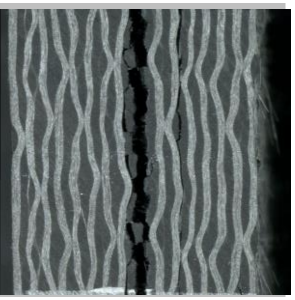
SAND2016-5132C

Bondline Boundary Assessment of Cohesive Bonded Solid Woven Carbon Fiber Composites Using Advanced Diagnostic Methods



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505-844-7095

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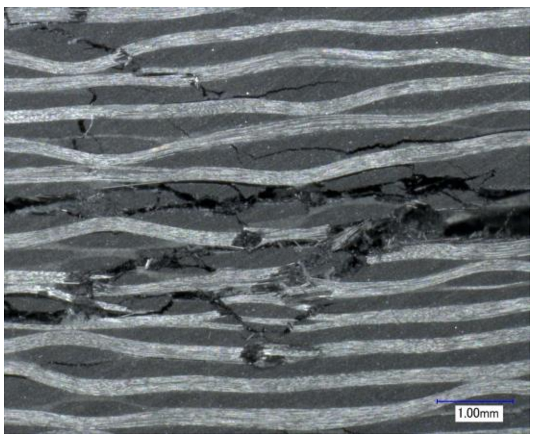
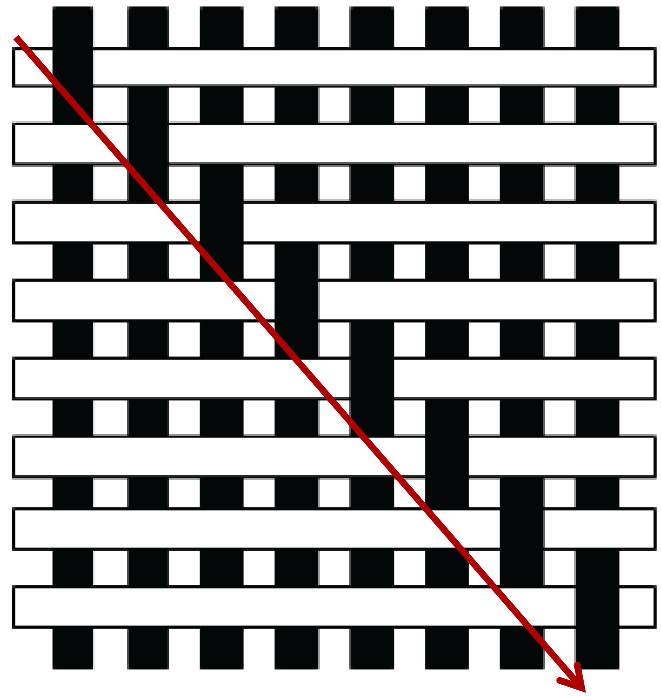
Solid Laminate Layup

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

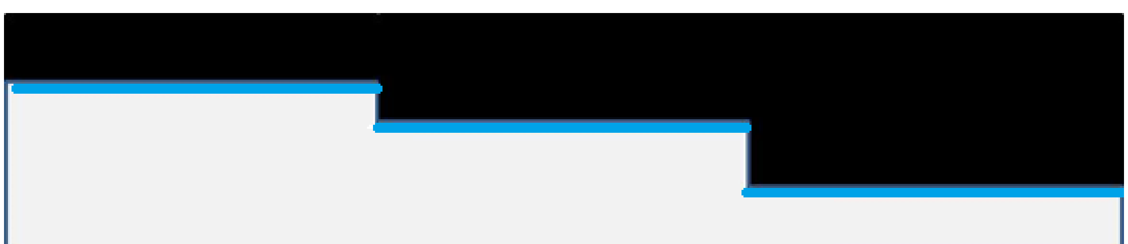


4 ply $[0/90]_2]_s$
8 ply $[0/90]_4]_s$
12 ply $[0/90]_6]_s$

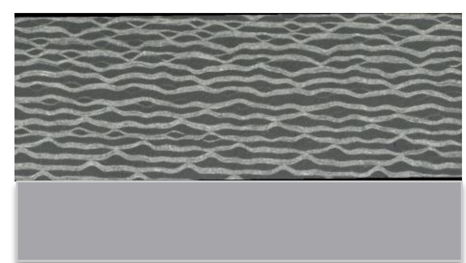
Side view



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



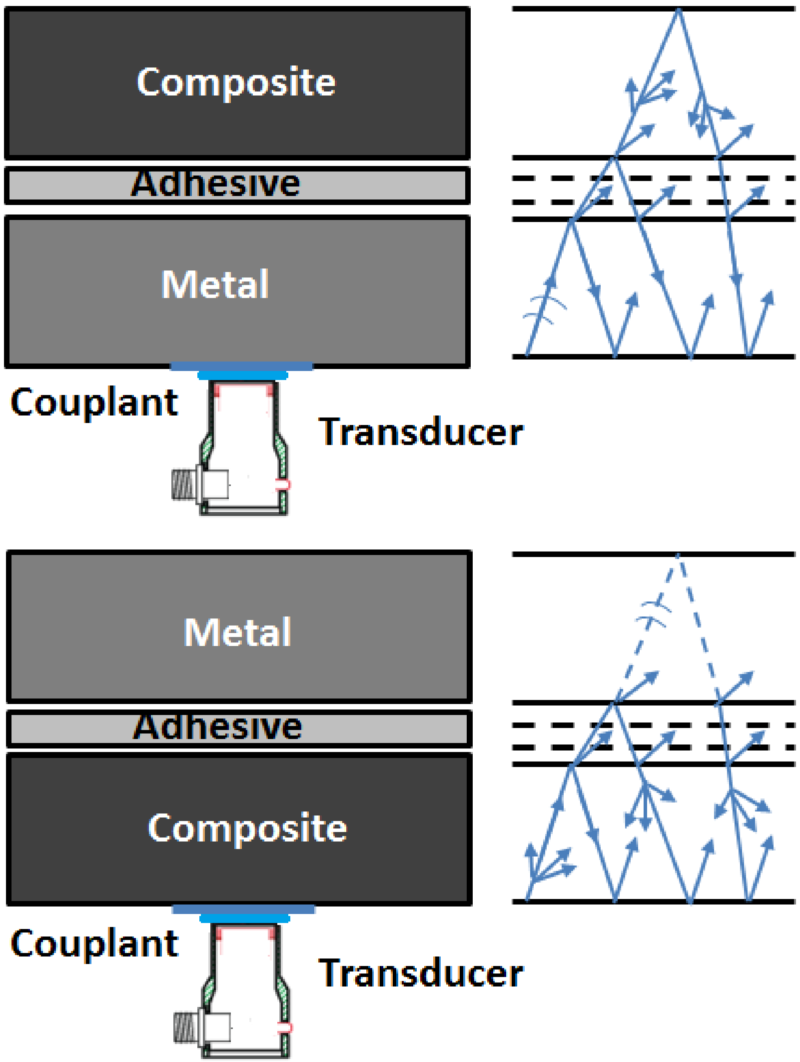
End view



12 plies

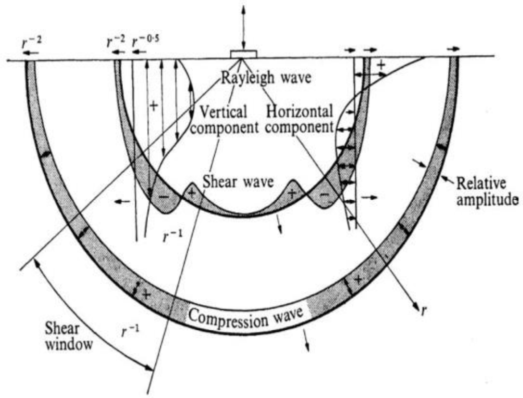
Wave Scatter Theory 1/2

- 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 2/2

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.



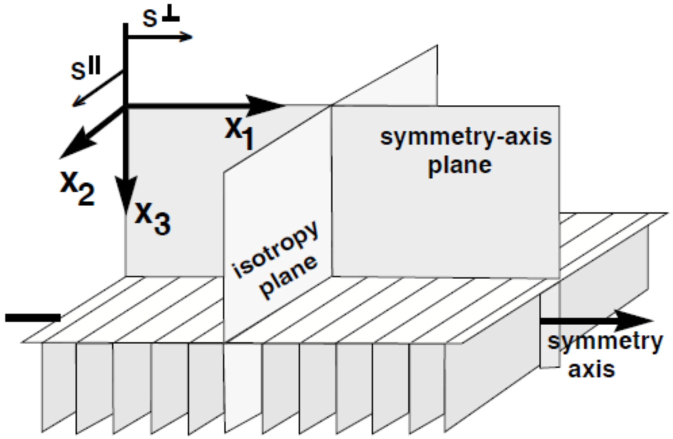
Source "Elastic Wave Propagation in Materials" , Walley, S.M., Field, J.E. Materials Science and Technology, Elsevier 2005.

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

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.

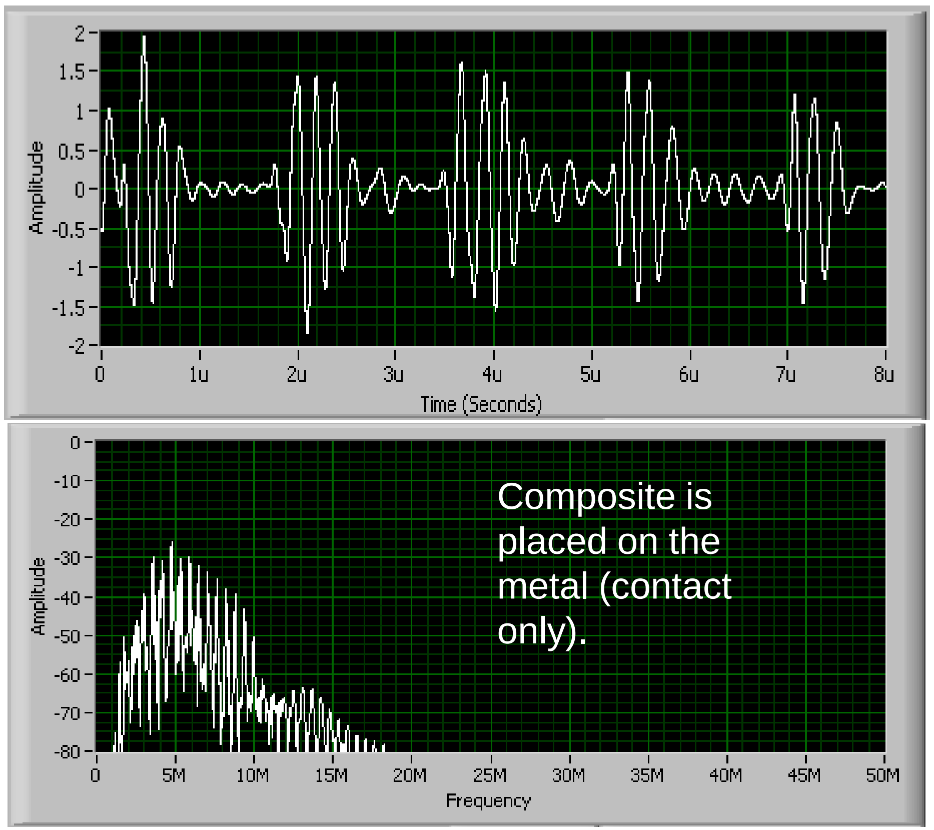
These two velocities are related to each other through dispersive properties (frequency dependence of the phase velocity).

