Fracture behaviour and damage characterisation in composite impact panels by laboratory X-ray computed tomography

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Fracture Behaviour and Damage Characterisation in Composite Impact Panels by Laboratory X-ray Computed Tomography

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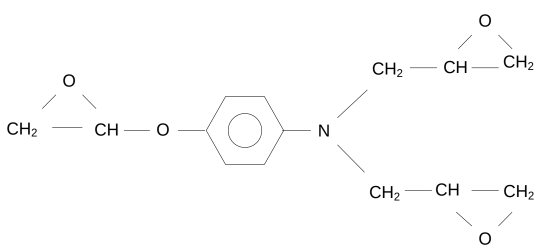
Outline

- Introduction
  - Overview
- Experimental procedures
  - Materials
  - Manufacturing
  - Characterisation (SENB fracture, Mode-I ILFT, XCT)
- Results
  - Plane-Strain Fracture Toughness of Matrices
  - XCT of As-prepared Panels
  - Mode I Interlaminar Fracture Toughness
  - Impact Behaviour
  - XCT of Impact Damage
- Conclusions

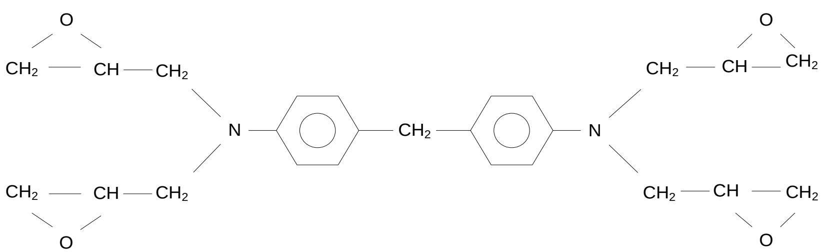
Base system

- Base System
  - Formulated using Factorial Experiment Design (FED) based on;
    - T_g
    - Heat of reaction
    - Viscosity
  - Chemical structures;

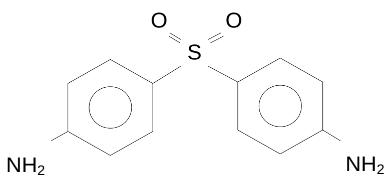
(a) TGAP (Araldite® MY0510, Huntsman)



(b) TGDDM (Araldite® MY721, Huntsman)



(c) DDS (Aradure® 976-1, Huntsman)



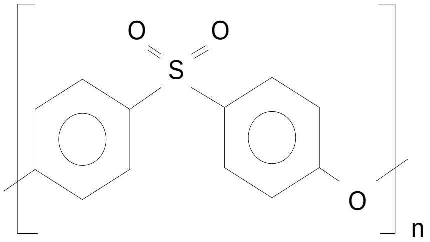
Toughening agents

- PES

  (a) Reactive high molecular weight (47k) - Virantage® **VW10200 RFP,** Solvay

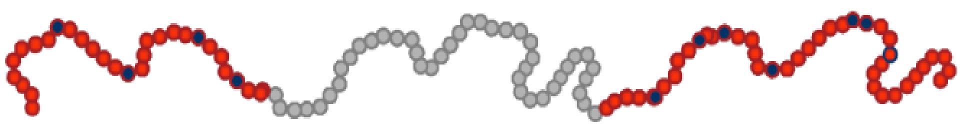
  (b) Reactive low molecular weight (21k) - Virantage® **VW10700 RFP ,** Solvay

  (c) Non-reactive medium molecular weight (36k) - Virantage® **VW10300 FP ,** Solvay



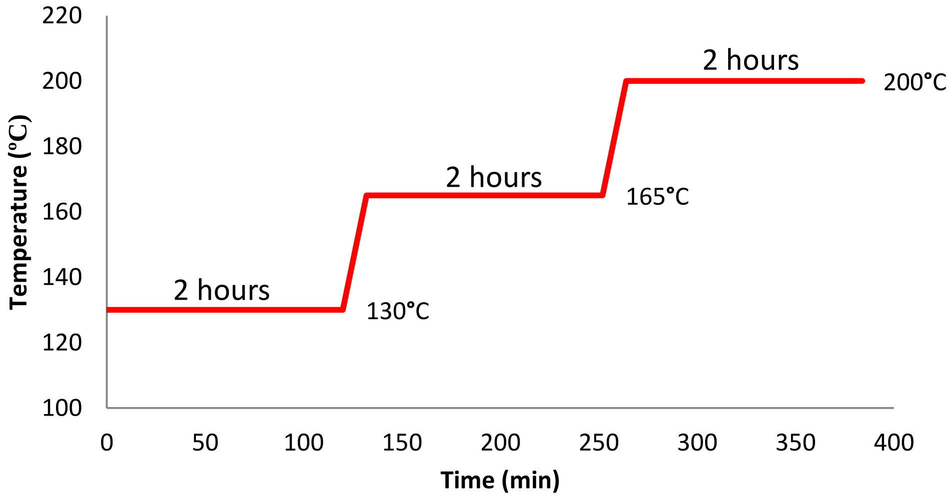
- Tri-block copolymer (dimethylacrylamide-modified) MAM

  (a) Functional MAM -Nanostrength® M52N NP, Arkema

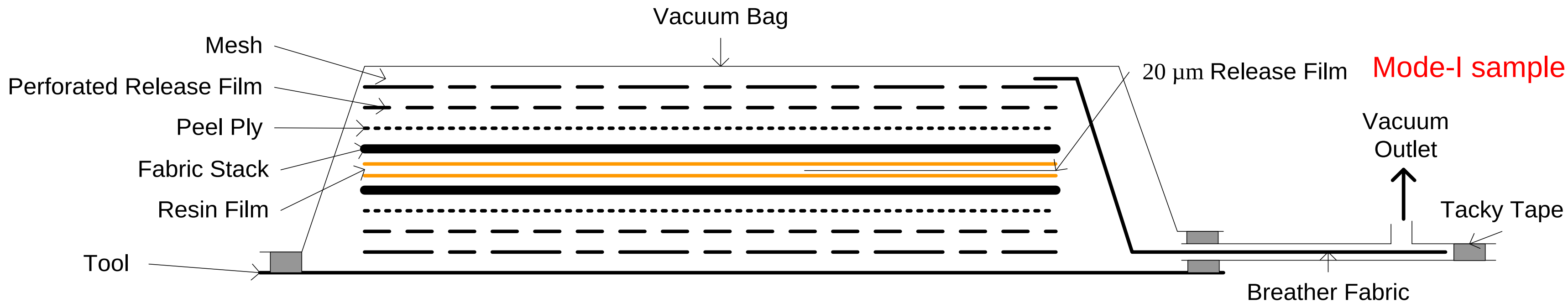


Cure cycle optimisation and RFI

- Cure cycle
  - Optimised cure cycle based on the degree of cure of the neat resin
  - Degree of cure > 95 %



