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Dynamic Mode-II Characterization of A Woven Composite

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Introduction

- Motivation
  - Delamination strength of fiber reinforce composite subjected to external impact
- Loading rate effect on the fracture toughness properties in composite
  - Different results are reported: increasing, decreasing, increasing then decreasing, independent, etc.
  - Great care must be taken when conducting high rate experiments.

  (G. C. Jacob et al., Journal of Applied Polymer Science, Vol. 96, 899–904, 2005)
- Fundamental issues in Hopkinson Bar Loaded Fracture Experiments
  - **Stress-state equilibrium**
  - **Stress-wave propagation behavior within the cracked sample**
  - **Pulse-shaping effect**
  - …

  (Jiang & Vecchio, Applied Mechanics Reviews, vol. 62, November 2009)

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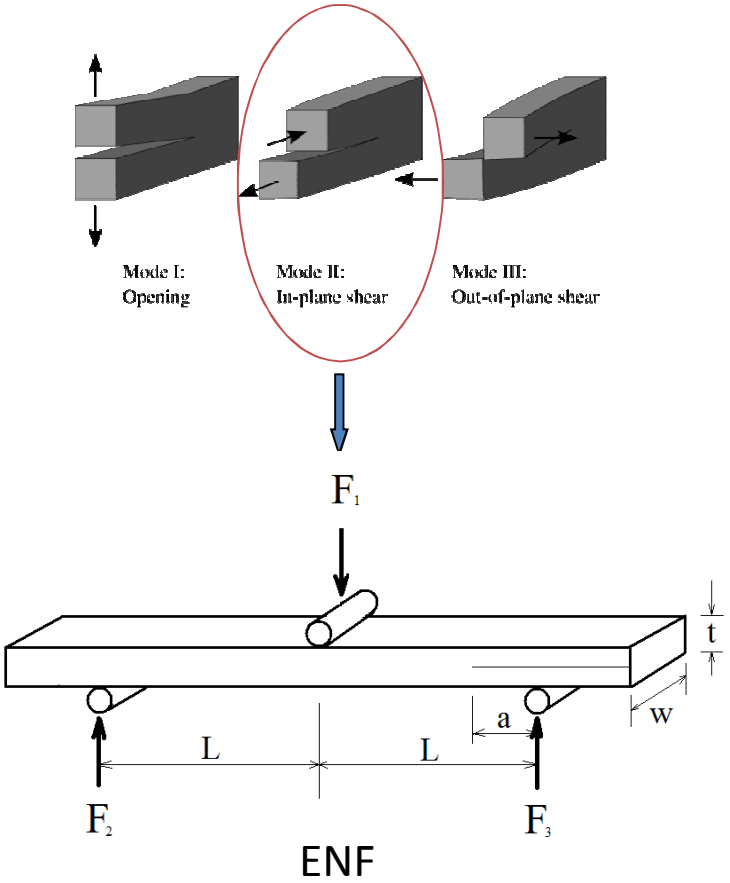
Dynamic Mode-II Fracture of Composite

- Fracture Modes



ENF

Quasi-static Experiment:

$$P = F_1 = 2F_2 = 2F_3$$

$$G_{IIC} = \frac{9a^2P^2}{16E_f w^2 h^3}$$

$$h = \frac{t}{2} \qquad E_f = \frac{2L^3 + 3a^3}{8wh^3} \cdot \frac{1}{C} \qquad C = \frac{\delta}{P}$$

Dynamic Experiment:

$$P = F_1 \overset{?}{=} 2F_2 \overset{?}{=} 2F_3$$

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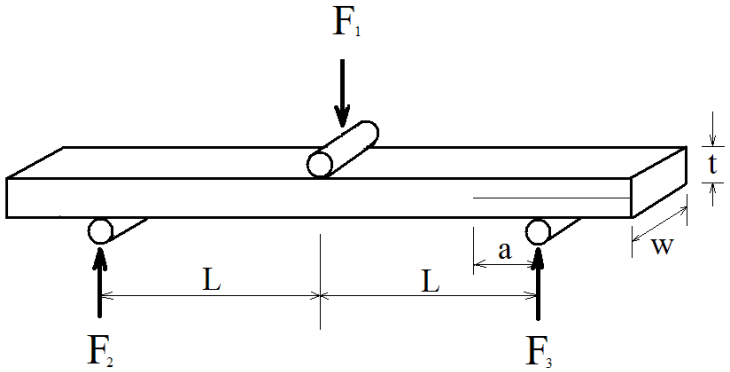
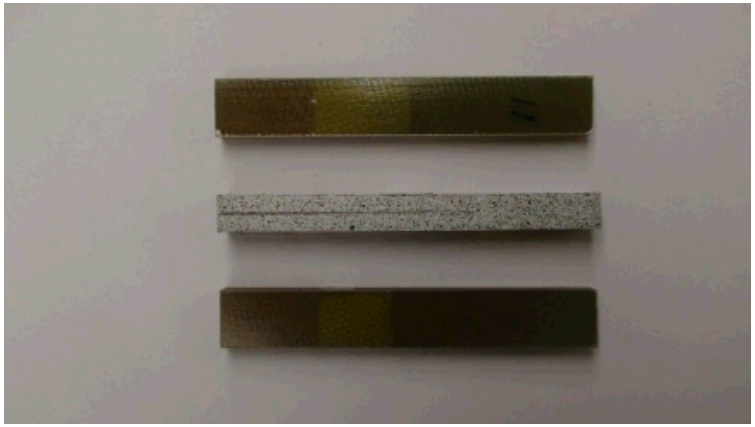
Approach

