Fibre Sizing Effect on the Adhesion Between a Carbon Fibre and a Reactive Thermoplastic Polymer

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Presentation Outline

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- Introduction
  - *Thermoplastic: Monomer to Automotive Parts (TMAP) project*
- Experimental
  - *Fibre Re-treatment Process*
  - *Single Fibre Fragmentation*
- Results
  - *Apparent IFSS measured for different sized fibres at 10 mm gauge*
  - *Apparent IFSS measured for different sized fibres at 20 mm gauge*
- Conclusions
- Future Work

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Introduction

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- Global interest in cleaner, more sustainable forms of transport
  - *Lightweighting via thermoplastic composite materials*
- Fibre–matrix interface influences key mechanical properties
  - *Traditionally the interface for thermoplastics is weaker than that for thermosets*
- Primary theory for interface revolves around chemical bonding
  - *Bulk of fibre coatings (sizings) developed for last generation thermosetting systems*
  - *How do thermoplastic sizings compare to thermoset in terms of performance?*
- Investigation into the impact of sizing chemistry on interfacial properties for a reactive thermoplastic (Elium®) with carbon fibre

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Thermoplastic: Monomer to Automotive Parts TMAP

- Innovate UK funded project with consortium containing 4 partners:
  - *Far-UK Ltd*
  - *M. Wright & Sons Ltd*
  - *University of Derby*
  - *OXECO Ltd*
- To meet the future needs of the vehicle production, industry techniques of reducing CO_2 are required
- Programme to develop materials that could provide weight reduction for the automotive sector without affecting performance, safety or quality of vehicles
- Materials developed based around thermoplastics due to enhanced recyclability and the processes focussed on ensuring materials are cost effective in structural applications in the automobile industry

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Fibre Re-Treatment Details

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- Fibre re-treatment process led by OXECO
- 3D woven carbon fibre developed & supplied by M. Wight & Sons
- Derived formulations specifically designed to work with Elium®
- Removed commercial sizing from 3D-woven fabric via fabric washing/clean process
- Various processes investigated for re-sizing fibre fabrics
  - *Dip coating*
  - *Fibre spraying*
  - *Infusion of fabric*

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Development of Re-treatment Process

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Code	Binder	Fabric Pre-Wash	Formulation % solids (wt/wt)	Coat Weight (wt/wt)	Coating Method
11	Low Viscosity Poly Vinyl Acetate Ethylene Dispersion	Acetone	0.95%	0.9%	Dip
12	Low Viscosity Poly Vinyl Acetate Ethylene Dispersion	1,3-Dioxolane then Acetone	0.95%	0.9%	Dip
13	Low Viscosity Poly Vinyl Acetate Ethylene Dispersion	None	0.95%	0.8%	Dip
14	Low Viscosity Poly Vinyl Acetate Ethylene Dispersion	Acetone	1.73%	1.0%	Infusion
15	High Viscosity Poly Vinyl Acetate Ethylene Dispersion	Acetone	0.95%	0.9%	Dip
16	High Viscosity Poly Vinyl Acetate Ethylene Dispersion	Acetone	1.71%	1.1%	Infusion
17	High Viscosity Poly Vinyl Acetate Ethylene Dispersion	Acetone	0.85%	0.7%	Infusion
18	High Viscosity Poly Vinyl Acetate Ethylene Dispersion	None	1.71%	0.98%	Infusion
19	Low Viscosity Poly Vinyl Acetate Ethylene Dispersion	None	2.26%	1.12%	Infusion

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Development of Re-treatment Process

