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Digital Image Correlation Technique for High-rate Mechanical Testing

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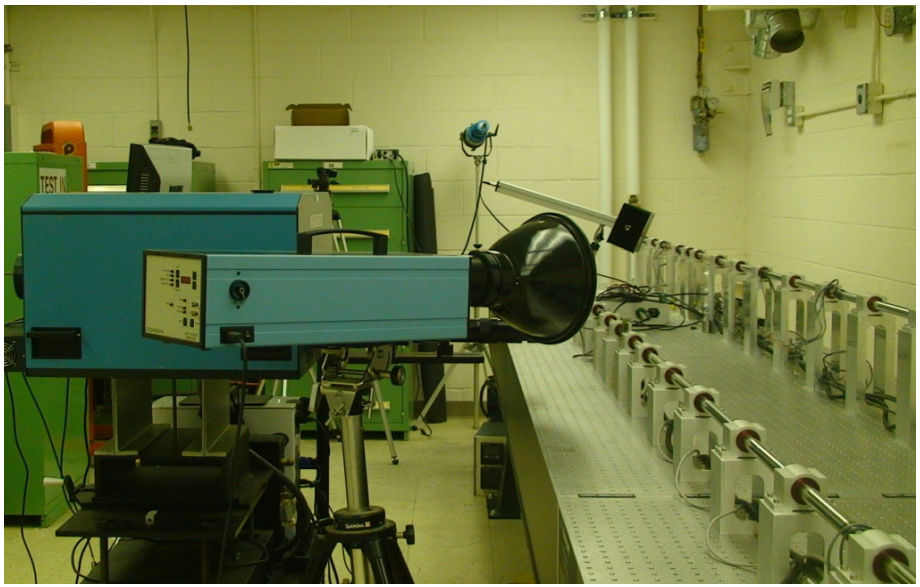
Improved Kolsky Tension and Compression Bar



- Improved Kolsky tension and compression bars were developed at Sandia.
- DIC was integrated into the high rate testing system.

Why do we need DIC for High Rate Test?

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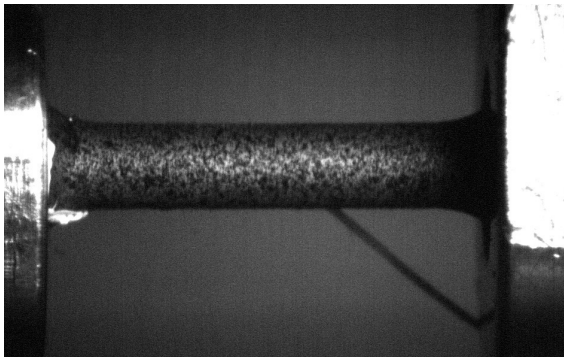
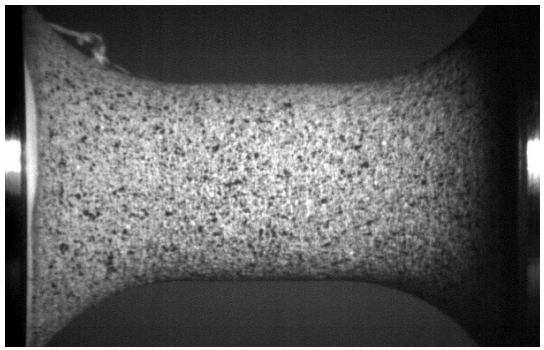
DIC Applications for High Rate Test

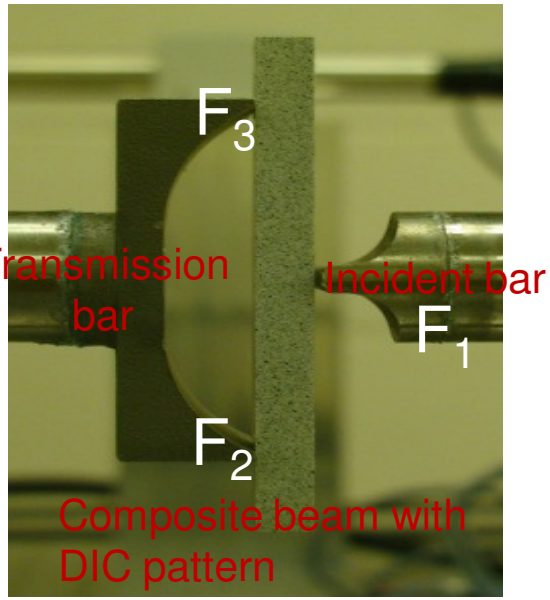
1. Verify stress equilibrium and uniform deformation:



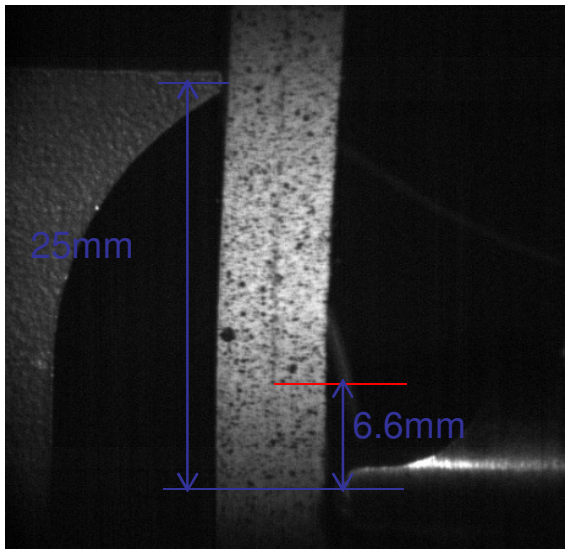
2. Measure longitudinal wave speed:



3. Measure transverse wave speed:



4. Study the crack propagation:



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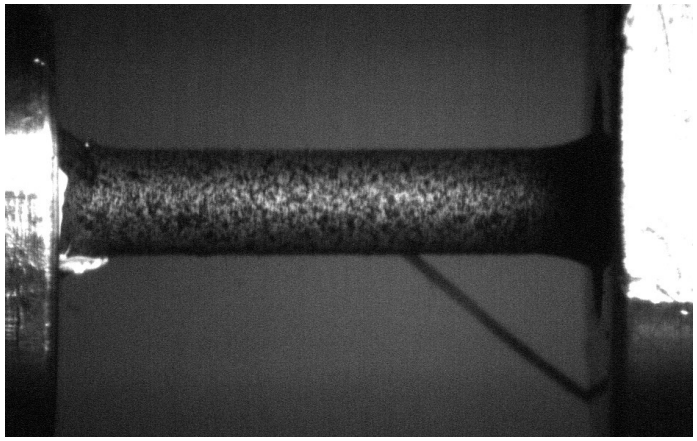
High Rate Tensile Testing of Steel



The specimen stress is calculated with the following equation under stress equilibrium:

$$\varepsilon_i(t)+\varepsilon_r(t)=\varepsilon_t(t);\quad \sigma(t)=\frac{A_0}{A_s}E_0\varepsilon_t(t);\quad \varepsilon(t)=\int_0^t\frac{2C_0\varepsilon_r(t)}{L_s}$$