- **PVDF force transducer**
- **High-speed DIC**
- MTS and SHPB (two-bar/3PB)
- Woven glass fiber composite





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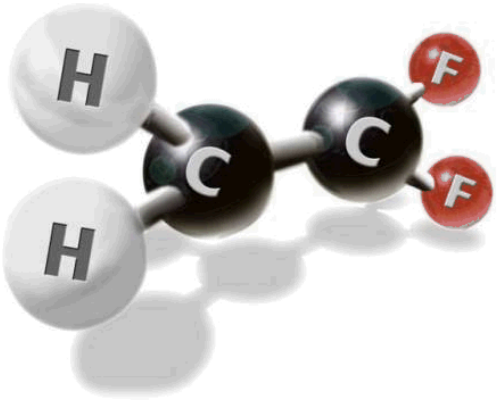
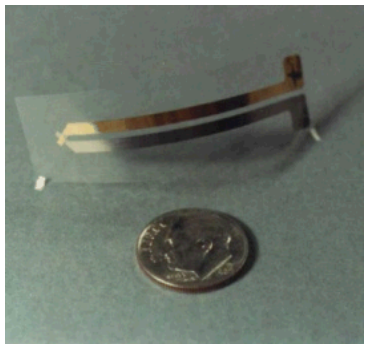
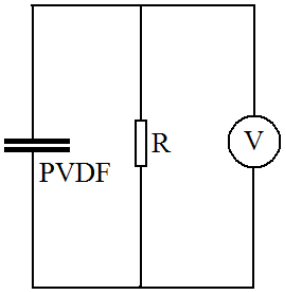
PVDF Piezoelectric Transducer



Polyvinylidene Fluoride (PVDF):

- A highly sensitive piezoelectric film force transducer
- **Force – Charge curve needs to be carefully calibrated in a large range of force before application**





$$Q = \int_0^t \frac{V(t)}{R}\,dt$$

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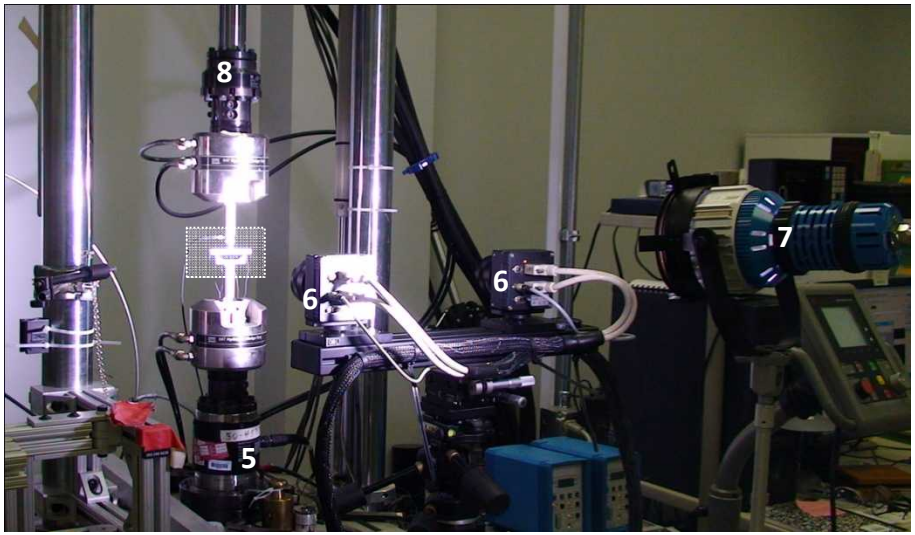
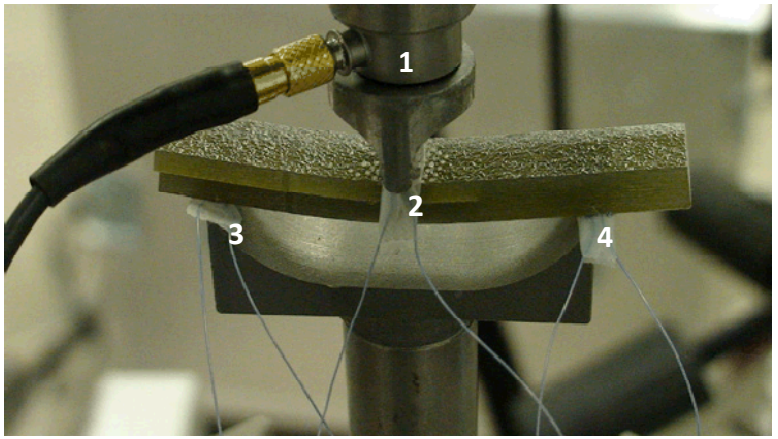
MTS Setup