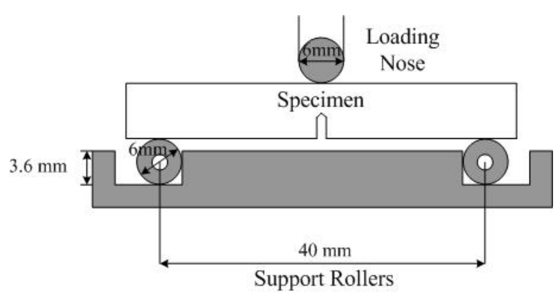
- Resin Film Infusion (RFI)



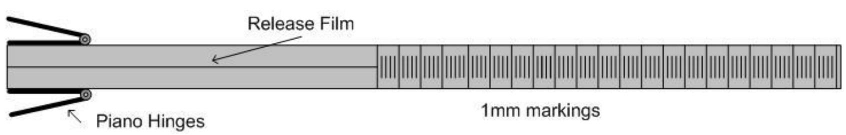
Stacks [90, 0, 90, 0] of UD carbon fibre fabric, of 445 gm^{-2}(Sigmatex, UK).
12k carbon tows bound by a fine glass fibre weft yarn at ≈ 6 mm intervals

Techniques

- XCT
  - Nikon Metrology 225/320 kV Custom Bay (see www.mxif.manchester.ac.uk)
- Impact
  - Instron Ceast 9350 Drop Tower
  - 89 mm x 55 mm, energies 5,10,15, 20 J
- Plane-Strain Fracture Toughness -K_{Ic}
  - ASTM D5045
  - 44 mm x 10 mm x 5 mm
  - at 10 mm/min crosshead speed



- Acid digestion – void volume %
  - ASTM D3171
  - Matrix digestion using sulfuric acid/ hydrogen peroxide
  - Specimen size ≈1 g
- Mode I Interlaminar Fracture Toughness- G_{Ic}
  - ASTM D5528
  - 125 mm x 25 mm x 5 mm
  - at 0.75 mm/min crosshead speed

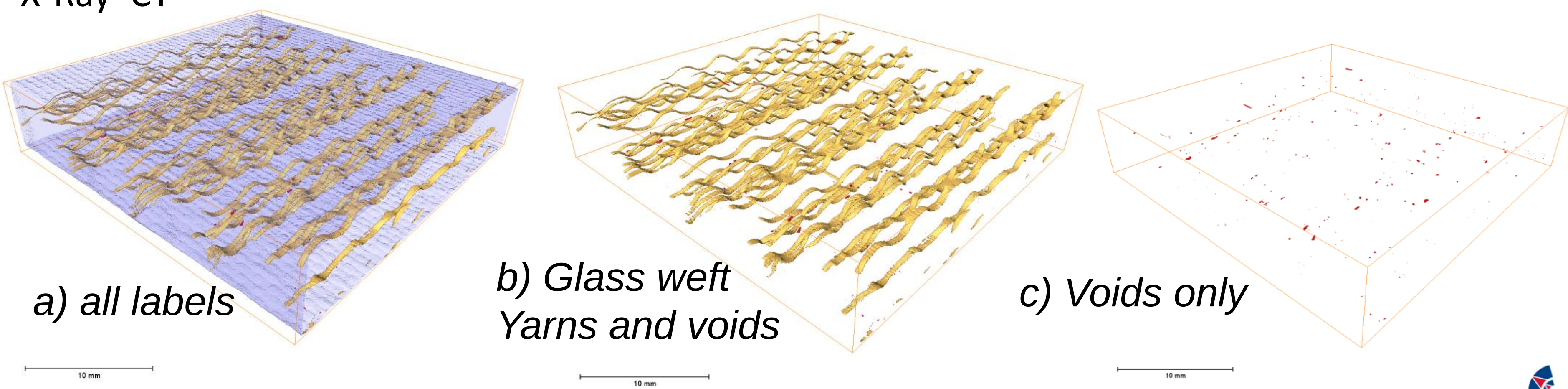


Composites

Table 1: Acid digestion results of manufactured laminates.

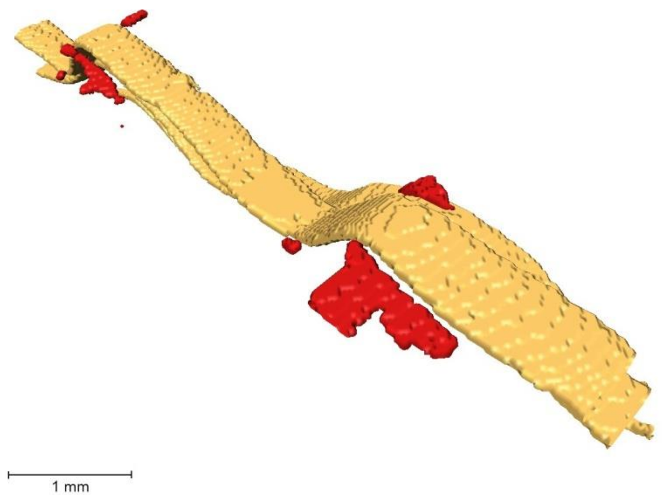
Laminates with	Additive wt. %	Fibre Content Vol. %	Void Content Vol. %
Neat Resin	0	68.4 ± 0.4	0.67 ± 0.10
RHMW PES	10	67.4 ± 2.0	1.23 ± 0.26
NRMMW PES	10	68.9 ± 0.1	1.35 ± 0.32
RBCP	5	69.6 ± 0.5	2.09 ± 0.05

