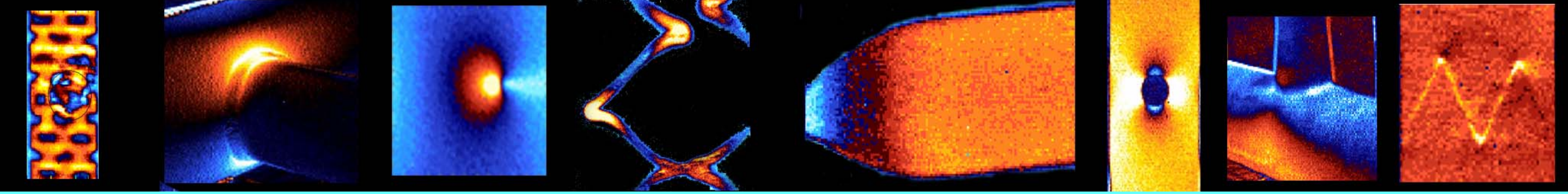

Thermoelastic methods for assessing hygrothermal ageing and damage in sandwich foam

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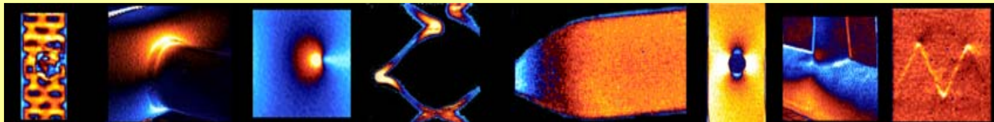
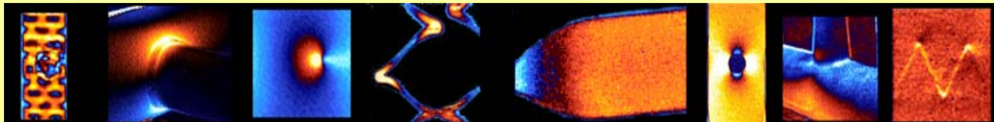
Overall objectives

- Assist designers in offering recommendations for damage severity and risk to structural integrity with refinement of core safety factors.
- Investigation of cellular response to in-service conditions: Long-term progressive/accumulative damage (ageing). Impending risk damage (crack).
- Application of remote detection method (TSA) to sensitive foam core. Evaluation of stress intensity factors about crack-tip.

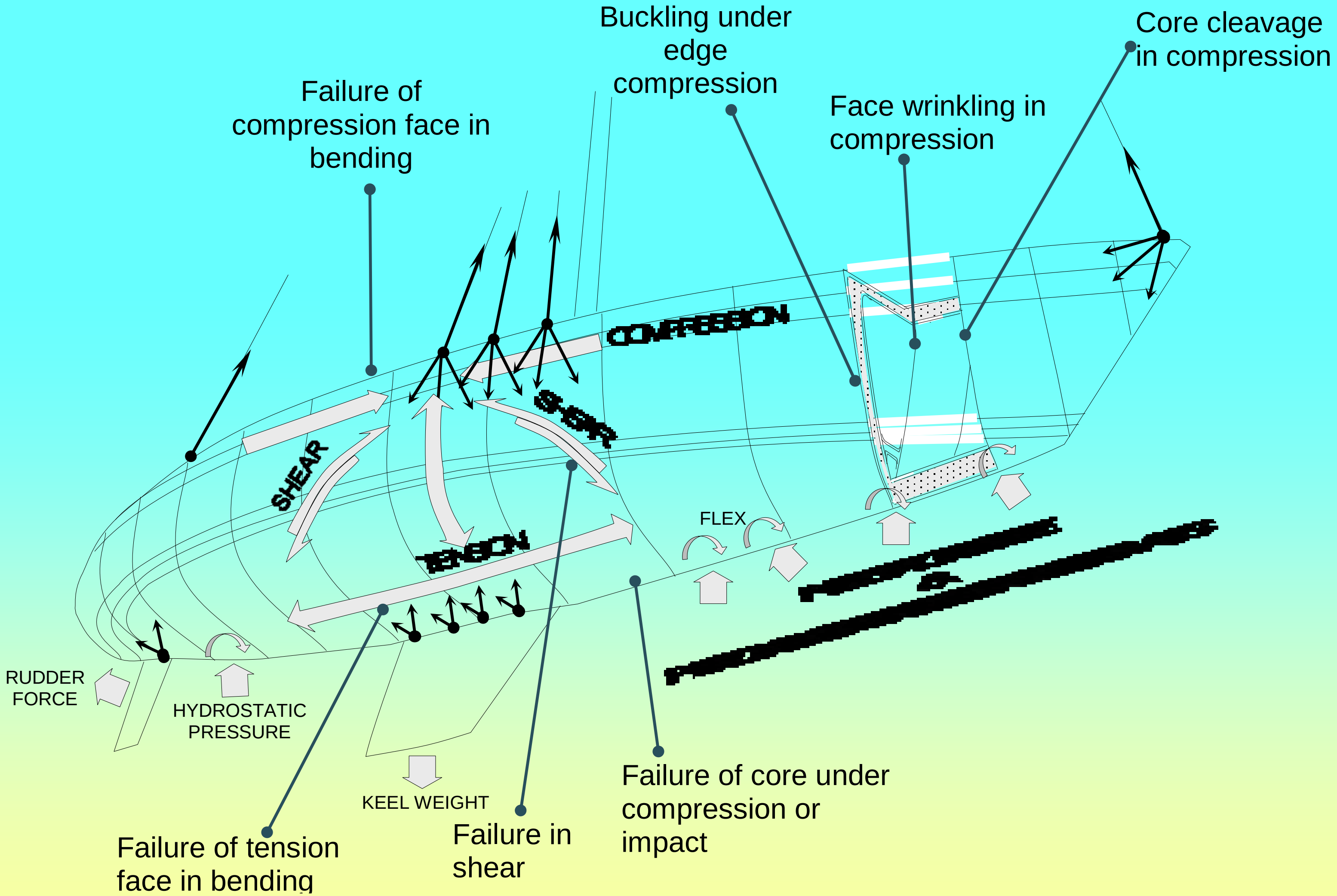


Overview

- Ship structure
- TSA
- Initial work on Tee-joints
- Hygrothermal ageing of Tee-joints
- Detailed investigation of foam –aged versus unaged
- Application of TSA to obtain SIFs from notched foam samples