1. Load washer, top
2. PVDF, top
3. PVDF, bottom, pre-crack
4. PVDF, bottom, no crack

5. MTS load cell, bottom
6. Camera
7. Cool light
8. Actuator



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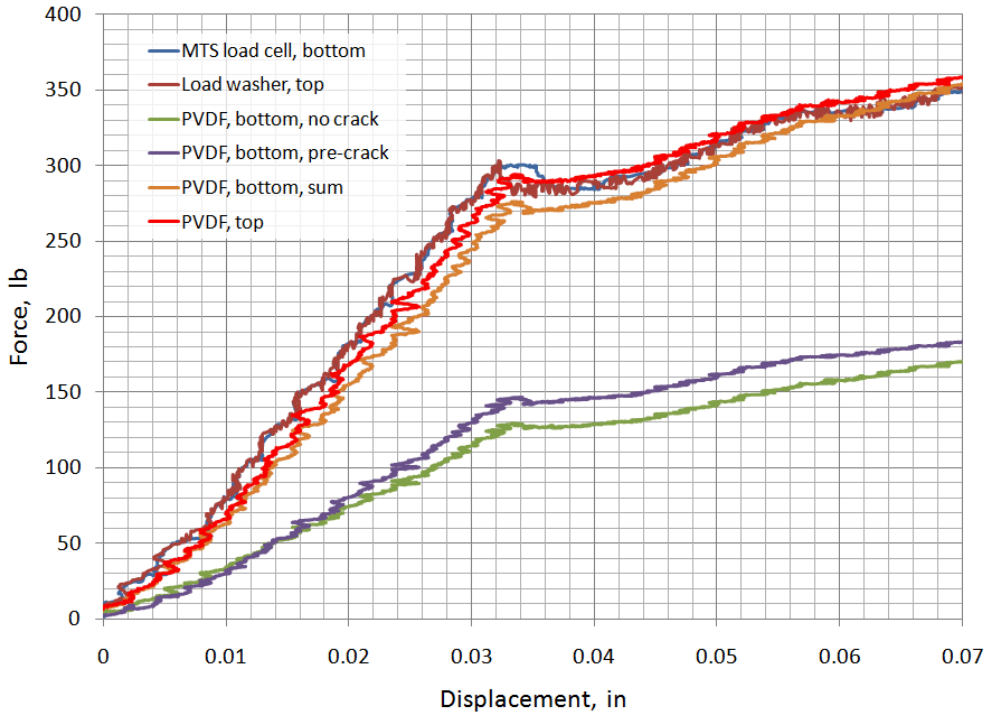
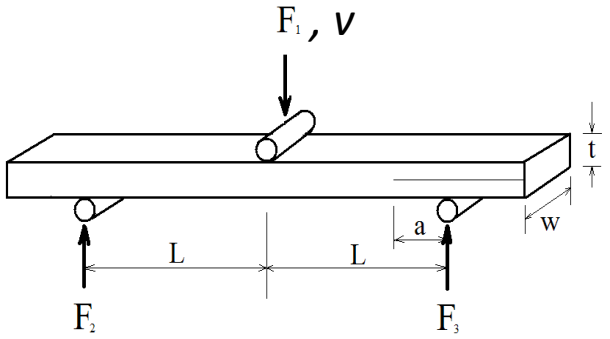
MTS ENF Experiment

V = 0.24 m/s (9.5 in/s)





L = 1.0” w = 0.5”

t = 0.25”

a = 0.4”

$$P = F_1 = 2F_2 = 2F_3$$

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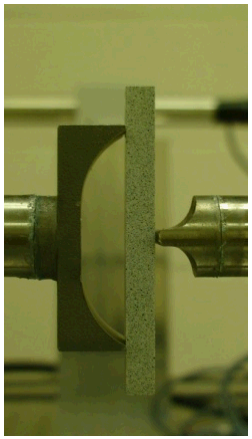
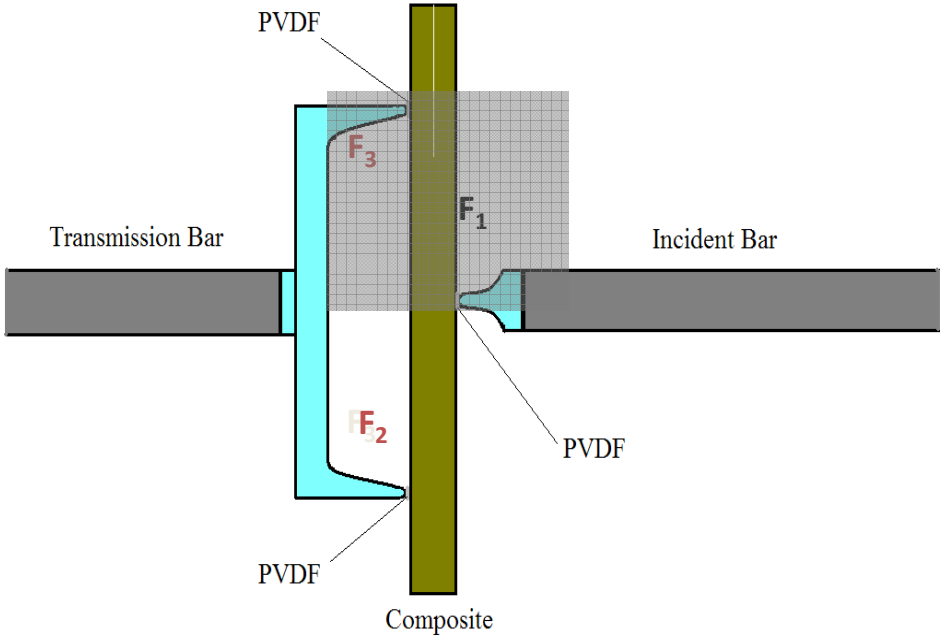
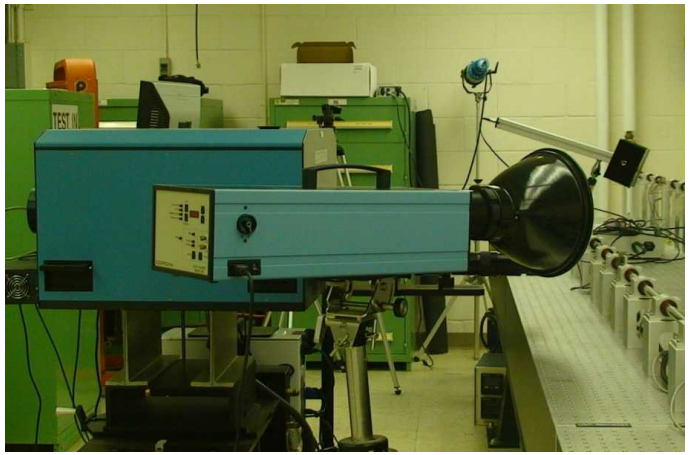
Dynamic ENF Test