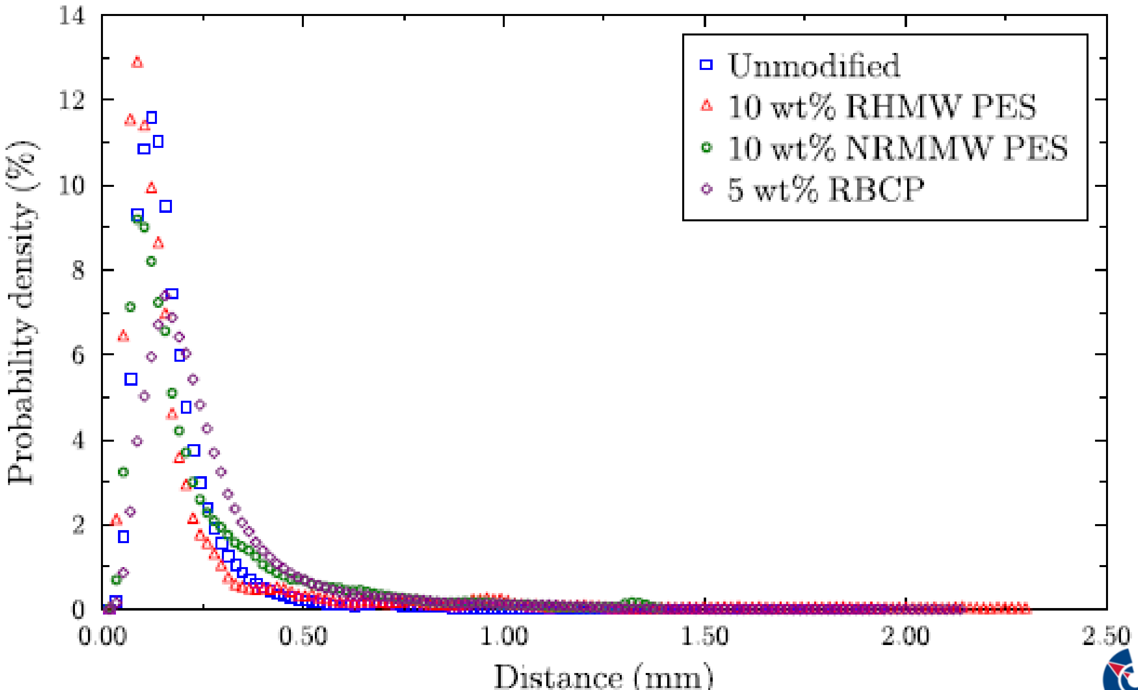
X-Ray CT



Examples of segmentation: matrix (blue), yarn (yellow), and pores (red) (10 mm scale bar).

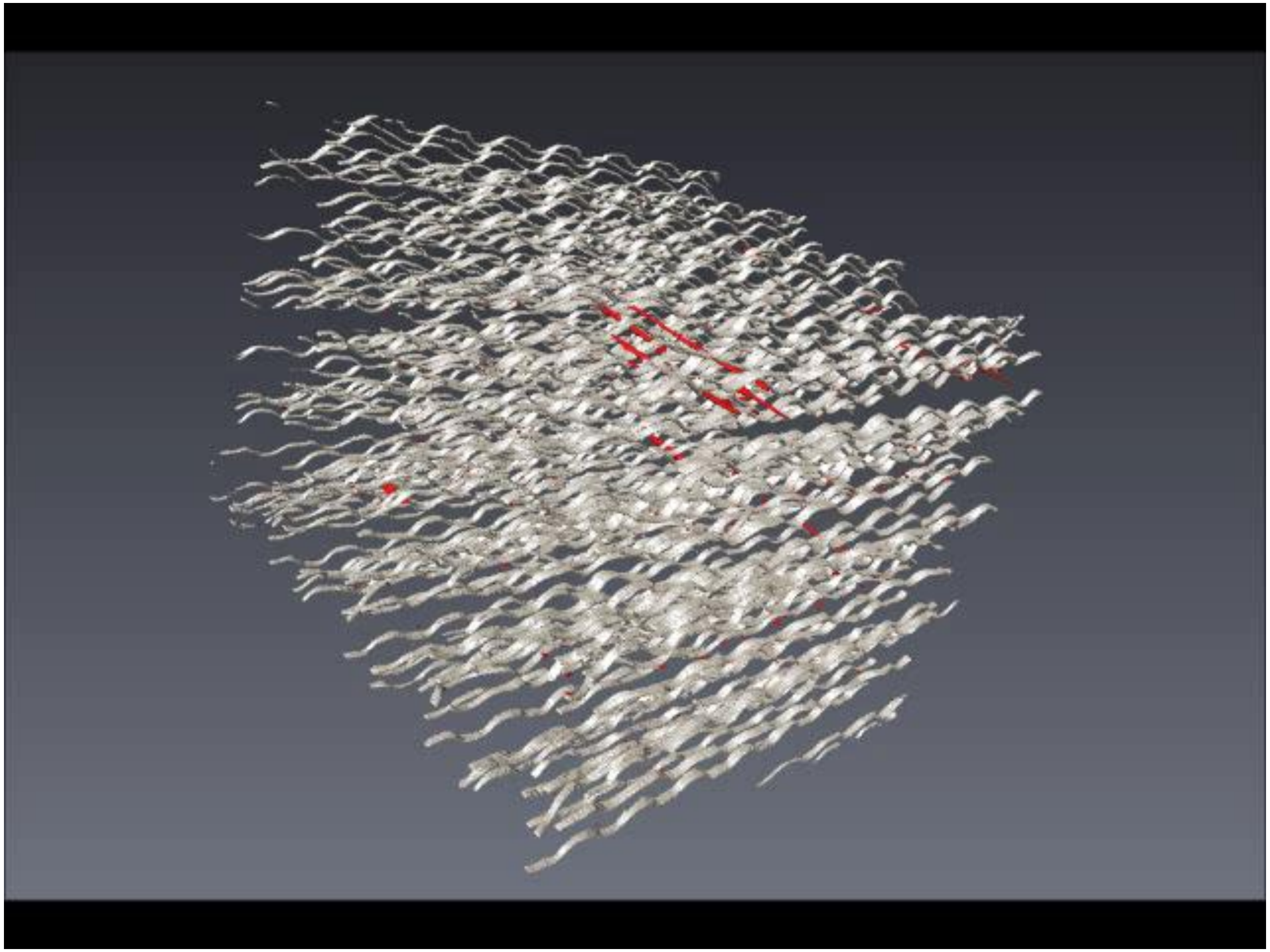
XCT statistical analysis of void positions



