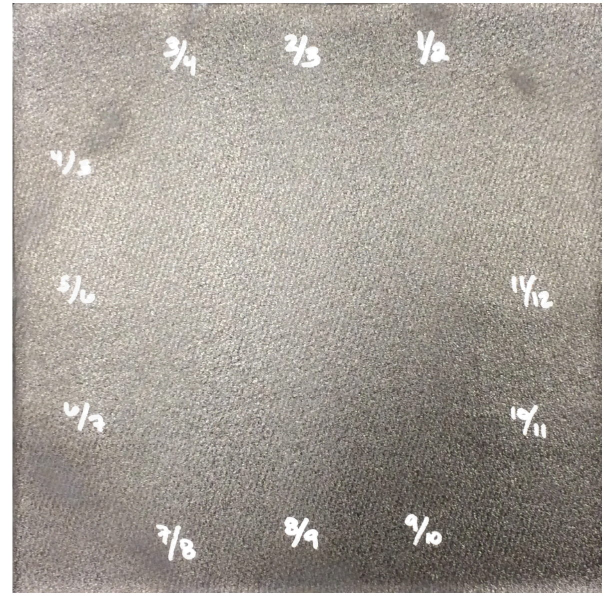
End view

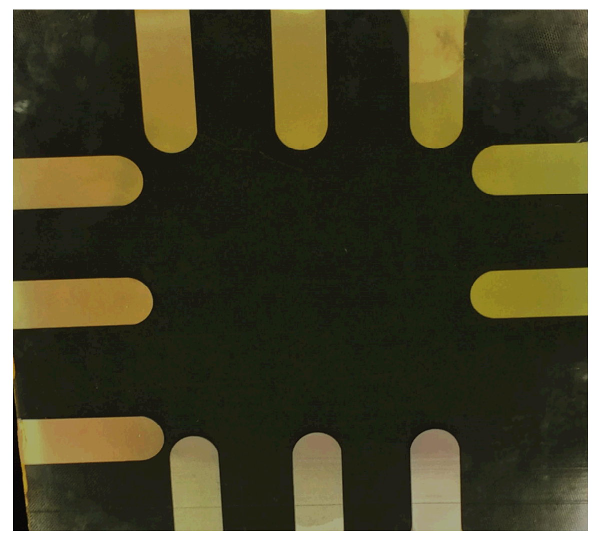


12 plies

Solid Laminate Pull Tab Configuration

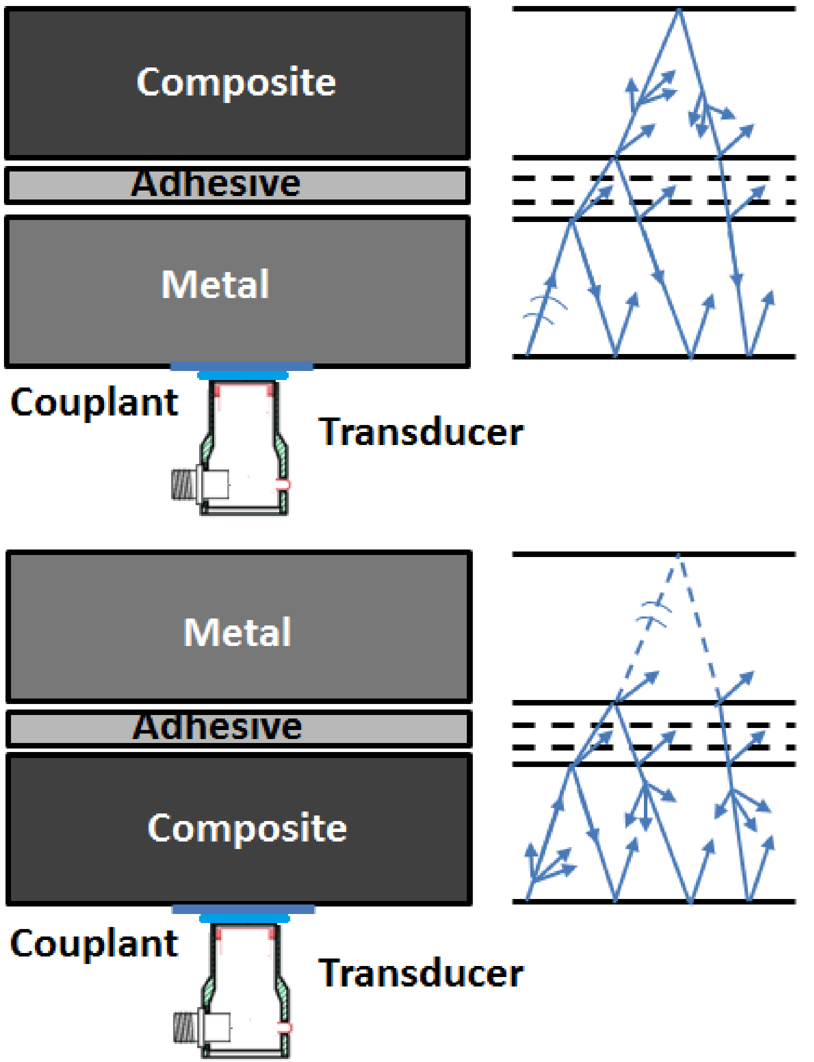
Specimens are constructed with carbon fiber reinforced plastic (CFRP) $[[0/90]_n]_s$ preimpregnated “prepreg” 8 harness-satin weave with UF3352 TCR™ Resin. Pull tabs were placed between each ply. Pull tabs are cured in place.





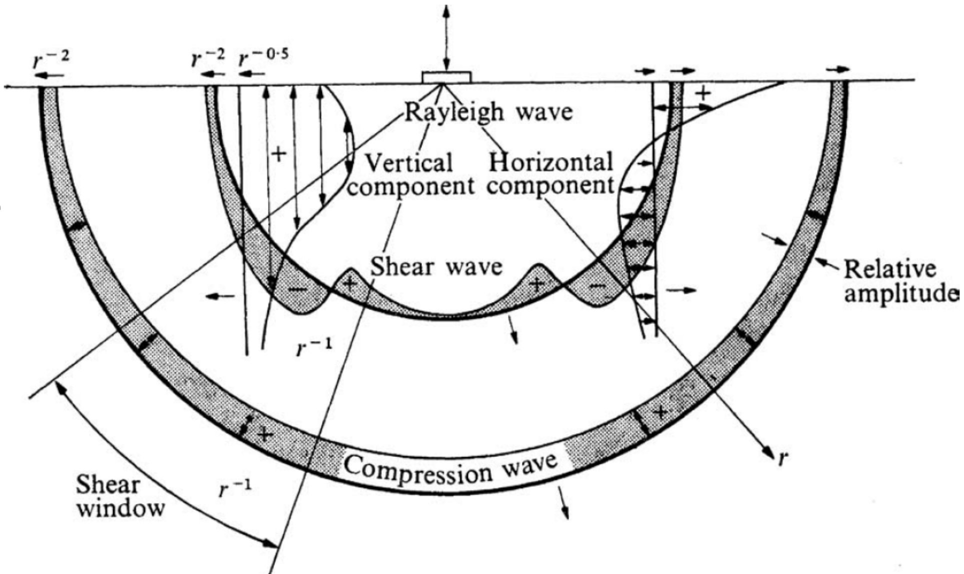
Wave Scatter Theory 1/3

- A wealth of information can be collected on the bondline when one studies the incident wave and preselected incident angles.
- The elastic wave interacts with the materials and its fiber/polymer structure. Scattering is frequency dependent.
- Factors that affect the ability to detect bondline variance are: composite surface texture (random or periodic surface roughness, fiber orientation and binder concentration.



Wave Scatter Theory 2/3

Materials that demonstrate frequency dependent velocity variation are known as dispersive materials. In these types of materials there is a distinction made between the group velocity and the phase velocity.



Source "Elastic Wave Propagation in Materials" , Walley, S.M., Field, J.E. Materials Science and Technology, Elsevier 2005.

$$v_g = v_p + f \frac{\delta v_p}{\delta f}$$

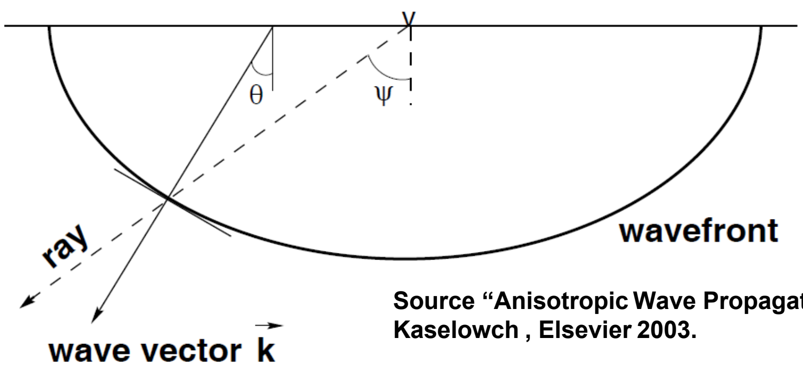
Group velocity (v_g) is defined as a rate at which the point of maximum amplitude in the ultrasonic pulse (many frequencies) propagates through the material.

Phase velocity (v_p) is defined as the velocity of a continuous sinusoidal wave (one frequency) in the material.

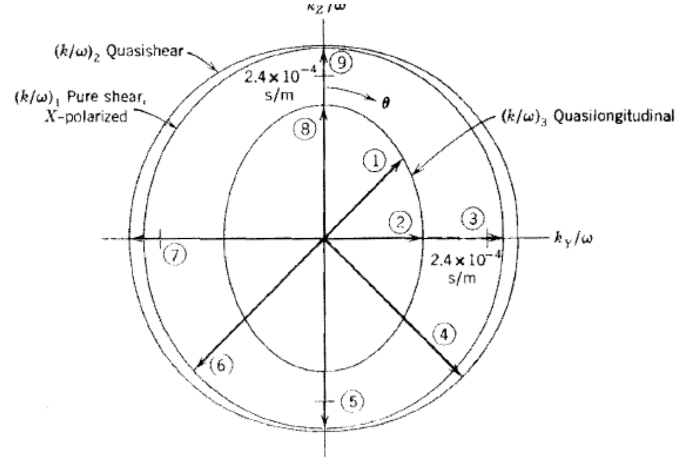
These two velocities are related to each other through dispersive properties (frequency dependence of the phase velocity).

