University of Sheffield

Engineering and Physical Sciences Research Council

Incremental Forming of Composites: A Mould Free Future

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Why ?: Challenges of composites production

Large autoclave oven for aircraft structures [1]

- Large parts require large molds
- Require long curing time in autoclaves:
  - Dependent on thickest section.
- Mold size is limited by autoclave size
- Molds wear over time:
  - Depends on complexity

Composites.media, “Pressing ahead with the oven”, [online],
1998 - 2019 © MIT Publishing, visited on 03/September/2019 at 13:33pm,
URL: https://www.composites.media/pressing-ahead-oven/

Composites Manufacturing

Innovative Composite Parts & T

HOME ABOUT MARKET SEGMENTS COLUMNS MAGAZ

Premier Composite Technologies is working on the World's Largest Sliding Dome in Mecca

For small production runs a mould could be 80-90% of the cost

Composites Manufacturing

MORE PRODUCTS EXP

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New Apple Campus Features World's Largest Freestanding Carbon Fiber Roof

Transporting Turbine blades

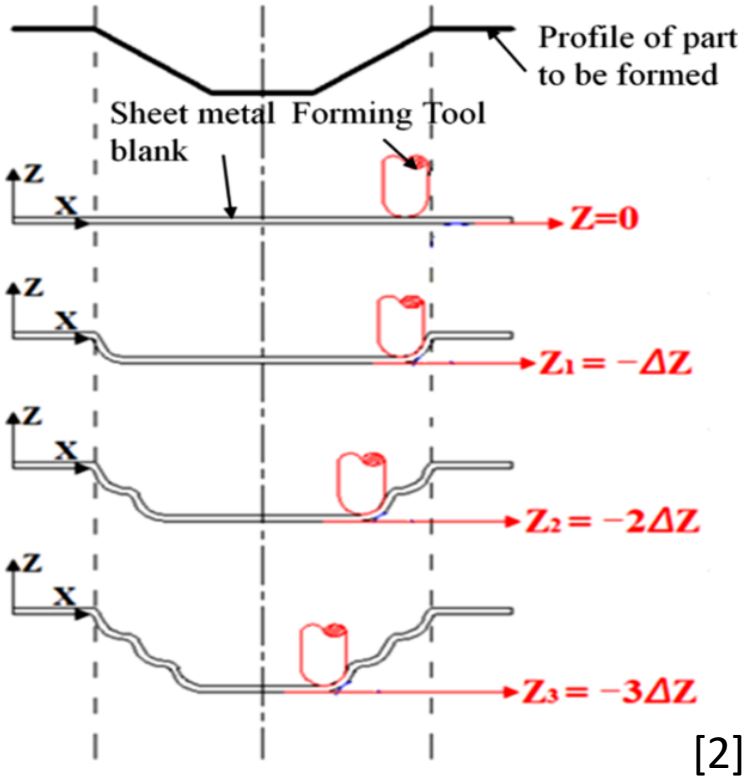
- One of 198 x V117 blades being transported from Ashaig Airfield to Stronelairg wind farm in Scotland. Its only 57.5 m long.

- Vestas YouTube channel: https://www.youtube.com/watch?v=iTpZ5V4HrK4

Long term vision: (Or delusion)

- Can we create a **scalable** technology for composite parts.
- Can we minimise curing energy input.
  - Tailor it to the part geometry (thickness)
    - Chemical Kinetics of curing → exotherms in thick sections
- 3D weave a part and cure it at the locality.
  - Transport high density materials
    - Fibres, fabric and liquid resin not large cured hollow parts

What is Incremental forming?



[2]

Incremental forming of aluminium sheets

Relies on ductility of the metal → Glare Al/CF panels[1] MS/PP/MS sandwich[2]

Fibres are not ductile, but we can weave into the desired shape.

3D weaving, handling and curing

1. R. Kuitert, J. Sinke, TUDelft MSc Thesis http://resolver.tudelft.nl/uuid:ea8c5ea7-d7ad-471f-a300-69e3dc5fa6d3
2. K.P. Jackson, J.M. Allwood, M. Landert, Incremental forming of sandwich panels, https://doi.org/10.1016/j.jmatprotec.2007.11.117.