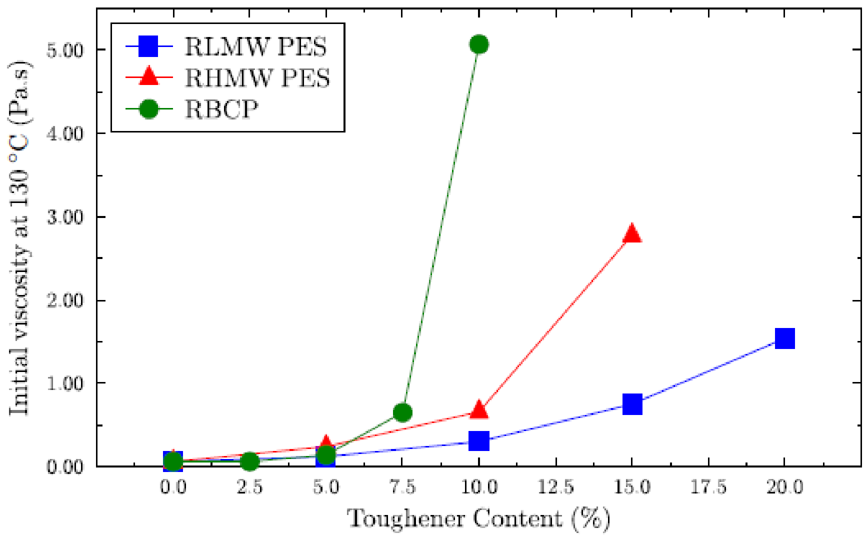


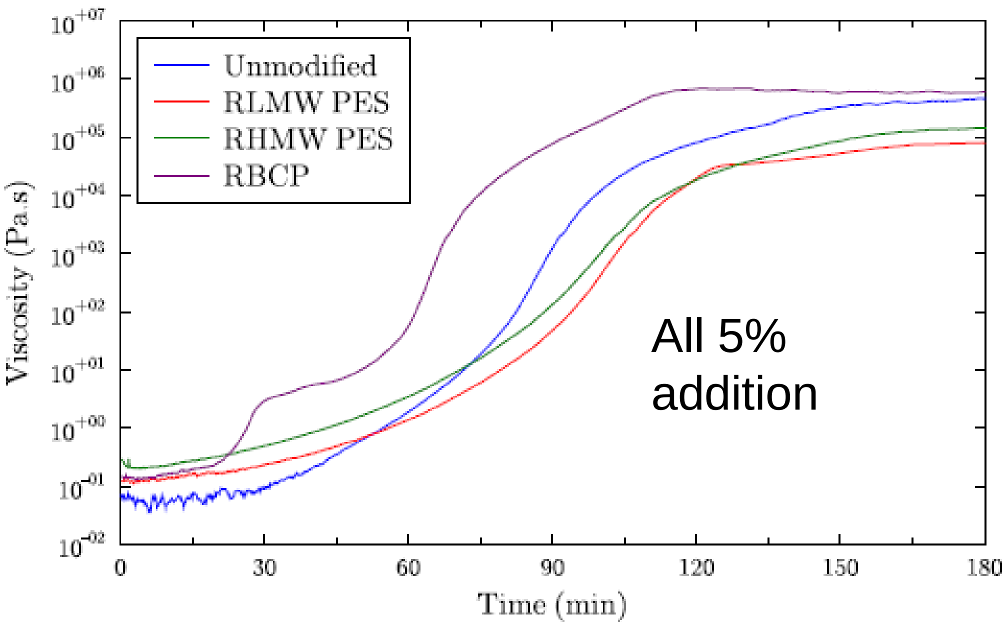
Probability density - void to yarn distance