Plane Wave in Orthotropic Materials 3/3

Phase (Wavefront) Velocity (Angle θ) and Group (Ray) Velocity (ψ)



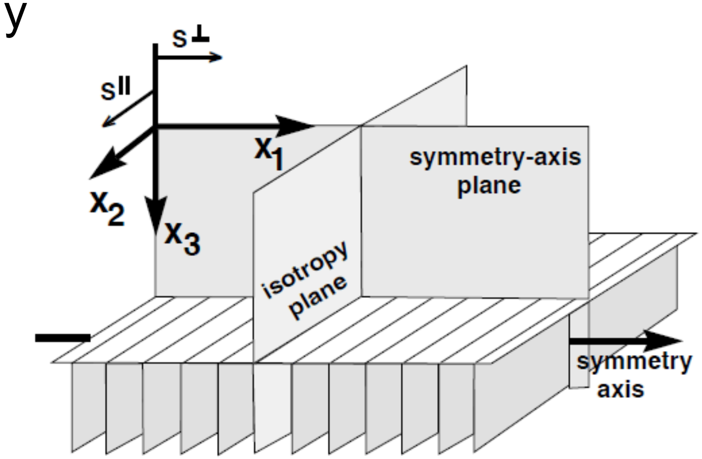
Source "Anisotropic Wave Propagation", Kaselowch , Elsevier 2003.



Source "Acoustic Fields and Waves in Solids", Appendix 3 , B. A. Bauld, Wiley, New York 1973.

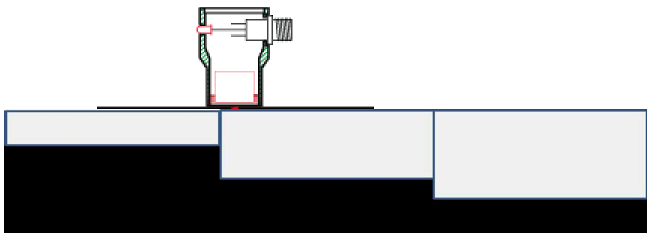
The elastic modulus for composite materials is generally not isotropic in nature, but is orthotropic. Most composites contain voids and micro-cracks within the structure. These manufacturing anomalies result in; a higher ultrasonic noise and texture appearance in the inspection images.

Sound dispersion and absorption causes signal losses as thickness increases. All these variables make the bondline interface between metals and composites more difficult to detect and quantify.

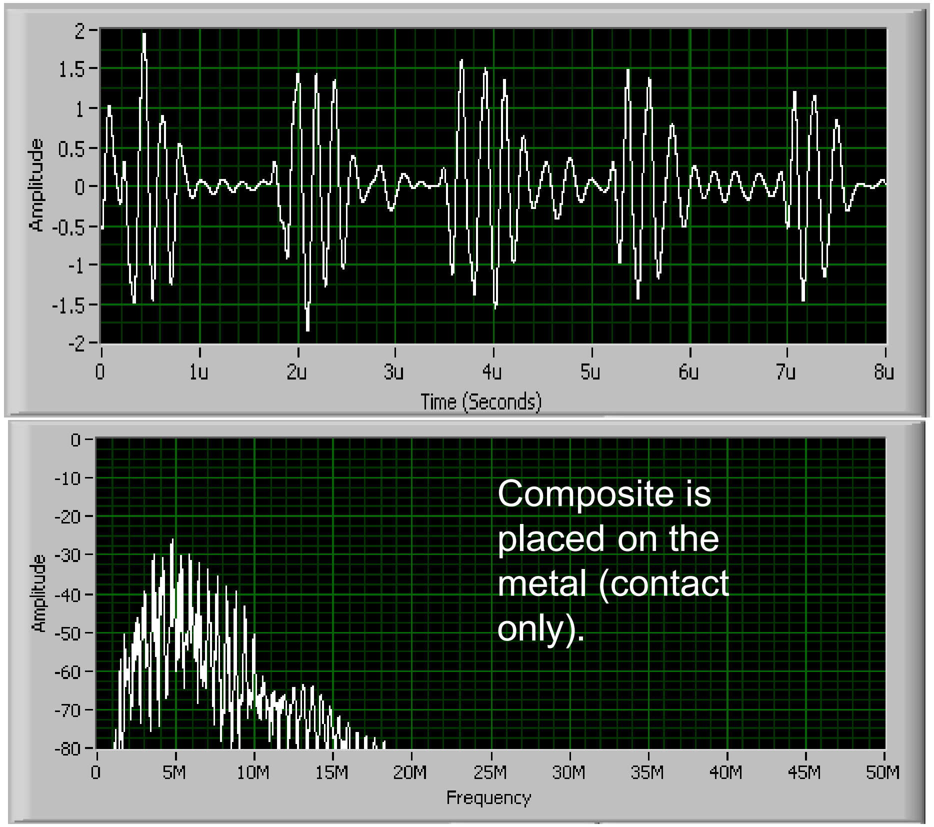


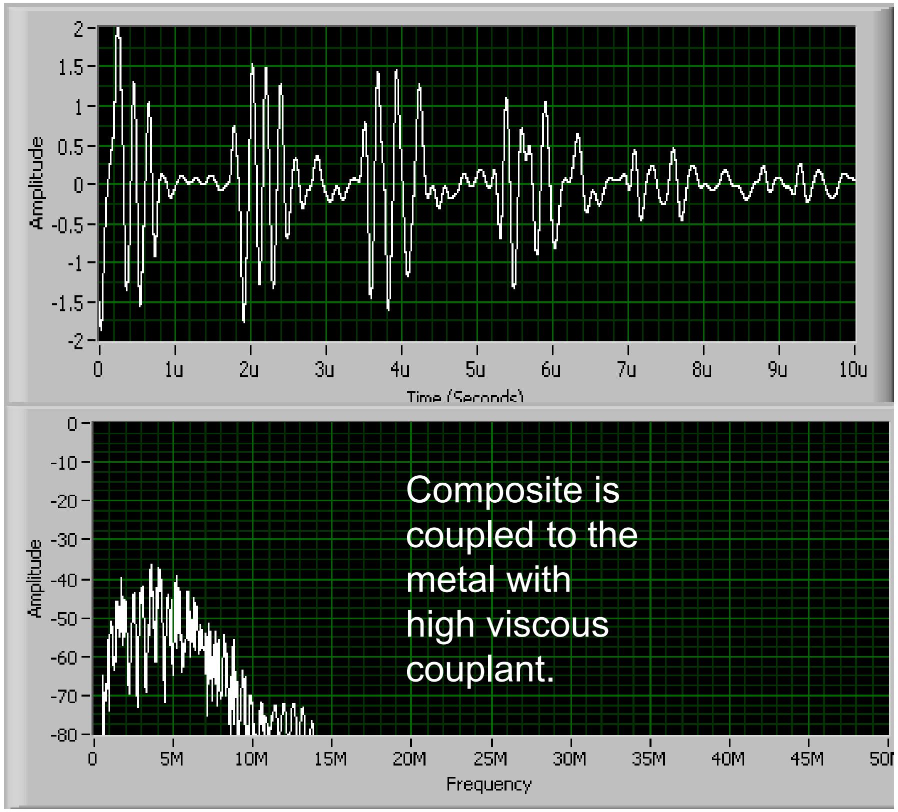
Source: Horizontal Transverse Isotropic axis defination, MIT OpenCourseWare http://ocw.mit.edu/terms/

Metal to Composite - Conventional Ultrasonics



Contact: 5 Mhz A-Scan of 6.30 mm thick aluminum and composite placed on top.





