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Novel Strain Based NDE (SBNDE) methodology for online inspection and prognostics of composite sub-structures with manufacturing induced defects

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Background

- Current manufacturing stage inspection approaches for composite components described in cannot provide details directly on how a defect may affect service life.
- To save time and reduce wastage it is essential that an inspection technology is developed that can intervene at the manufacturing stage and provide high fidelity data for model based prognostic capability.
- A novel inspection procedure for cured composite components is proposed known as Strain Based NDE (SBNDE).

Aim and objectives

Devise a high fidelity means of obtaining local strain/stress data to inform model-based prognostics will be developed to define how a given defect will evolve under service load.

- Demonstrate the viability of the experimental methodology providing the data necessary for the model based prognosis system by demonstrating the approach at a sub-structural level.
- Scope a system that is flexible, portable, lightweight and robust – suitable for deployment in the production environment

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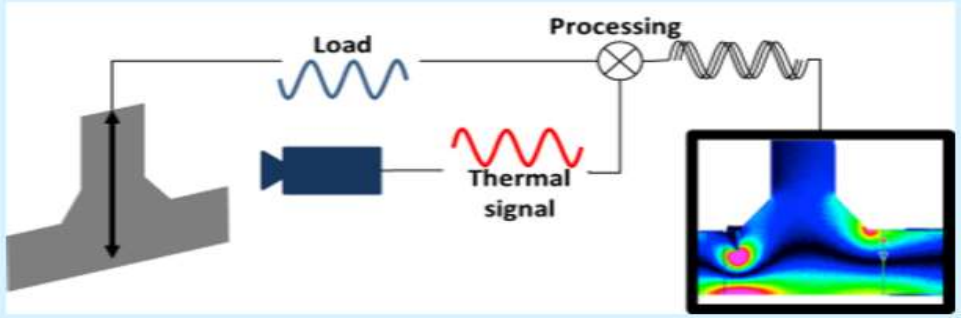
Experimental technique

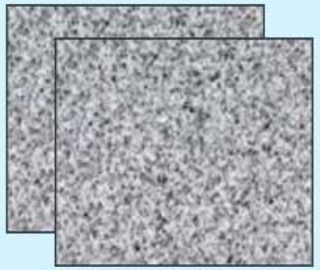
Thermoelastic stress analysis (TSA)



$$\Delta T = -\frac{T}{\rho C_p}\left(\alpha_1 \Delta\sigma_1 + \alpha_2 \Delta\sigma_2\right)$$

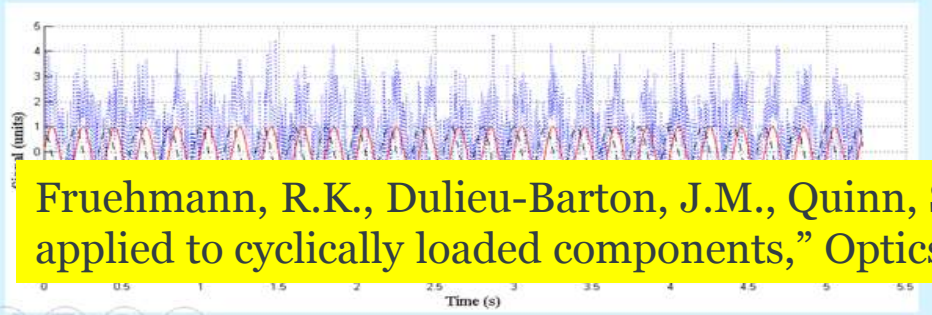
⇨ Provides a stress metric

Digital Image Correlation (DIC)



Uses surface contrast to track displacements between two images to provide the component strains ε_x, ε_y and ε_{xy}