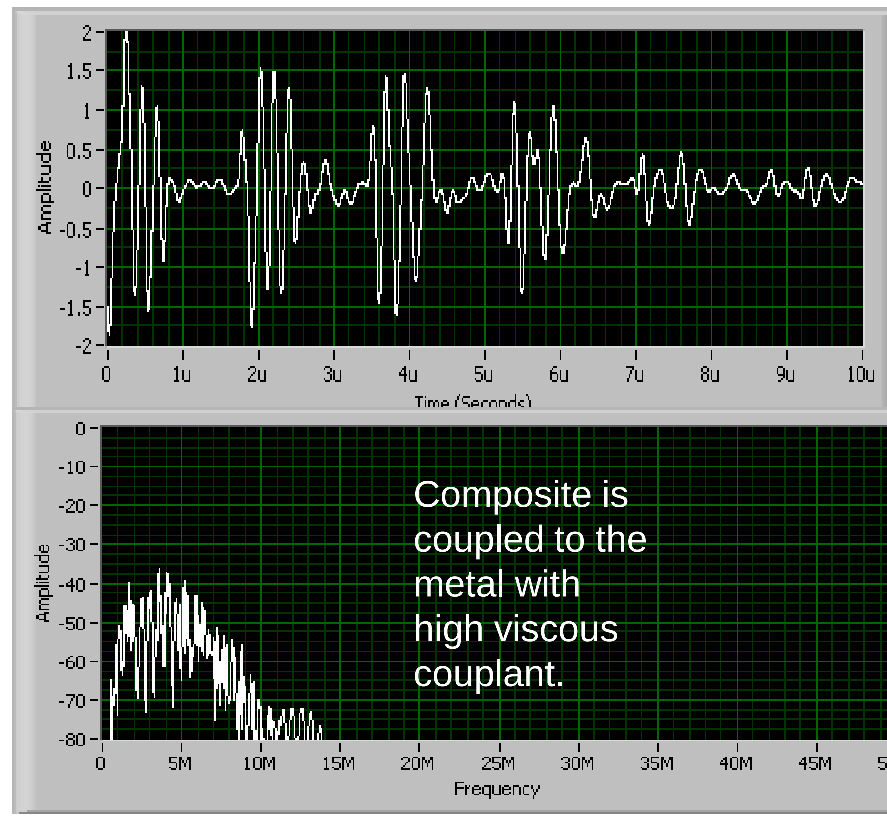


Source: Horizontal Transverse Isotropic axis defination, MIT OpenCourseWare http://ocw.mit.edu/terms/

Metal to Composite - Conventional Ultrasonics

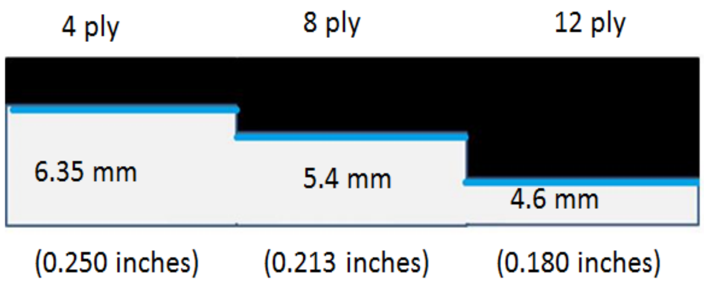
Contact: 5 Mhz A-Scan of 6.30 mm thick aluminum and composite placed below.

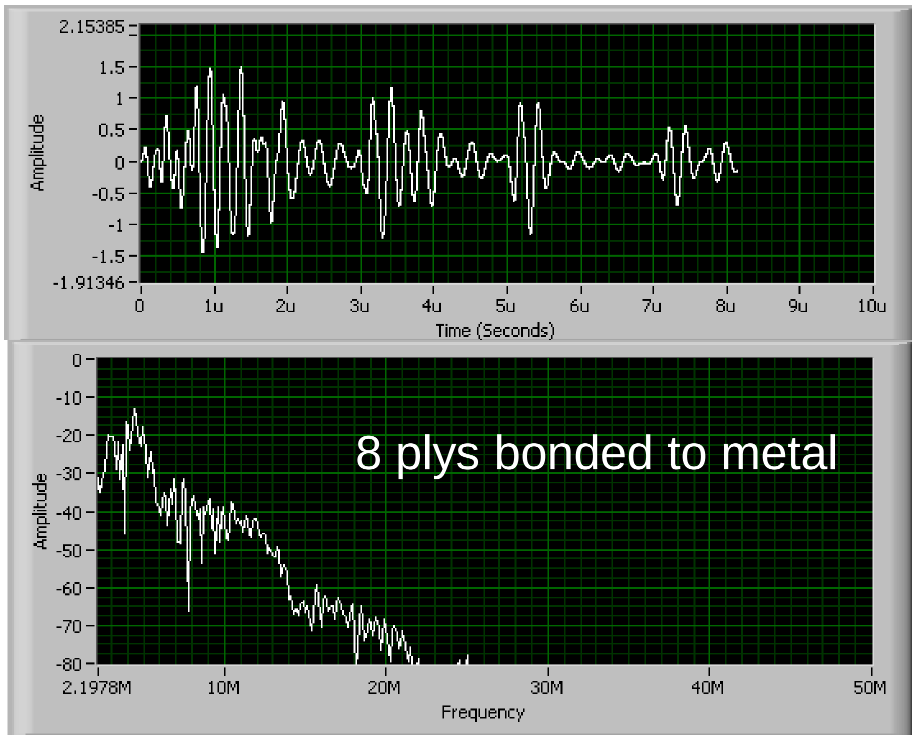


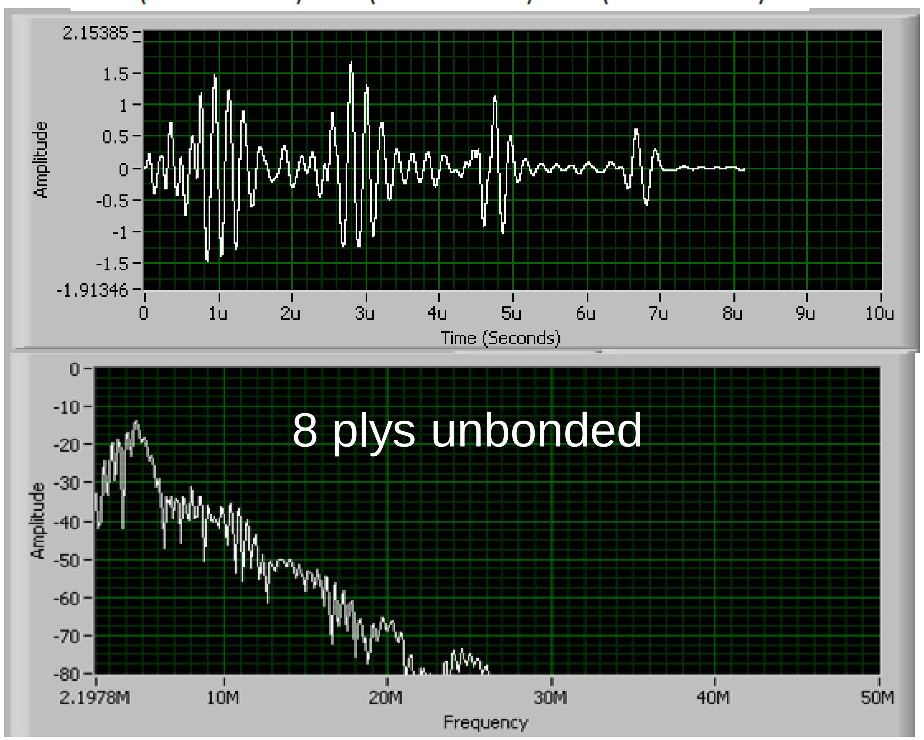


Composite to Metal - Conventional Ultrasonics

Contact: 5 Mhz A-Scan of (8 ply) 1.68 mm thick composite bonded to aluminum.

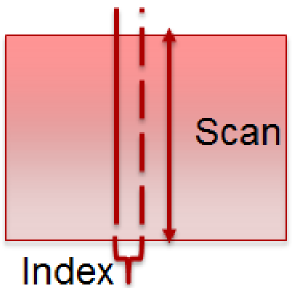


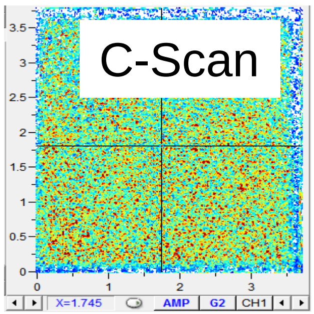


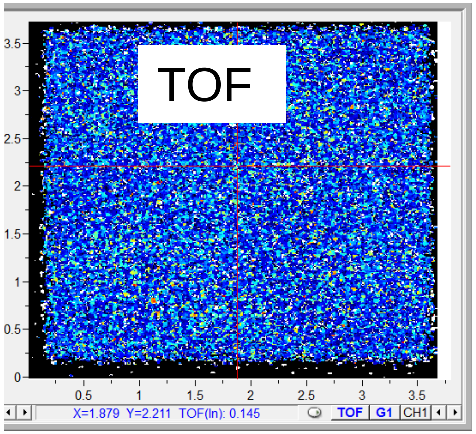


Interface Detection with Immersion Ultrasonics (1 of 3)

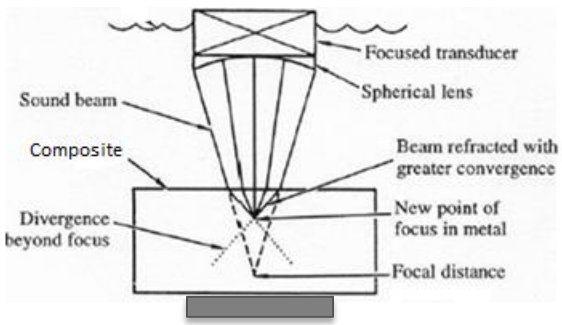
In immersion testing, the part and the transducer are placed in a tank filled with water. This allows for better movement of the transducer while maintaining consistent coupling. Its disadvantage is that the part must sit in water for long periods of time. Immersion testing can also measure backwall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





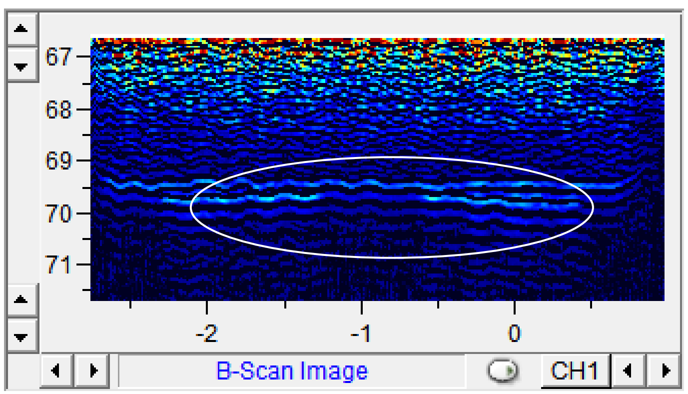


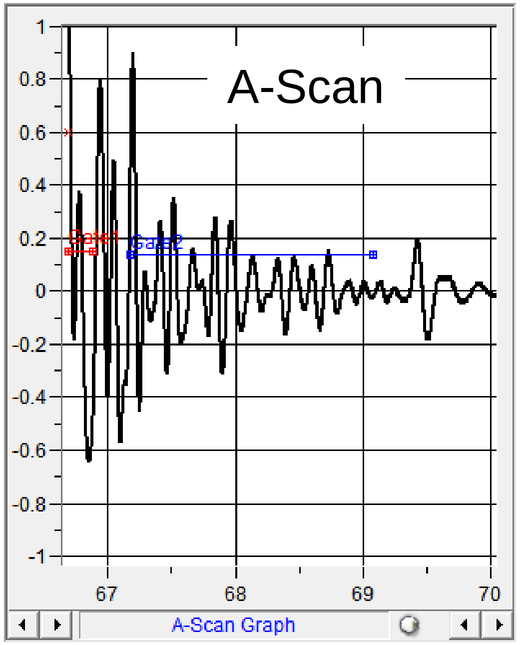
Immersion:10 Mhz
12 ply composite only
thickness 4.60 mm
V_c = 2.85 km/sec



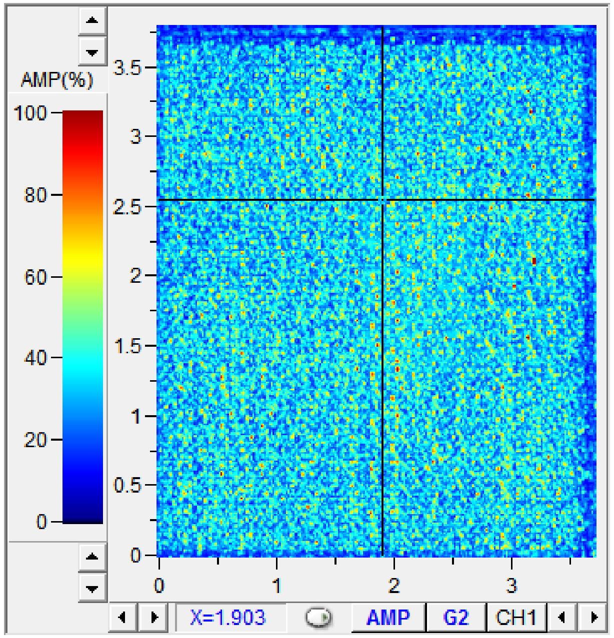
Metal standoff

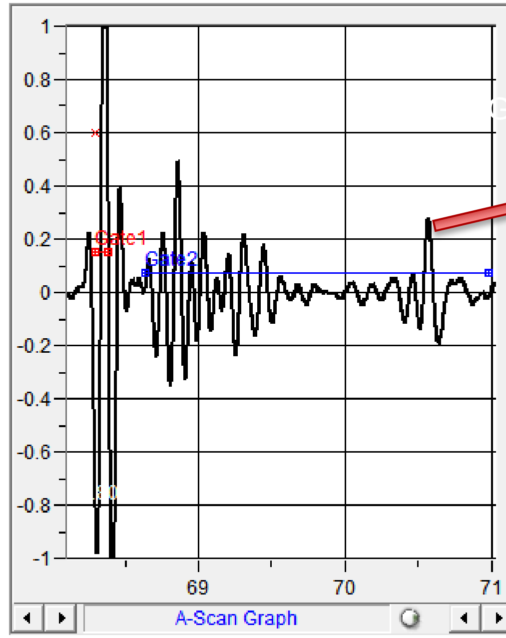
B-Scan

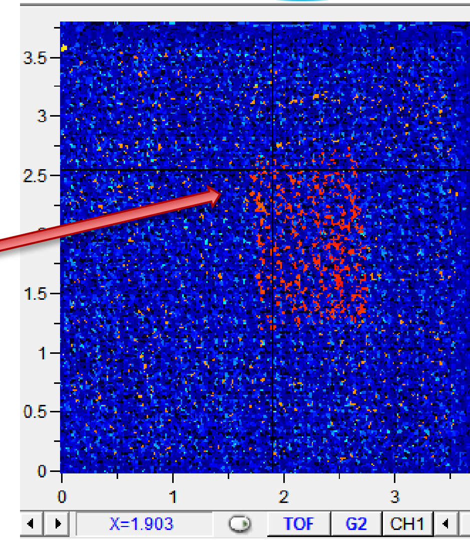




Interface Detection with Immersion Ultrasonics (2 of 3)