A_0 and A_s - cross section area of the bar and the specimen

E_0 - Young's modulus of the bar

$\varepsilon_t(t)$ - Strain of the transmission bar measured with strain gage

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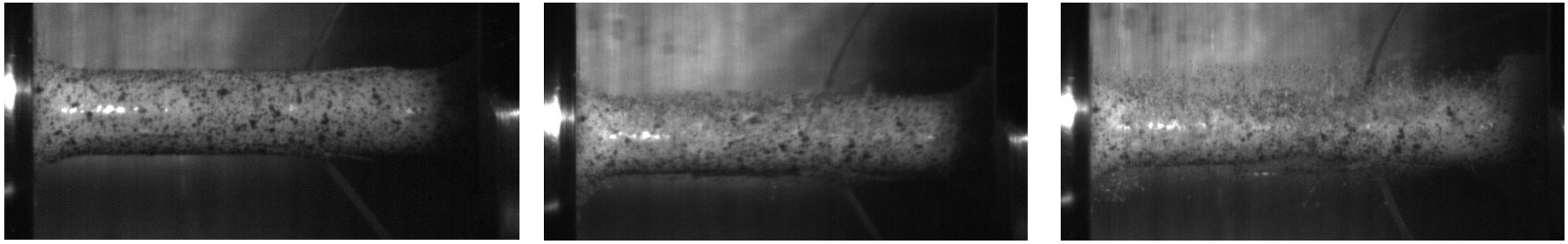
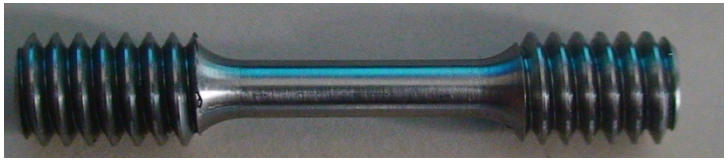
DIC Patterns for the High Rate Test of Steel



1. Sand blast of the specimen surface

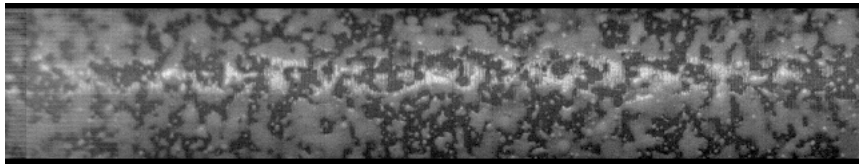


Before sand blast

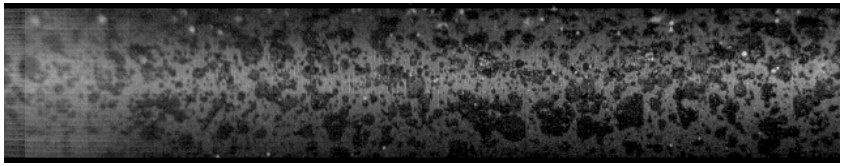
After sand blast

2. Ultra sonically clean the specimen surface

3. Apply speckle of white or black paint instead of a base layer



White speckle



Black speckle

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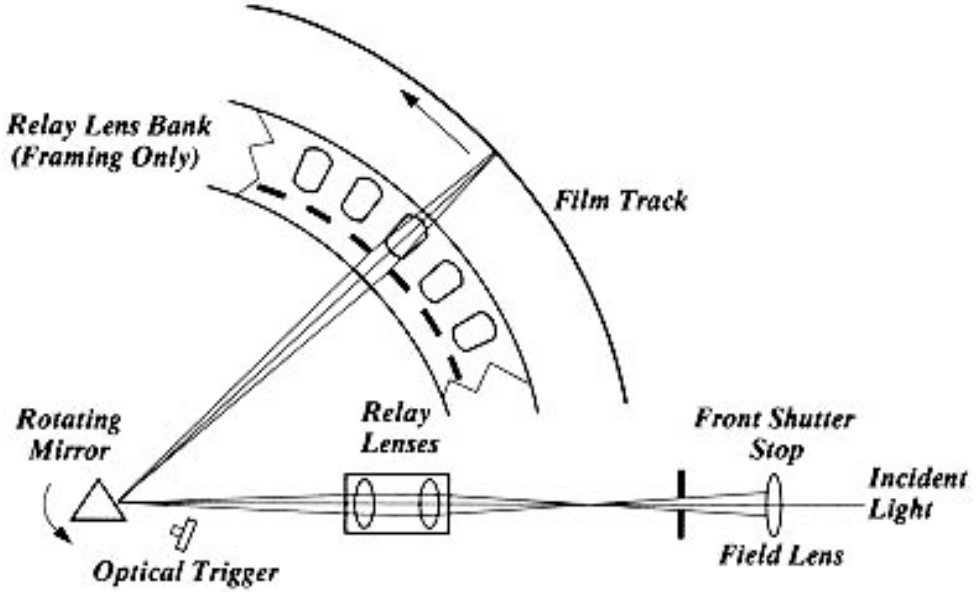
High Speed Camera with Rotating Mirrors

Cordin 550



Each image in the sequence is from different CCD at different location and angle, which will cause slight differences in the image. This might introduce artificial displacement and strain in the DIC data.

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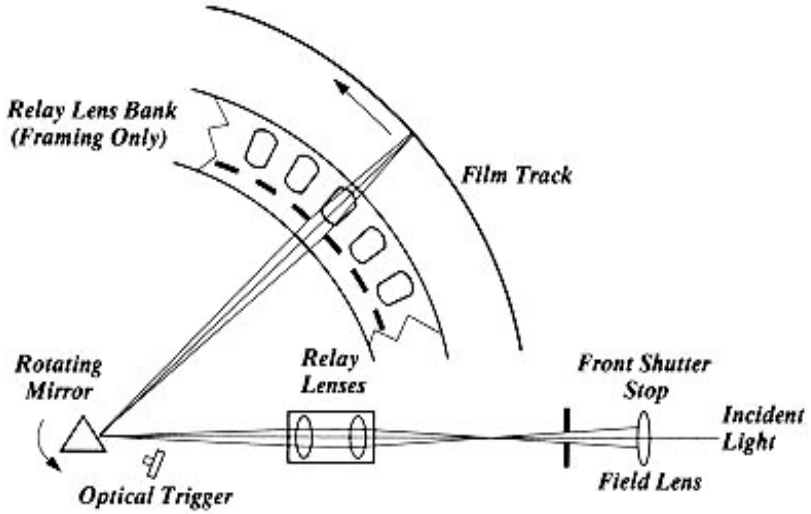
Rematch the CCD Sequence of the Reference and Deformed Images



(1) Reference image sequence with starting CCD of #$n_{0;}$

(2) Deformed image sequence with starting CCD of #$n_{1;}$

(3) Rearrange the reference image sequence to have same CCD order as deformed image sequence;

(4) Apply DIC to the reference and deformed image sequences with same CCD order.