TSA uses lock-in processing to extract ΔT from a noisy signal



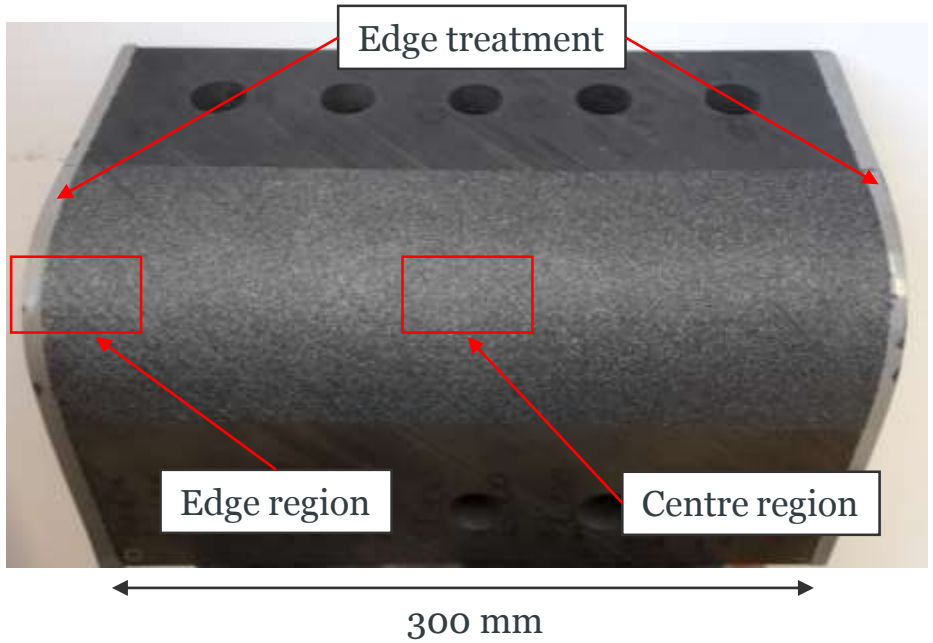
Lock-in DIC (LIDIC)

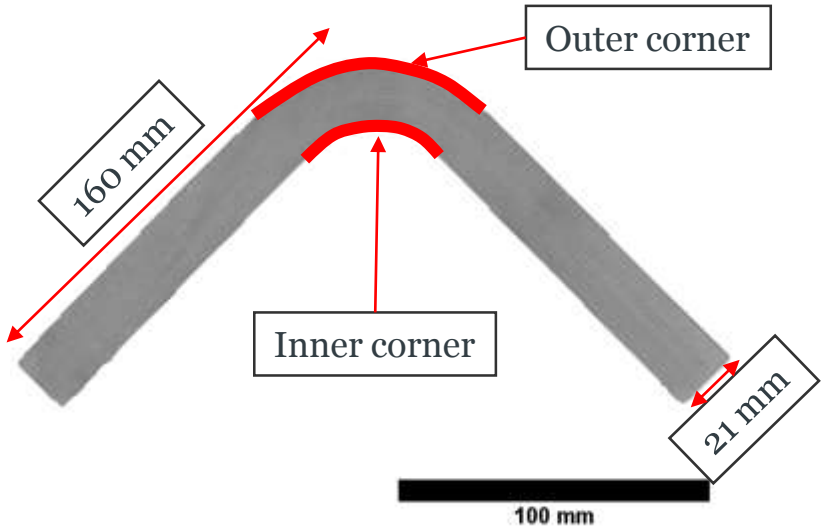
Uses lock-in processing to extract strains during cyclic loading so DIC and TSA are performed

...vide ...ΔT

Fruehmann, R.K., Dulieu-Barton, J.M., Quinn, S., and Tyler, J.P., "Digital image correlation applied to cyclically loaded components," Optics and Lasers in Engineering. 2015.

The test component





Surface preparation: thin layer of matt black paint for TSA
Fine white speckle for DIC (~6 speckles per mm)

T.A. Fletcher et al., Resin treatment of free edges to aid certification of through thickness laminate strength. Composite Structures 146 (2016) 26-33