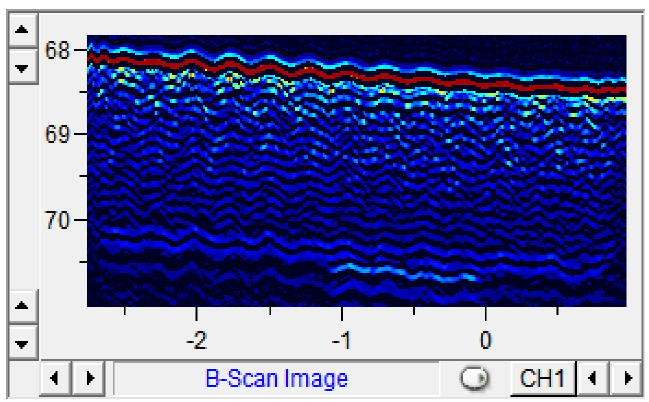


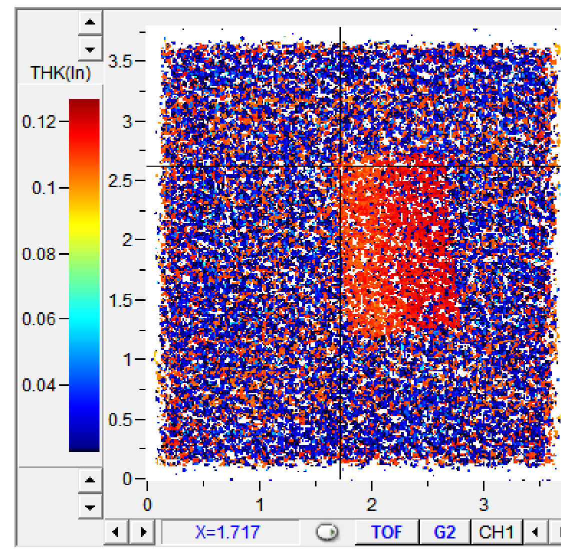
Immersion: 10 Mhz

8 ply composite only

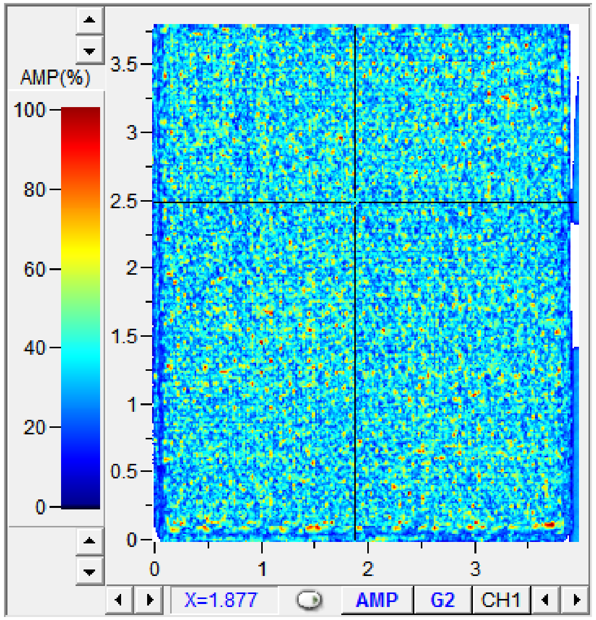
thickness 3.11 mm

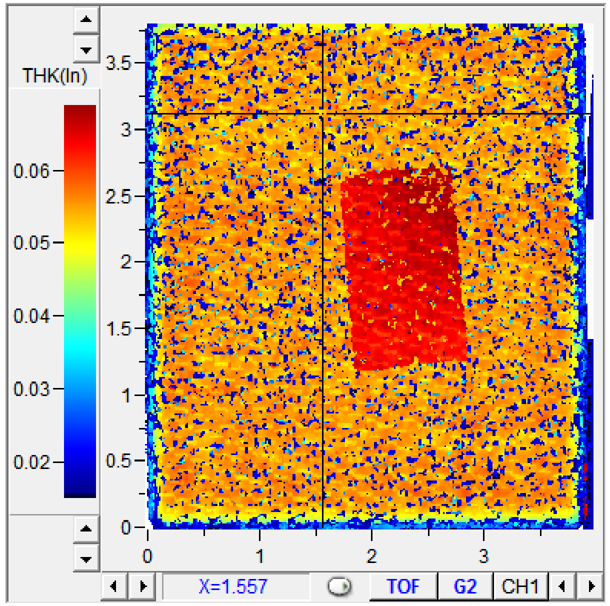
V_c = 2.93 km/sec



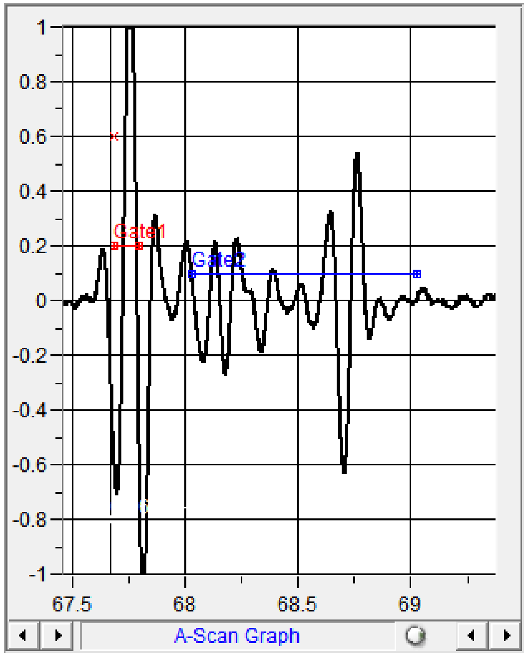


Interface Detection with Immersion Ultrasonics (3 of 3)



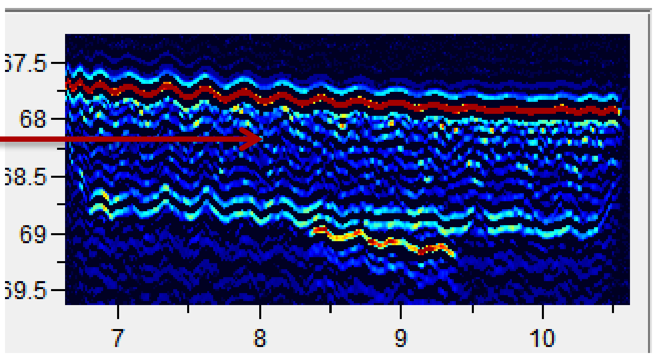


Time of flight



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

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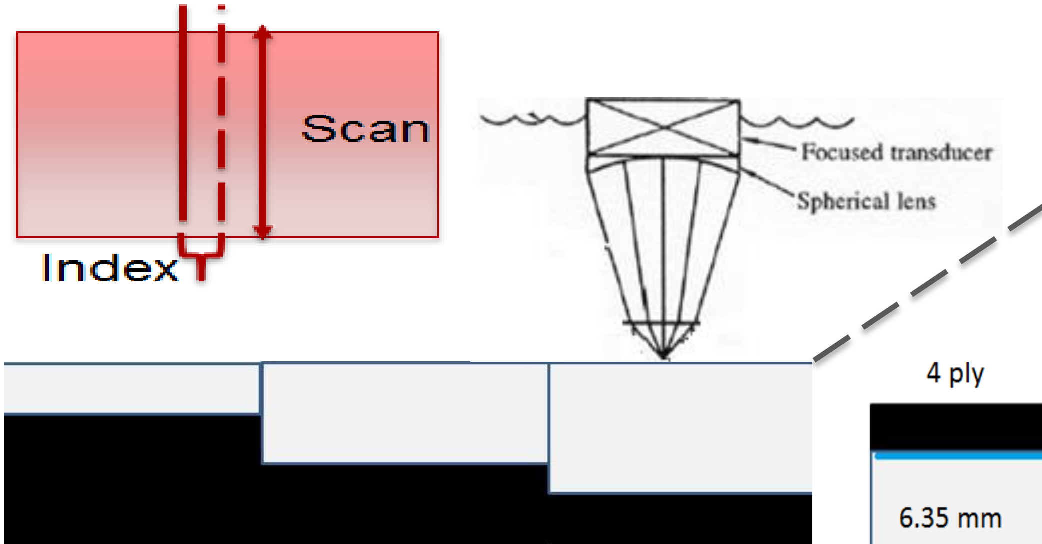
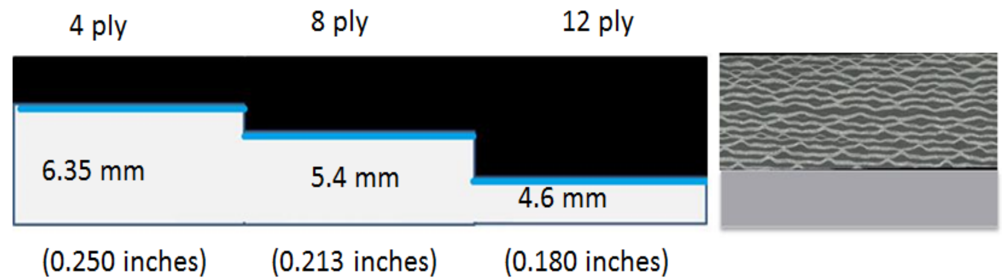
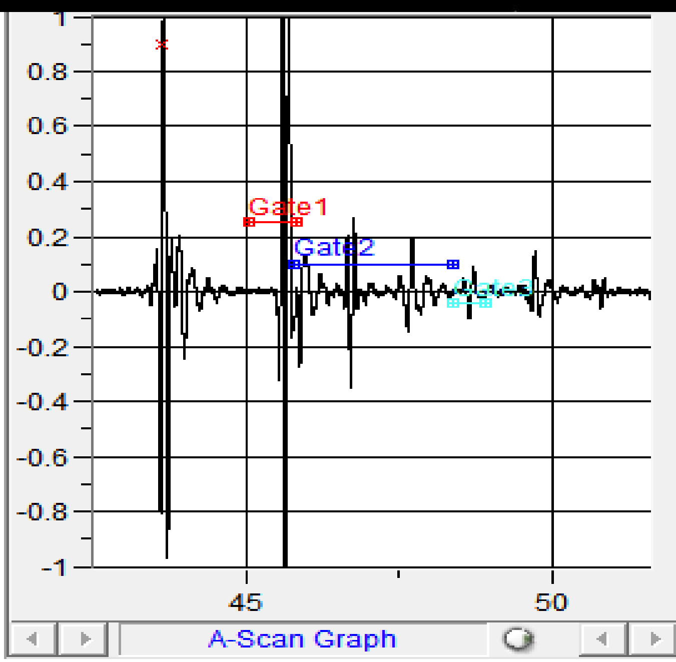
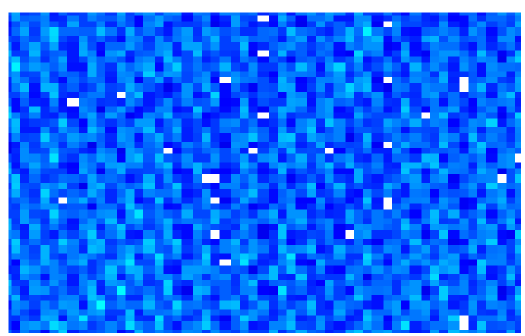