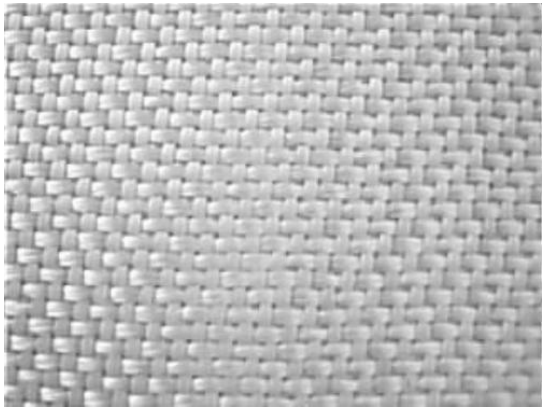
Thermosets and Thermoplastic

Thermoset

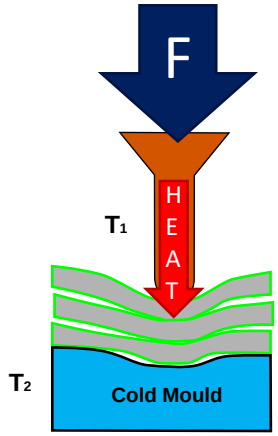
- Carbon-Epoxy Twill
- Pre-preg: Carbon fibre coated with epoxy
- Cure at 130 °C
- Fibres are good conductors of heat

Thermoplastic

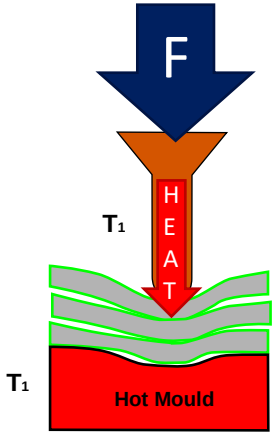
- Woven Polypropylene tape (2mm)
- Melt at 160 °C
- Poor conductor of heat
- Heat stays localised



Single Point Incremental forming: With Mould

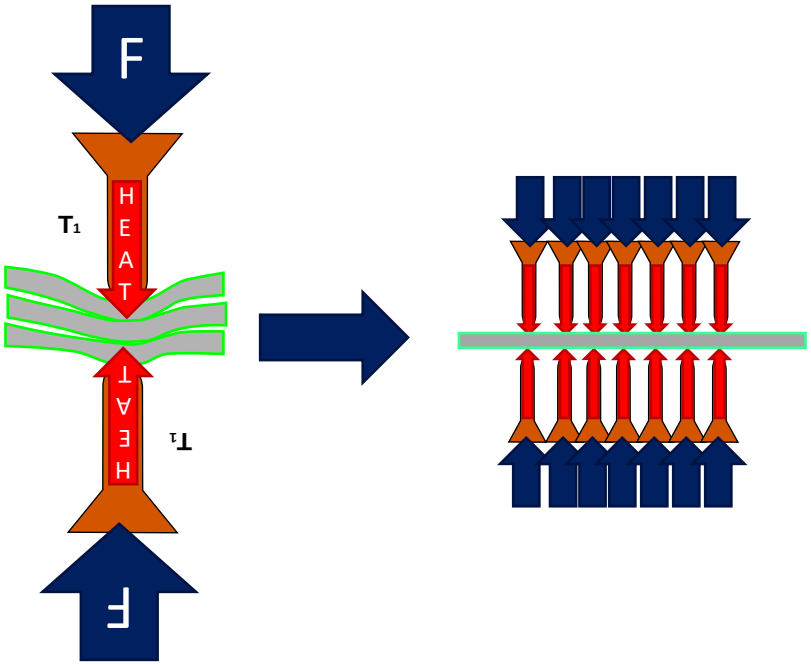


- **Cold Mould:**
- Very slow process.
- Heat Conduction limits
  - Thickness
  - Speed



- **Hot mould:**
- Faster (but still slow).
- Impingement contact increases heat transfer but still slow.
- Suitable for thermoplastics due to mould providing heat to bring part close to melting point.
- Unsuitable for prepreg thermosets as hot base cures the material

