



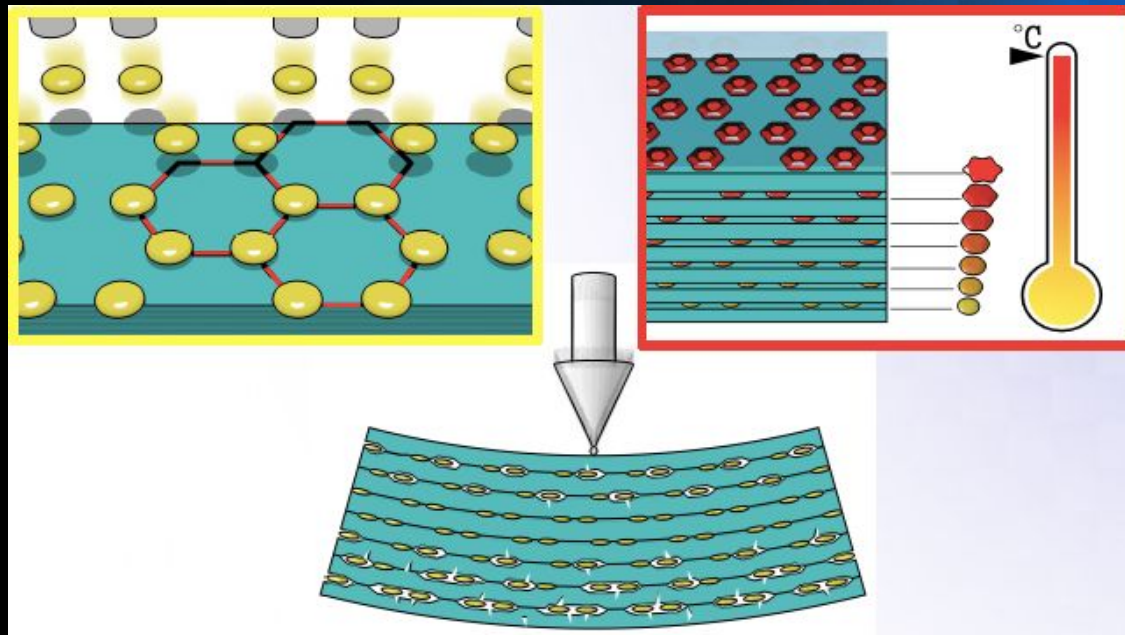
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Composites in the growing field of carbon nanotubes and other carbon nano-forms

Professor Alma Hodzic, The University of Sheffield



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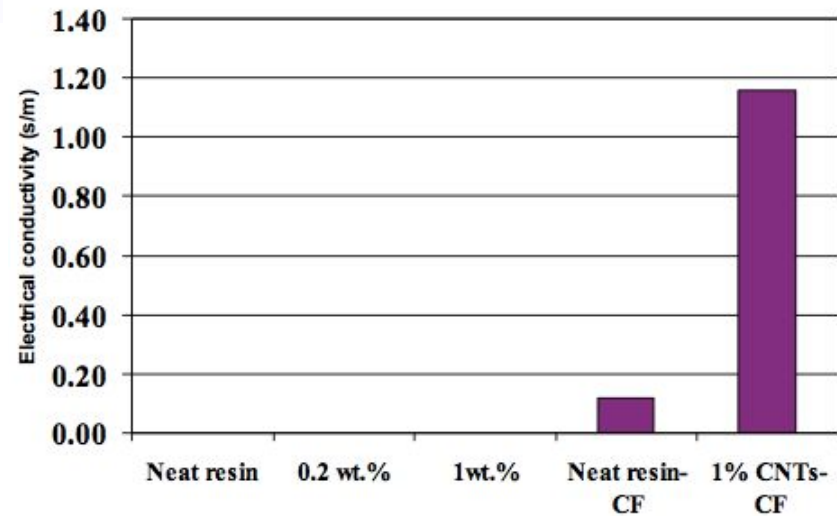


Initial studies in carbon nanotubes and nanoclay modified composites

	Storage Modulus at 25°C (GPa)	T _g (°C)
Neat resin	2.76	206.6
0.2 wt % CNTs	2.85	206.7
0.4 wt % CNTs	2.63	205.9
0.6 wt % CNTs	2.65	205.1
0.8 wt % CNTs	2.94	206.8
1 wt % CNTs	2.92	206

Cytec Engineering Materials. CYCOM 977-20, 177°C curing epoxy resin with 126-138°C dry and 104°C wet service capability, used in Dreamliner Boeing 787.

Achieved mechanical properties did not differ from the original system which was seen as the advantageous aspect compared to graphene particles which reduce the property of epoxy modified systems by a significant percentage with each added layer, levelling at 30% loss in mechanical properties, However, the increased electrical conductivity of CFRP modified with 1% CNT was tenfold.