SHPB without Pulse-shaper

- **PVDF films** were embedded at loading points
- Beam deformation was measured using DIC method
- Loading speed was about 3.7 m/s







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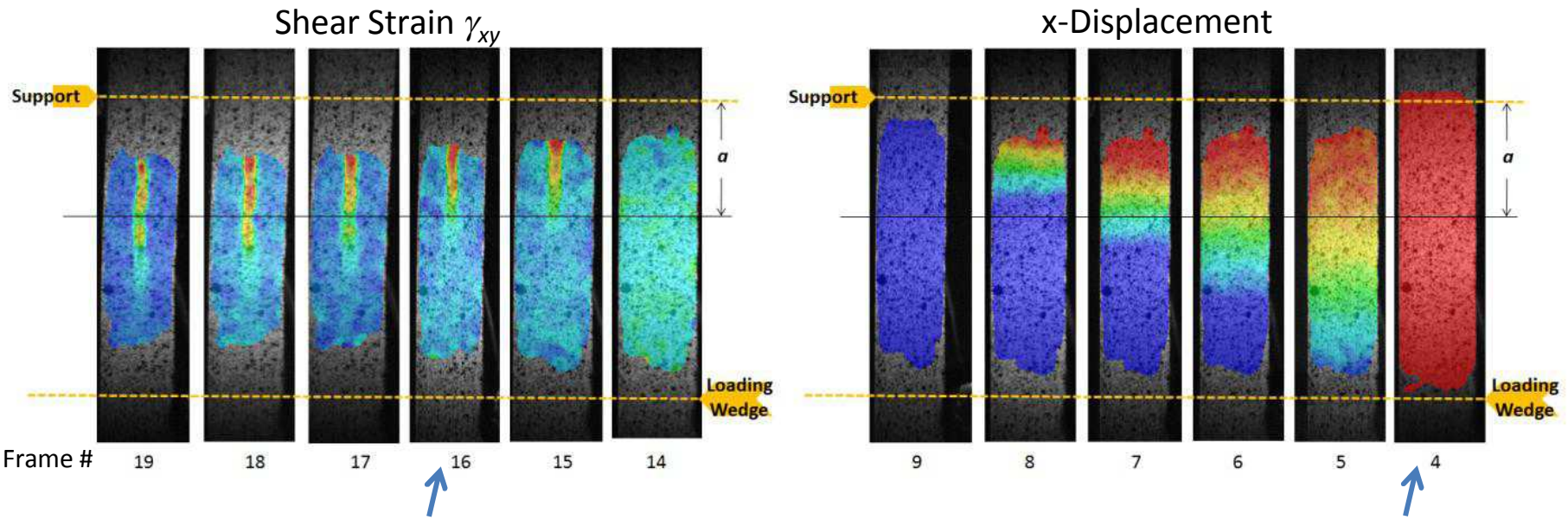
Wave & Crack Propagation

- DIC results



- Loading started between Frame #4 & 5
- The crack started to propagate between Frame #16 & 17, about 60 μs after loading started

