Characterization of Impact Damage in Composite Plates

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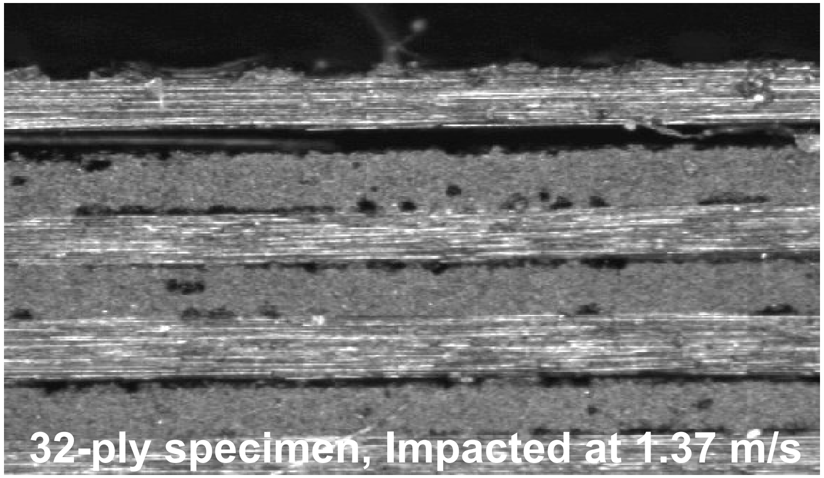
Motivation

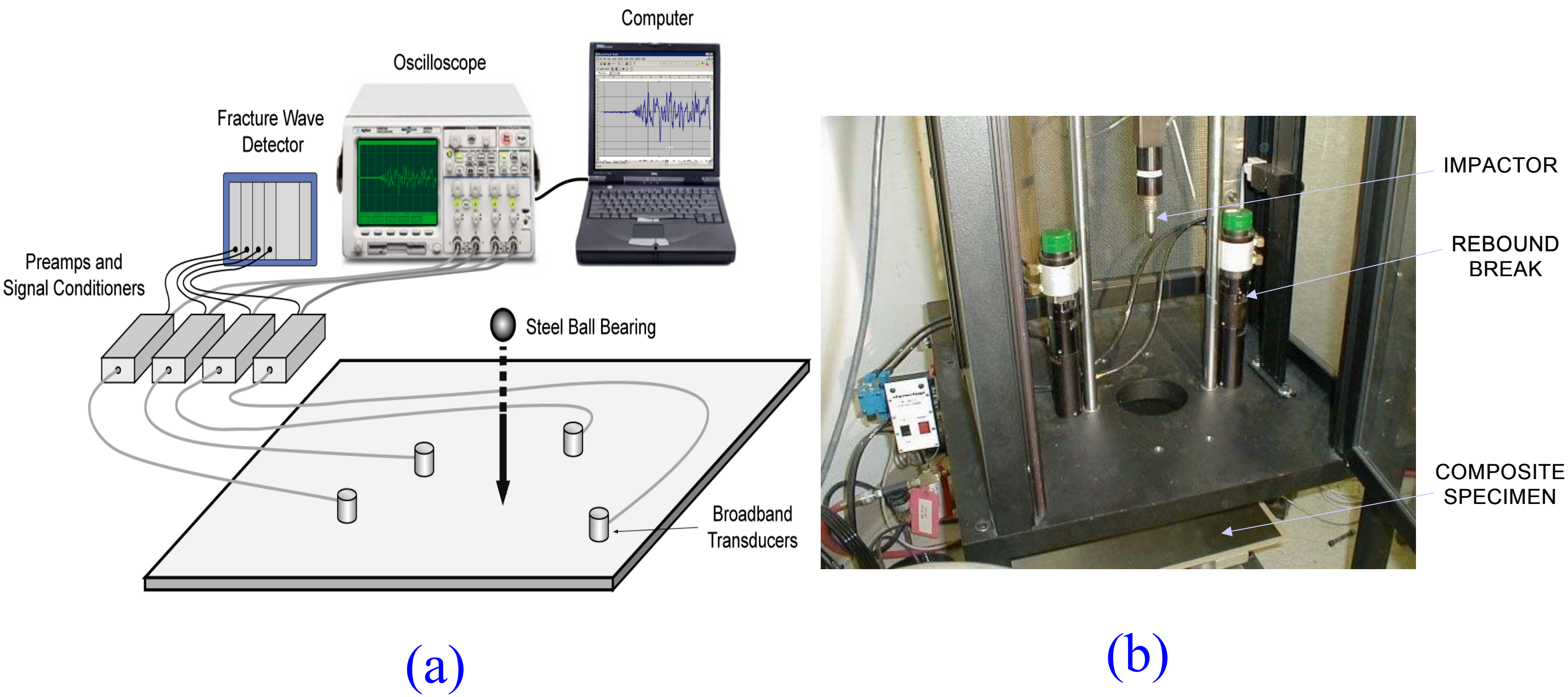
- Composite structures are often subjected to foreign object impact which may initiate inter-ply delaminations at depth
- If left undetected, hidden damages can grow and lead to catastrophic failure of the structure
- This study is concerned with the detection of low velocity foreign object impact and the resulting damage, if any, in composite structures in real time
- Defects-critical structures require regularly scheduled inspection and maintenance that are costly and often unnecessary
- Continuous monitoring of emerging flaws in advanced structures can save cost and improve safety