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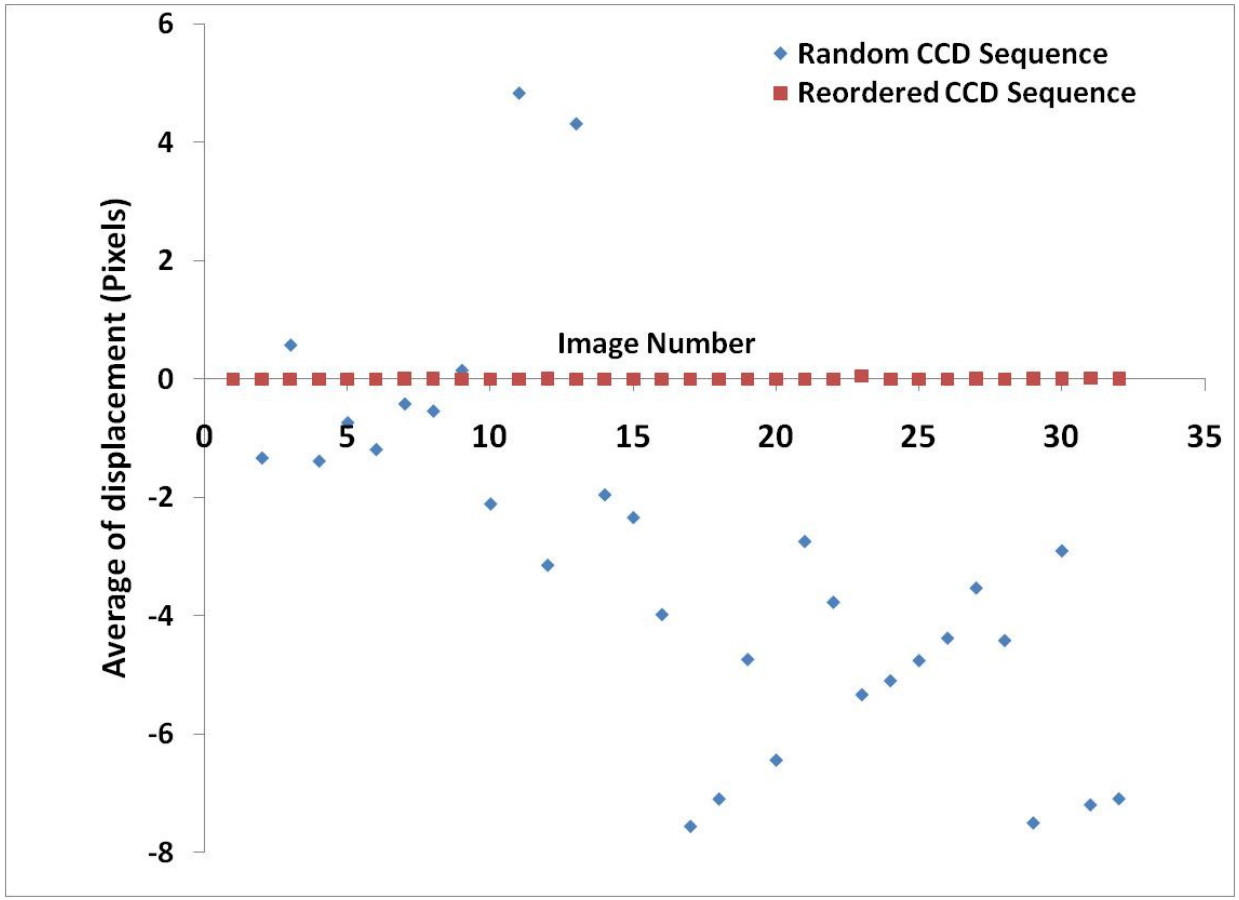
Errors Were Dramatically Minimized



- There is significant error in DIC displacement field caused by the difference in images from different CCDs.
- However, the error in DIC displacement results between two images from same CCD is negligible.

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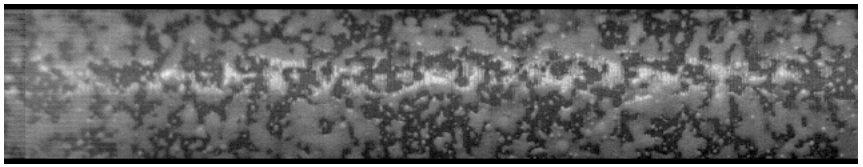
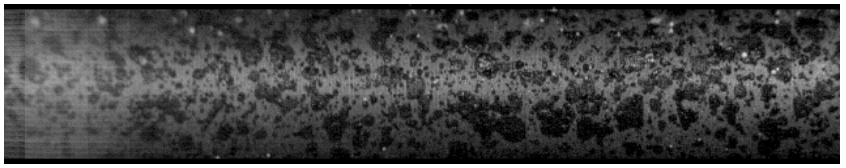
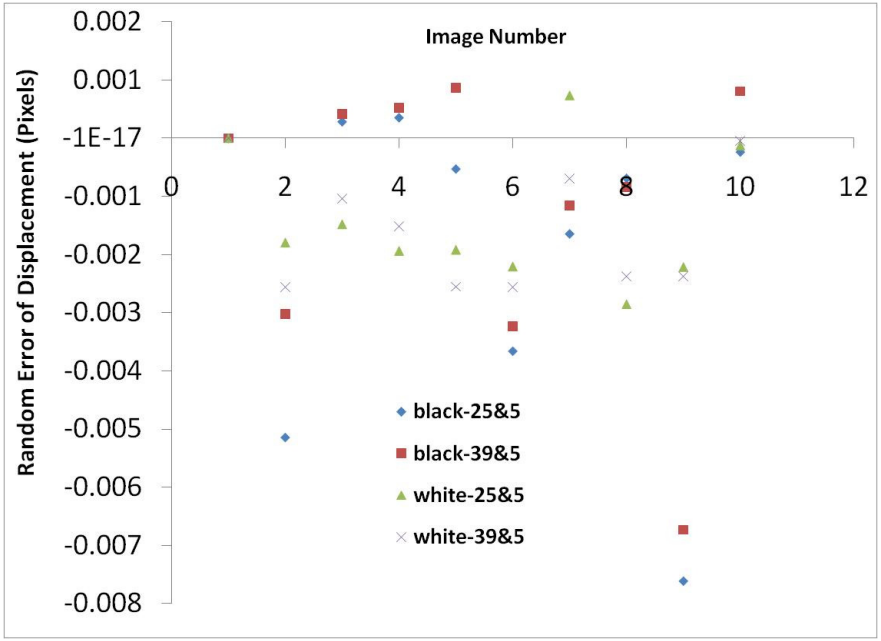
Random Error from the System