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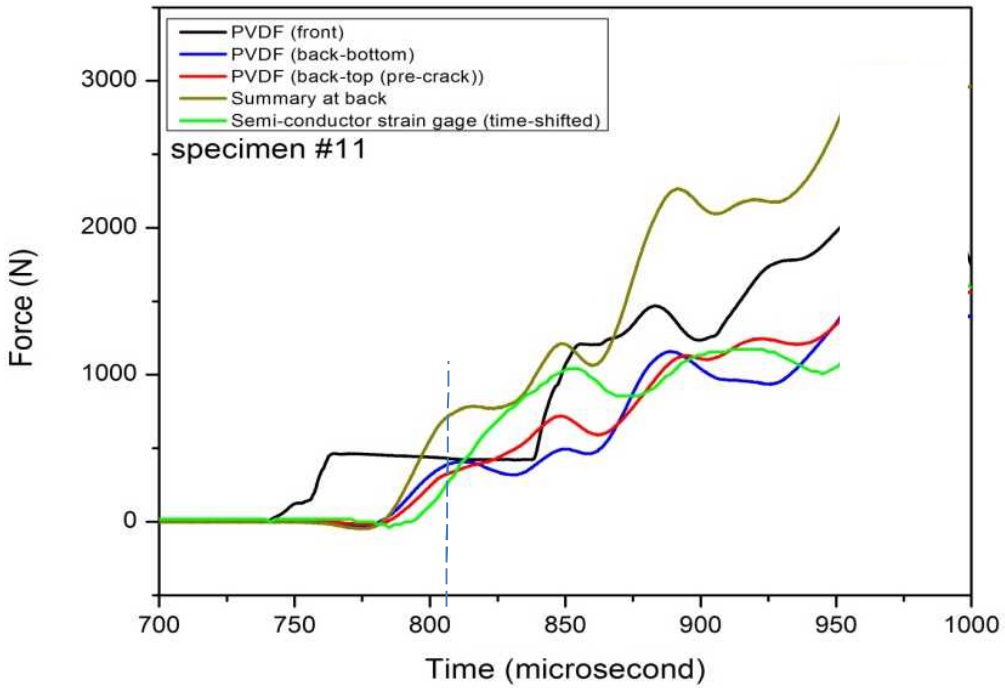
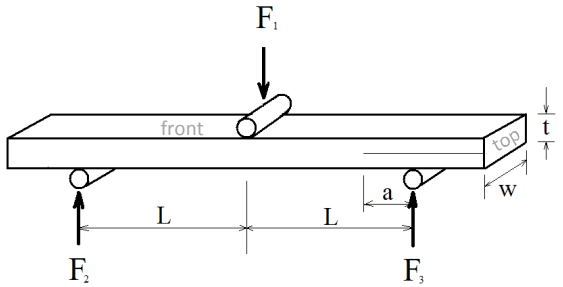
Experimental Results





- Approximately 30-40 μs delay of the back side PVDF signals w.r.t the front side PVDF signal.
- The equilibrium condition was not satisfied when the crack started to propagate.

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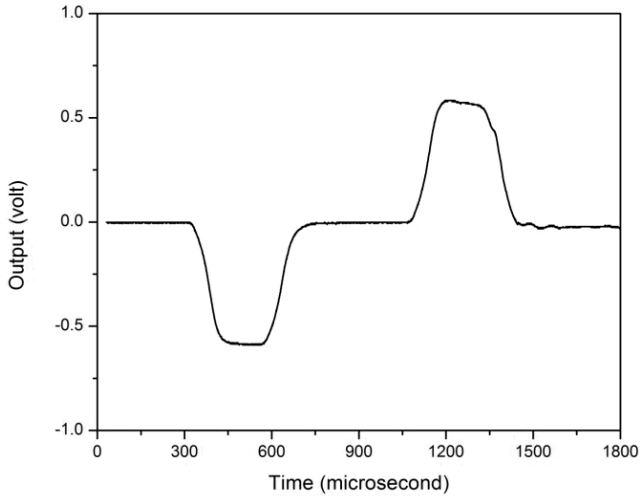
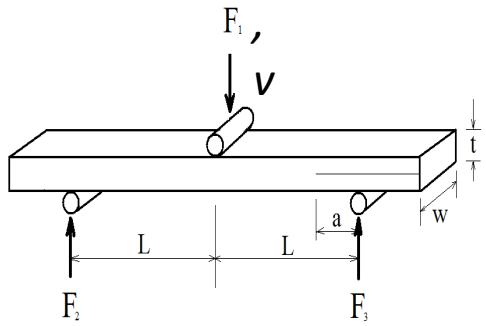
Dynamic ENF Test

SHPB with Pulse-shaper

- A ø1/8×0.02” annealed copper disk was attached to the impact surface of the incident bar
- **PVDF films** were embedded at loading points
- Beam deformation was measured using DIC method (83,000 fps)
- Loading speed: ~ 5.6 & 9.2 m/s
- The modified incident pulse possesses a rise time of approximately 130 µs





L = 1.0”

w = 0.5”

t = 0.25”

a = 0.25”

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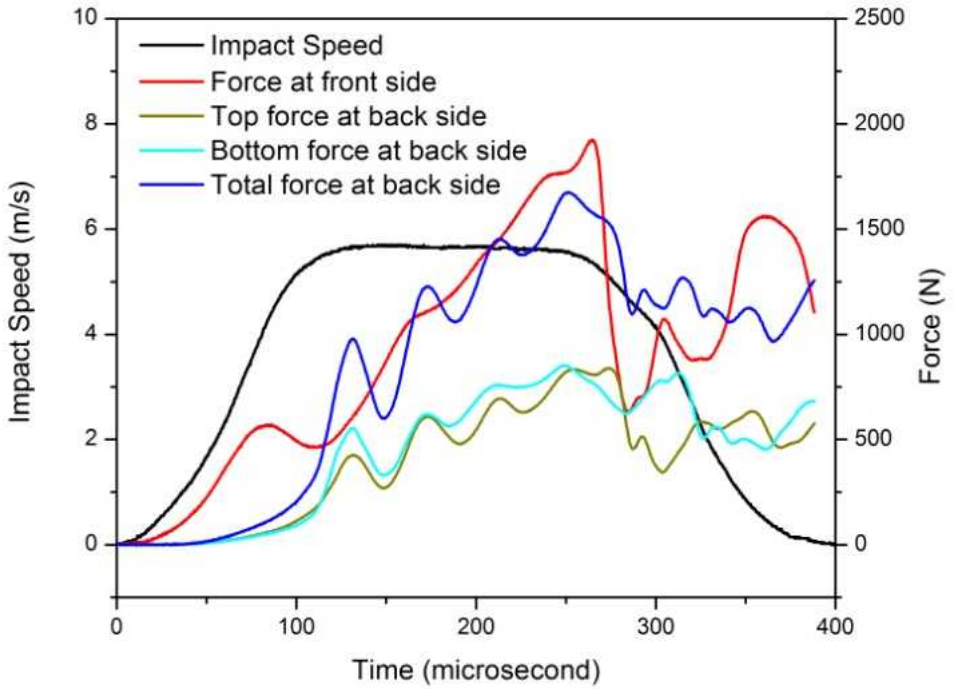
Impact Speed & Force Histories