Double Point Incremental* forming: Mould Free



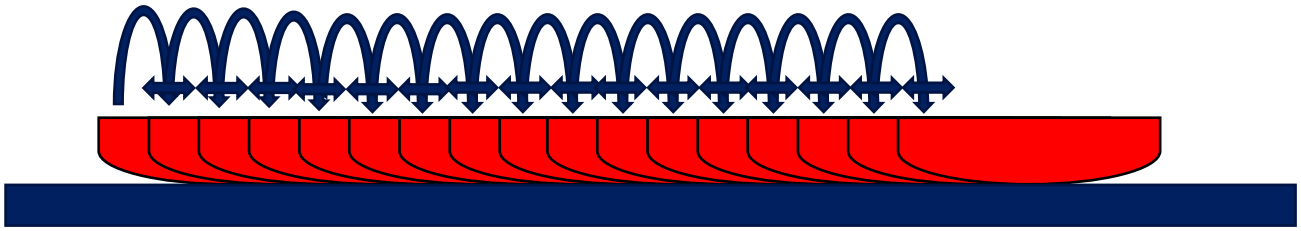
- Double point allows you to create parts direct from software.
- **BUT:**
  - It is too slow if using thermal contact to cure[1]
- **Solutions:**
  - Thermoplastics: Ultrasonic welding
  - Thermosets: Electrical cure.

* Some authors use the term Twin Point Incremental forming (TPIF)

1. Victor M. Cedeno-Campos, Pablo A. Jaramillo, Christine M. Fernyhough, J. Patrick A. Fairclough, https://doi.org/10.1016/j.procir.2019.09.020.

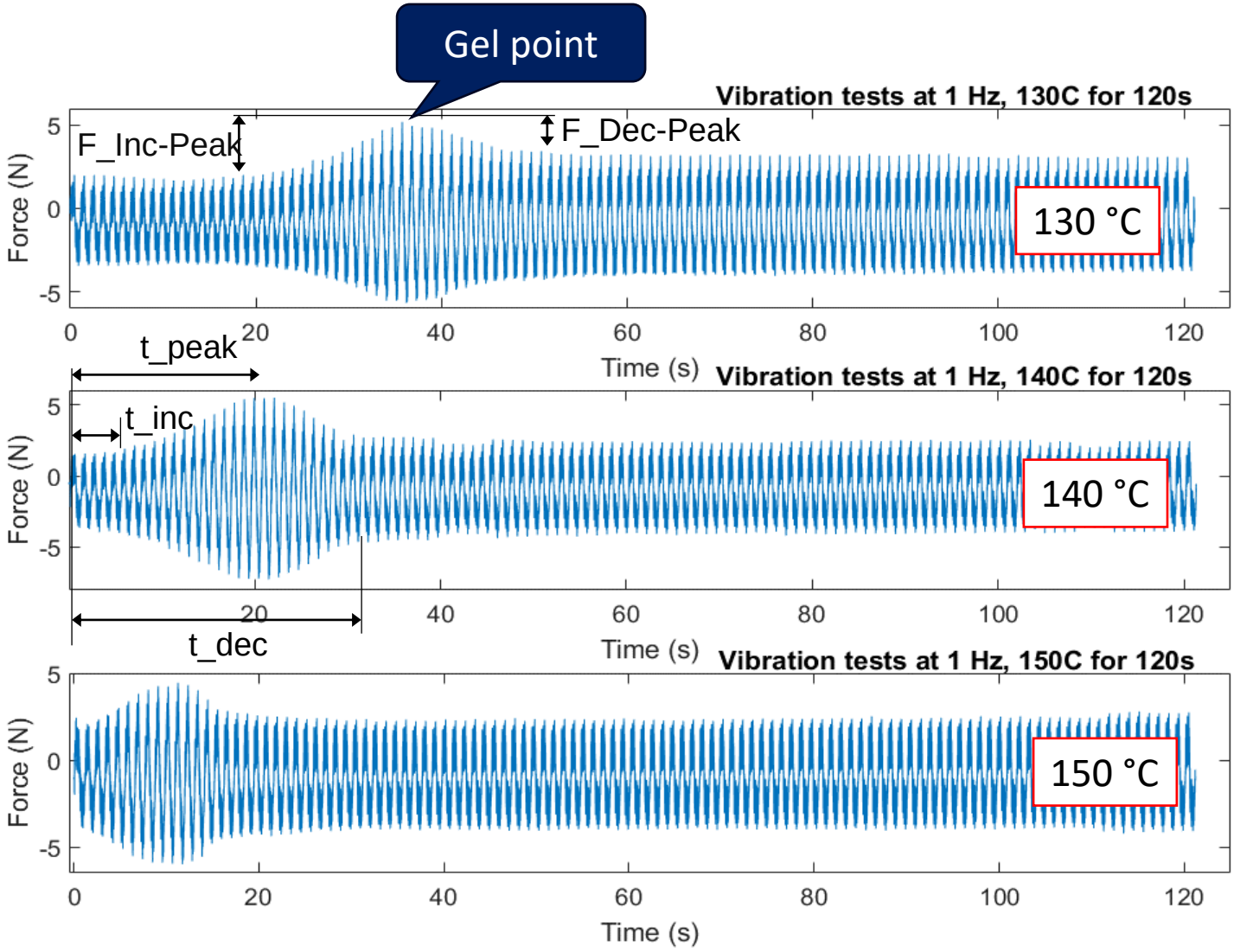
Cure Monitoring: In situ Rheometry

- Small oscitation superimposed on lateral motion.