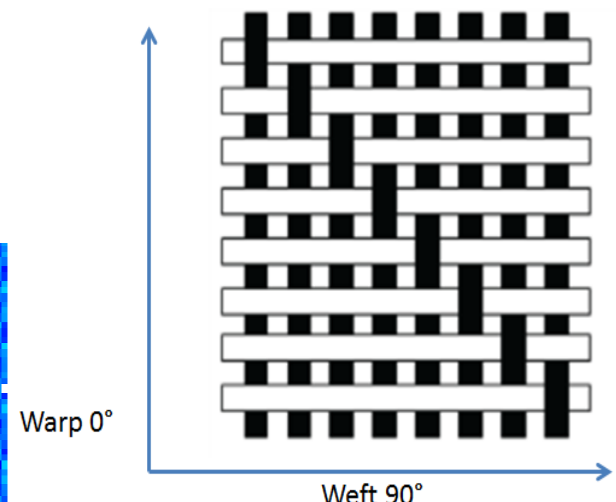
Part is scanned from both sides





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





Bondline Detection Aluminum Over Composite

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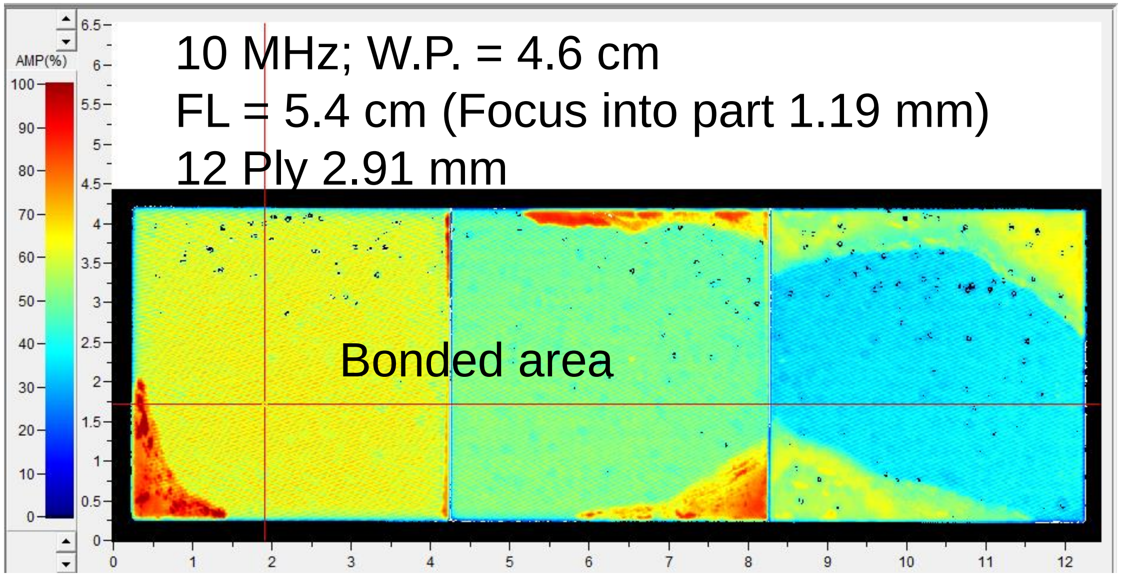
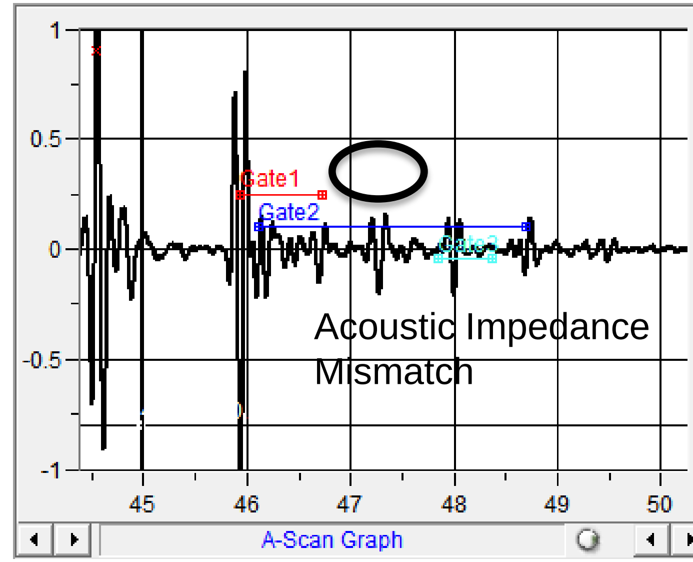
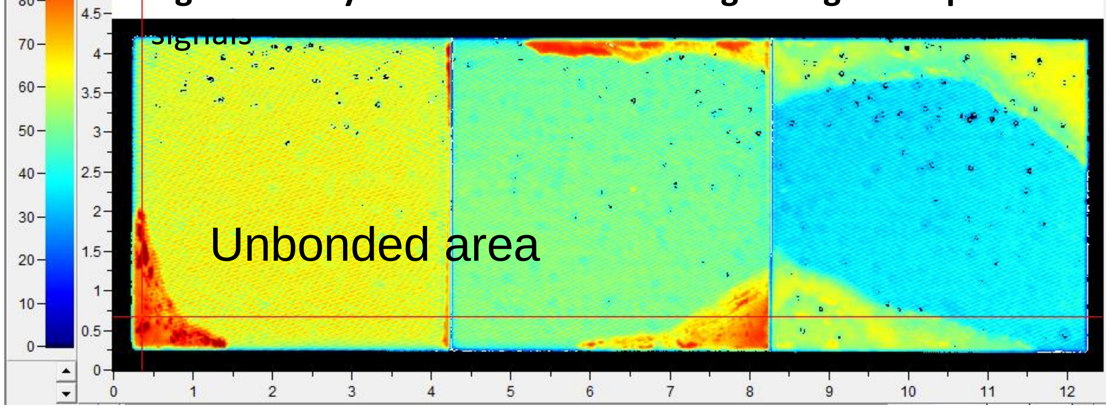
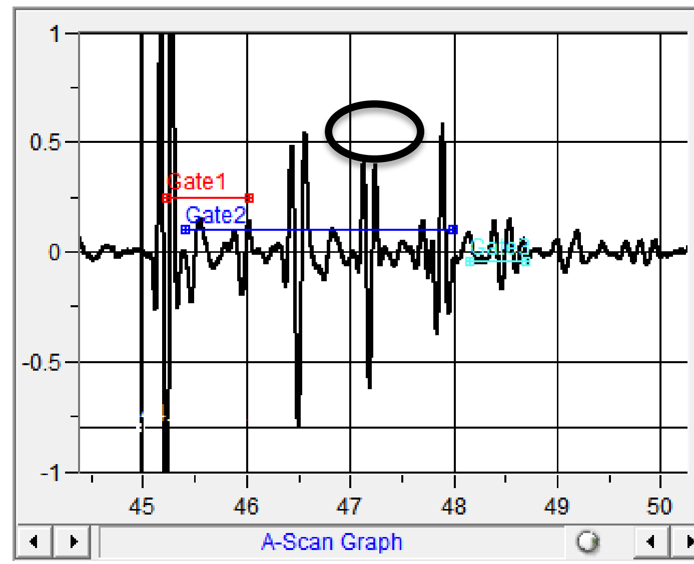




In well bonded areas the sound transmits through the aluminum and into the composite (yellow, green and blue <u>thickness change in aluminum</u>) and returns a lower amplitude signal. Poorly bonded areas return higher signal amplitude.





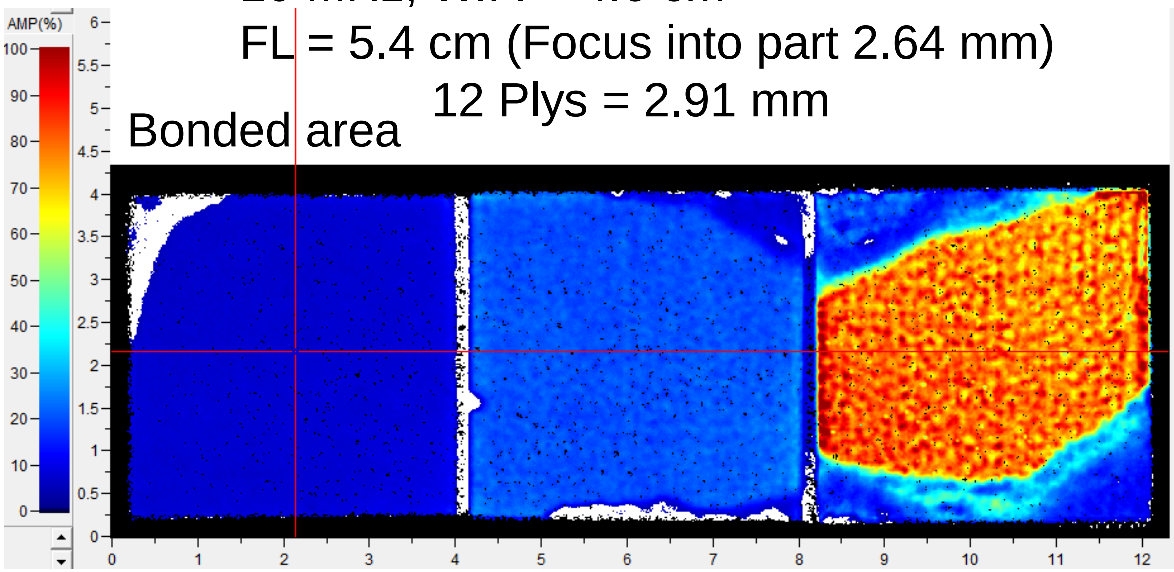
Bondline Detection Composite over Aluminum 1 of 2

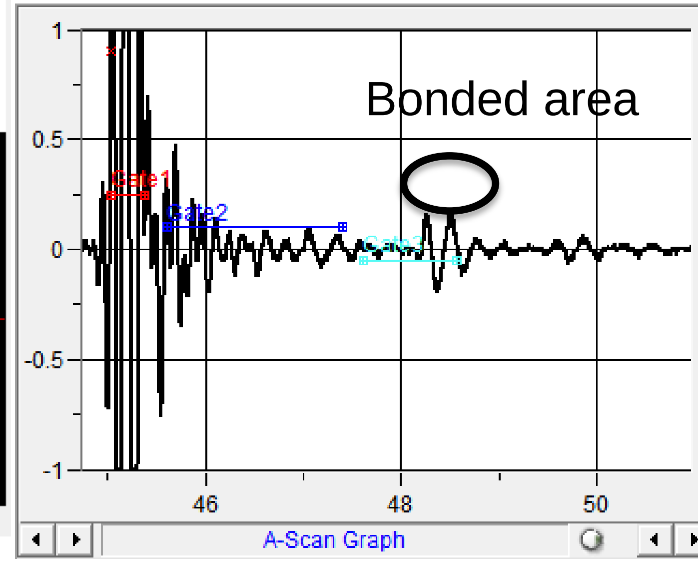
10 MHz; W.P. = 4.6 cm

FL = 5.4 cm (Focus into part 2.64 mm)

