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Non-Destructive Inspection of Composite Wrapped Thick-Wall Cylinders

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Introduction

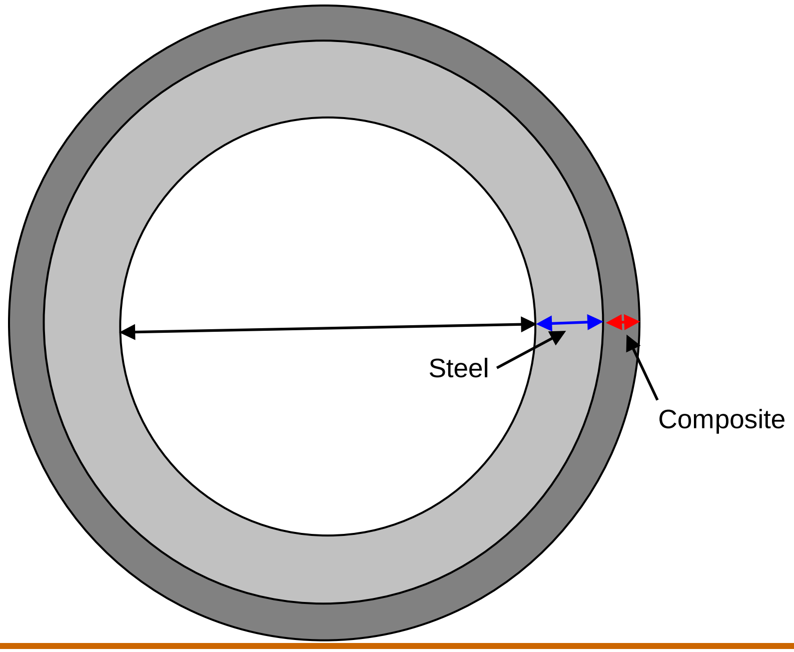
- Compared to all-steel cylinder, composite wrapped cylinder can reduce weight.
- Appropriate evaluation techniques are necessary for the evaluation of cylinder's structural integrity, especially the property of composite layer and the interface condition between composite and steel layer.
- Our research work focus on the experimental and theoretical study of various ultrasound techniques for the inspection of such multilayer cylindrical structures.

How Ultrasound Works

- Ultrasound is acoustic wave with frequency higher than 20 KHz.
- Ultrasound is mechanical wave that can travel in solid media. Its traveling velocity and attenuation are related to material properties such as density and elastic constants.
- When ultrasound propagates in materials, reflection and refraction may occur at acoustic discontinuities such as delaminations and inclusions.

Challenges of the Acoustic Evaluation

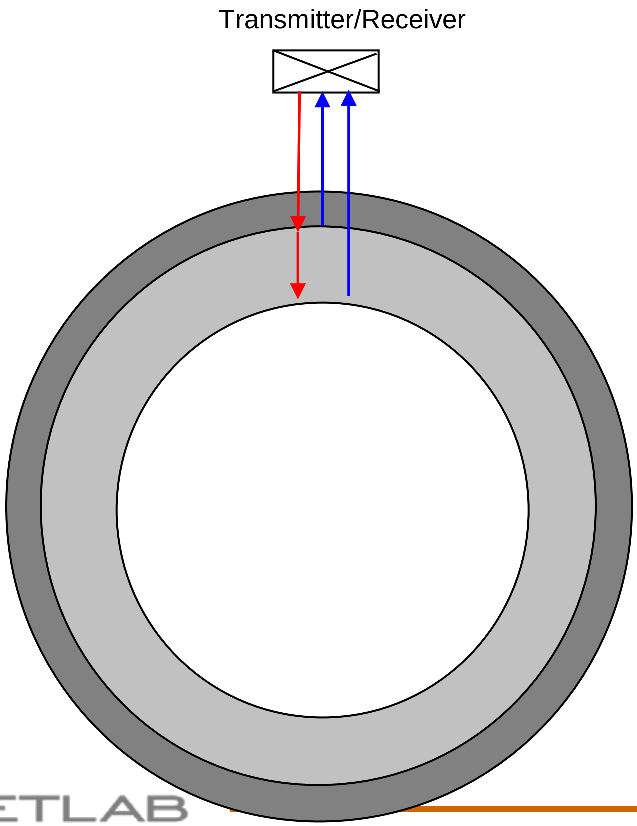
- High acoustic attenuation caused by the thick composite layer.
- The complexity of the acoustic propagation in multilayer cylindrical structure.
- Various types of defects: steel layer, composite layer, and steel/composite interface.



Ultrasound C-Scan Technique

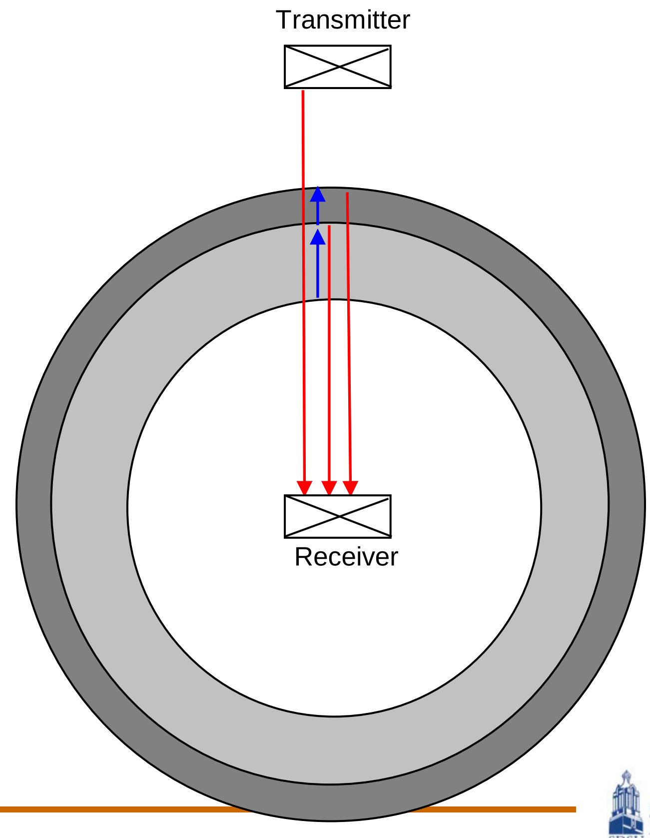
Reflection Mode

- Pros: simple system setup and easy signal analysis.
- Cons: high attenuation.