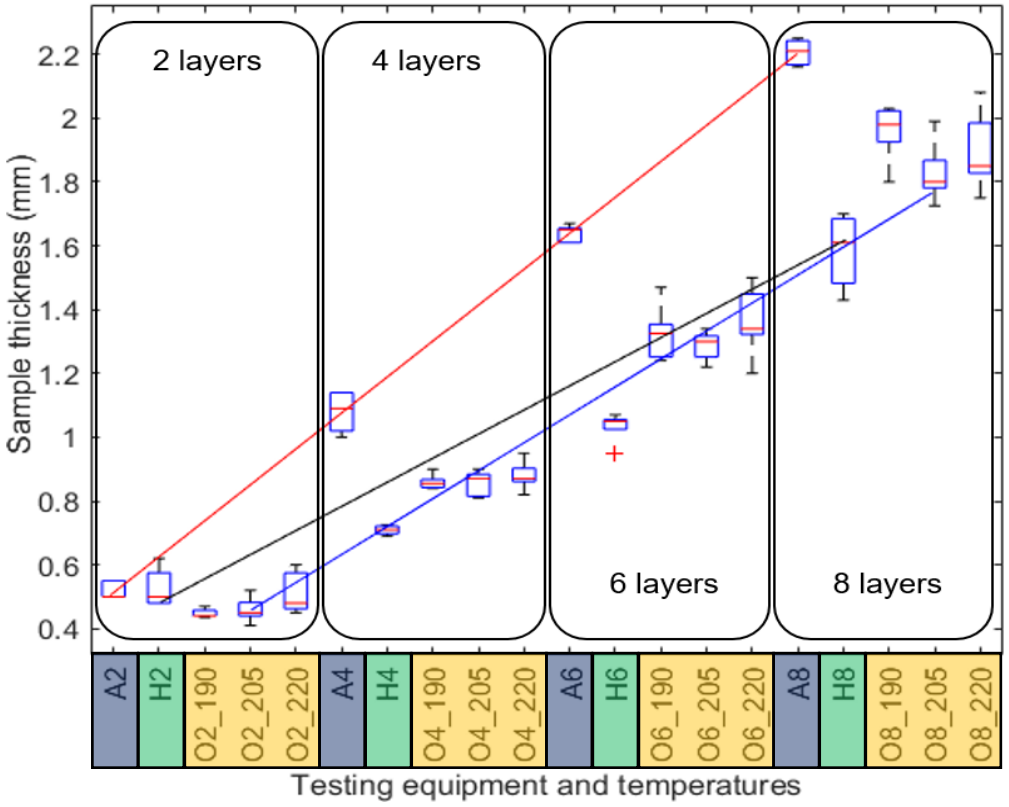
- When resin is uncured:→ “tacky”
- As the resin cures→ gel point→ highly dissipative→ very sticky
- Cured resin→ hard→ no longer sticky.
  - Optimisation of process speed.