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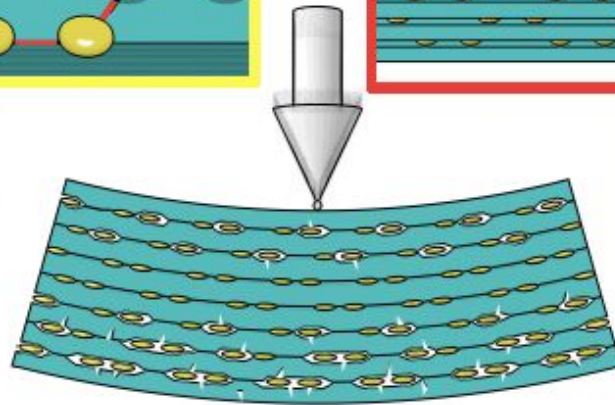
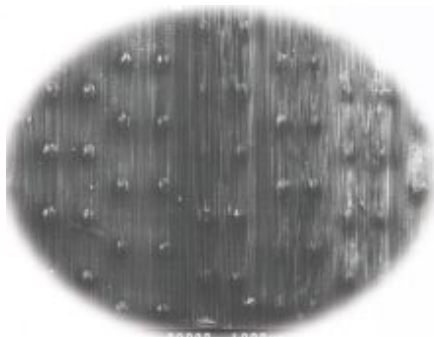
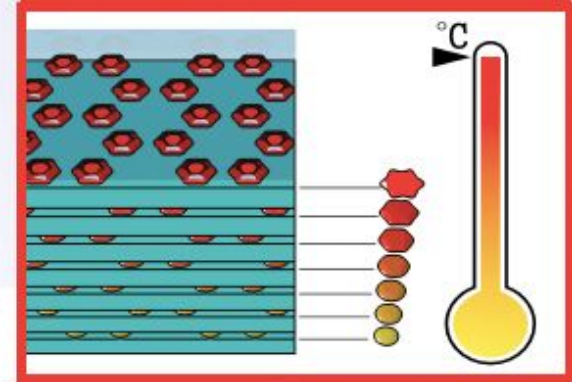
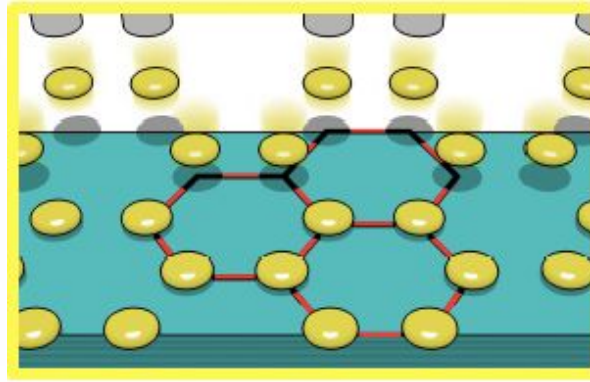
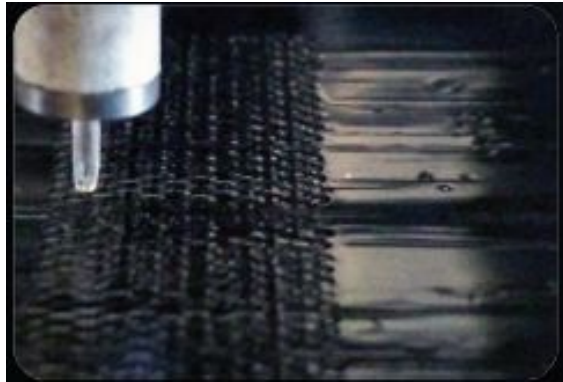
Composite Systems Innovation Centre



Advanced Manufacturing Research Centre



Inkjet printing of PMMA in CFRP laminates as the alternative to toughening improvement



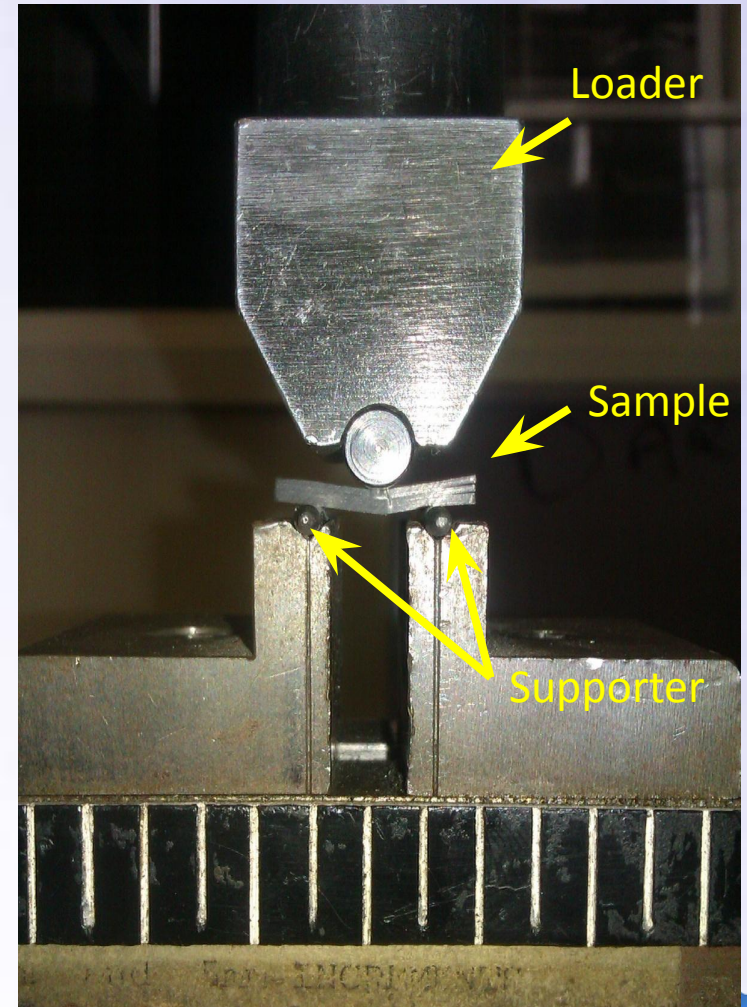
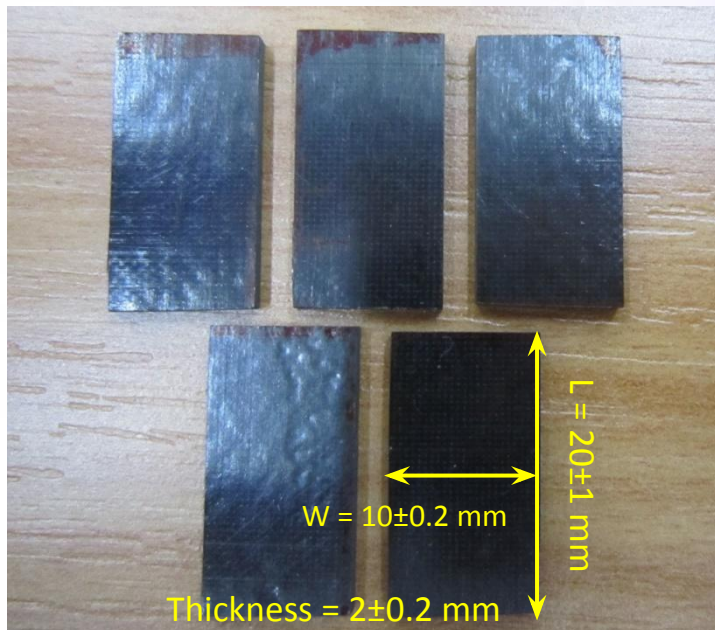
Funded by AFOSR 2011-2014, and US Army & AFOSR in 2015