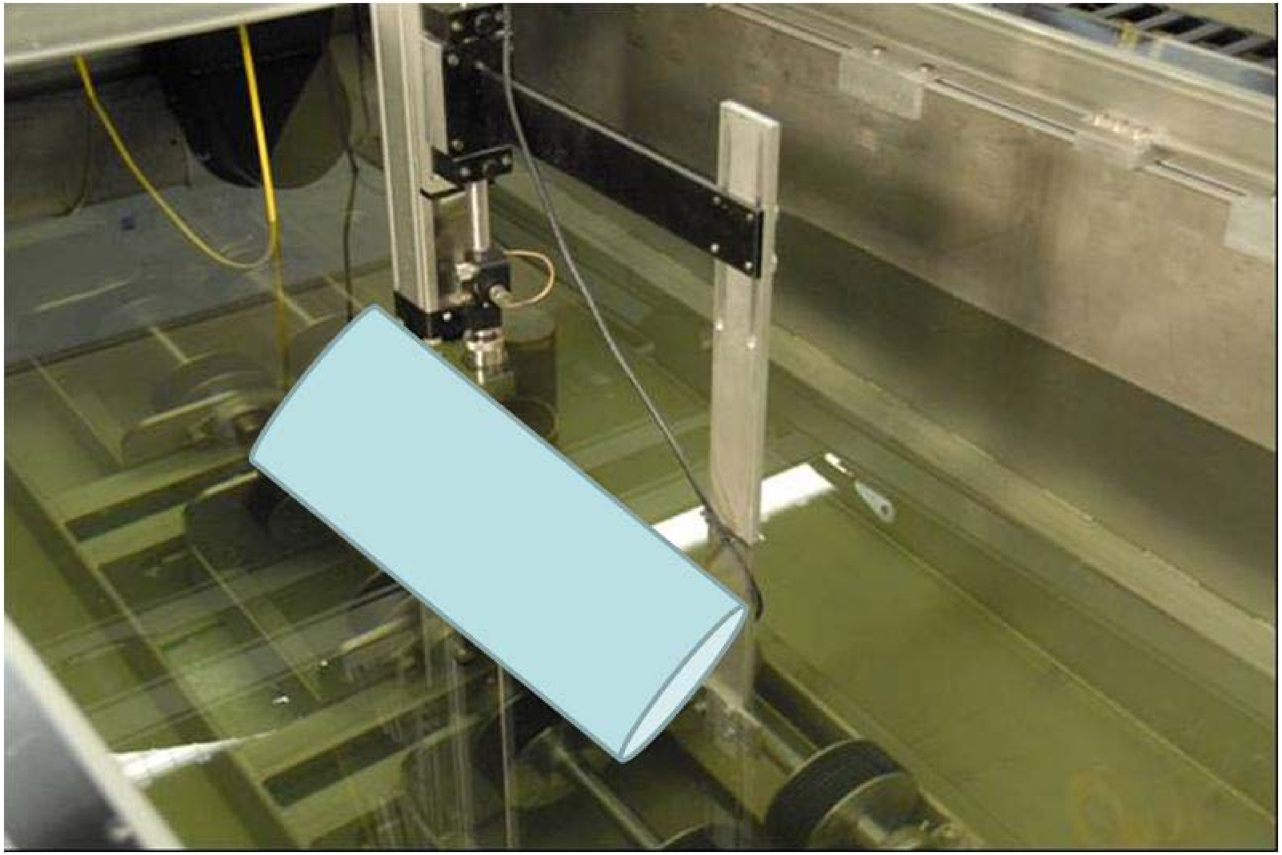


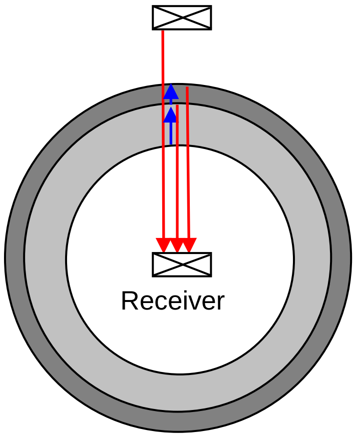
Transmission Mode

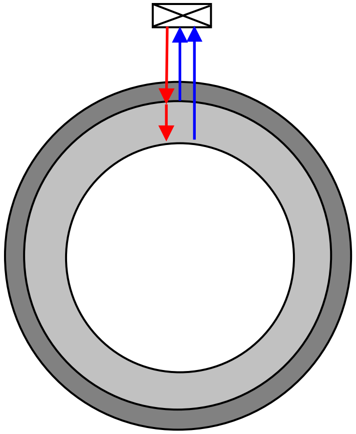
- Pros: low attenuation.
- Cons: Complex system setup and difficult signal analysis.



Ultrasound C-Scan System

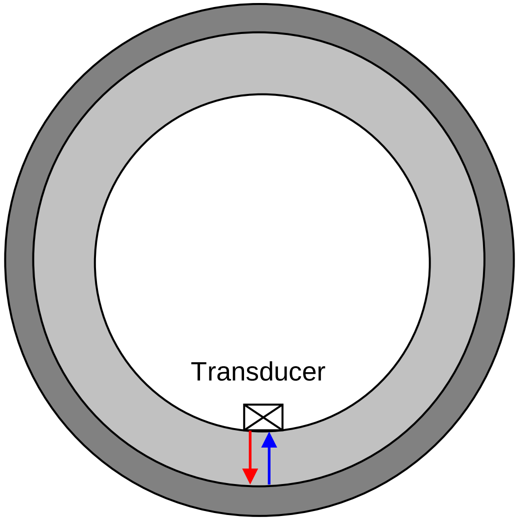


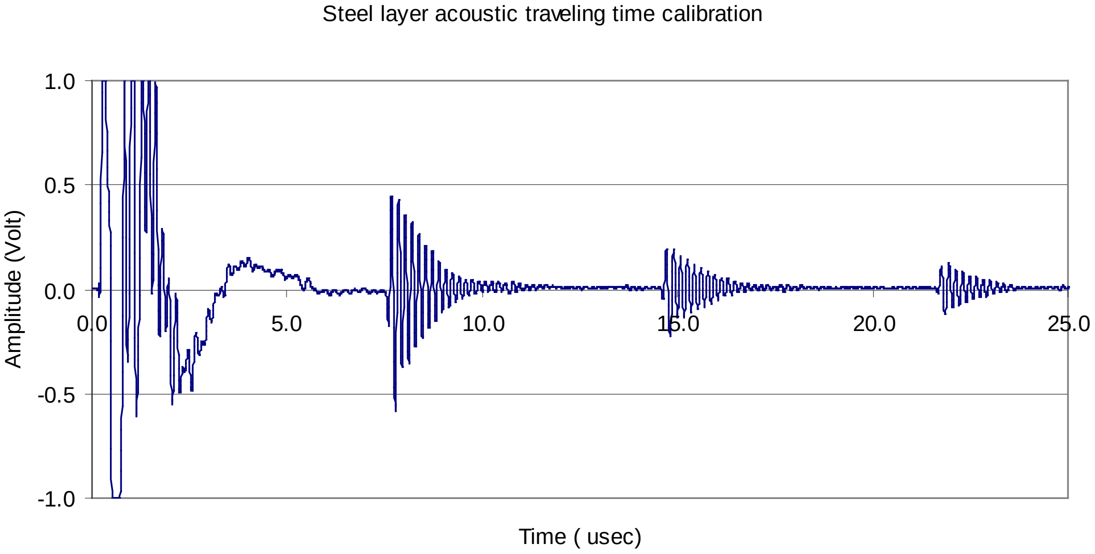




Steel Layer Ultrasound Signal Calibration

- Transducer: Freq. 10 MHz, dia. 0.25”, contact.
- Ultrasound velocity: 0.235 in/μsec.





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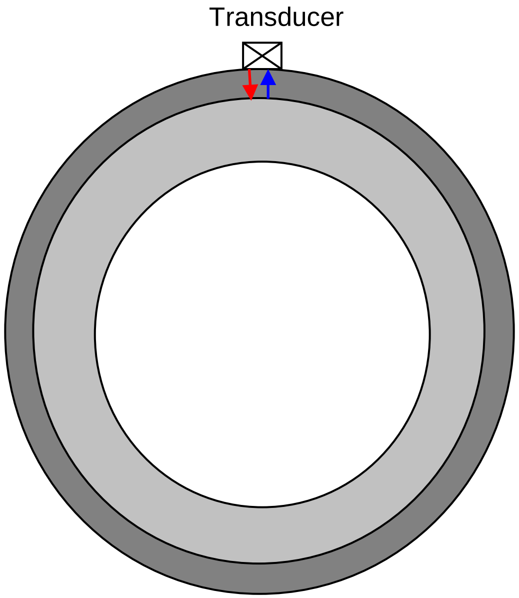
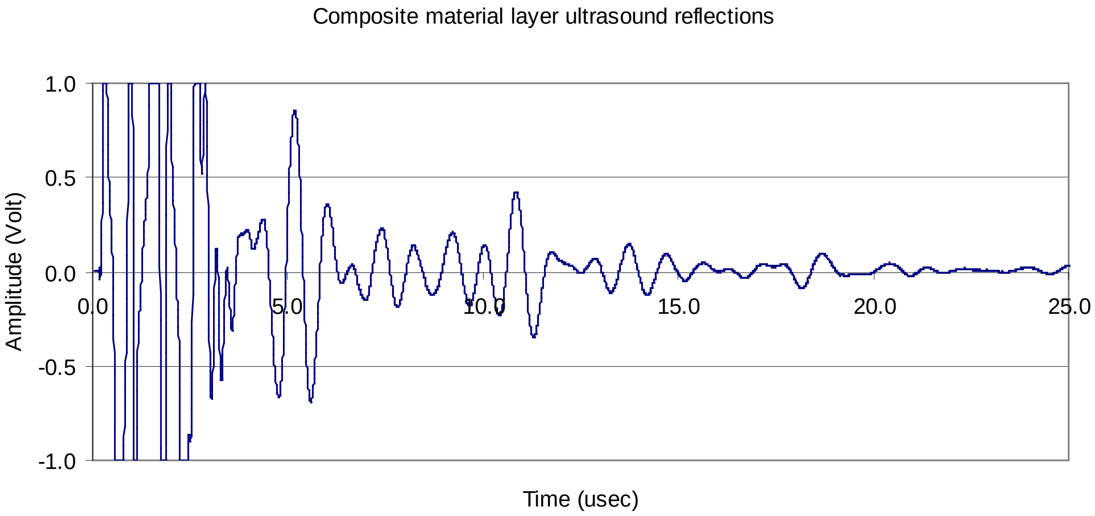
Composite Layer Ultrasound Signal Calibration

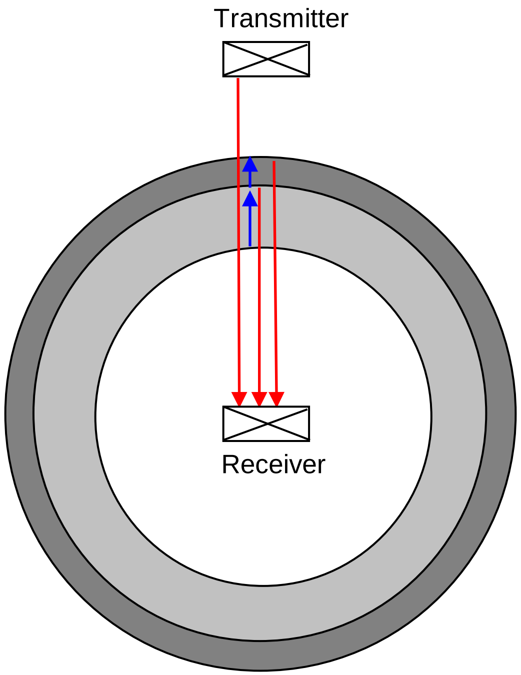
- Transducer: Freq. 0.5 MHz, dia. 0.75”, unfocused.