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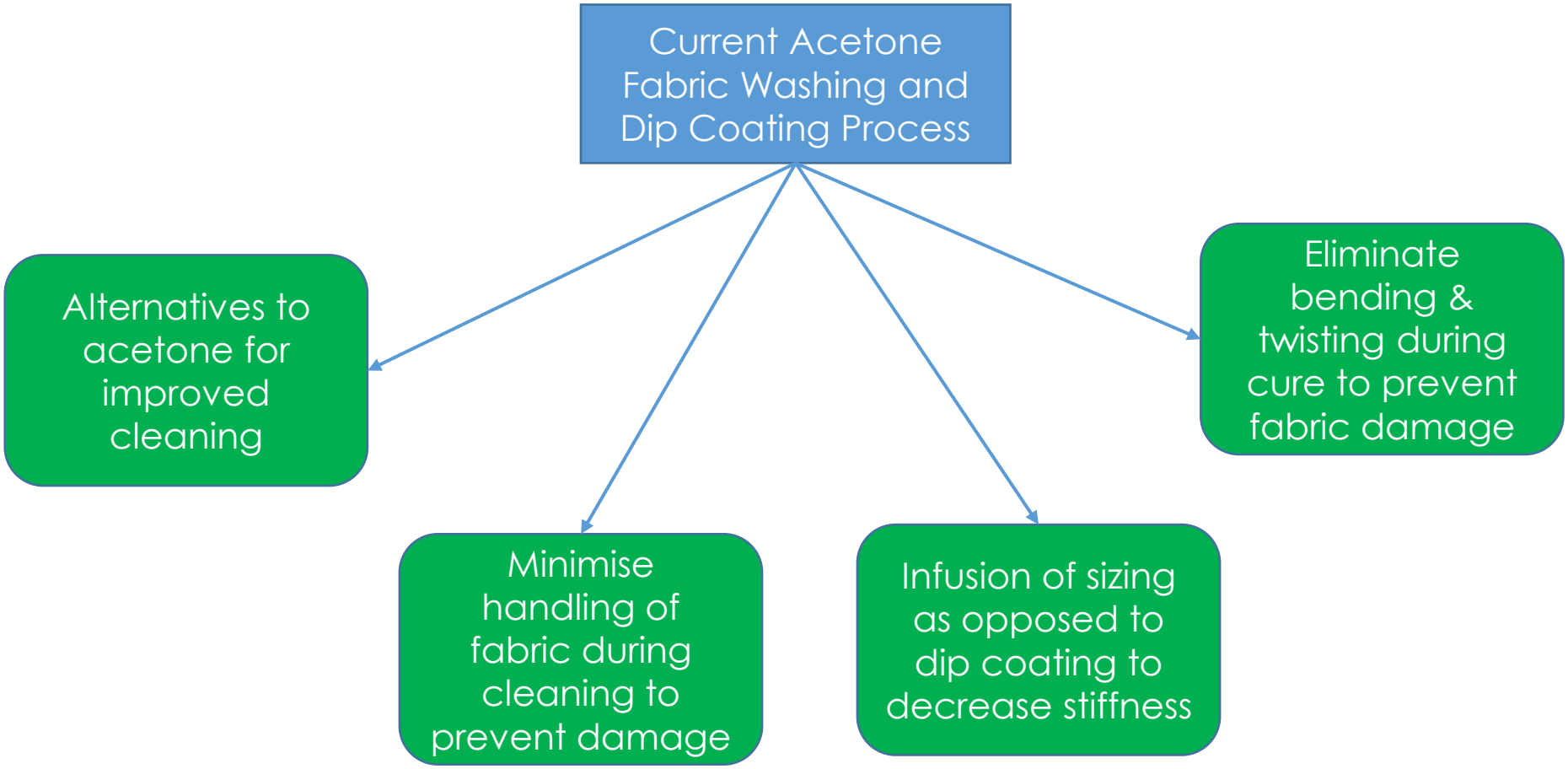

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Single Fibre Fragmentation Geometry