Composite to Metal - Conventional Ultrasonics

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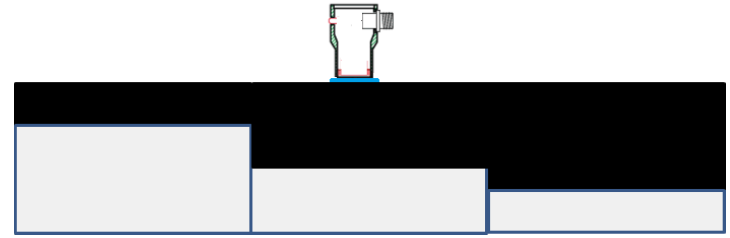
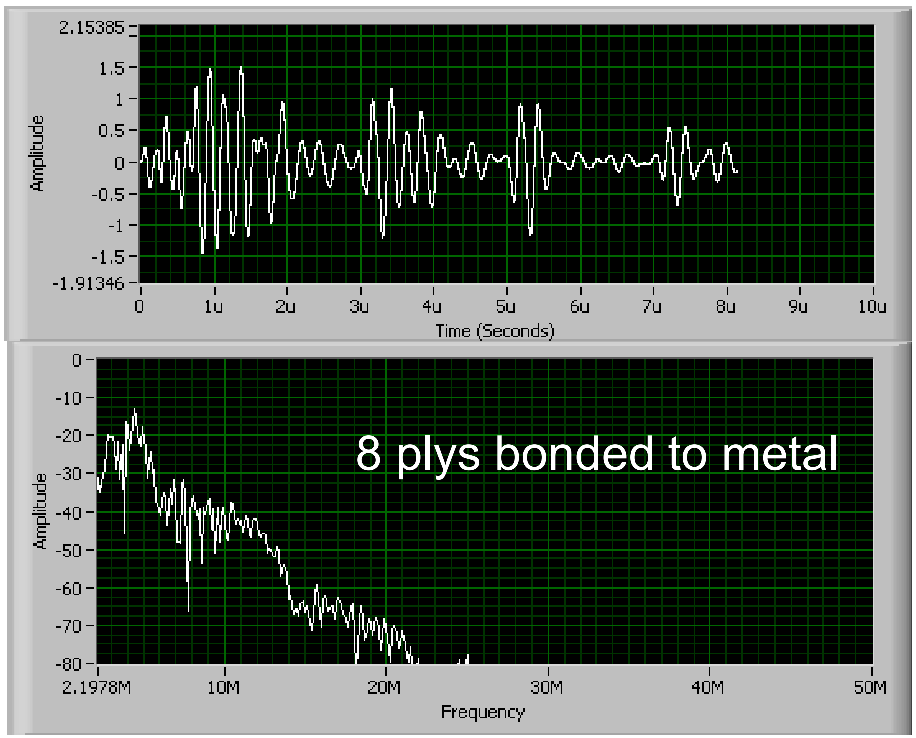
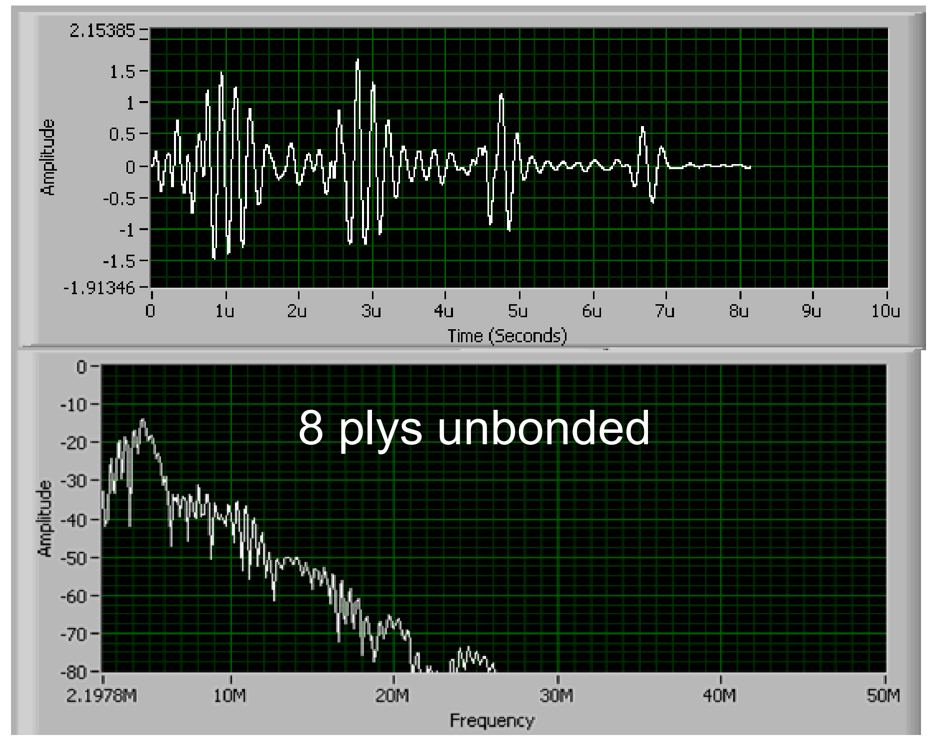
Contact: 5 Mhz A-Scan of 1.68 mm thick composite bonded to aluminum.

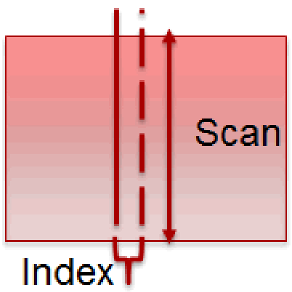


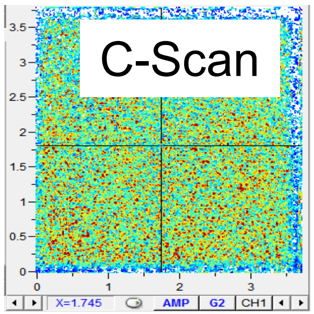


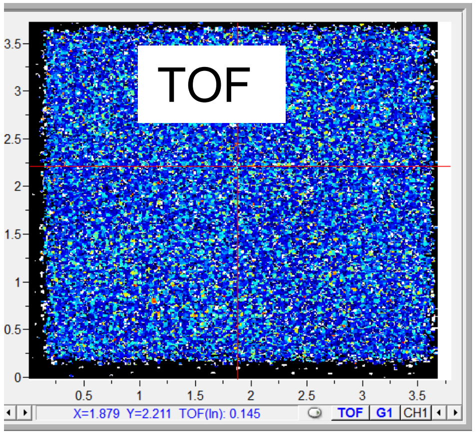


Interface Detection with Immersion Ultrasonics (1 of 3)

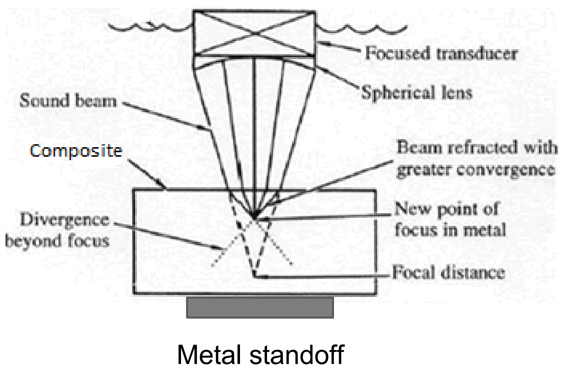
In immersion testing, the part and the transducer are placed in a tank filled with water. This allows for better movement of the transducer while maintaining consistent coupling. Its disadvantage is that the part must sit in water for long periods of time. Immersion testing can also measure backwall signals changes, small amplitude changes and variation in the time of flight measurement from the front to back surfaces.



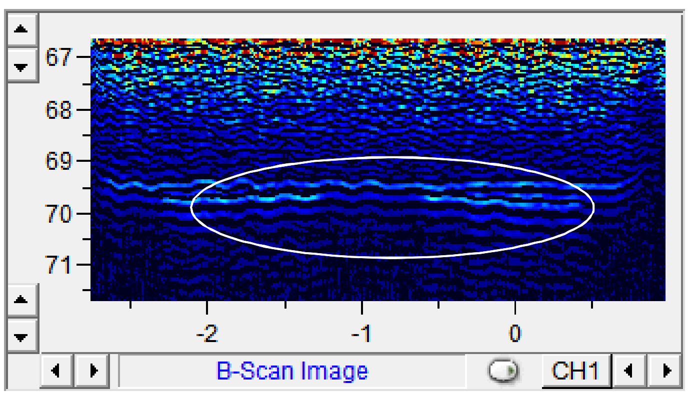


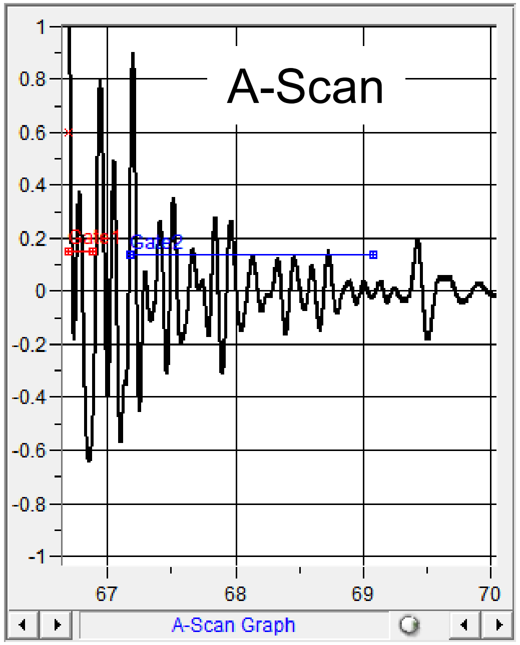


Immersion: 10 Mhz
12 ply composite only
thickness 4.60 mm
V_c = 2.85 km/sec

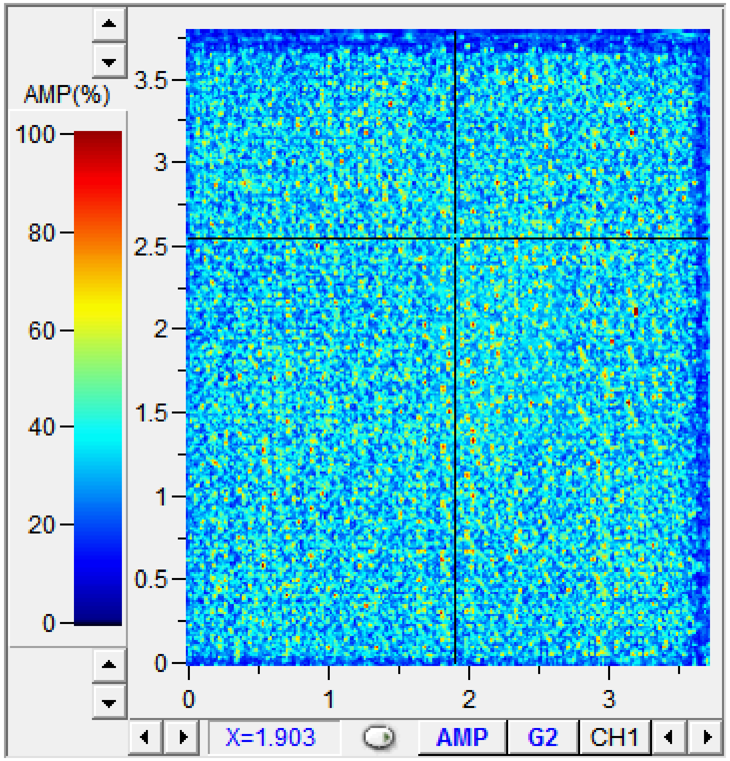


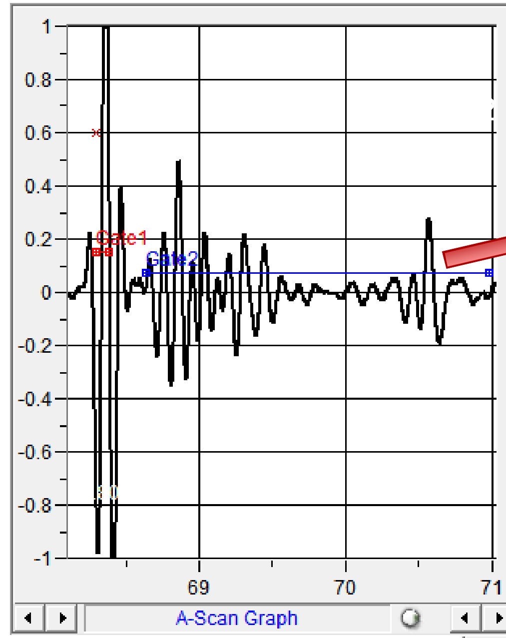
B-Scan

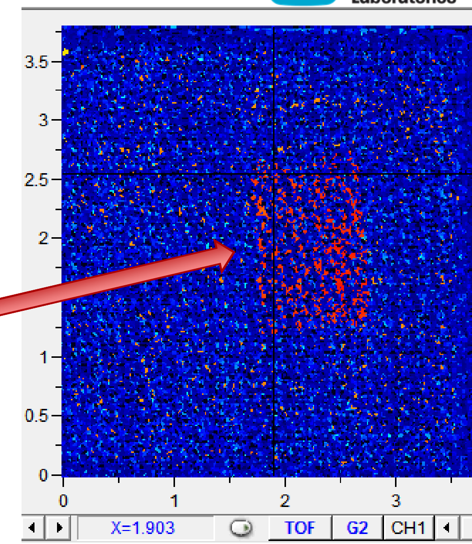




Interface Detection with Immersion Ultrasonics (2 of 3)