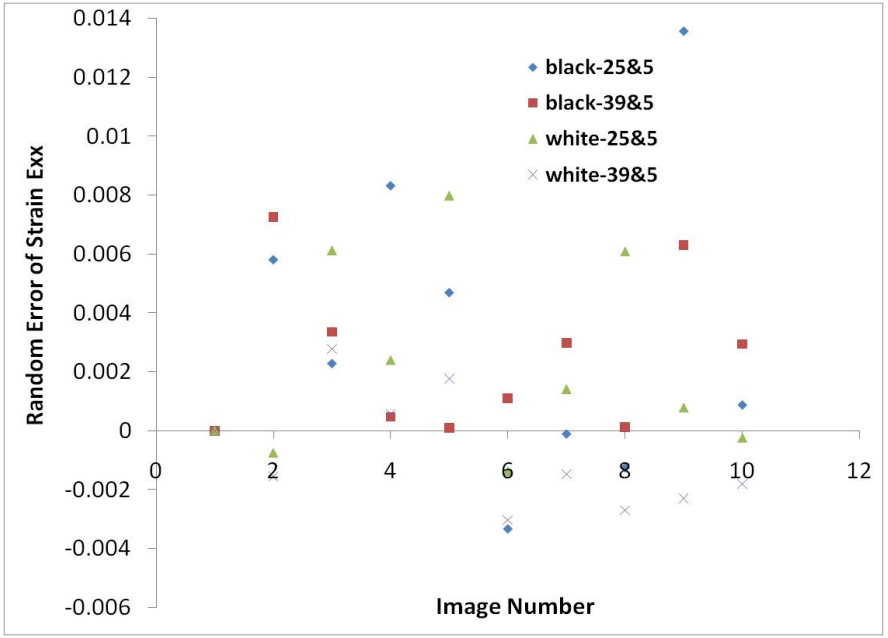
White speckle



black speckle



Random error of displacement



Random error of strain Exx

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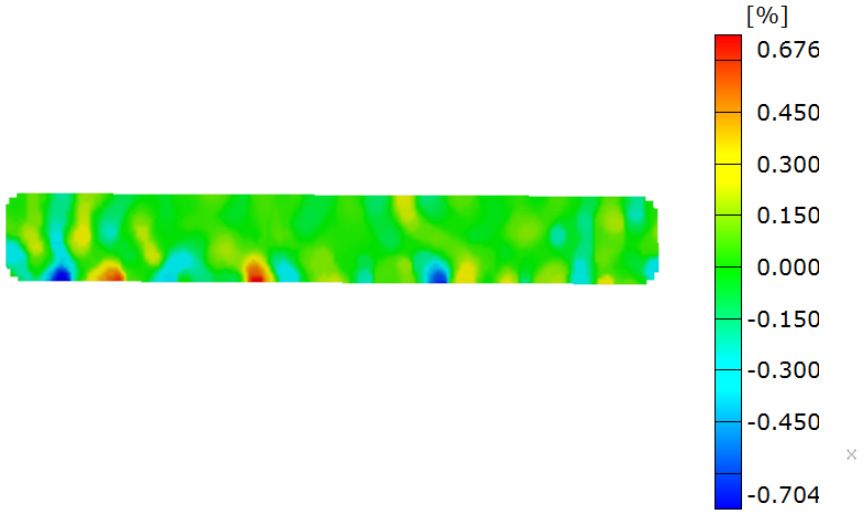
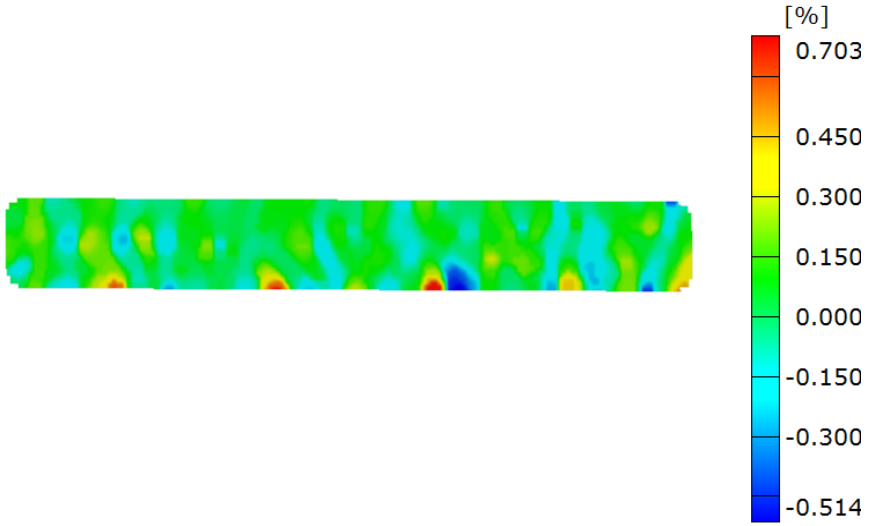
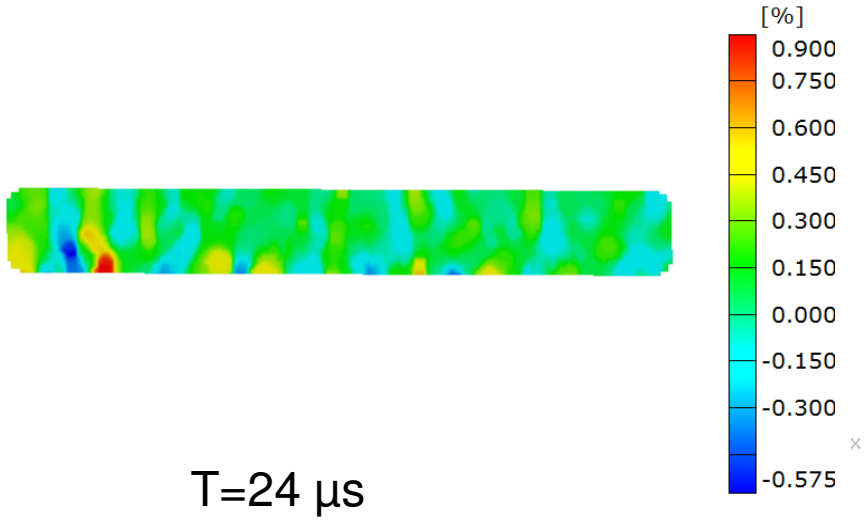
Exx in High Rate Tensile Test of Steel