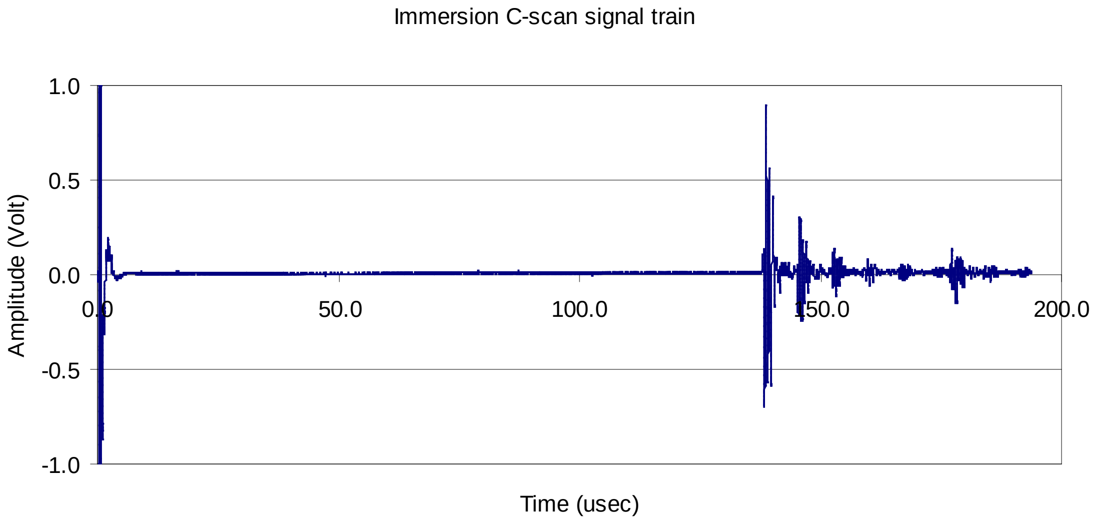




C-Scan Transmission Mode System Setup

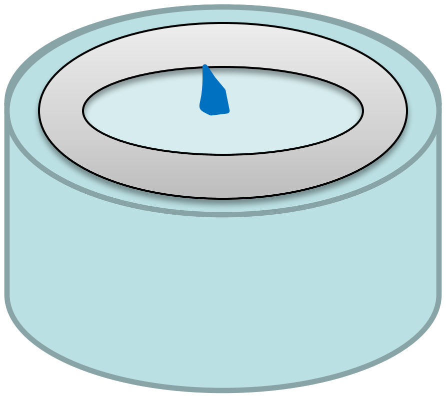
- Transmitter: Freq. 1.0 MHz, dia. 1.125”, unfocused.
- Receiver: Freq. 0.5 MHz, dia. 0.75”, unfocused.
- Distance between transmitter and receiver: optimized experimentally.

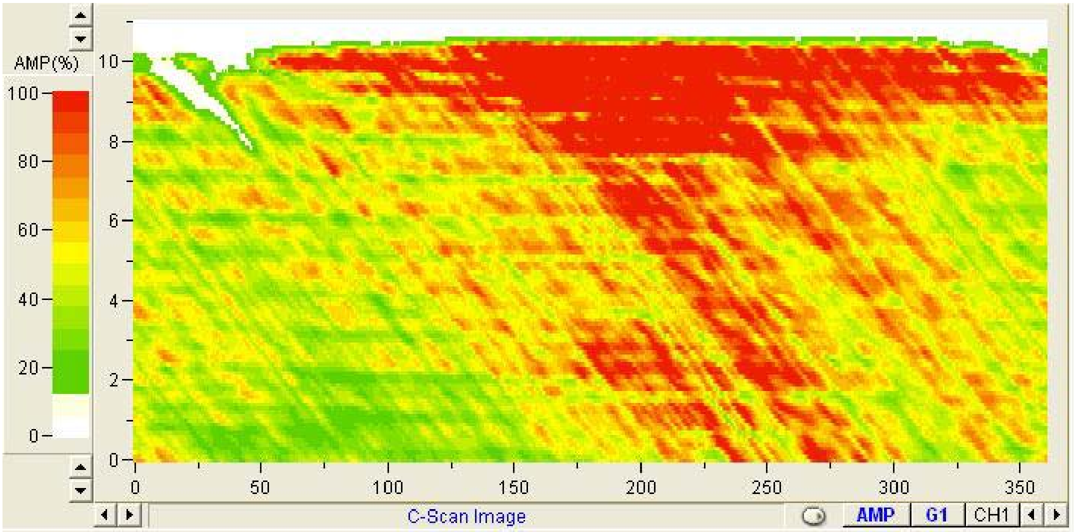




C-Scan Transmission Mode of Known Defect in Steel Layer(1)

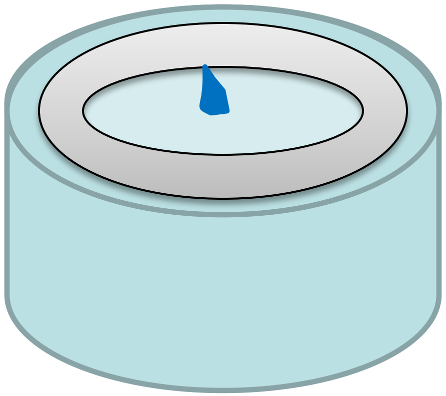
- Defect can be seen in the inner steel layer at the end of the cylinder (see picture).
- The first transmitted acoustic signal was used for imaging.
- C-Scan image size is 360 degrees by 11 inches (about half the length of the cylinder).

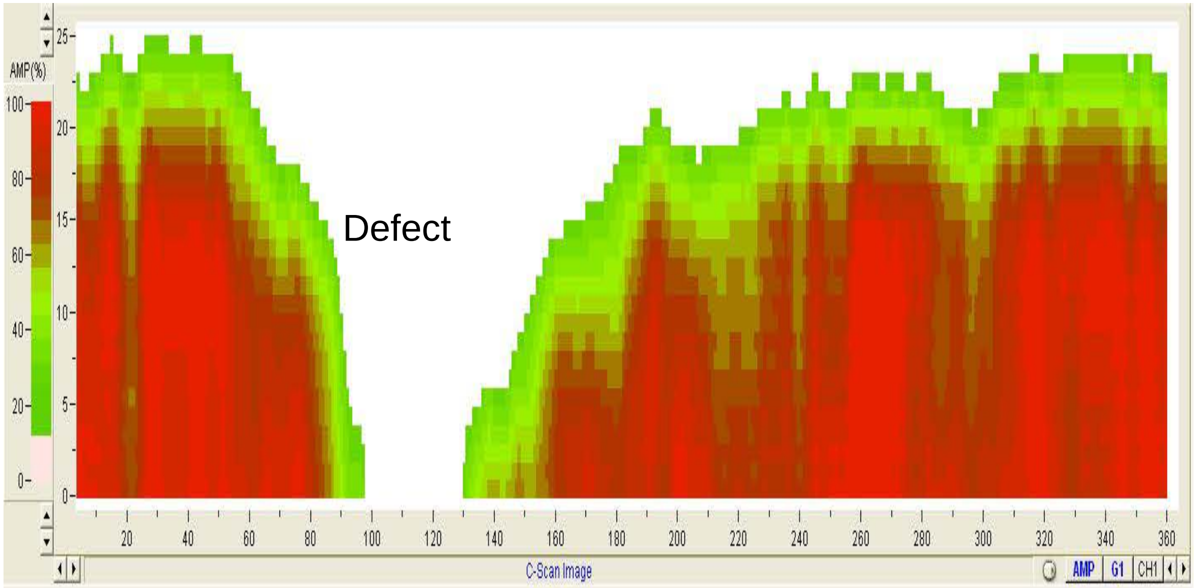




C-Scan Transmission Mode of Known Defect in Steel Layer (2)

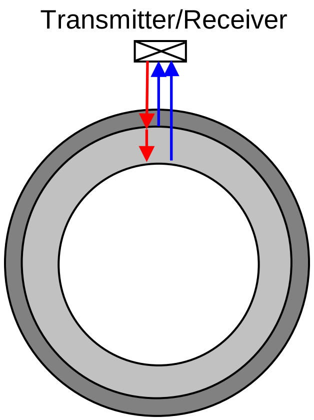
- Image size: 360 degrees by about 25.0 mm.