X-33 LH2 composite tank failure



Photomicrograph of Delamination

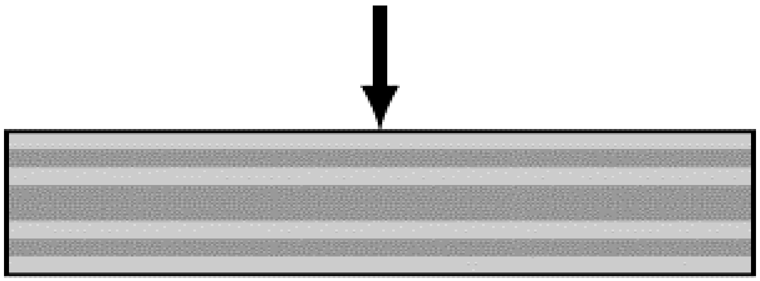
Experimental Setup of the Impact Test



Non damaging and damaging impact tests: (a) Main data acquisition system

(b) Close-up of the Instron/Dynatup impact machine

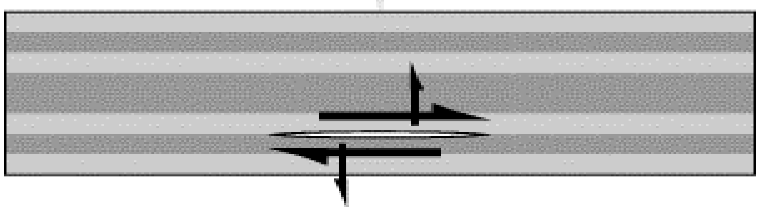
Theoretical Modeling



1. Initial contact load

Source modeling

$$S(t) = \begin{cases} 0 & t < 0 \\ \sin^2\left(\dfrac{\pi}{2}\dfrac{t}{\tau_1}\right) & 0 < t < \tau_1 \\ 1 - \sin^2\left(\dfrac{\pi}{2}\dfrac{t-\tau_1}{\tau_2}\right) & \tau_1 < t < \tau_1 + \tau_2 \\ 0 & \tau_1 + \tau_2 < t \end{cases}$$



2. Shear delamination

$$S(t) = \sin^2(\pi t / 2\tau) H(t - \tau)$$

Vertical surface displacement

Frequency-Wavenumber domain

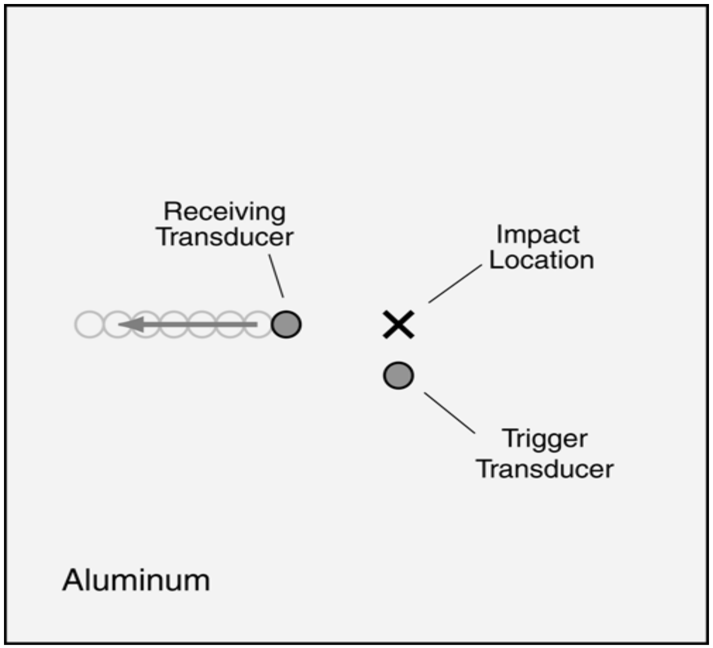
$$\hat{u}_3(x_1, x_2, \omega) = \frac{S(\omega)}{4\pi^2} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{f(k_1, k_2, \omega)}{g(k_1, k_2, \omega)} e^{i(k_1 x_1 + k_2 x_2)} dk_1 dk_2$$