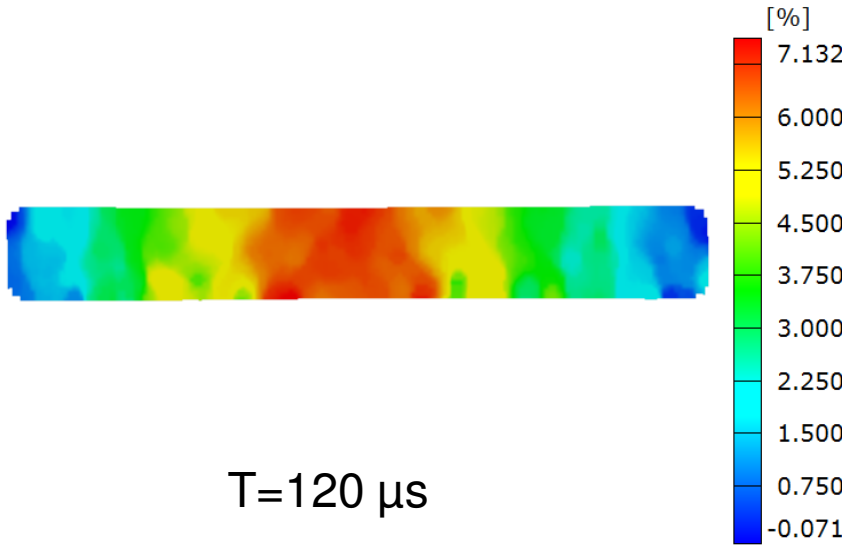
T=0



T=12 µs



T=24 µs



T=120 µs

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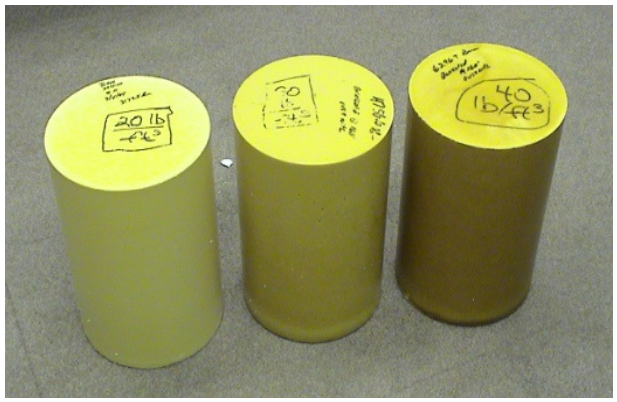
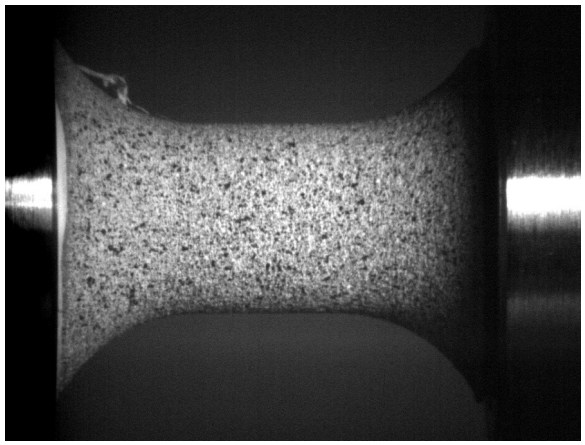
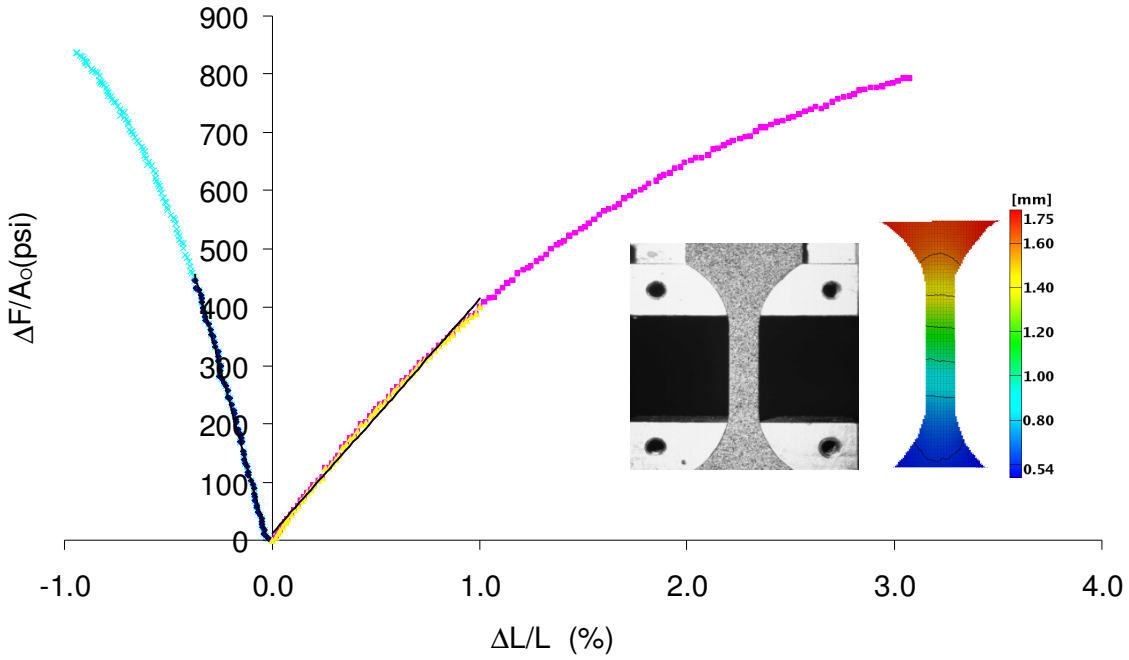
Foam Tension Test







- Specimen is large.
- Wave speed is lower.
- Wave speed may vary with strain rate.

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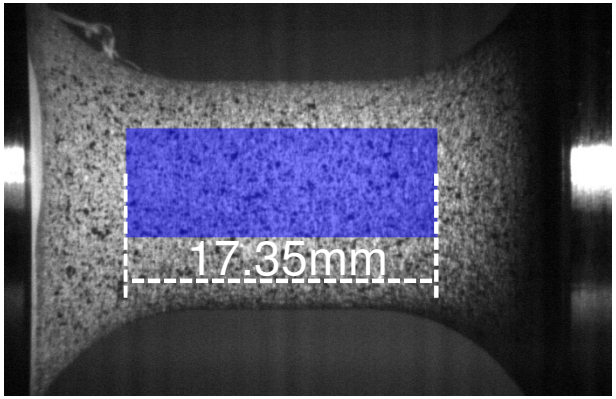
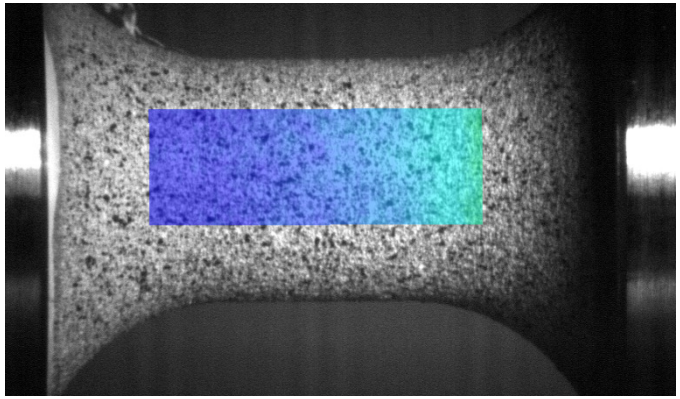
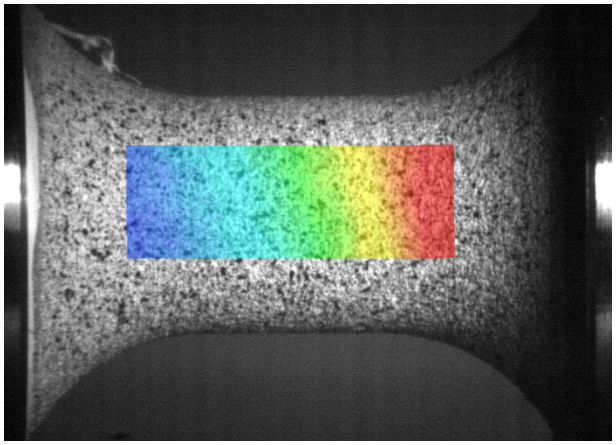
Wave Speed in Foam Tension Test



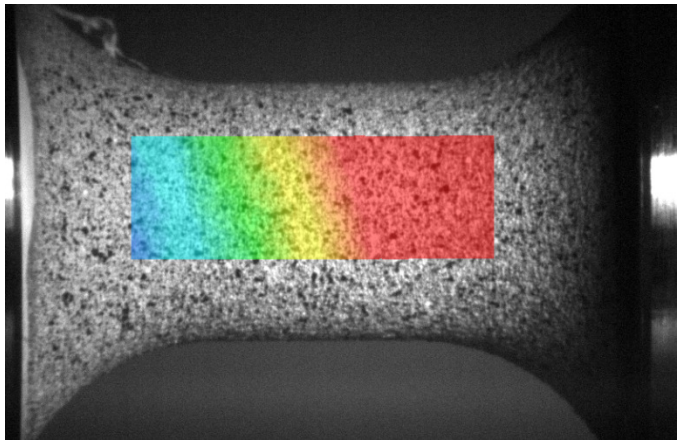
T = 0 µs



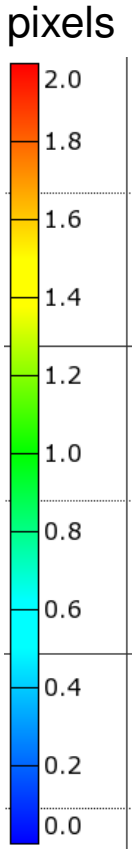
T = 19.8 µs



T = 26.4 µs



T = 33 µs



Travel length is 17.35 mm and travel time is 33µs.