Loading test rig in test machine

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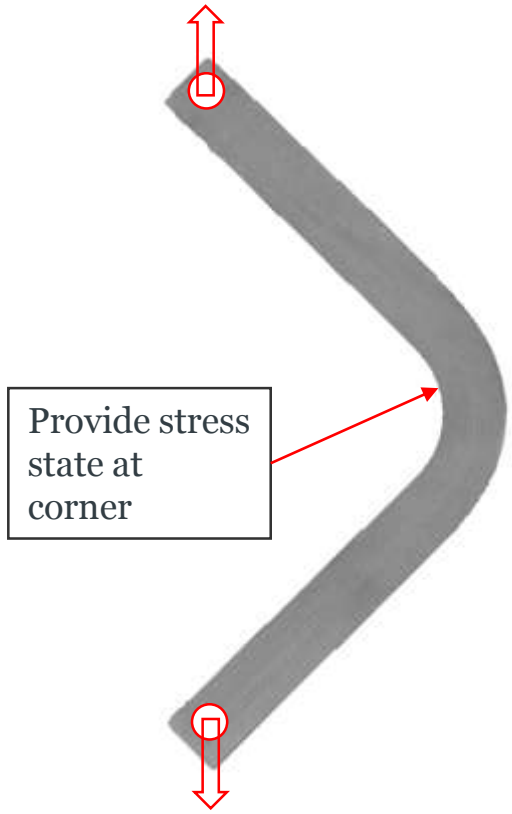