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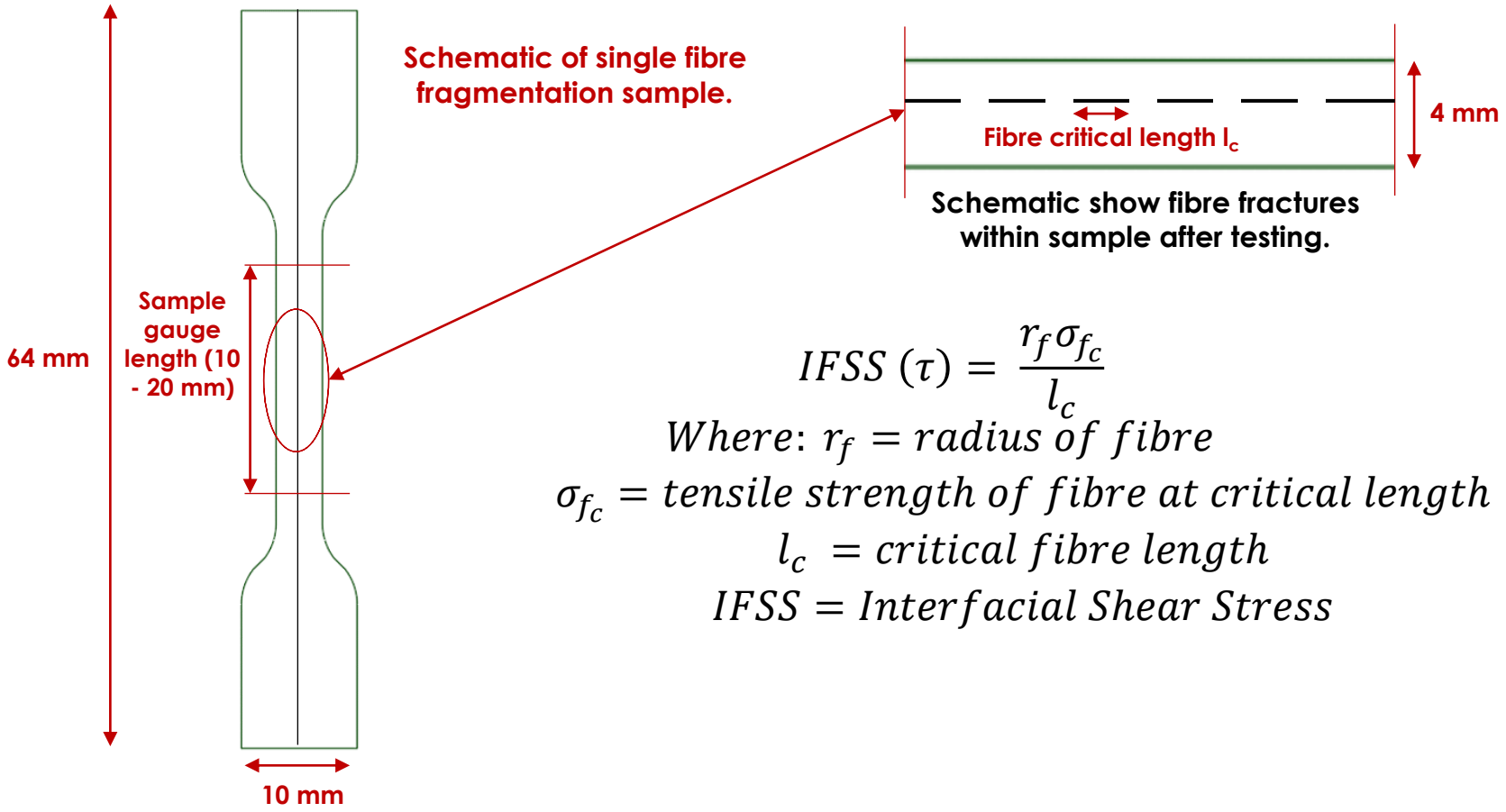

$$IFSS\ (\tau) = \frac{r_f \sigma_{f_c}}{l_c}$$

$$Where:\ r_f = radius\ of\ fibre$$

$$\sigma_{f_c} = tensile\ strength\ of\ fibre\ at\ critical\ length$$

$$l_c = critical\ fibre\ length$$

$$IFSS = Interfacial\ Shear\ Stress$$

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SFFT Sample Manufacture

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Fragmentation mould prior to sealing and addition of resin

