Structural Health Monitoring for Life Management of Aircraft

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FAA Sponsored Project Information

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- FAA Technical Monitor
  - David Westlund
  - Curt Davies

Monitoring of disbond damage in adhesively-bonded composites

- Motivation and Key Issues
  - Disbond defects are of serious concern in safety-critical aerospace composites.
  - The influence from a disbond defect on Lamb wave propagation is significant.
- Objective
  - Quantitatively demonstrate an integrated diagnostic/prognostic system to make predictions of the structural health and remaining life of adhesively-bonded composite structures.
- Approach
  - Ball drop test to induce disbond defects
  - Thermal imaging technique
  - Lamb wave testing technique
  - Finite element method (FEM) to simulate Lamb wave propagation

GLARE Laminates

- GLAss-REinforced (GLARE) laminate is a class of fiber metal laminates, which are hybrid composites consisting of thin alternating bonded layers of metal sheets and fiber-reinforced epoxy prepreg.

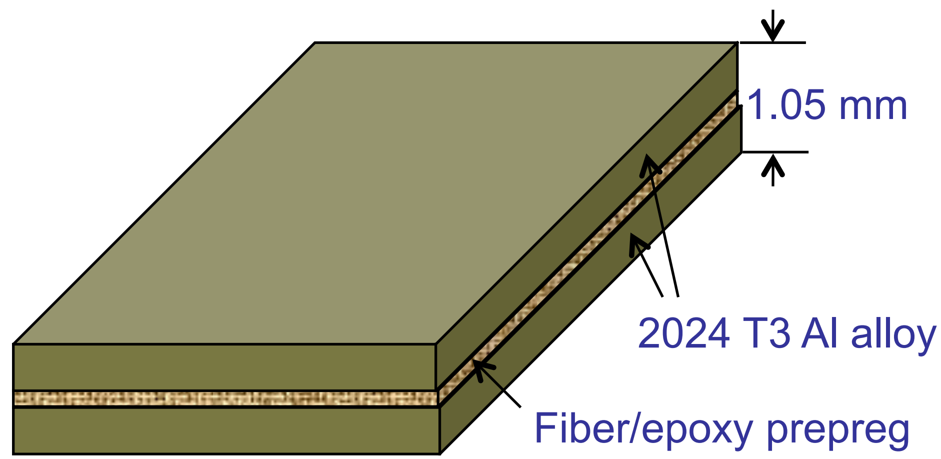


Fig.1: Configuration of GLARE 2A-2/1-0.4

Ball drop induced disbond defects in a GLARE plate

- A ball drop was used to introduce disbond defects in the GLARE plate.
- A 1-inch diameter steel ball was released from 3 feet high to strike the center point of the GLARE plate.
- The impact energy was 606 mJ converted from the kinetic energy of the falling ball.
- The impact events was applied between 1 and 200 times.

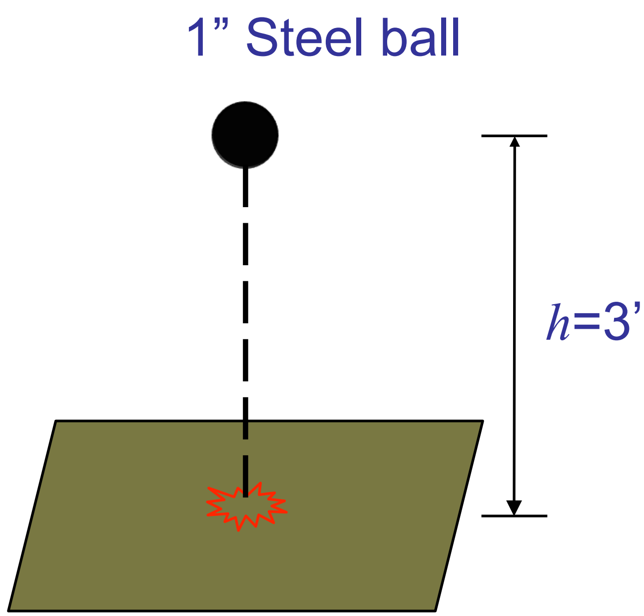
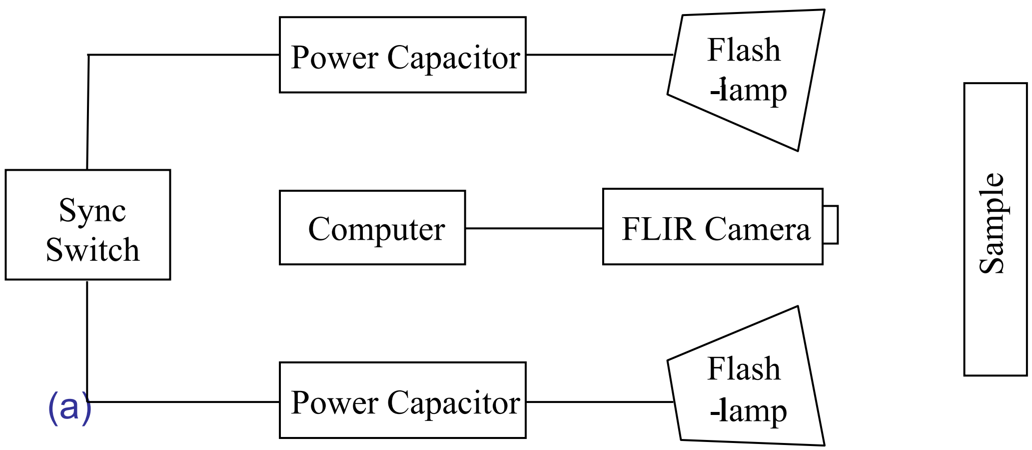


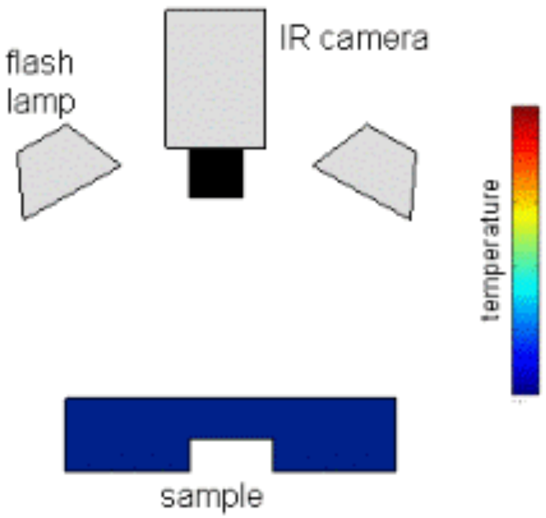
Fig. 2: A schematic of the ball drop test.