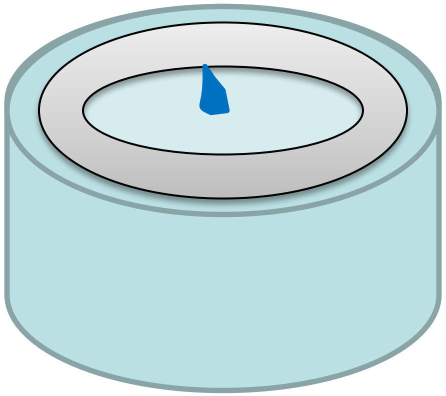


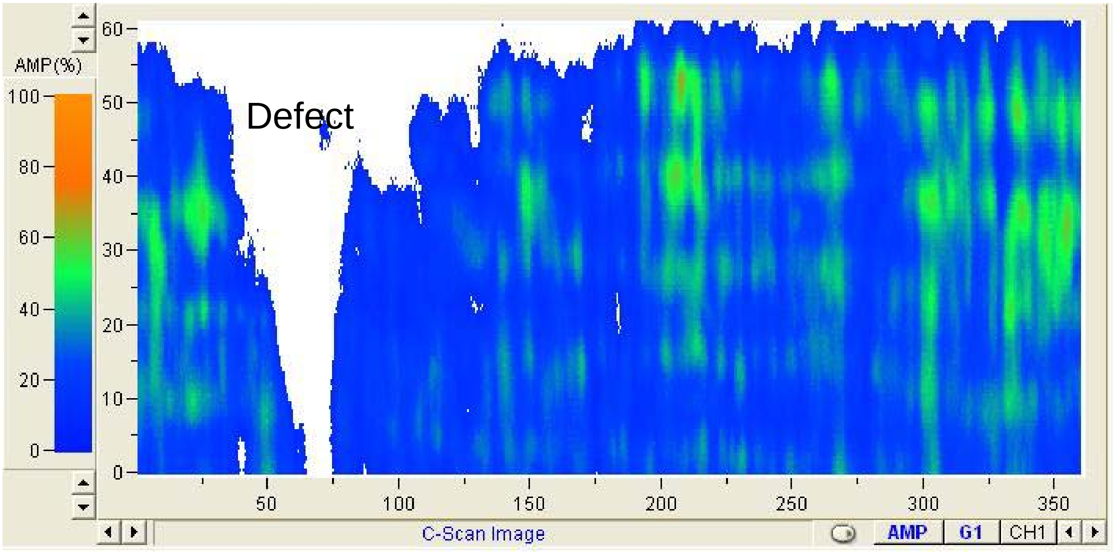


C-Scan Reflection Mode of Unknown Defect in Composite Layer

- Reflection mode: 0.5 MHz, dia. 0.75”, unfocused.
- Image size: 360 degrees by about 60.0 mm.
- Defect in composite layer can be detected.

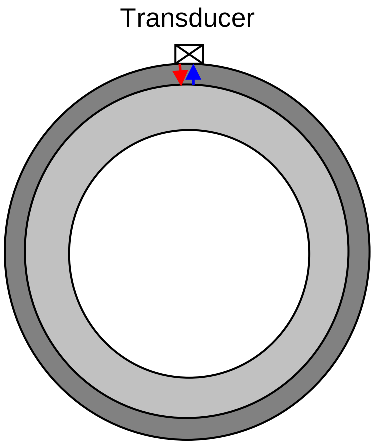


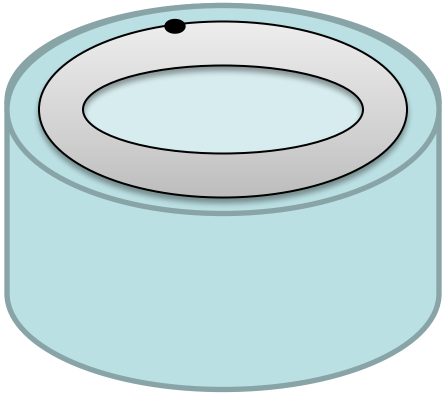


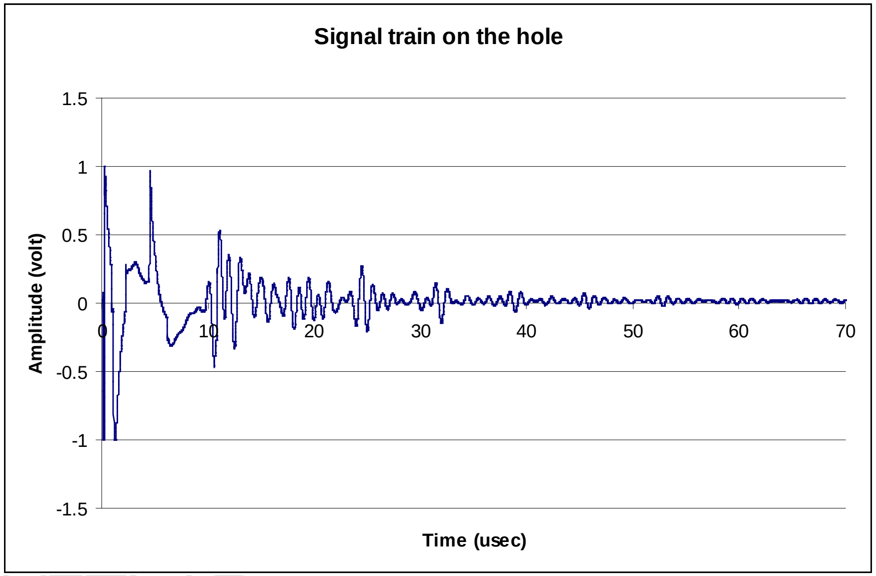


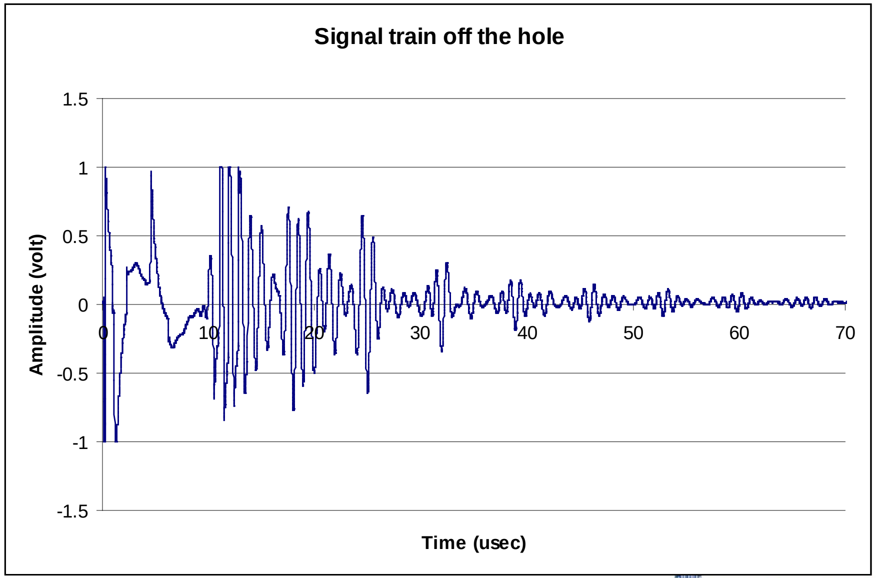
Inspection of Composite/Steel Interface

- Drilled hole: diameter 2.5 mm and depth 25.0 mm
- Transducer: Freq. 0.5 MHz, dia. 0.75”, unfocused.



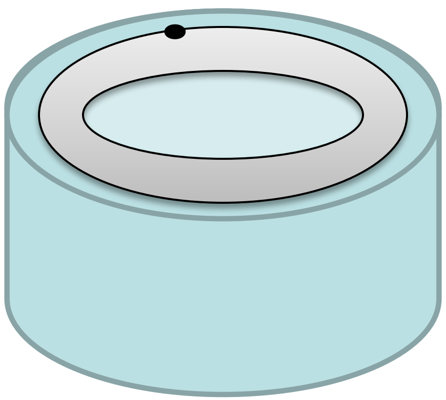


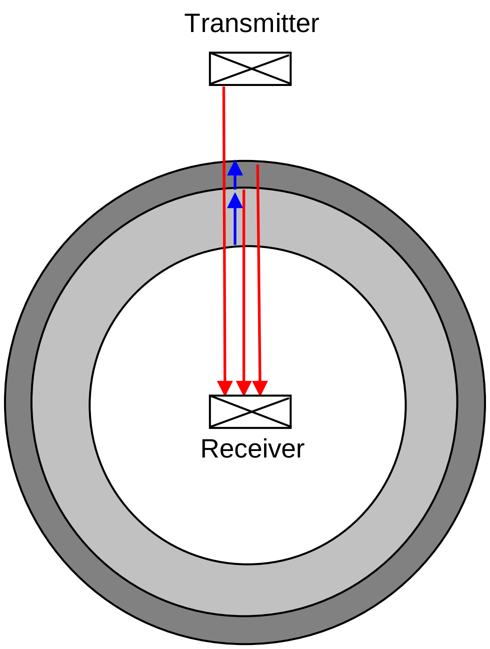


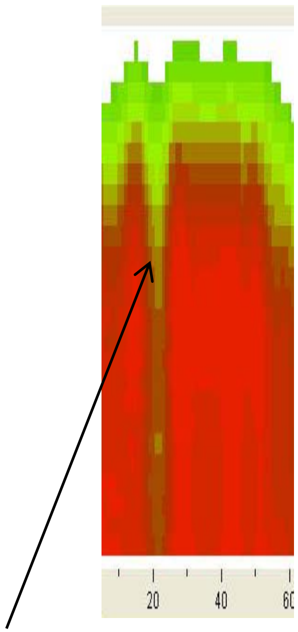


C-Scan Imaging of Composite/Steel Interface (1)

- The drilled hole can be imaged by ultrasound C-scan transmission mode.



