Use of DIC for the failure analysis of complex composite structures

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Overall objectives of project

- to develop digital image correlation procedures for capturing deformations at high velocity based on the use of high speed digital cameras which would lead to an ability to produce a full-field high resolution map of the strains during the high strain rate events.
- to obtain a full field picture of the temperature evolution during the high strain event using infra-red thermography
- to provide a thermomechanical characterisation of the material performance using experimental data to validate existing measured data and models.
- to use full-field techniques to assess the performance and damage tolerance of materials after experiencing high strain rate events.

Apply to a complex composite construction

Synchronised DIC + IRT

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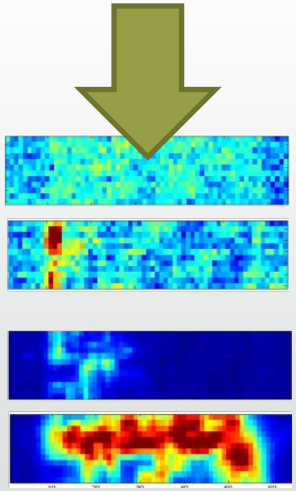
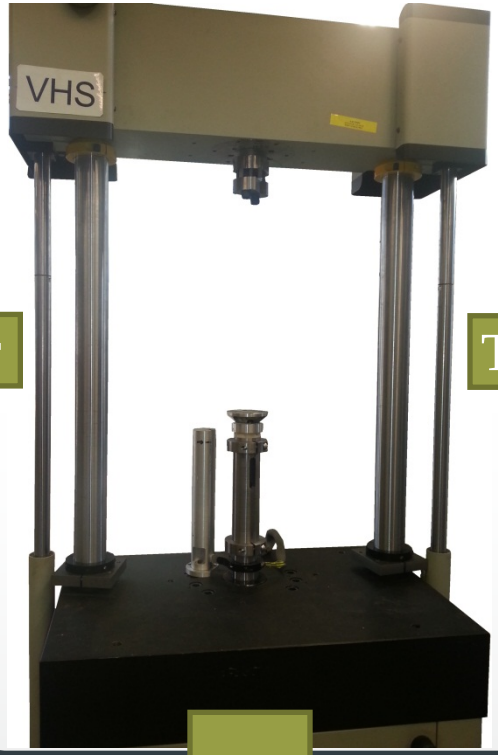
Infra-red thermography (IRT)

Trigger





Load

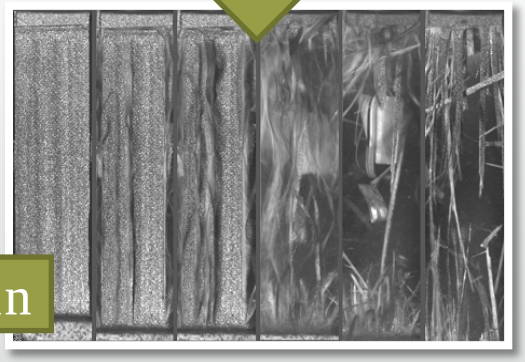
Thermal

Material Characterisation

Strain

Trigger

Digital Image correlation (DIC)



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Application to complex composite construction

- Equipment – high magnification
- Speckle pattern repeatability
- Component strain evaluation – quasi static loading
- Principal stresses
- Failure observation
- Validation – against other experimental technique
- High speed testing

Digital Image Correlation

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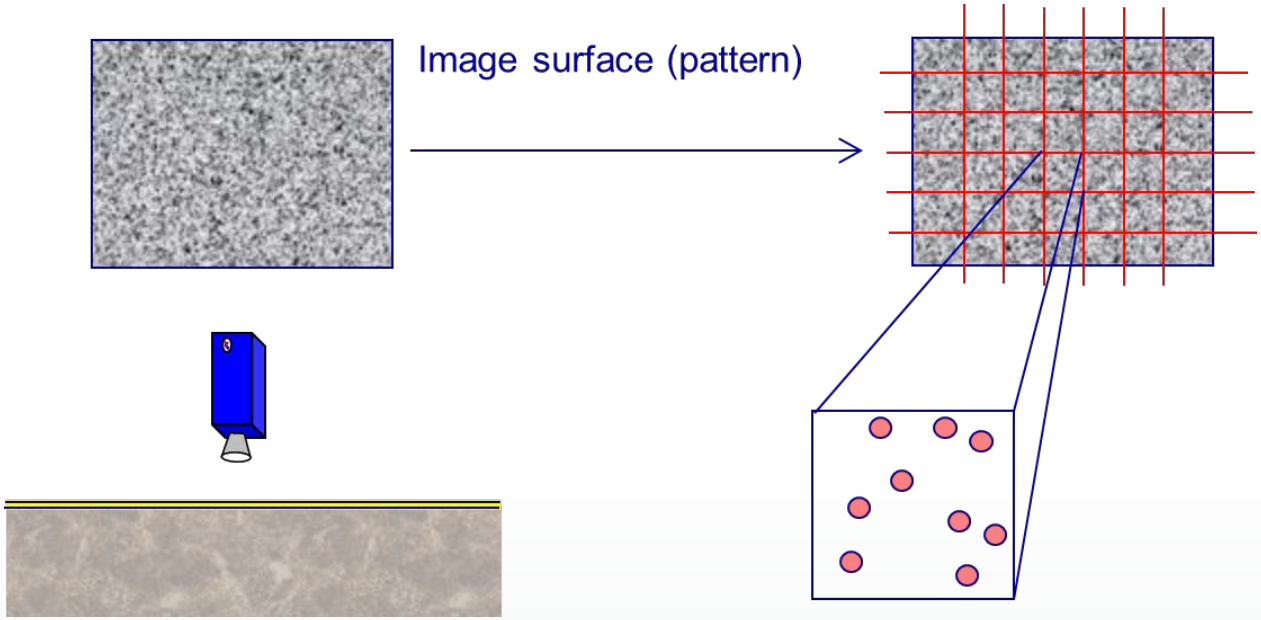

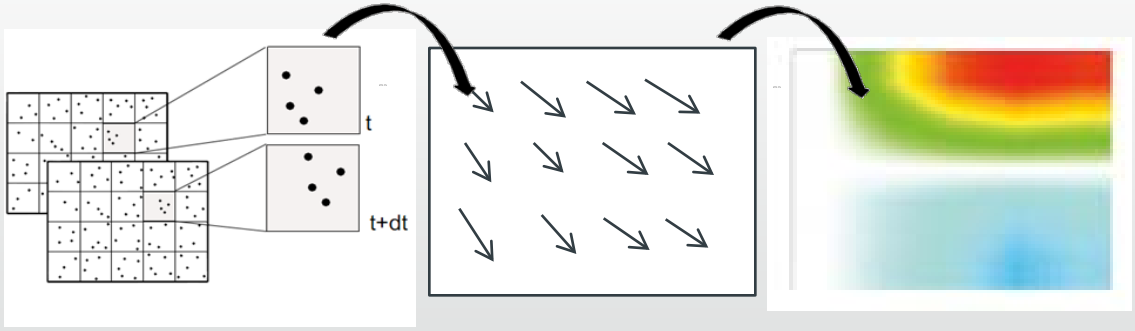

Deformed speckle pattern

Deformation vector field

Strain field

Joint configuration

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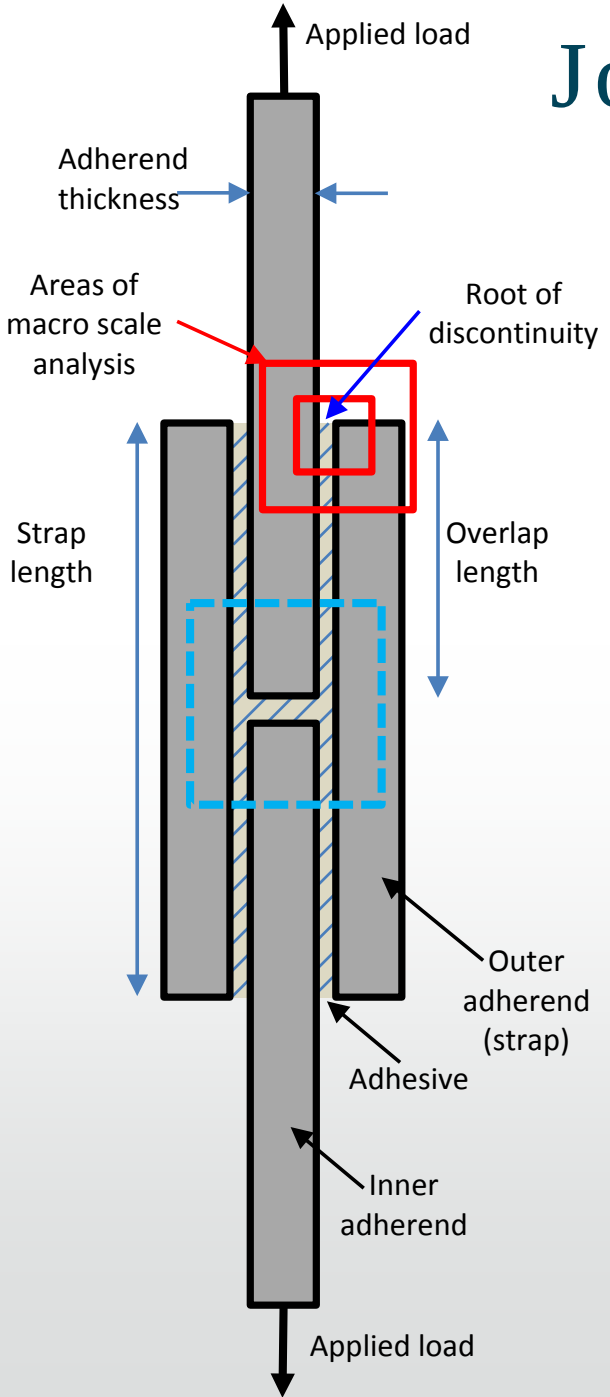
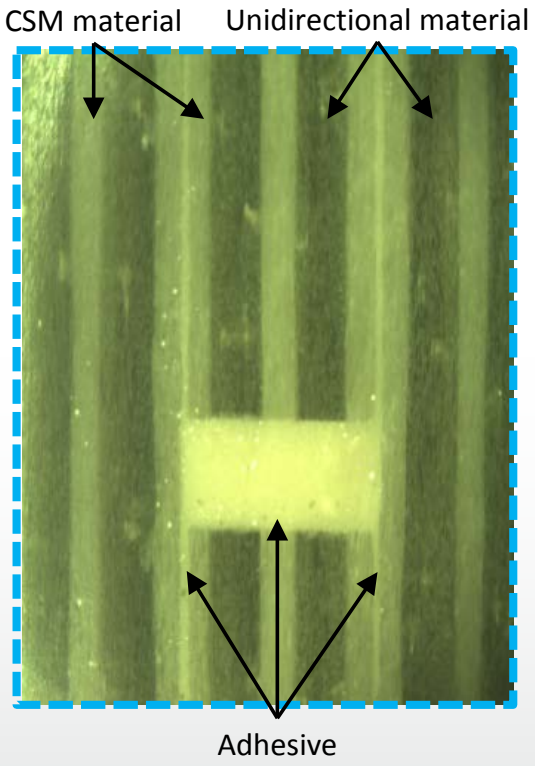
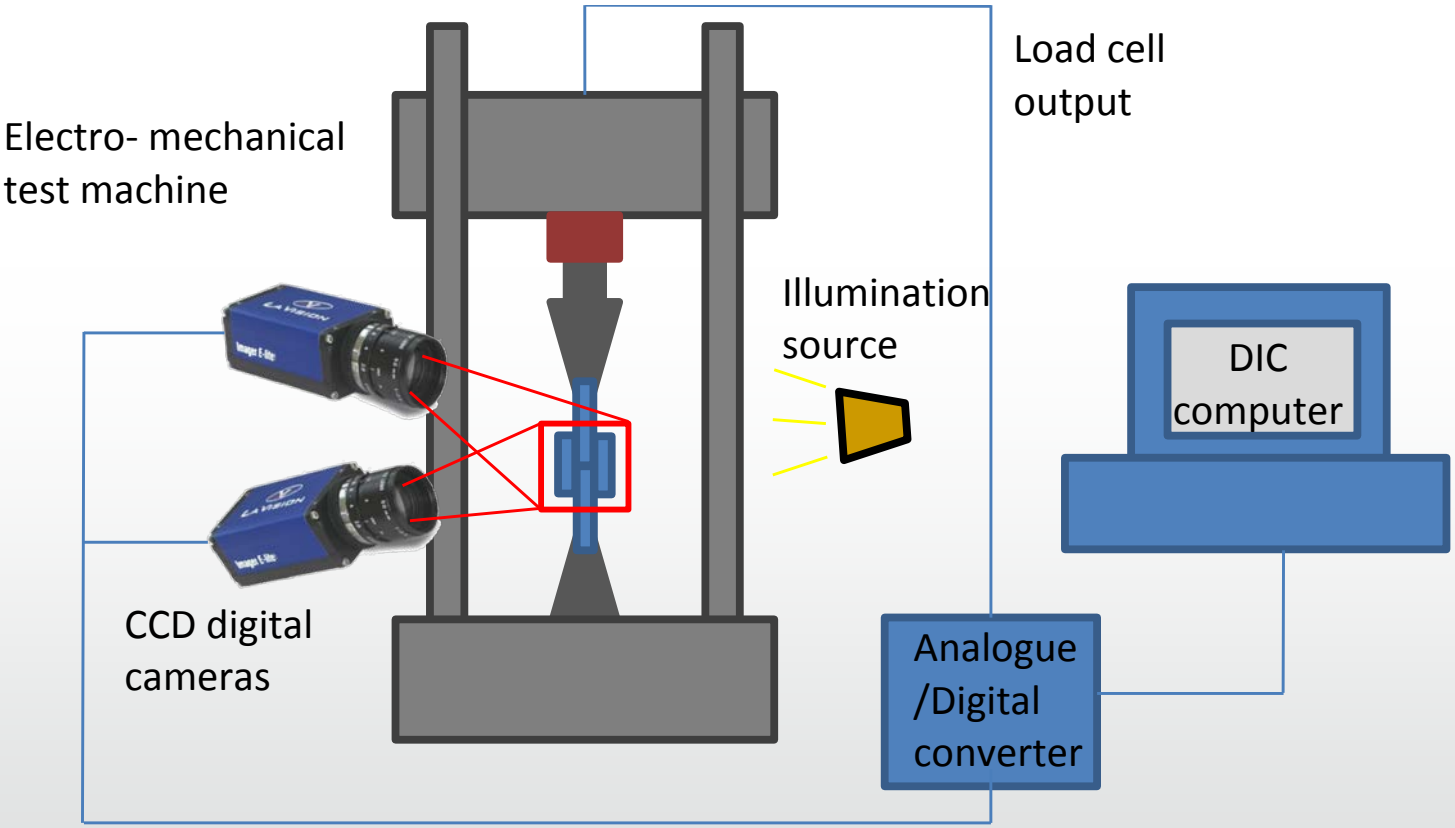