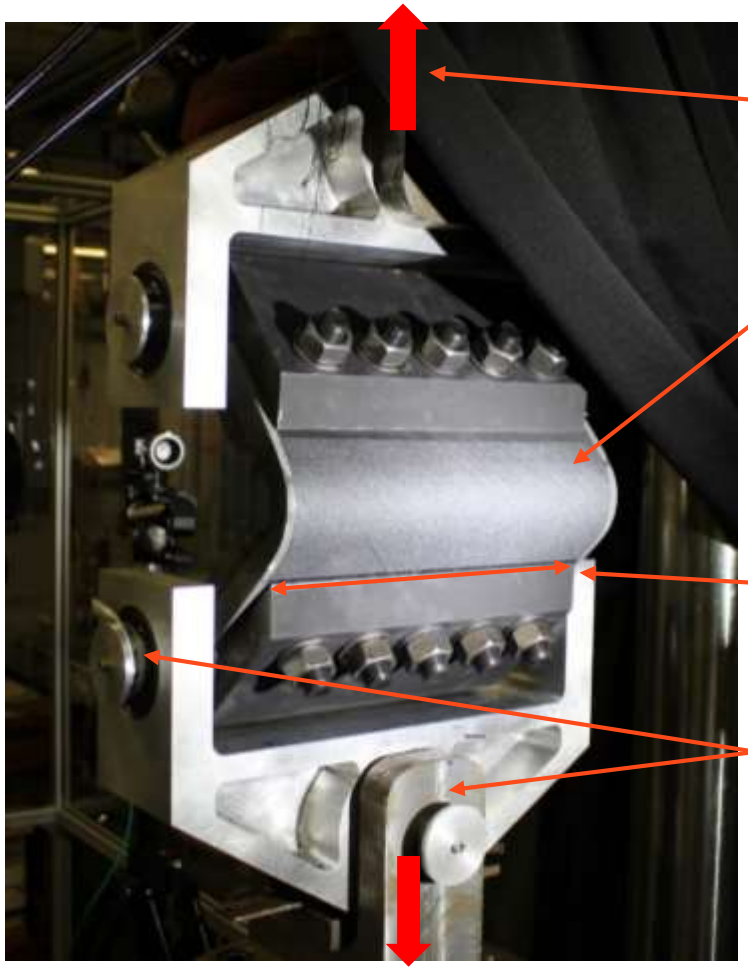

Results

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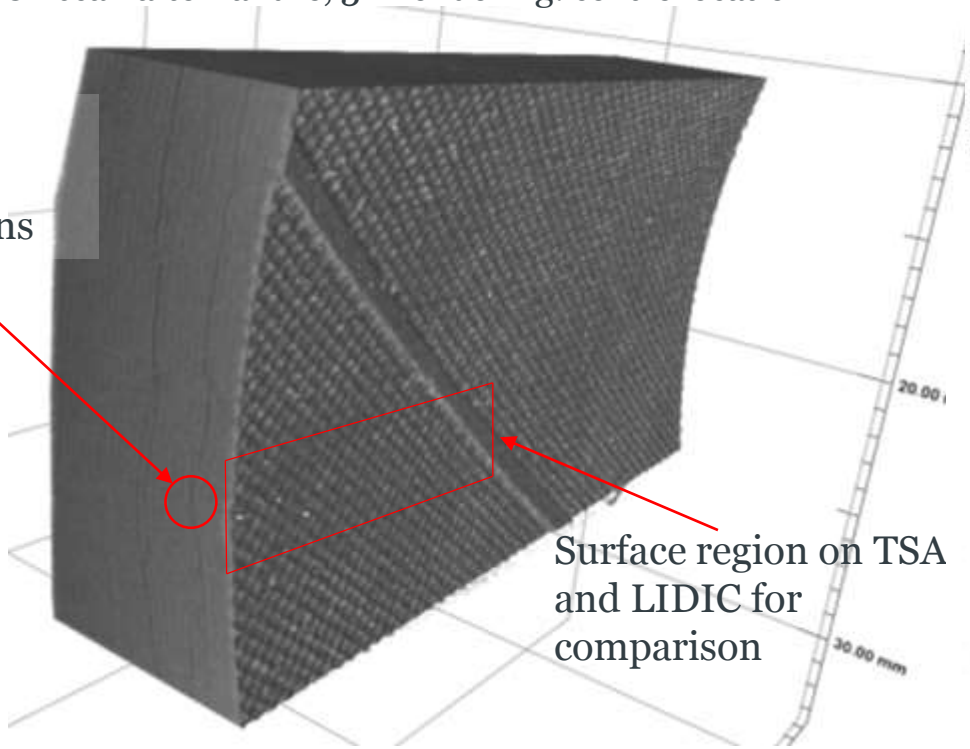
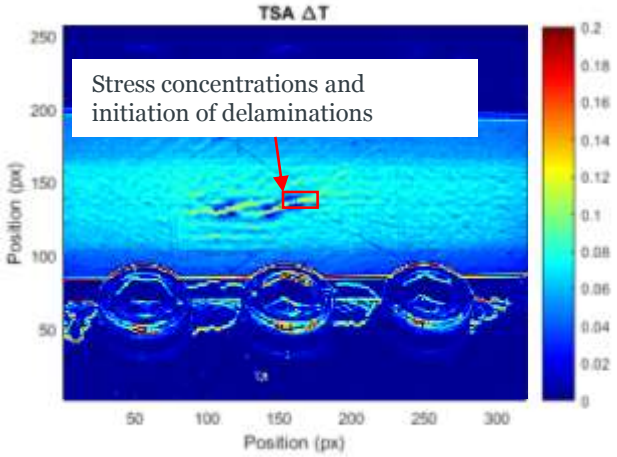
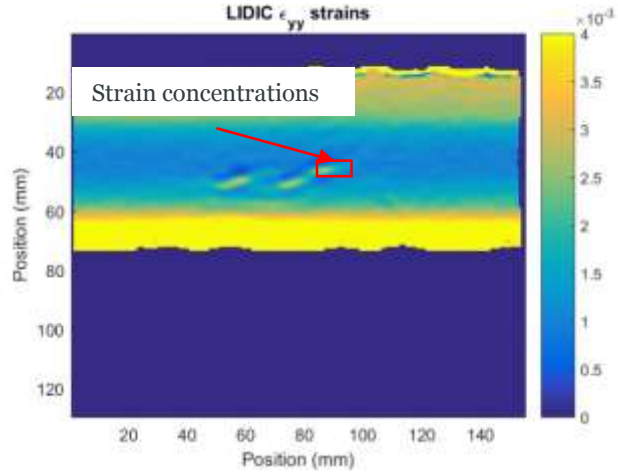
X-ray CT scan after failure, 3D rendering: centre location