Thermal imaging system

After each ball-drop test, the GLARE plate was examined with pulsed thermography (single-sided inspection).



(a)

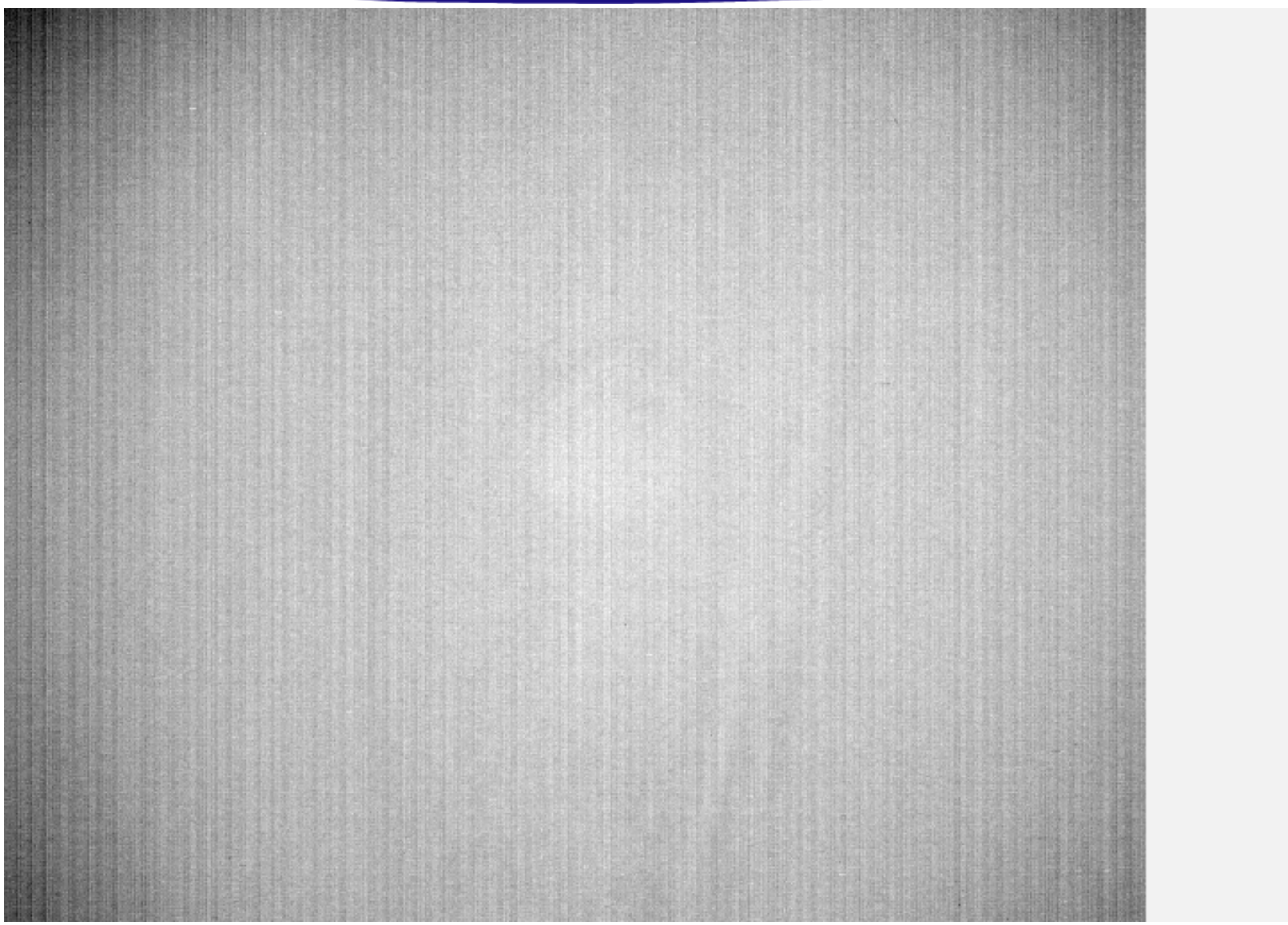


(b)

Animation Courtesy of Thermal Wave Imaging, Inc.

Fig. 3: A pulsed thermography system for imaging: (a) system schematic and (b) experimental setup.

