UNIVERSITY OF
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School of Engineering Sciences

Application of Strain Gauge Techniques in the Measurement of the Coefficients of Thermal Expansion

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Summary

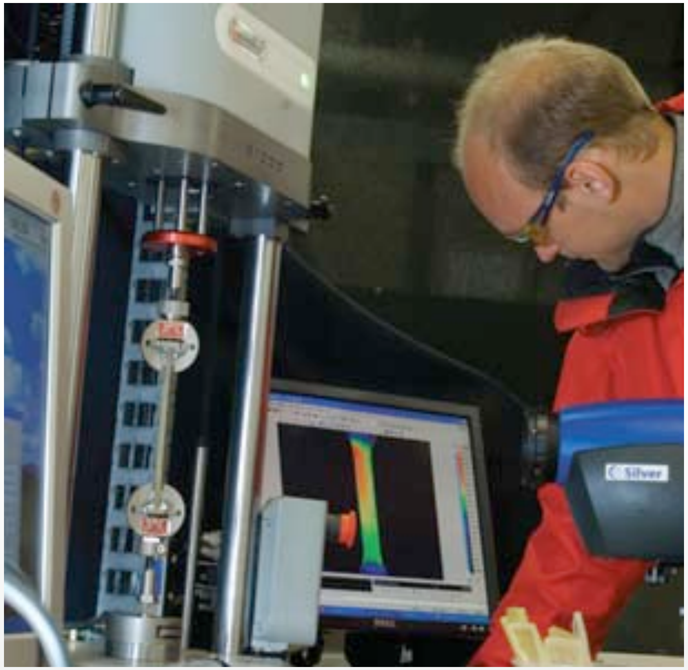
- Why?
- Composite materials
- Importance in experimental mechanics
- Derivation from strain gauges
- Reliability and uncertainty

Motivation

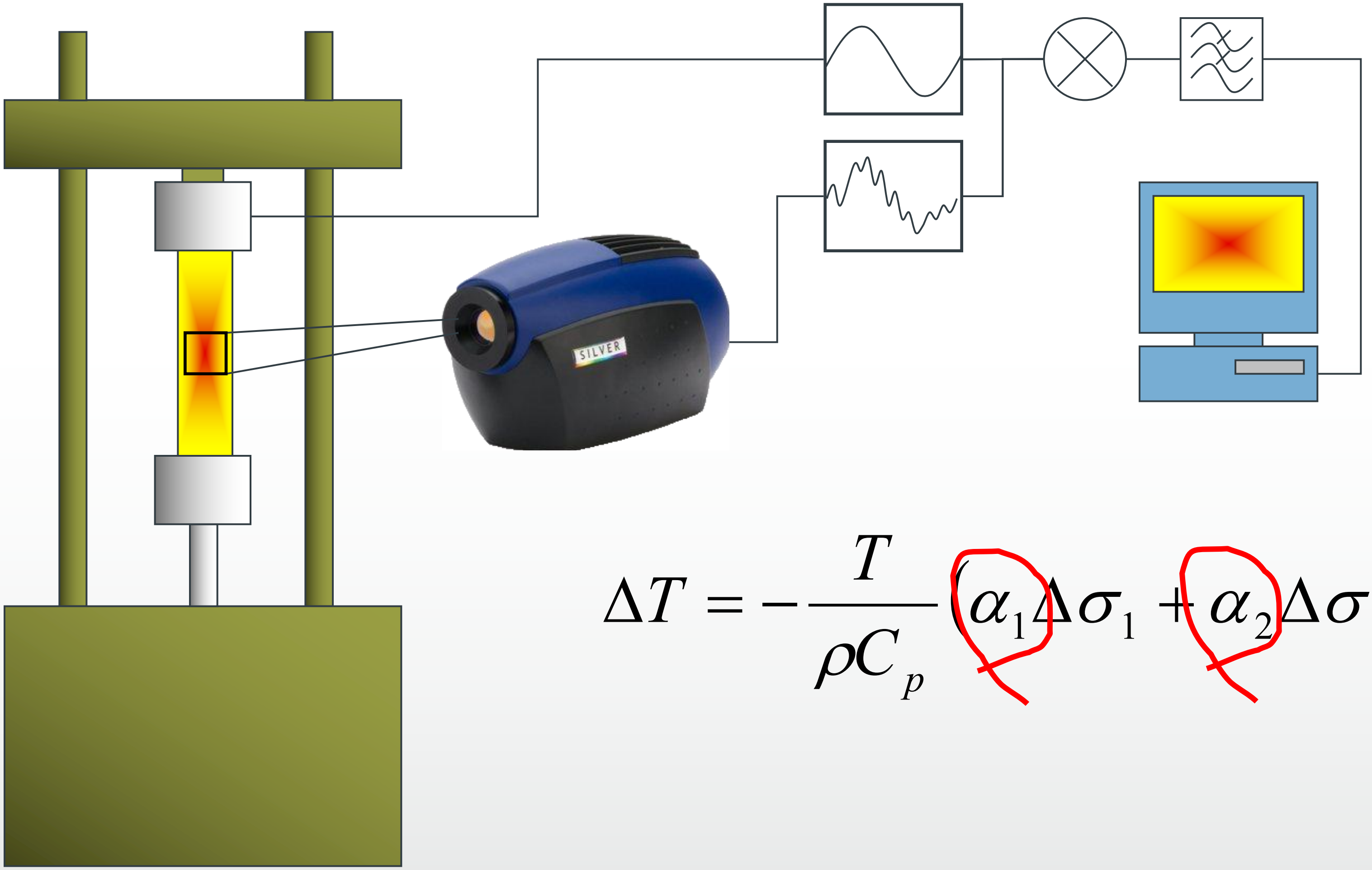
- Accurate derivation –large variations in values in literature for nominally identical materials
- Crucial in understanding the thermal stress conducting work at elevated or varying temperatures
- Particularly important in composite materials – variations depend on manufacturing process etc
- Essential in the interpretation of data from experimental mechanics techniques