- Approximately *30-40 μs* delay of the back side PVDF signals w.r.t the front side PVDF signal
- Front and back forces were equilibrated when $t > 113\ \mu s$
- Impact speed nearly constant during $100 < t < 270\ \mu s$



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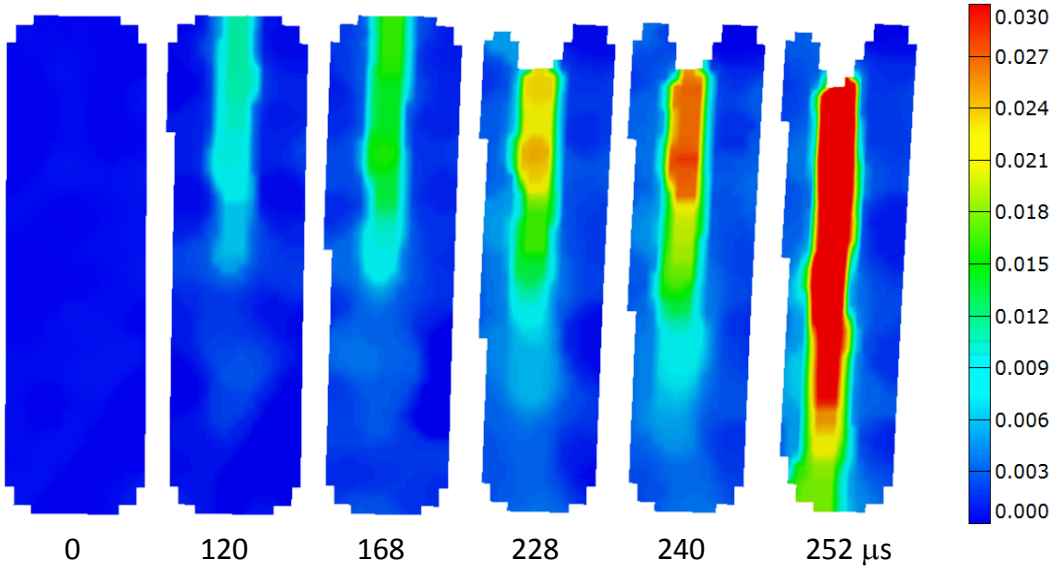
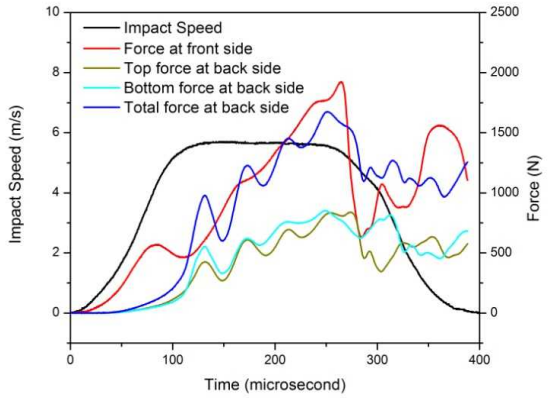
Crack Propagation

- DIC shear strain results show the crack started to propagate at approximately $t = 252\ \mu s$, near the peak load was reached and was within the range of constant speed.