Elastic wave speed is approximately 525 m/s.

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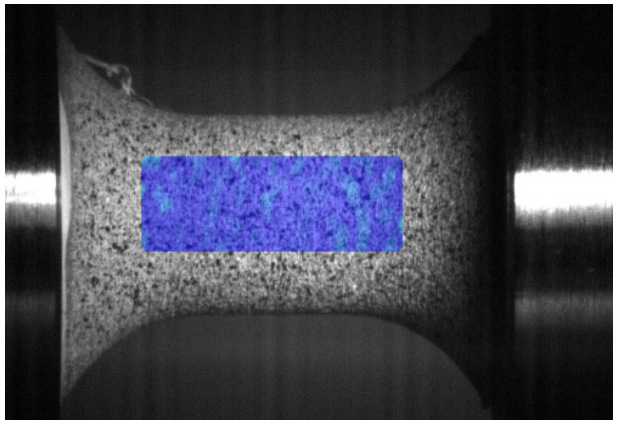
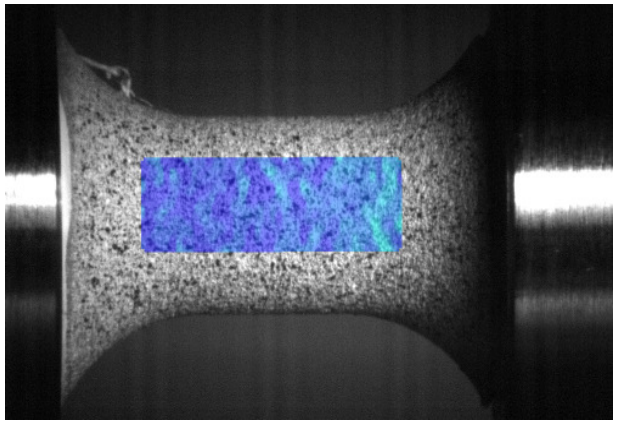
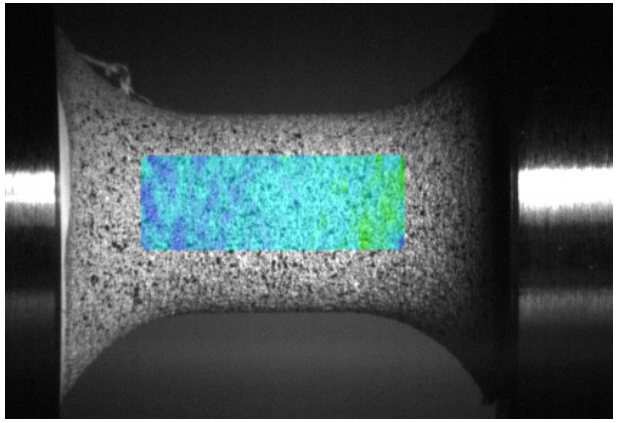
Strain Exx in Foam Tension Test



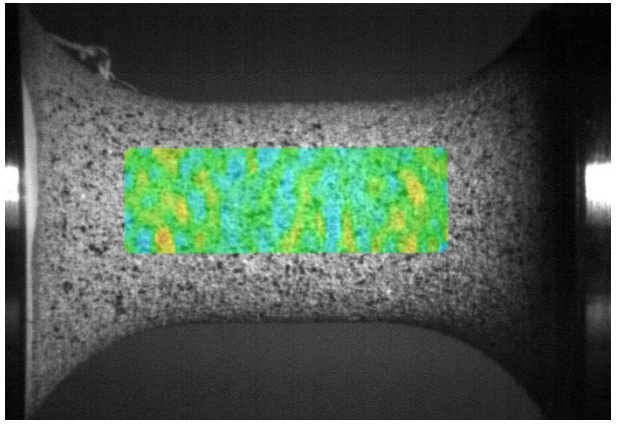
T = 0 µs



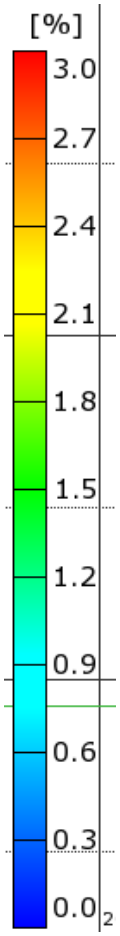
T = 19.8 µs



T = 39.6 µs



T = 52.2 µs



It takes about 52 µs to reach equilibrium state.

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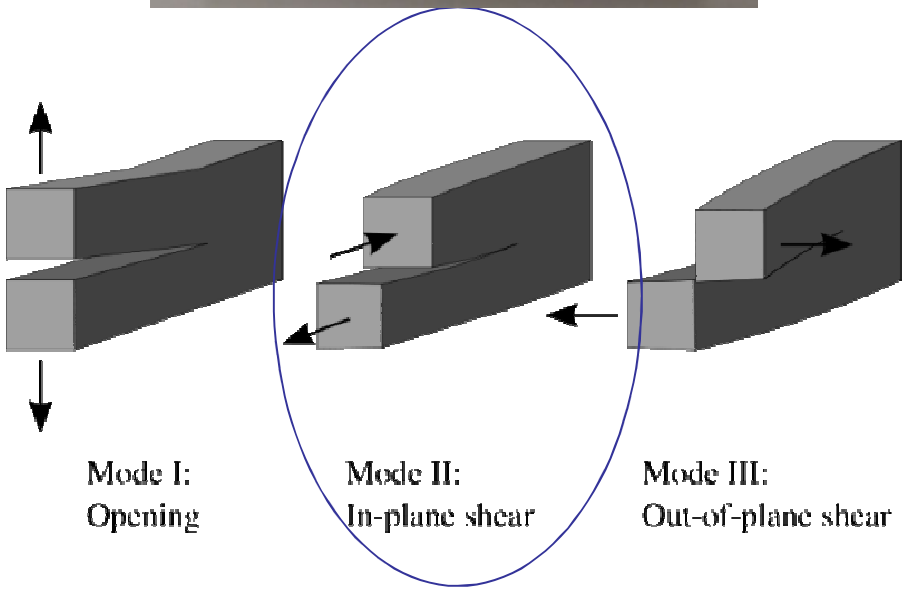
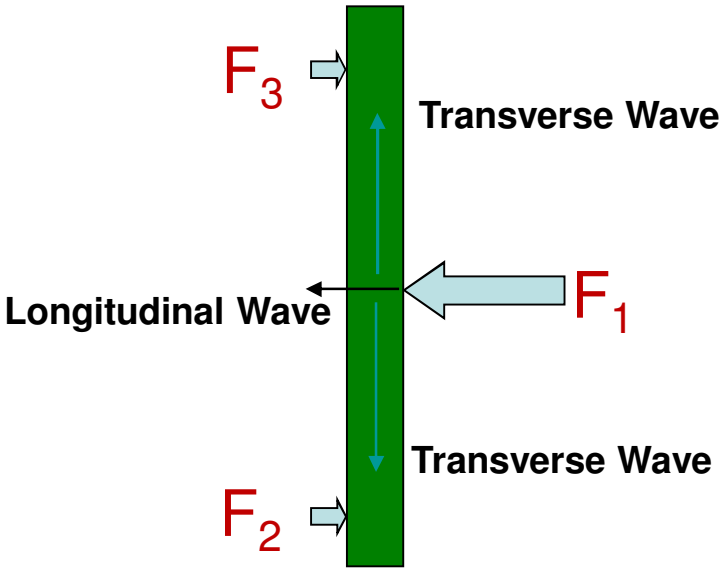
Transverse Impact of Composite Beam





- Transverse wave speed.
- Crack propagation.