Time domain

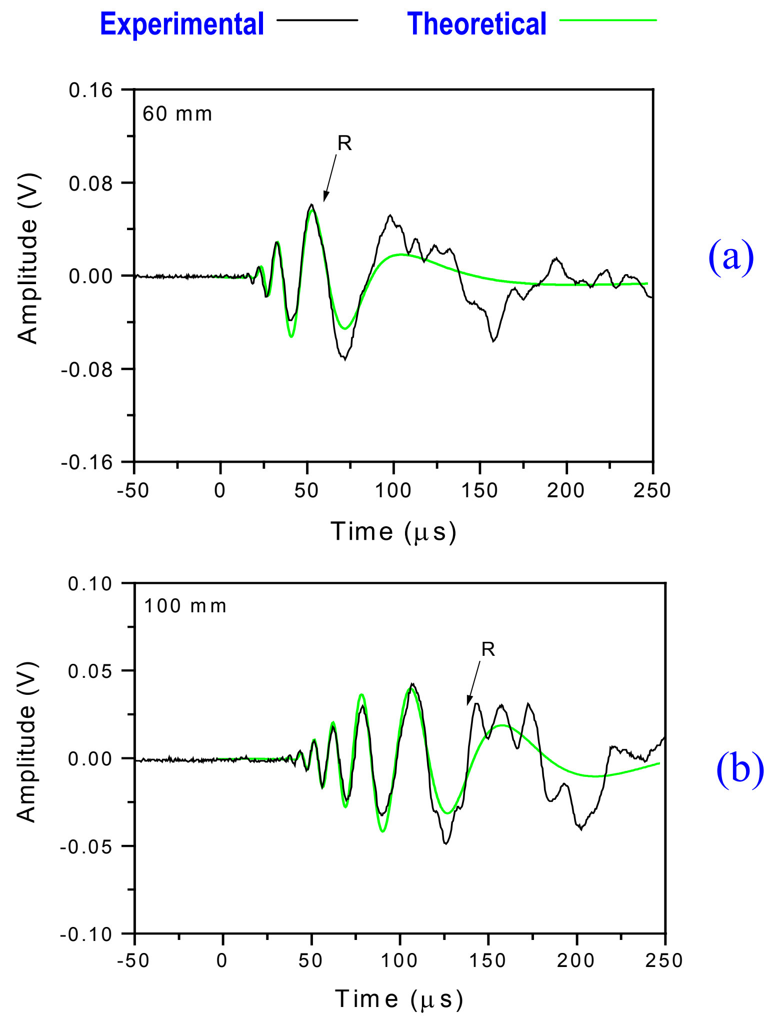
$$u_3(x_1, x_2, t) = \mathrm{Re}\,\frac{1}{\pi}\int_0^{\infty} \hat{u}_3(x_1, x_2, \omega) e^{i\omega t} d\omega$$

Non-Damaging Impact on Plates

Aluminum



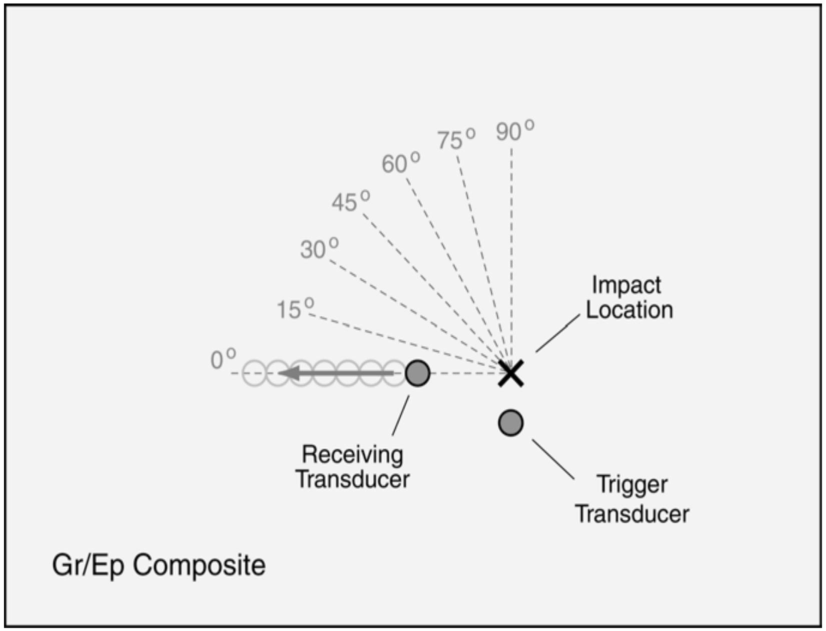
- Thickness: 1/16” (1.6 mm)
- 2.1 m/s impact velocity using a steel ball
- Constant trigger source for the experimental results