Loading and failure zones in hull structure



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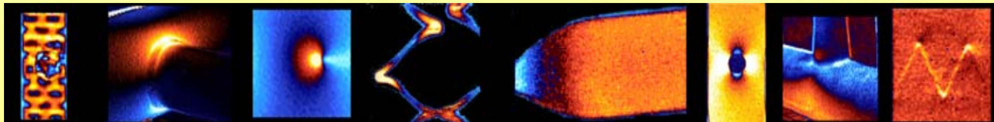
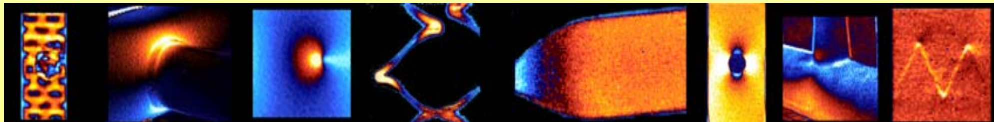
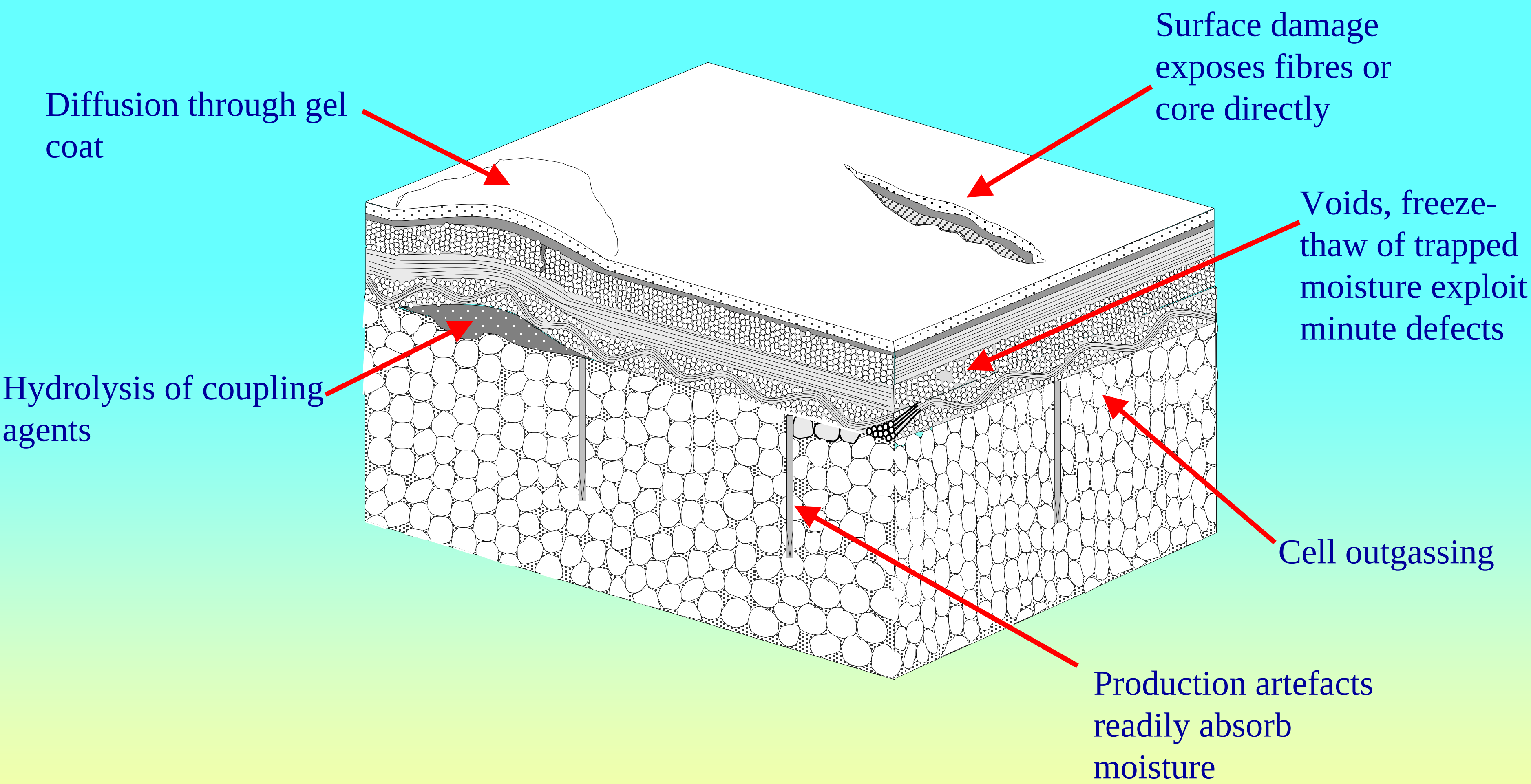


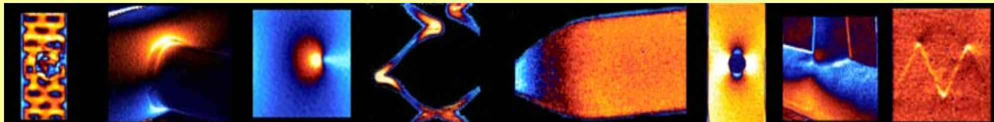
Motivation

- Structural safety emphasis on face sheets
- Environmental degradation analogous to corrosion but unspecified in design rules
- Ageing has focuses on aerospace materials
- Core vulnerable because of slamming loads, rigging loads, grounding- skin abrasion, environmental temperature cycling, numerous moisture access routes etc. may lead to delamination and core property alteration



Moisture Access Routes





Thermoelastic Stress Analysis (TSA)

Isotropic materials:

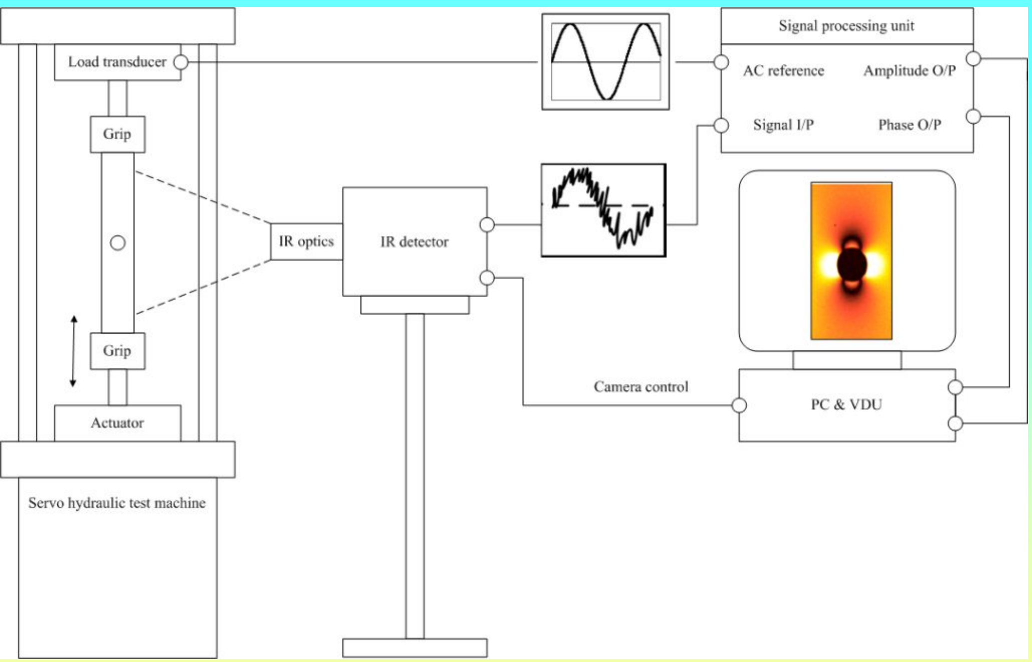
$$\Delta T = -\frac{\alpha T}{\rho C_p} \Delta(\sigma_1 + \sigma_2)$$

$$AS = \Delta(\sigma_1 + \sigma_2)$$

Orthotropic materials:

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

$$A * S = (\alpha_1 \Delta\sigma_1 + \alpha_2 \Delta\sigma_2)$$



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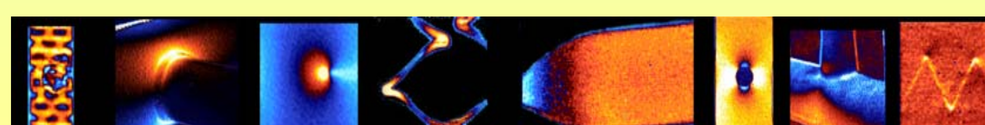
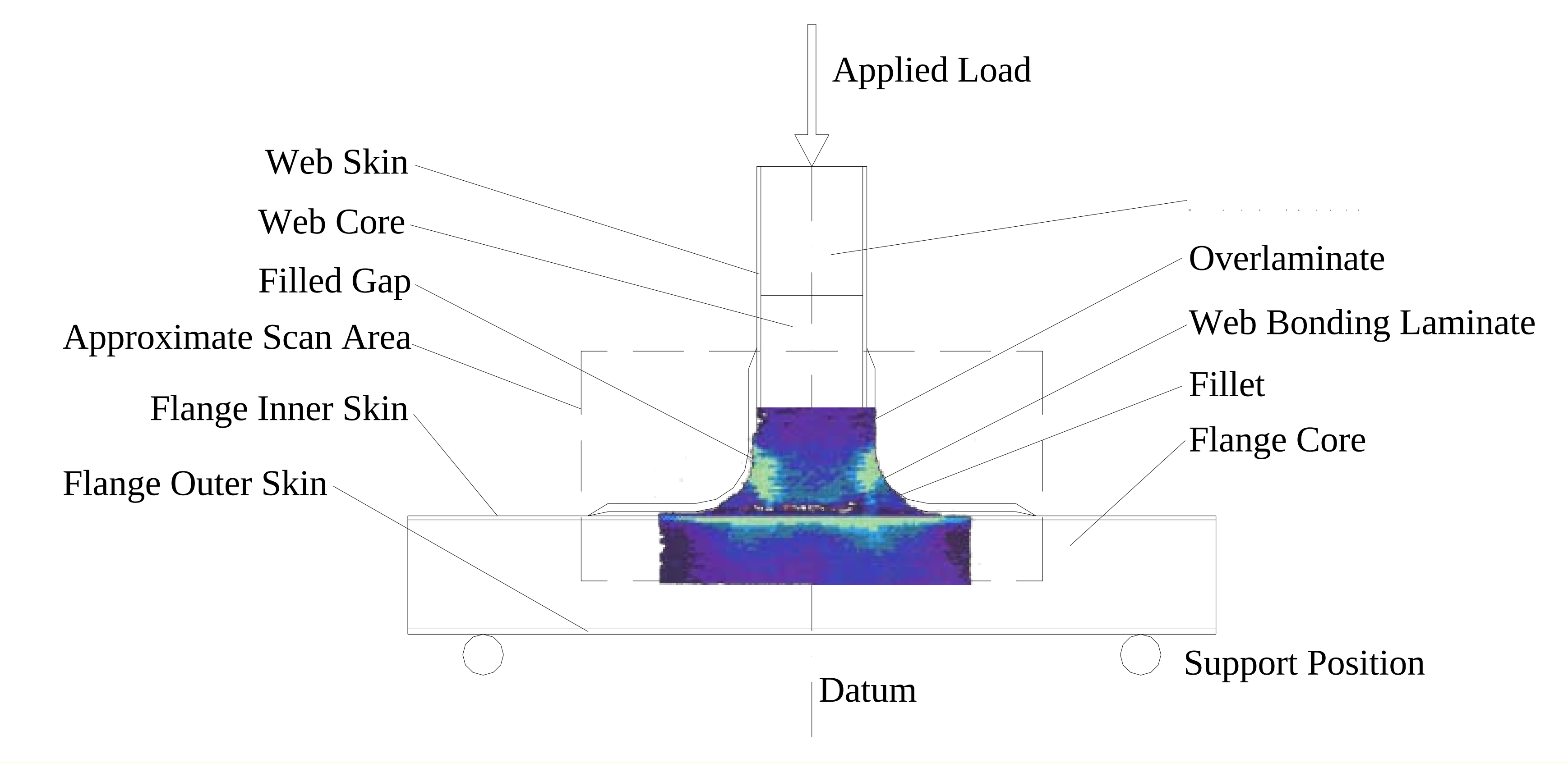


Sandwich tee joints-dry



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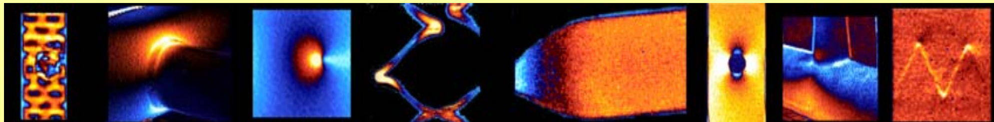
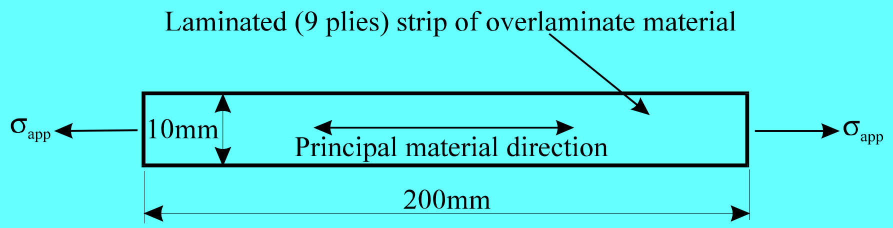
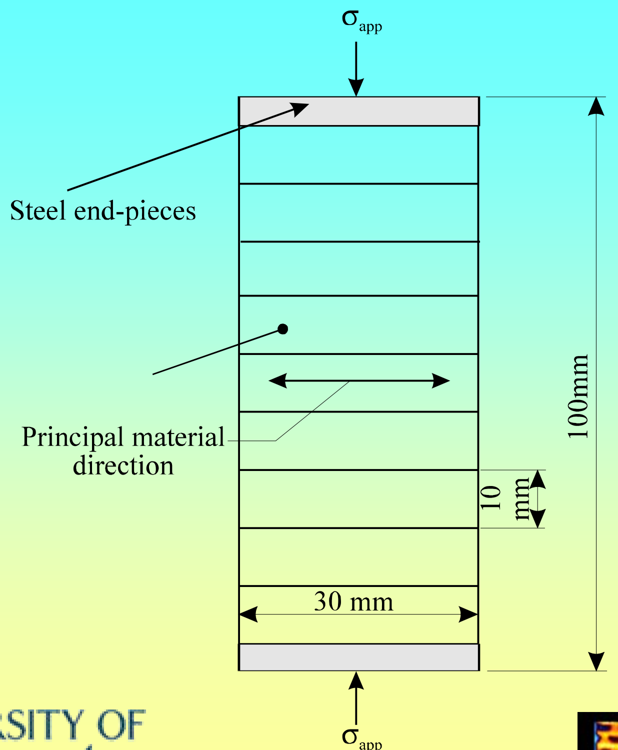


Calibration of overlaminate



$$A^{**} = \frac{\Delta\sigma_{app}}{S}$$



$$\alpha^{*} = \frac{A^{**} S}{\Delta\sigma_{app}}$$

$A^{**} = 16.03 \times 10^{-3}$ MPa U^{-1} (14%)

$\alpha = 1.61$ (11%)

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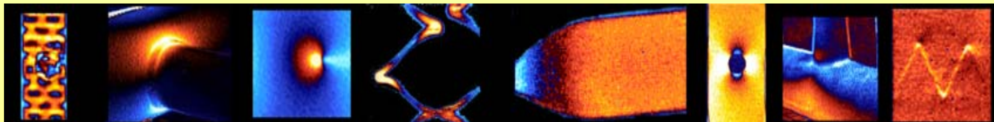

Calibration of foam

Quasi-isotropic so a tensile specimen was made from the foam and SPATE readings taken so that

$$A = \frac{\Delta\sigma_{app}}{S}$$

$A = 7.07 \times 10^{-4}$ MPa U^{-1} for the flange
$A = 2.89 \times 10^{-4}$ MPa U^{-1} for the web