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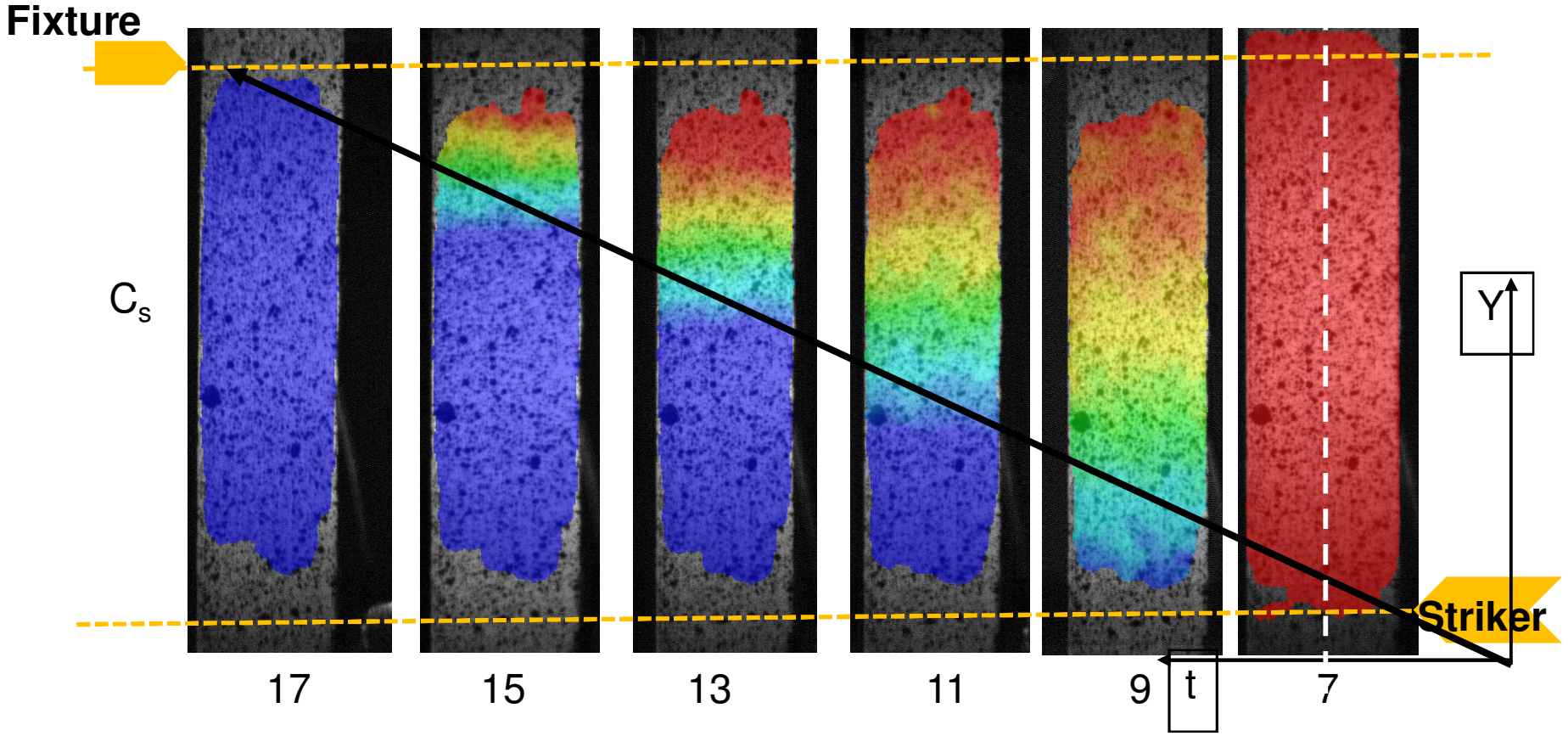
Wave Propagation in Fracture Test of Composite without Crack



Transverse wave propagation can be clearly observed from the DIC displacement field.