Subsurface winkle & delaminations



Surface region on TSA and LIDIC for comparison





Vibration based loading

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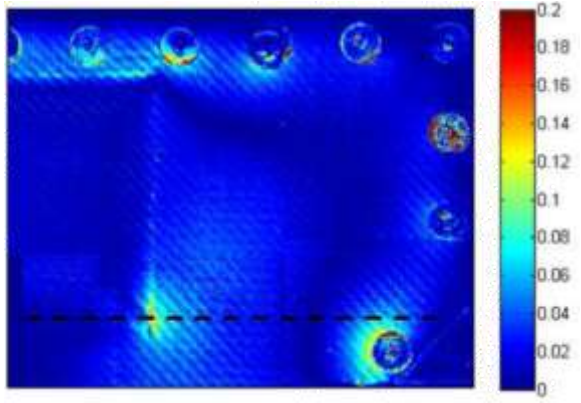
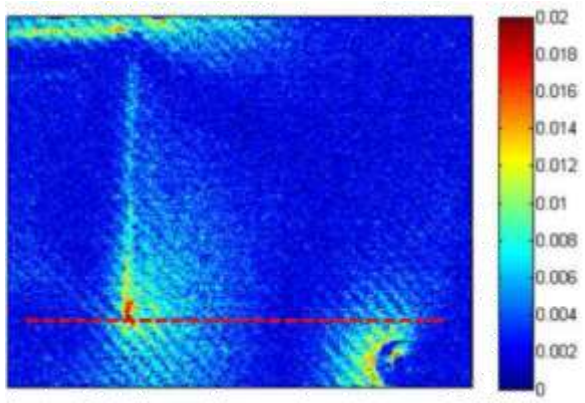
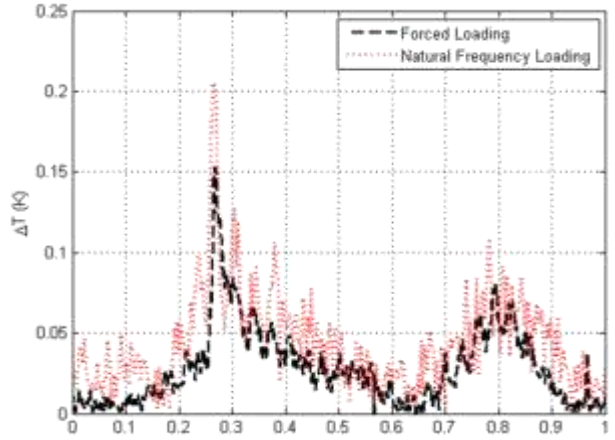
Thermoelastic stress analysis (TSA) inspection of a composite panel using:

- Forced loading
- Natural Frequency excitation

Natural frequency excitation is able to produce the same level of feature identification as forced loading thus enabling TSA to be carried out without a test machine.







Crump, D.A., Dulieu-Barton, J.M., Savage, J., "Design and commission of an experimental test rig to apply a full-scale pressure load on composite sandwich panels representative of an aircraft secondary structure," Measurement Science and Technology 21, 1-16 (2010).
Dulieu-Barton, J.M., Fruehmann, R.K., and Quinn, S., "A full-field stress based damage assessment approach for in-situ inspection of composite structures," Key Engineering Materials, 569, 3-10 (2013).