12 Plys = 2.91 mm

Bonded area



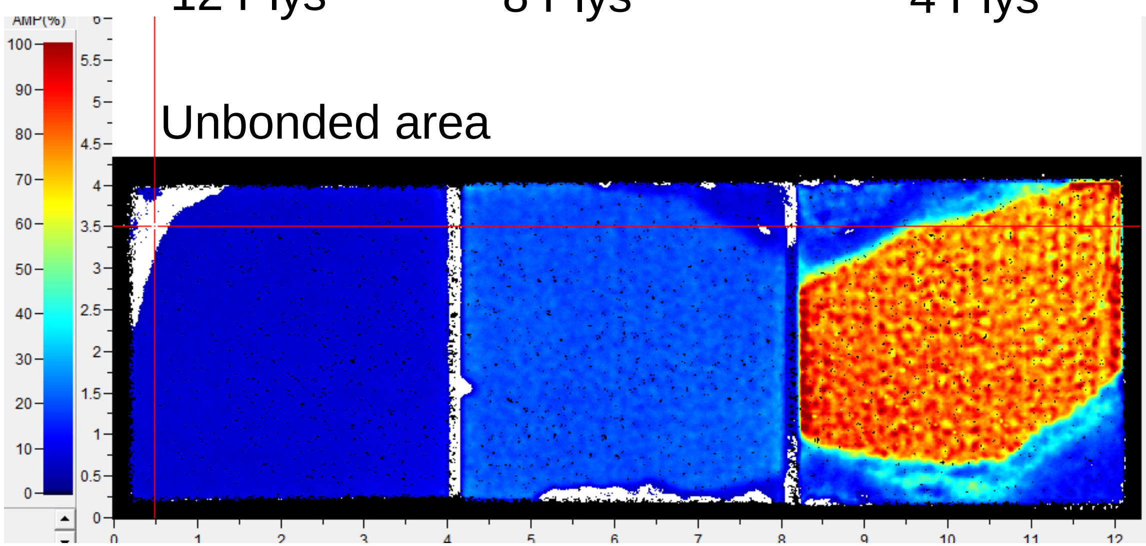


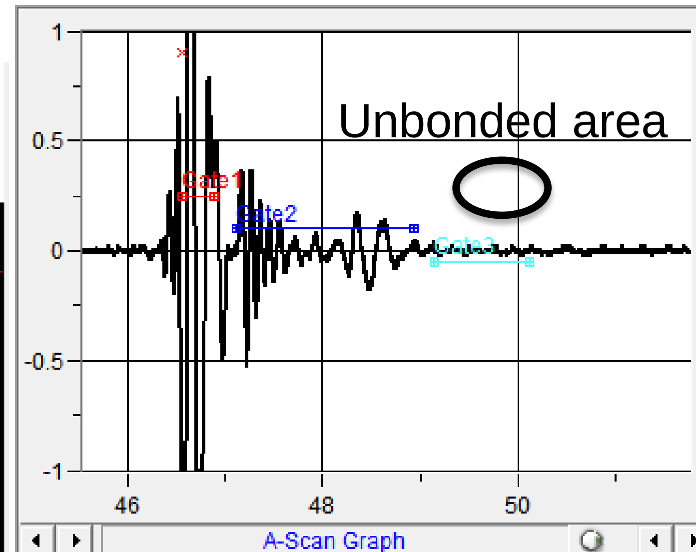
12 Plys

8 Plys

4 Plys

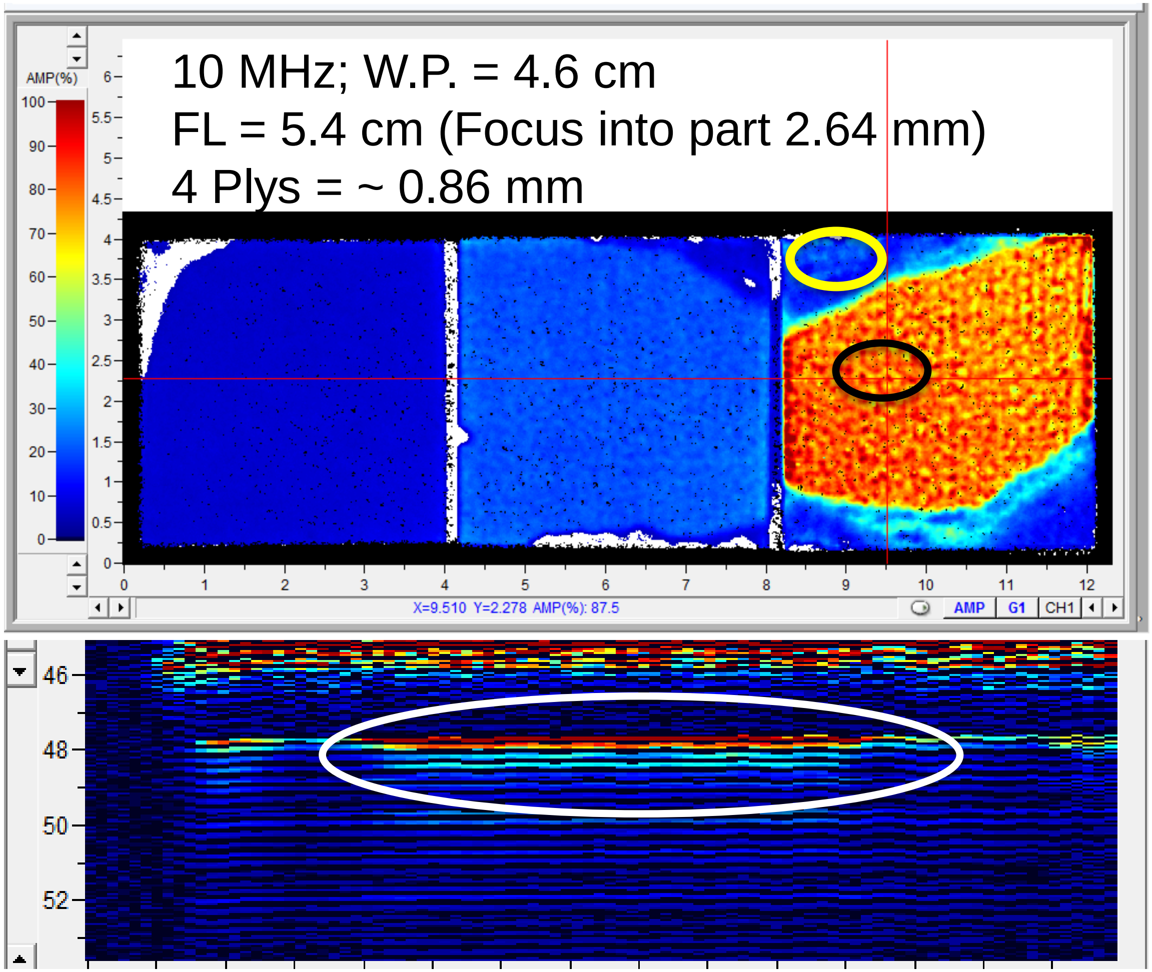
Unbonded area

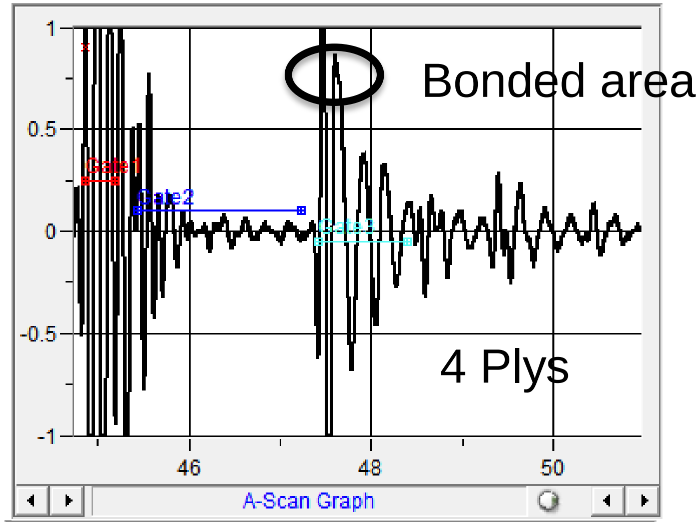


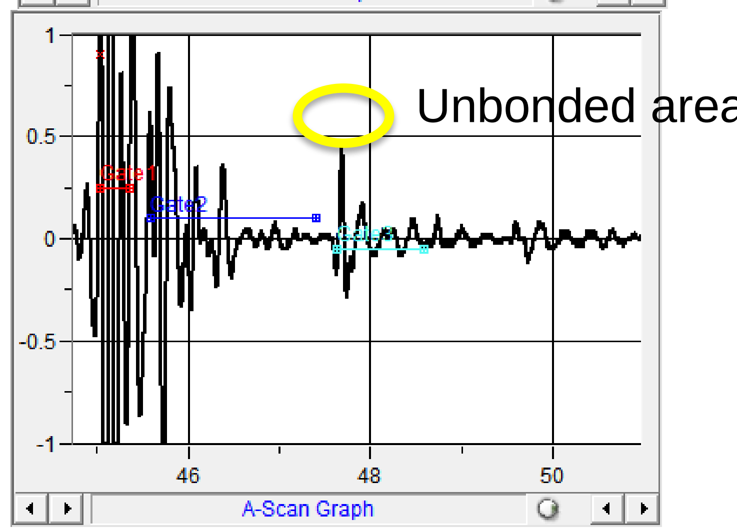


Bondline Detection Composite over Aluminum 2 of 2

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





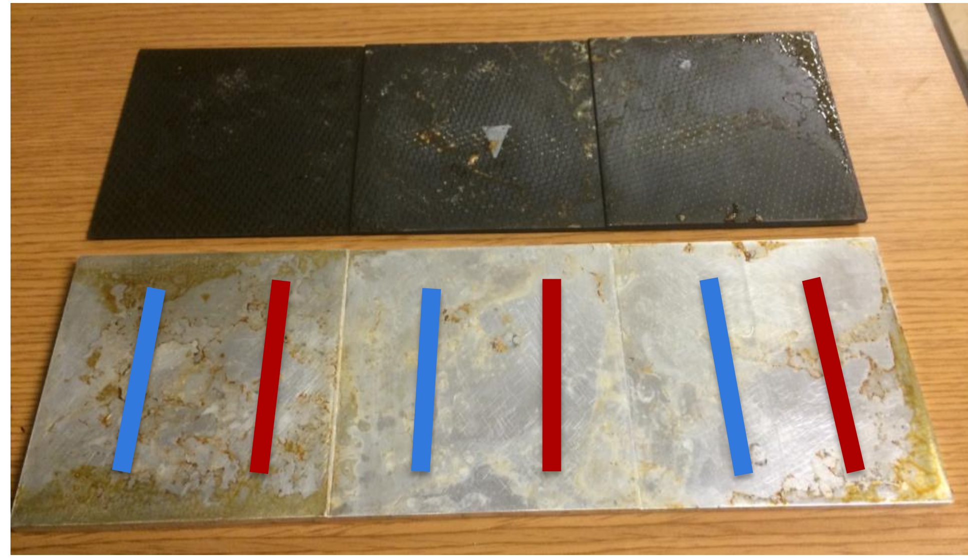


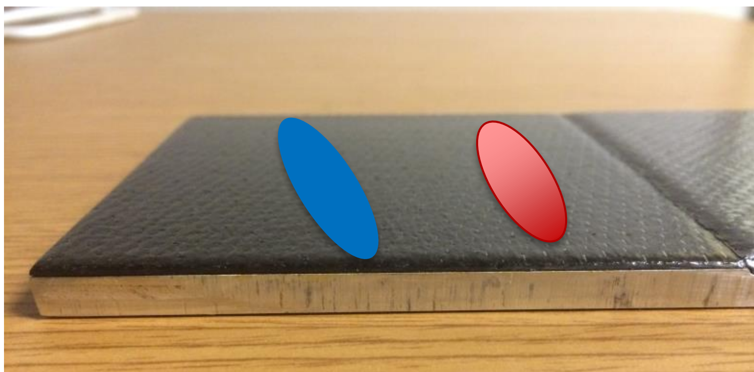
Poorly bonded areas return no interface signal from the aluminum this results in a lower amplitude signal.

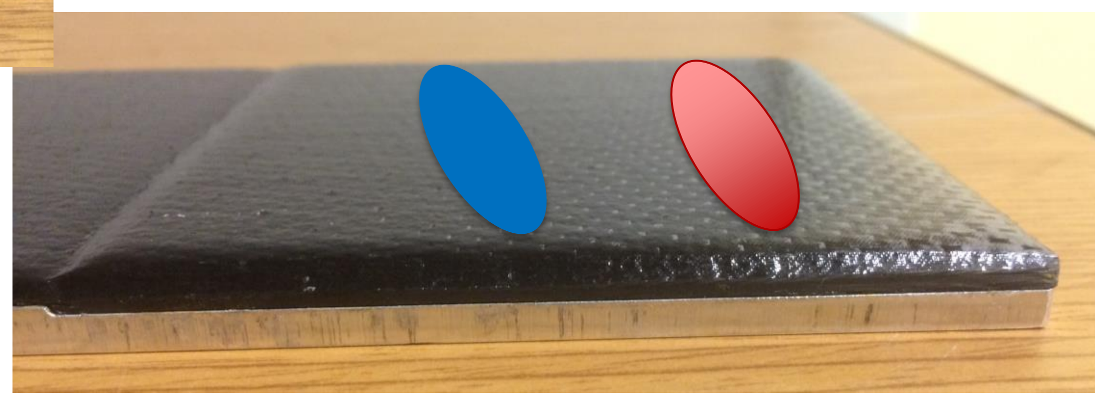
Interface Detection Using Couplant on Dissimilar Materials