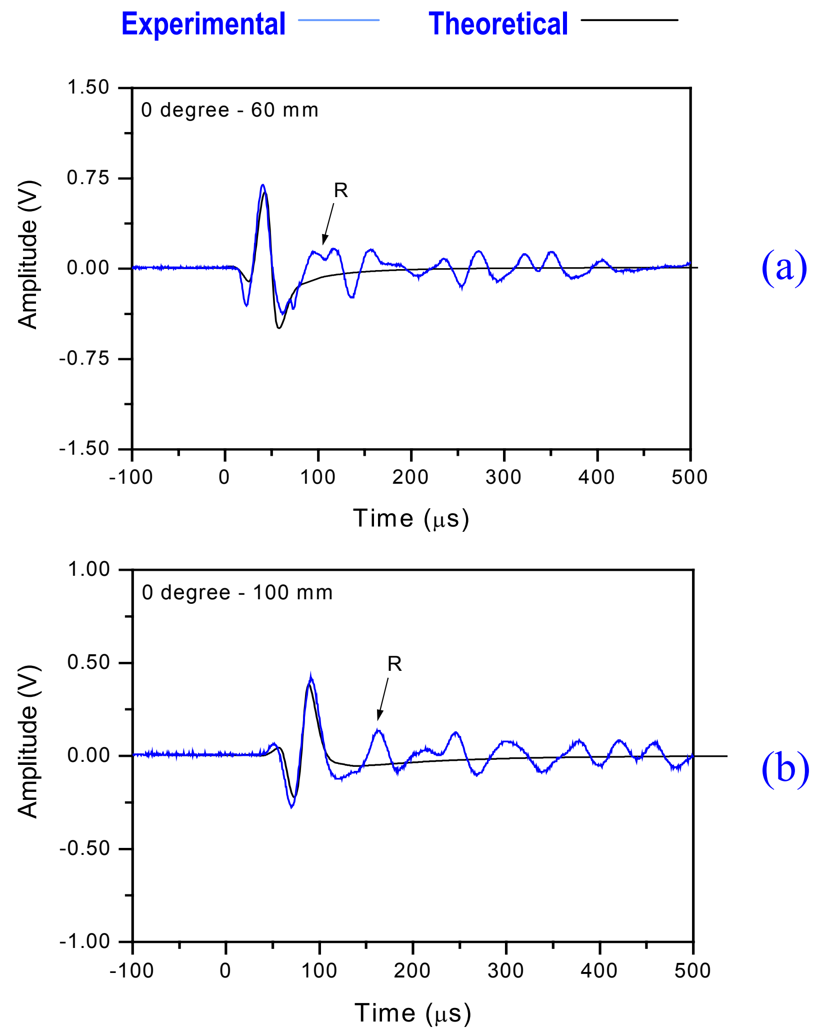
Typical waveforms at (a) 60 mm and (b) 100 mm away from impact location

Non-Damaging Impact on Plates (cont.)

32 layered cross-ply composite



- Thickness: 4.3 mm
- 15 degree interval, 10 mm increments
- Same experimental condition as that of aluminum impact tests



Typical waveforms at (a) 60 mm and (b) 100 mm away from impact location

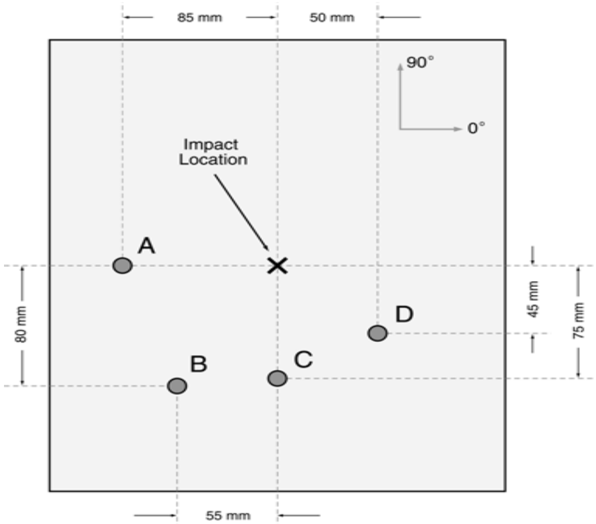
Damaging Impact on Plates

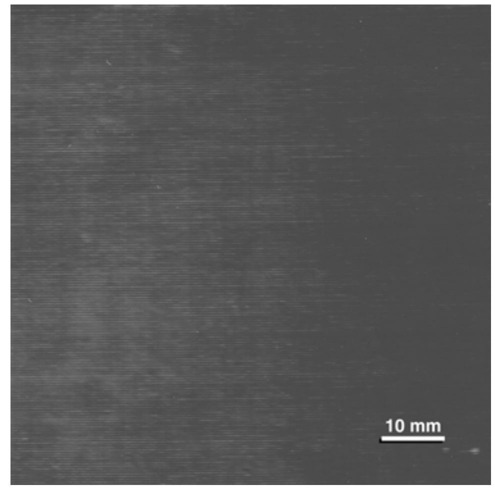
Sensor locations on the 32 layered cross-ply plate