Example video for acquiring thermal images



Impact:
150 times

Frame rate: 50 Hz

Temp. ^oF

Ball-drop induced disbond defects

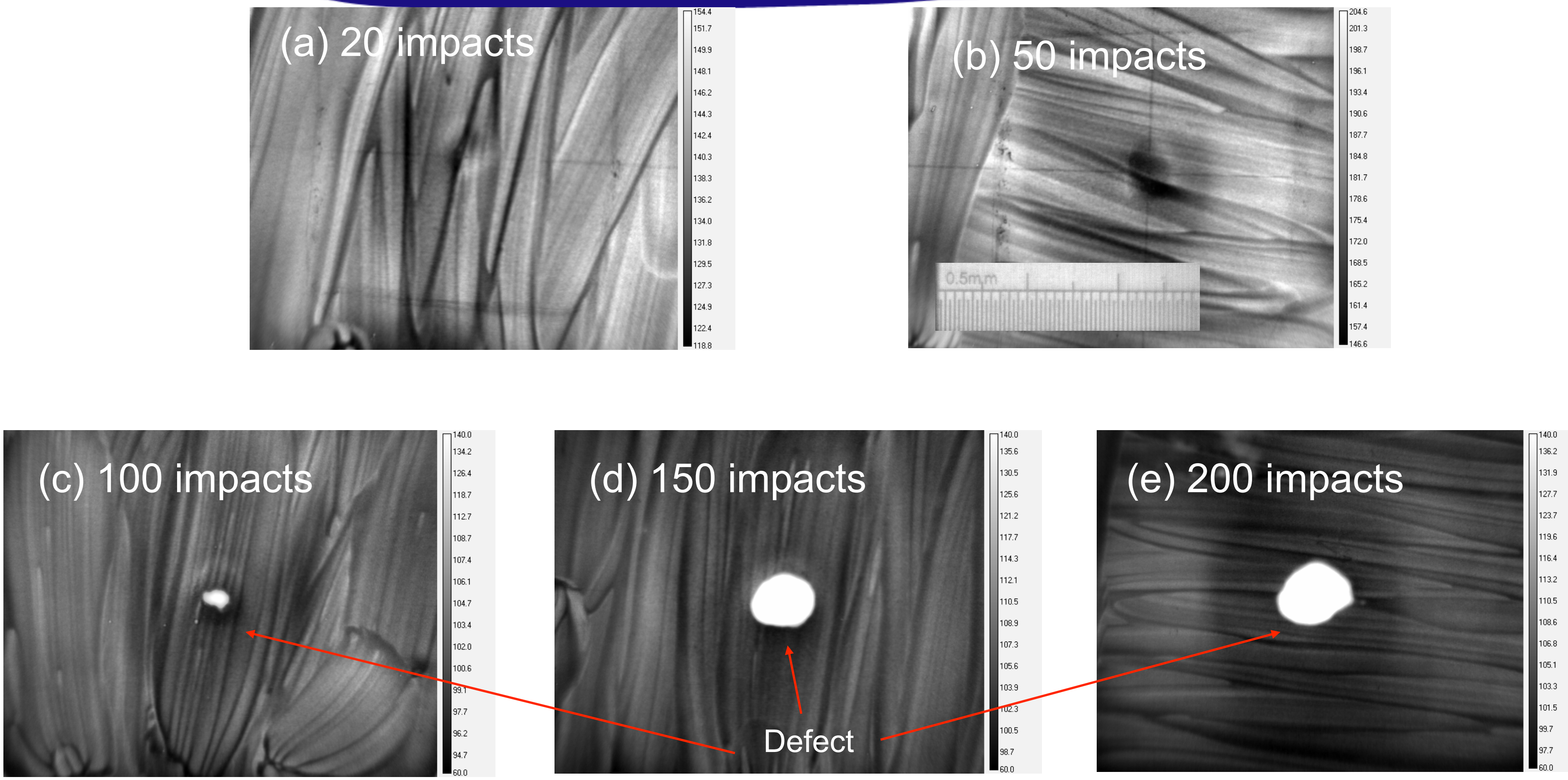


Fig. 4: Thermal images of the defect area.

Ball-drop induced disbond defects

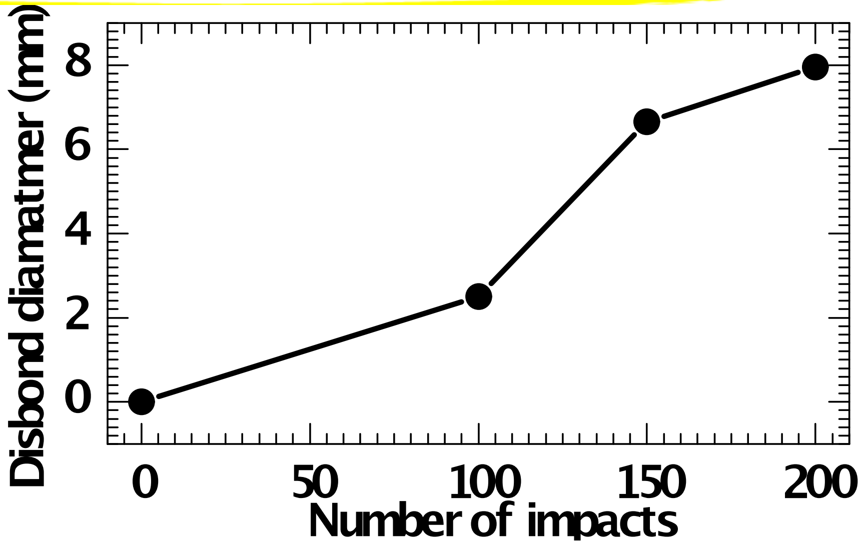
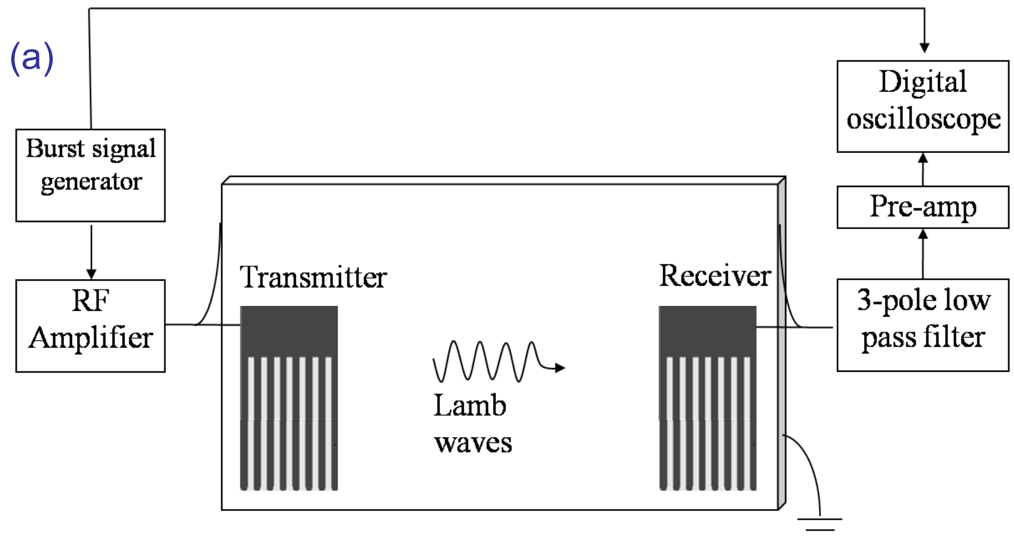


Fig. 5: The growth of disbond sizes at the impact energy of 606 mJ.

- The size of the disbond defect was scaled from the images.
- The disbond defect diameter increases with the number of impacts.
- The disbond defect of 50 or less ball impacts was not detected using the thermal imaging system raw data in its current configuration.