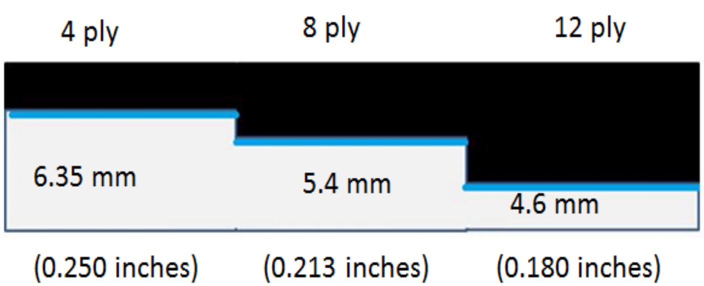
High viscous v_c = 2030 m/sec

Glycerin Oil v_c = 1920 m/sec

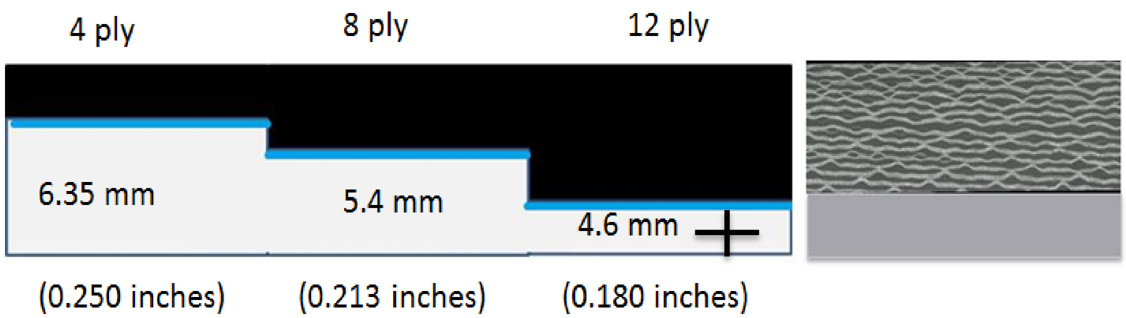


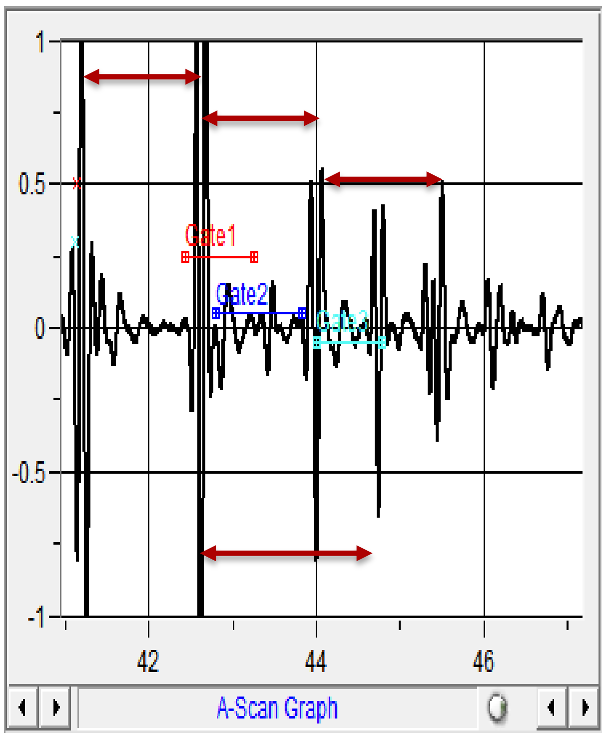




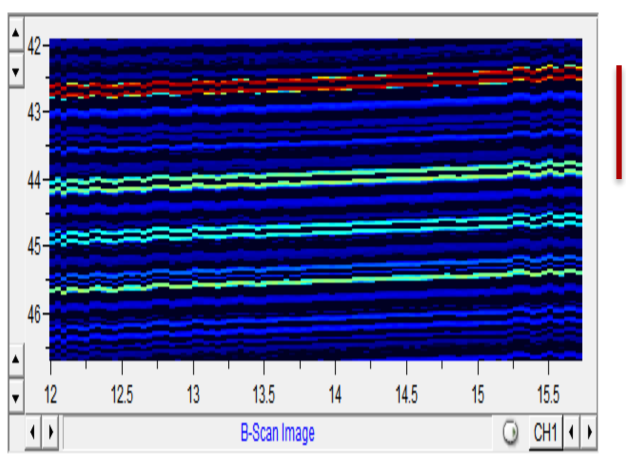


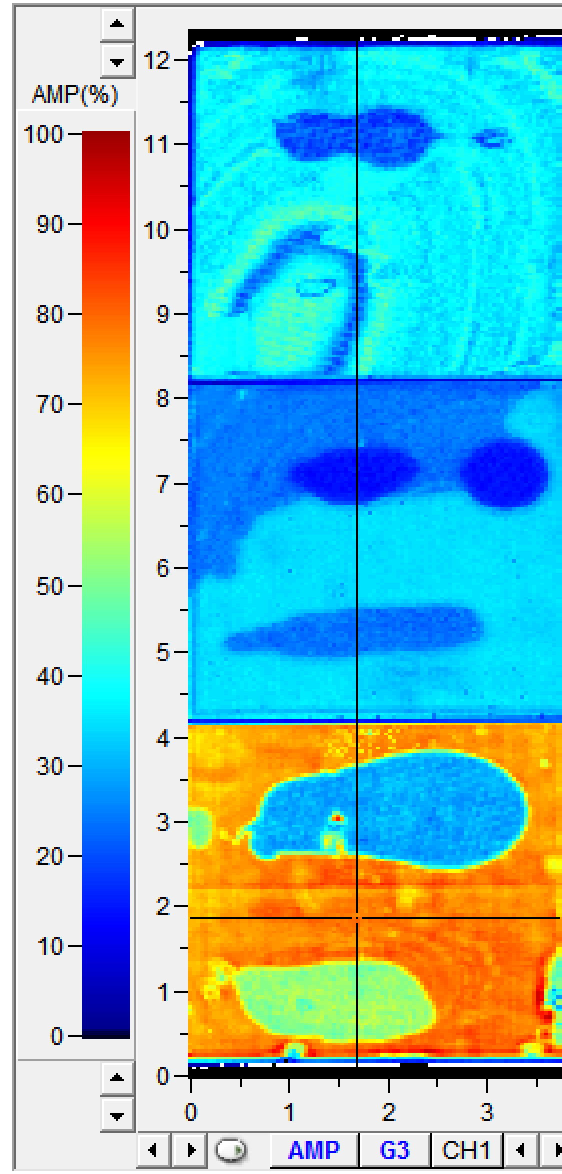
Couplant Between Two Dissimilar Materials 1 of 5



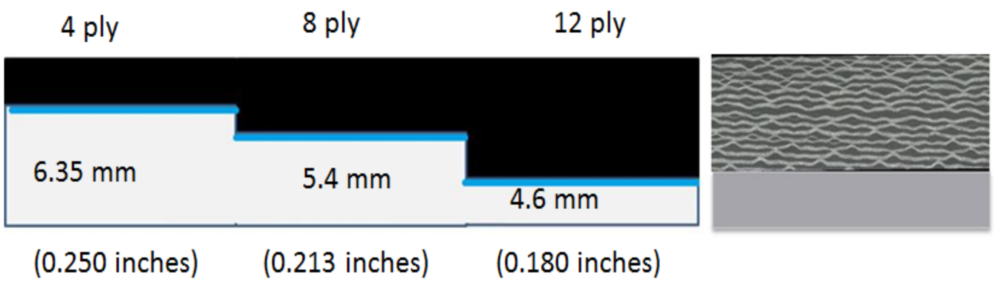


No bond
aluminum side up

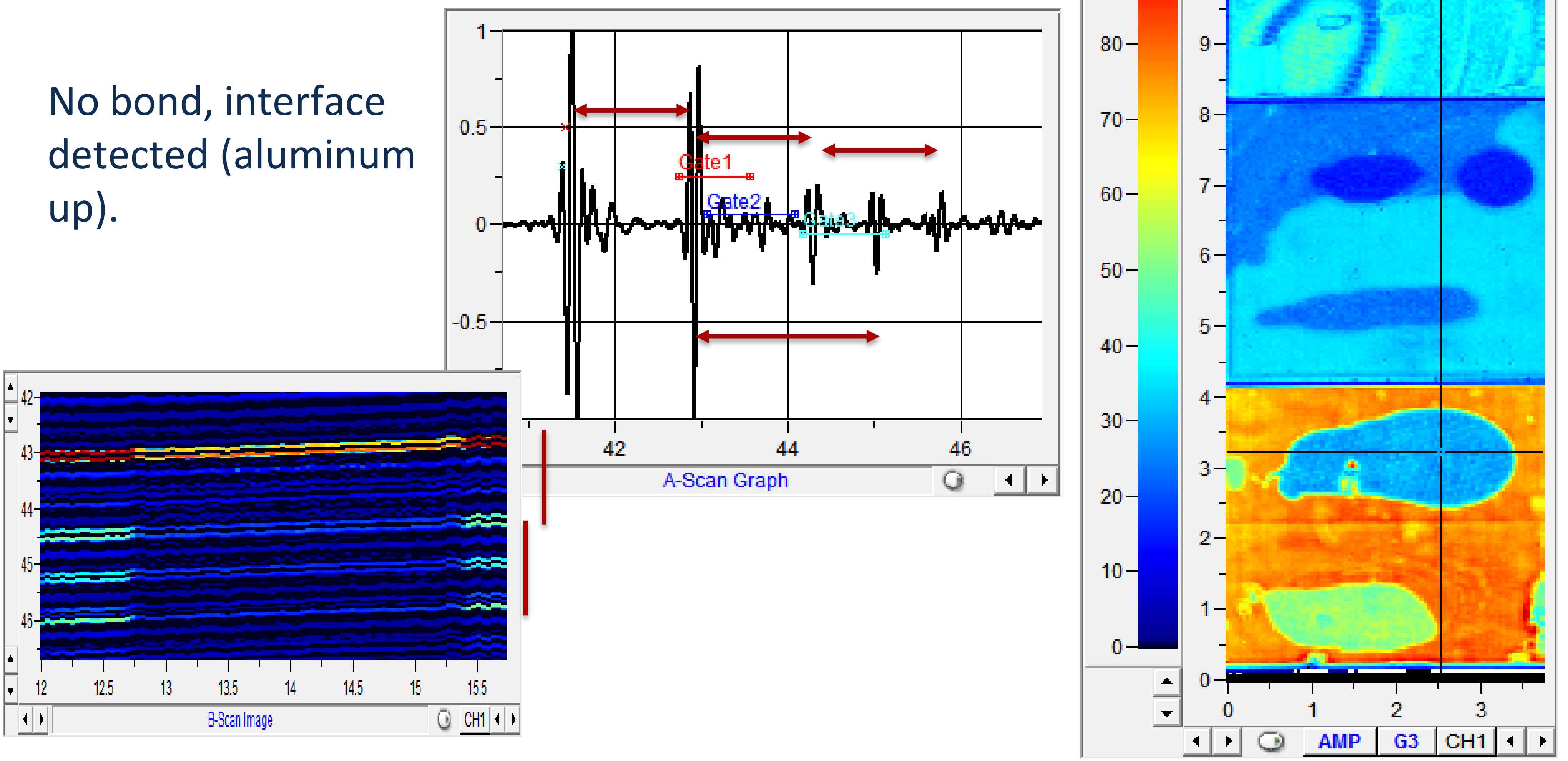




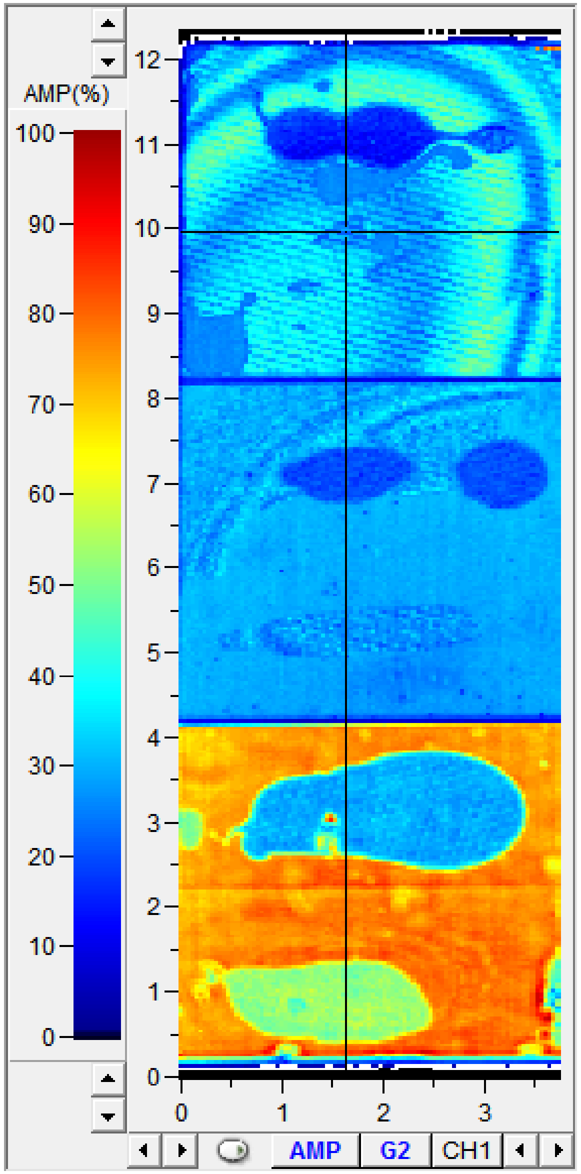
Couplant Between Two Dissimilar Materials 2 of 5



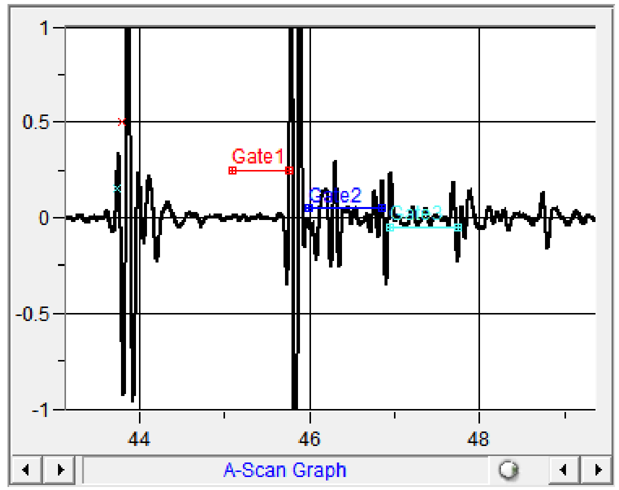
No bond, interface detected (aluminum up).