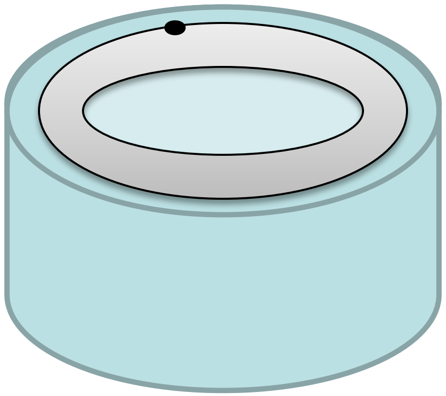


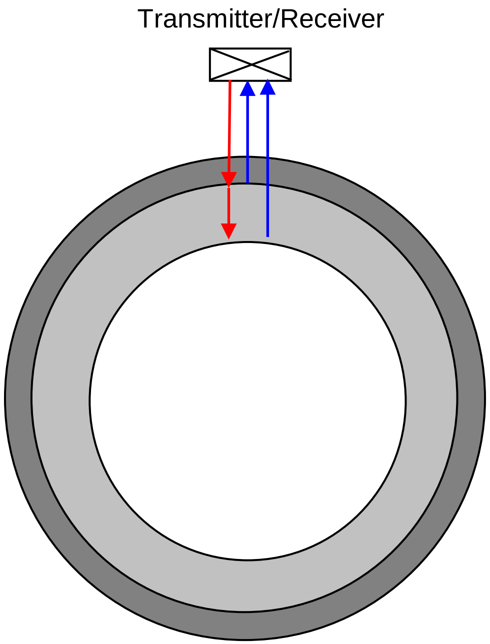


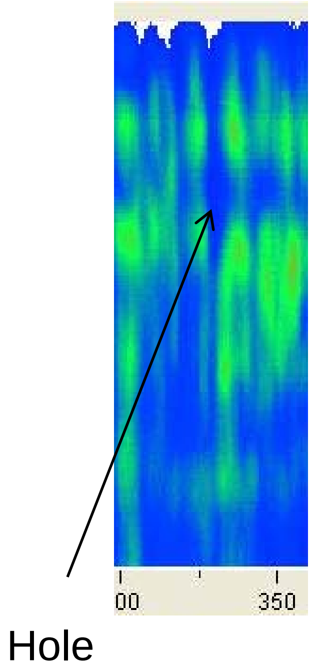
Hole

C-Scan Imaging of Composite/Steel Interface (2)

- The drilled hole can be barely detected with reflection mode.

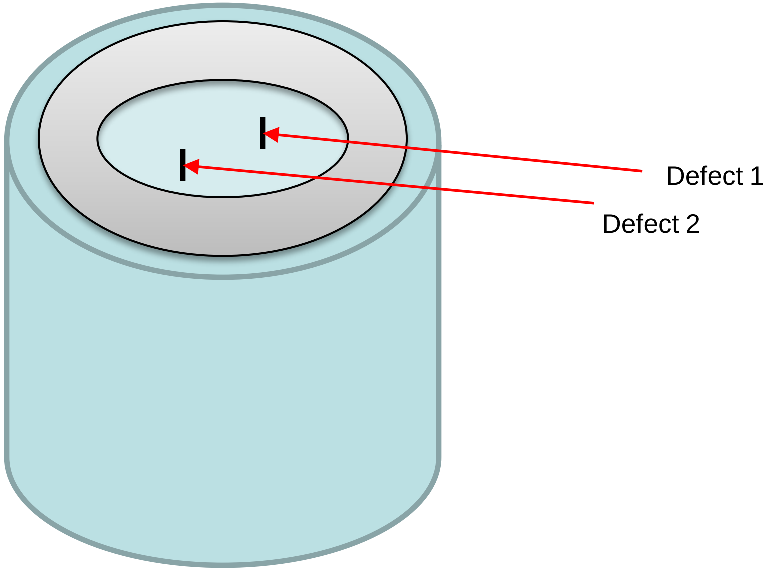






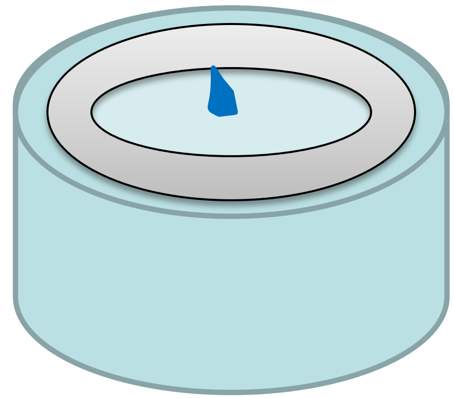
Ultrasound Guided Wave for Steel Surface Inspection

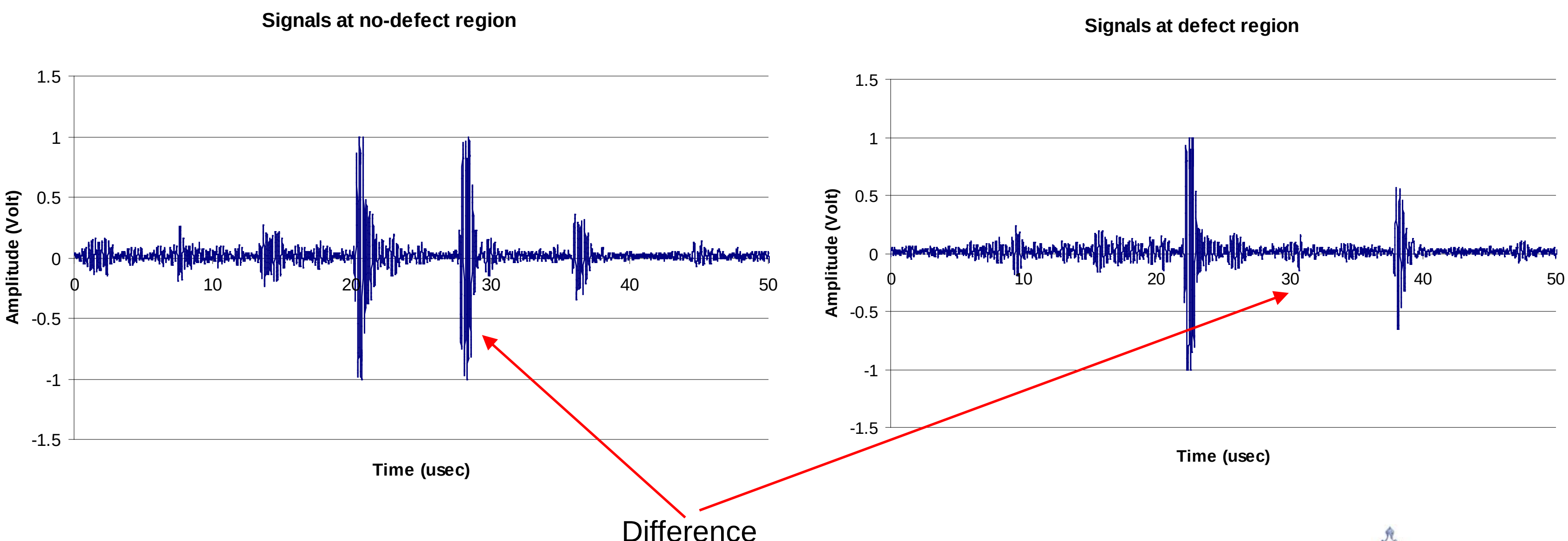
- The above C-scan technique failed to detect two small steel surface defects: defect 1 at 70 mm from edge and defect 2 at165 mm from edge.
- Ultrasound guided wave technique with angle beam transducer is applied.
- Various frequencies and incident angles were tested.



Ultrasound Guided Wave for Known Defect

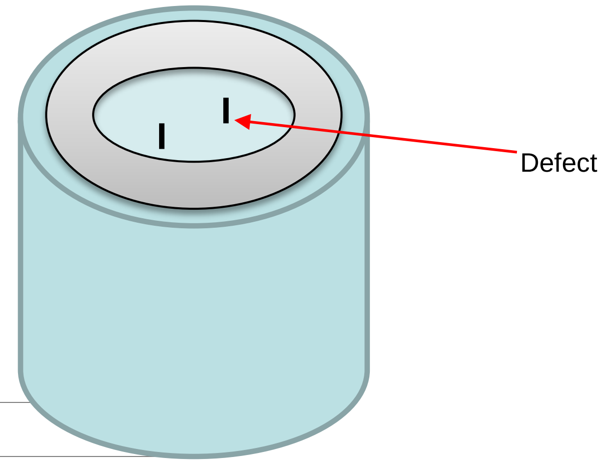
- Ultrasound system: Pocket UT^{TM} system
- Transducer: 3.5 MHz
- Wedge: 60^0
- Detection direction: axial direction