Experimental setup of Lamb wave testing on a GLARE laminate



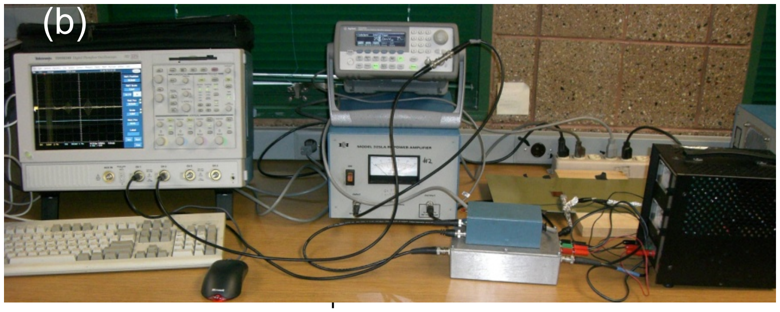


Fig. 6: An examination system for Lamb wave test: (a) system schematic and (b) experimental setup.

- Source: Ten cycles of a Hanning windowed tone burst signal
- f_o= 695 KHz, $V_{p\text{-}p}$=250mV
- Gain of RF amplifier: 377
- Low pass filer: f_c=~1 MHz
- Gain of Pre-amp: 34 dB

PVDF comb transducers:

- 10 fingers
- Finger length=20mm
- Λ=2.45mm

Generation and detection of Lamb waves with the PVDF comb transducers

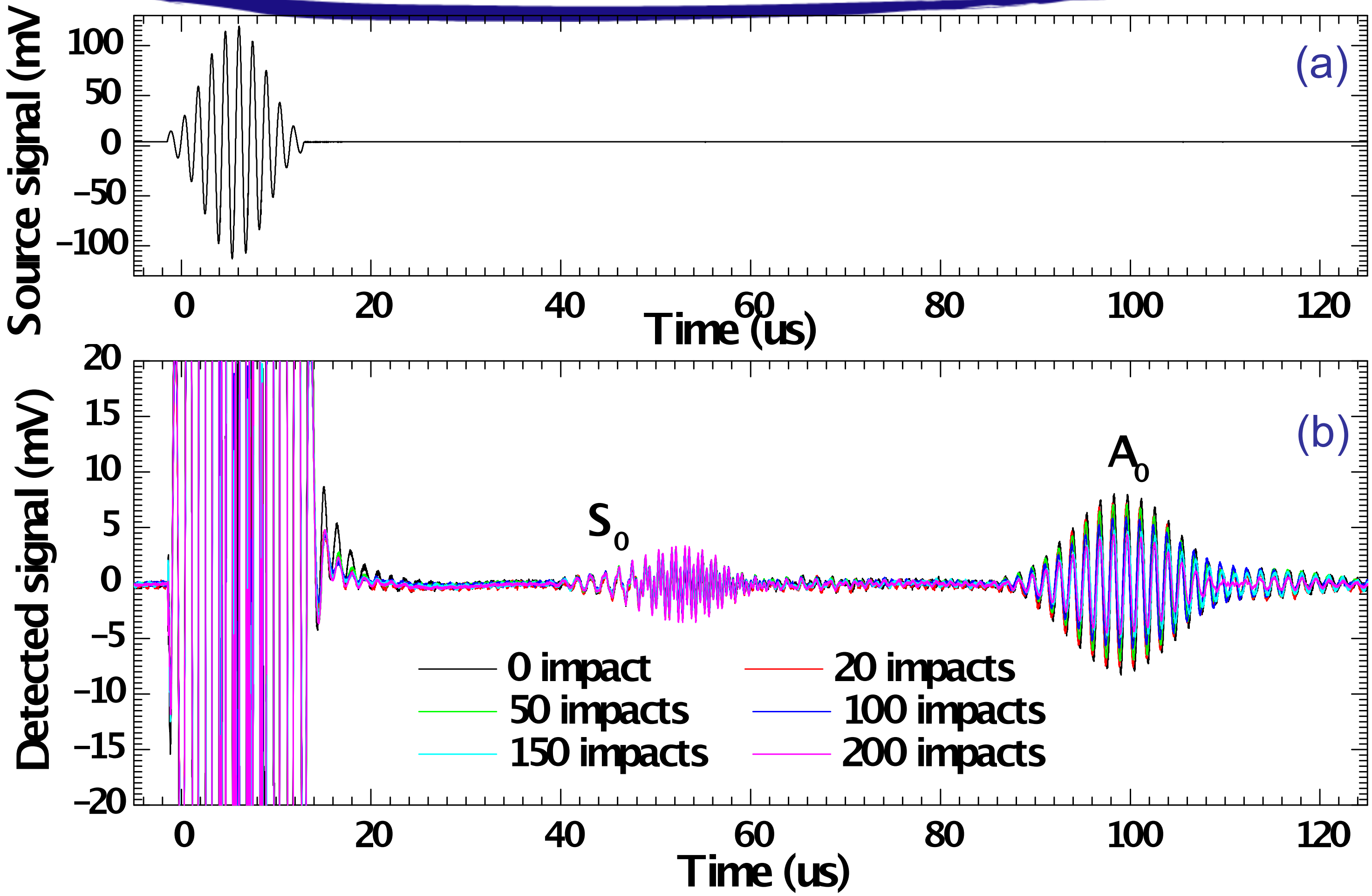


Fig. 7: Lamb wave testing at f = 695 KHz: (a) Launching signal, (b) Detected signal for various ball impacts.