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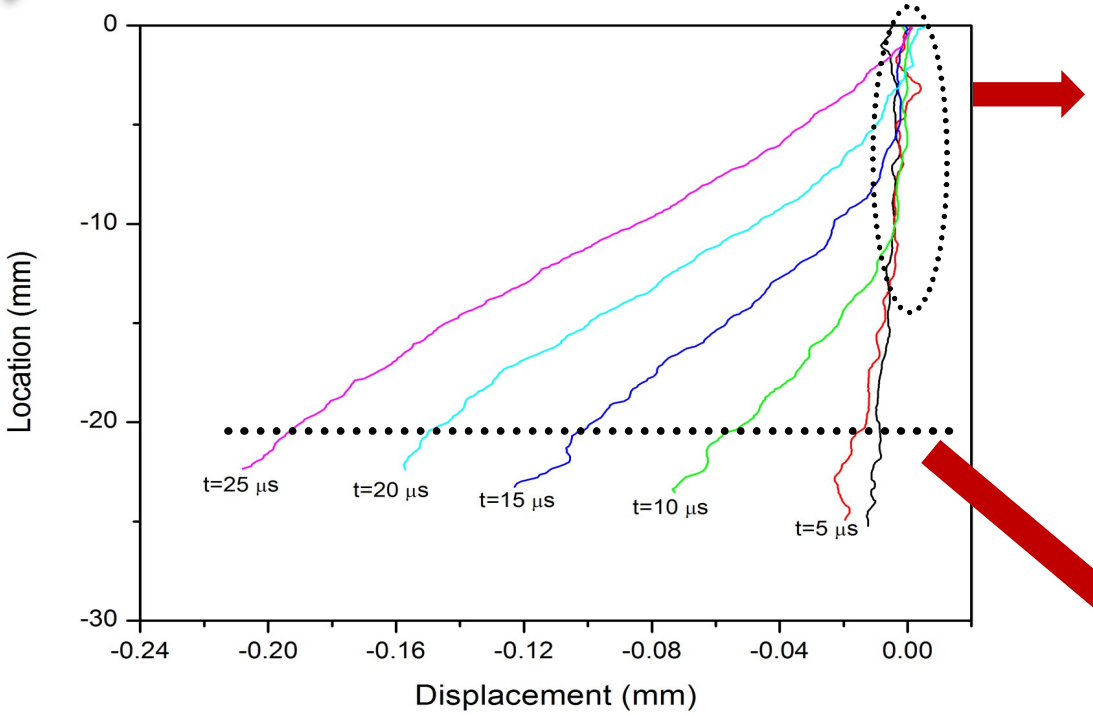
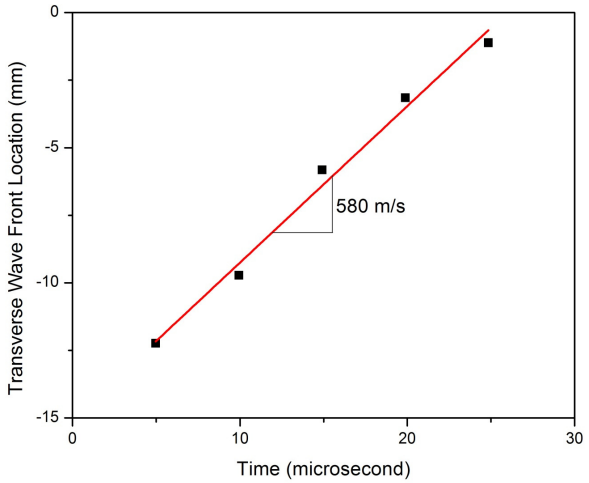
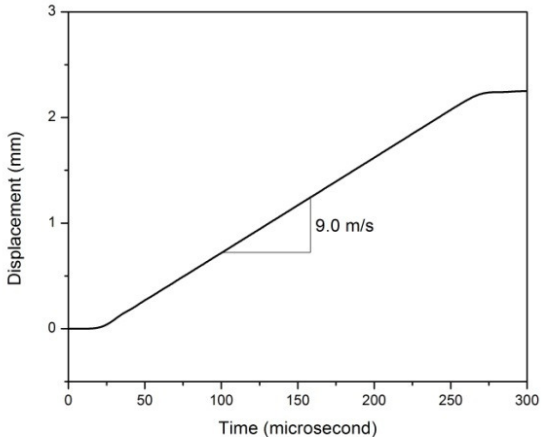
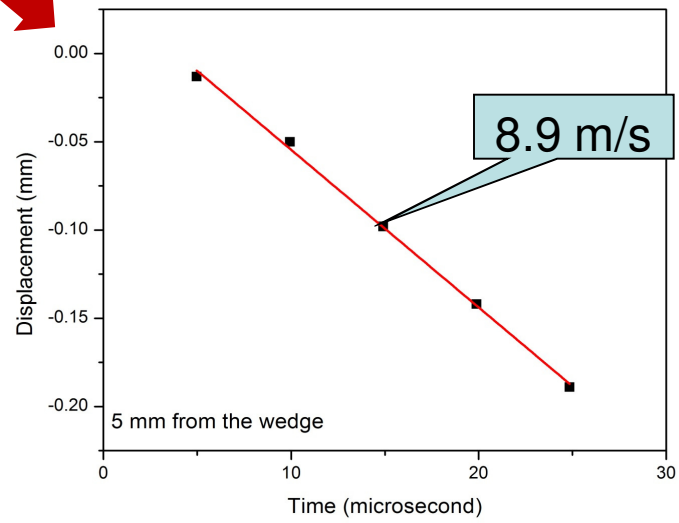
Wave Propagation History





Transverse wave speed





Particle speed

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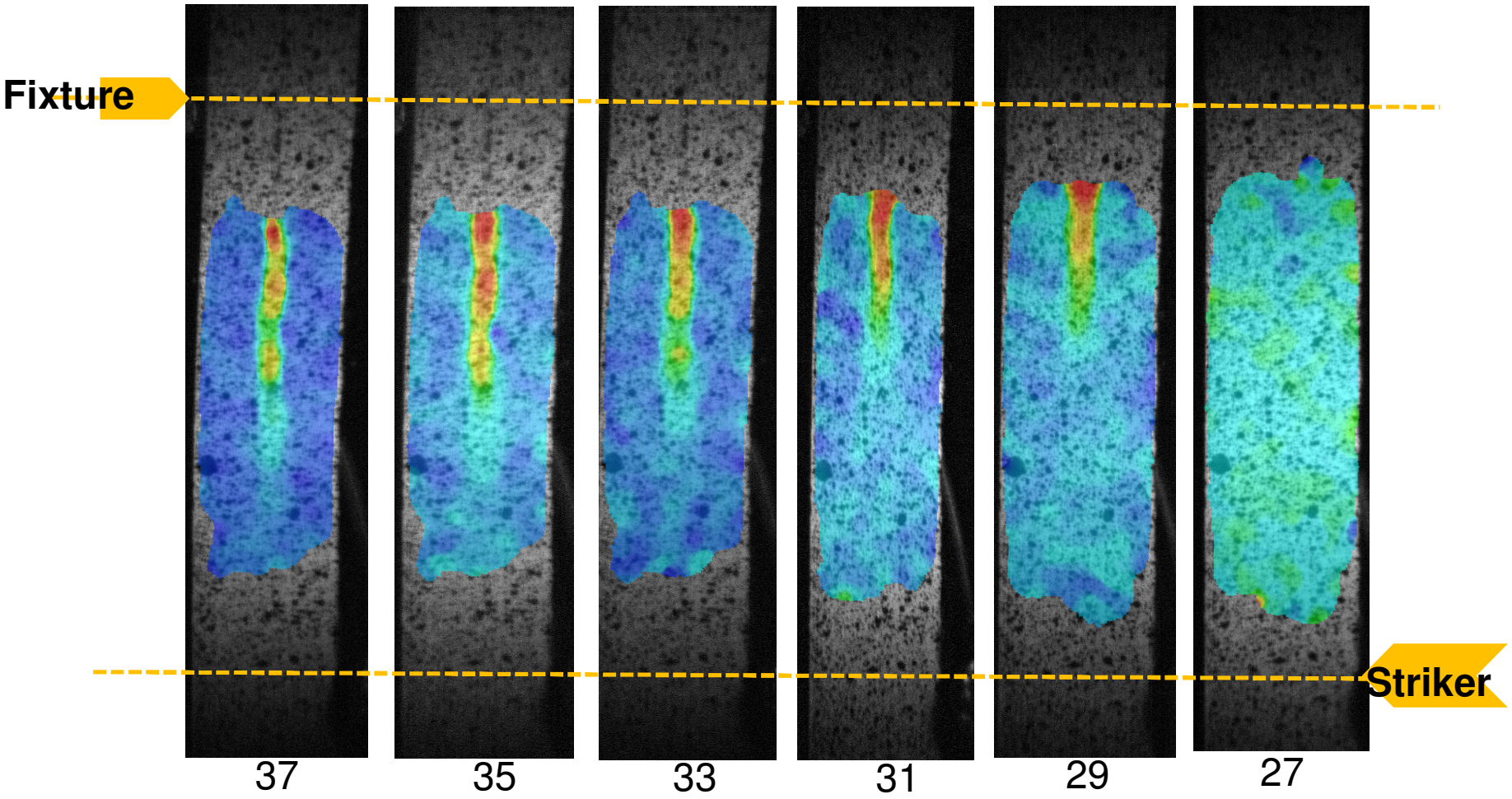
Shear Strain γ_{xy} at Different Stages of the TPB Test



DIC data clearly shows the crack opening and propagation inside the composite beam.

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Summary

- Kolsky compression and tension bar were employed for dynamic mechanical characterization of various materials.
- High speed digital image correlation was integrated into the dynamic tests.
- The images from high speed camera need to be preprocessed to improve DIC results.
- The DIC technique provided valuable full-field deformation information for the Kolsky bar tests.