Experimental techniques

- Thermoelastic stress analysis (TSA)
- Digital image correlation (DIC)
- Acoustic emission
- Electronic speckle pattern shearing interferometry (ESPSI)
- Optical fibre sensors (FBGs on silica and polymers)

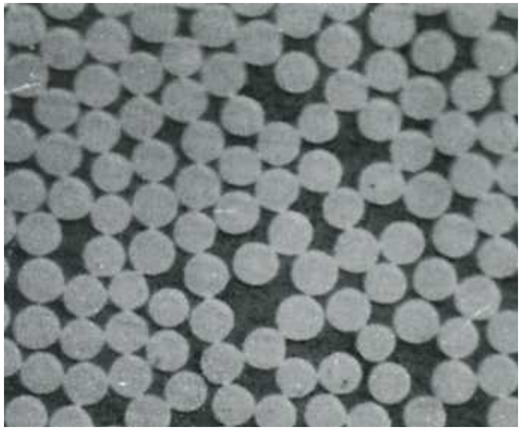


Thermoelastic stress analysis

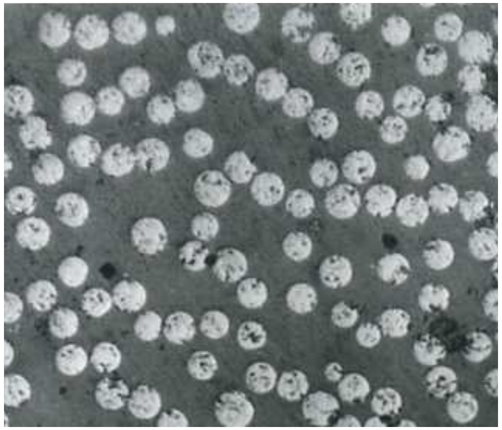


$$\Delta T = -\frac{T}{\rho C_p}\left(\cancel{\alpha_1}\Delta\sigma_1 + \cancel{\alpha_2}\Delta\sigma_2\right)$$

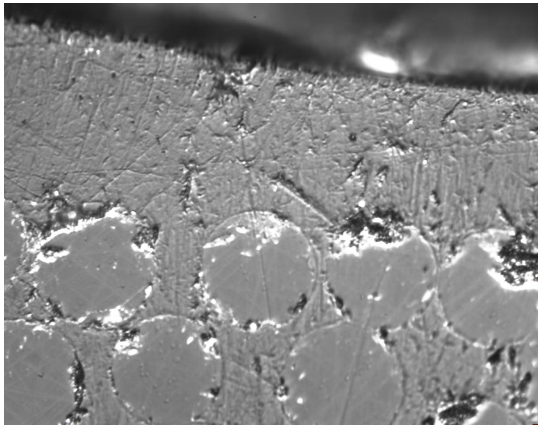
Micrographs of typical composites



Carbon/epoxy 8 μm
$V_f = 70\%$



Silicone carbide/glass 15 μm
$V_f = 40\%$



Glass/epoxy 25 μm
$V_f = 66\%$

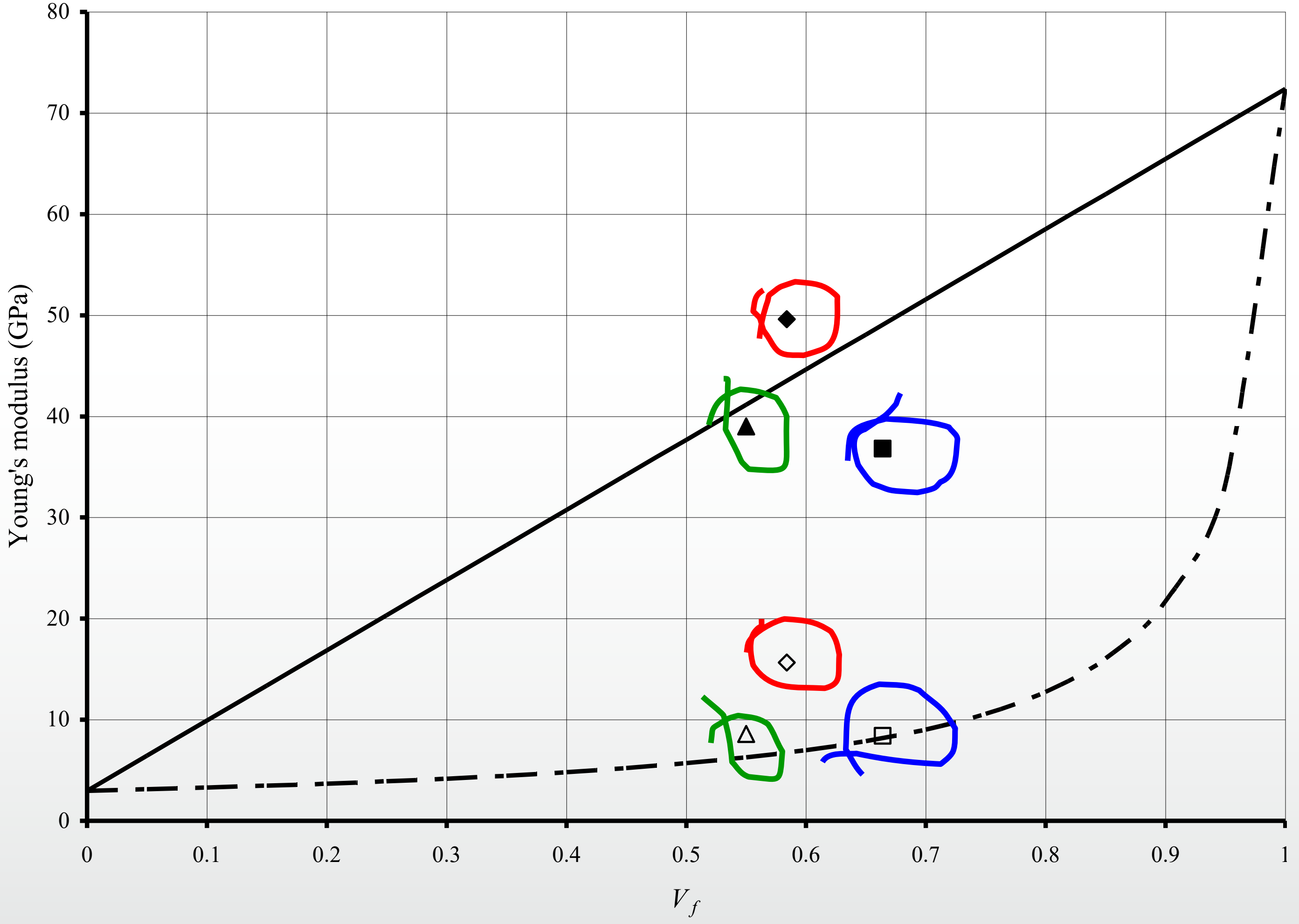
Typical glass and epoxy material properties