The influence of the ball impact on the detected A_0 mode Lamb wave signal

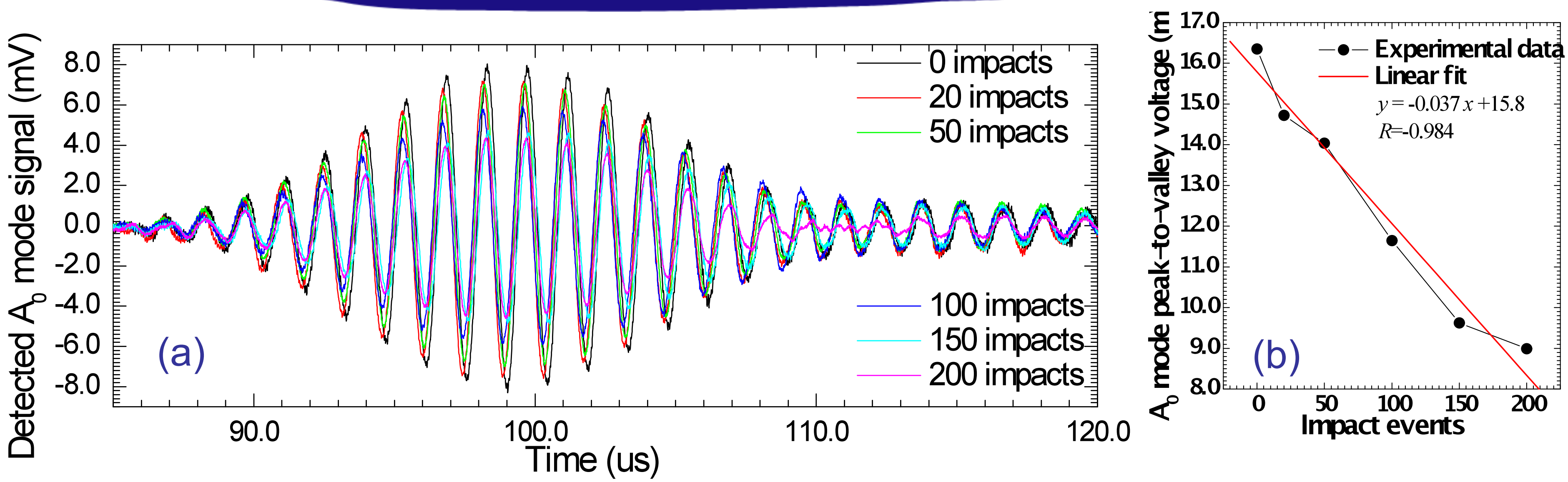


Fig. 8: (a) Detected A_0 mode Lamb wave signal for various ball impacts; (b) The influence of the ball impacts on the detected A_0 mode Lamb wave maximum peak-to-valley voltages.

The measured A_0 mode Lamb wave signals decrease linearly as a function of the ball impact events.

The influence of the disbond defect on the detected A_0 mode Lamb wave amplitude

- The reduced A_0 mode amplitudes can be attributed to the wave reflection, scattering, and mode conversion in the disbond defect area.
- The fitting parameter D_0 represents the sensitivity of the Lamb wave detection system.
- The disbond defect sizes can be predicted from the amplitude monitoring of the selected Lamb wave signals when parameter D_0 is identified.

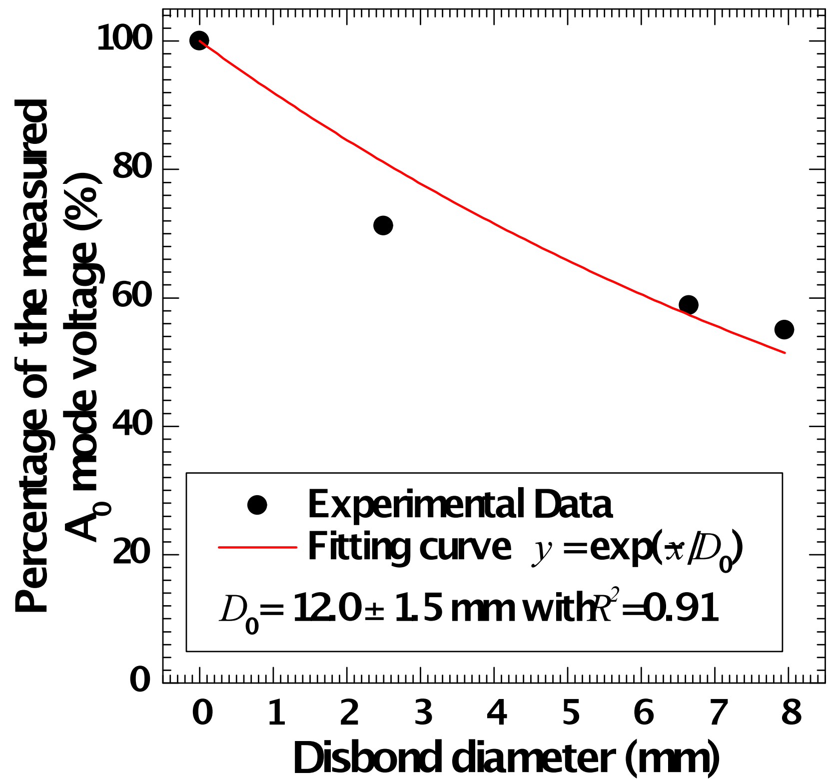
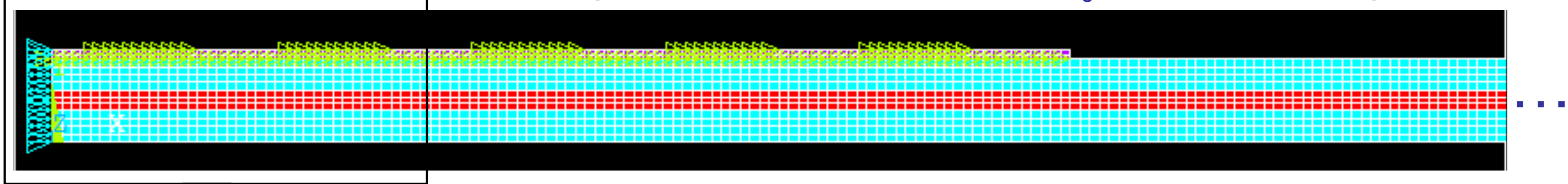


Fig. 9: Percentage of the measured A_0 mode Lamb wave signal as a function of the disbond diameter.

Lamb wave simulation with Finite Element Method (FEM)