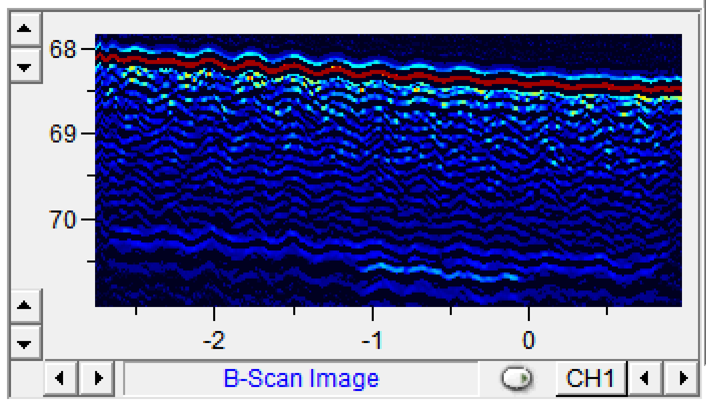


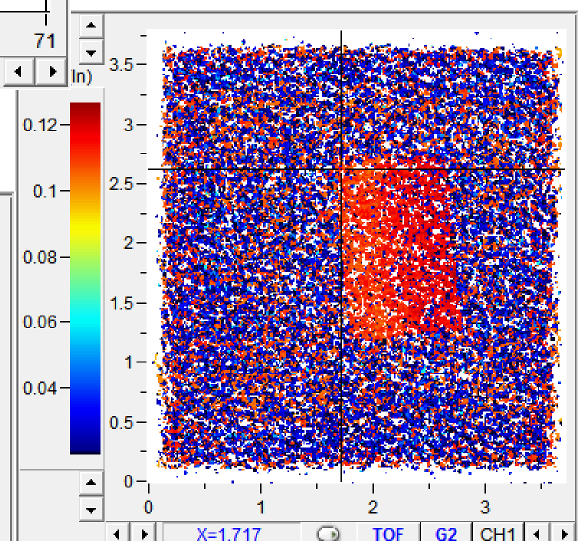
Immersion: 10 Mhz

8 ply composite only

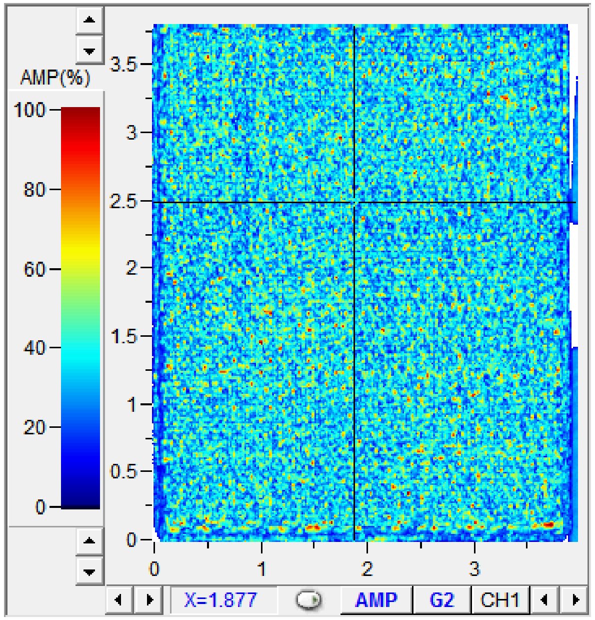
thickness 3.11 mm

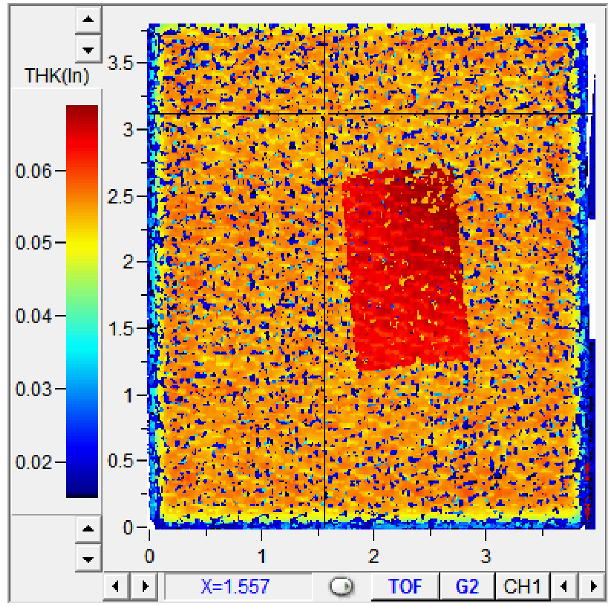
V_c = 2.93 km/sec



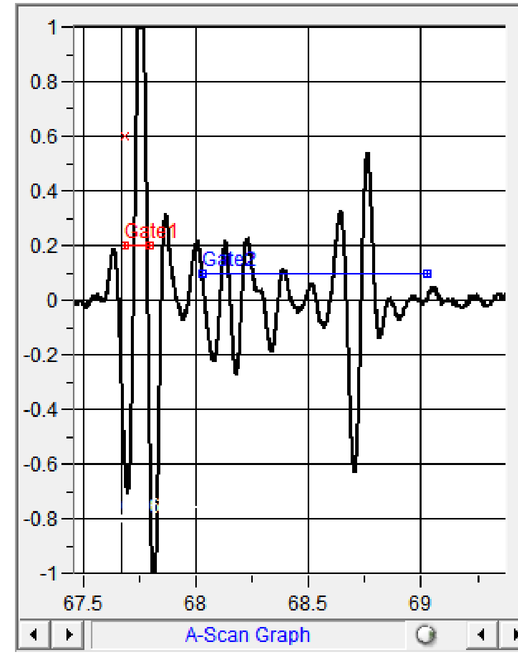


Interface Detection with Immersion Ultrasonics (3 of 3)

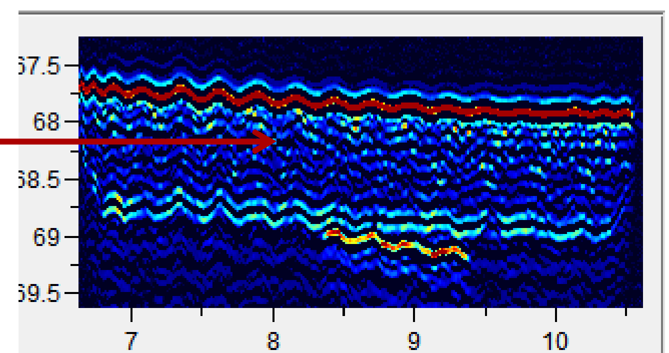




Time of flight



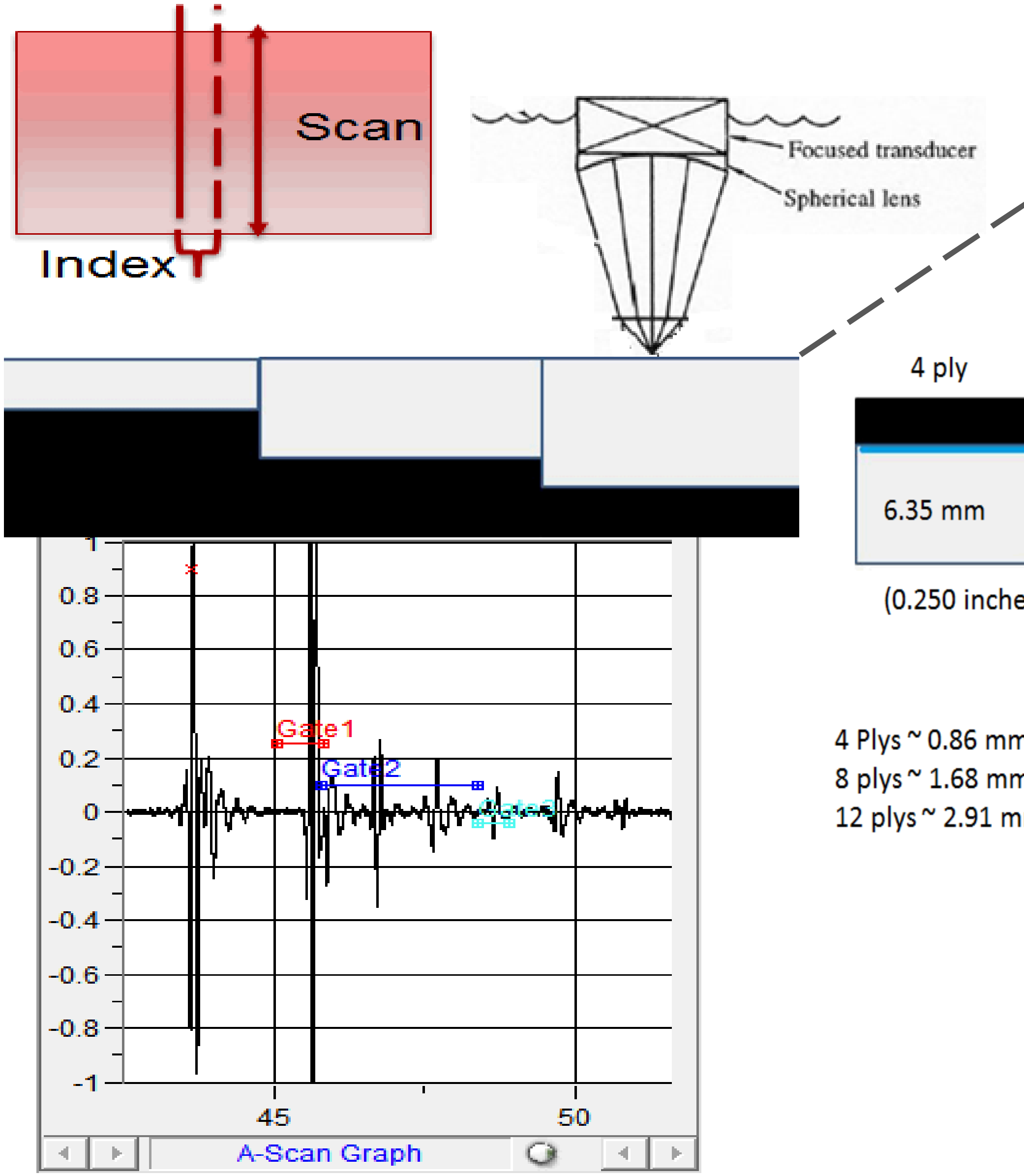
Immersion:10 Mhz 4 ply composite only thick 1.53 mm
V_c = 3.23 km/sec