	Young's Modulus (GPa)	Poisson's Ratio
Fibre	72.4	0.20
Matrix	2.97	0.44

$$E_1 = E_{1f} V_f + E_m \left(1 - V_f\right)$$

$$\nu_{12} = \nu_{12f} V_f + \nu_m \left(1 - V_f\right)$$

Young’s modulus



Oven consolidated pre-preg Emery et al Comp Sci Tech 2008

Vacuum infused Fruehmann et al JSA 2008

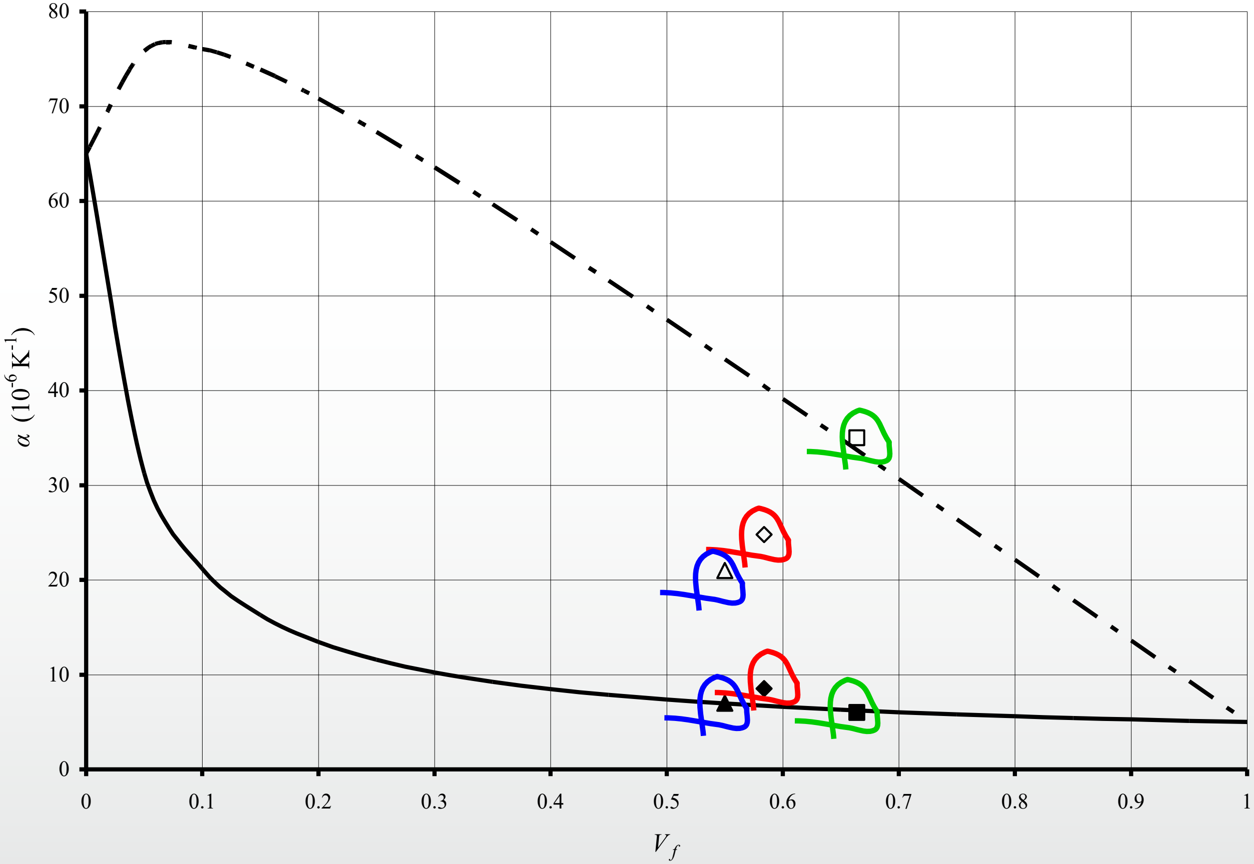
Daniel and Ishai 1994

Coefficients of thermal expansion α_1 and α_2

$$\alpha_1 = \frac{\alpha_f E_f V_f + \alpha_r E_r \left(1 - V_f\right)}{E_f V_f + E_r \left(1 - V_f\right)}$$

$$\alpha_2 = \alpha_f \left(1 + \nu_f\right) V_f + \alpha_r \left(1 + \nu_r\right)\left(1 - V_f\right) - \alpha_1 \nu_{12}$$