- FEM model



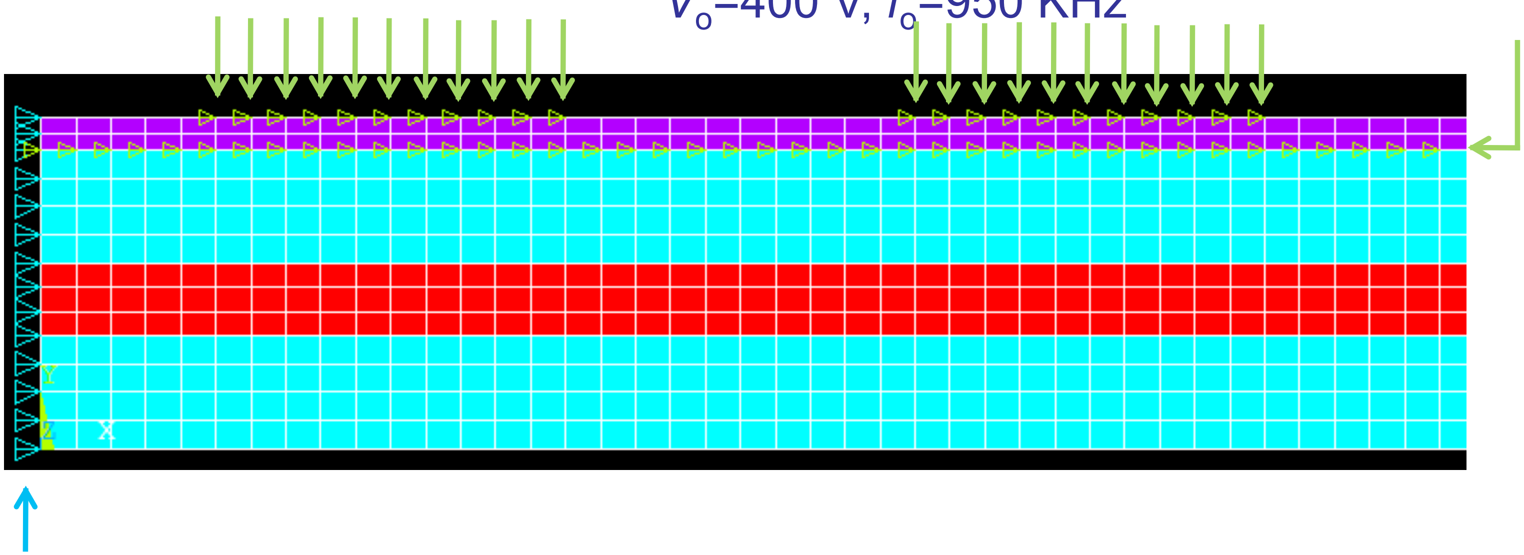
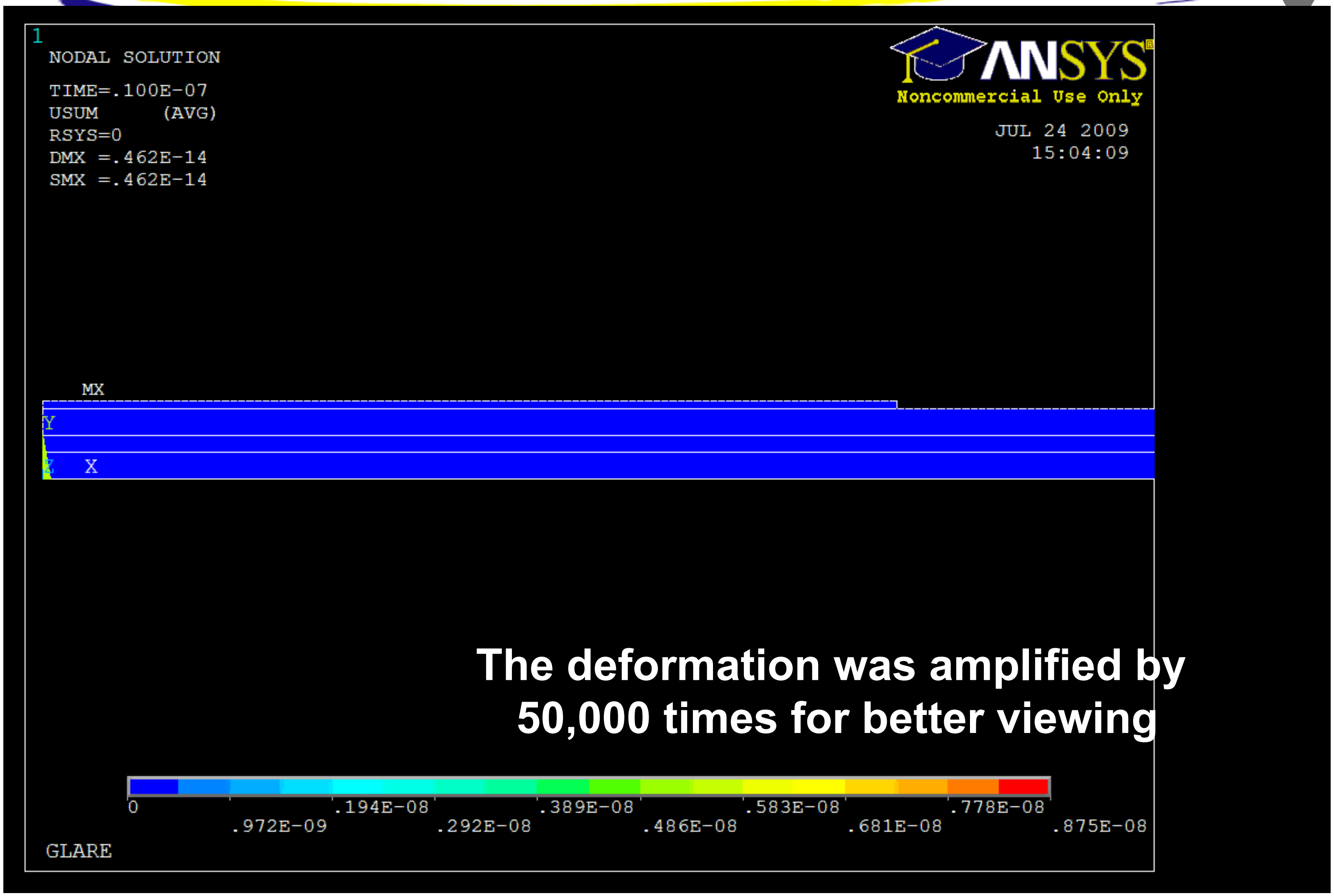