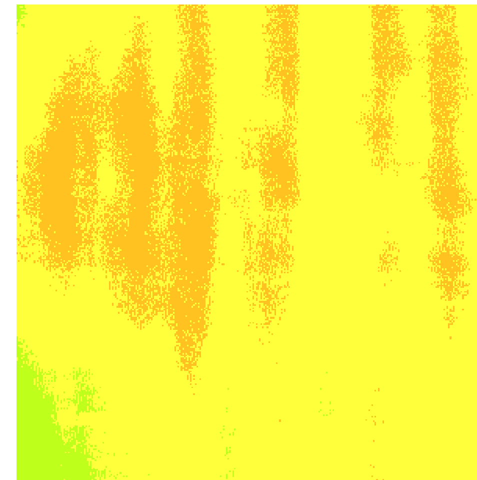
External appearance

Immersion ultrasonic C-scan

14 lb impactor

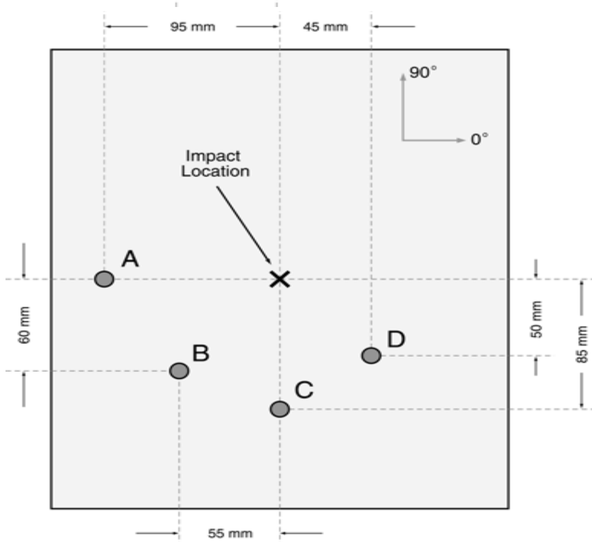


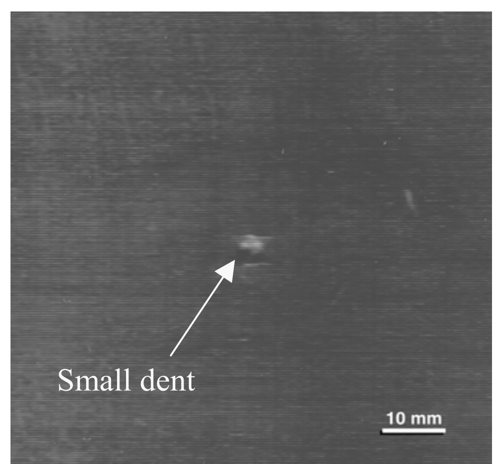


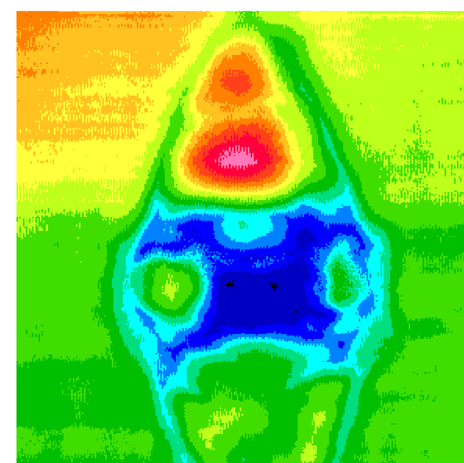


(No major internal damage)

61 lb impactor







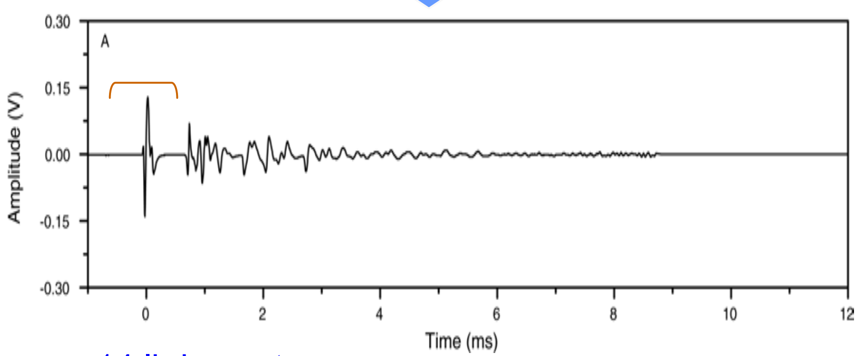
(Internal delamination)

Damaging Impact on Plates (cont.)