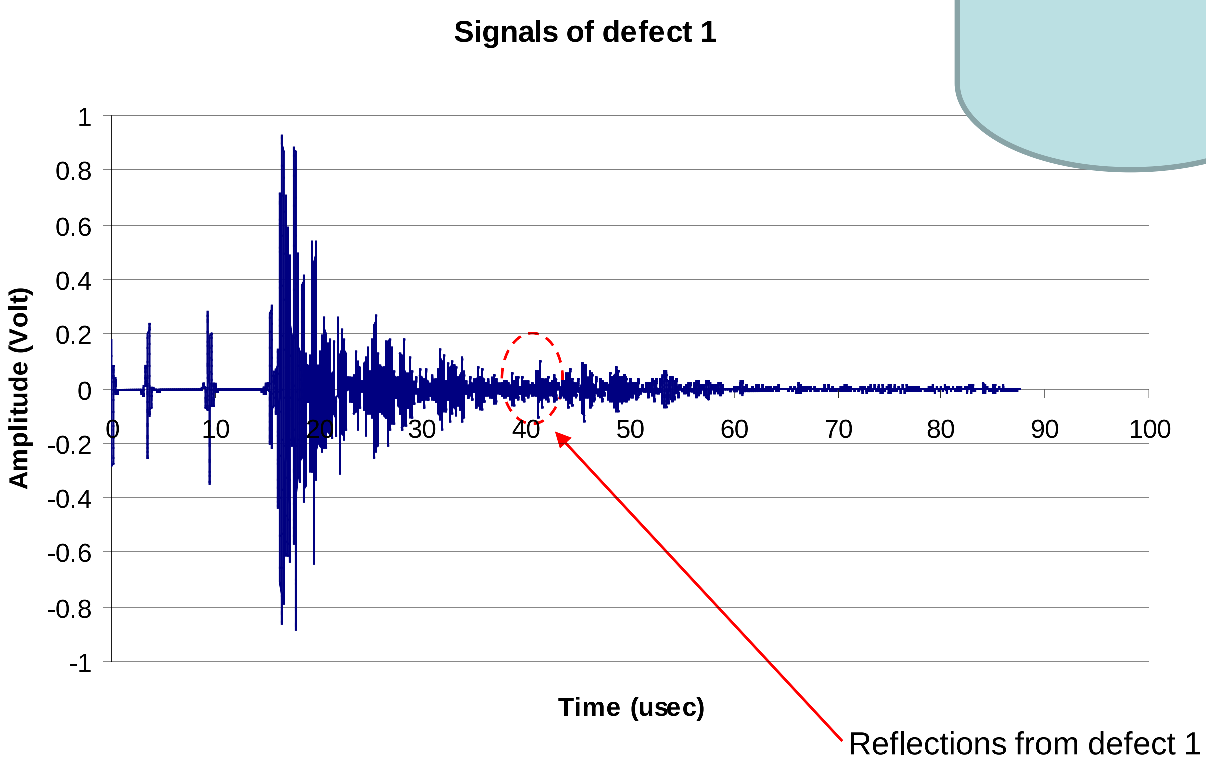




Ultrasound Surface Wave for Surface Defect (1)

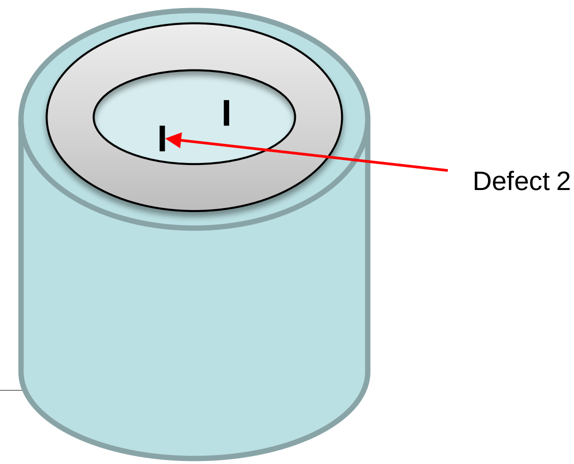
- Ultrasound system: Pocket UT^{TM} system
- Transducer: 3.5 MHz
- Wedge: 90^{0}
- Detection direction: axial direction

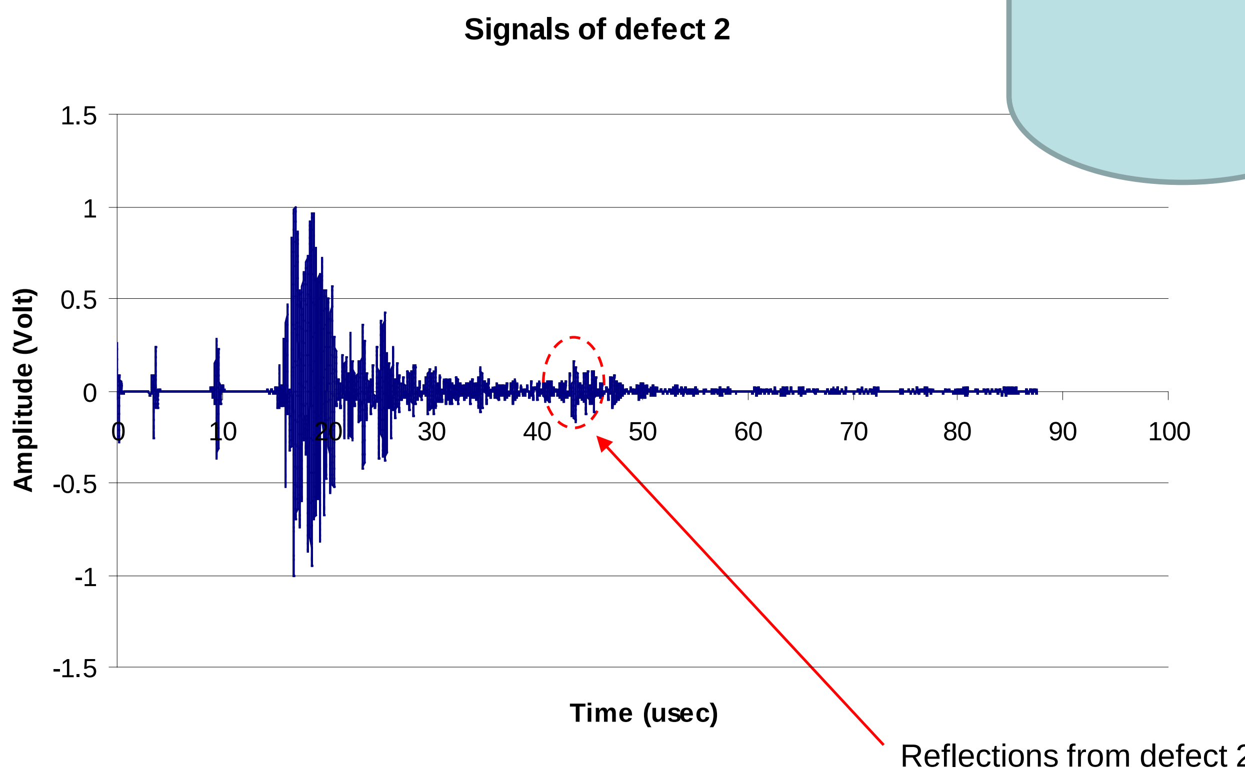




Ultrasound Surface Wave for Surface Defect (2)

- Ultrasound system: Pocket UT™ system
- Transducer: 3.5 MHz
- Wedge: 90^0
- Detection direction: axial direction



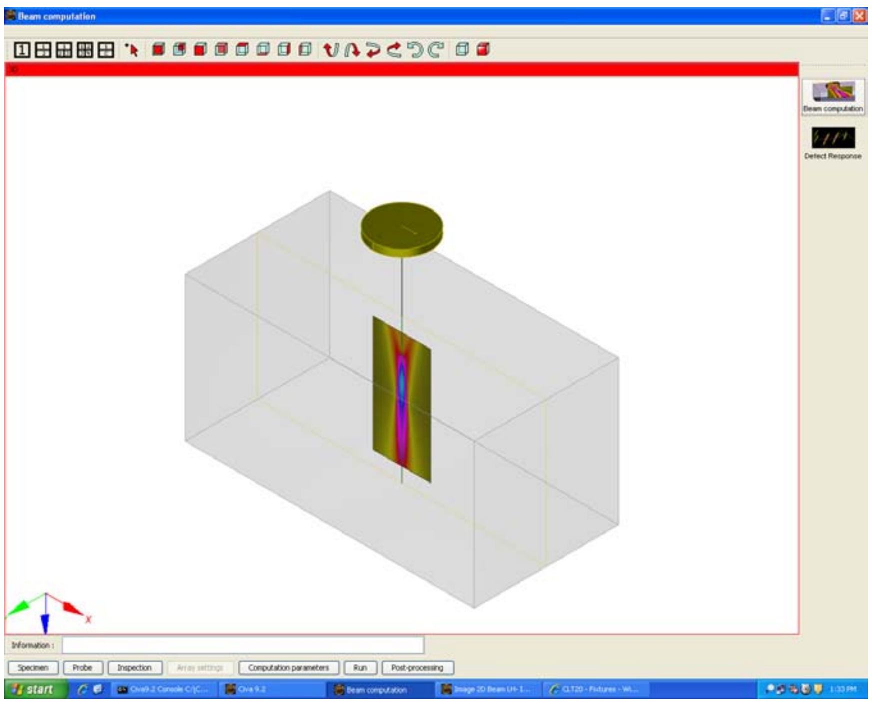


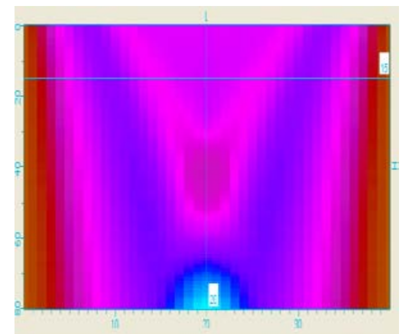
Summary of Experimental Results

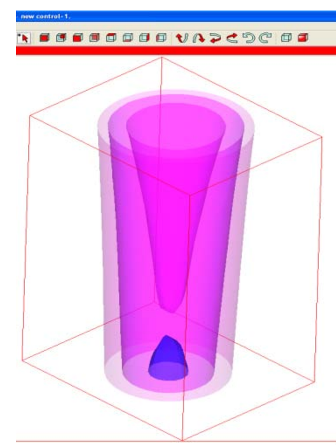
- Defects in both steel layer and composite layer can be imaged by ultrasound C-scan technique.
- Dia. 2.5mm drilled hole can be imaged with ultrasound C-scan transmission mode, but cannot be detected with ultrasound C-Scan reflection mode.
- Because of the high acoustic attenuation caused by the composite layer, ultrasound frequency at about 1.0 MHz is applied.
- Ultrasound guided wave with 60^0 angle beam transducer is suitable for detecting defects from long distance.
- Ultrasound surface wave with 90^0 angle beam transducer is sensitive to surface small defects which may be difficult for C-Scan imaging technique.