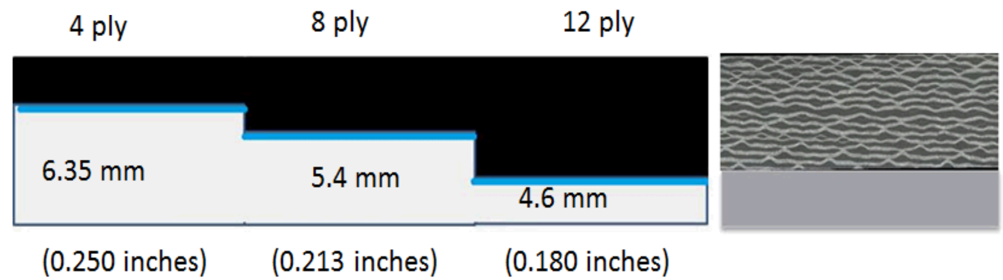
High noise signal within the thickness of the composite is due to porosity and weave pattern

As thickness increases the wave speed decreases.

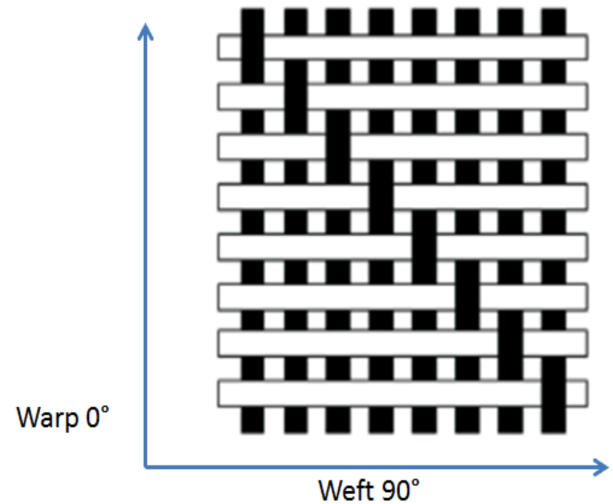
Inspection Scan Plan for Bonded Sample



Parts are scanned from both sides



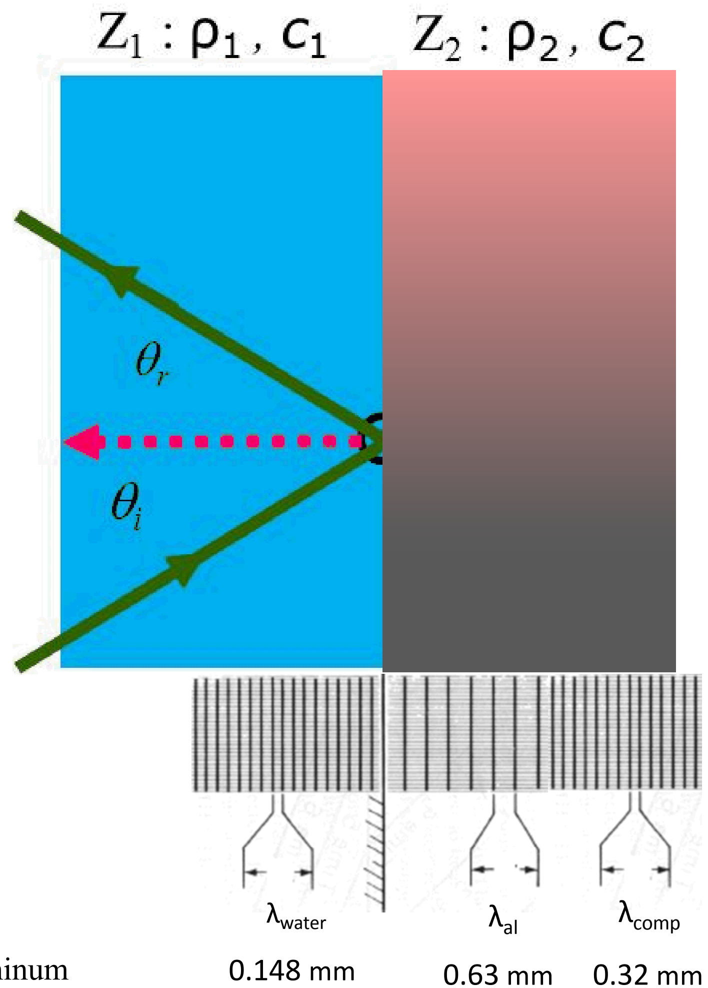
4 Plys ~ 0.86 mm (0.034 inches)
8 plys ~ 1.68 mm (0.066 inches)
12 plys ~ 2.91 mm (0.115 inches)



Plane Sound Waves at Boundaries

A sound waves **always require** particle movement. When the sound hits a boundary, it will either be reflected back toward the source (the probe) or scattered (smooth versus rough surfaces). If two materials are "bonded" the boundary becomes a point of interest. Strong bonds allow the forces to be transmitted into the second material and the wave will continue to propagate.

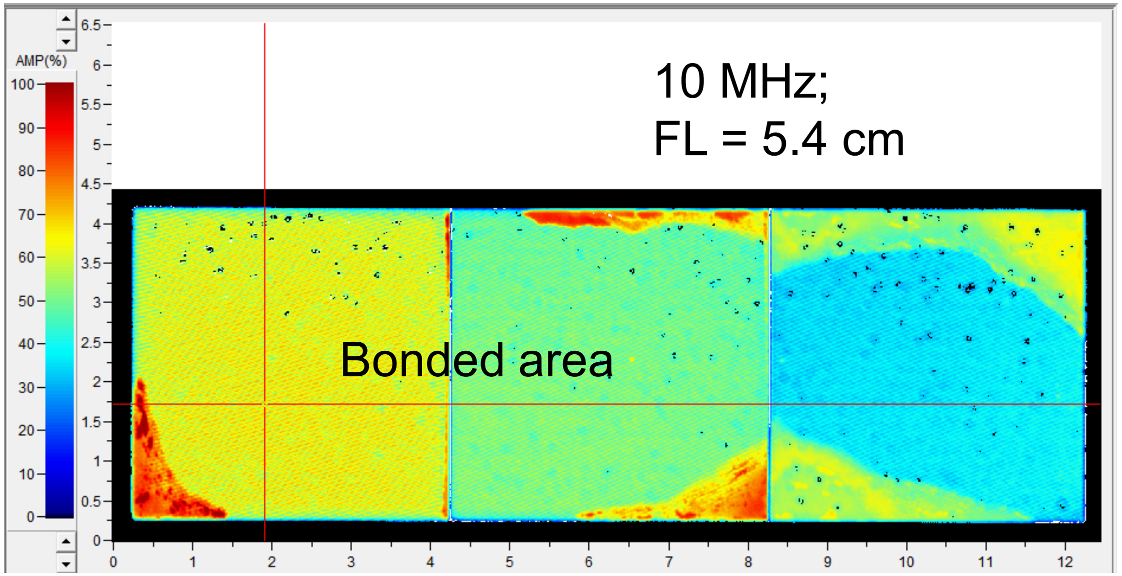
Sound intensity, direction and/or mode change occur when a boundary is encountered. Material boundaries have a strong influence on the propagation of sound. Defects within a material are detected by the change in wave propagation (reflected or transmitted). If we consider our case: aluminum to composite; the acoustic impedance of the first two materials is the driving condition

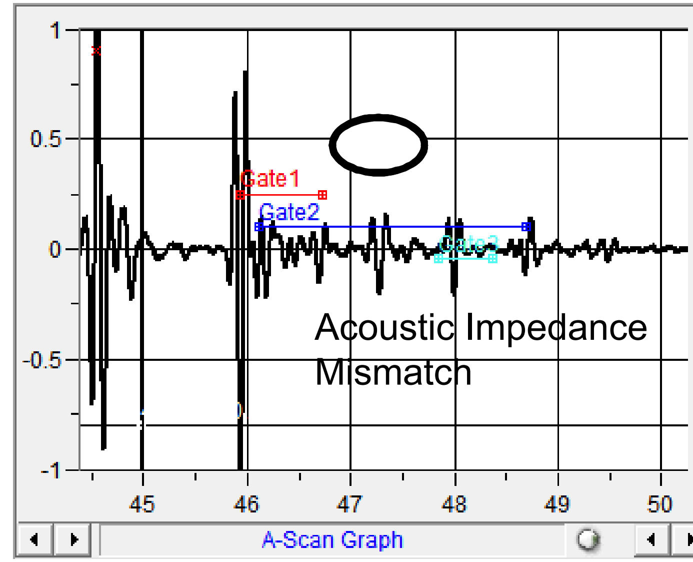


Z_{water} = 1.48 (Pa s/m) = $\rho_1 c_1$ water;
$Z_{aluminum}$ = 17.06 (Pa s/m) = $\rho_2 c_2$
$Z_{air} = 0$
$Z_{composite}$ = ~ 5 Pa s/m