XCT

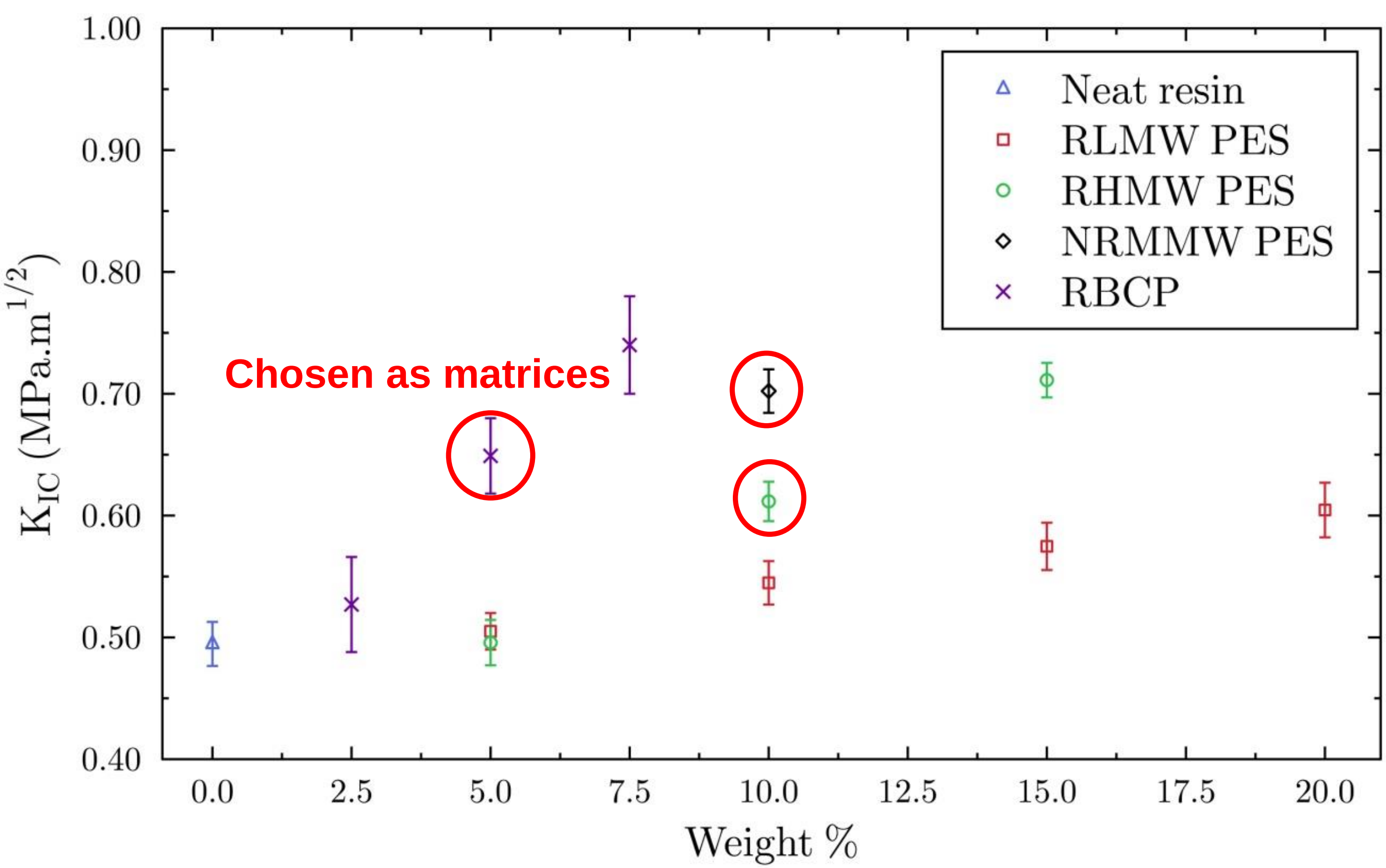


Comparative Rheology



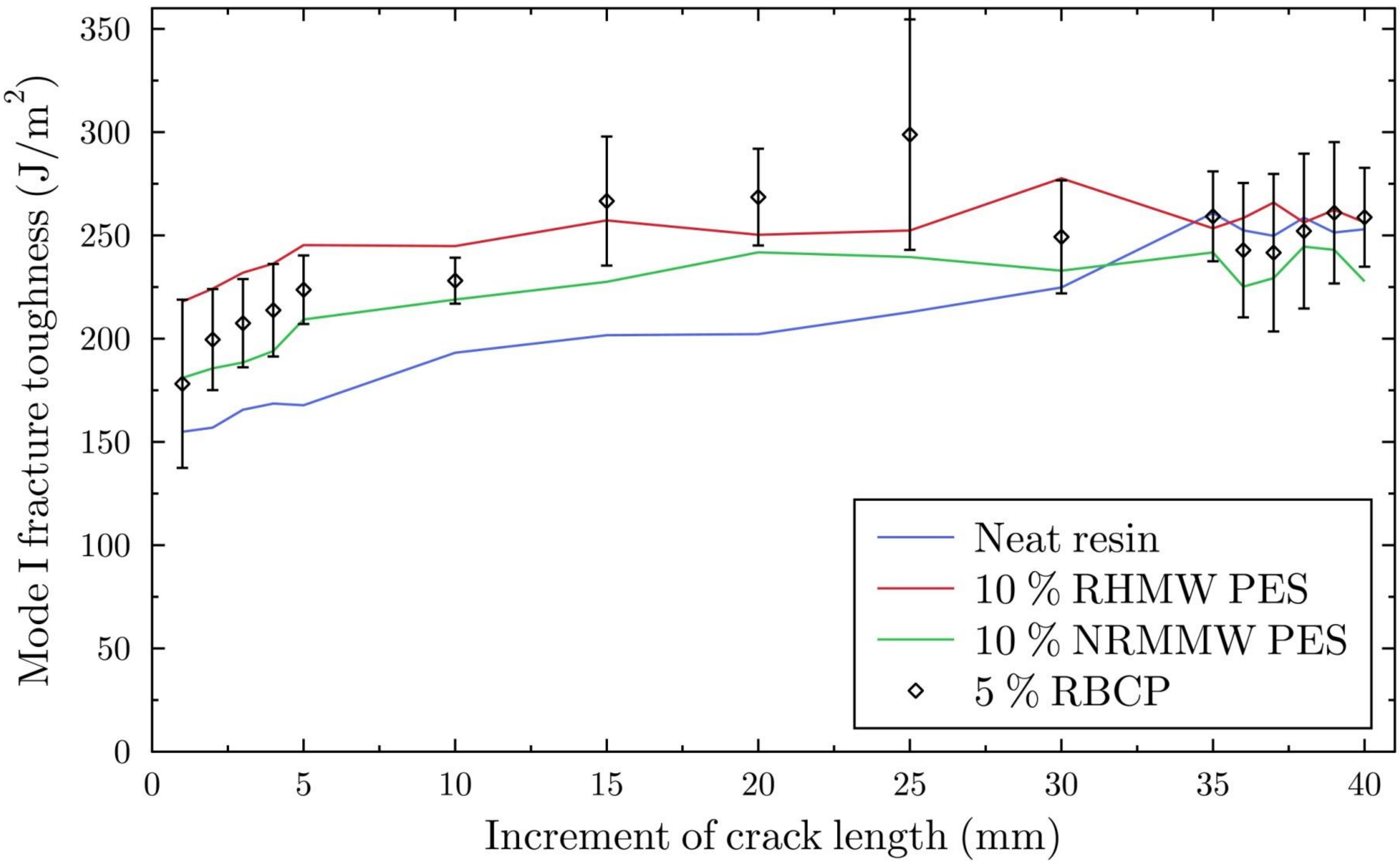


Plane-Strain Fracture Toughness of Bulk Matrices -K_{Ic}

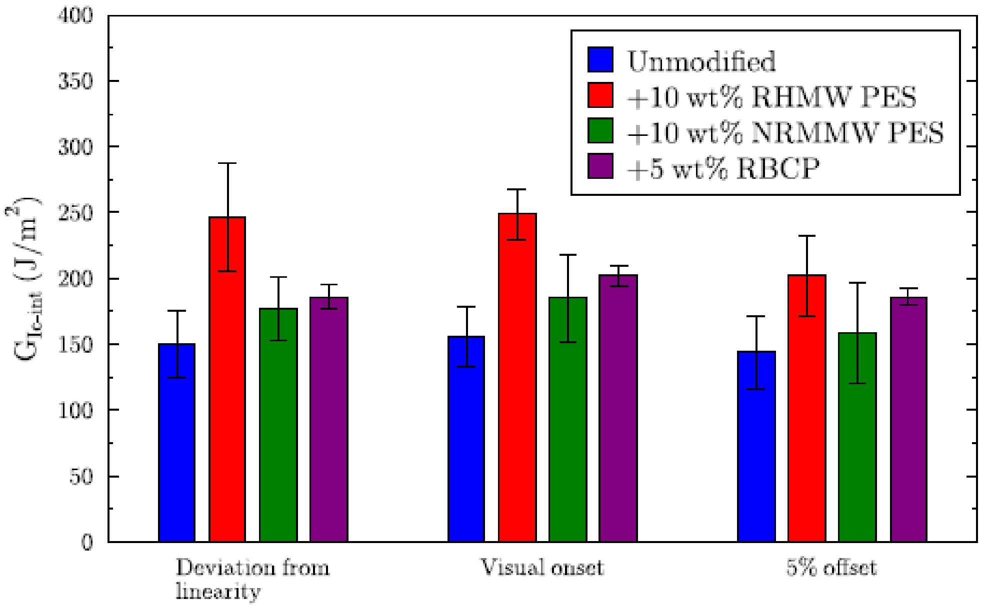


- Molecular weight ↑ - toughening effect ↑
- Reactivity - toughening effect ↓
- Tri-block copolymer has the greatest effect