Sealed fragmentation mould with resin and fibres

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SFFT Sample Manufacture

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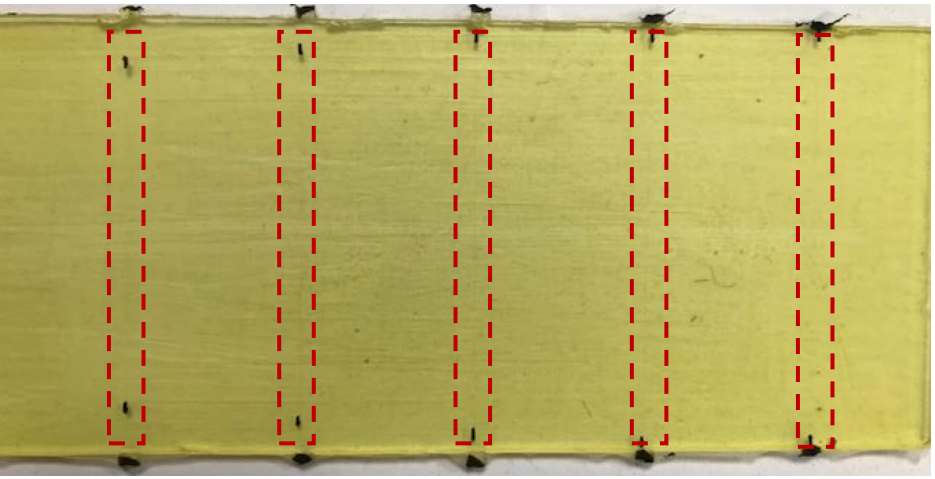
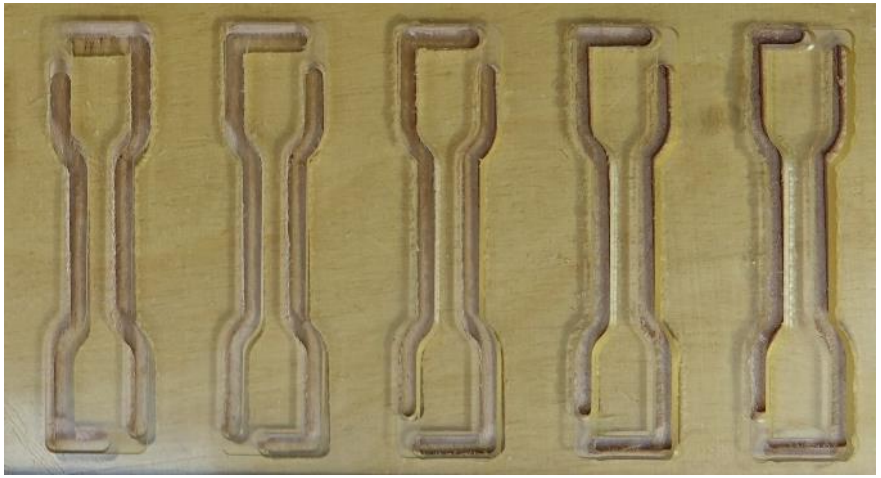
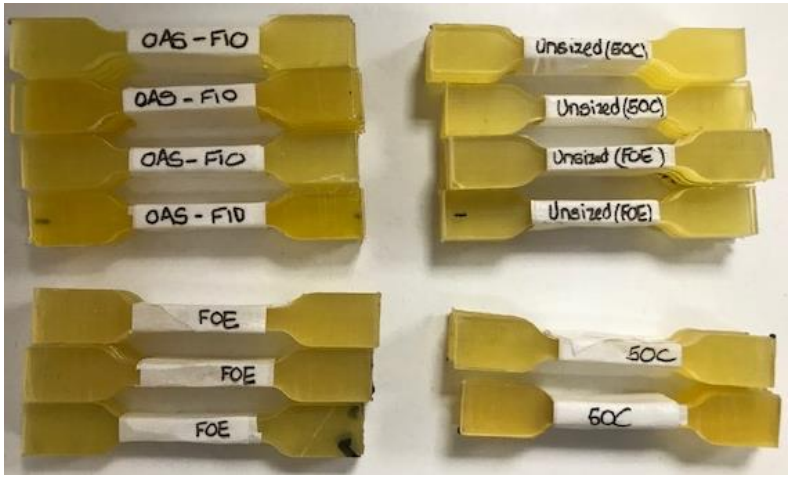


Elium® plaque containing fibres prior to machining



Fragmentation samples after CNC machining

Fragmentation samples prepared for testing



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Single Fibre Fragmentation Test