Simultaneous Validation of cure



Notice the time axis. This is very slow

Consolidation: Thermosets and Thermoplastic



A: Autoclave

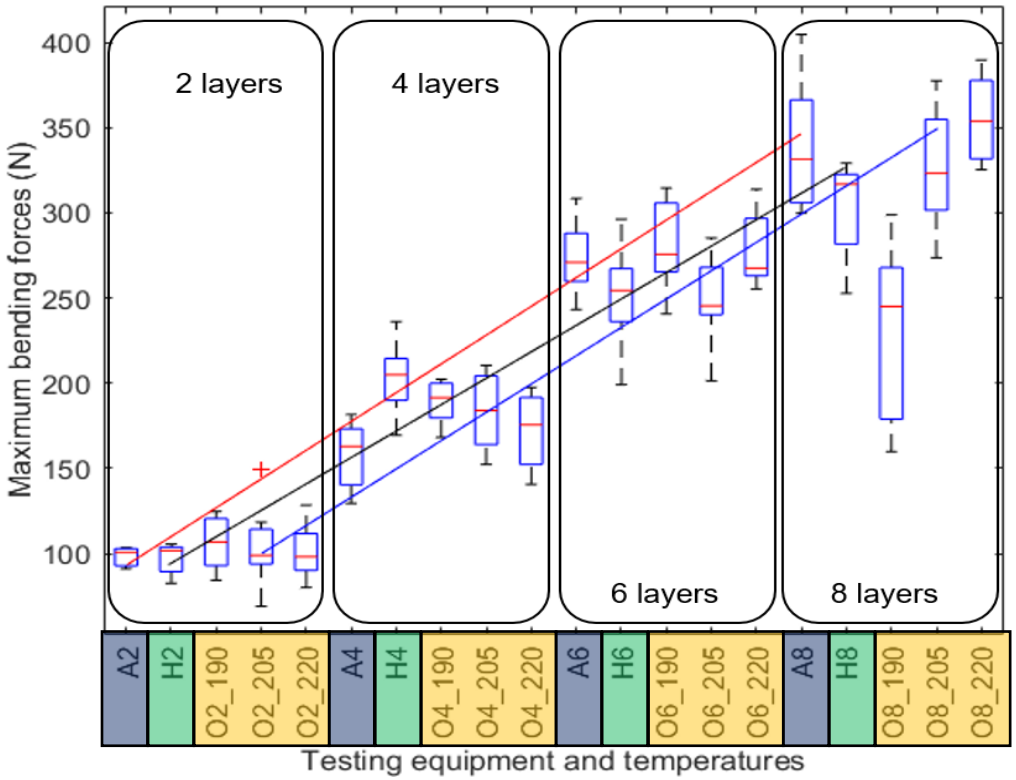
H: Hot press

O: DPIF system (ICULPH)

	Autoclave	Hot press	DPIF system
Layers	StdDev	StdDev	StdDev
2	0.02	0.06	0.03
4	0.06	0.01	0.03
6	0.02	0.04	0.07
8	0.04	0.11	0.09

https://doi.org/10.1016/j.procir.2019.09.020

Bending: Thermosets and Thermoplastic



A: Autoclave

H: Hot press

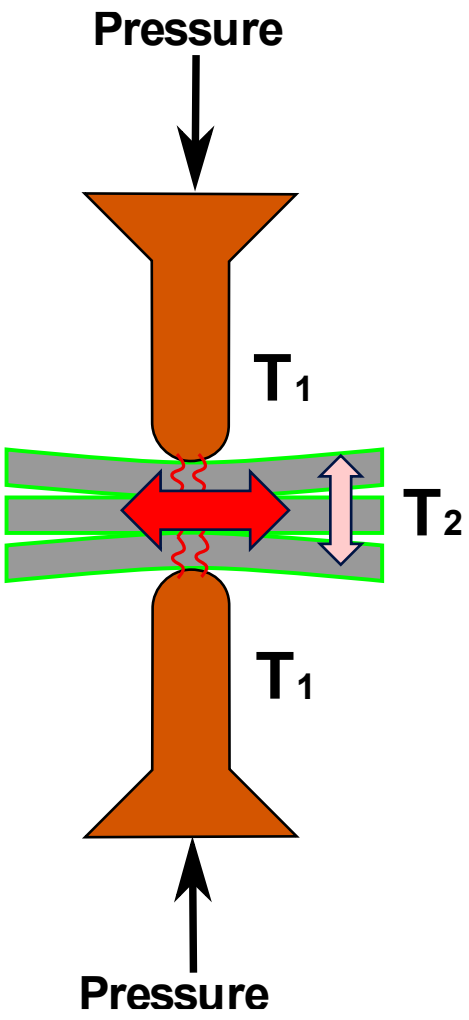
O: DPIF system (ICULPH)

Material: 3K 200gsm LTC150-C(t)200 UCFE twill prepregs, novolac from SHD.