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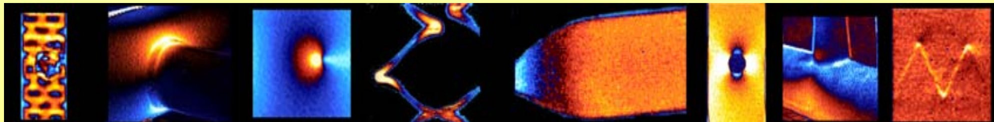
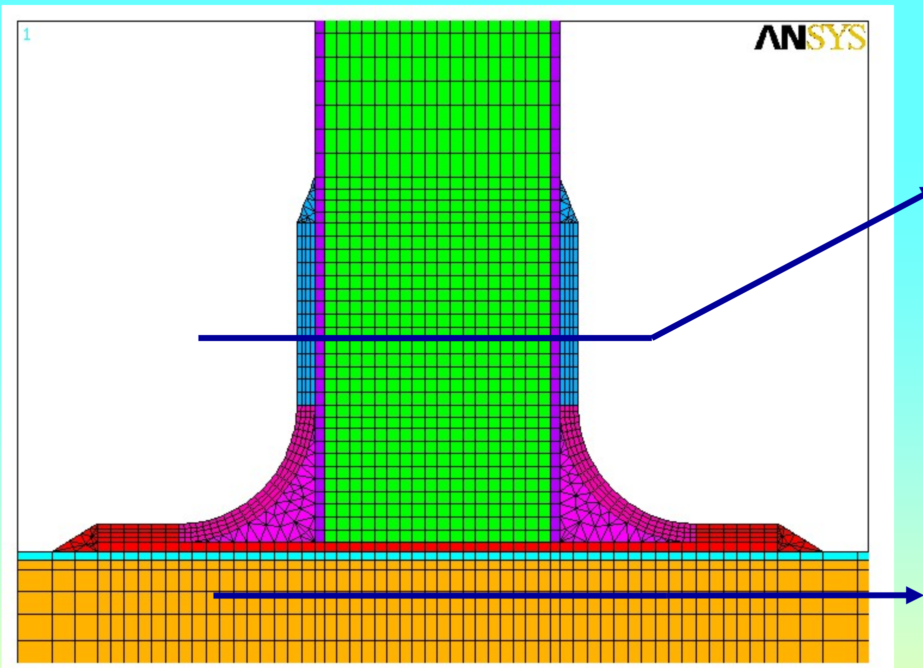
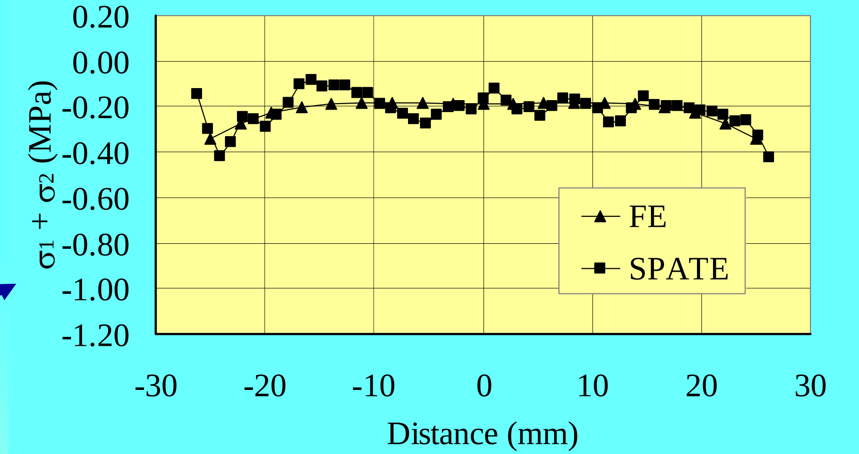
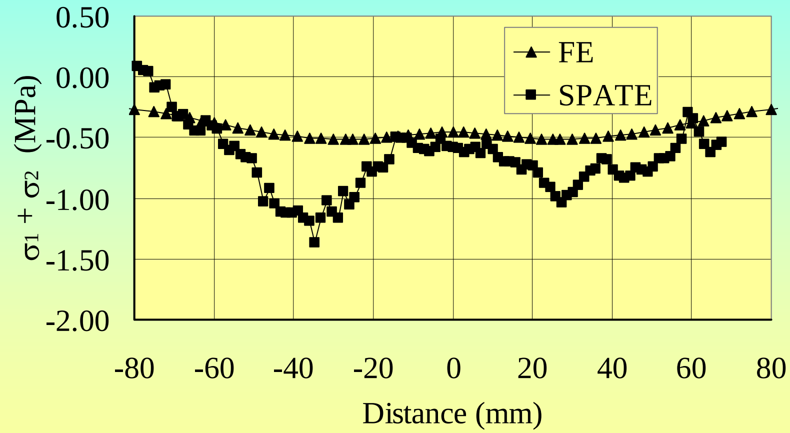


FEA validation







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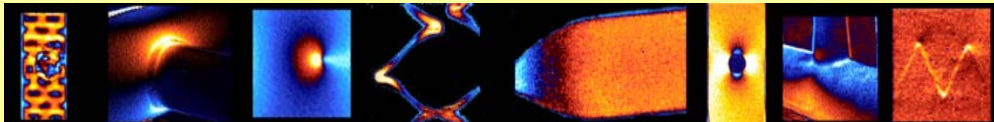
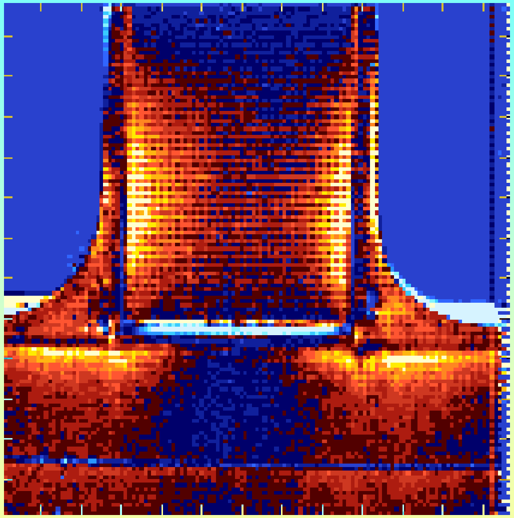
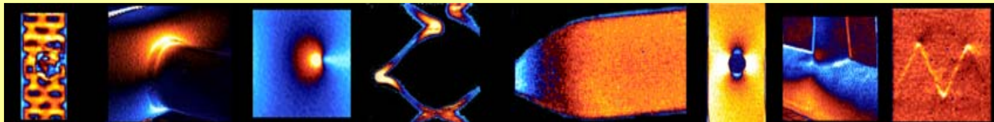


Tee-joints-aged

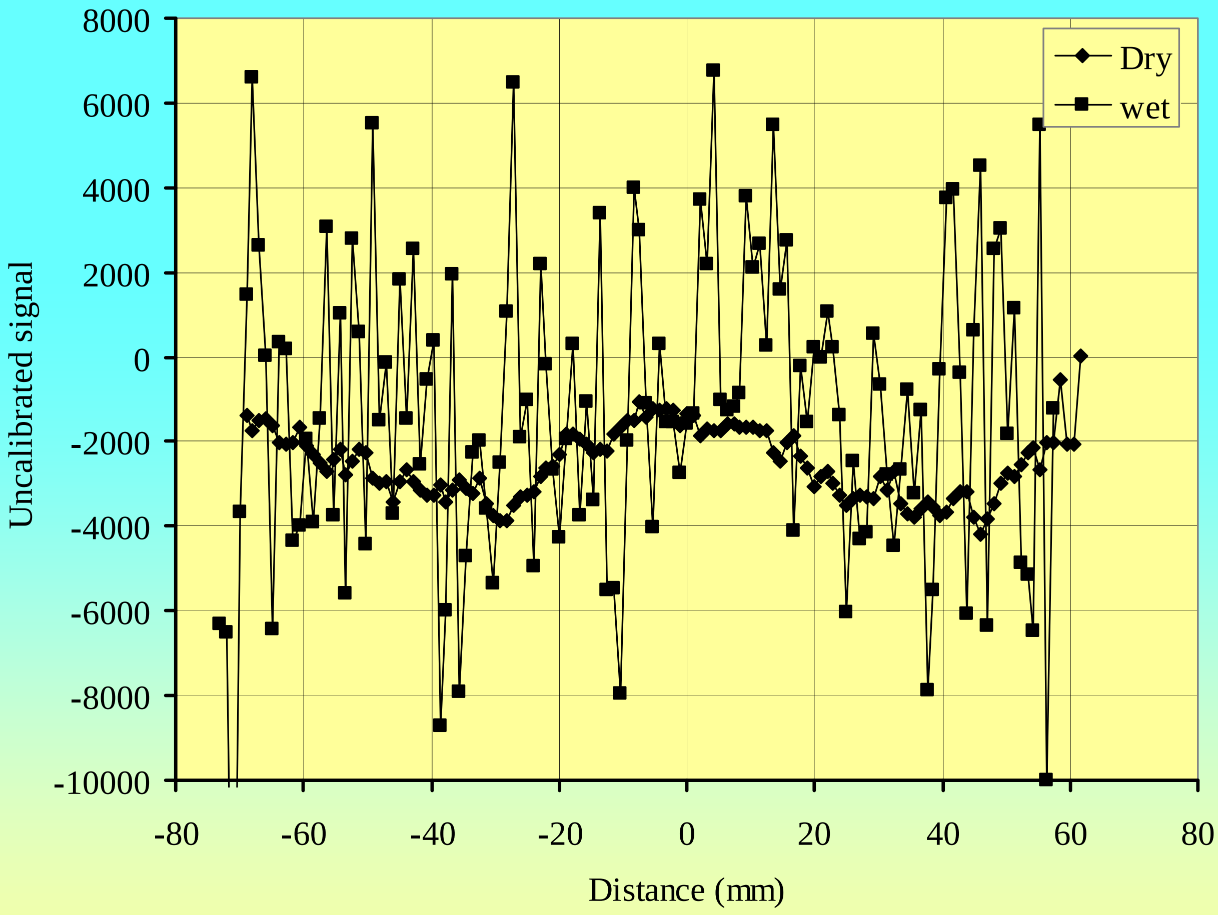
Thermoelastic tests

- Specimens removed from chamber twice
- After 60 days and then after 144 days
- Loaded to 6.4 kN ± 3.4 kN at 8 Hz
- Readings taken every 30 minutes
- No paint
- 2 hours before reasonable results could be obtained