Coefficient of thermal expansion

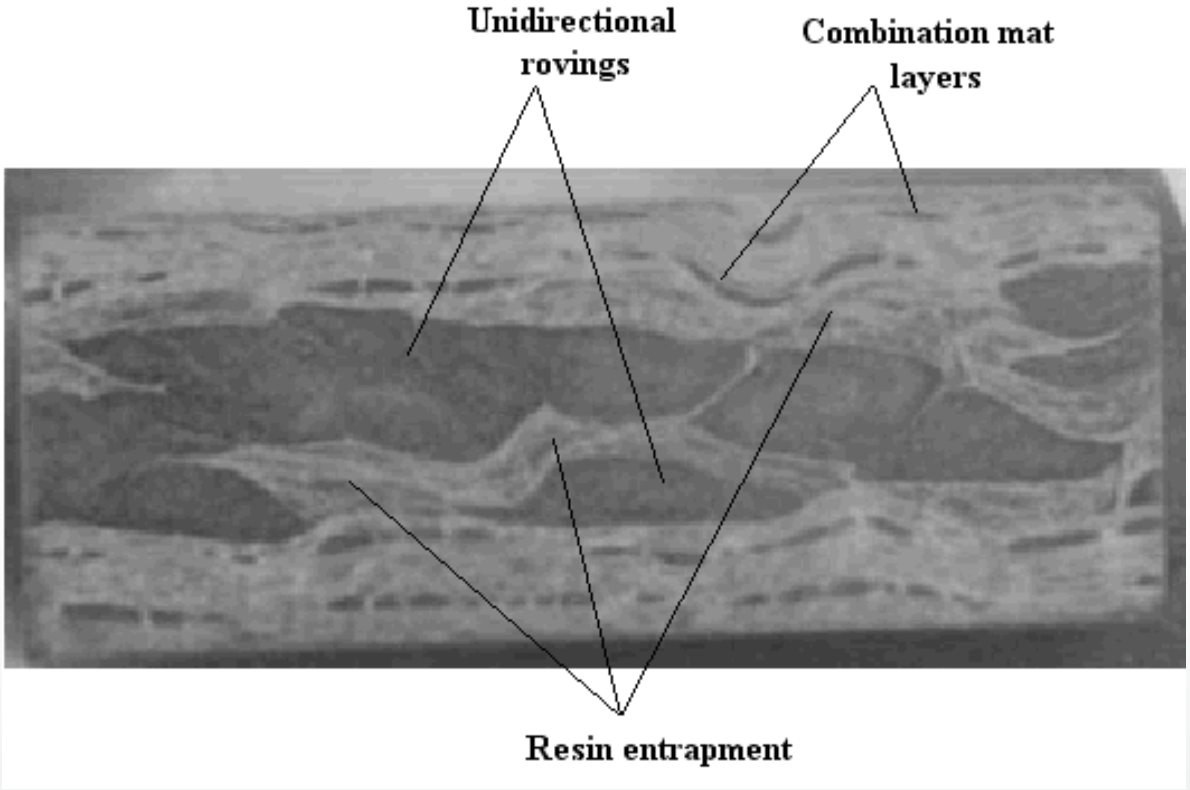


Harwood and Cummings 1991

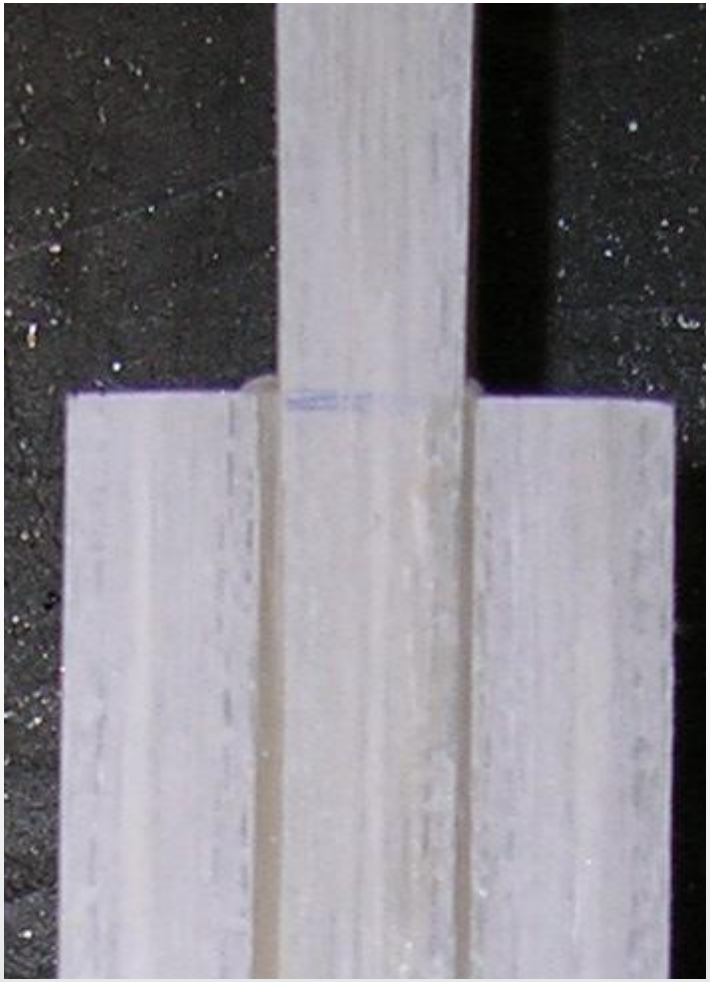
Vacuum infused Fruehmann et al JSA 2008

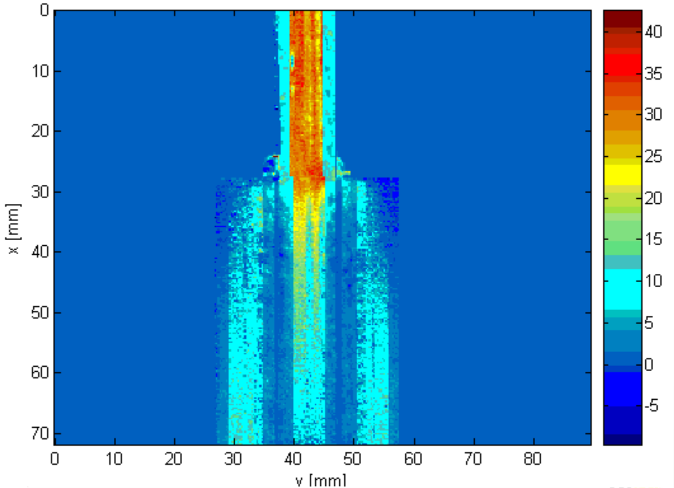
Daniel and Ishai 1994

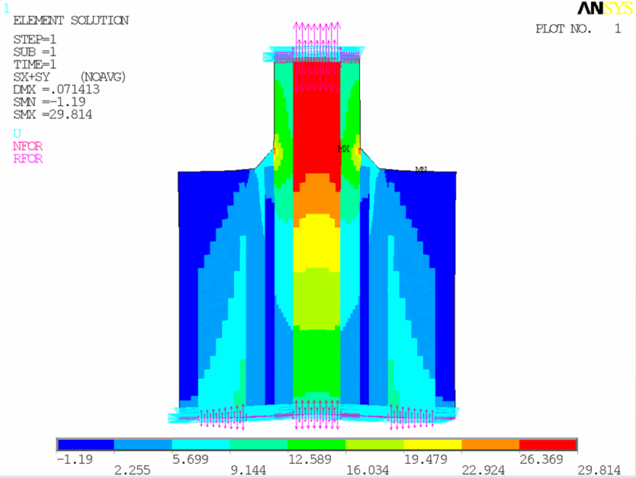
Putruded materials



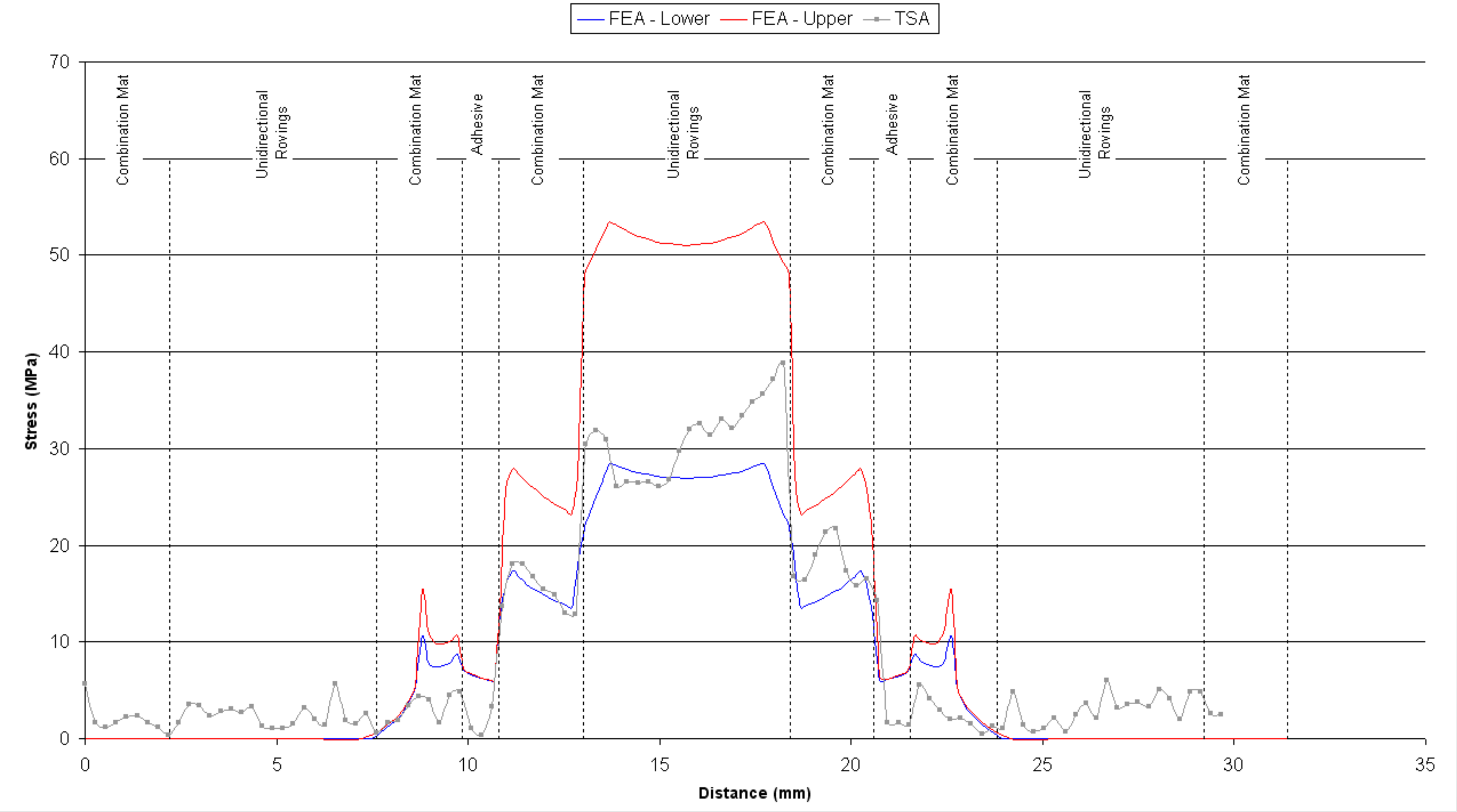