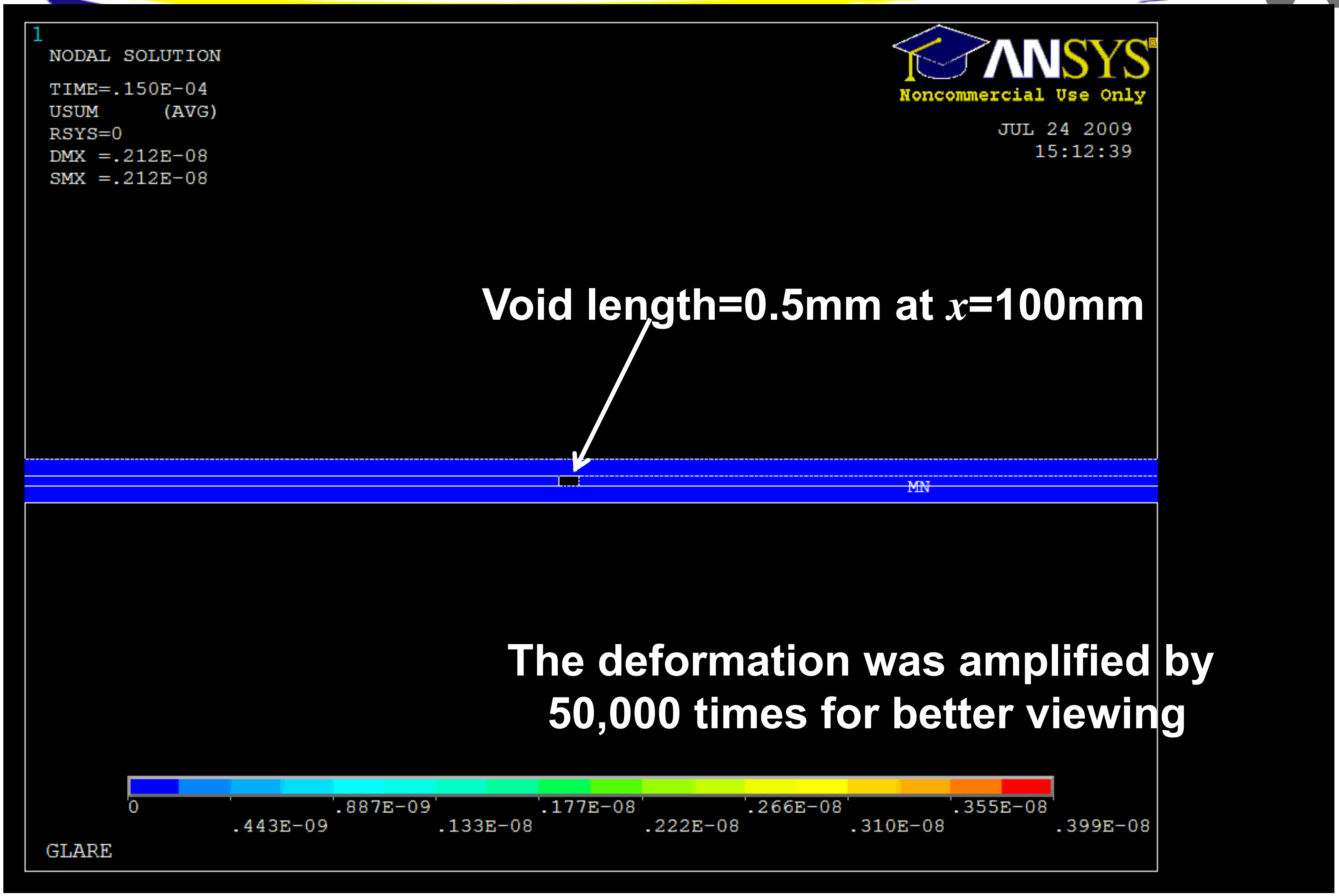
Fig. 10: Finite element model setup

Video of Lamb wave launching at PVDF transducer (Deformation)

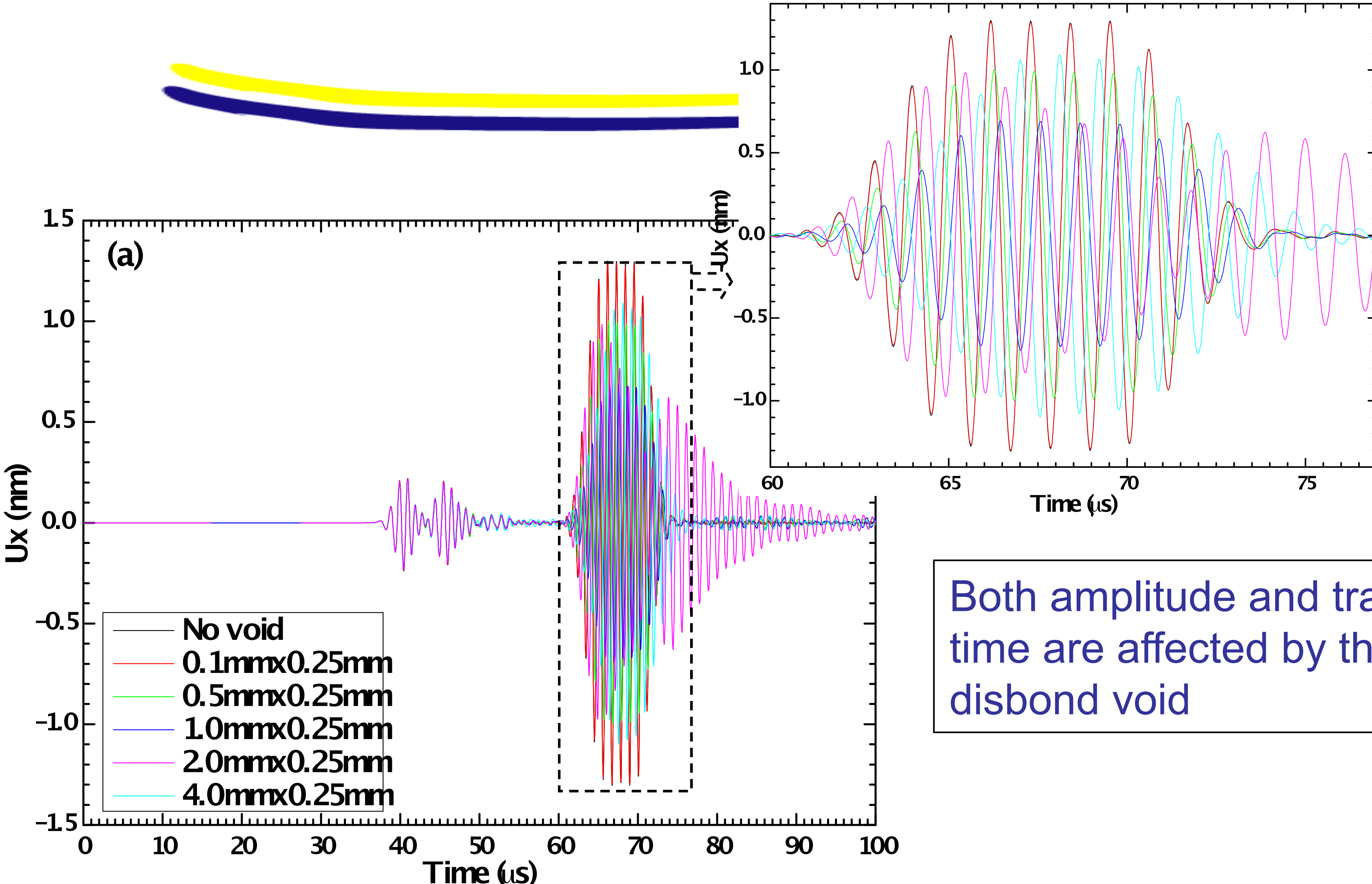


The deformation was amplified by 50,000 times for better viewing

Video of Lamb wave at the disbond void (Deformation)