Initial set-up



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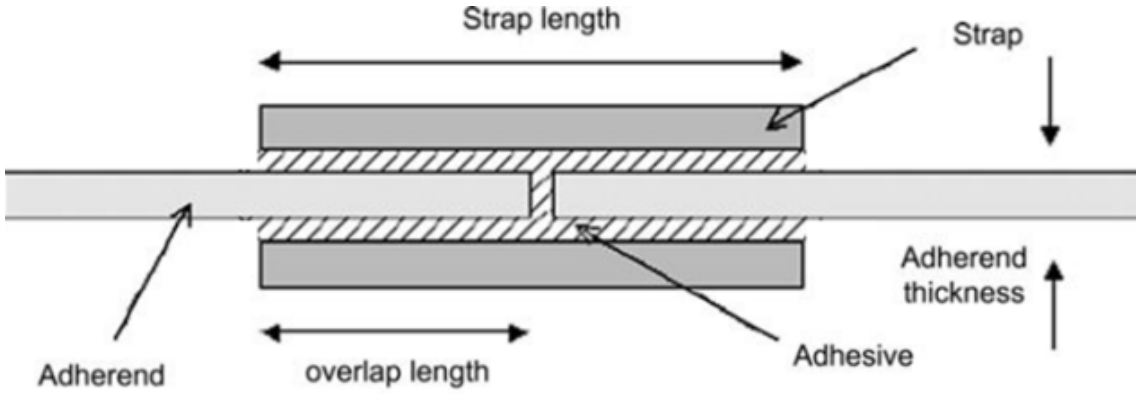
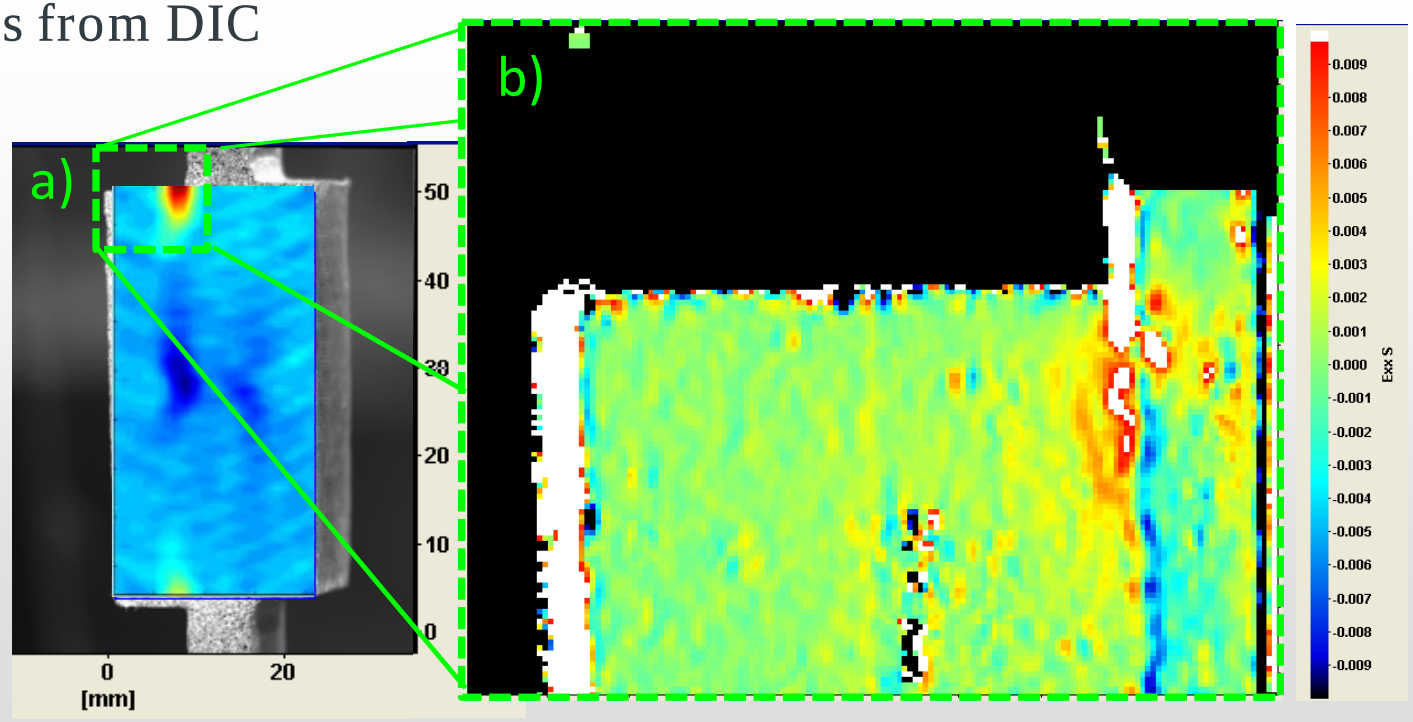
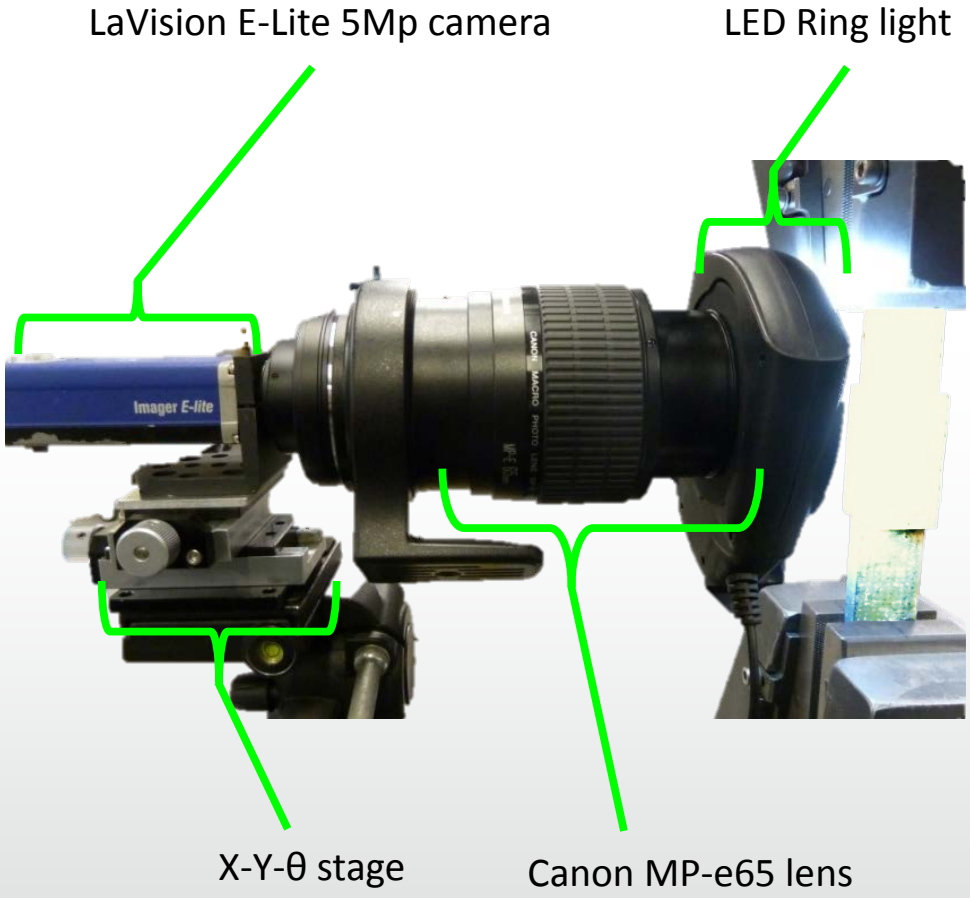
Double butt strap joint