Comparison between wet and dry surface



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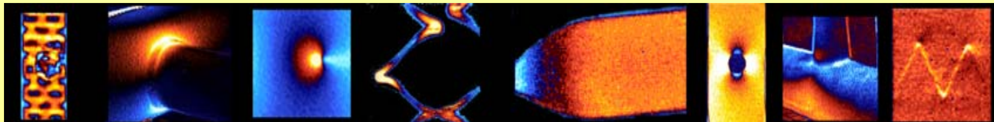
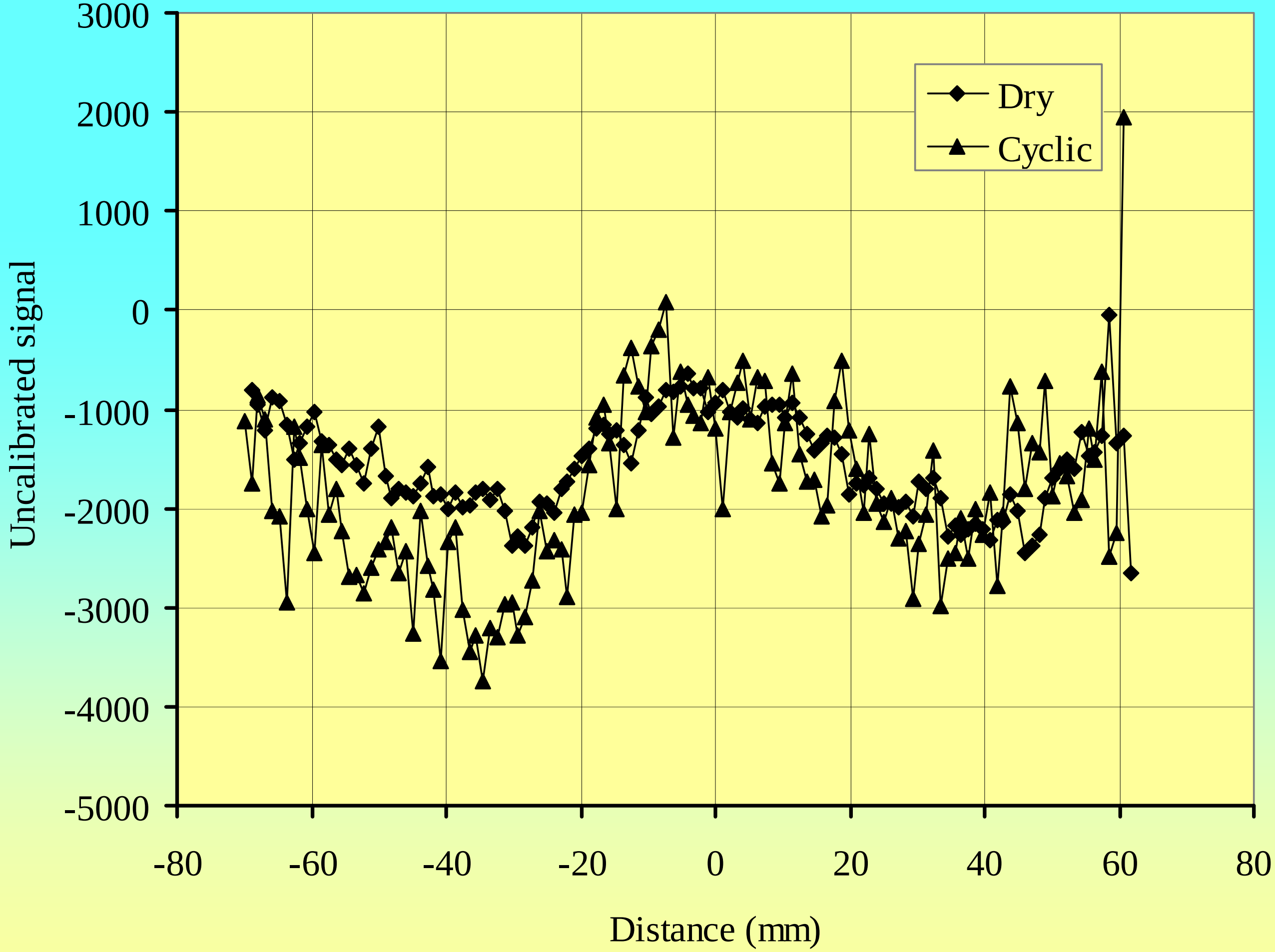


Comparison between dry and cyclically loaded



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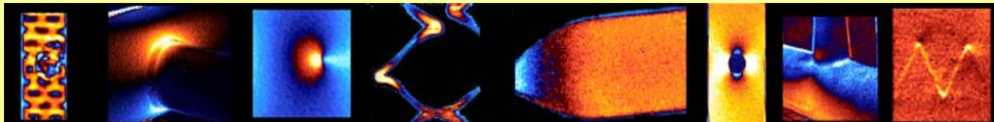
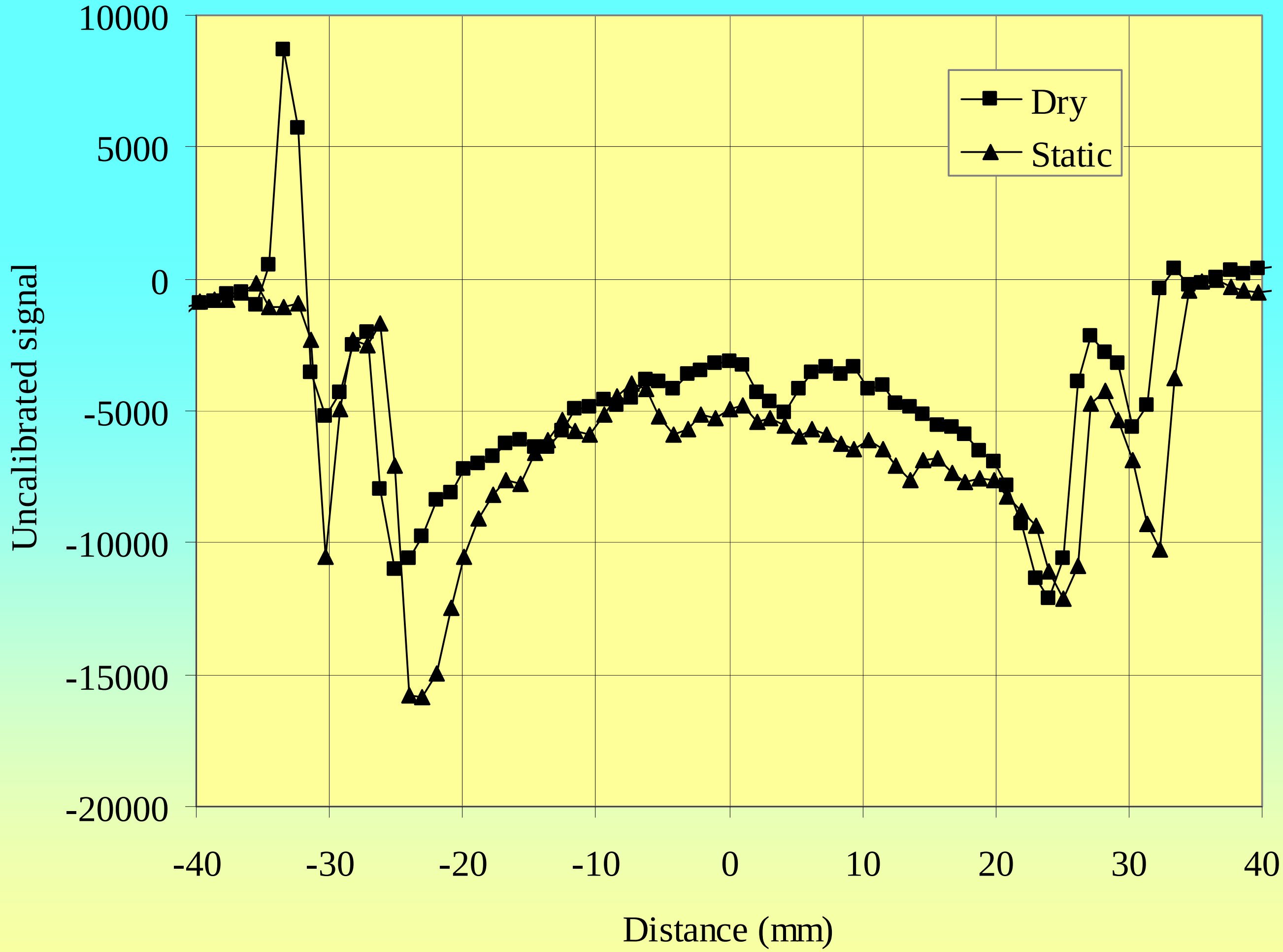