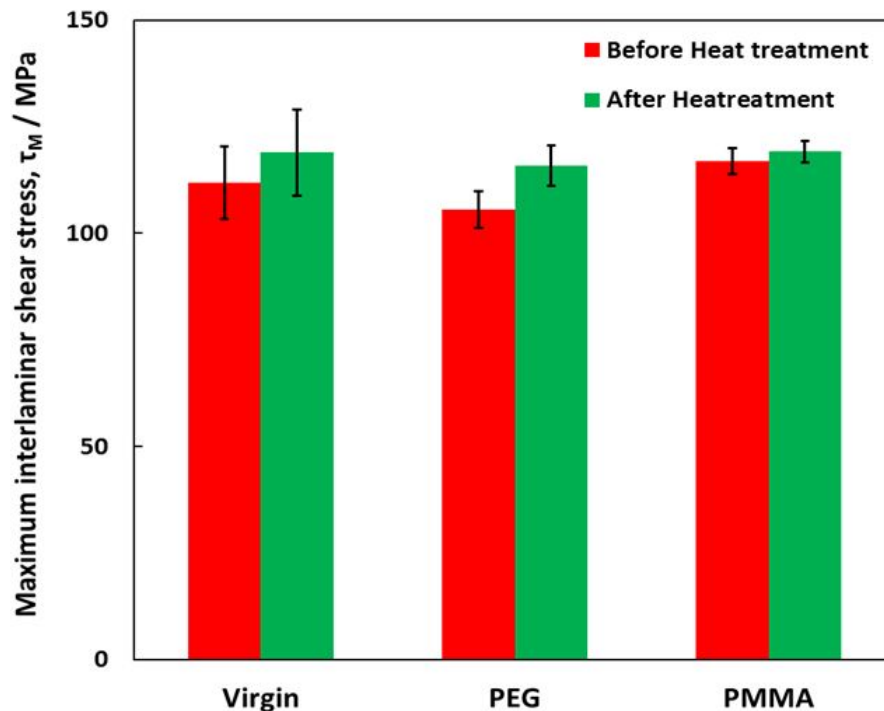
Shear Modulus & ILSS

Fibre-reinforced plastic composites —
Determination of apparent interlaminar shear strength by short-beam method. (BS EN ISO 14130:1998)



ILSS

- ILSS: Maximum interlaminar shear stress (τ_M)
- No damage introduced, investigation of undamaged parameters and postcuring effect of potential un-crosslinked group



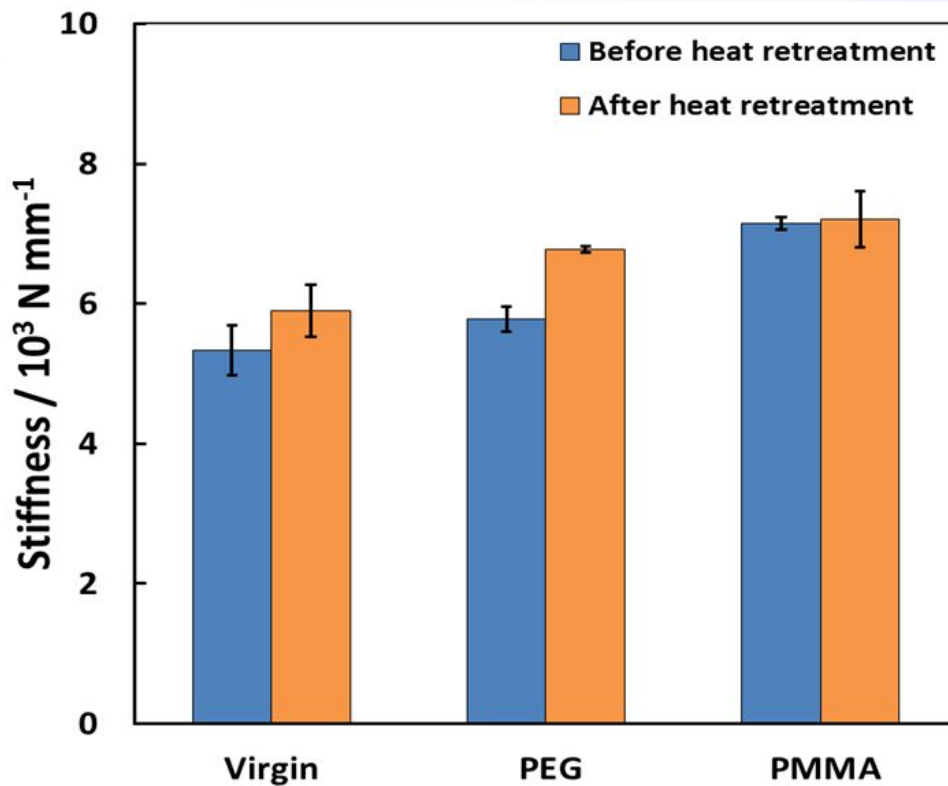
Note: error bar represents standard deviation, n = 5

Heating cycle: 177°C for 2 hours,
(harshest conditions)

Purpose: to investigate any potential reduction of the ILSS, due to the presence of printed surface. ILSS values of all groups are enhanced after heat treatment, which indicated the existence of post curing.