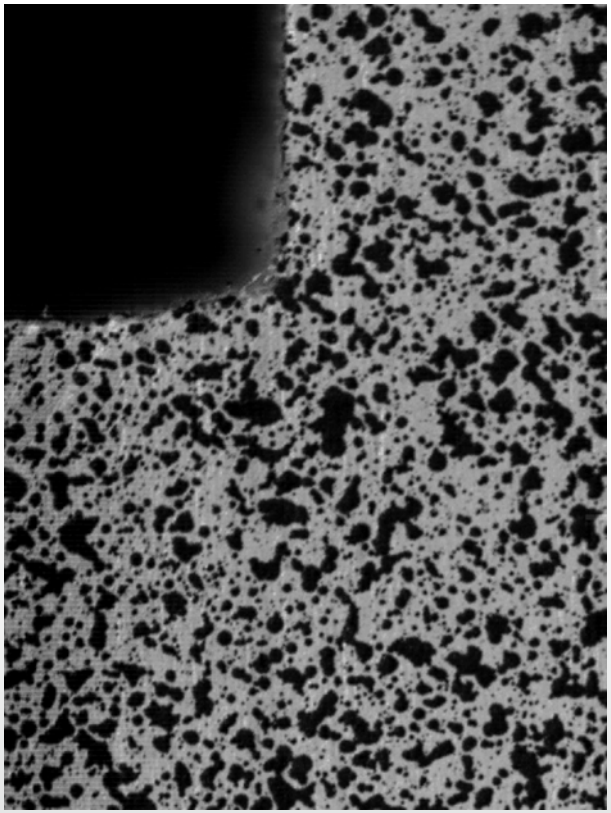


Peel strains from DIC



High magnification camera set-up





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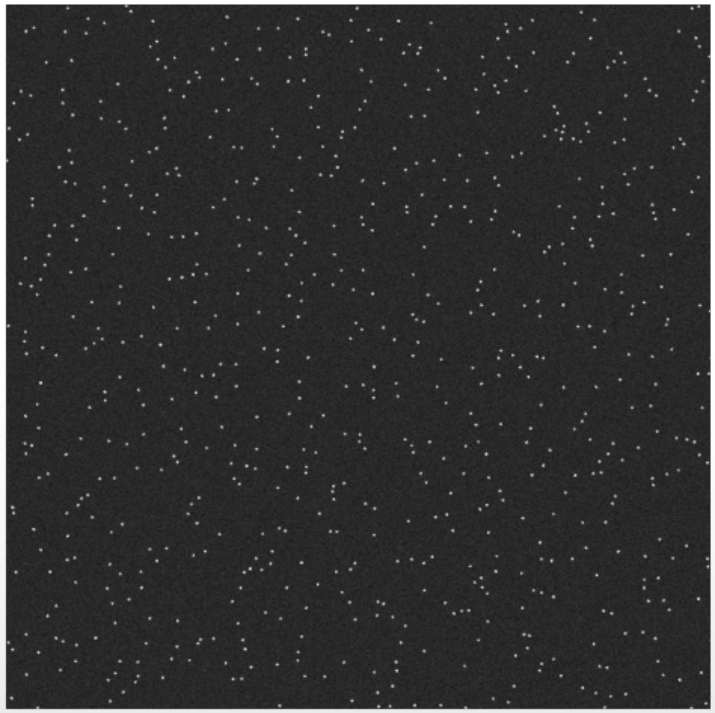
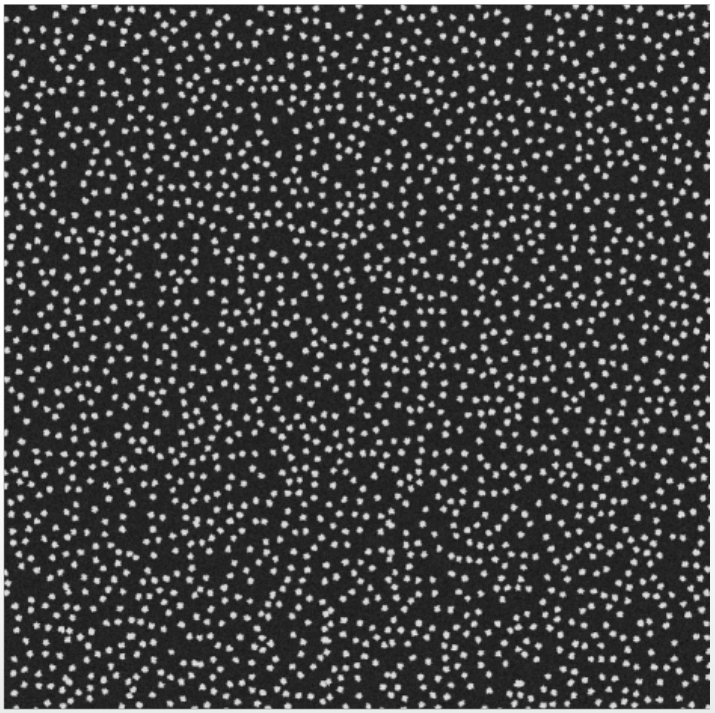
What is the best speckle pattern?



Generated pattern with 6 speckles per subset, and a speckle radius of 3 pixels



Generated pattern with 18 speckles per subset, and a speckle radius of 8 pixels

Scatter in strain data

$$SD_\varepsilon = \sqrt{\frac{n\sum(\varepsilon_{DIC} - \varepsilon_{imposed})^2 - \left(\sum(\varepsilon_{DIC} - \varepsilon_{imposed})\right)^2}{n(n-1)}}$$

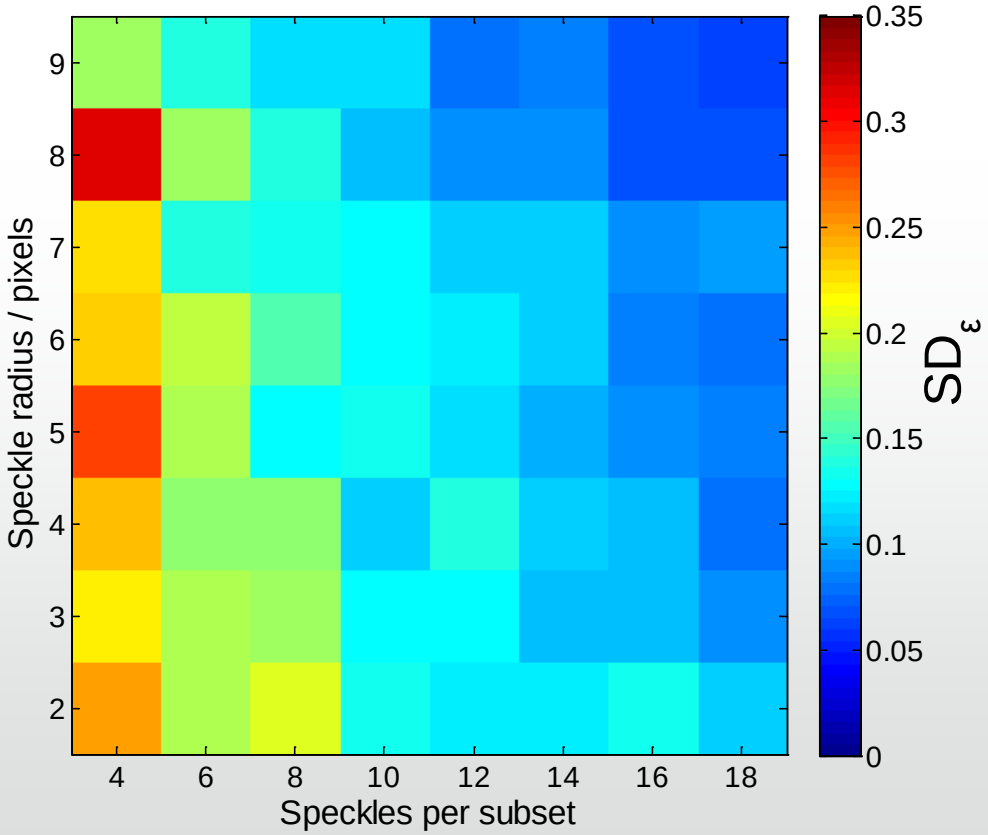
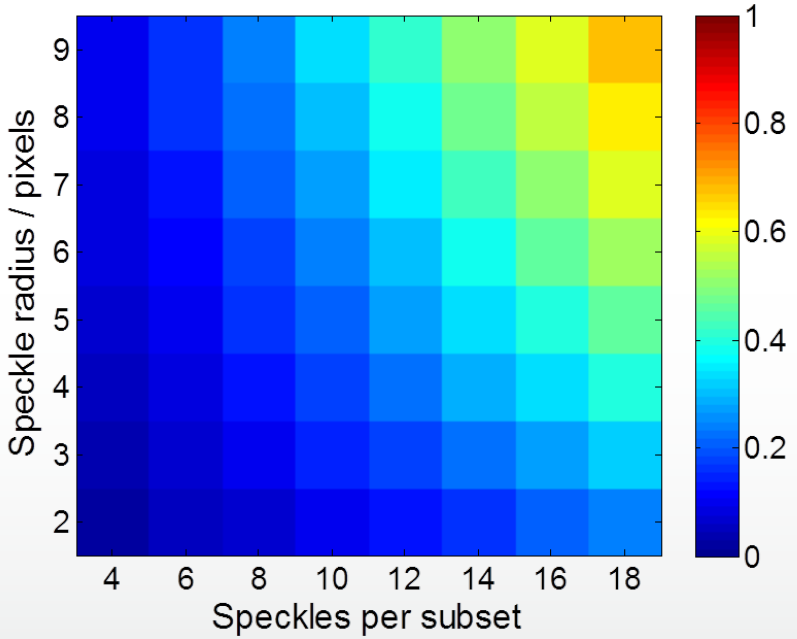


Image assessment

Parameter from information theory known as Shannon entropy evaluates the randomness, or texture, of a form or pattern.

$$\text{Shannon entropy} = \sum_{i=1}^{N} p(x_i) \log(p(x_i))$$

A pattern with a high Shannon entropy value indicates a high level of texture, or broadness in the grey scale distribution of the image



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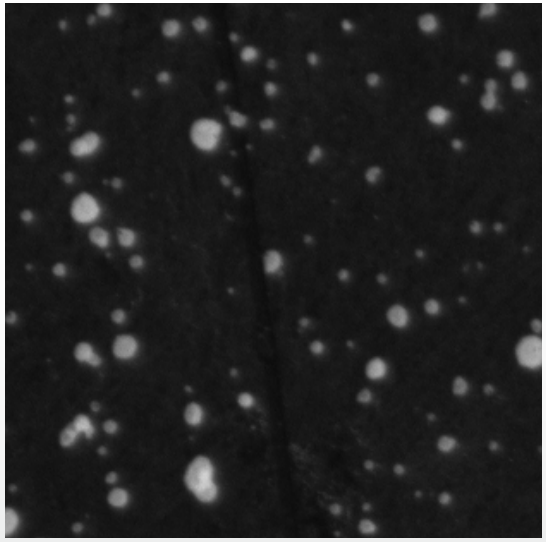
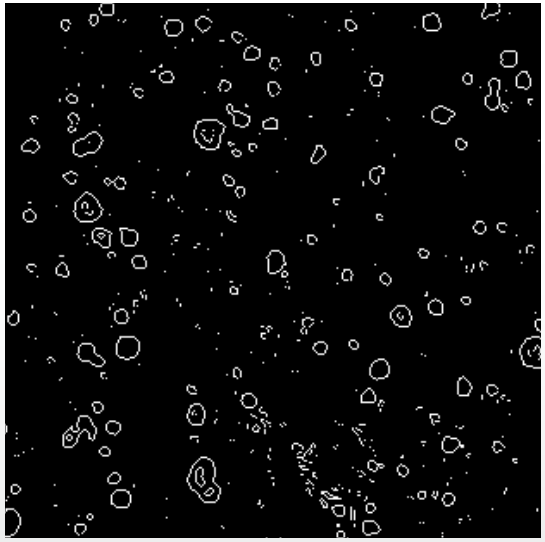
Application to actual speckle pattern

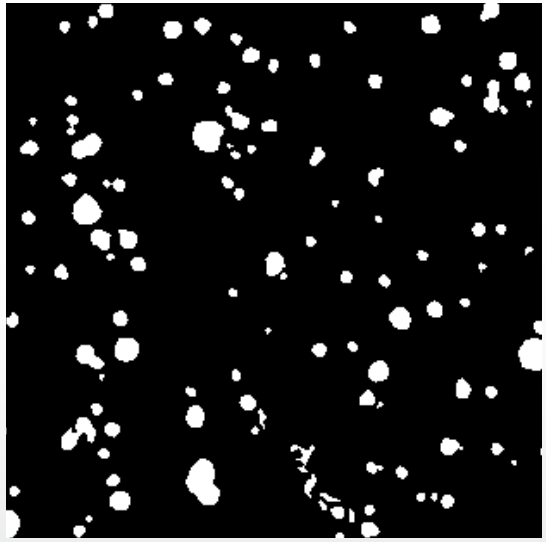
Speckle pattern



Edge detection



Binary speckle pattern



Typical speckle patterns

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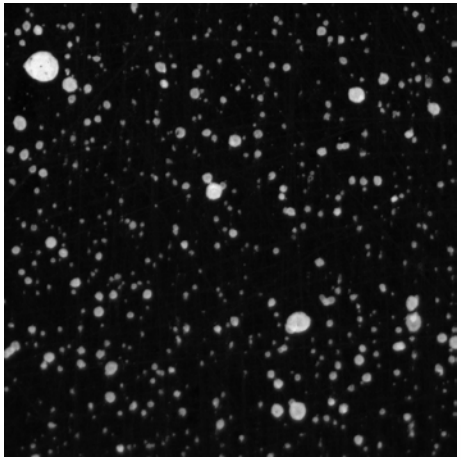
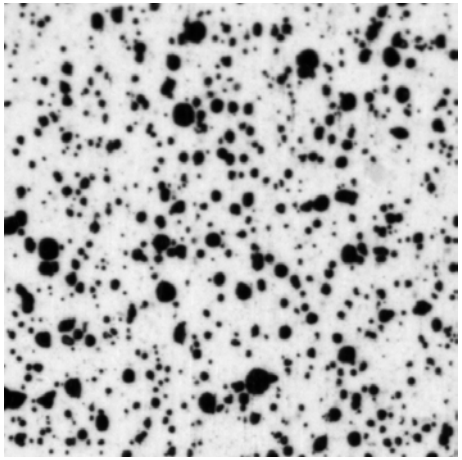
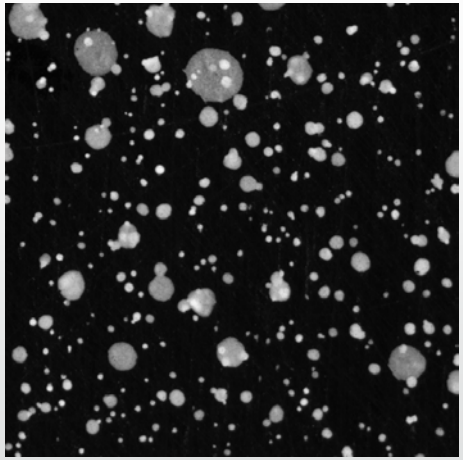


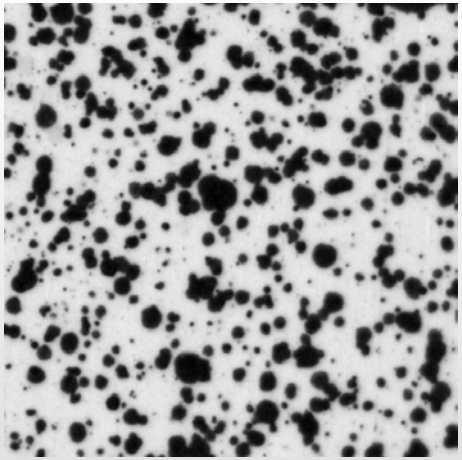
a) Pattern A (Airbrush)



b) Pattern B (Airbrush)



c) Pattern C (Spray paint)



d) Pattern D (Spray paint)