Comparison of FEA and TSA



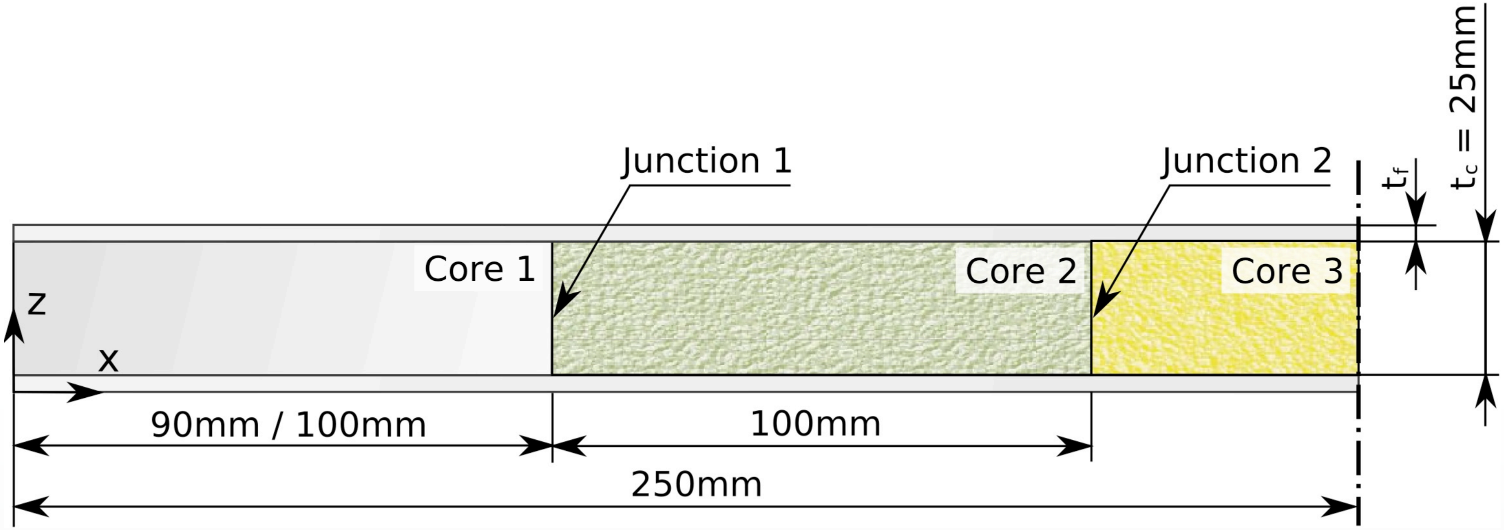




Comparison between FEA and TSA



Sandwich structures and core junctions



Type	Face Material	t_f [mm]	width [mm]	Core Material 1	Core Material 2	Core Material 3
1	Aluminium alloy	1.0	45.6	Aluminium alloy	Rohacell 51WF	Rohacell 200WF
2	PMMA	1.5	47.2	PMMA	Dynathane 1000	Rohacell 51WF