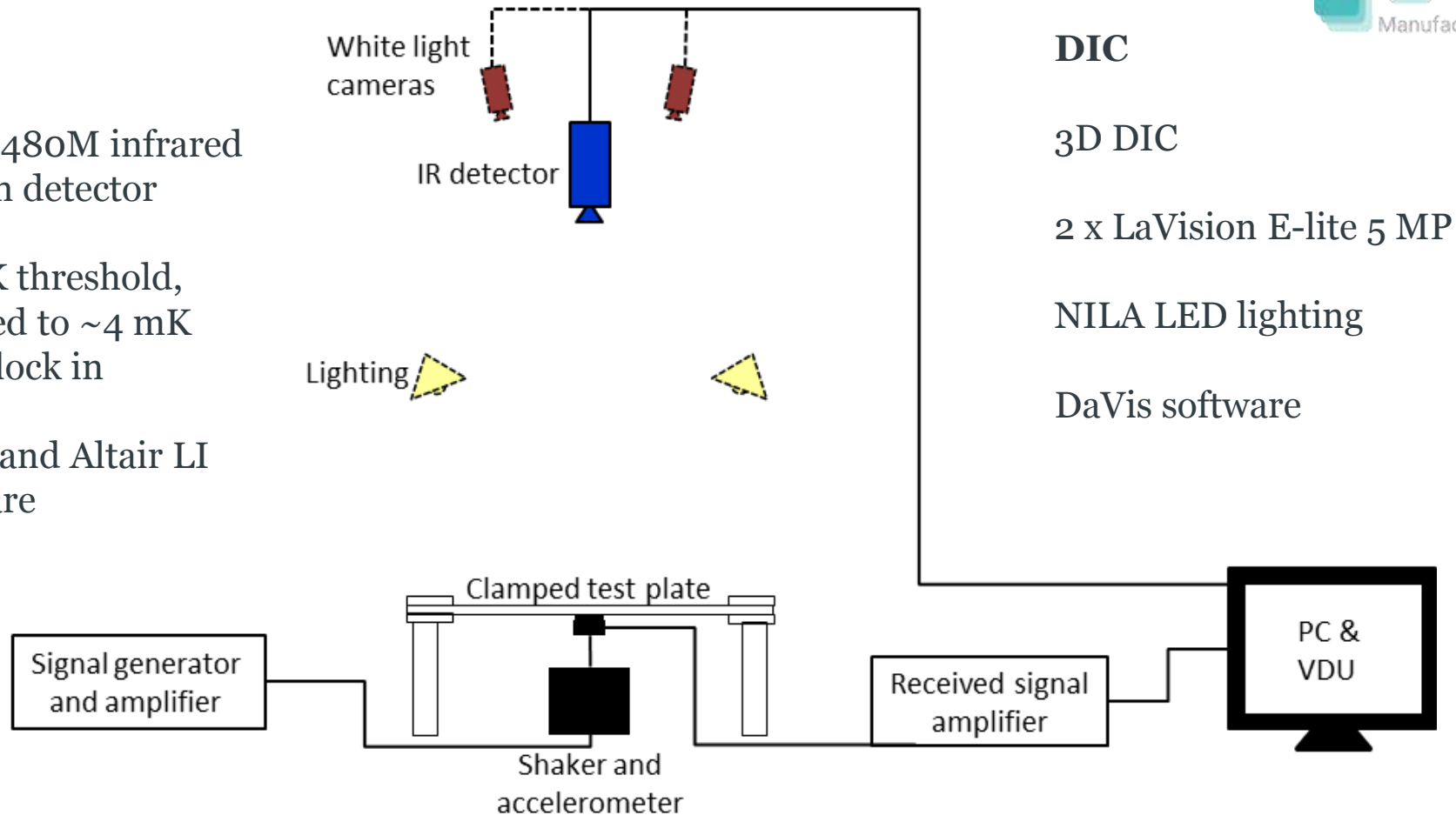
Experimental procedure

TSA

Cedip 480M infrared photon detector

20 mK threshold, reduced to ~4 mK using lock in

Altair and Altair LI software



DIC

3D DIC

2 x LaVision E-lite 5 MP

NILA LED lighting

DaVis software

Loading

LDS V201 permanent magnet shaker from Brüel & Kjær
Rigid stinger used to impart load attached via beeswax.

Undamaged GFRP plate

31 x 31 overlap 50%, Speckle size 5-10 pixels, 4-5 speckles per subset, Noise 0.004 mm, 0.25 subsets/mm

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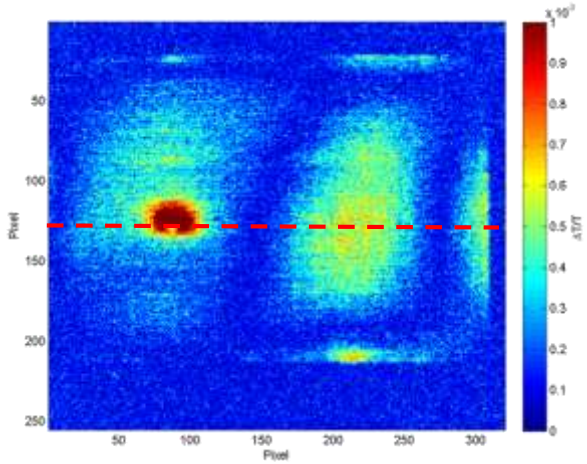
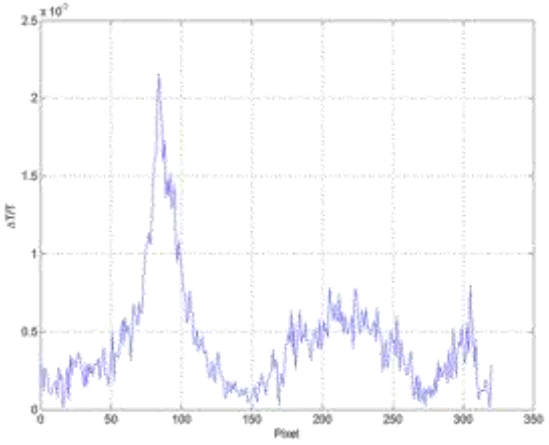
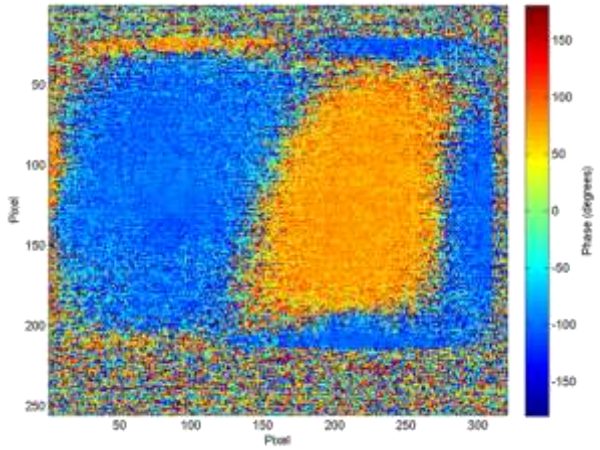
ΔT/T