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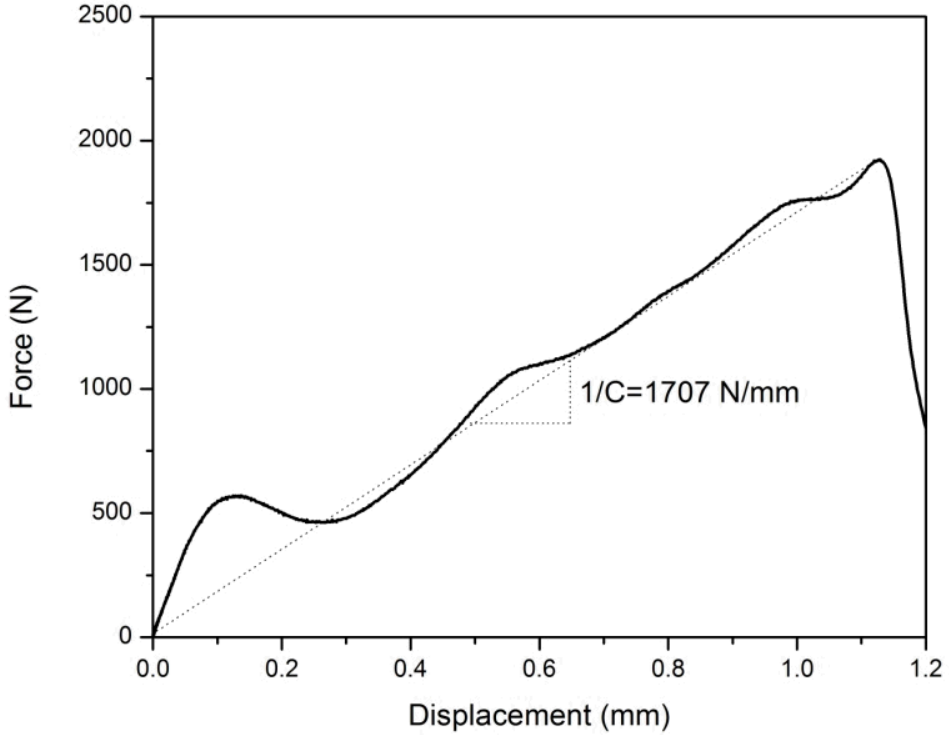
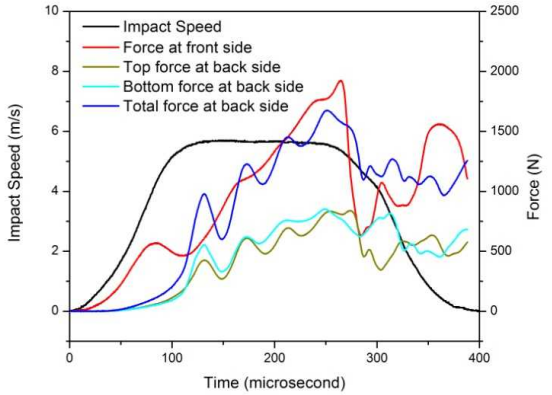
Load-Displacement Curve





$$G_{IIC} = \frac{9a^2P^2C}{2w\left(2L^3 + 3a^3\right)}$$

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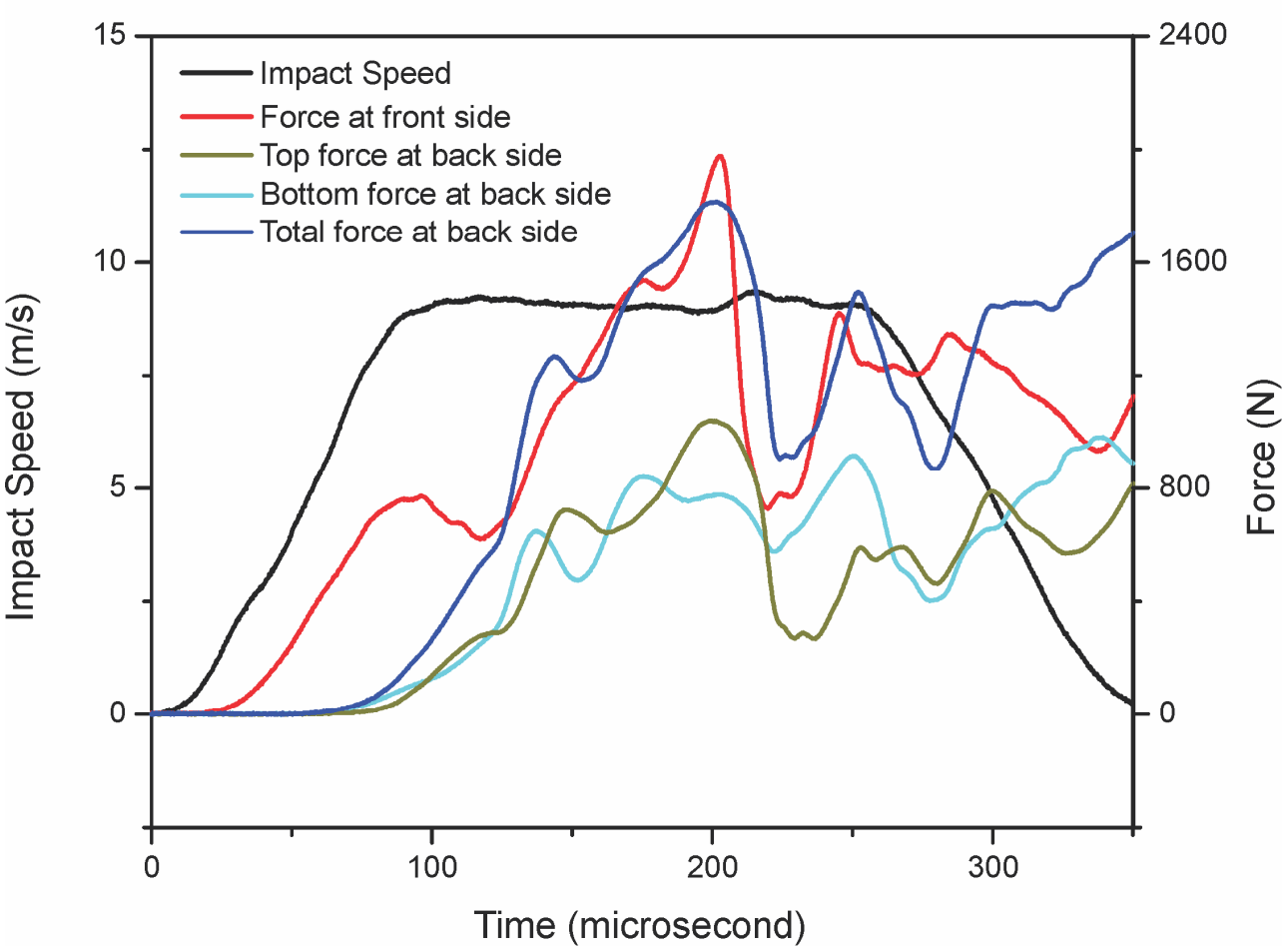
Dynamic ENF Test @ 9.2 m/s