3	GFRP-CSM	1.2	46.8	PMMA	Dynathane 1000	Rohacell 51WF
4	GFRP-NCF	2.8	49.0	Aluminium alloy	Rohacell 51WF	Rohacell 200WF

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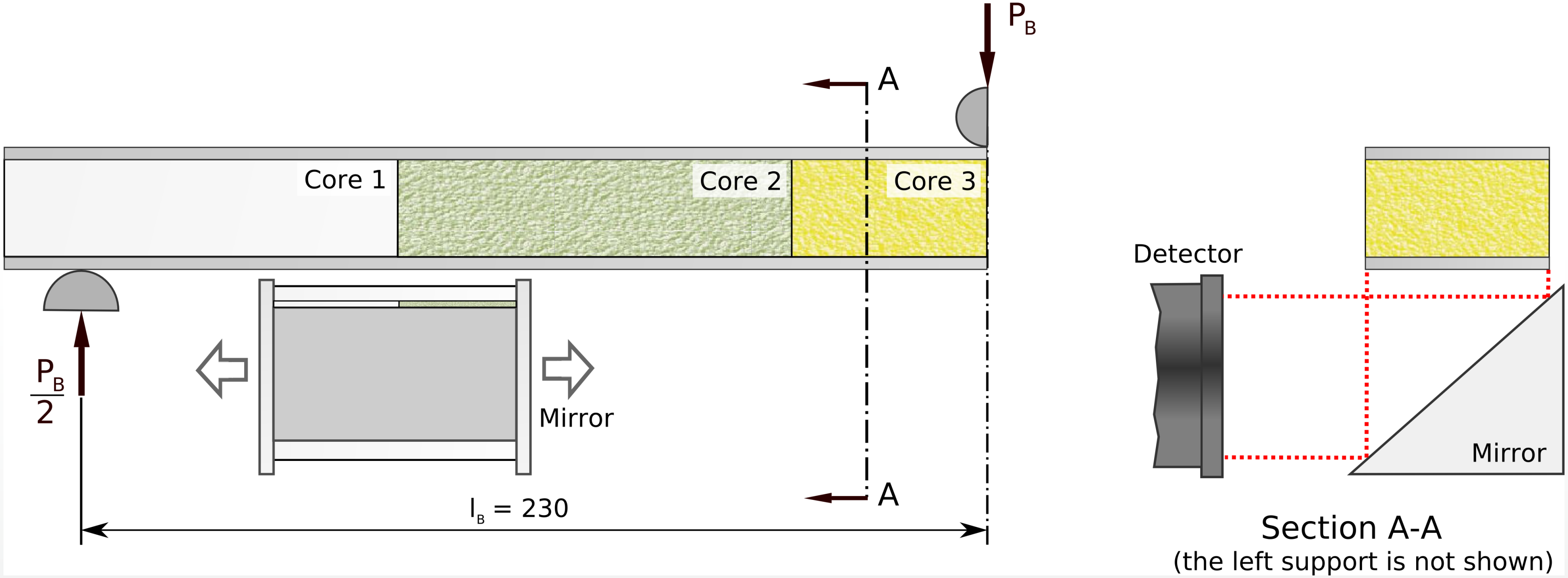
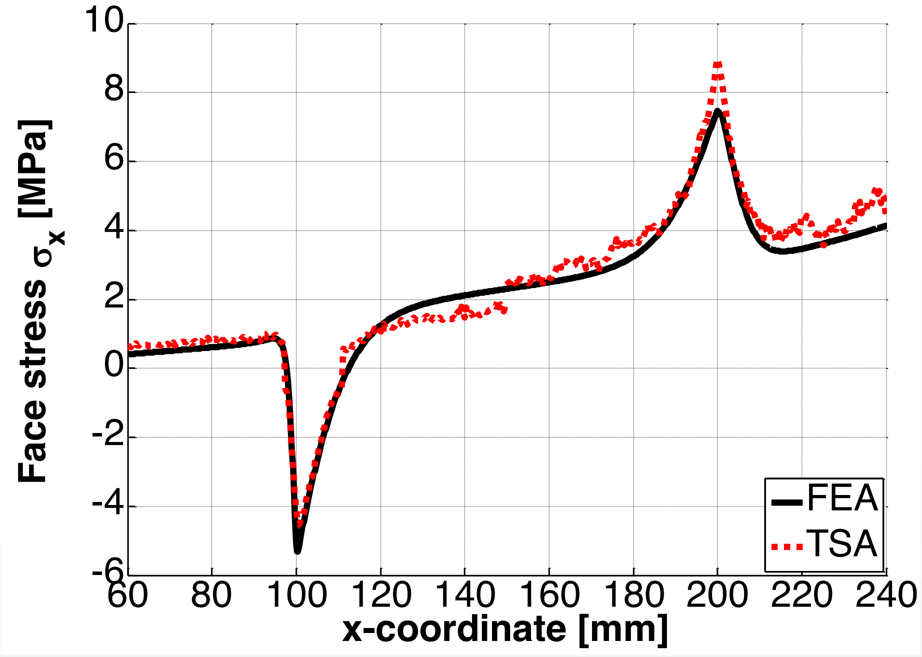
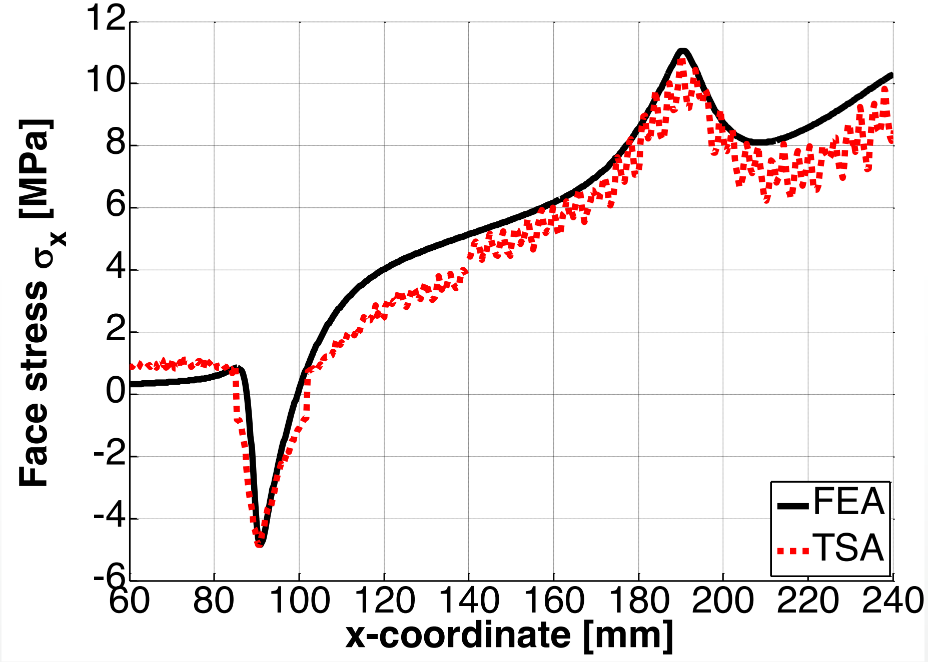
Loading configuration