Stiffness



Heating cycle: 177°C for 2 hours,
(harshest conditions)

Purpose: to investigate effect of
printed additions on the material's
stiffness.

The effect achieved successfully. The
printed surface noticeably increased
the stiffness of the material both
before and after heat treatment
compared to virgin group.

Note: error bar represents standard deviation, $n = 5$

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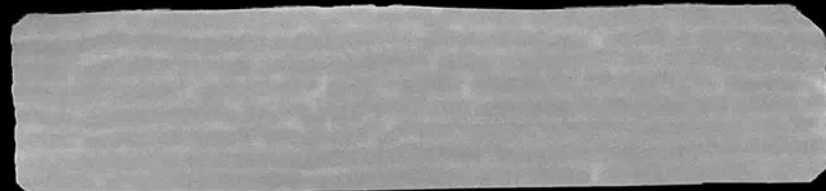


X-ray tomography

NP

PMMA

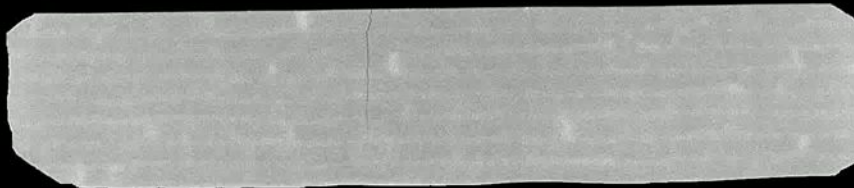
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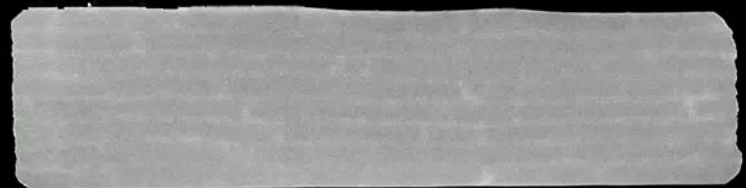
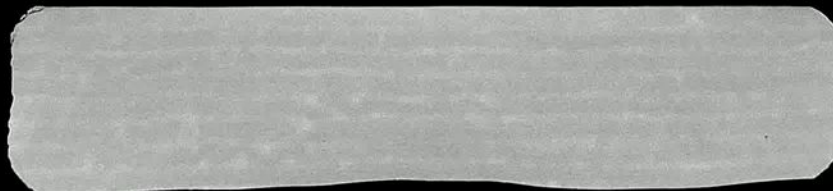
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02