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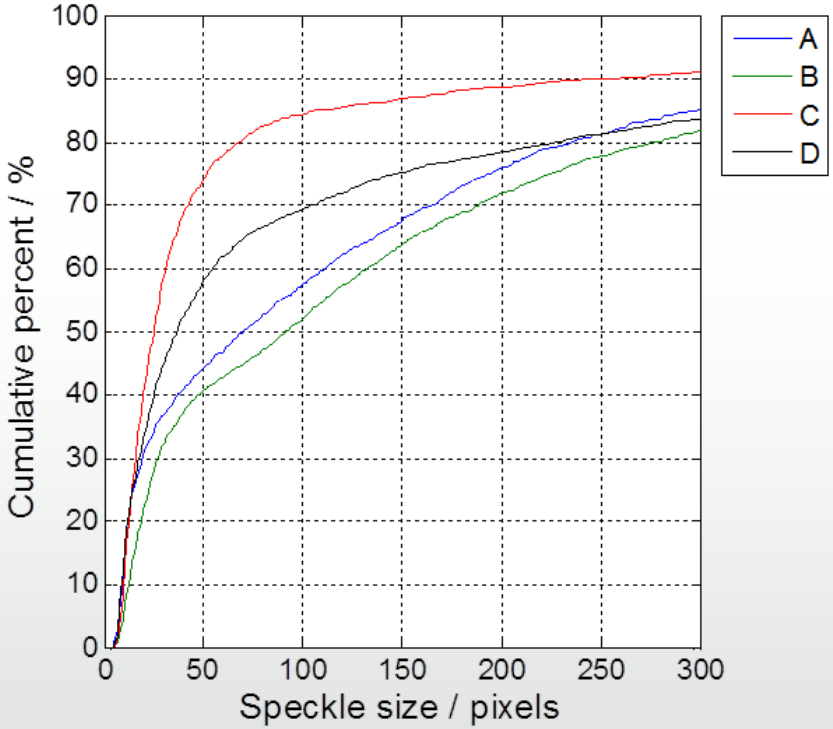
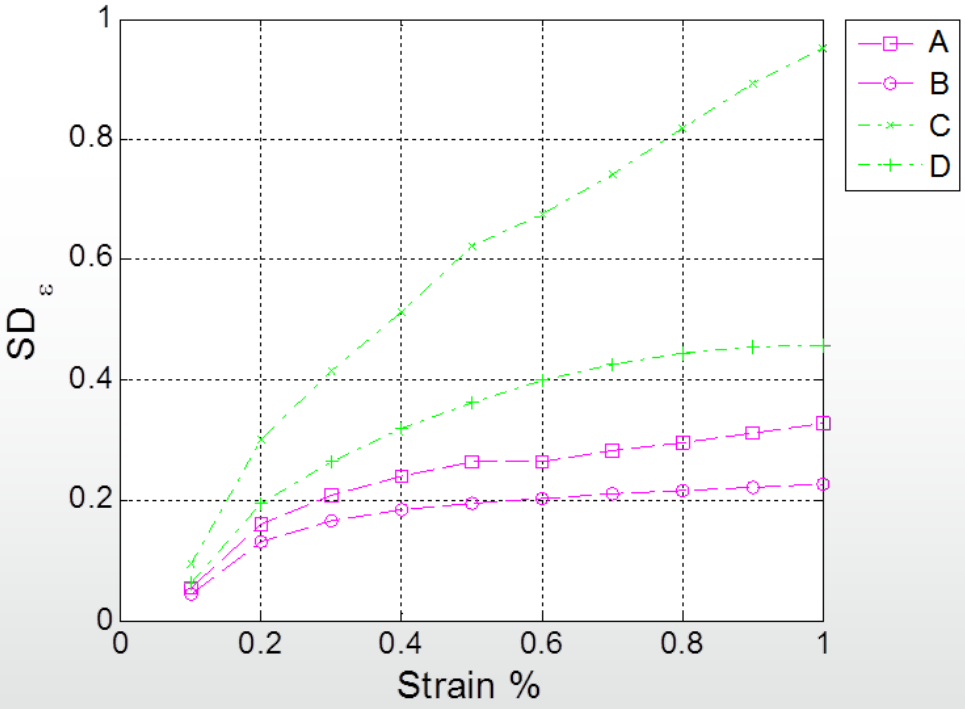
Evaluation of patterns-imposed strain





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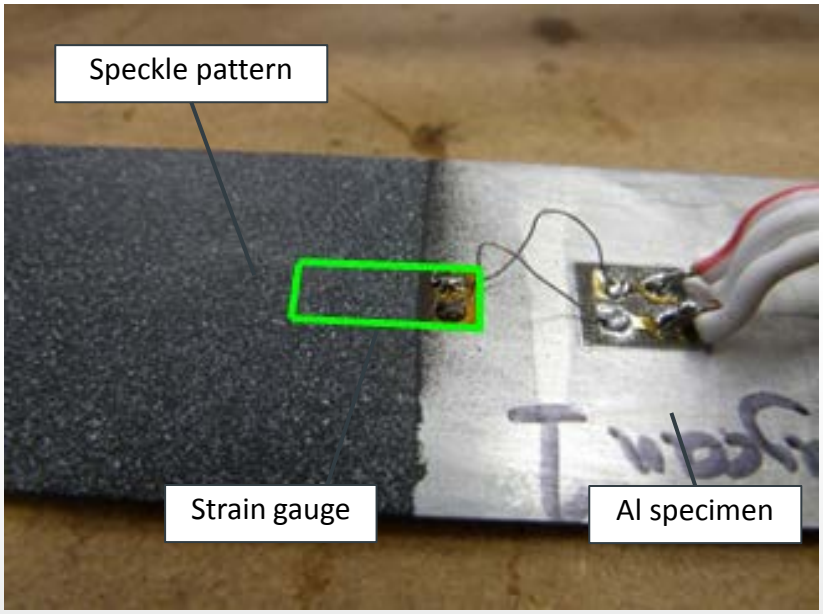
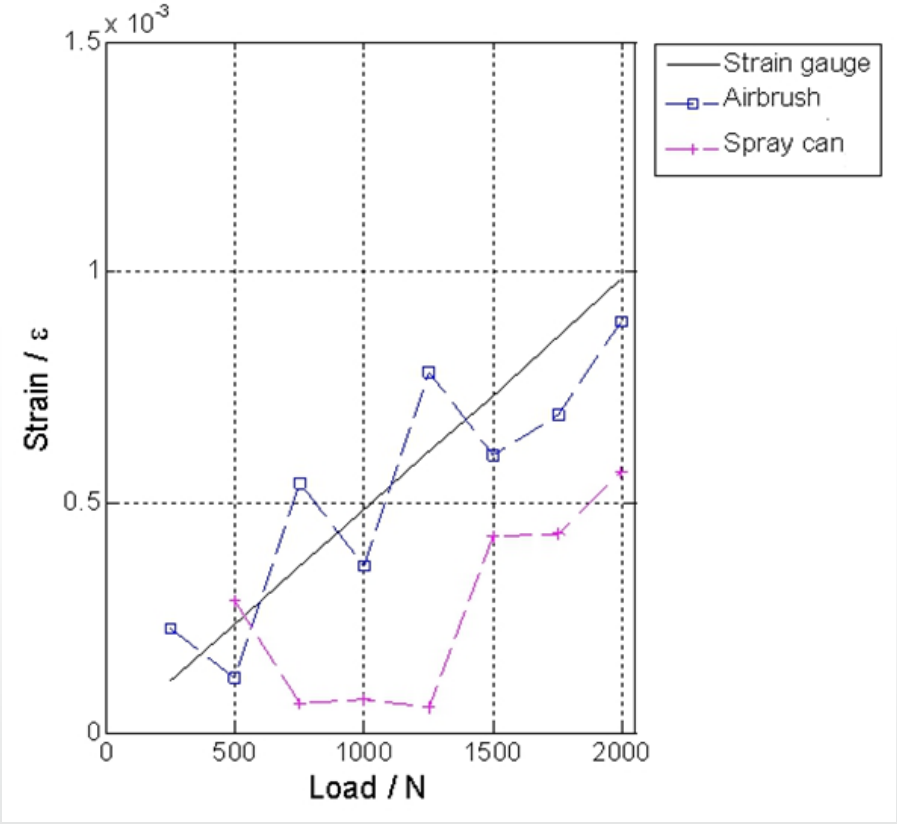
Evaluation against measured strain





Crammond, G., Boyd, S.W. and Dulieu-Barton, J.M., "Speckle pattern quality assessment for digital image correlation" , Optics and Lasers in Engineering –accepted for publication.

Component strains
705 pixels/mm

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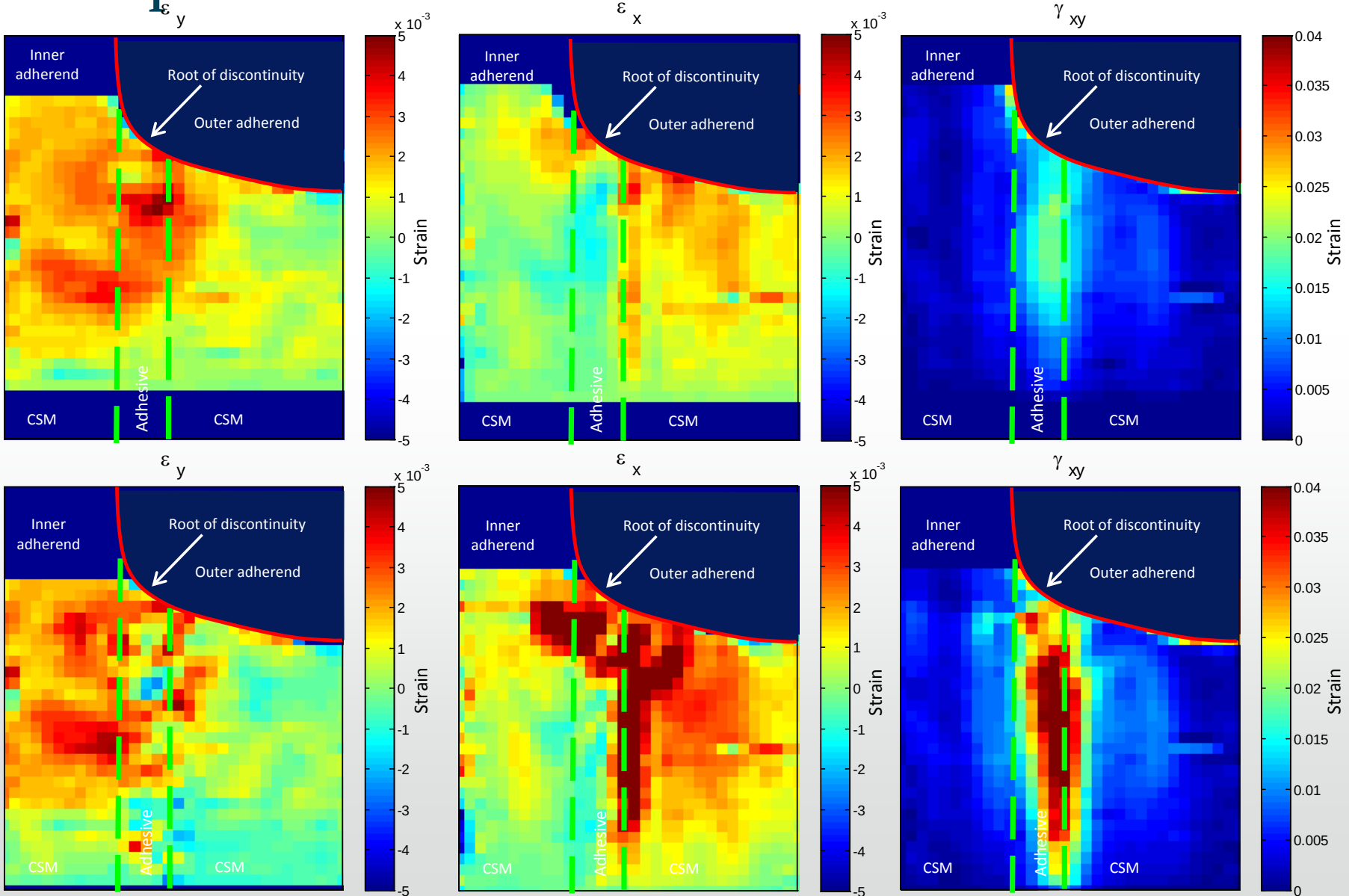

Evaluation of elastic properties (principal material directions xy = 12)