Ultrasound Simulation with CIVA

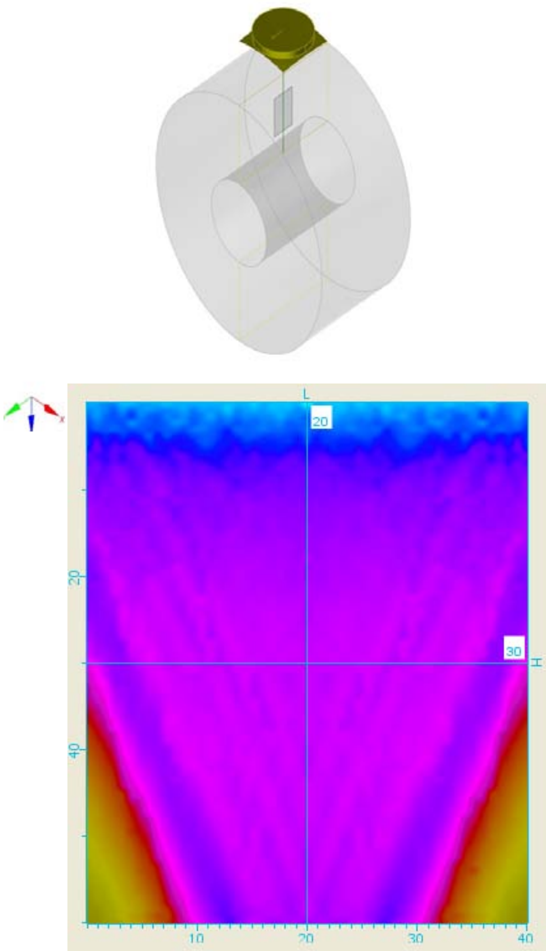
- CIVA is an ultrasound simulation software that can simulate acoustic wave propagation and its interaction with flaws.
- CIVA can simulate with both single element acoustic sensor and phased array acoustic sensors

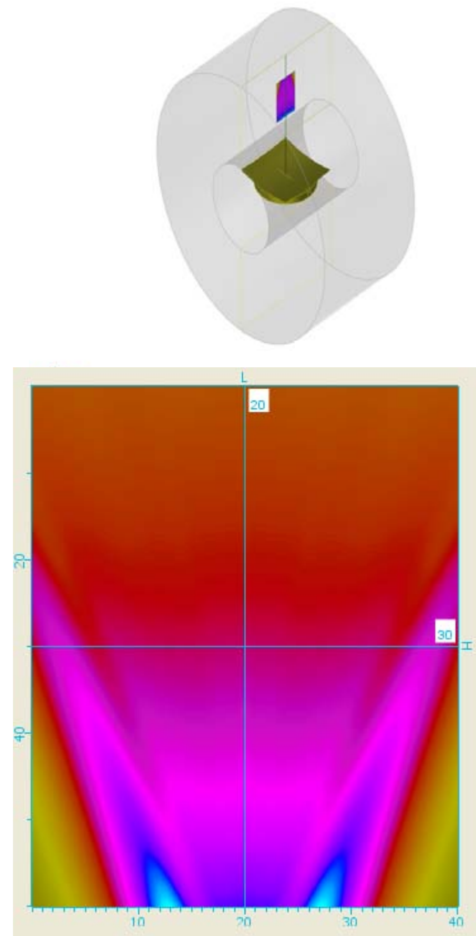






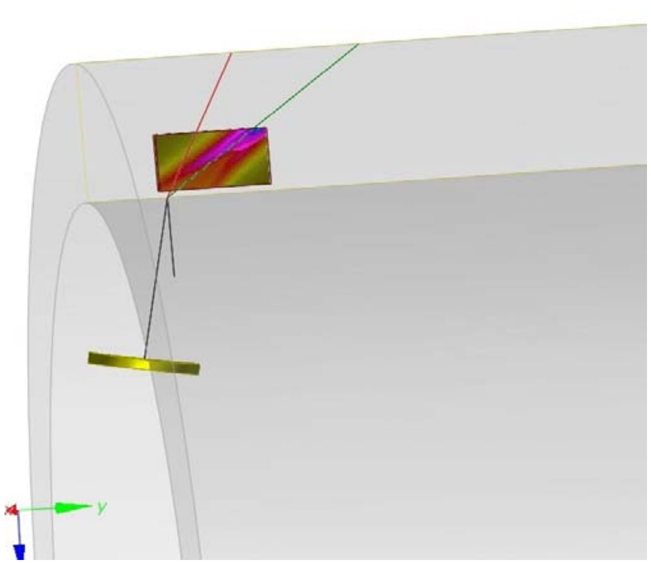
Ultrasound Simulation with Cylindrical Structure (1)

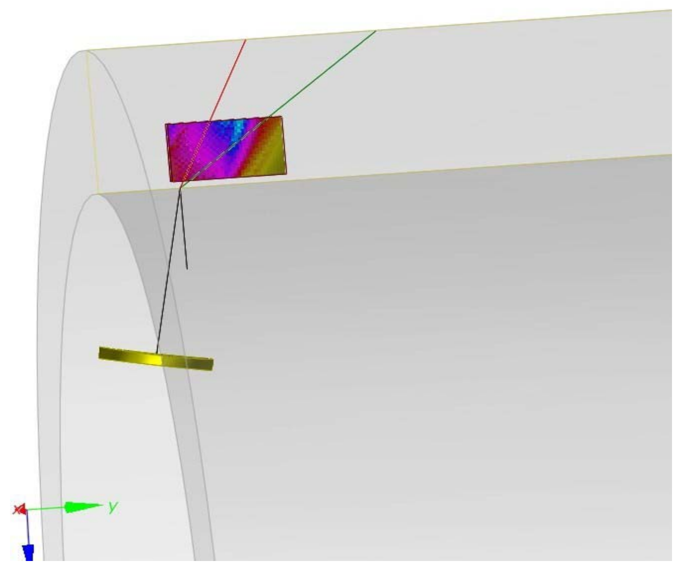




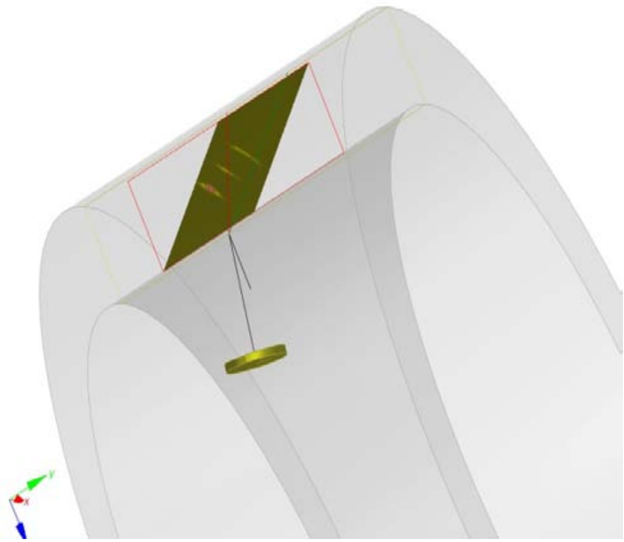
Ultrasound Simulation with Cylindrical Structure (2)

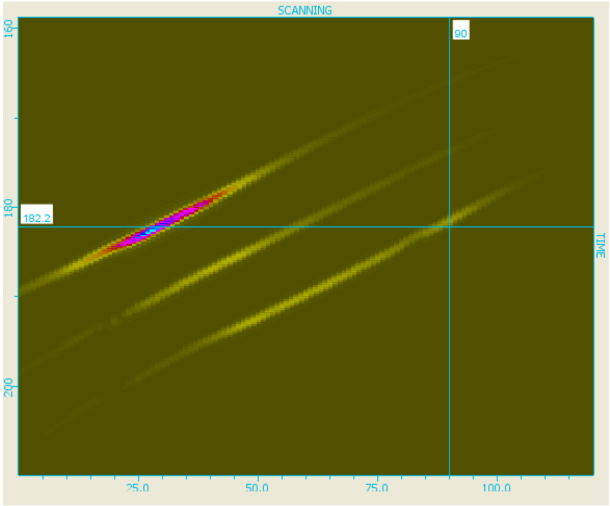
- Longitudinal and shear wave test configuration for a cylindrical structure