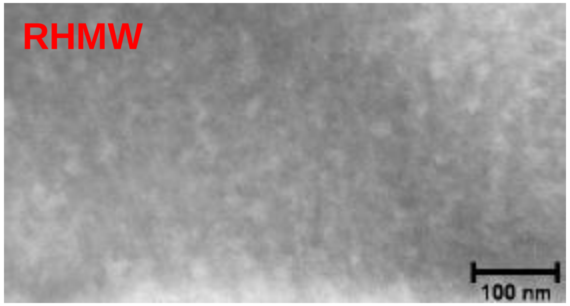
Mode I Interlaminar Fracture

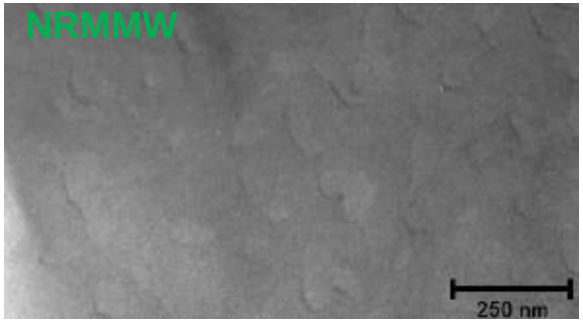


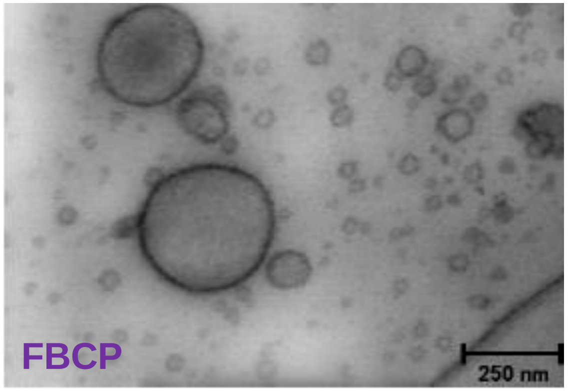
Mode I Interlaminar Fracture



Mode-I initiation G_{IC} values





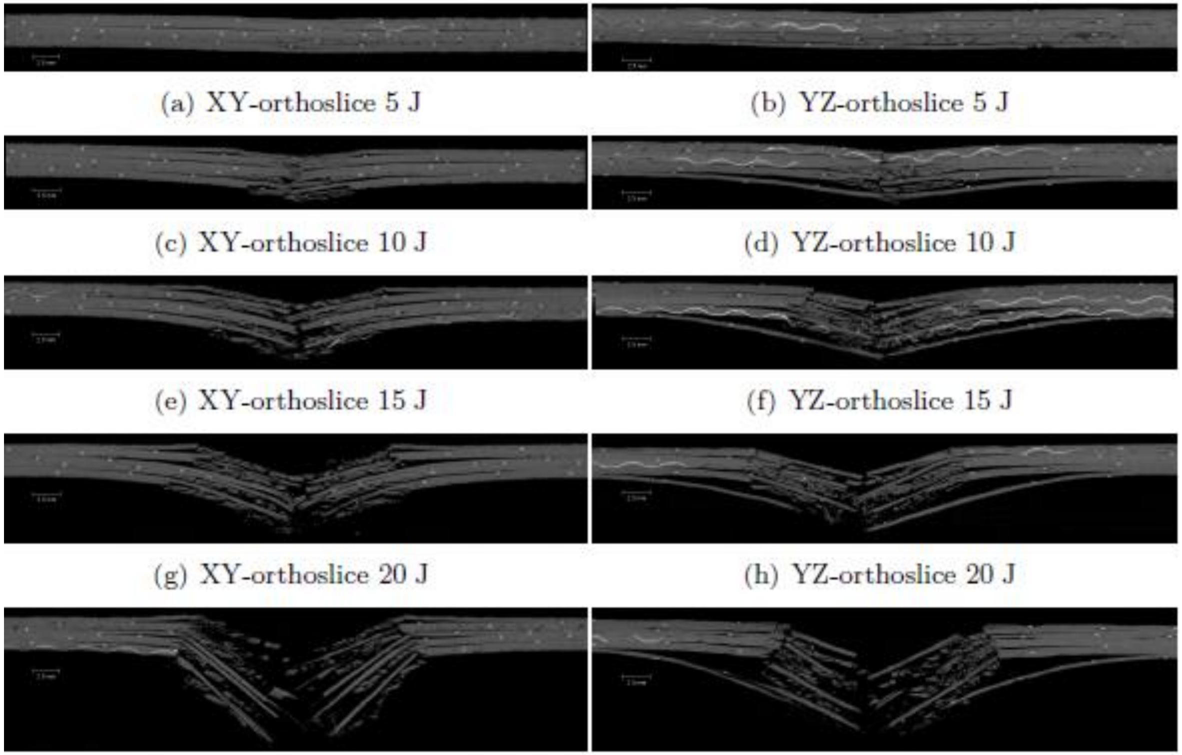


Mean Mode-I propagation values

Matrix Resin	Mean $G_{Ic-prop}$ (J/m^2)
Unmodified	211 ± 40
+ 10 *wt*% RHMW PES	249 ± 16
+ 10 *wt*% NRMMW PES	221 ± 22
+ 5 *wt*% RBCP	241 ± 31