Phase

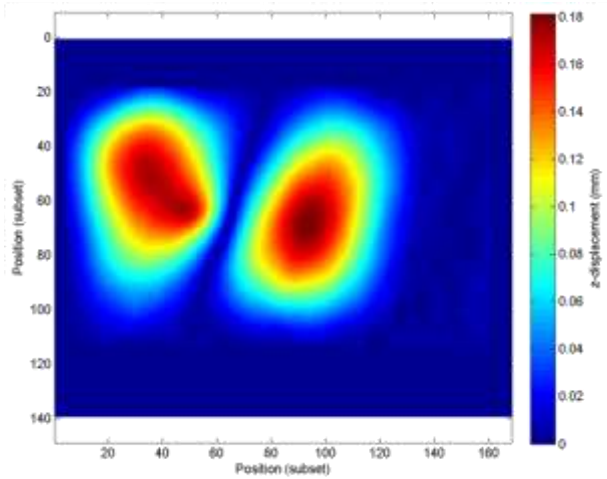
TSA

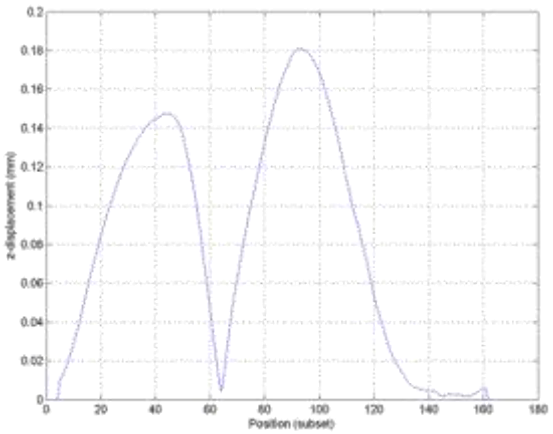


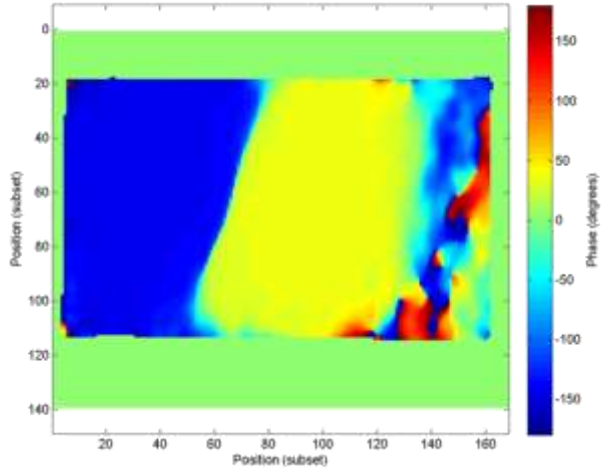




DIC







z-displacement

Way forward for feasibility study

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- Extract strains from vibration loaded object using LIDIC
- Perform TSA and LIDIC simultaneously
- Extract stress data from TSA
- Develop model
- Assess production components with features
- Automotive materials

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