Section A-A
(the left support is not shown)

Stresses in face sheets





Principles of measuring the CTE

- Thermal expansion (temperature induced strain) - material response to change in the temperature
- As the thermal strain in the material changes, output of the strain gauges changes accordingly
- Challenge : resistivity of the strain gauge grid changes with temperature, additional resistance change occurs because the expansion of the strain gauge grid alloy
- "The output from the strain gauge is a combination of resistance changes from the material and the grid"

Principles of the technique

- **Solution:** a strain gauge is installed on a specimen (test material) of unknown expansion coefficient $\alpha_{Specimen}$ *and* same type of gauge installed on a standard reference material with a known expansion coefficient $\alpha_{Ρεφερενχε}$

$$\varepsilon_S = \left[\frac{\beta_G}{F_G} + \left(\alpha_s - \alpha_G\right)\right]\Delta T$$

Specimen

$$\varepsilon_R = \left[\frac{\beta_G}{F_G} + \left(\alpha_R - \alpha_G\right)\right]\Delta T$$

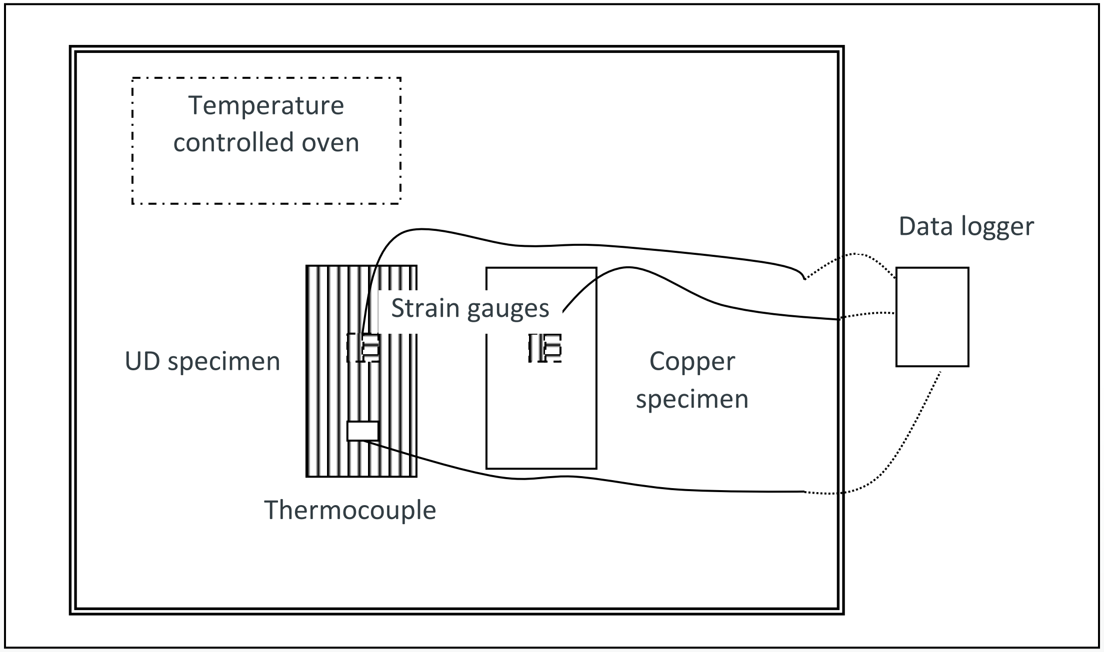
Reference specimen

$$\boxed{\varepsilon_R - \varepsilon_S = \left[\left(\alpha_R - \alpha_S\right)\right]\Delta T}$$