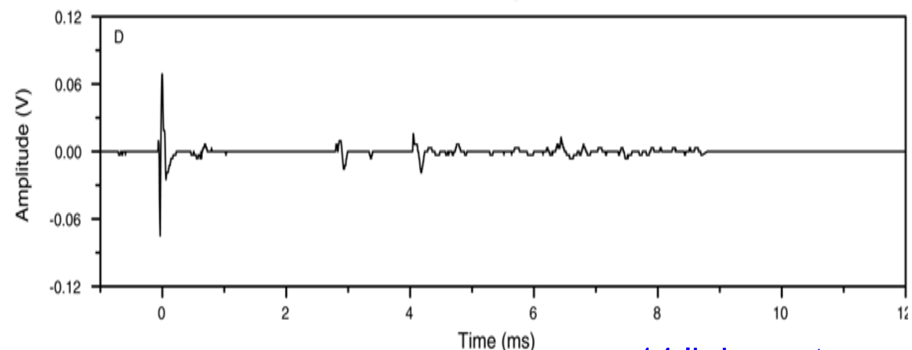
Typical recorded acoustic emission waveforms

Sensor located at A

Sensor located at D



14 lb impactor



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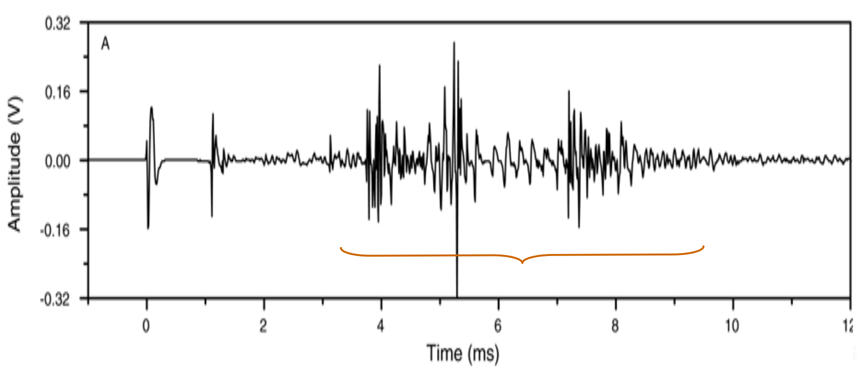
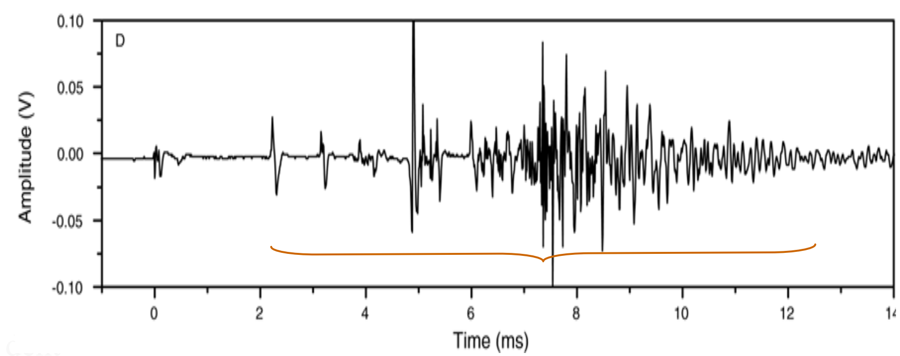