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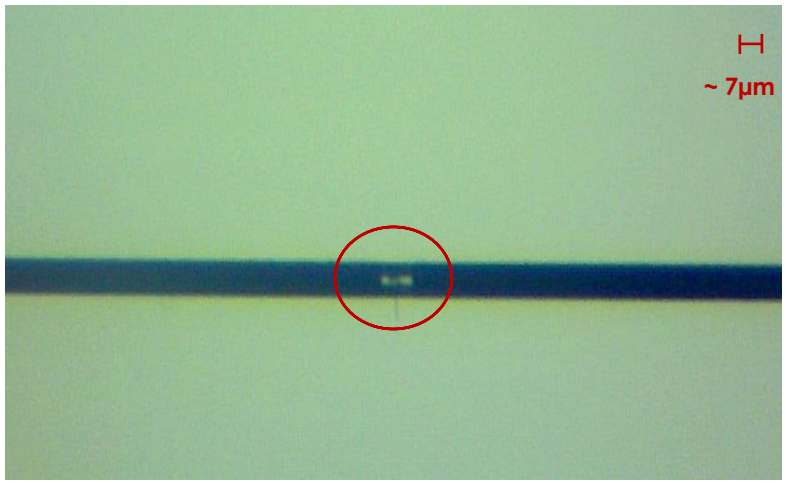
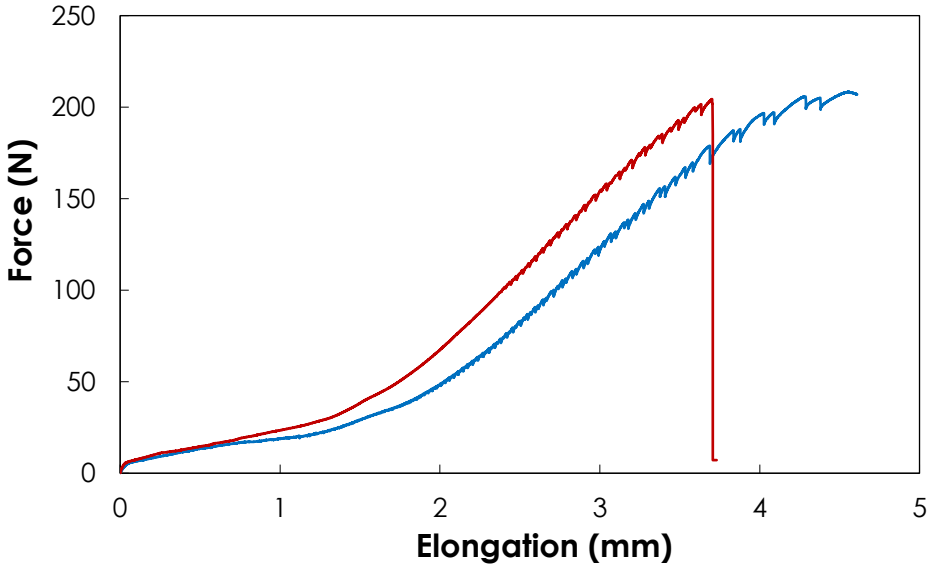
- Testing conducted using a Testometric M500 machine, equipped with 1 kN load cell and specialized grips for testing SFFT samples
- In-house environmental chamber constructed to allow for testing at ~ 50 °C



Microscope photo at 250x magnification with fibre breakage highlighted.



Force-displacement plot for fragmentation tests

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Single Fibre Fragmentation Test

