European Commission | Horizon 2020 European Union funding for Research & Innovation

The Tony Davies High Voltage Laboratory

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Analysis of through-thickness thermal conductivity of wind turbine blade CFRP materials

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Introduction

Unidirectional CFRP laminates with a fibre volume content of 57% were manufactured using Vacuum Assisted Liquid Resin Infusion in three different thicknesses to assess the measuring capabilities of the apparatus. The through-thickness thermal conductivity was examined by means of a steady-state technique based on the Guarded Hot Plate (GHP) method. By establishing one-dimensional heat flow through the sample and measuring the heat flux the thermal conductivity was determined.

To validate the technique, measurements were conducted in two different materials with well-defined values. PTFE and Fused Silica samples were employed as reference materials. Calibration runs showed good correlation with the expected literature values for both of the reference materials. Consistent results were obtained for all three laminate thicknesses thus validating the efficiency and accuracy of the technique.

Description of apparatus

- Steady-state technique based on the guarded hot plate method
- Direct heat flux readings from a thin film flux sensor, Omega HFS-4
- A screw actuator was utilised to apply 0.28 MPa to improve interface conductance and to promote reproducibility
- Steady-state conditions were achieved with temperature fluctuations were not higher than ±0.5°C for more than 30 min
- Assuming one-dimensional heat flow the thermal conductivity were calculated with the use of eq.1
- A silicone based thermal paste, Electrolube HTSP, was utilised to mitigate the interfacial thermal resistance

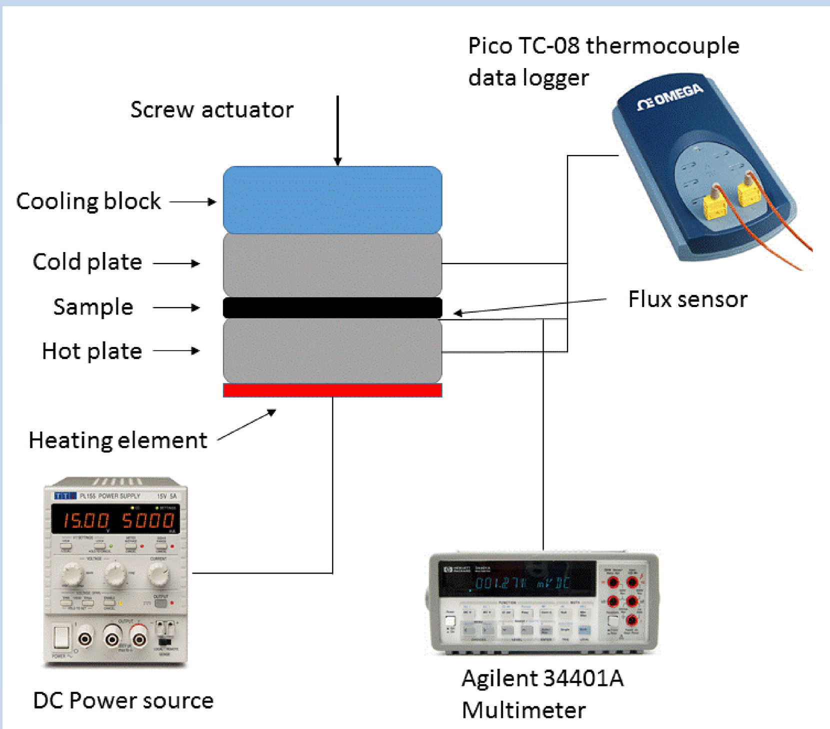

Figure 1: Schematic representation of the apparatus without the insulation

$$q = -k\frac{\Delta T}{\Delta x} \quad \text{Eq.1}$$

Where,

q (W/m^2) is the heat flux,

k (W/mK) is the thermal conductivity and

$\frac{\Delta T}{\Delta x}$ is the temperature gradient over the sample's thickness.