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01_bottom





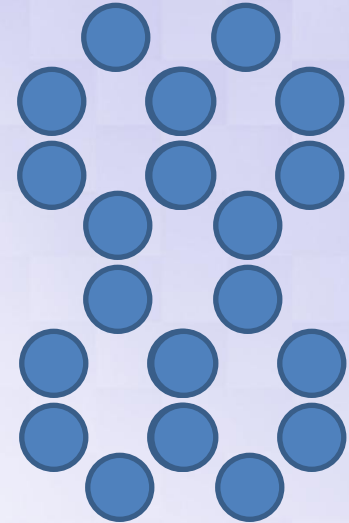
Printed surface ratio & volume fraction

Printed surface ratio between the plies:
30 ~ 40%

Volume fraction: ~ **0.025vol.%**

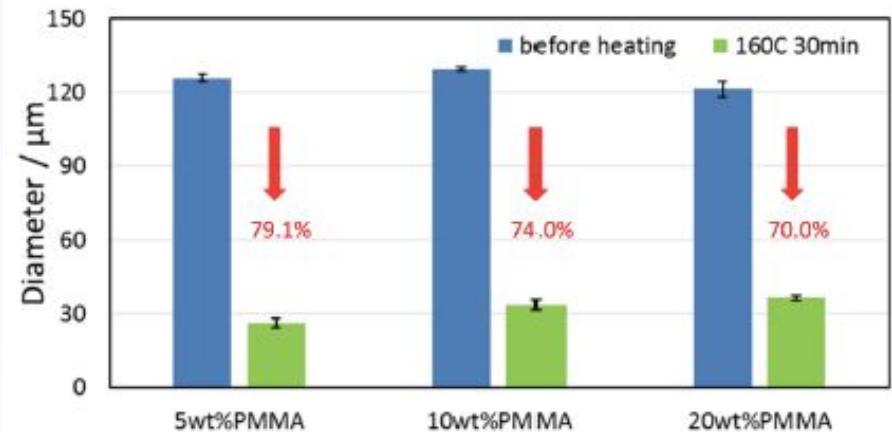
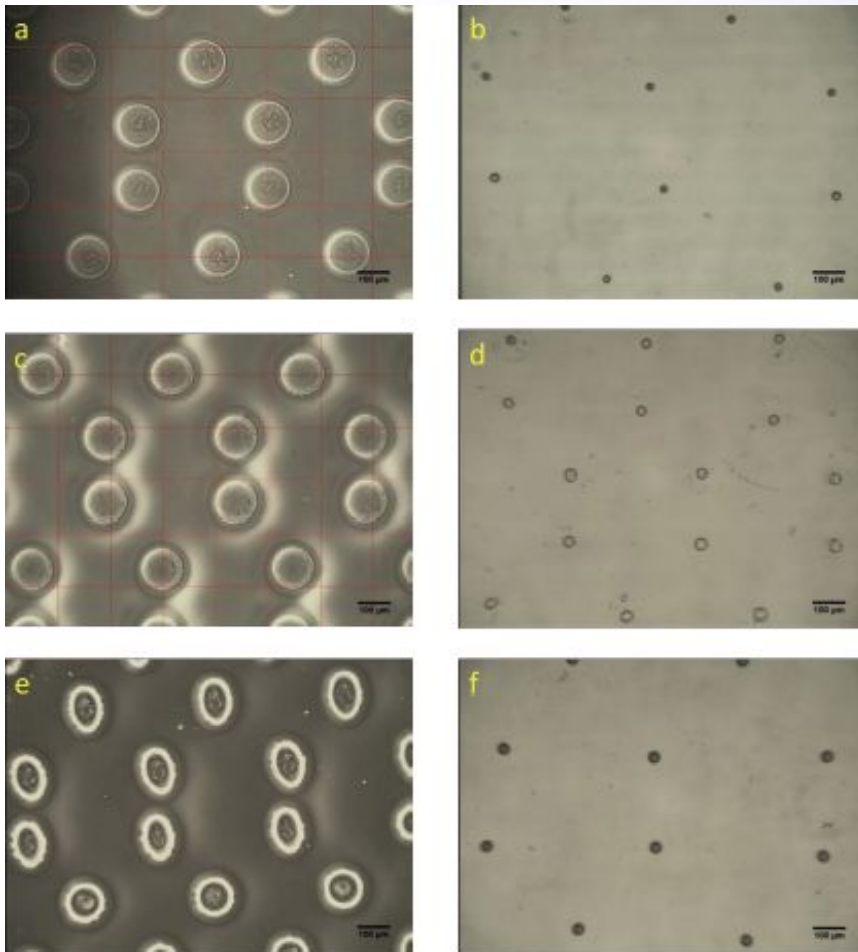
Weight increased: ~ **0.020wt.%**

(Negligible, within the manufacturing error margin)



Printed PMMA droplets on epoxy coated glass substrate

Optical images of epoxy coated glass substrates with printed PMMA droplets:
5, 10 and 20% PMMA deposits before and after the heating cycle.

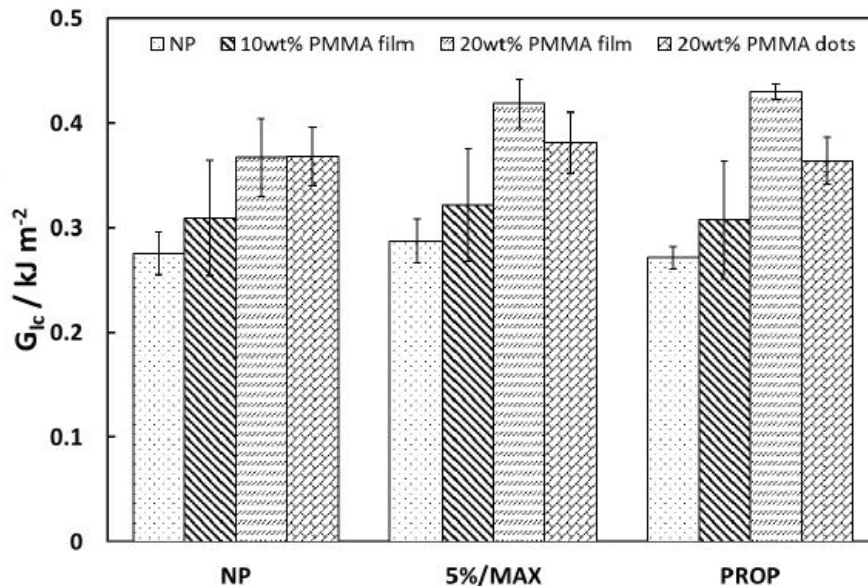
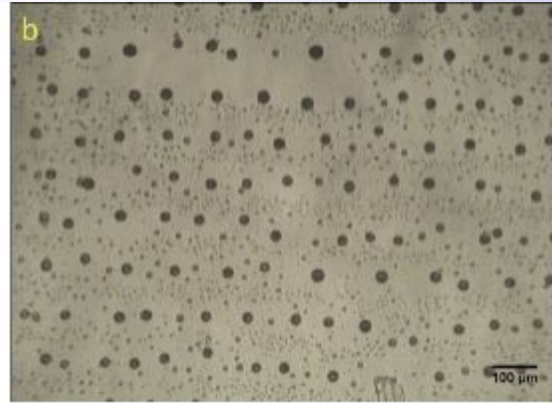


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PMMA film between CFRP plies before and after heating