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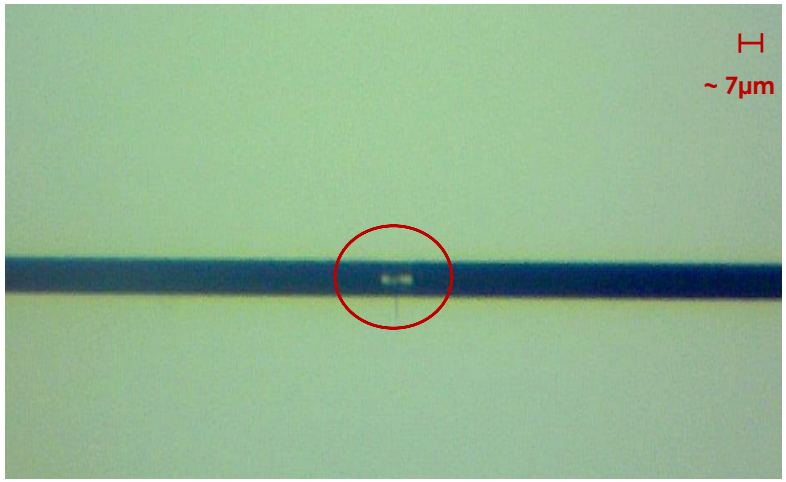
- Samples tested until saturation observed, with 10 mm & 20 mm gauge lengths studied per sample
- Fragmentations within gauge observed via microscopy following testing



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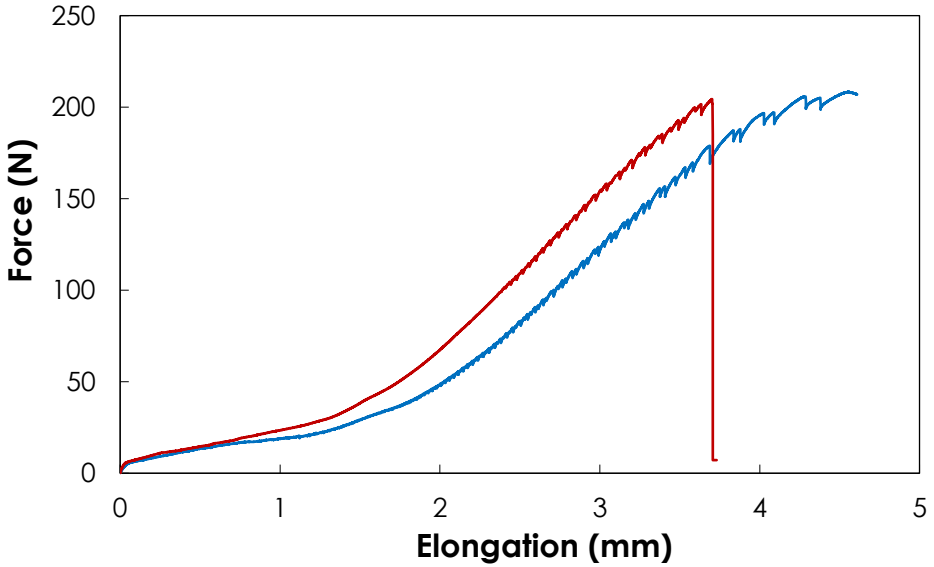

Force-displacement plot for fragmentation tests

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Results: IFSS (10 mm Gauge)