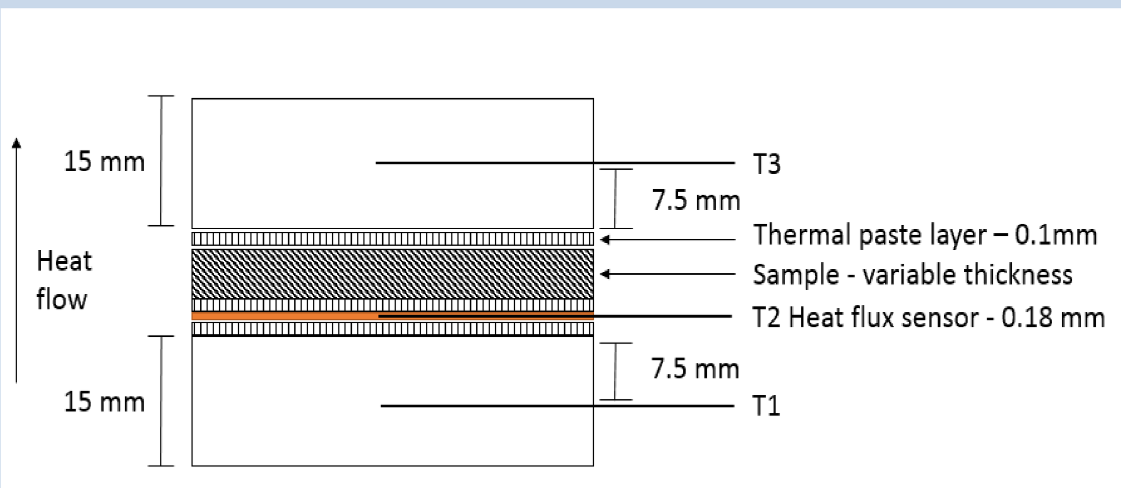

Figure 2: Schematic of the thermal interfaces

Validation of the technique

- Validation of the technique was achieved with Fused Silica (quartz-glass) and PTFE reference materials
- Samples with different thicknesses were tested to estimate the interface conductance and
- Measurements were conducted at q levels of 500 W/m^2 and 1000 W/m^2
- Each sample was tested at least twice

Table 1: Results from the characterization of reference materials

Material	Thermal conductivity (Literature) W/mK	Thermal conductivity (Measured) W/mK	Interface conductance h (W/m²K)
PTFE	0.245 ±0.043	0.277 ±0.0015	754
Fused Silica	1.38 (20°C)	1.428 ±0.05	1234

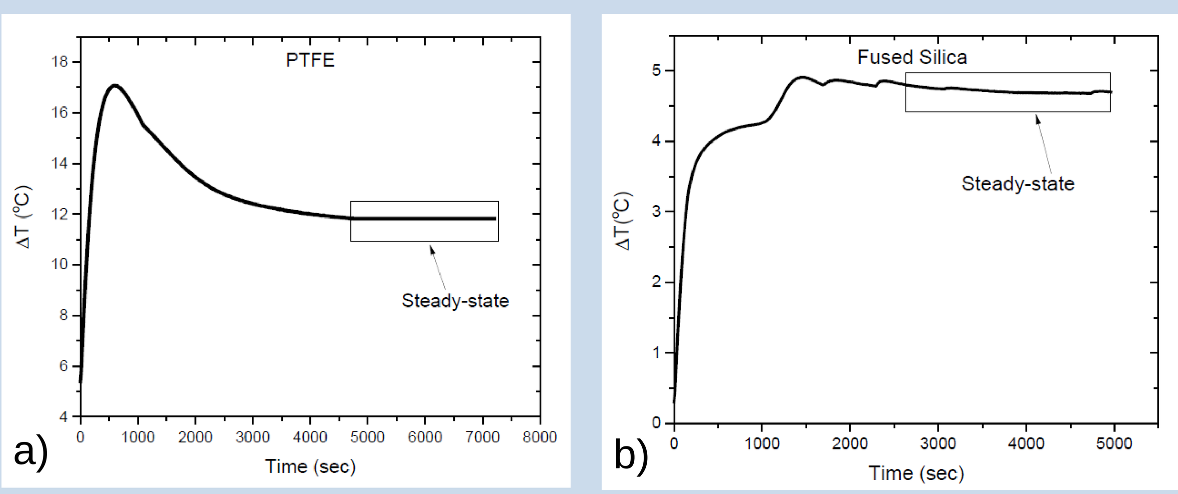

Figure 3: Steady-state plots for a)PTFE and b) Fused Silica reference materials

Sample preparation

- Unidirectional laminates with fibre volume content of 57% were manufactured by means of vacuum infusion
- Materials:
  - Unidirectional non-crimp carbon fabric with an areal weight of 882 gr/m2
  - BASF Baxxores ER5300 epoxy resin and Baxxodur EC 5310 curing agent
- Disk shaped samples with a diameter of 50mm were waterjet cut from the manufactured plates