β_G thermal coefficient resistivity of grid material

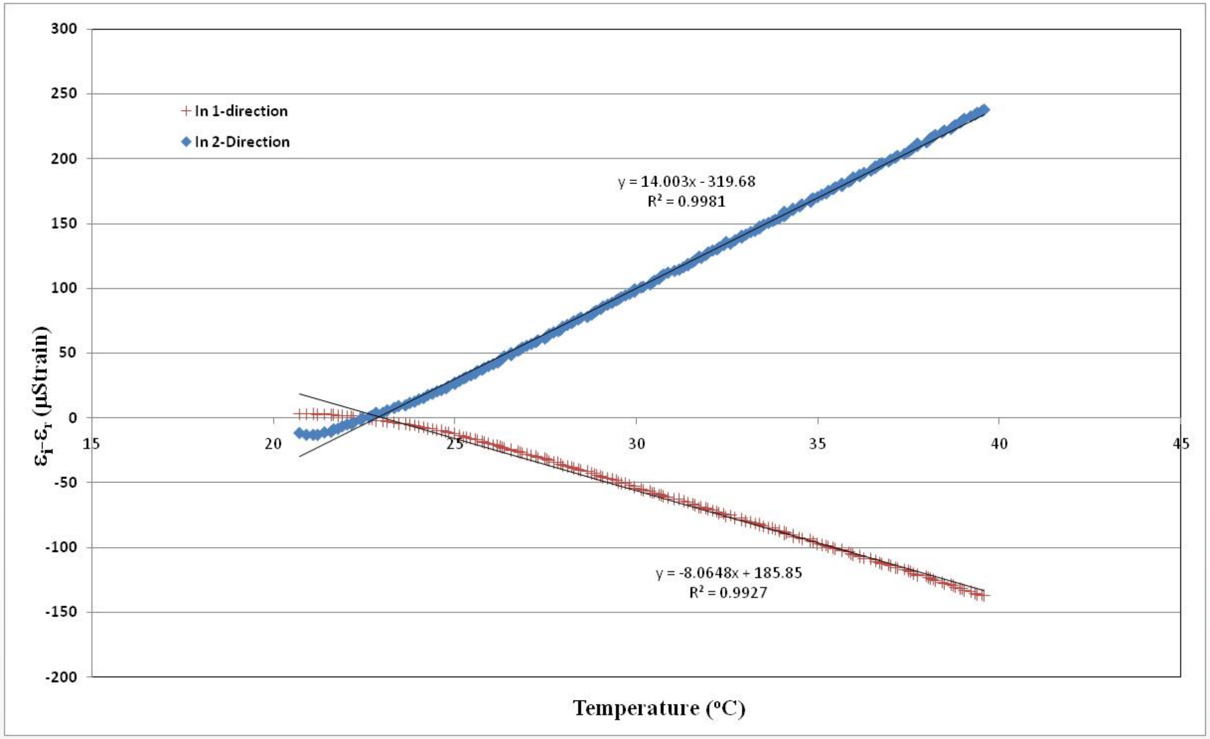
F_G gauge factor of strain gauge

Experimental setup



- Specimens: Unidirectional composite specimen (test specimen), Copper Specimen (reference)
- Type K thermocouple (Sensitivity is approximately 41 µV/° C)
- Data logger : Vishay strain smart system
- Temperature ramp rate : 1°C/Min

Test results



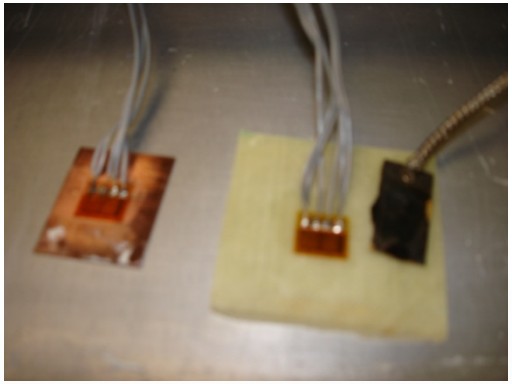
$$\alpha_i = \alpha_{ref} + \frac{\varepsilon_i - \varepsilon_r}{\Delta T}$$

- CTE in the principal material direction of the composite, α_i (i= 1,2) $\alpha_{ref} = 17 \times 10^{-6}/^{o}C$

Thermal expansion of composites

- Comparison of experimental data and external resources

Specimen	α_1 (10^{-6}/°C)	α_2 (10^{-6}/°C)	External data
Epoxy	57 ± 0.13	-	50-60*
Uni-directional	9 ± 0.11	31 ± 0.16	8.6 and 22.1**
Cross Ply	10.59 ± 0.31	-	-
Angle Ply	16.2 ± 0.28	-	-
Quasi-Isotropic	9.25 ± 0.34	-	-



- Strain gauge type: CEA-06-125UT-350
- Error analysis : Copper as a reference material (± 0%), strain gauges (0.1-0.5%), thermocouple type K (± 2.2°C)
- Total experimental error = 5.04%

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* Supplied by Primco (manufacturer)

** Introduction to composite material by Stephen W Tsai and H. Thomas Hann

Conclusions

- Shown that the CTE is an important quantity in stress/strain anlysis
- Demonstrated the variability in CTEs for composite materials
- Shown how this can be measured with reasonable accuracy using a simple set-up and standard strain gauges