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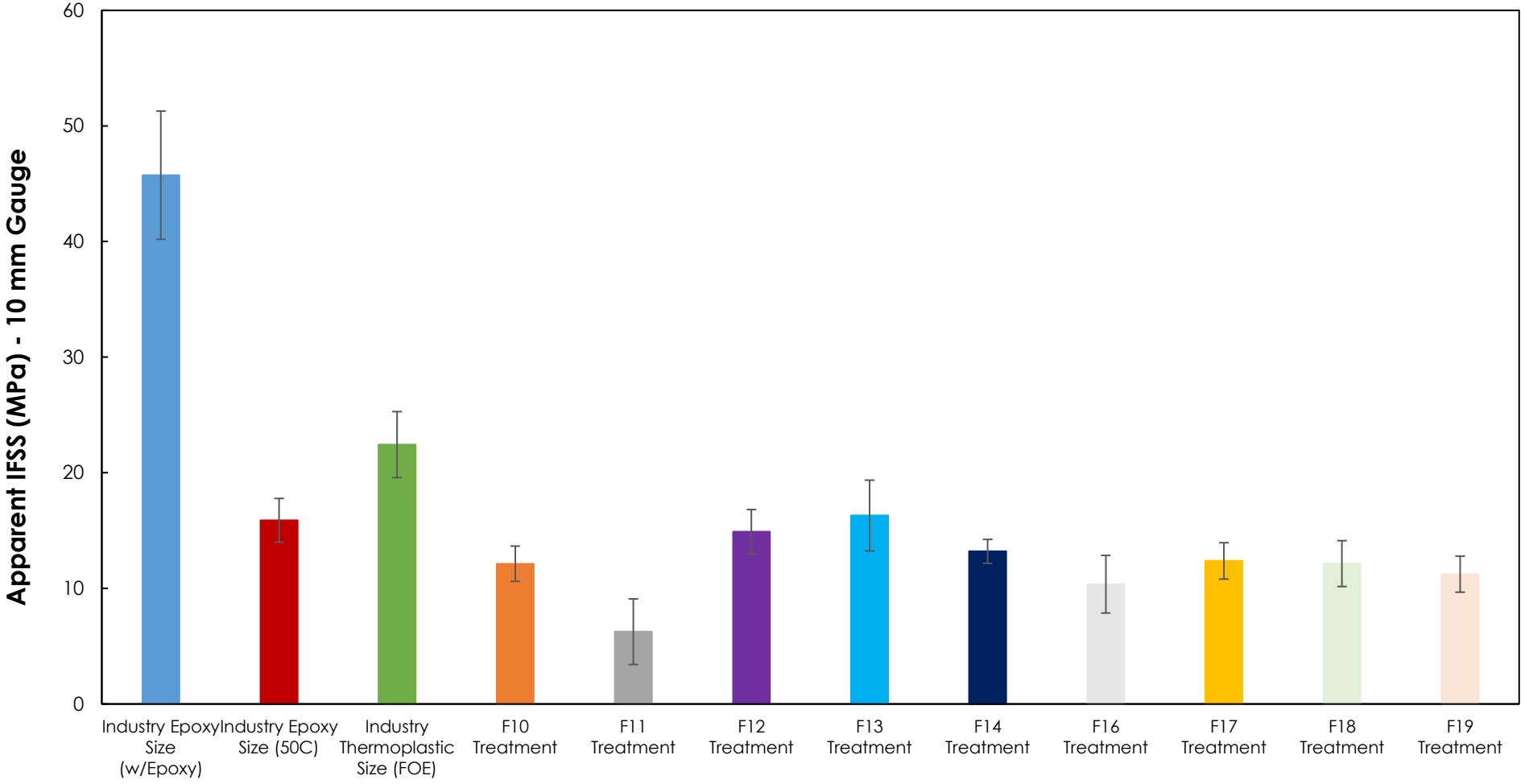

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Results: IFSS (20 mm Gauge)