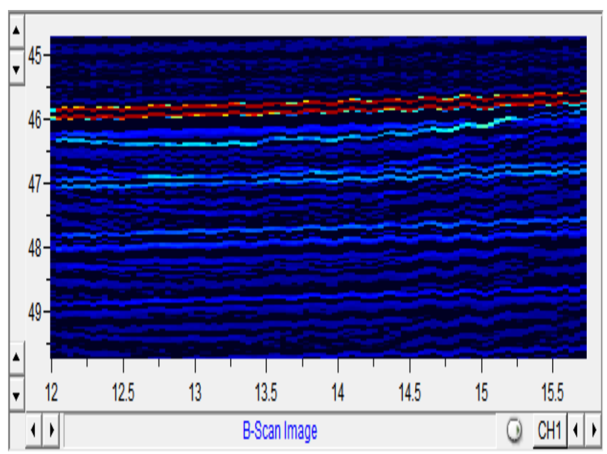


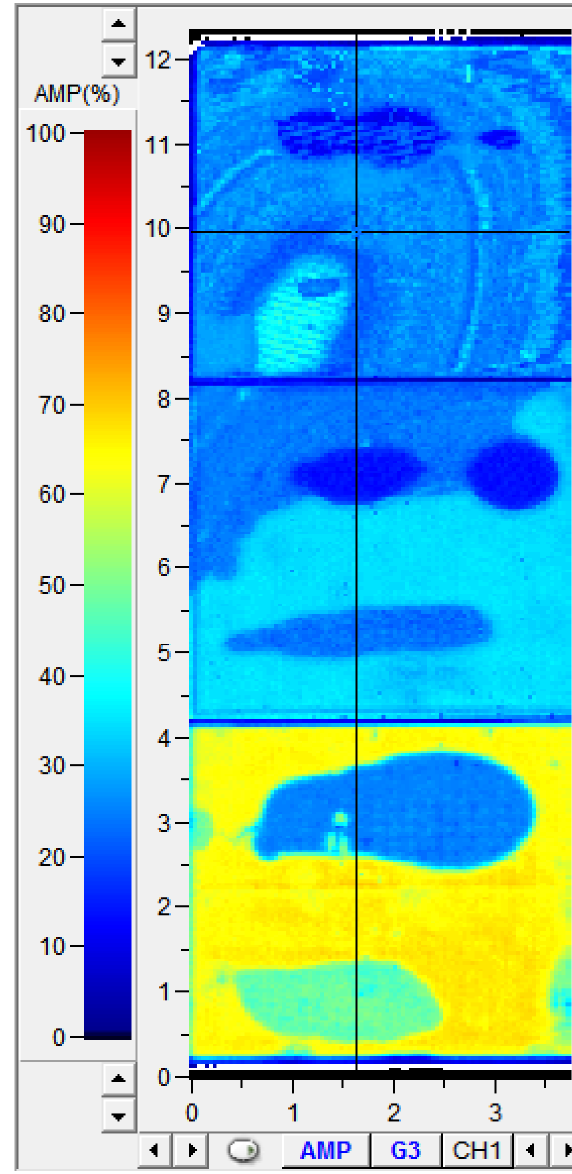
Couplant Between Two Dissimilar Materials 3 of 5



No bond, interface detected (aluminum up).







Couplant Between Two Dissimilar Materials 4 of 5

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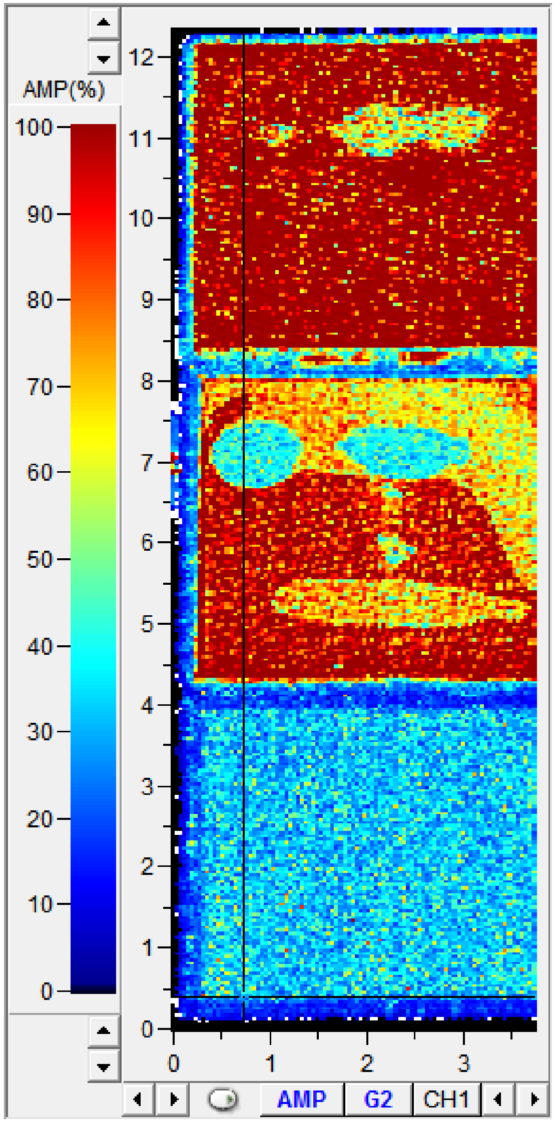
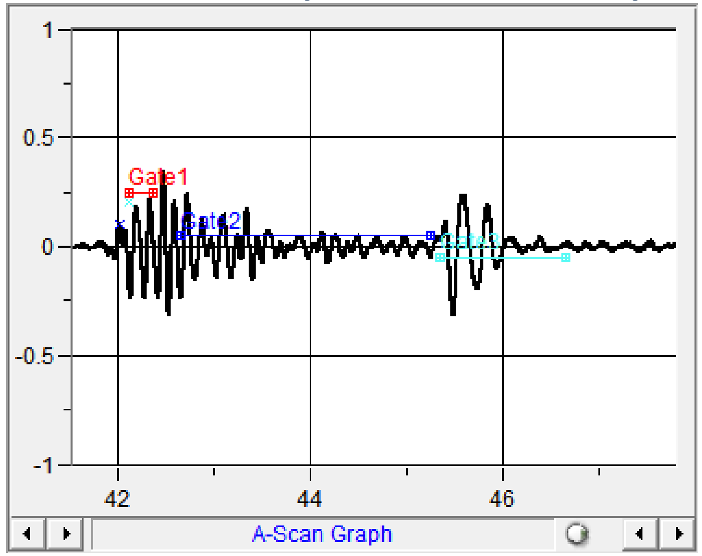
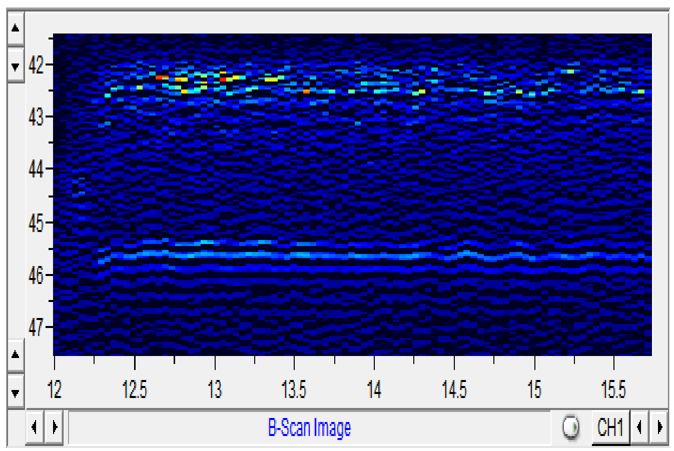
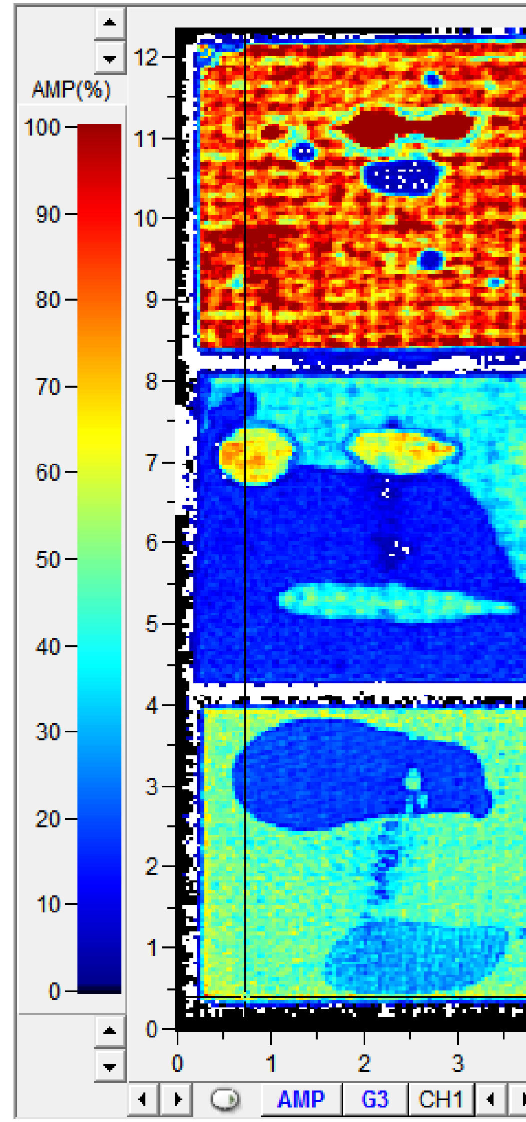
No bond composite side up