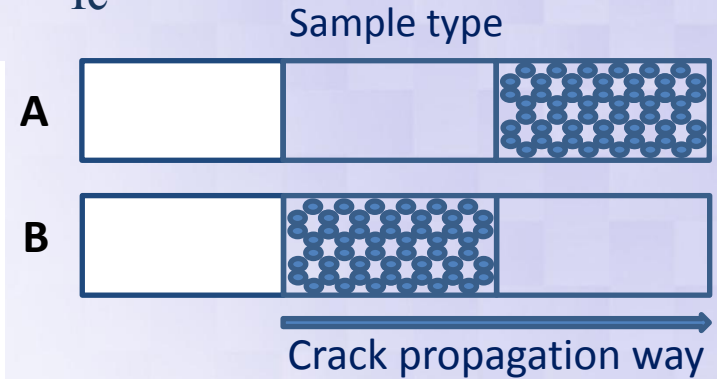
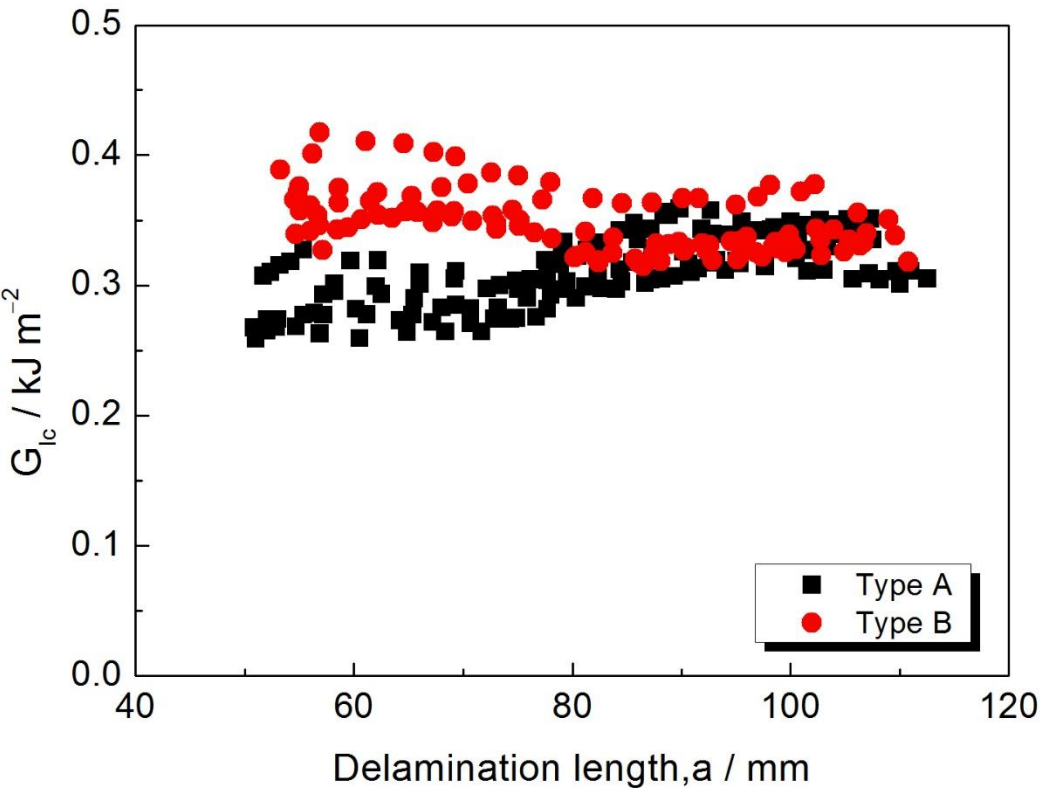


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PMMA film is comparable to inkjet printed area that is double the percentage of concentration of the film pattern. 10% film pattern is comparable to 20% PMMA droplets due to the volume fraction of PMMA in those two systems.



Evidence of selective printing on G_{Ic} of CRFP laminates



G_{Ic} values of printed areas are comparatively higher than unprinted areas, which means inkjet printing can be applied to delicate material design work, and manufacture property graded multifunctional materials.



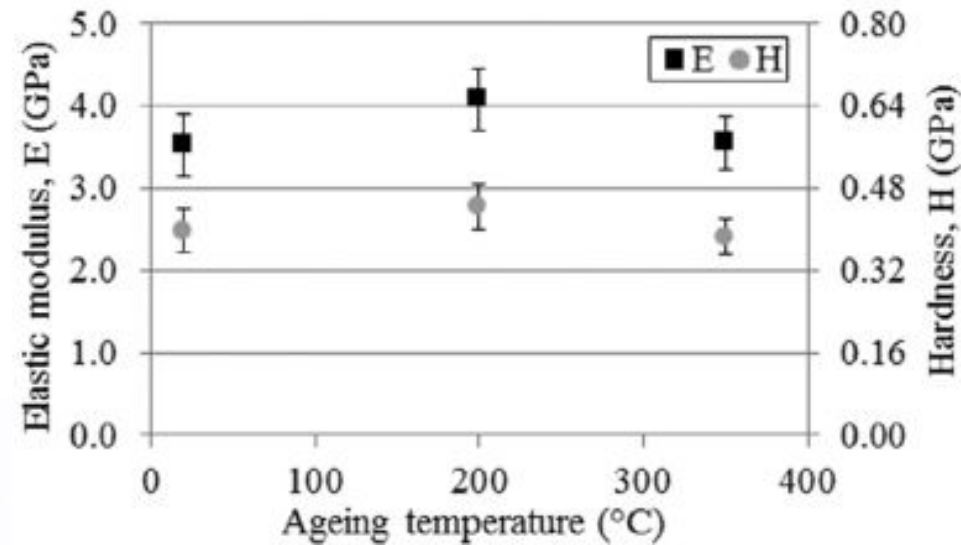
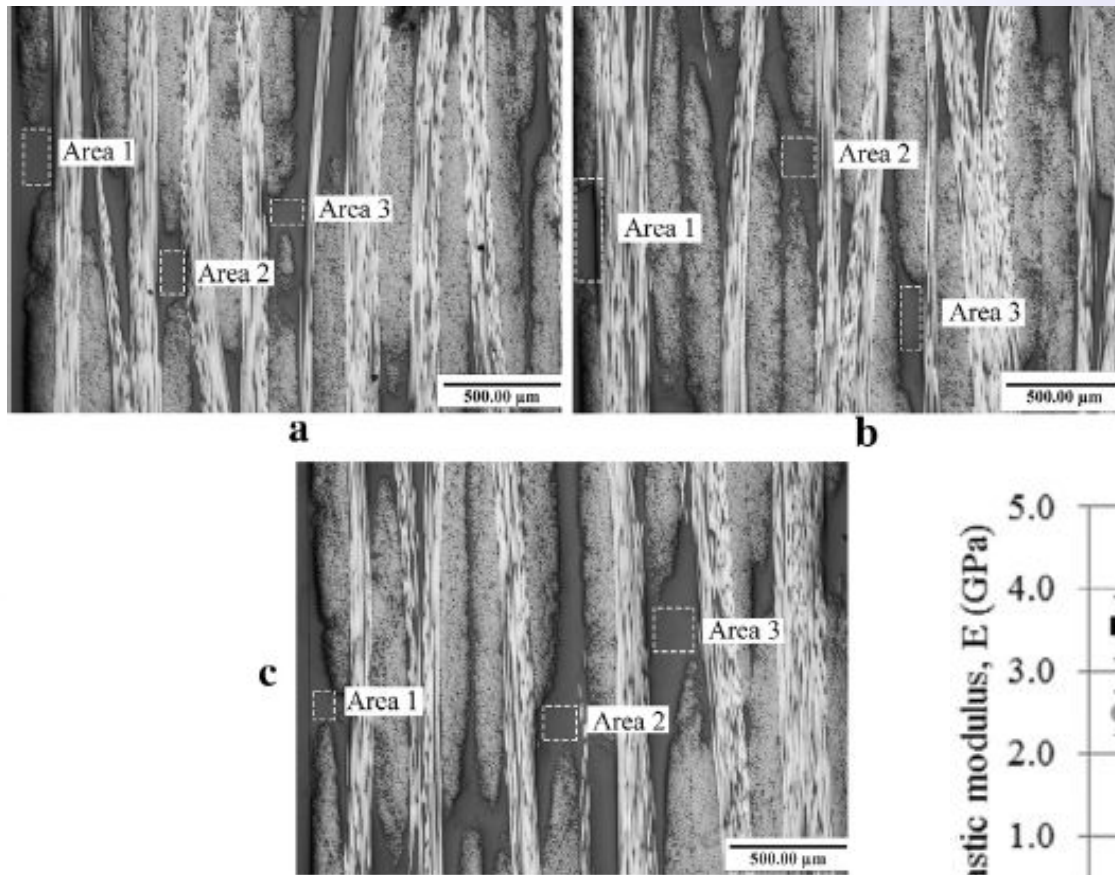
PMMA contribution to CFRP properties