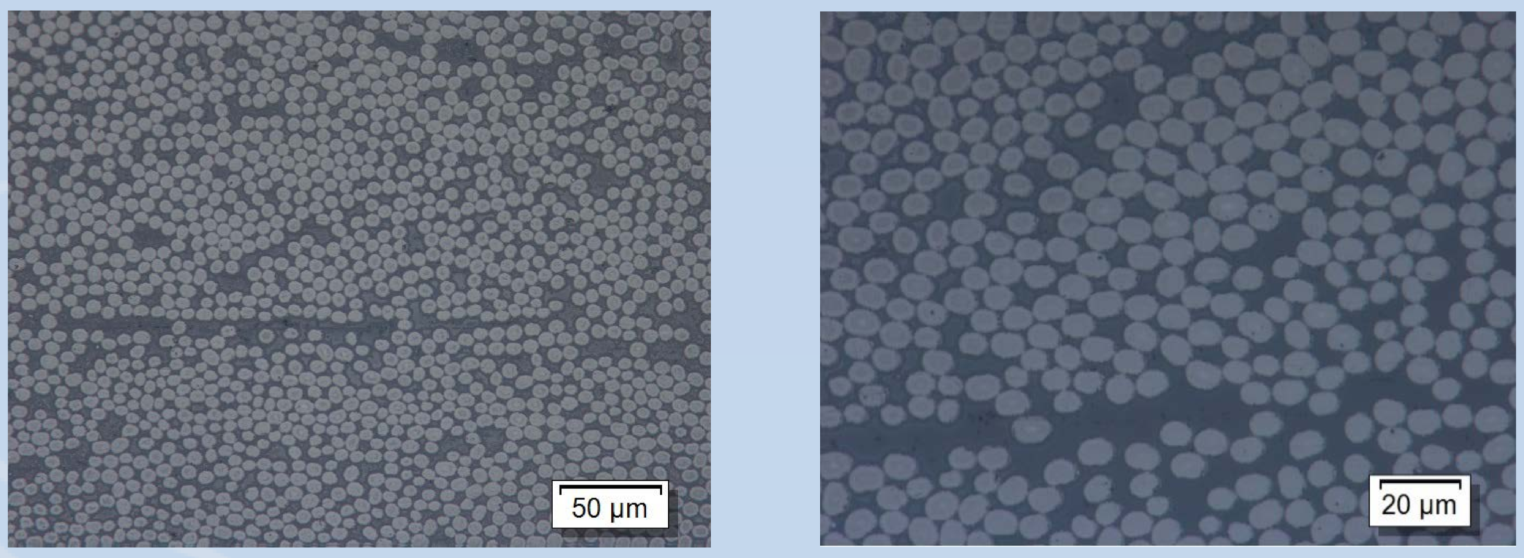

Figure 4: Micrographs for the manufactured laminates corresponding to 57% fibre volume content

Results

- The mean heat flux during the measurements was 1380 W/m^2
- Each sample was tested at least twice
- Estimations of interface conductance were realised by plotting ΔT/ q versus Δx for three different sample thicknesses
- Interface conductance was found to be 1100 W/m^{2}K
- Corrections on the measured values were made with the use of eq.2

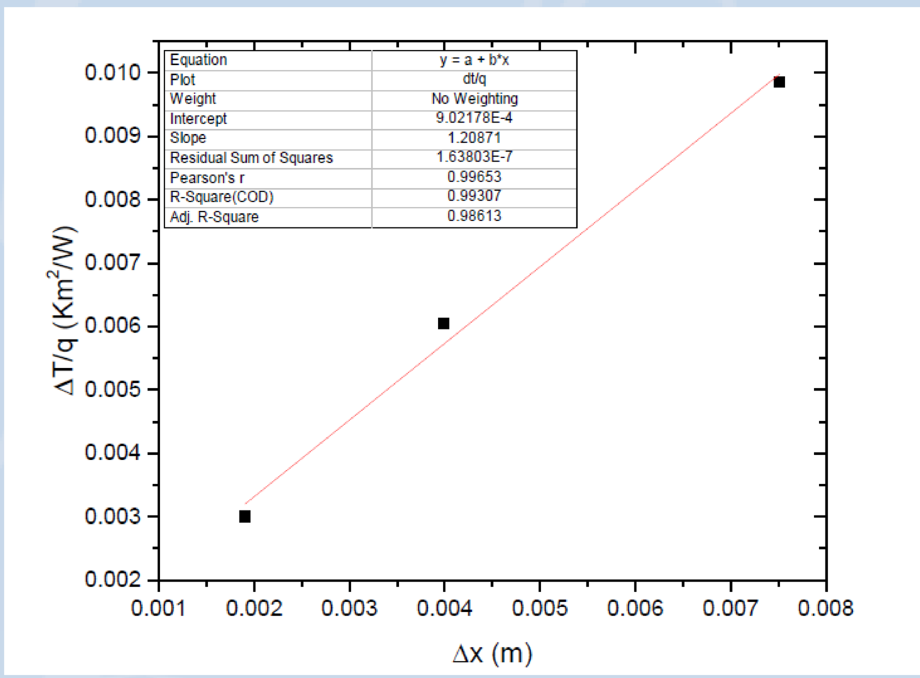

Figure 5: Plot of ΔT/q versus Δx for three sample thicknesses

$$\frac{1}{h}+\frac{\Delta x}{k_{true}}=\frac{\Delta x}{k_{meas}} \quad \text{Eq.2}$$

Where,

h (W/m^{2}K) is the interface conductance

Δx (m) is the sample's thickness

k_{true} (W/mK) is the corrected thermal conductivity value

k_{meas} (W/mK) is the measured thermal conductivity value

Table 2: Thermal conductivity results for the characterized CFRP materials

Sample	Thermal Conductivity (W/mK)
$[0^o]_2$	0.894 ±0.160
$[0^o]_5$	0.770 ±0.049
$[0^o]_{10}$	0.758 ±0.040

Conclusions

- The technique is simple and applicable in a wide range of sample thicknesses
- Measurements can be achieved in a wide range of polymers and polymer matrix composites
- No additional information about the sample are required besides its thickness
- The higher discrepancies observed in the 2-ply laminate are associated with the sample's aspect ratio
- Minor alterations in the sample design will enable the characterization of the transverse direction thermal conductivity

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 642771.
Weblink: http://sparcarb.com/
The authors would like to express their gratitude to Dr. Wendell Bailey for providing components and knowledge during the development of the thermal conductivity apparatus.

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