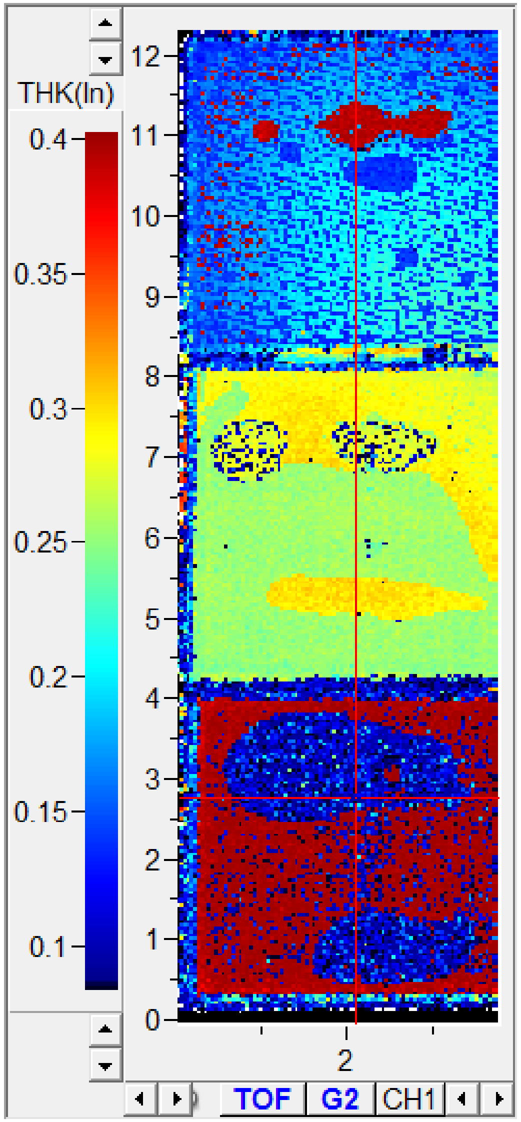




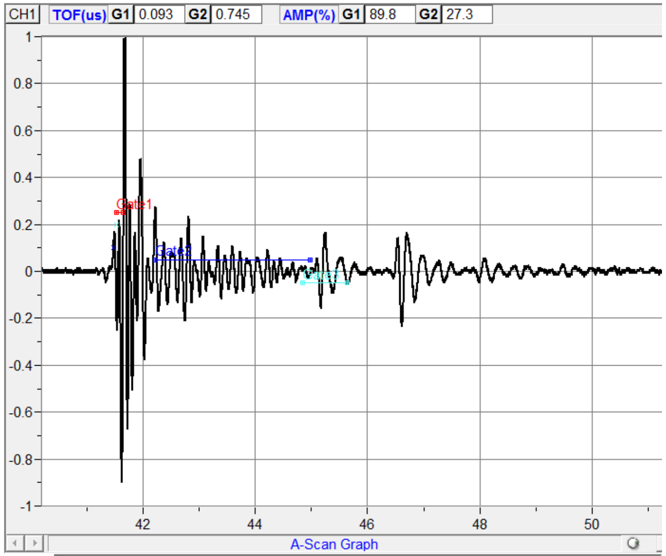


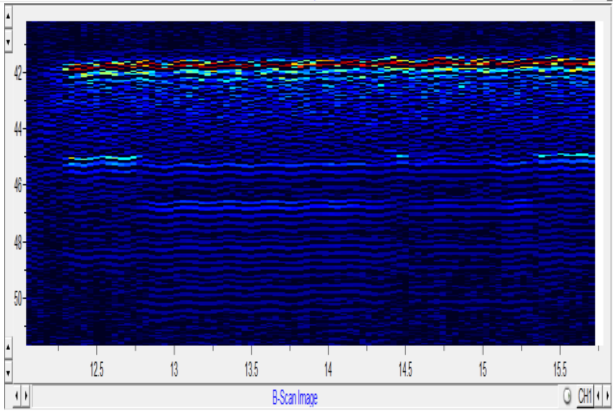


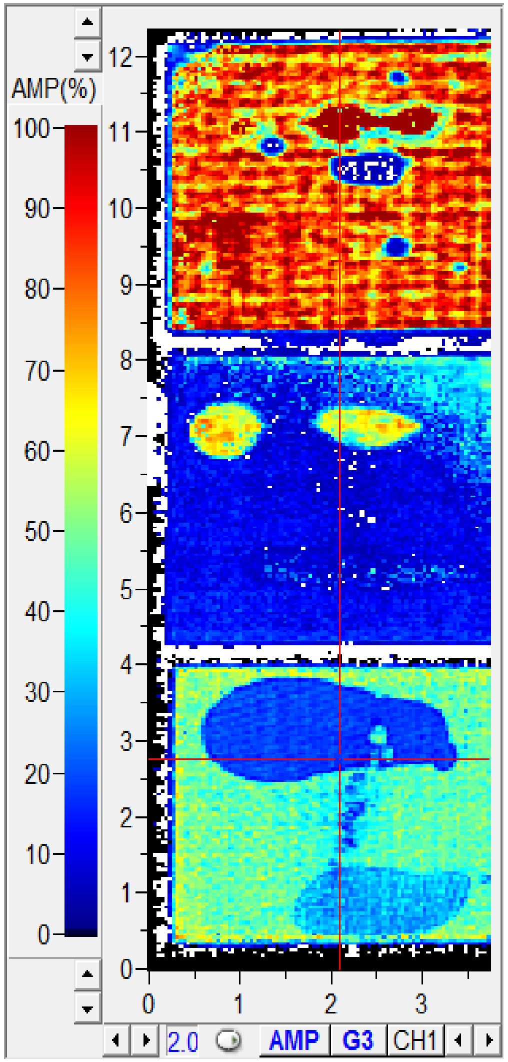
Couplant Between Two Dissimilar Materials 5 of 5



No bond composite side up





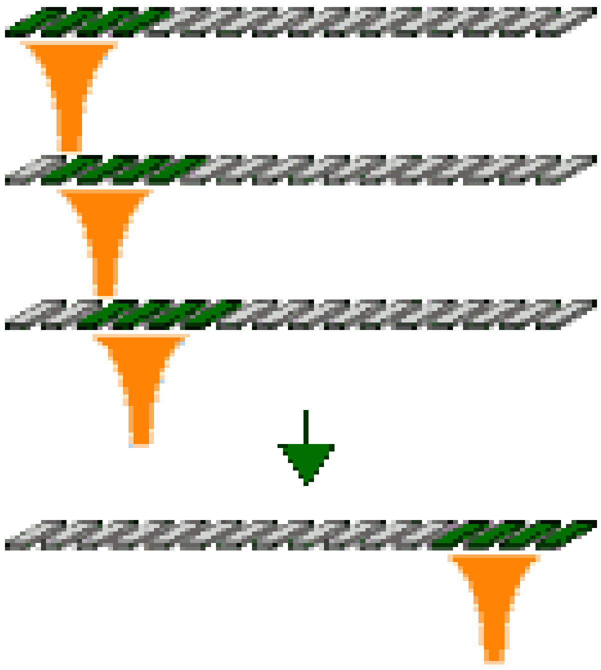


Phased Array (PA) Inspection Method

Phased array (PA) probes are comprised of many small piezoelectric elements embedded into a polymer base material. **Each ultrasonic element** is individually wired (connector, time delay circuit, and A/D converter) and is acoustically isolated from the other elements.

The elements can then be pulsed in groups, or apertures, with **pre-calculated time delays** for each element (phasing).

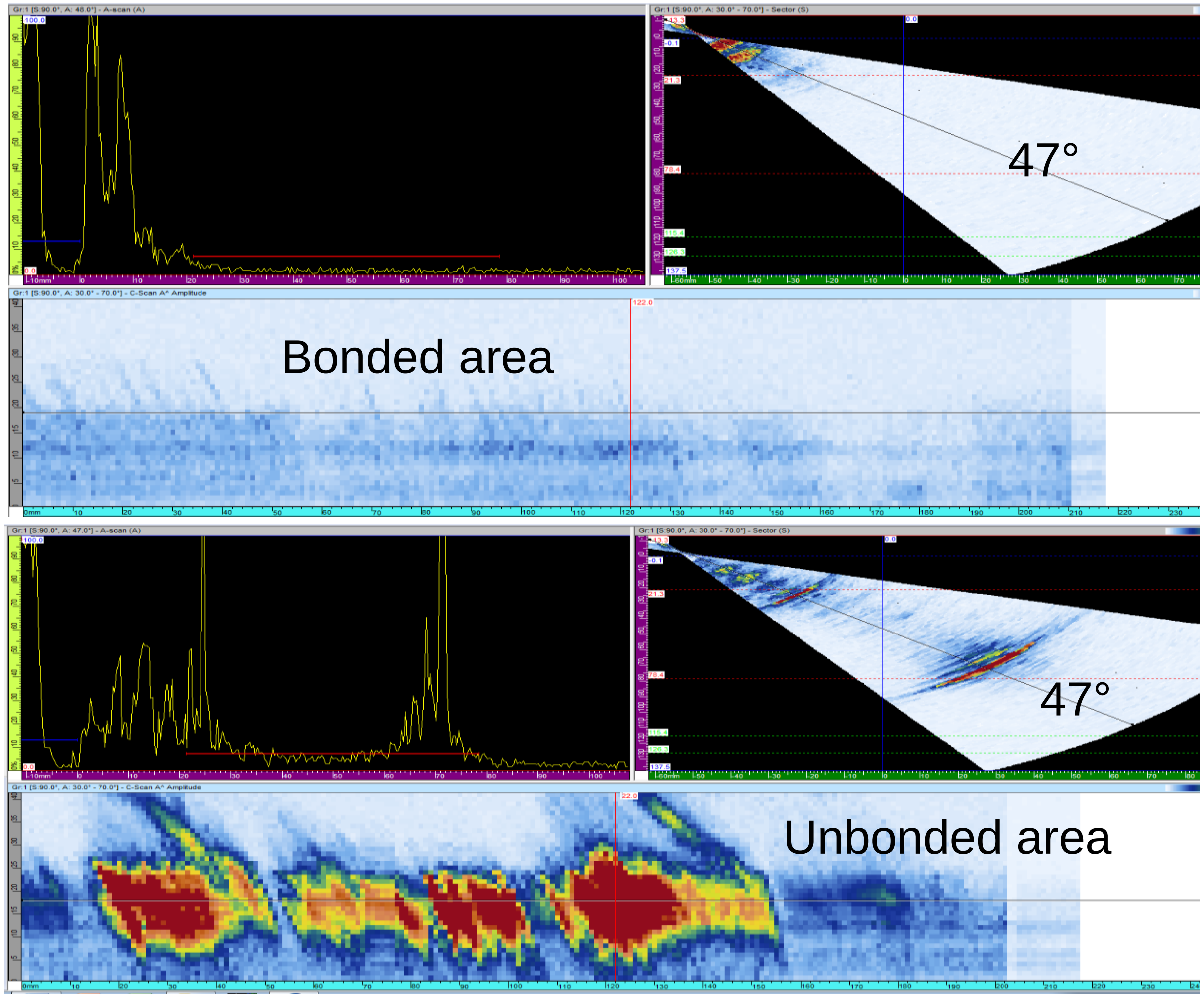
Phased Array (PA) probes move the pulse sequence from aperture to aperture to form focused scan Line's.

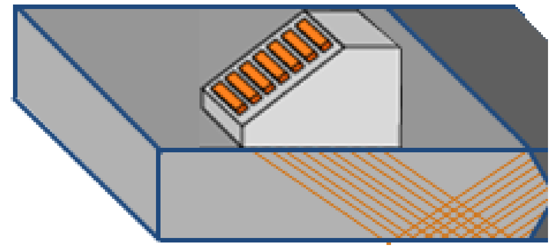


Courtesy of Wayne Weisner Olympus NDT
www.olympus-ims.com/en/probes/pa/

Bondline Detection Aluminum over Composite Phase Array

The line of elements in a **Phased Array** probe are typically configured perpendicular to the inspection area. In this configuration the elements can inspect the total thickness of a part as the probe is moved parallel to the inspection area.





30° to 70° Sectorial scan
Probe: 10L64-I1
Wedge: SI1-L45S-IHC
Aluminum side only

Conclusions

- Contact, immersion and array methodologies can identify wave scattering. If the composite layer is thin enough 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 bondline 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 presentation is 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.
- Ultrasonic techniques described above can detect most discontinuities types that are required. However, a high variance in the material properties or surface roughness may not allow for a reliable assessment. The most important variable to understand for all composite inspection is the role of attenuation and on the selected frequency.

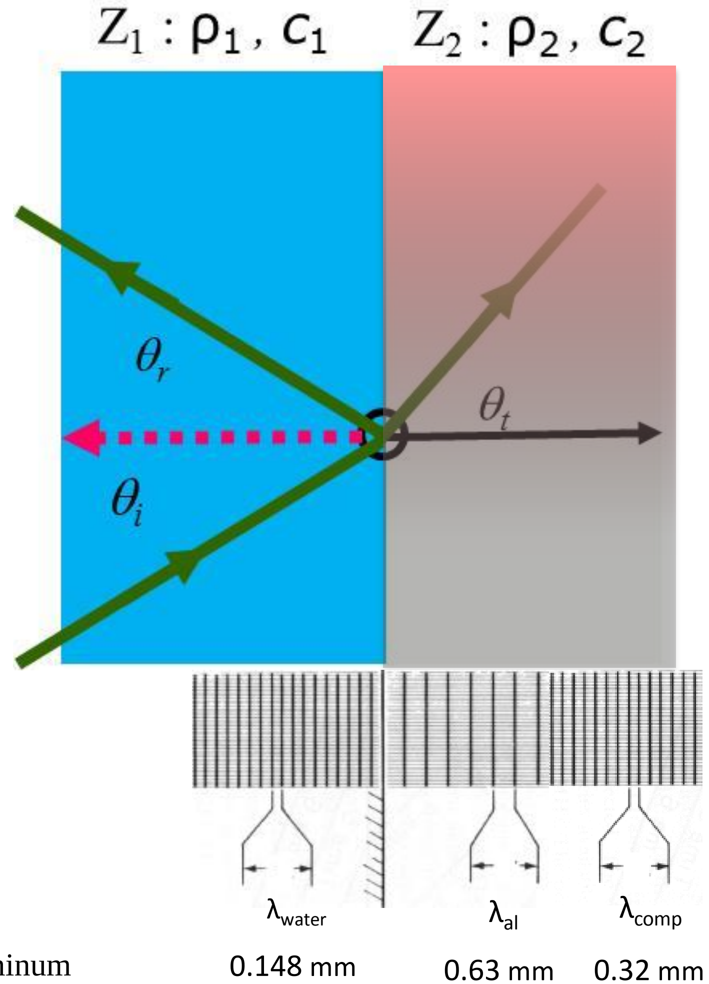
Future Work

- Develop equations for wave scattering in the 8 satin weave material.
- Create new samples at varying thickness and determine the optimal frequency.
- Measure elastic wave speeds and calculate elastic constants.
- Characterize different material interfaces.

Back up Slides

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