- ✧ PMMA droplets act as plastic zones that can absorb energy by plastic deformation. Due to the viscoelastic nature of PMMA, those well dispersed microphases by inkjet printing provide an energy-absorption path by thermoplastic deformation, which can decelerate crack growth as the crack tips are shielded by those plastic zones.
- ✧ Crack propagation is arrested by the combination of crack-diverting discretely deposited droplets and the higher fracture toughness of PMMA. The second option can be further evidenced by the lower standard deviation in the system with hexagonally printed 20% PMMA system.



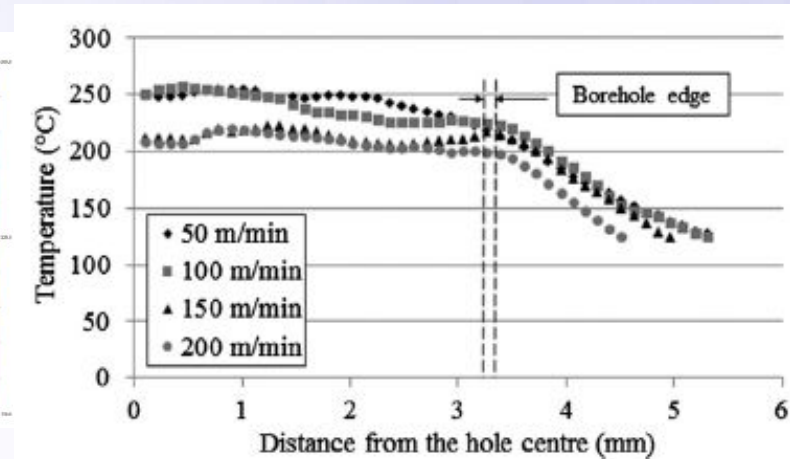
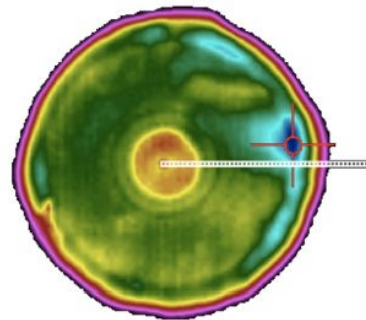
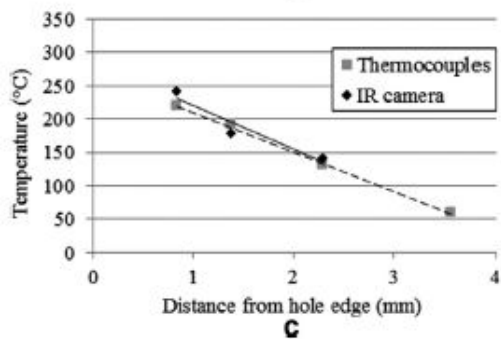
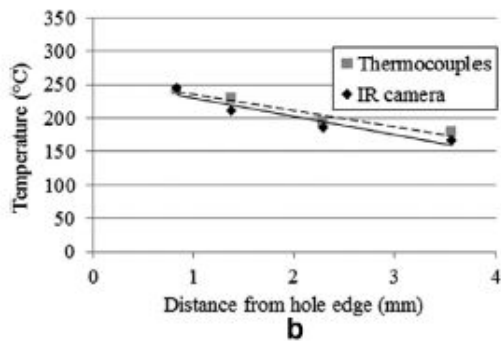
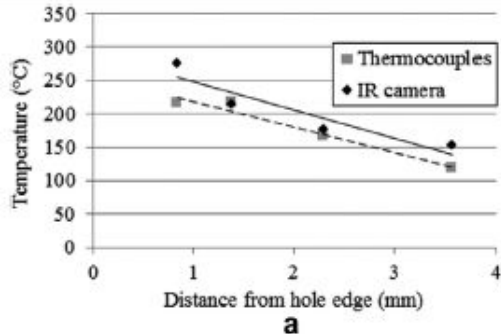
Influence of the machining parameters in CFRP laminates I