Results

Impact

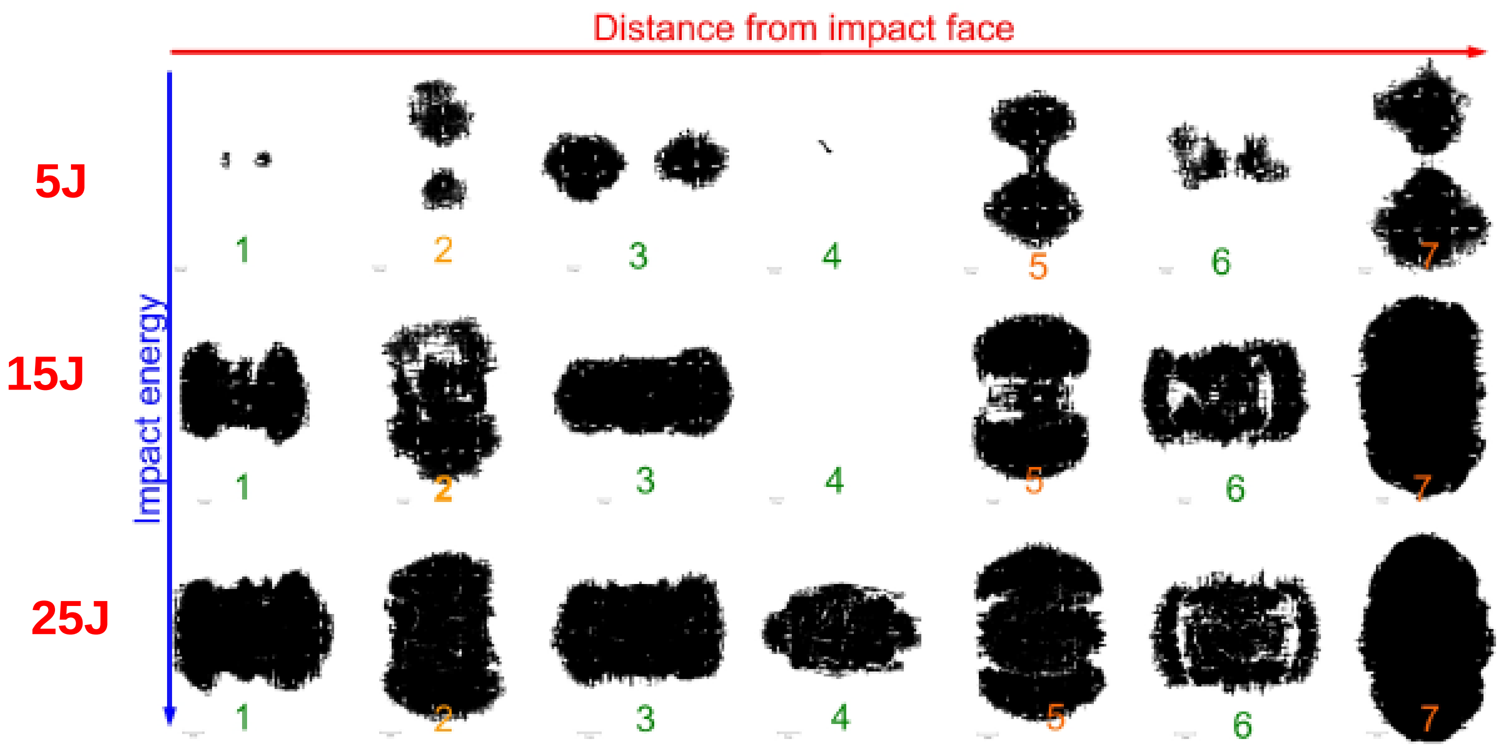


(a) XY-orthoslice 5 J (b) YZ-orthoslice 5 J
(c) XY-orthoslice 10 J (d) YZ-orthoslice 10 J
(e) XY-orthoslice 15 J (f) YZ-orthoslice 15 J
(g) XY-orthoslice 20 J (h) YZ-orthoslice 20 J
(i) XY-orthoslice 25 J (j) YZ-orthoslice 25 J

Cross-sectional orthoslice views (XZ, YZ) – unmodified resin system

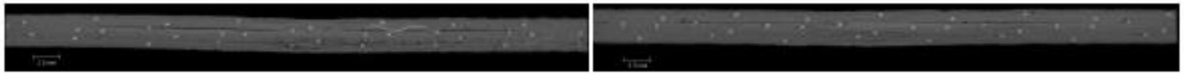
Results

Impact

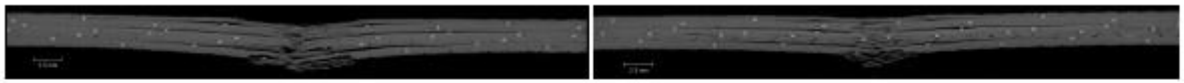


Interfacial damage area progression with impact energy. The numbers indicate the interlaminar regions below the impacted face – unmodified resin system

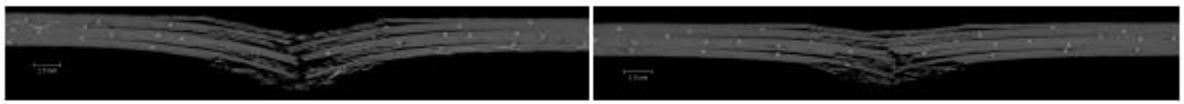
Impact



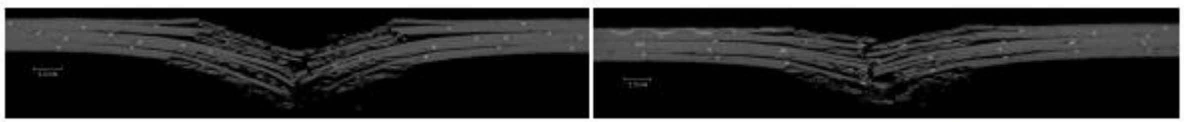
(a) 5 J unmodified (b) 5 J +5$wt\%$ RBCP