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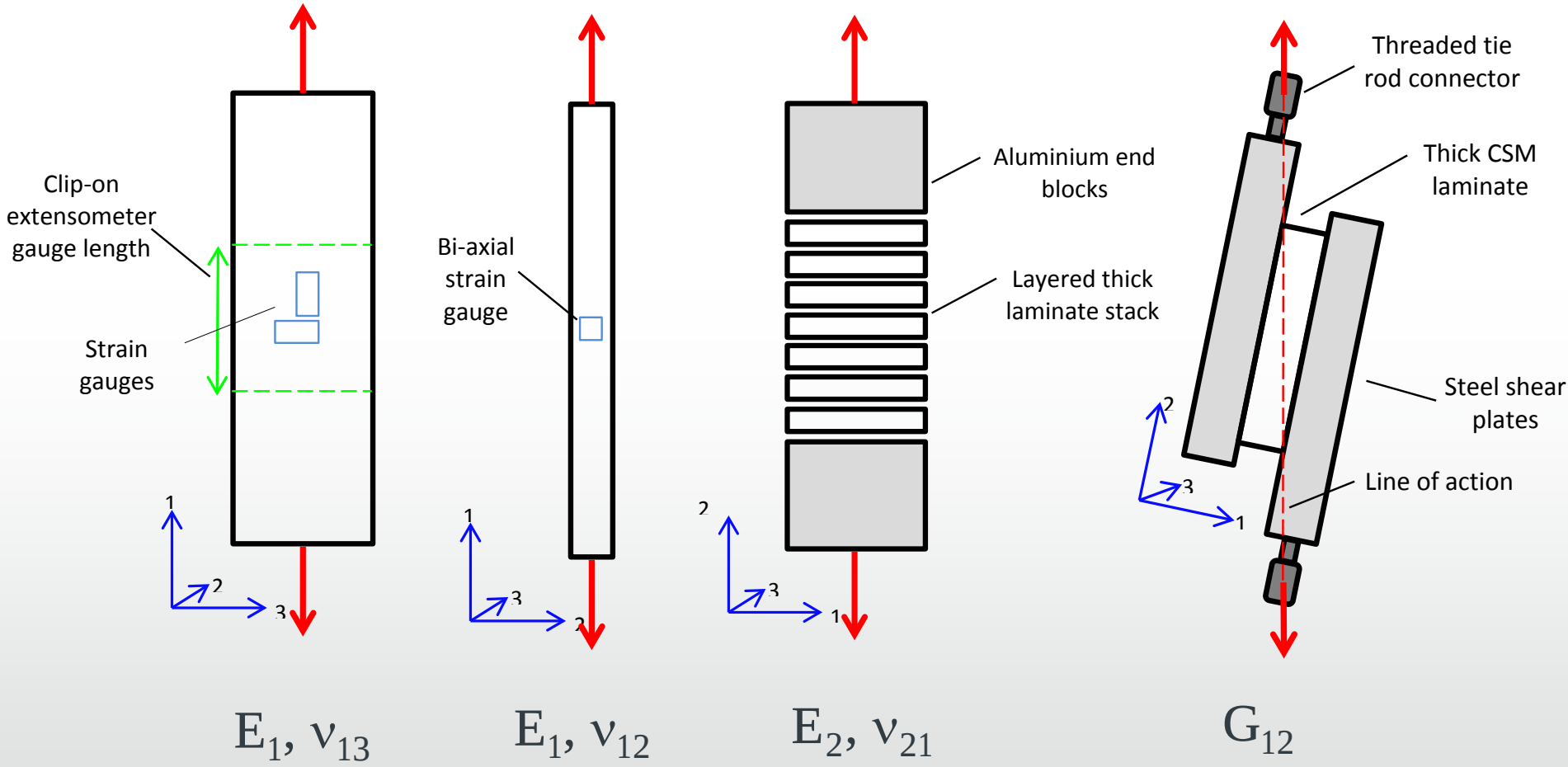

E_1, ν_{13} E_1, ν_{12} E_2, ν_{21} G_{12}

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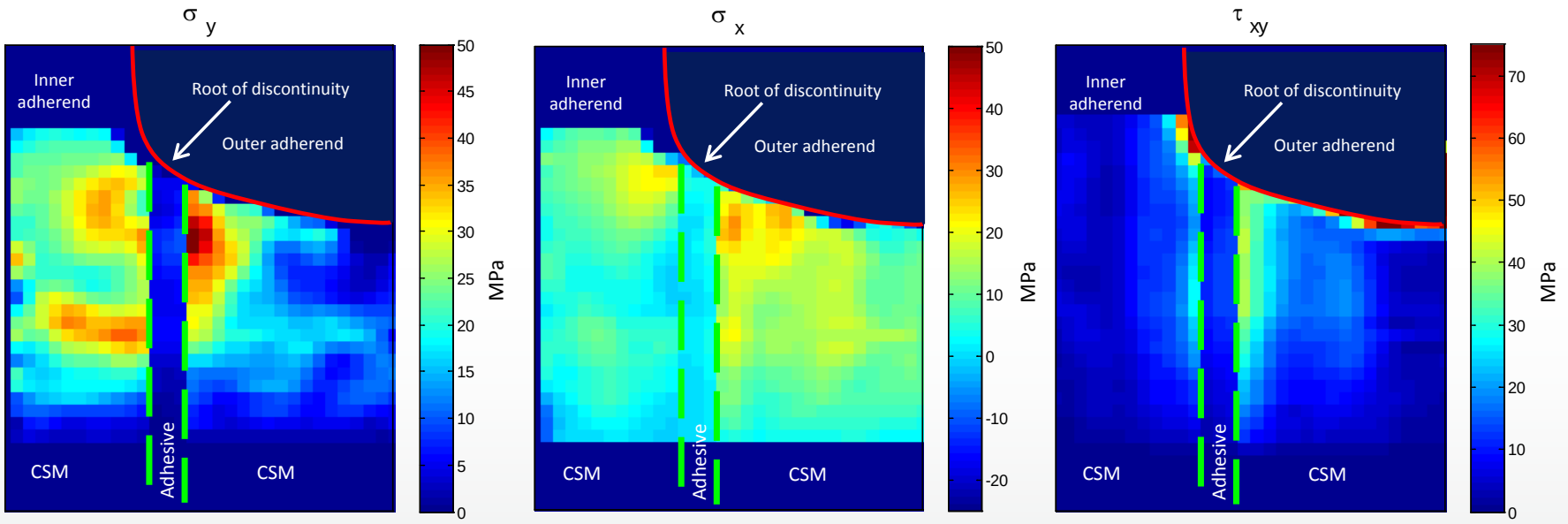
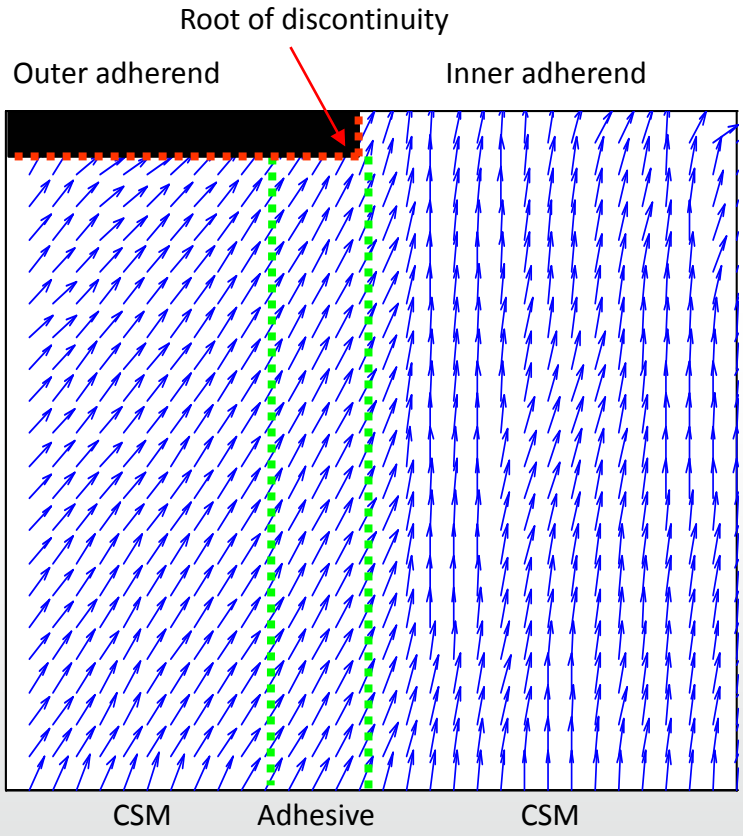
Component stresses in joint



Principal stress direction



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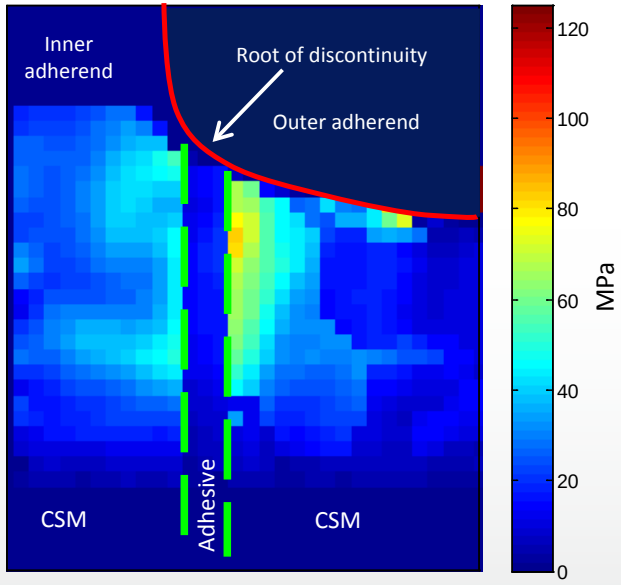
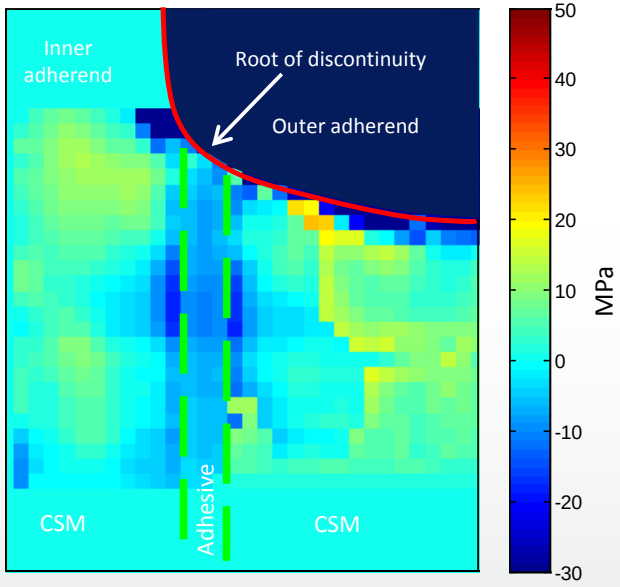
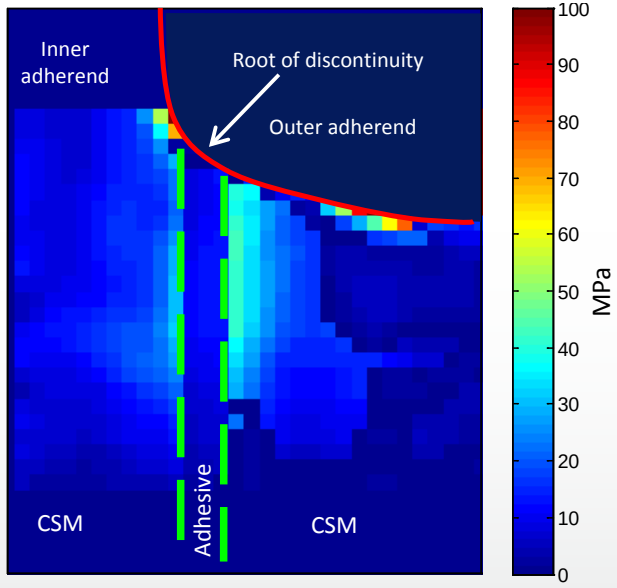
Principal stresses