Comparable to hot press results in thin sections.

https://doi.org/10.1016/j.procir.2019.09.020

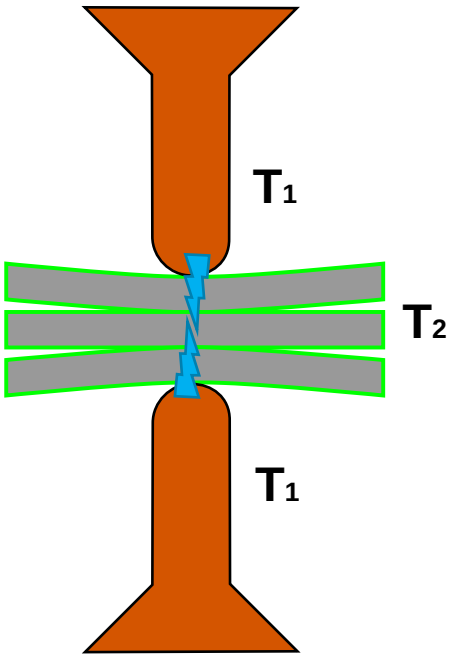
Heat Conduction in Carbon Fibre



- Thermal conduction between layers is poor
- Need to get heat into thicker samples
- Microwaves:
  - Carbon conducts → Faraday cage → poor penetration.
- Induction:
  - See above: Better penetration with low frequency
- RF Heating:
  - Control of localisation
- Ultrasonic:
  - Probes are large, control and safety are issues

Electrical Resistance heating

Conduction in Carbon Fibre

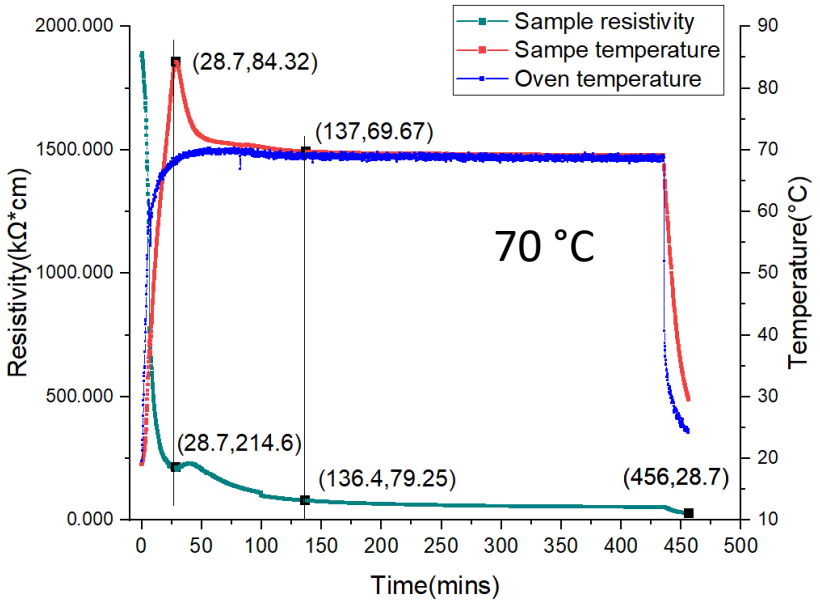


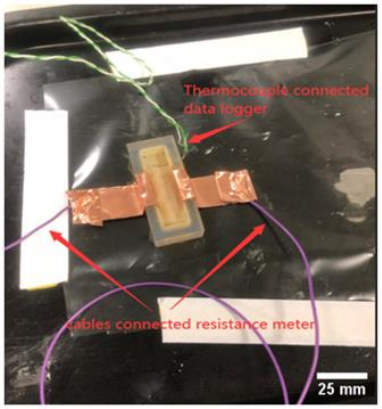
- Carbon fibre conducts.
  - Electric cure has been widely used in Sheffield (Simon Hayes).
  - Mainly along the fibres.
- Advantages
  - High localised power.
  - Highly controllable.
  - Low cost equipment.
  - Low input energy → Reduce cost and carbon footprint.
  - No radiation shielding required.

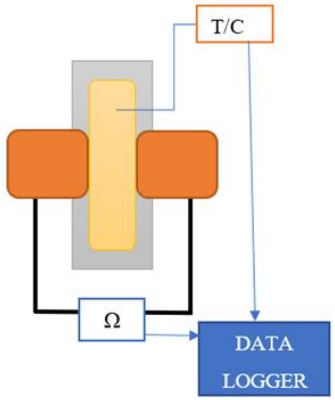
BUT Epoxy resin does not conduct….