61 lb impactor



61 lb impactor

Waveforms from the initial contact

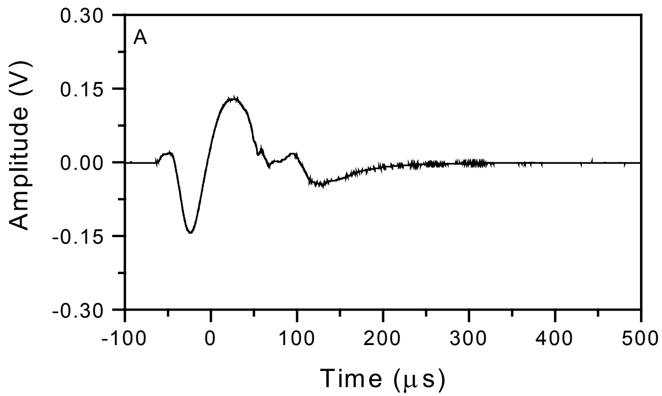
Waveforms from delamination events

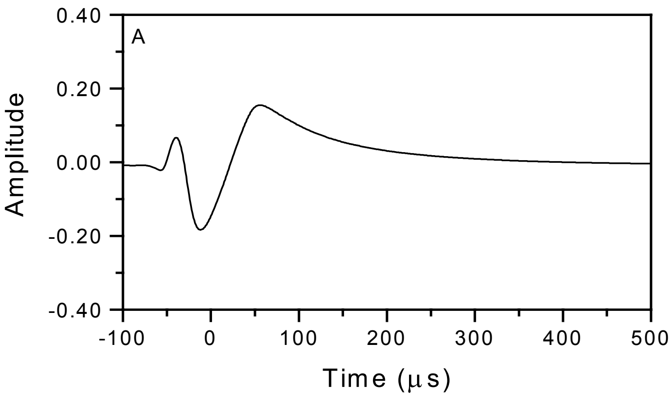
Waveforms from Initial Contact Load

Experimental

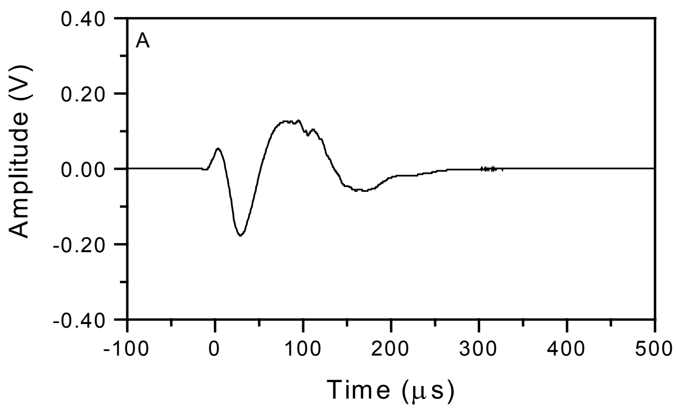
Theoretical

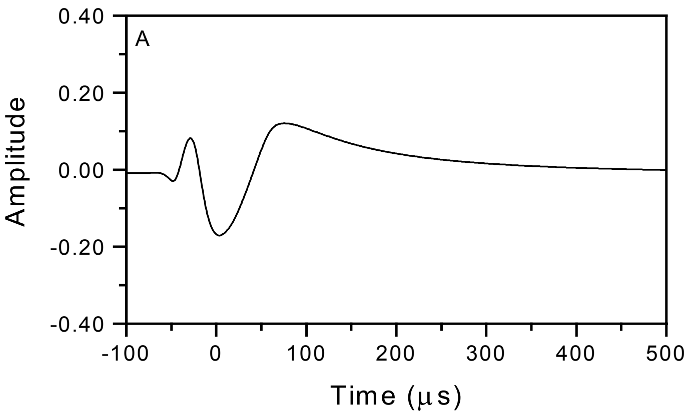
14 lb impactor





61 lb impactor





Waveforms from the initial contact load for sensor location A

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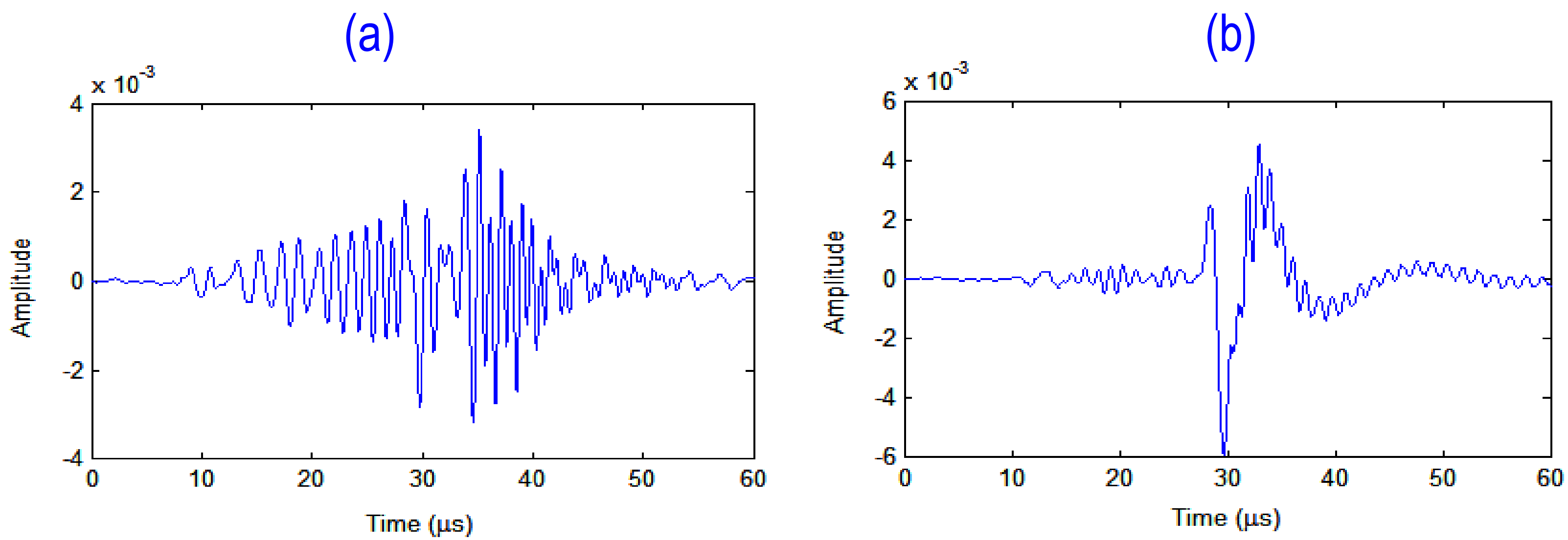
Waveforms from Delamination Initiation