σ_1^p



σ_2^p



τ_{max}

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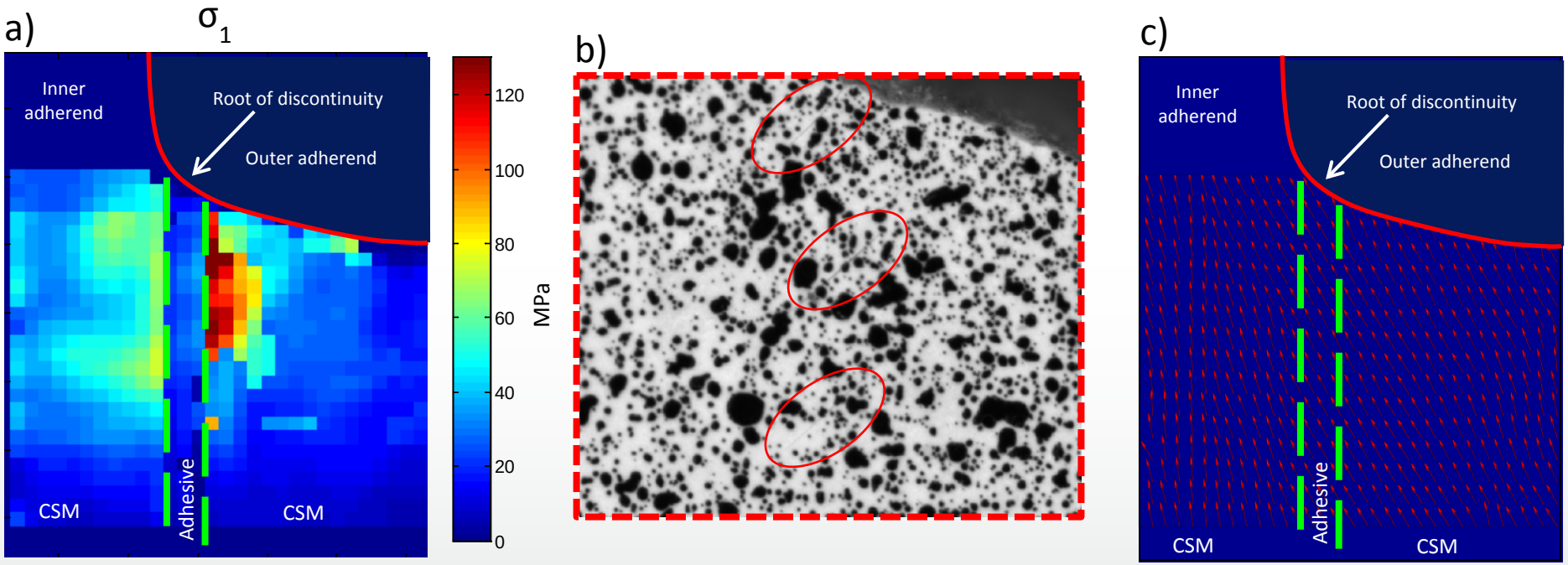
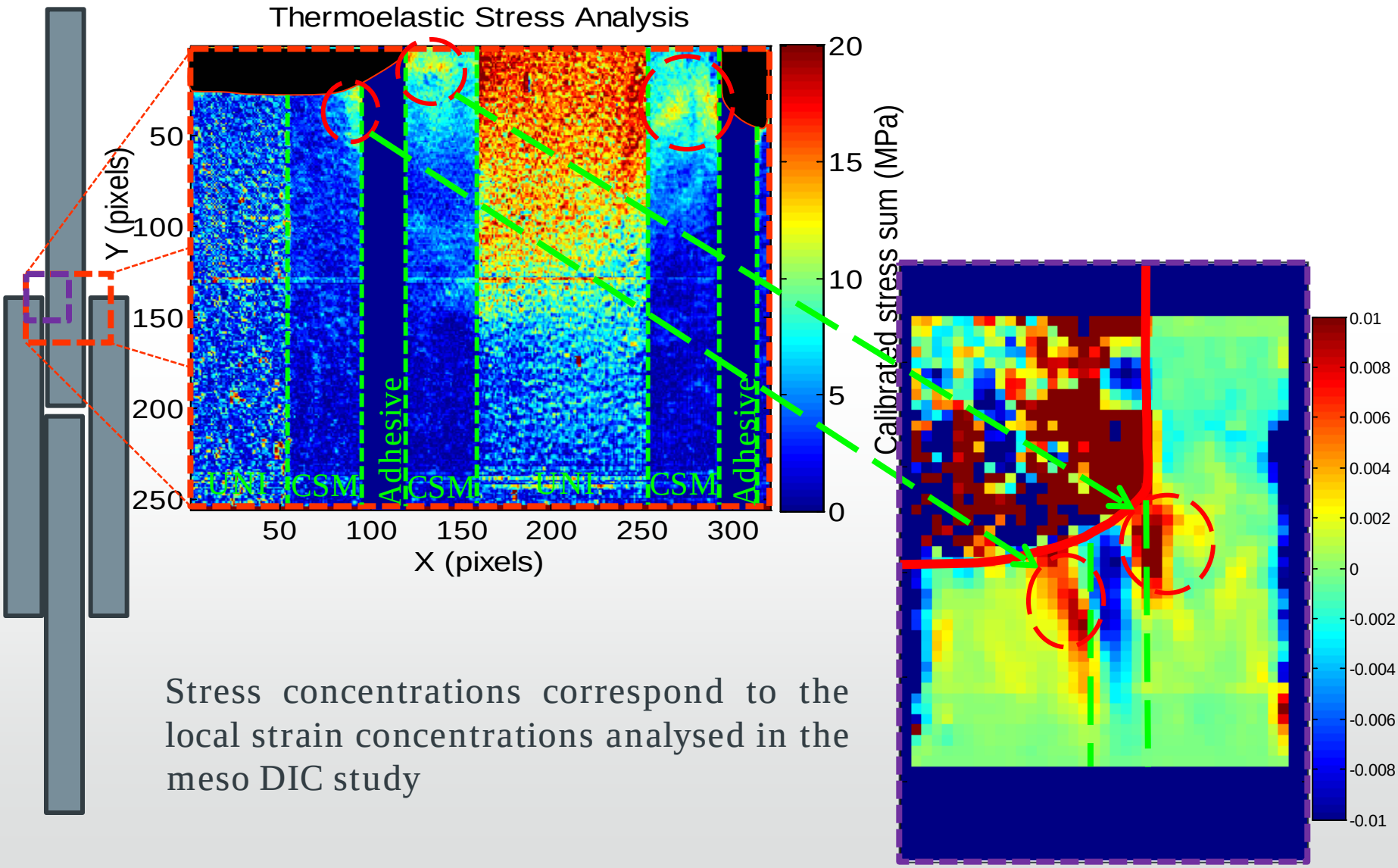
Crack development



Macro TSA/ Meso DIC



Stress concentrations correspond to the local strain concentrations analysed in the meso DIC study

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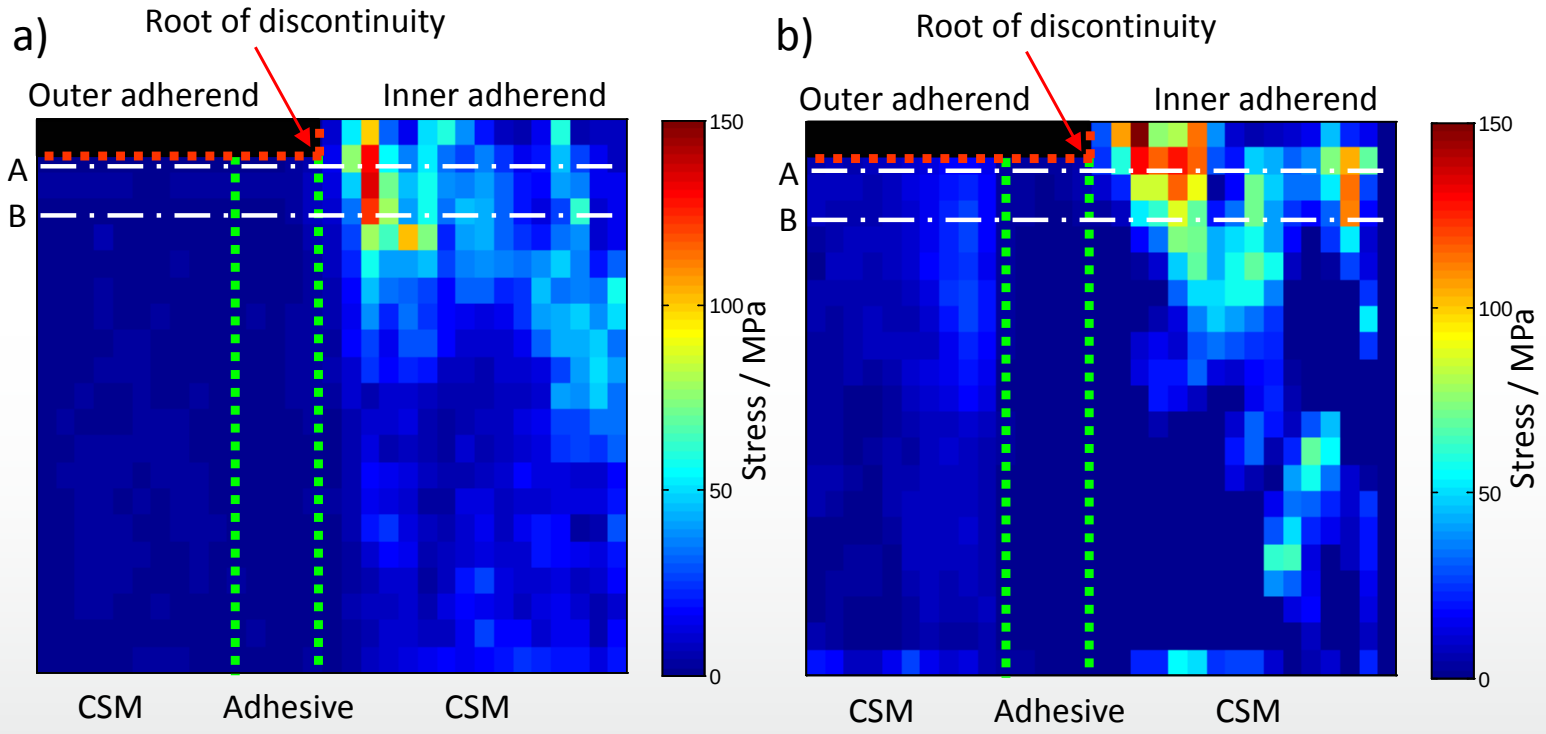
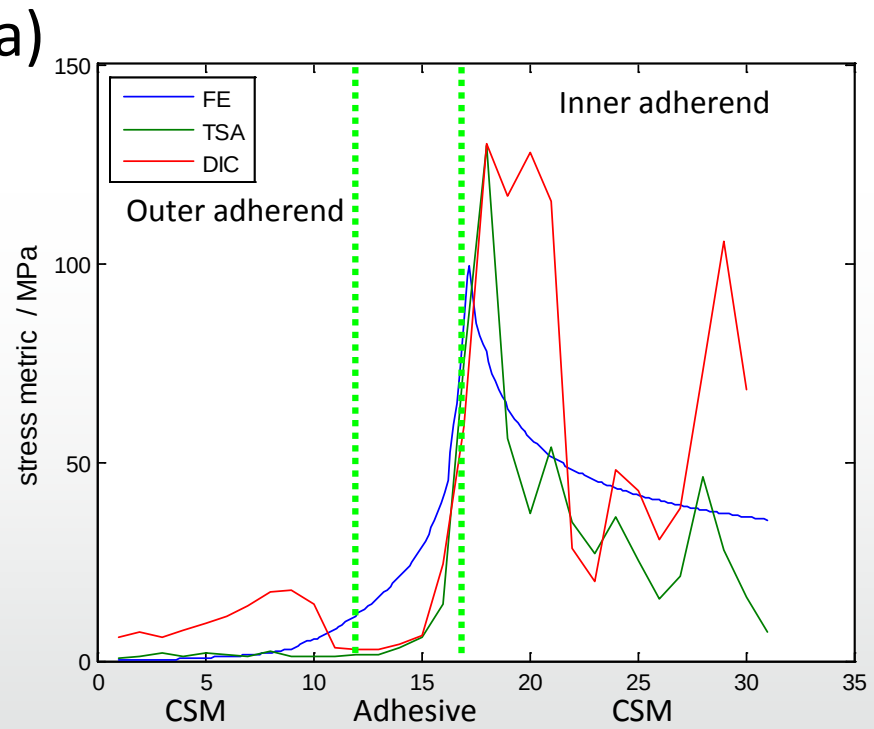
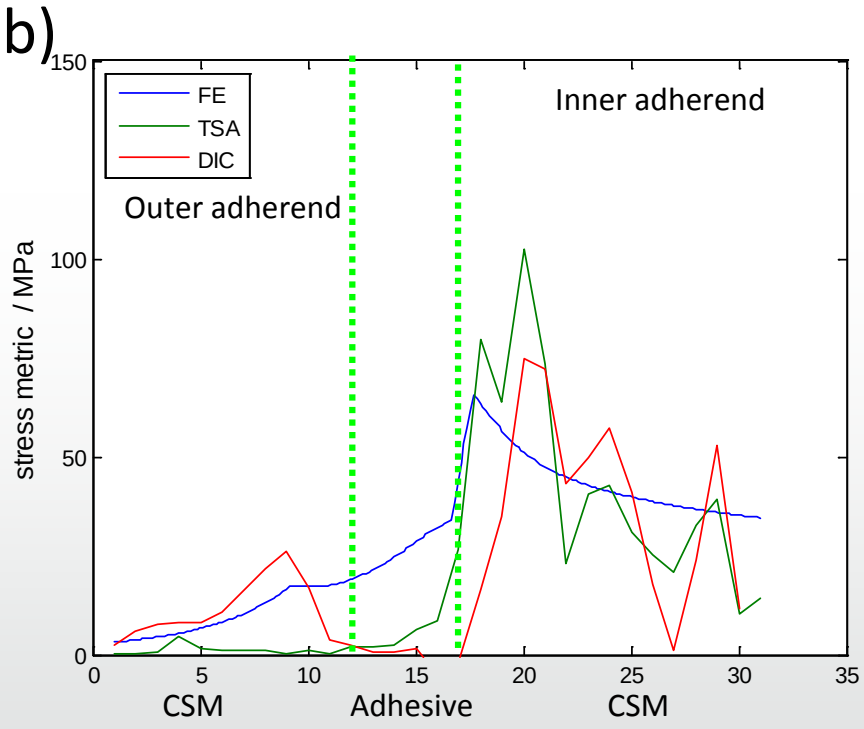
Verification against TSA