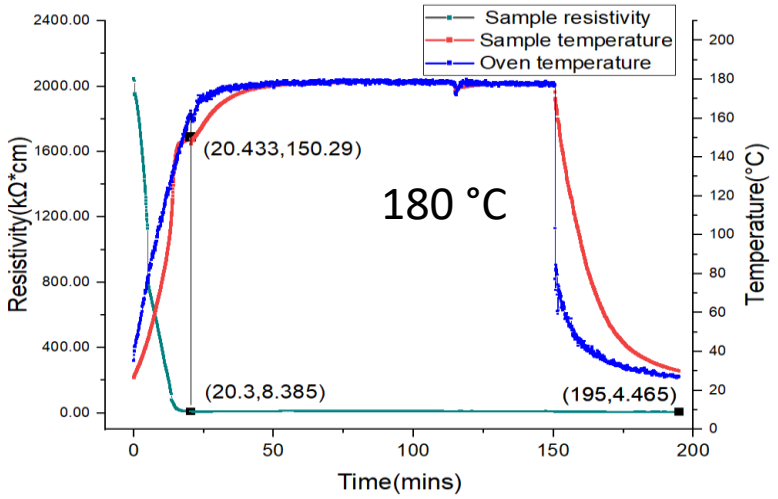
Option 1: Epoxy + 2wt.% Carbon Black

- DC Resistivity drops dramatically as the epoxy is cured.
- This is probably driven by reaction induced phase separation (RIPS)





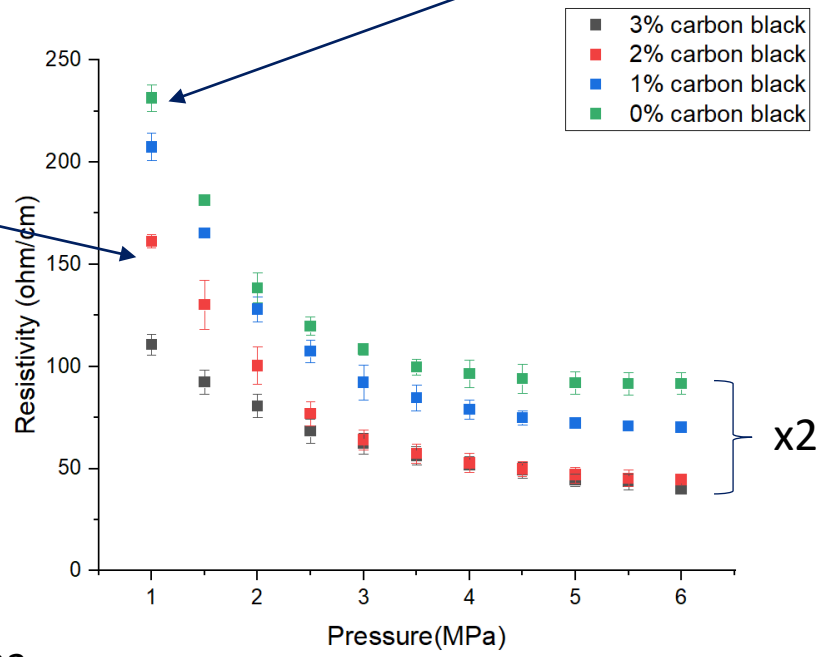




Tang, Cepero Mejías, Fairclough, submitted May 2023

Conduction through Carbon Fibre

- Option 1: ■ ■ ■
  - Add Carbon Black to the resin
  - Create a pre-preg
  - Cure via electrical conduction through the panel.
- Option 2: ■
  - Compress a standard pre-preg until the resistance falls
  - Cure via electric cure



Tang, Cepero Mejías, Fairclough, submitted June 2023

First results: Carbon Black + Carbon Fibre

- July 2023
- Electric curing of thick panel via DPIF.
- 20mm tool
- 15 layers
  - 30W for 60s per point (1.8 kJ)
    - Cure control required
  - 145 x 100 mm in 80 mins. (139 kJ)
  - Consolidation needs to be improved to compete.

Conclusions and future work

- A novel process to cure prepreg composites without moulds is under development.
- For simple parts the process could be cheaper, faster and it has a lower carbon footprint that an autoclave
- Future work
  - Focus on testing with the dual point machine configuration
    - 6 axis machine: Cooperative Robots
  - SNAP cure and fast cure systems.
    - Importance of the cure chemistry to improve collateral curing.
  - Investigate the effect of other carbons on the curing process
    - Graphene and CNT: practical cost limitations?
  - Speed up the curing process:
    - integrating the rheometry and resistivity with the power control.
    - Larger tooling for larger parts.