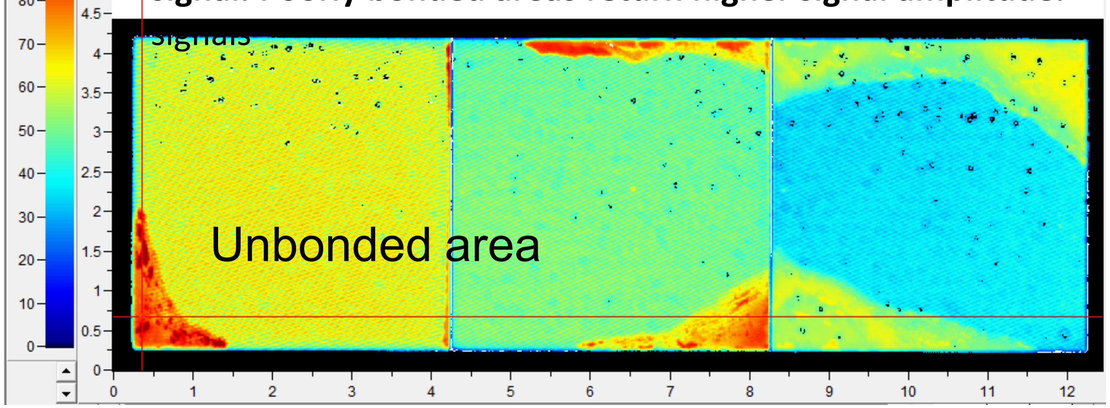
Coefficient of reflection 80% water to aluminum
20% of sound energy enters aluminum
Coefficient of reflection 55% aluminum to composite
Coefficient of reflection 54% water to composite

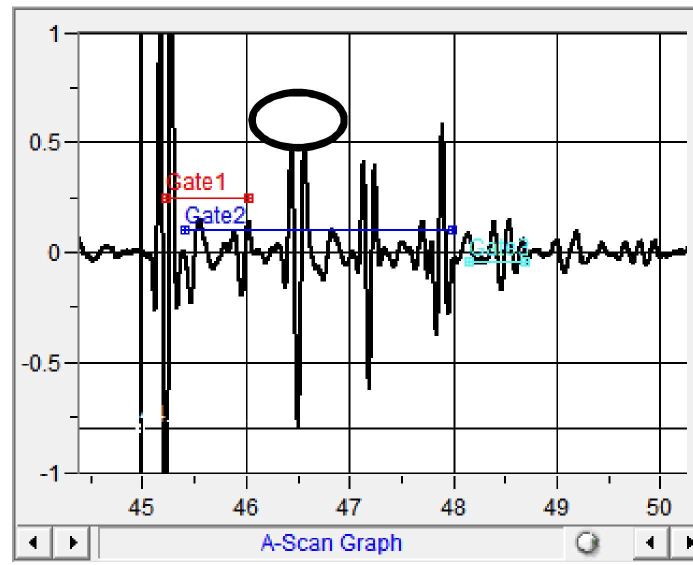
Bondline Detection Aluminum Over Composite





In well bonded areas the sound transmits through the aluminum and into the composite (yellow, green and blue <u>thickness change in aluminum</u>) and returns a lower amplitude signal. Poorly bonded areas return higher signal amplitude.





Bondline Detection Composite over Aluminum 1 of 2

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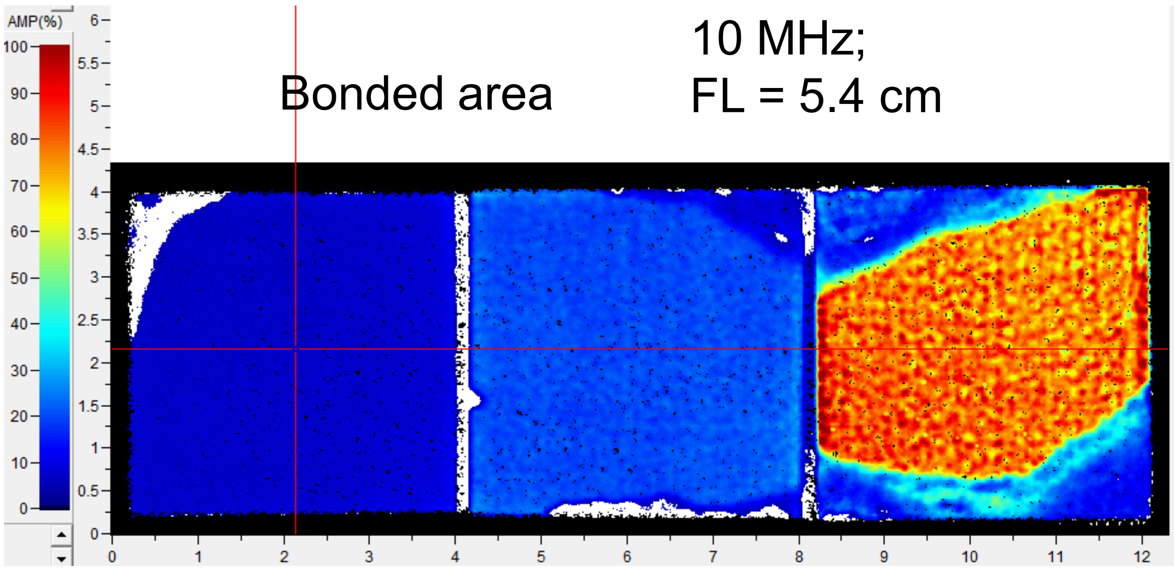
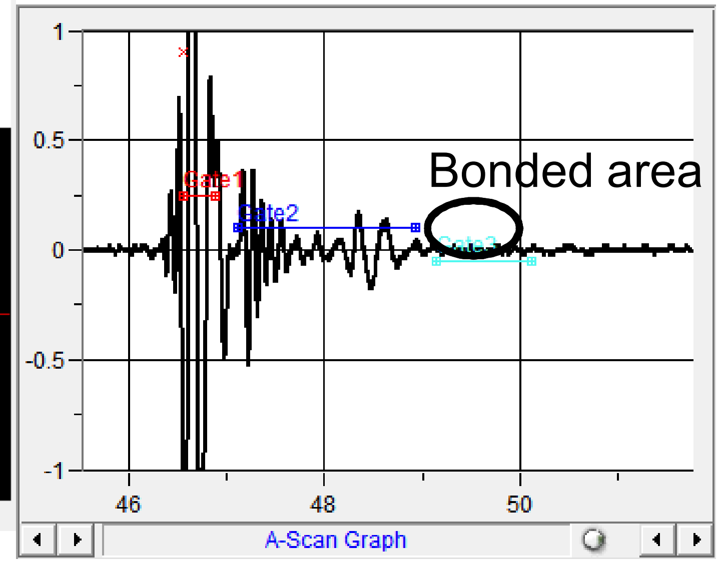
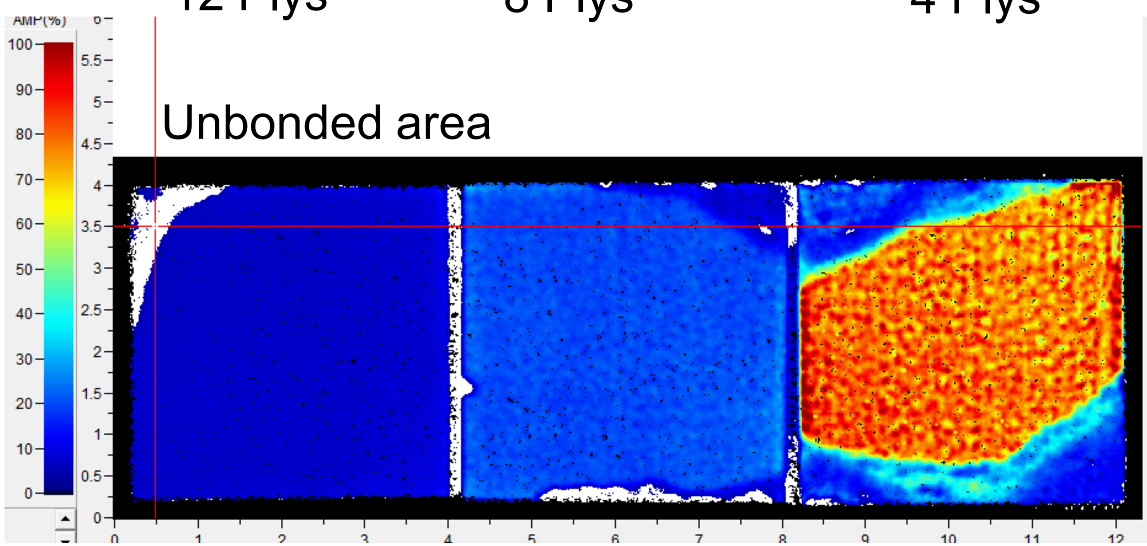
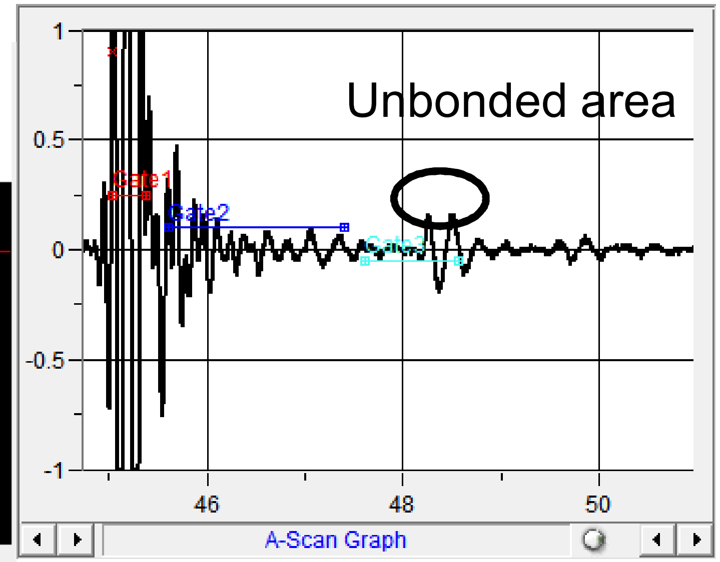