Indented areas on (a) the non-aged specimen and the specimens aged at (b) 200 C and (c) 350 C, in MTM44-1 CF0300. MTM44-1 resin is a toughened phenol-formaldehyde (PF)-based aerospace grade resin, CF0300 is a 2/2-twill carbon fabric, (HS) carbon fibre reinforcement.



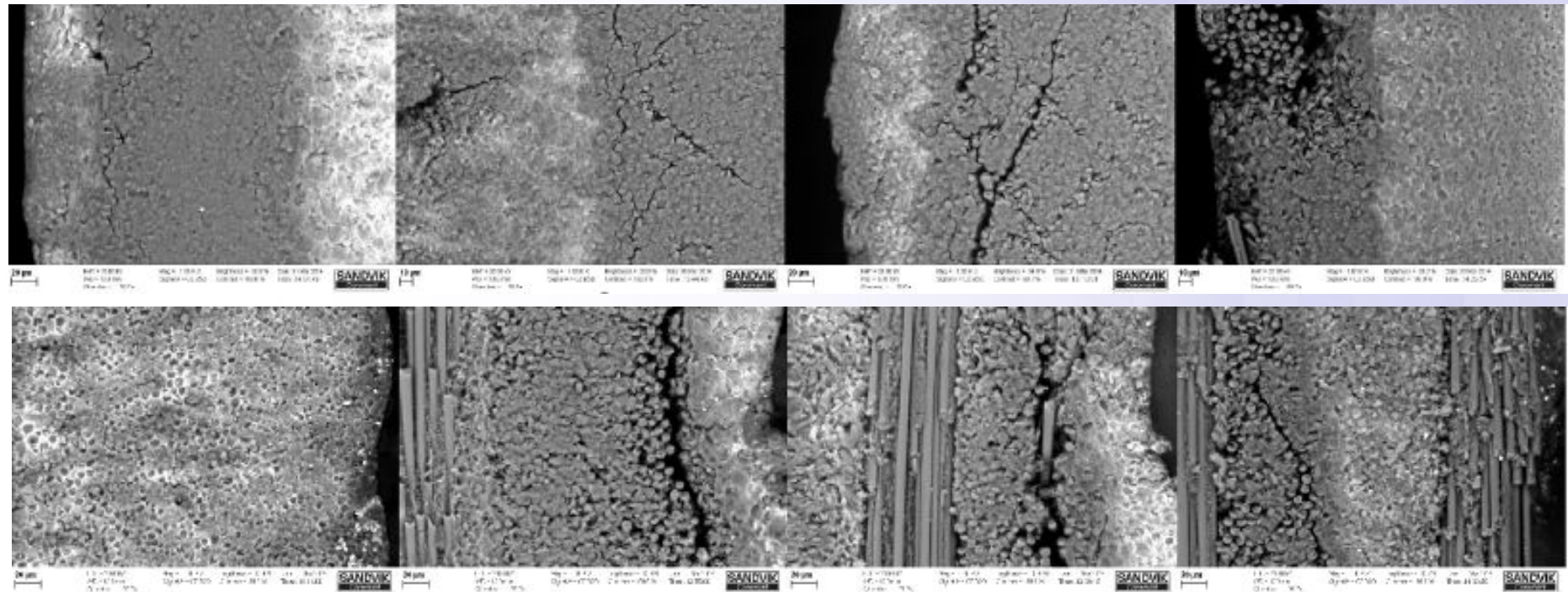
Influence of the machining parameters in CFRP laminates II

Maximum temperatures developed in the drilling of selected CFRP systems: (a) MTM44-1 CF0300, (b) MTM44-1 CF2216 and (c) MTM28B CF0300 at different distances away from the hole edge, measured using thermocouples and thermal imaging (IR camera).





Damage to CFRP laminates due to machining



Julian Marino-Perez, The University of Sheffield

Left to right: SEM images at the hole exit corresponding to 49.8 m/min, 99.6 m/min, 149.4 m/min and 199.2 m/min cutting speeds. Above: fibres at 90° (perpendicular to the machining direction), below: fibres at 0° and 90°.



Potential benefits of graded functionalised composites

- ✧ The initial study has shown that CNTs contribute increased electrical conductivity in aerospace grade composites such as Cycom 977-2 used in Boeing 787, commercial toughened grade that is difficult to post-manufacture and to be modified due to the presence of toughening and hardening agents.
- ✧ The follow-up study has shown that inkjet printed PMMA was capable of increasing the fracture toughness properties by 40% with less than 0.02% addition of PMMA droplets in distinct areas of the same CFRP composite laminates.
- ✧ The complementary study investigating the influence of machining parameters in CFRP laminates discovered that the influence of temperature and speed of cutting was essential to the final results in the manufacturing of composite laminates, and that the damage within the laminates was significant compared to the benefits obtained from other studies.
- ✧ The investigation of CNTs inside PMMA droplets should be capable of conducting the heat away from the damage zone, including the better dispersion of heat energy during the microwave curing process in the automotive industry (results pending after successful nanocomposite results obtained in 2015).