Theoretical signals from initiation of shear delamination at interfaces between (a) layers 4-5 (b) layers 16-17

- Surface motion is stronger for sub-surface delamination
- The theoretical calculations somewhat conform the experimental results. The photomicrograph showed the presence of major sub-surface delamination
- The depth of the delamination source can be identified with some confidence

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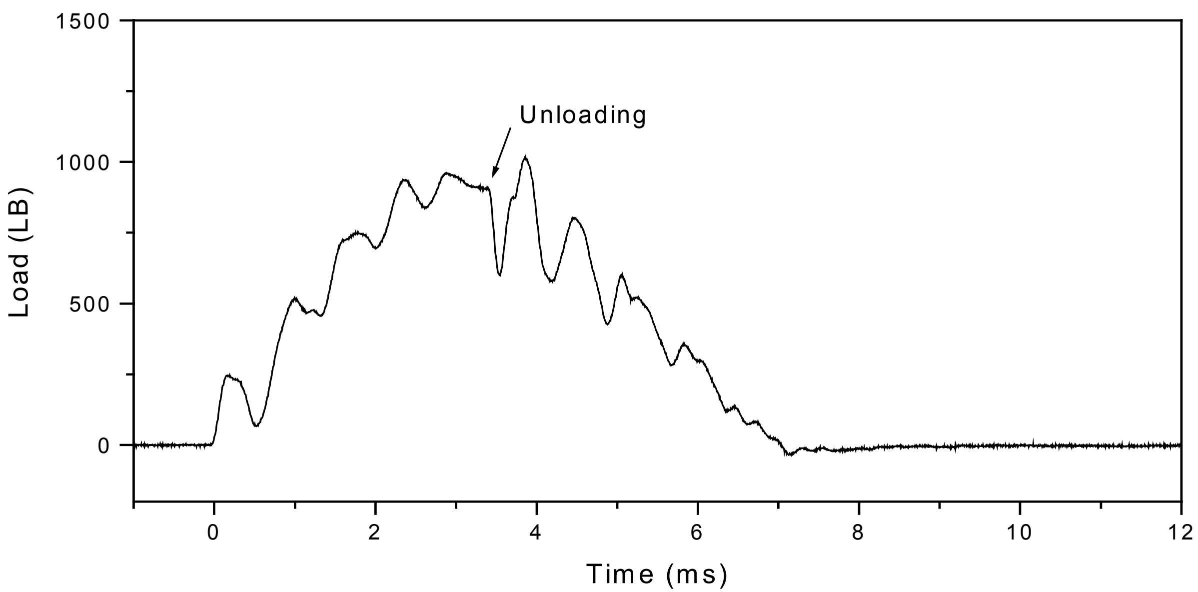
Correlation with Force-Time History

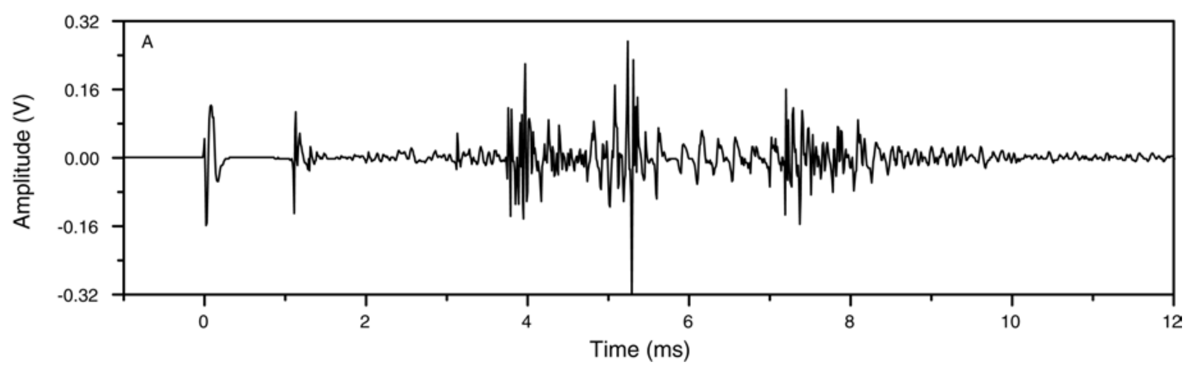
- Unloading occurs during delamination damage

Sensor location A

Force-time history



Recorded signal



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Concluding Remarks

- Model based prediction of far-field waveforms from impact and damage events was successful in both aluminum and thin composite plates
- Signals from impact and delamination damage can be identified from far-field waveforms using the improved experimental setup
- Failure events can be correlated with sudden unloading in the force-time curve
- Results of this research can be used to develop a more reliable nondestructive damage detection method than is currently available
- Distributed broadband sensors coupled with careful modeling can be used to develop viable health monitoring systems for composite structures

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