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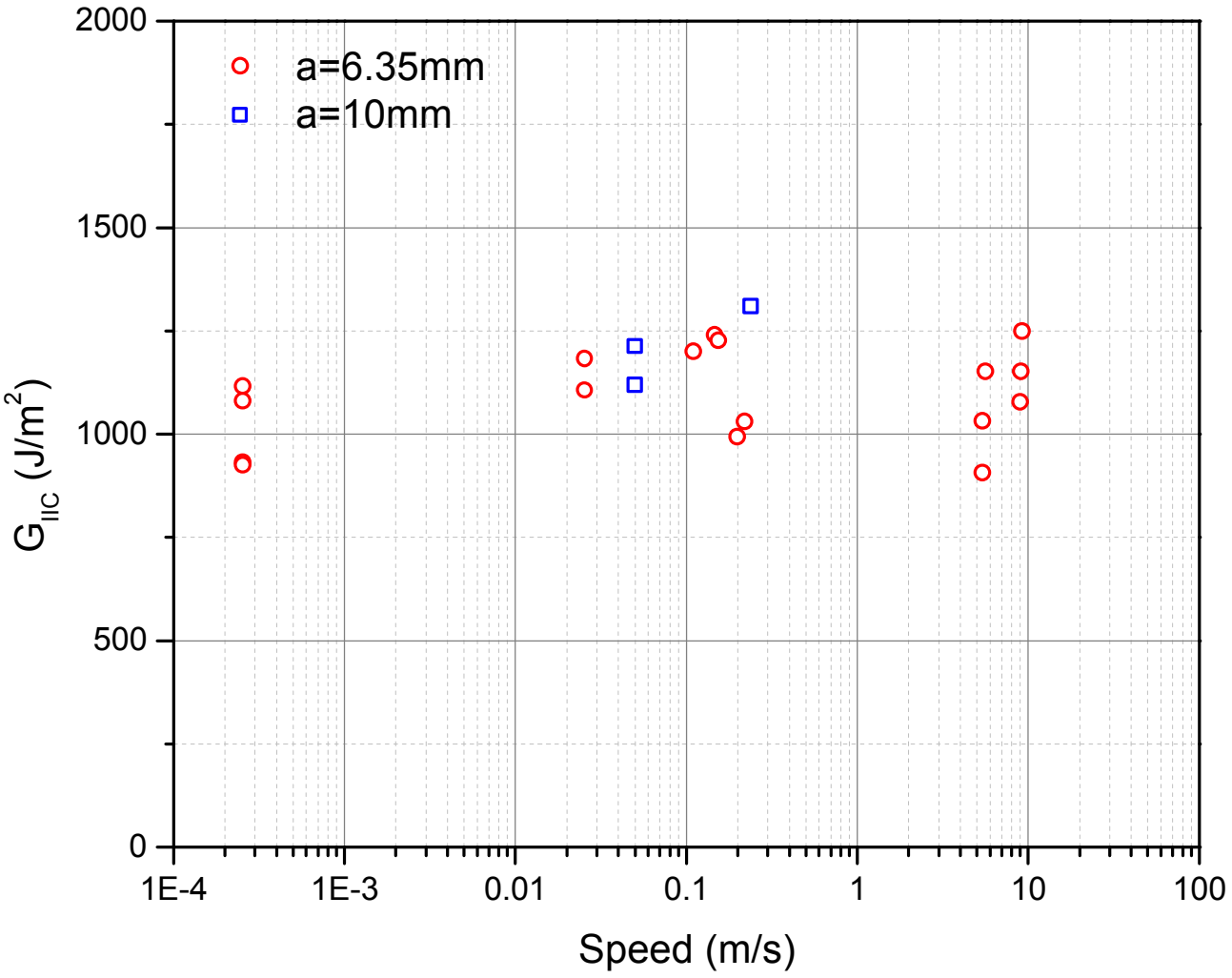
Mode II Fracture Toughness of A Woven Glass Composite



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Conclusions

- PVDF transducers are very useful in studying the equilibrium condition and stress wave propagation within cracked composite specimens of dynamic fracture tests.
- The DIC method can be utilized to analyze both crack and stress wave propagations in composite specimens.
- The quasi-static mode-II fracture toughness analysis can be applicable to dynamic experiments only when the equilibrium condition is satisfied.
- Pulse shaping needs to be properly designed such that the specimen can achieve stress equilibrium before the crack starts to propagate.
- For the woven glass composite studied, the mode II fracture toughness is independent of loading speed.