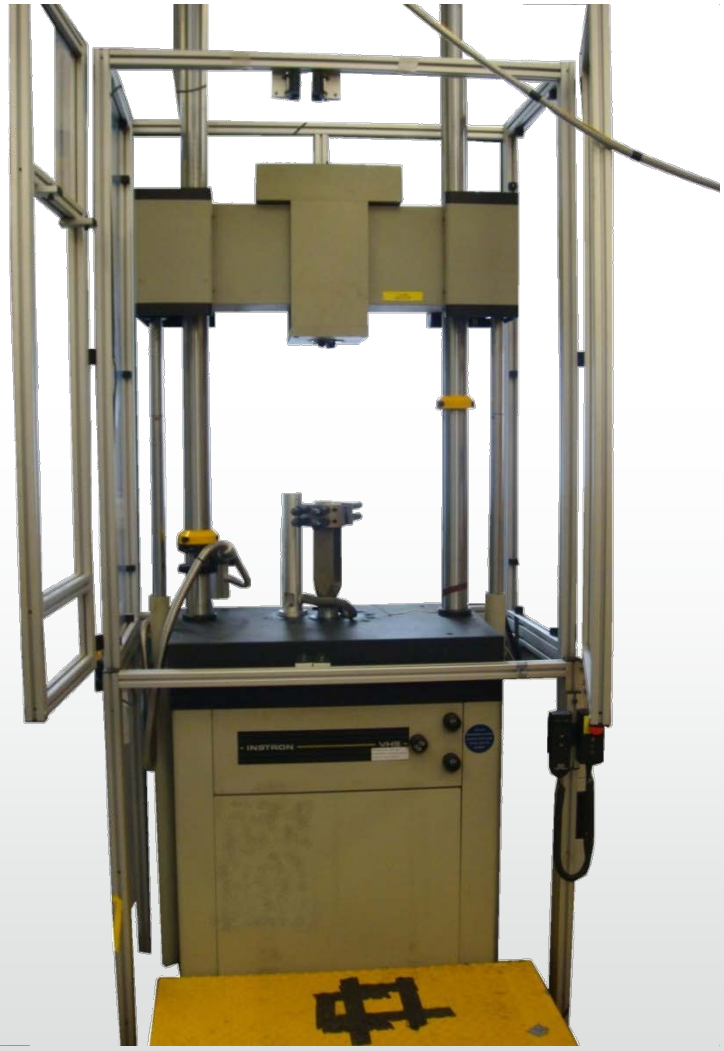


Line plot on A and B





VHS test machine



Technique	Strain rate (s^{-1})
Conventional Machine	≤ 0.1
Falling Weight	≤ 10
Servo-hydraulic	**0.1 → 100**
Charpy pendulum	≤ 100
Split Hopkinson bar	$100 \rightarrow 10^4$
Expanding ring	10^4
Flayer plate, ballistic impact	$\geq 10^5$

Machine Modifications

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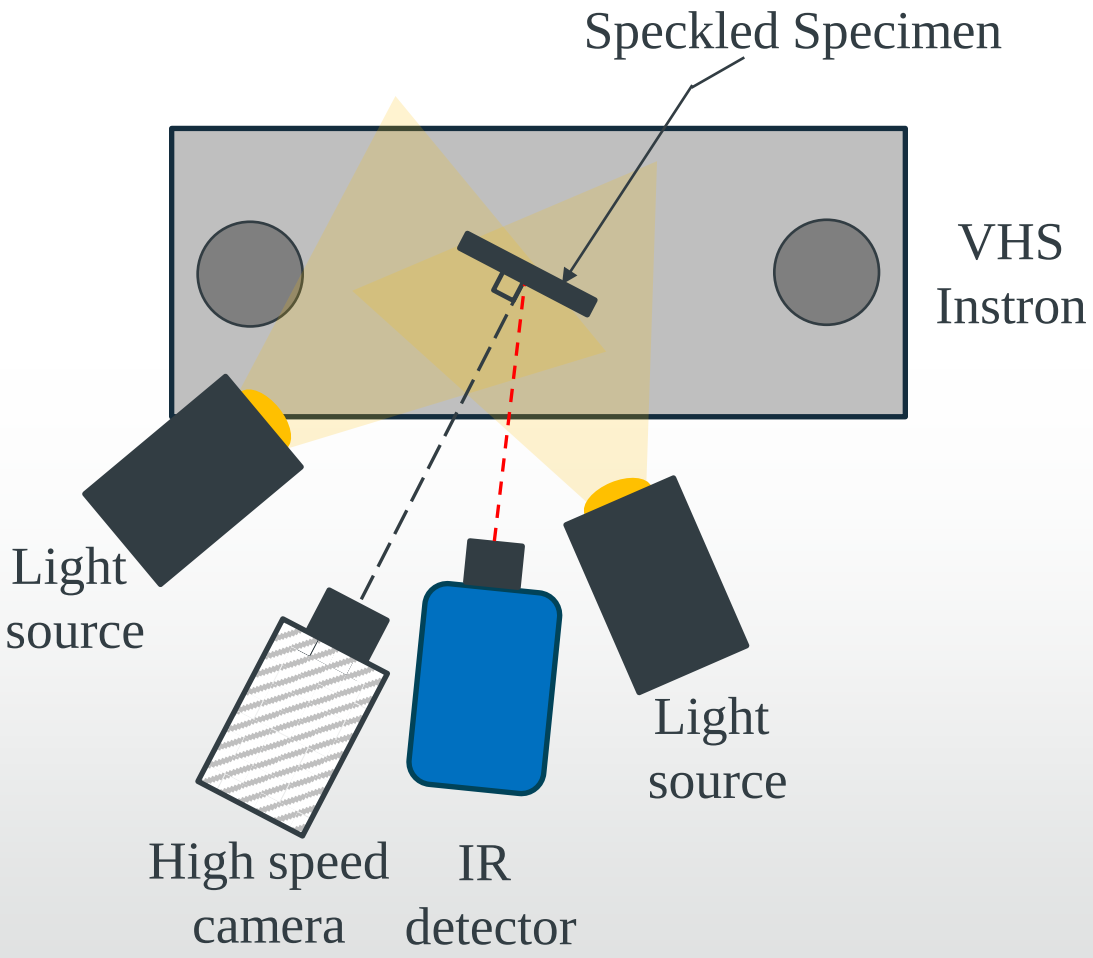

Machine modifications

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Photron SA5 HS camera

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- Model: Photron SA 5 Monochrome high speed camera
- Sensor: 12-bit ADC (Bayer system colour, single sensor) with 20 µm
- Memory: 8GB, 5,457 frames @ maximum resolution
- Max Resolution: 1024 x 1024
- 7000 fps at max resolution
- 1000000 fps at 64 x 16

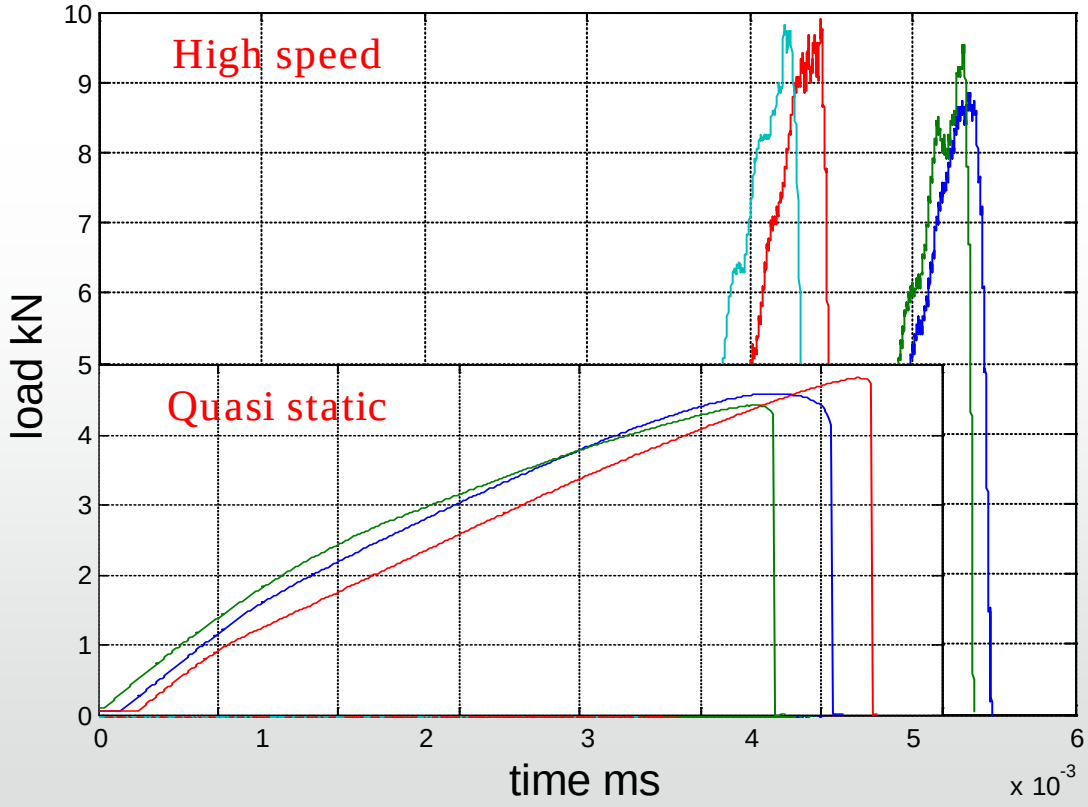
- Triggering: Selectable positive or negative TTL 5V or switch closure

High speed testing

Testing conducted at 2.5 m/s in the Instron VHS machine

Damtol project trigger and data capture methodology used

100% increase in tensile strength observed



High speed testing

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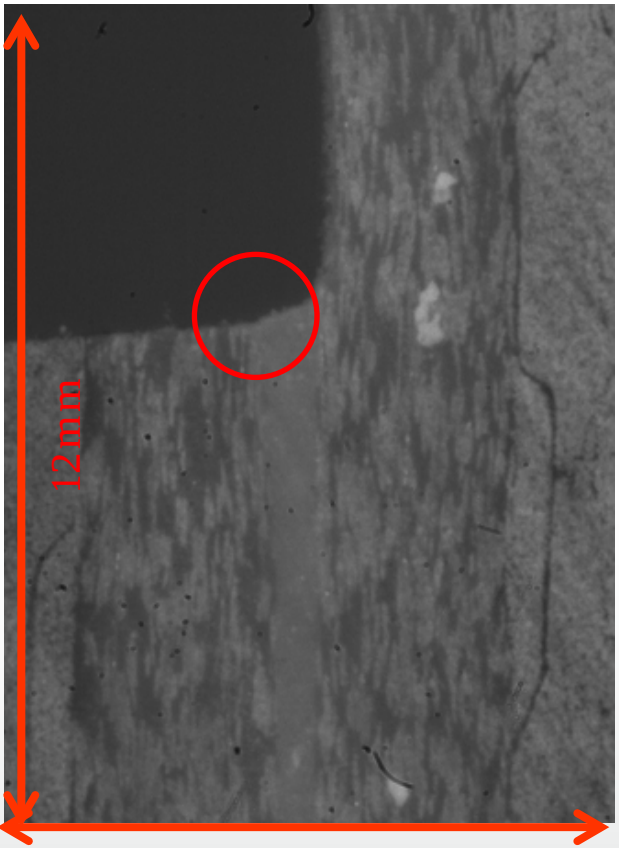