Comparison between dry and statically loaded



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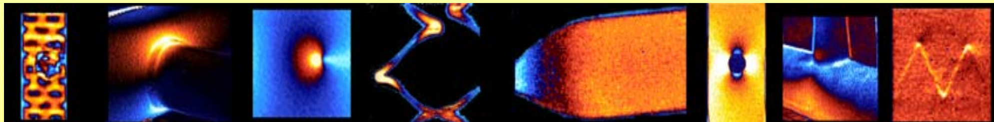
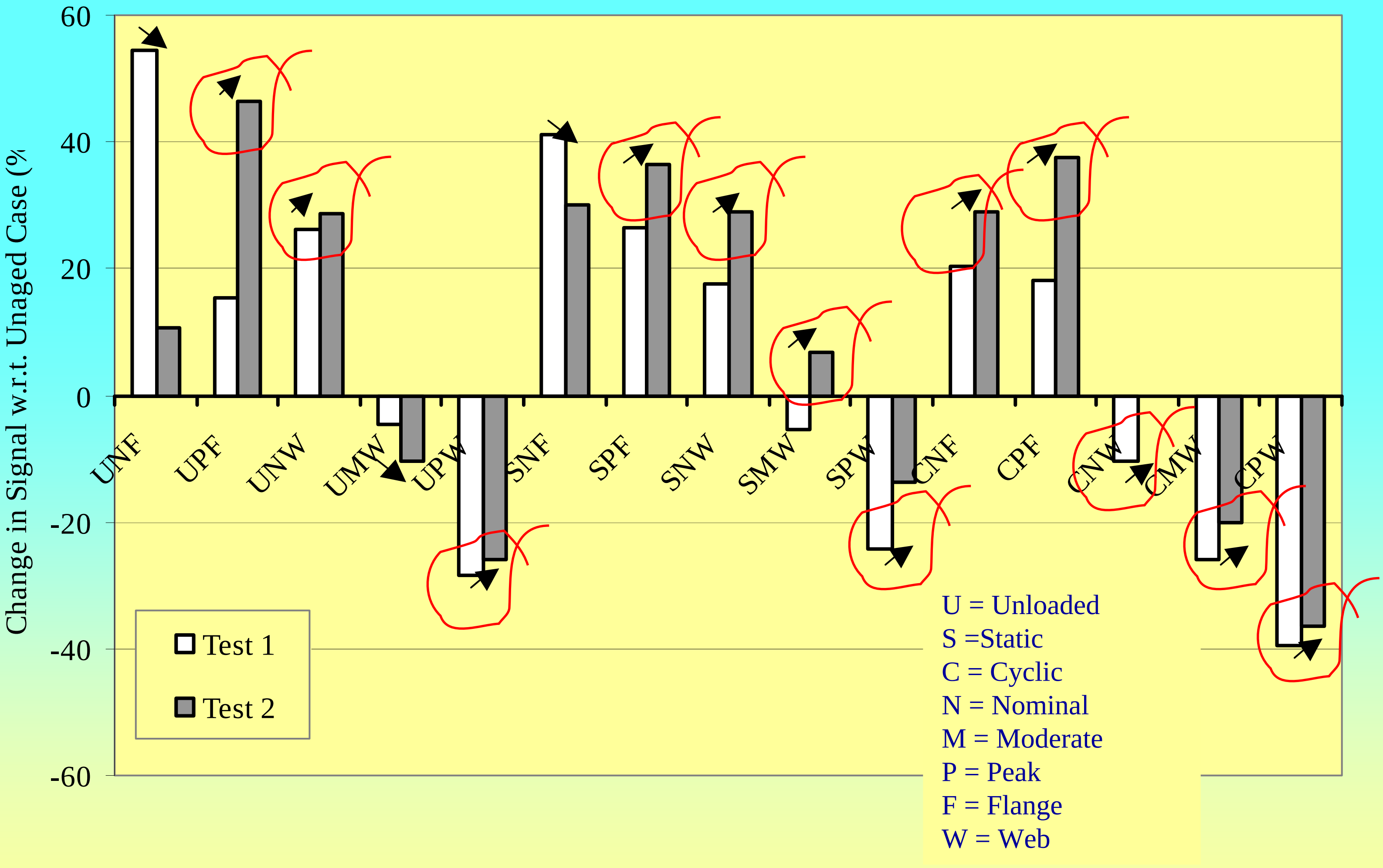


Percentage change due to ageing



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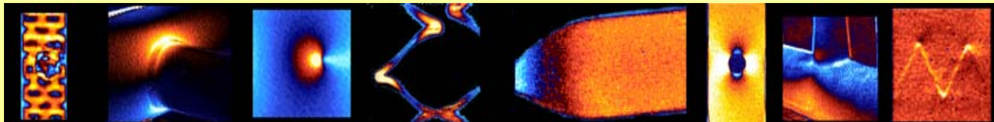
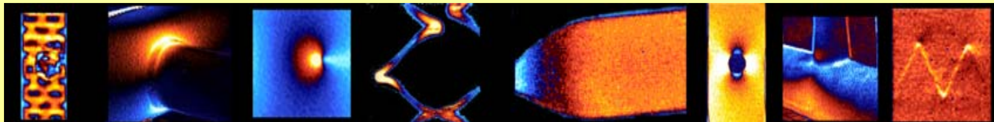


Changes in signal

- Greater rate of degradation in the face sheets than the core;
- Postcure of the materials due to elevated temperature exposure;
- Recovery or improvement of properties after exposure and re-drying;
- Aged material performing as a compliant surface layer on an unaged substrate;
- Changes in the material properties as a result of plasticisation.



Damage simulation-coupons

- Environmental ageing represented by 2yr. immersion in distilled water (fresh more aggressive than sea).
- Ageing accelerated with temperature 60°C (ASTM F1980-99).
- C70.130 & R63.140 foams used in final investigation.
- Ageing characterised by gravimetric, mechanical testing & microscopy
- Localised impending damage represented by edge crack. Initial slit inserted with scalpel & crack-tip grown until a/w=0.5
- In-service complex loading represented by mixed-mode loading of edge-crack from pure mode 1 (0°) to pure mode 2 (90°).