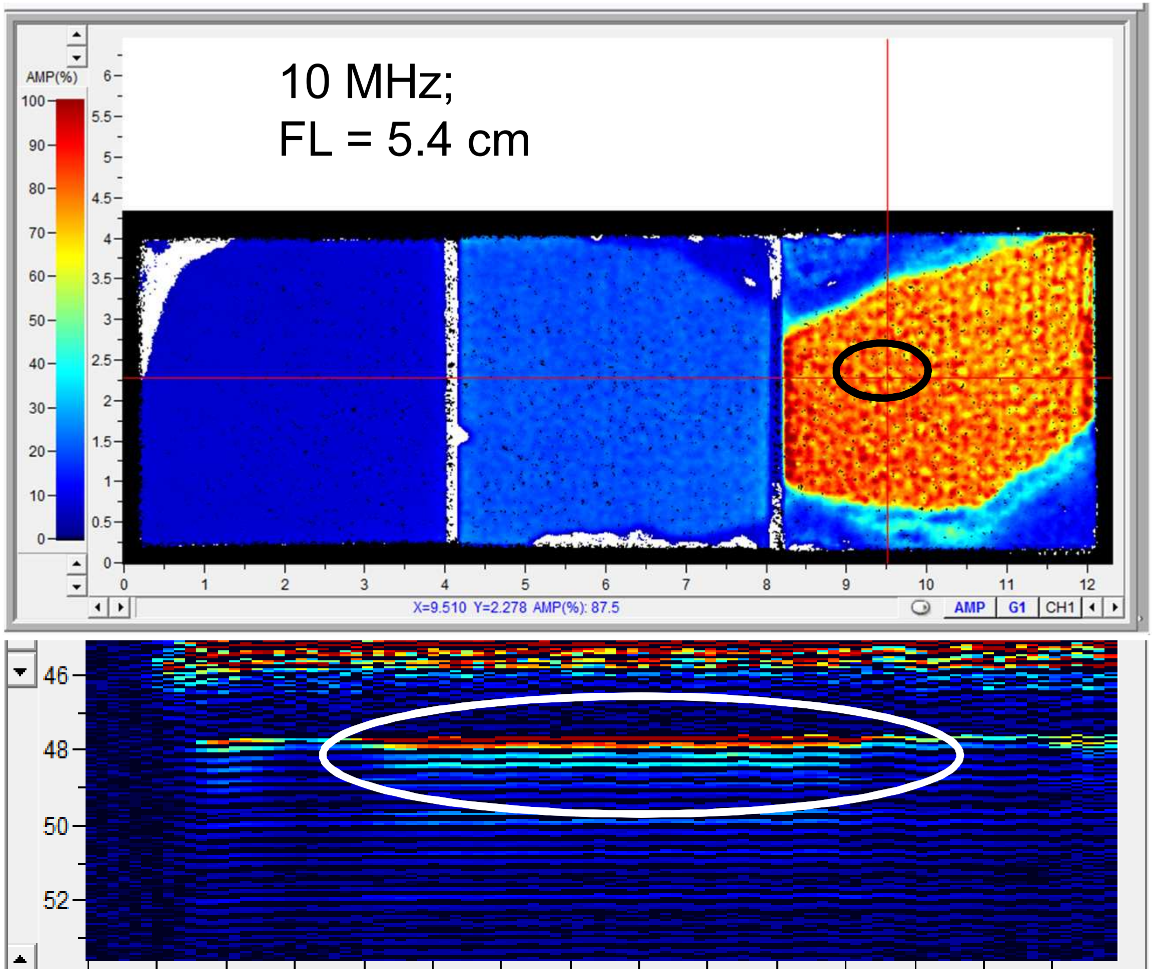
12 Plys 8 Plys 4 Plys

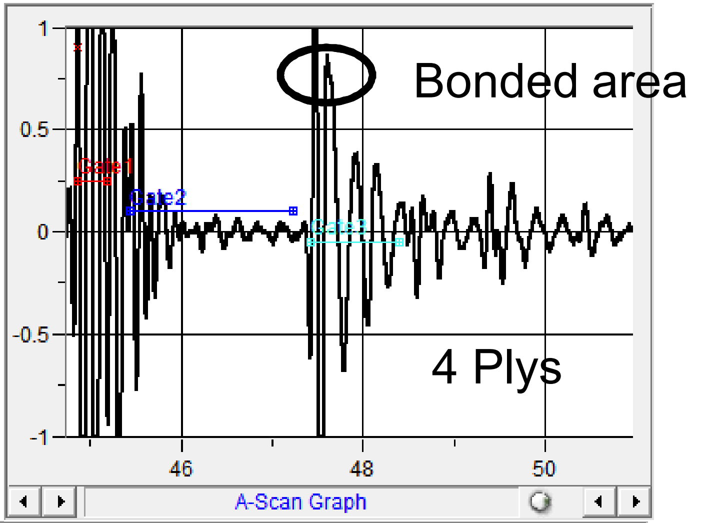


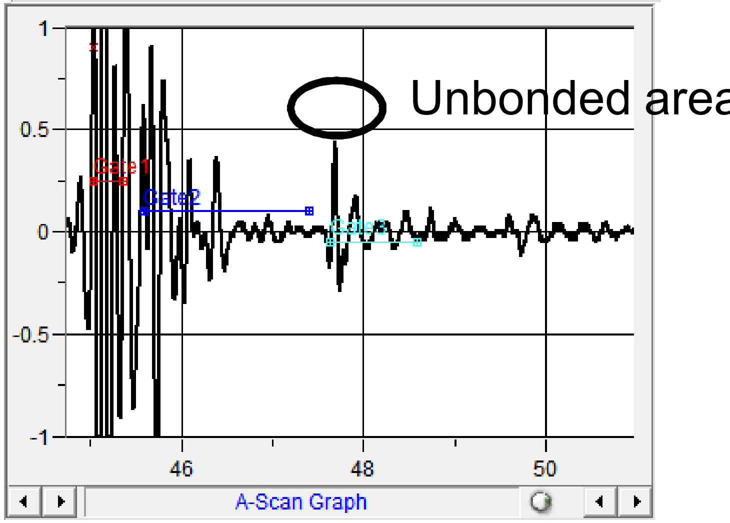


Bondline Detection Composite over Aluminum 2 of 2

Bonded area reflects sound from the aluminum and sends a stronger reflection back to the probe.