Damage initiation at root of discontinuity analysed under high speed loading

Photron SA5 capturing images with

Spatial resolution: 448 x 600 pixels

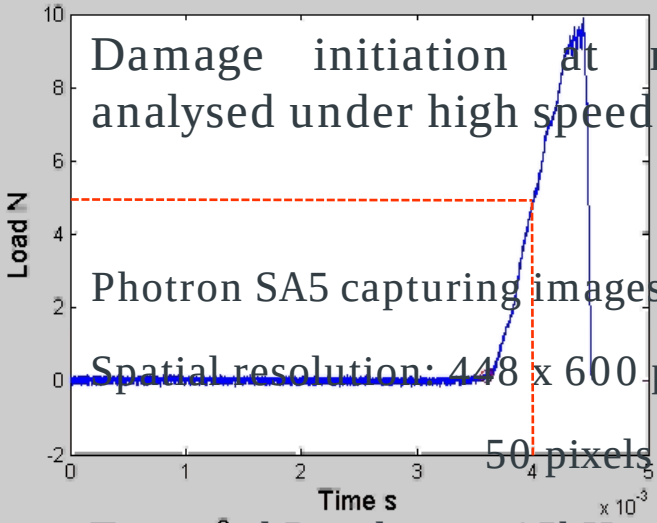
50 pixels / mm

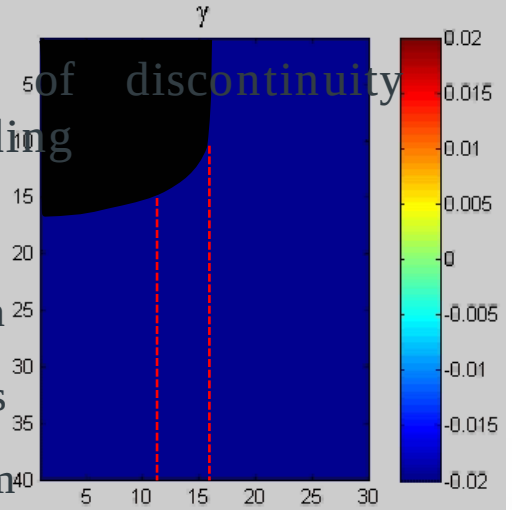
Temporal Resolution: 25kHz

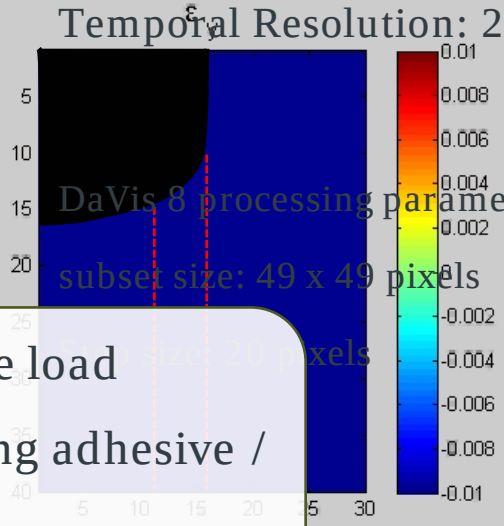
DaVis 8 processing parameters

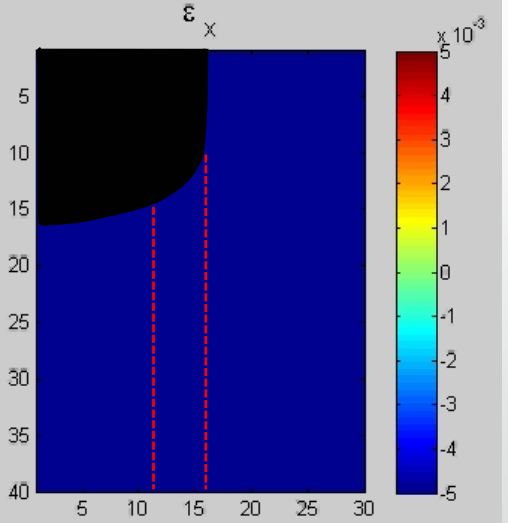
subset size: 49 x 49 pixels

step size: 20 pixels









Crack initiation at 50% failure load

Axial strain concentrated along adhesive / adherend interface

Low ε_x S-N ratio

High speed testing

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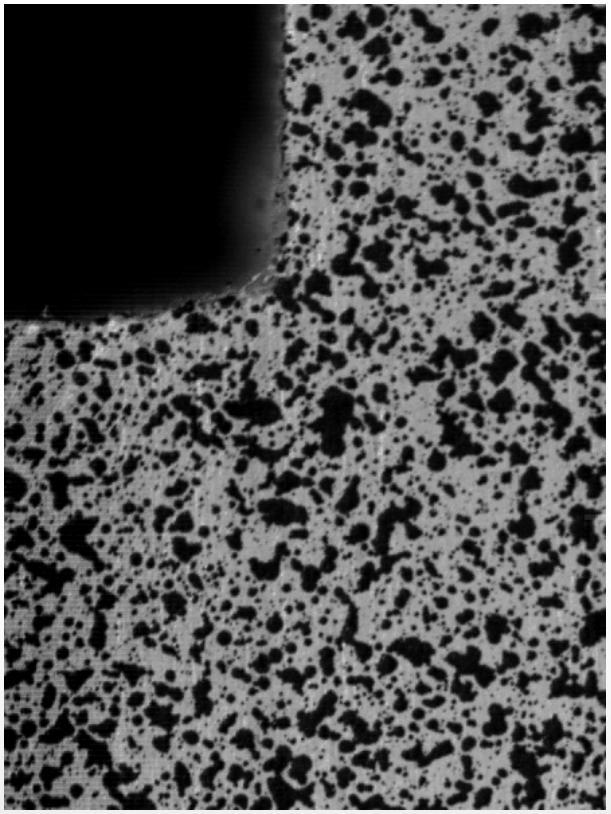

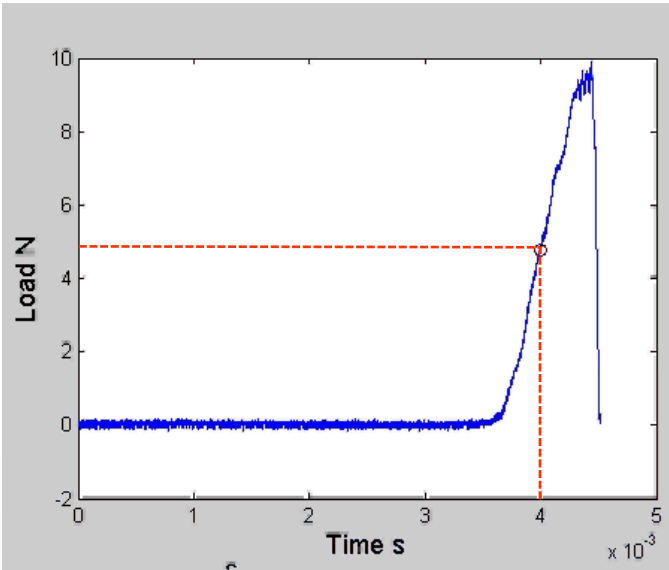

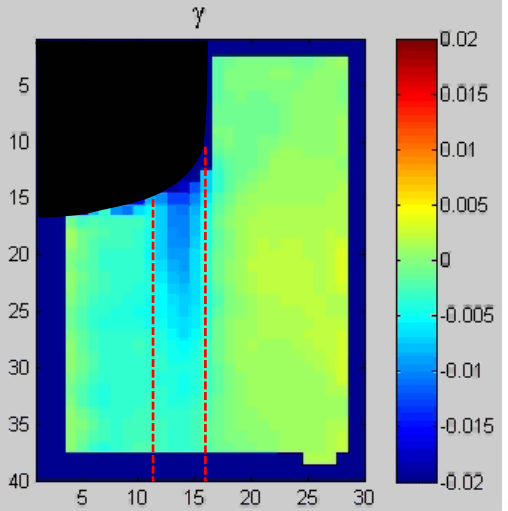

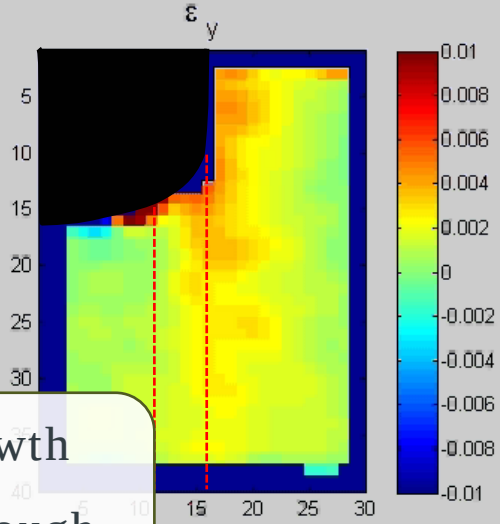

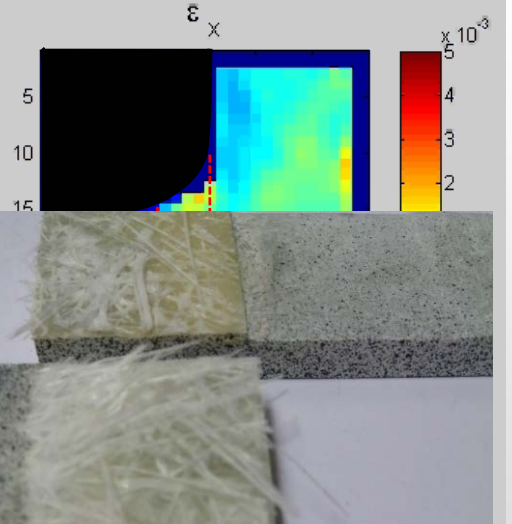

Rapid and unstable crack growth

Axial strain increases even though damage well developed

High speed testing

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2 mm/min

Crack growth along adhesive/adherend interface

Little ingression of crack into composite adherend

Much more violent failure surfaces observed at 2.5 m/s

Crack path less coherent

Greater interaction of fibres from within the adherend

2.5 m/s

Can we quantify the change in failure surface / load with a change in strain?

UNIVERSITY OF Southampton

Conclusions

- Methodology developed to accurately evaluate very small strains using DIC
- Speckle pattern evaluation routine established
- Demonstrated validity of the approach using quasi static loads
- Applied during high speed tests

16th International Conference on Experimental Mechanics First Announcement

ICEM·16

Cambridge • July 7-11 • 2014

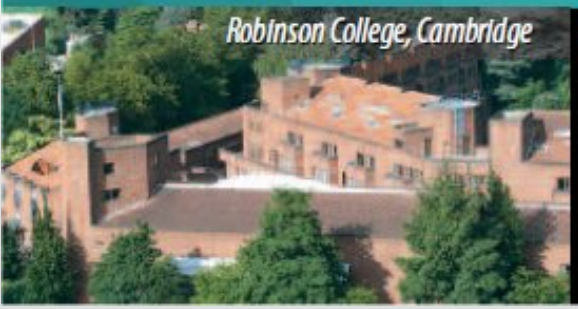
BSSM
BRITISH SOCIETY FOR STRAIN MEASUREMENT

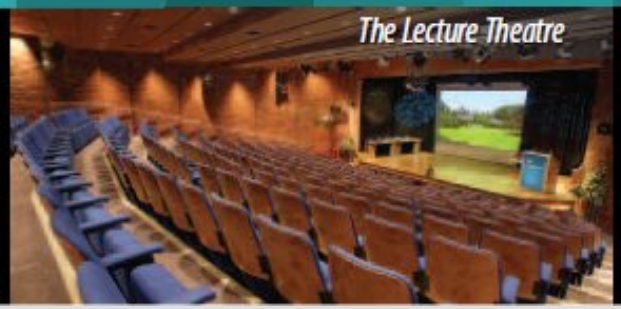
European Association for Experimental Mechanics
EURASEM

- The 16th in a series of conferences, starting in Delft in 1959, this is the premier event to showcase novel and innovative research in Experimental Mechanics
- The conference brings together internationally leading researchers across a wide range of disciplines in both academia and industry to interchange ideas and discuss new research
- An interactive exhibition of state of the art instrumentation will take place at the conference
- See the brightest early career researchers take part in the Young Stress Analyst Competition which is sponsored by industry
- Celebrate the 50th Anniversary of the journal Strain, the British Society for Strain Measurement and the 100th Anniversary of the Spilt Hopkinson Pressure Bar
- Enjoy the sights of Cambridge, the reception at the Fitzwilliam museum and the banquet under the wings of Concorde at the world famous Duxford air museum
- The conference is organised by the British Society for Strain Measurement on behalf of the European Society for Experimental Mechanics and Chaired by Professors Janice Dulieu-Barton and Fabrice Pierron from the University of Southampton and Professor Chris Truman from the University of Bristol

The BSSM and EURASEM welcome you to Cambridge and invite you to visit the conference web site for further details:

www.icem16.org


Robinson College, Cambridge


The Lecture Theatre


AirSpace at Duxford