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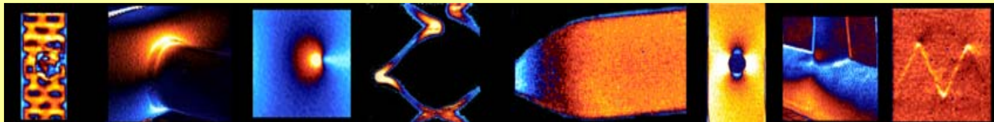
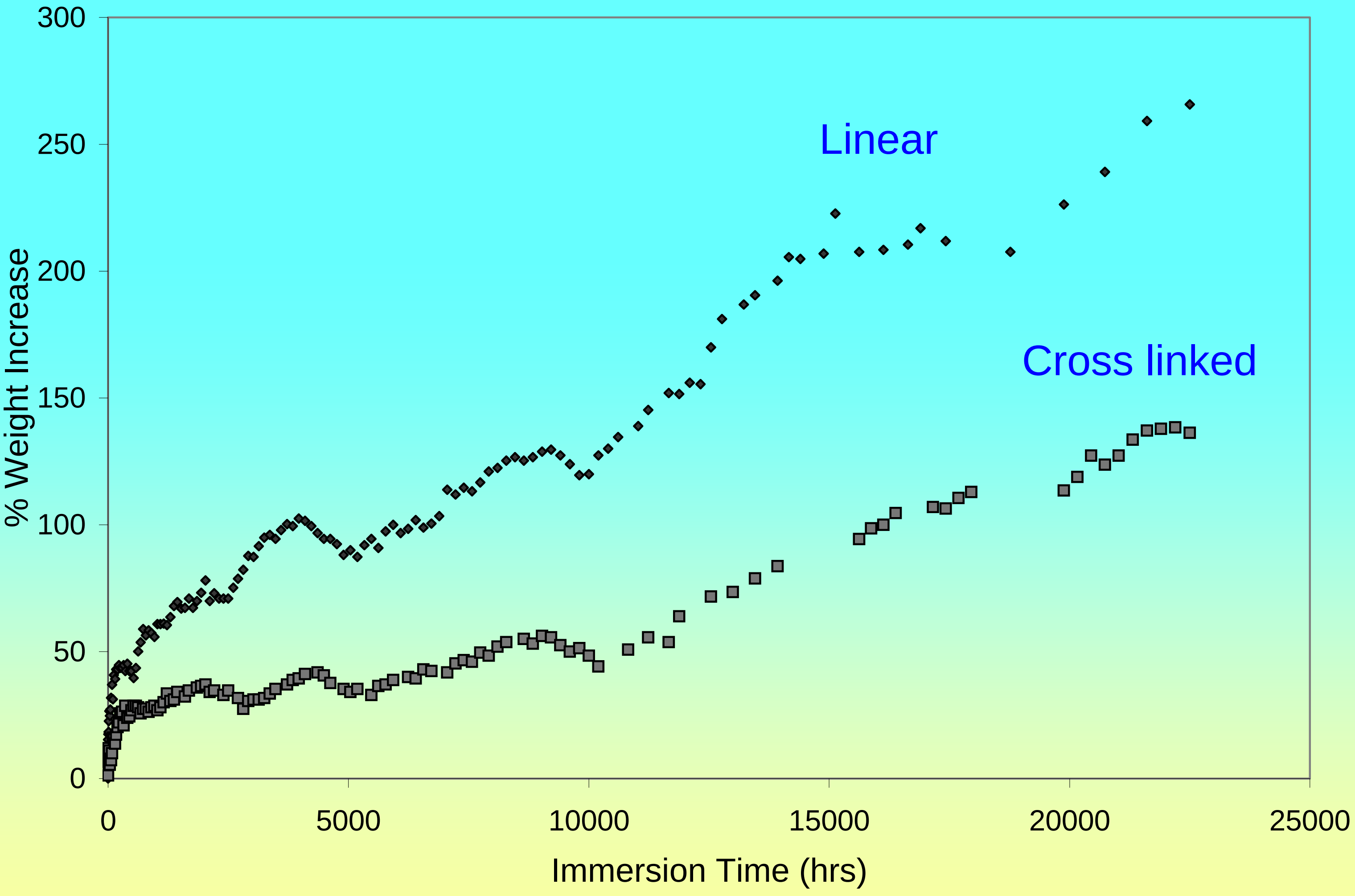
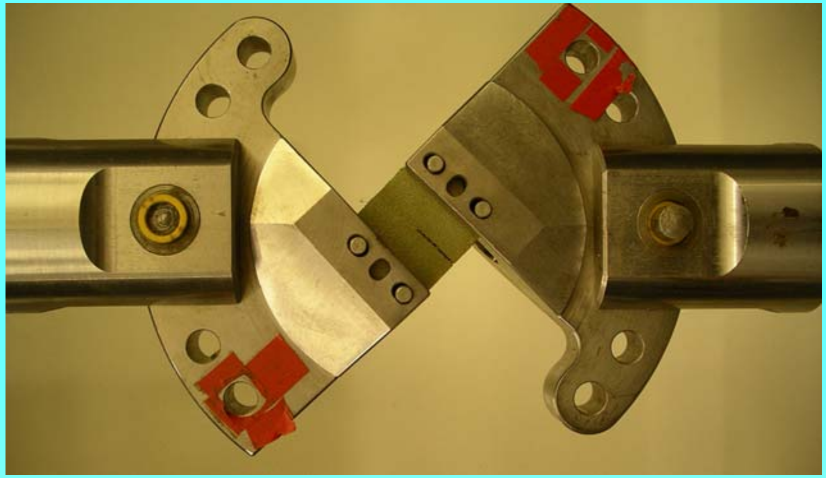


Moisture Uptake



Mixed-Mode Fracture Toughness



	Unaged C70K_{IC}	Unaged C70K_{IIC}	Aged C70 K_{IC}	Aged C70 K_{IIC}	Unaged R63 K_{IC}	Unaged R63K_{IIC}	Aged R63 K_{IC}	Aged R63 K_{IIC}
0	0.281	0	0.217	0	0.177	0	0.062	0
10	0.255	0.031	0.193	0.022	0.162	0.015	0.051	0.0047
30	0.227	0.063	0.174	0.04	0.143	0.04	0.046	0.013
45	0.167	0.074	0.128	0.054	0.105	0.047	0.036	0.016
60	0.102	0.086	0.078	0.06	0.064	0.055	0.024	0.018
80	0.058	0.116	0.043	0.081	0.026	0.084	0.016	0.025
90	0	0.144	0	0.095	0	0.116	0	0.034

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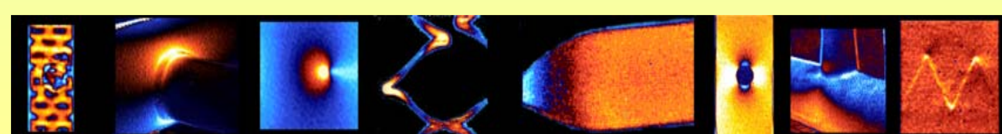
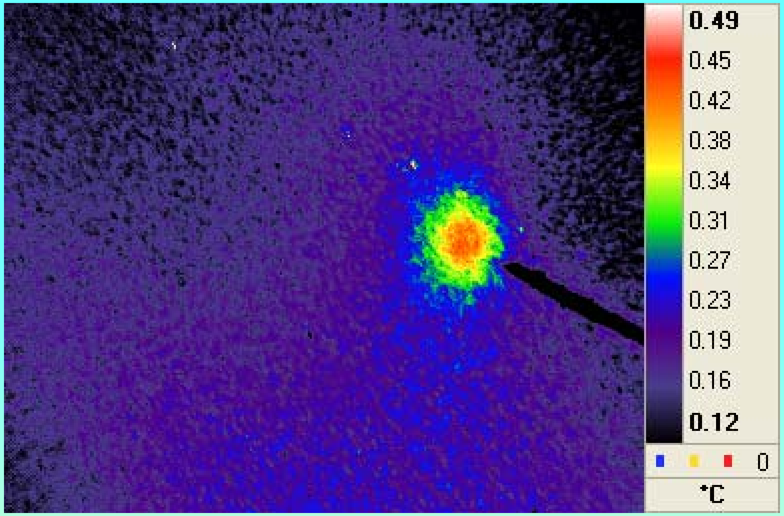