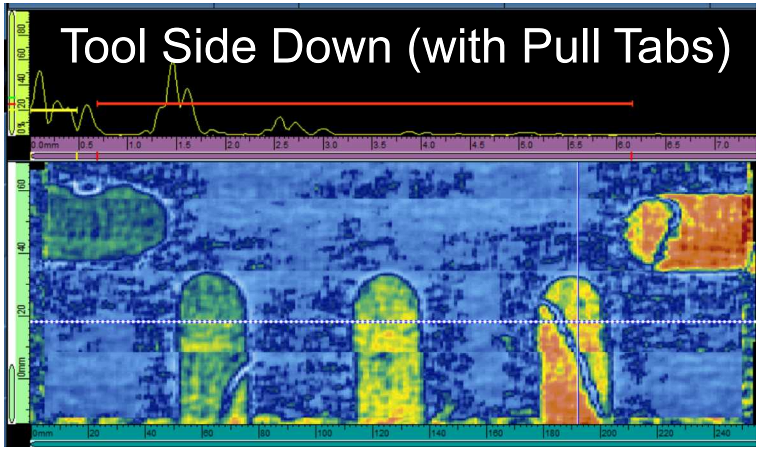


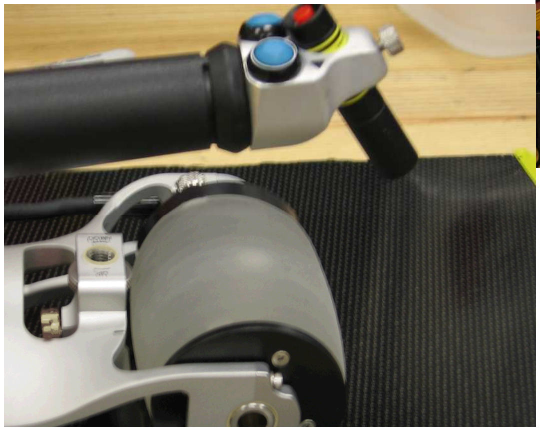


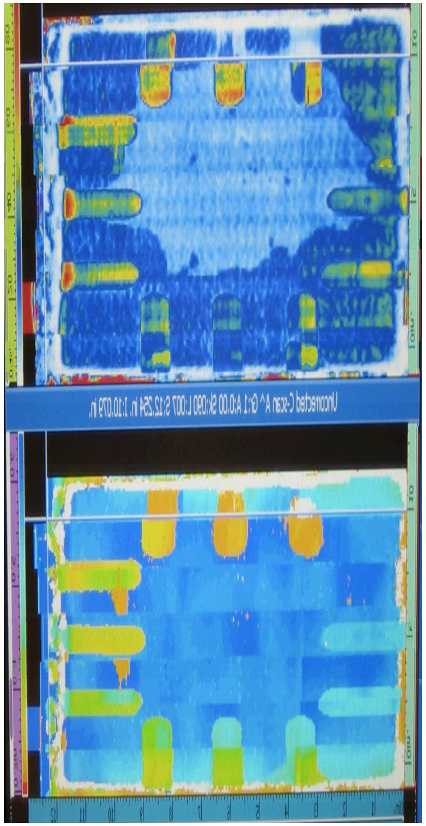


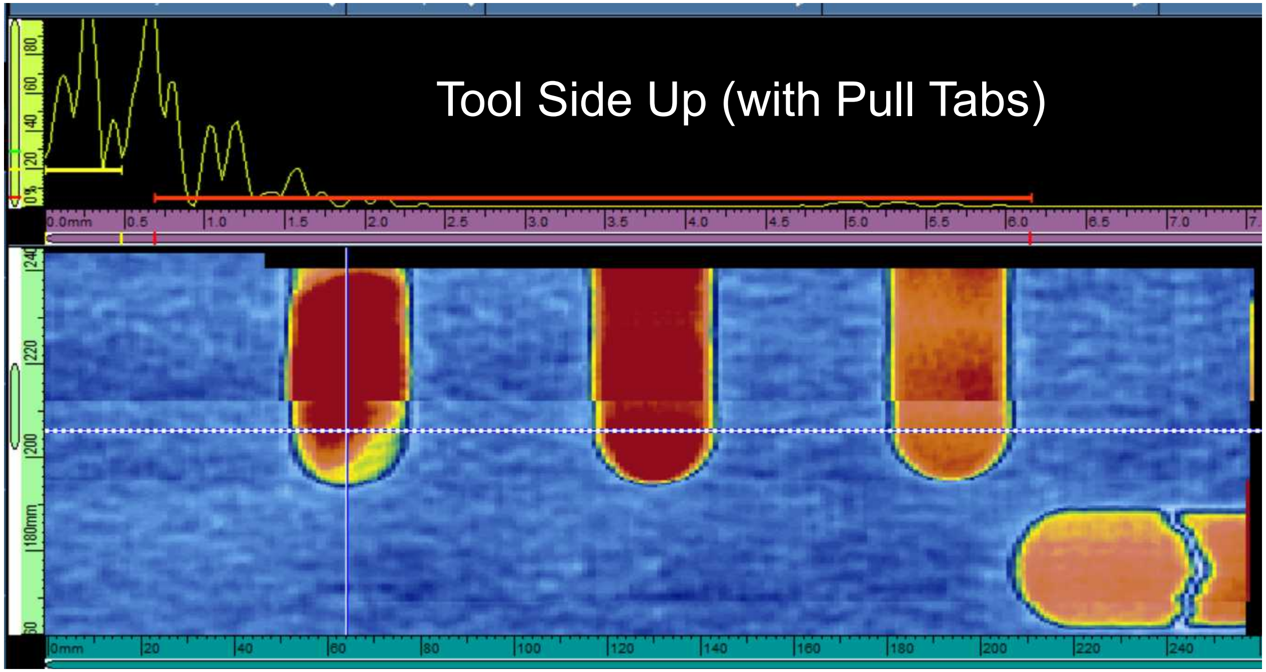
Poorly bonded areas return no interface signal from the aluminum this results in a lower amplitude signal.

Portable Roller Scanner

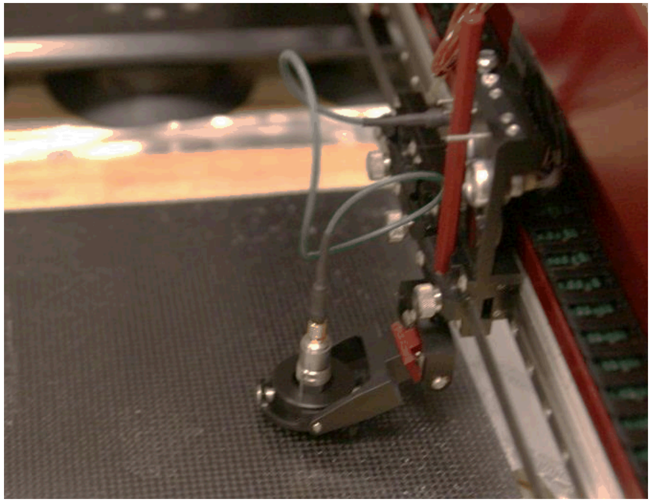




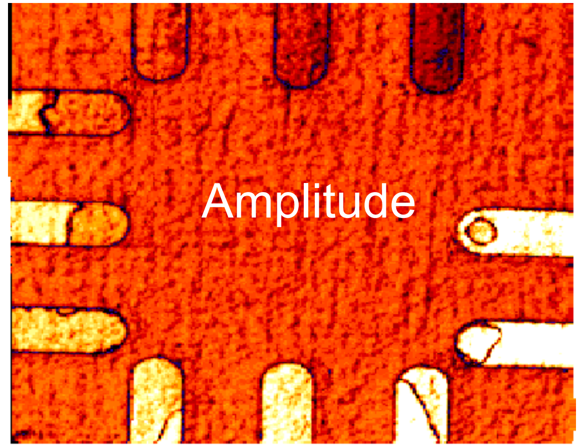


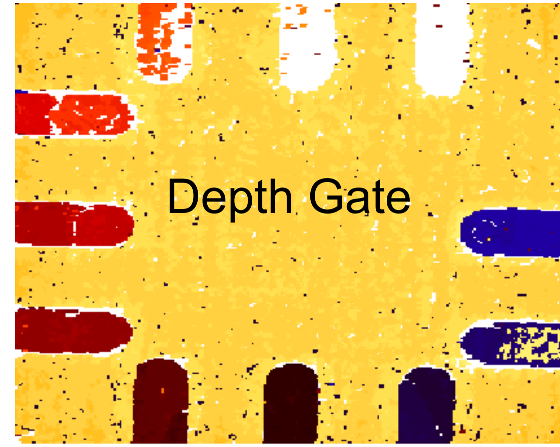


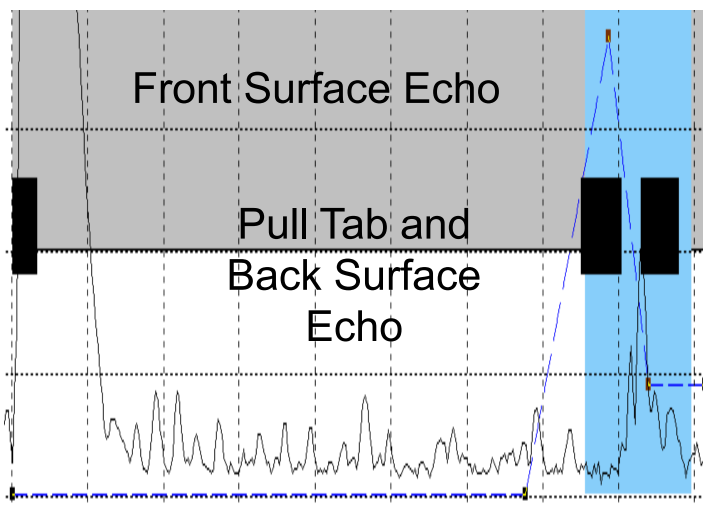
Semi-automatic Scanner



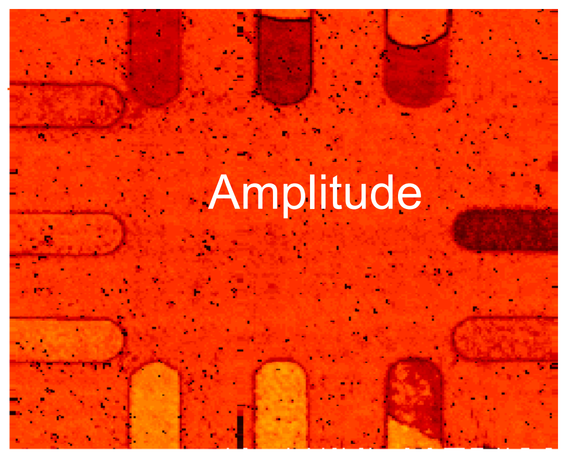
Tool Side Up (with Pull Tabs)

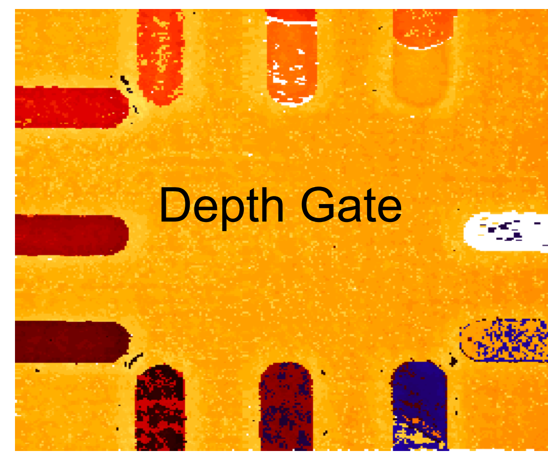






Tool Side Down (with Pull Tabs)





Conclusions

- Contact, immersion and array methodologies can characterize the interface wave scattering. If the composite layer is thin enough (less than eight plys) acoustic wave techniques can analyze the bondline. Both conventional and advanced ultrasonic methods can detect interfaces between the metal and composite. This comparison of the pulse-echo signal measured is based at the point of interest (the interface).
- It is difficult to correlate ultrasonic signal to the strength of a bond. Bond strength is not a physical property but a structural parameter. The inspection methods described in the paper are not designed to find the weakest of the weakest area (i.e. highest stress in the weakest specific area of failure). Understanding the behavior of bonded interfaces with the use of ultrasonic inspection will ensure safety and reliability of designs.
- The equations of wave propagation in composites can be applied for any angle of incidence which composite behave as a layer isotropic medium. Ultrasonic techniques described above can detect most discontinuities types that are required. However, a high variance in the material properties, surface roughness may not allow for a reliable assessment. The most important variable to understand for all composite inspection is the role of attenuation.

Abstract

- Solid woven carbon fiber reinforced plastic (CFRP) consist of two or more components. The constituents retain their individual material properties in the composite matrix at the macroscopic level. Generally, one of the materials acts as a reinforcing agent and the other constituent serves as a polymeric binder for the carbon weave. The binder also creates covalent bonds between the composite and metal surface. All composites and metal-to-composite interfaces contain voids and micro-cracks. These manufacturing anomalies result in; a higher ultrasonic noise signals in both A and B-scans. The C-scan scan produces a textured appearance. The interaction of sound dispersion and absorption within the composite makes the bondline interface between reinforced plastic and metal more difficult to evaluate. This presentation explores nondestructive inspection techniques to evaluate the bondline and documents the elastic wave scattering through the metal-to-composite interface. A summary of the detection and analysis techniques developed to identify: inserts, lack of bonding and porosity levels within a solid laminate and bondline are presented.