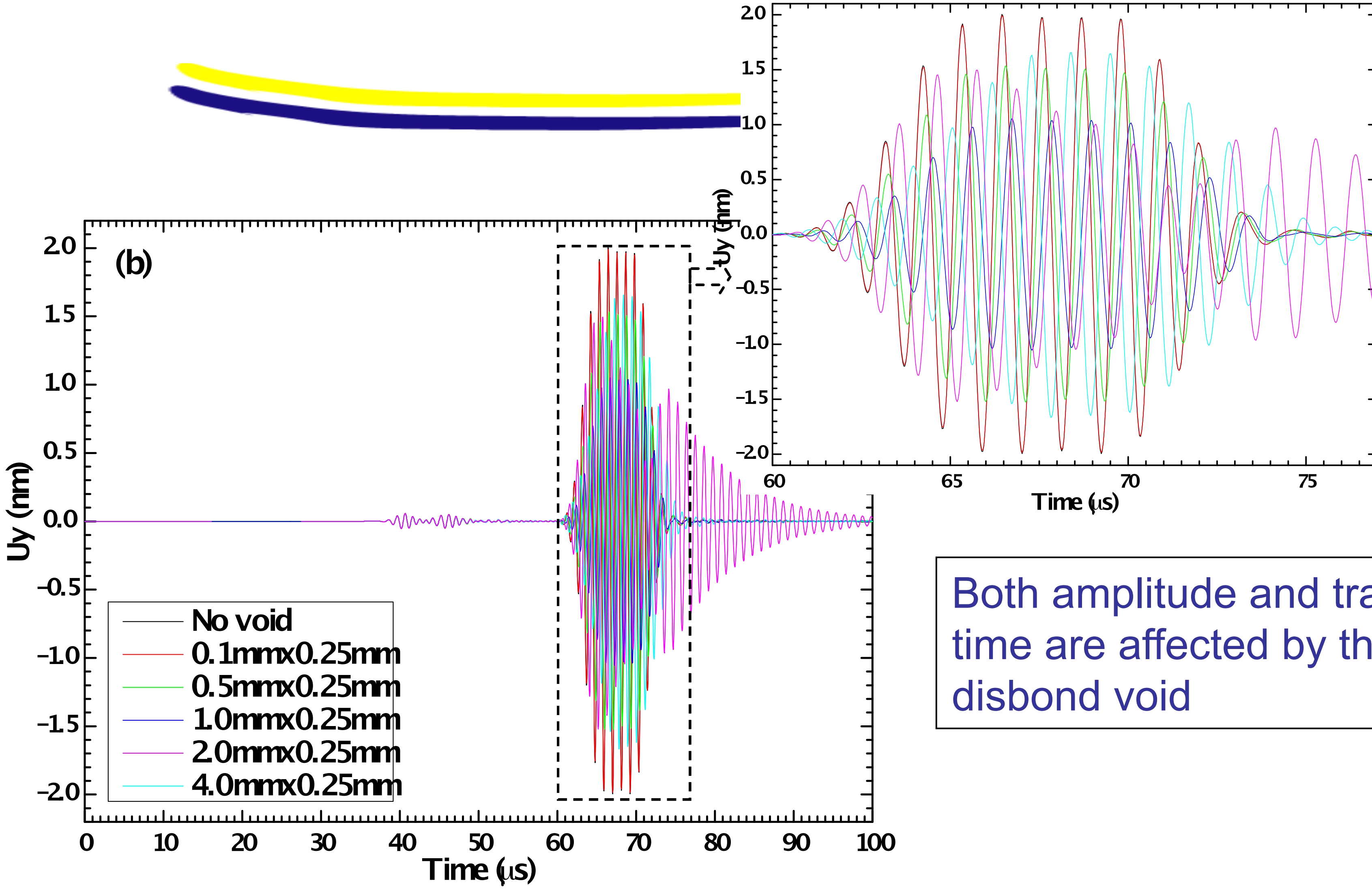
Influence of a disbond void on U_x



Both amplitude and travel time are affected by the disbond void

Fig. 11: Displacement component U_x at x=200mm, y=1.05mm (top surface) for various void size.

Influence of a disbond void on U_y



Both amplitude and travel time are affected by the disbond void

Fig. 12: Displacement component U_y at x=200mm, y=1.05mm (top surface) for various void size.

Influence of a disbond void on the displacement

Tab. 1: Amplitudes and travel time of the displacement component (U_y) of the A_0 mode Lamb wave versus void sizes

Void length (mm)	Void height (mm)	U_y maximum amplitude (nm)	Percentage of U_y maximum amplitude	Arrival time of the first U_y peak (μs)	Time delay in U_y (μs)
0	0	2.00	--	61.23	--
0.1	0.25	1.99	99.5%	61.23	0
0.5	0.25	1.53	76.5%	61.29	0.06
1.0	0.25	1.05	52.5%	61.44	0.21
2.0	0.25	1.50	75.0%	61.56	0.33
4.0	0.25	1.65	82.5%	61.98	0.75

Concluding remarks

Experiments:

- The measured A_0 mode Lamb wave decays exponentially with increasing disbond diameter.
- The disbond defect sizes can be predicted from the measured Lamb wave signals using the exponential model.

FEM model:

- Both the displacement amplitudes and travel time of the A_o mode Lamb waves were shown to be influenced by the disbond void.
- The time delay increases with increasing disbond sizes, which can be used as a parameter to monitor the disbond growth

A Look Forward

- Benefit to Aviation

  The study of the influence of a disbond defect on Lamb wave propagation can be used for SHM of safety critical structures.

- Future needs
  - More testing and field application.