Thermoelastic Stress Analysis



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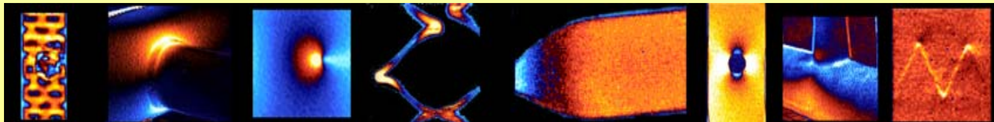
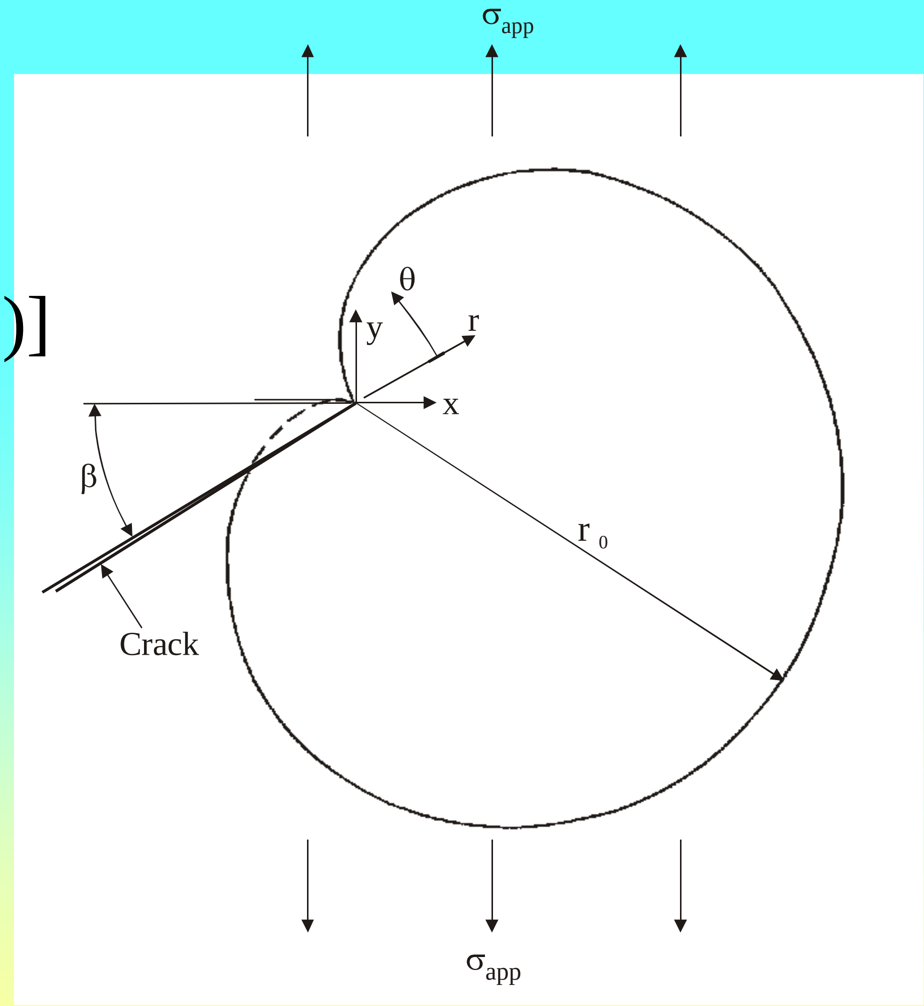


Derivation of SIFs from TSA

$$r = \frac{K_1^2 + K_2^2}{\pi A^2 (S + S_0)^2}[1 + \cos(\theta + 2\phi)]$$

$$\tan^{-1}\phi = K_2 / K_1$$



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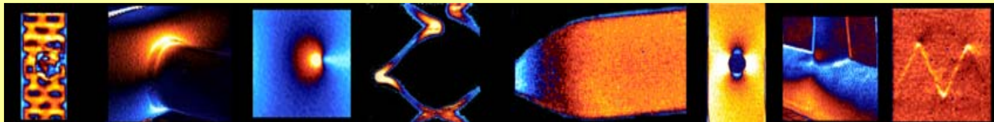
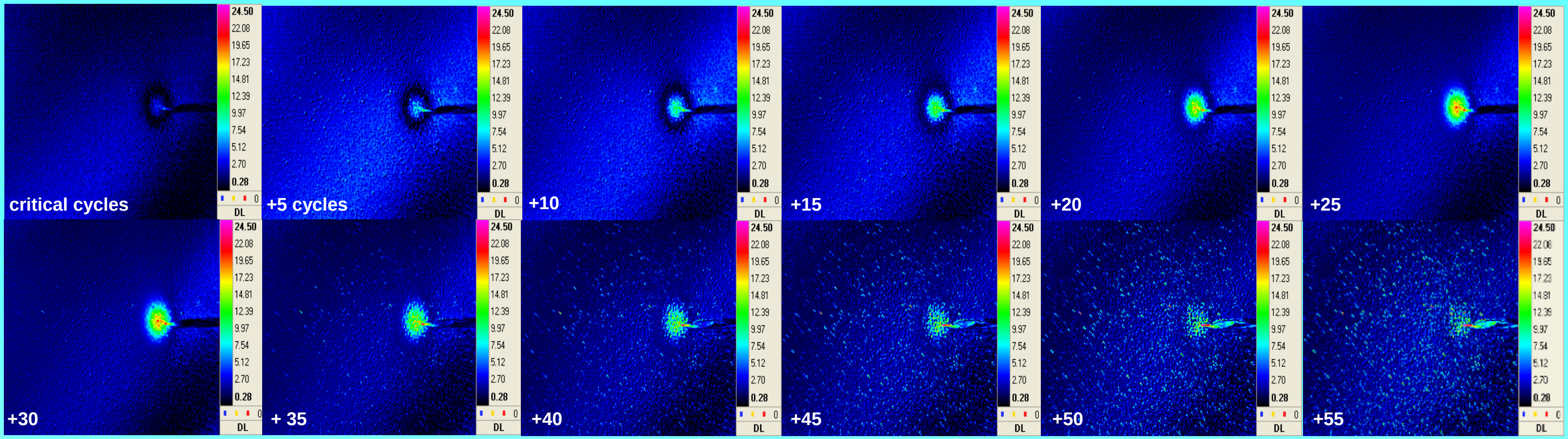
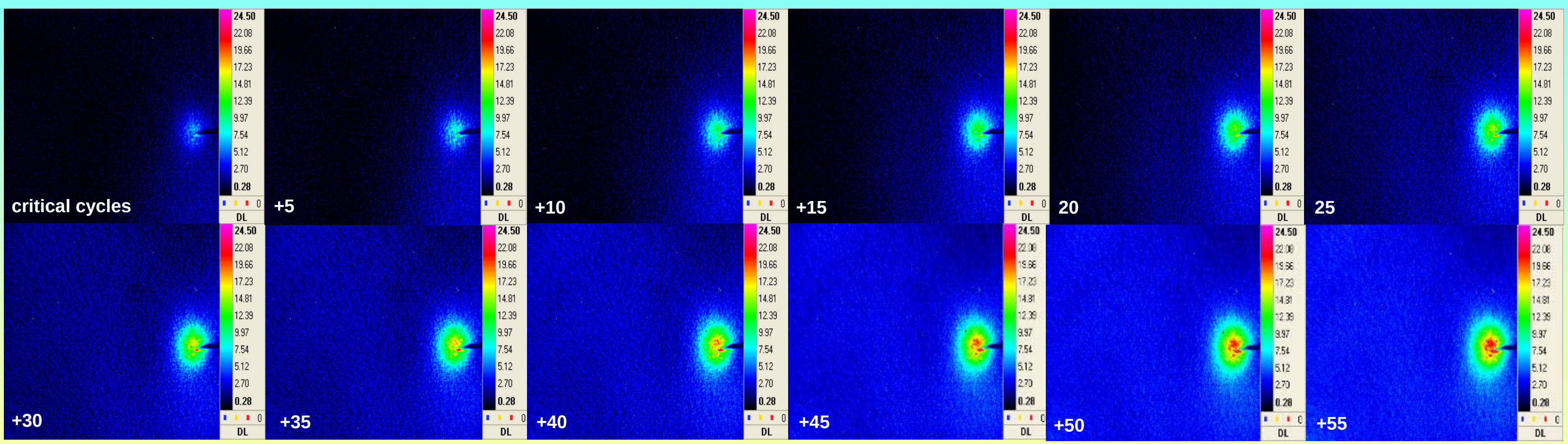


TSA data from a growing crack





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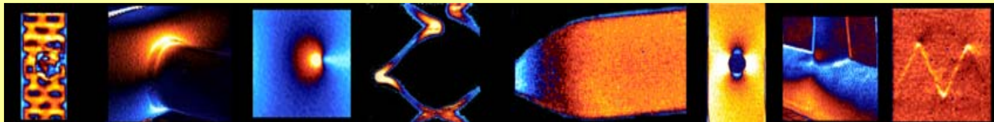

Conclusions

- TSA successful in deriving stresses from foam cored sandwich structure tee joints
- Hygrothermal ageing study on joints showed trends that could be linked to degradation of face sheets and core materials
- Linear foam is sensitive to temperature and when hygrothermally aged at 60°C will increase in weight almost twice as much a cross-linked foam.
- In the aged state preliminary tests showed a significant drop in fracture toughness caused by embrittlement of the cells for linear foam.
- TSA can be applied to foam materials and the advance of a crack can be monitored in real time but cell morphology can be a source of scatter in results.
- Mode I specimens produced expected cardioid forms.

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