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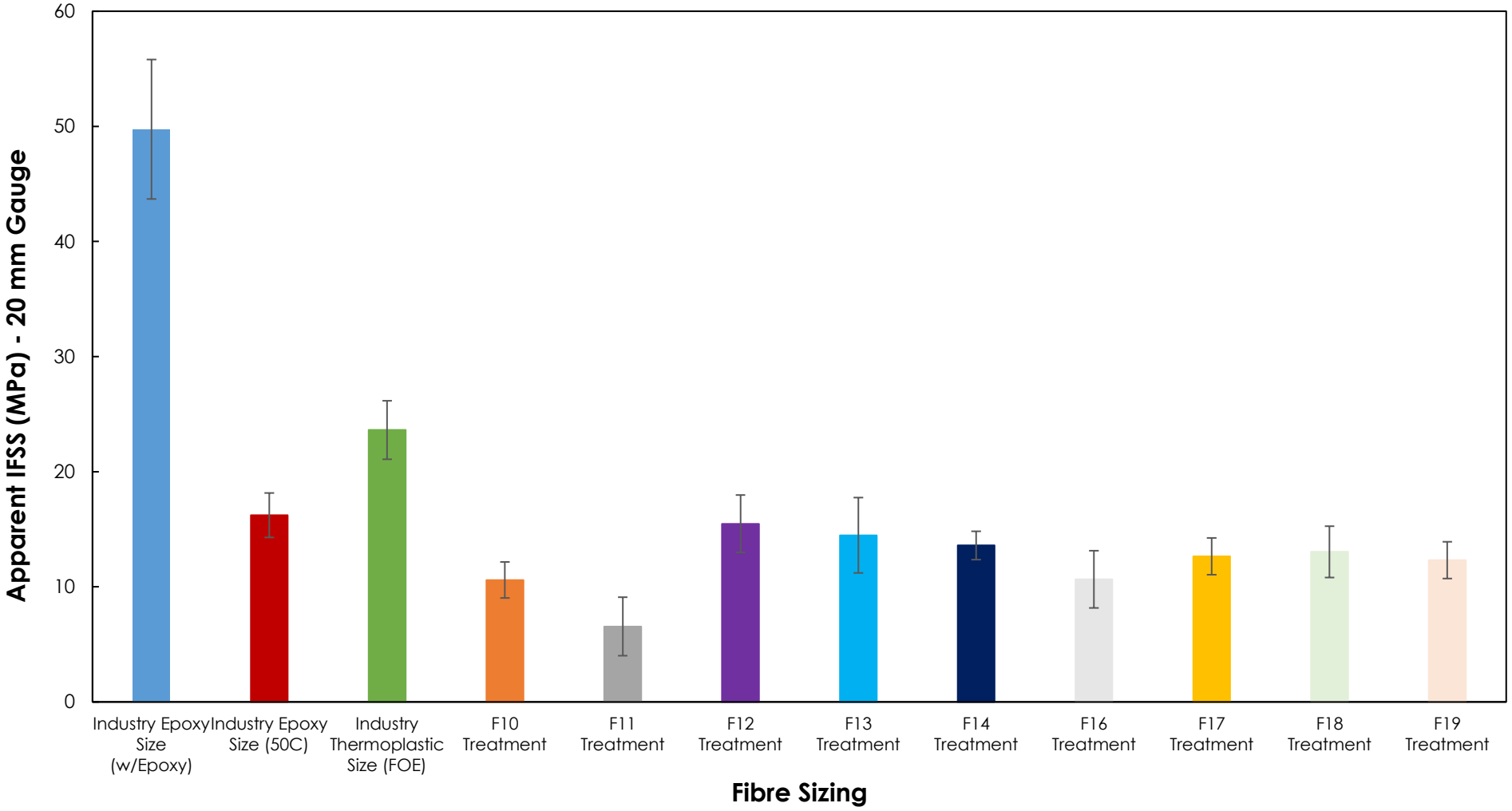

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Observations

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- Location of fragments on re-treated fabric/fibre samples were inconsistent, with localised areas containing multiple fragments whilst the rest of the fibre contained none
  - *Suggests inconsistencies with coating application & issues with acetone solvent consistency*
- Fibre diameter values for re-treated fabric/fibre samples were consistently larger than for the 'as-received' commercial samples
  - *Hypothesised that this extra diameter is from the coating process*
- Commercially thermoplastic sized fibres observed to possess highest IFSS with Elium®
- Adhesion between fibre & thermoplastics still seems to be lagging behind comparable thermosets

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Conclusions

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- Results presented show that that the IFSS was strongly dependent on the sizing chemistry applied with the commercial thermoplastic sizing applied providing the largest respective IFSS
- Degree of adhesion observed for a thermoplastic polymer bonded to a fibre coated in a thermoplastic sizing was lesser than the equivalent epoxy combinations
- Whilst the IFSS values for the re-coated fibres were observed to be smaller, this may have been more down to the removal of the initial sizing, and re-coating process for the fibre in its 3D-woven form
- Challenges encountered may mirror those when investigating recycled fibres, given these too will require the development of scalable re-treatment processes

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Next Steps

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- Building on the presented work:
  - Further study of Elium® with commercially sized glass & carbon fibres
  - Surface analysis of re-treated fibres via SEM & XPS
  - Interface investigation utilising different micro & macro-mechanical methods
  - Investigation of re-coating techniques specifically with recycled fibres

- My Research Pillars after returning to Strathclyde:
  - *Fibre-matrix interface characterisation/optimisation of new, sustainable fibre/polymer combinations*
  - *Development and characterisation of fibre sizings*
  - *Composite surface adhesion for multi-material structures*
  - *Composite meta-materials*

ACG Advanced Composites Group

http://www.strath.ac.uk/compositematerials/

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Thank you

Any Questions?