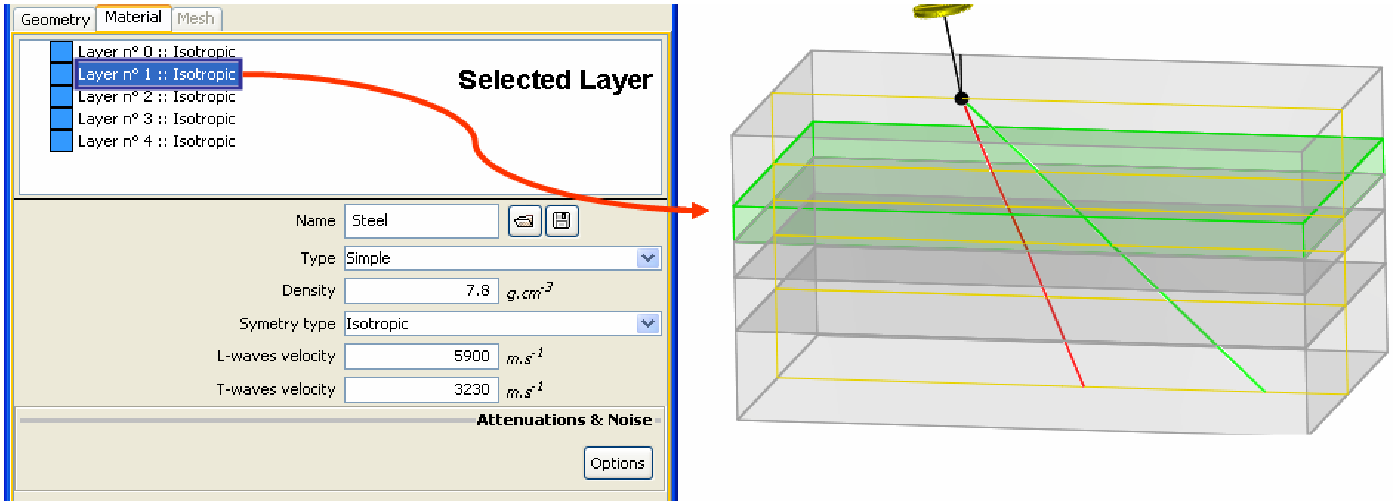
Ultrasound Simulation of Flaw Responses





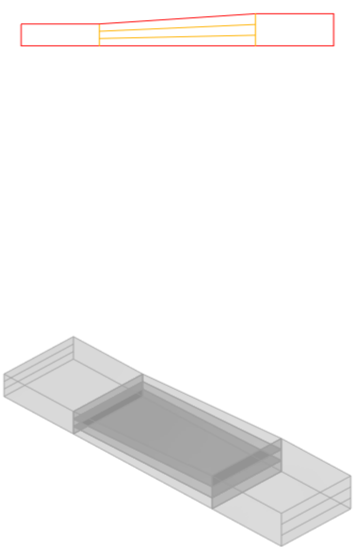
Ultrasound Simulation with Composite Materials (1)

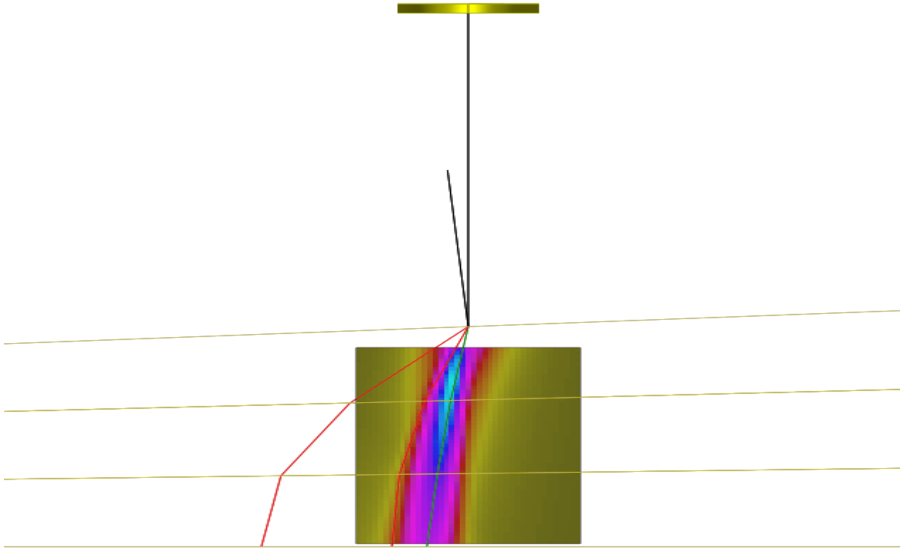
- Orientation and elastic properties of each composite layer can be determined.



Ultrasound Simulation with Composite Materials (2)

- Acoustic attenuation and beam bending can be simulated.





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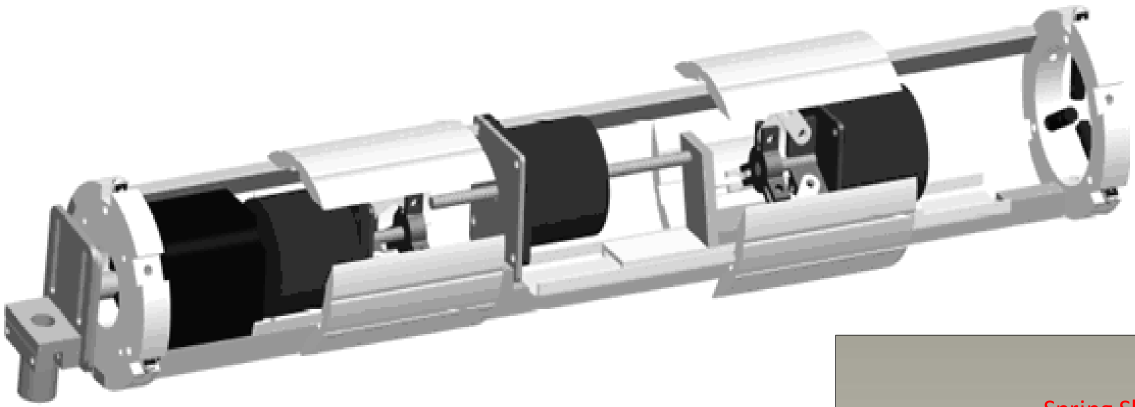
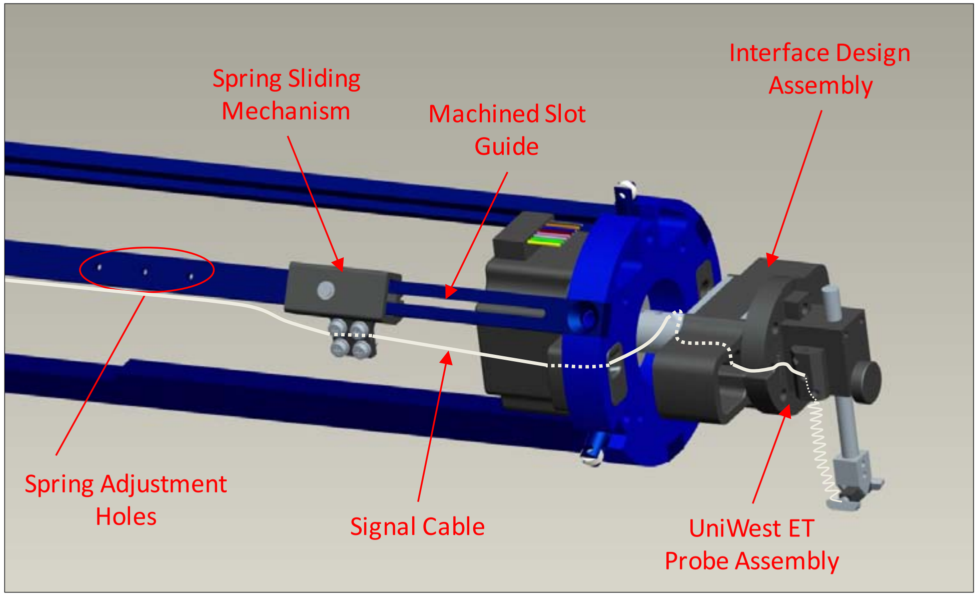
Conclusions

- Various ultrasound techniques have been applied for the evaluation of various types of defects in composite wrapped cylinder.
- The high acoustic attenuation caused by composite can be improved by low ultrasound frequencies, but this needs to be further studied.
- CIVA theoretical simulation may help to understand the ultrasound propagation in cylinder, and to optimize experimental parameters.
- Further quantitative comparison of CIVA simulation and experiments is necessary to improve the sensitivity of ultrasound inspection.
- Other NDE techniques, such as eddy current technique and ultrasound phased array technique, also have the potential for on-site evaluation of cylinders.

Portable Inspection System





Thank You!