(c) 10 J unmodified (d) 10 J +5$wt\%$ RBCP

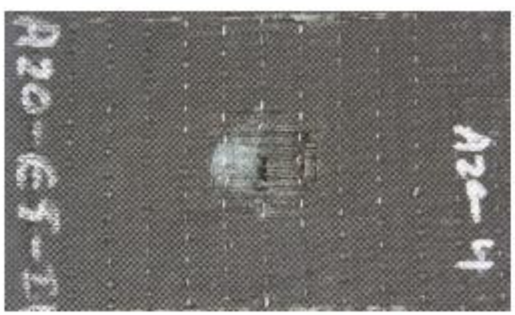


(e) 15 J unmodified (f) 15 J +5$wt\%$ RBCP



(g) 20 J unmodified (h) 20 J +5$wt\%$ RBCP

Unmodified resin FBCP modified resin



(a) Front unmodified

15J

(b) Back unmodified

(e) Front +5$wt\%$ RBCP

15J

(f) Back +5$wt\%$ RBCP

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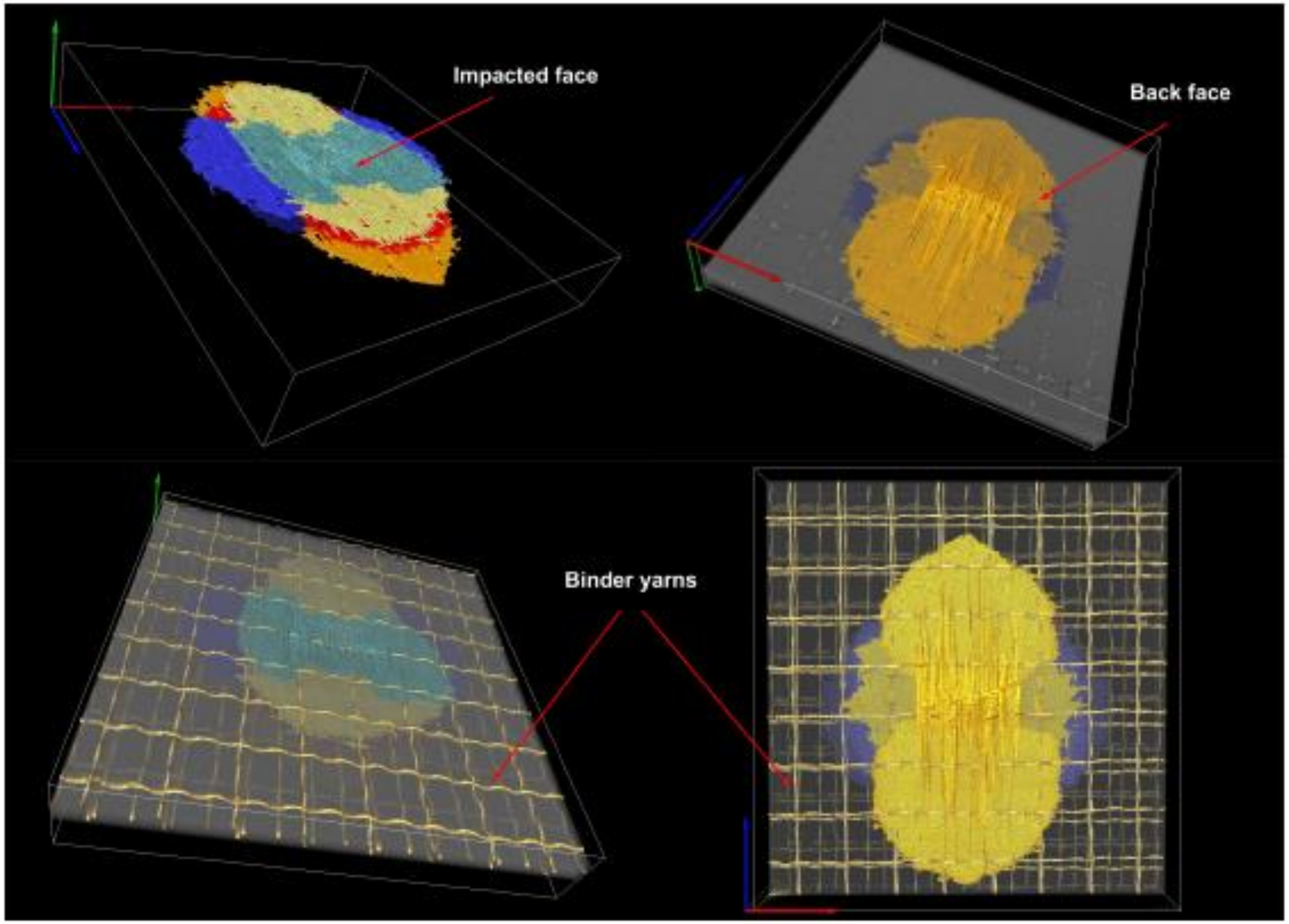
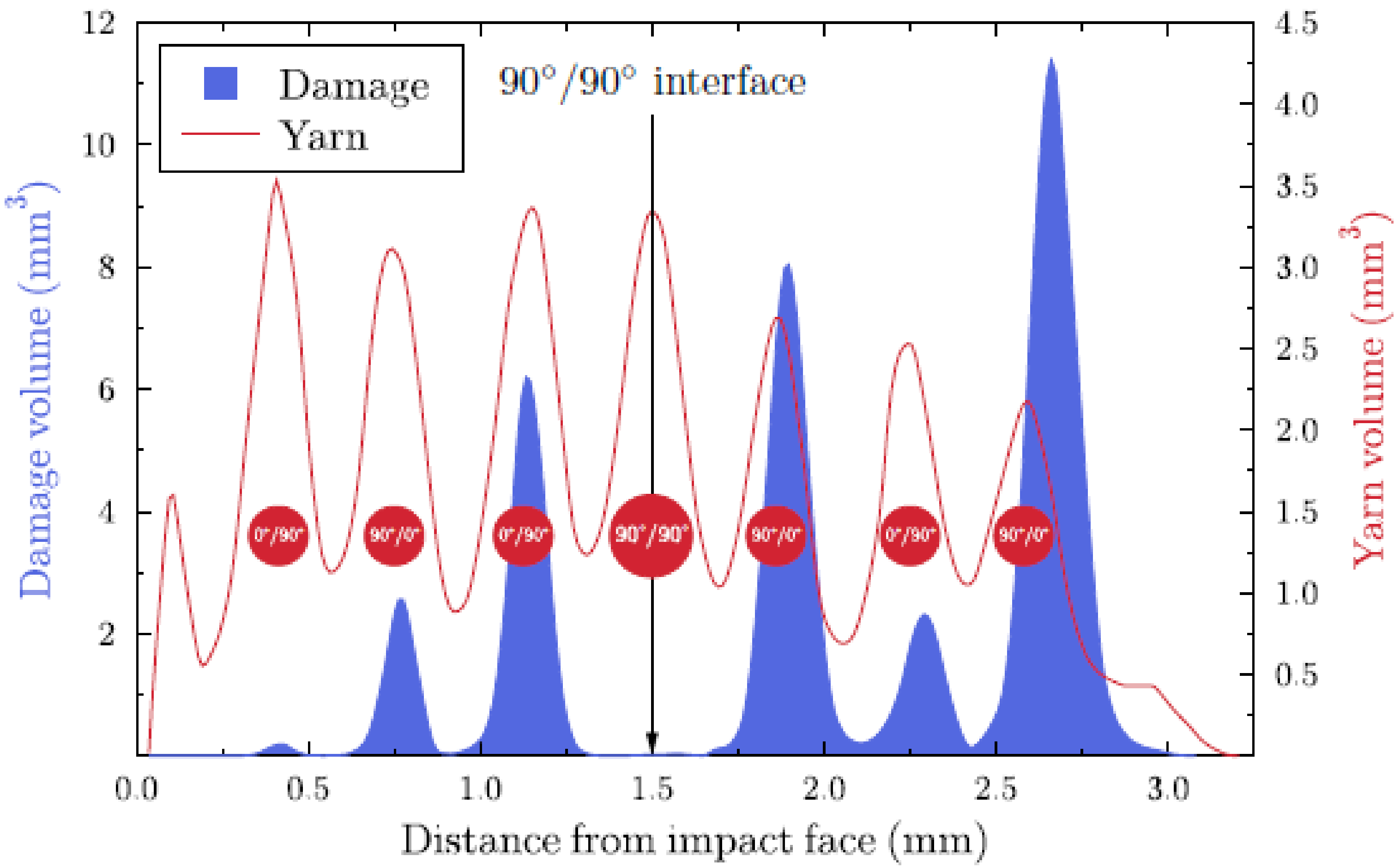
Impact

FBCP
15J



3-D view of impact damage; each interfacial damage is given a different colour

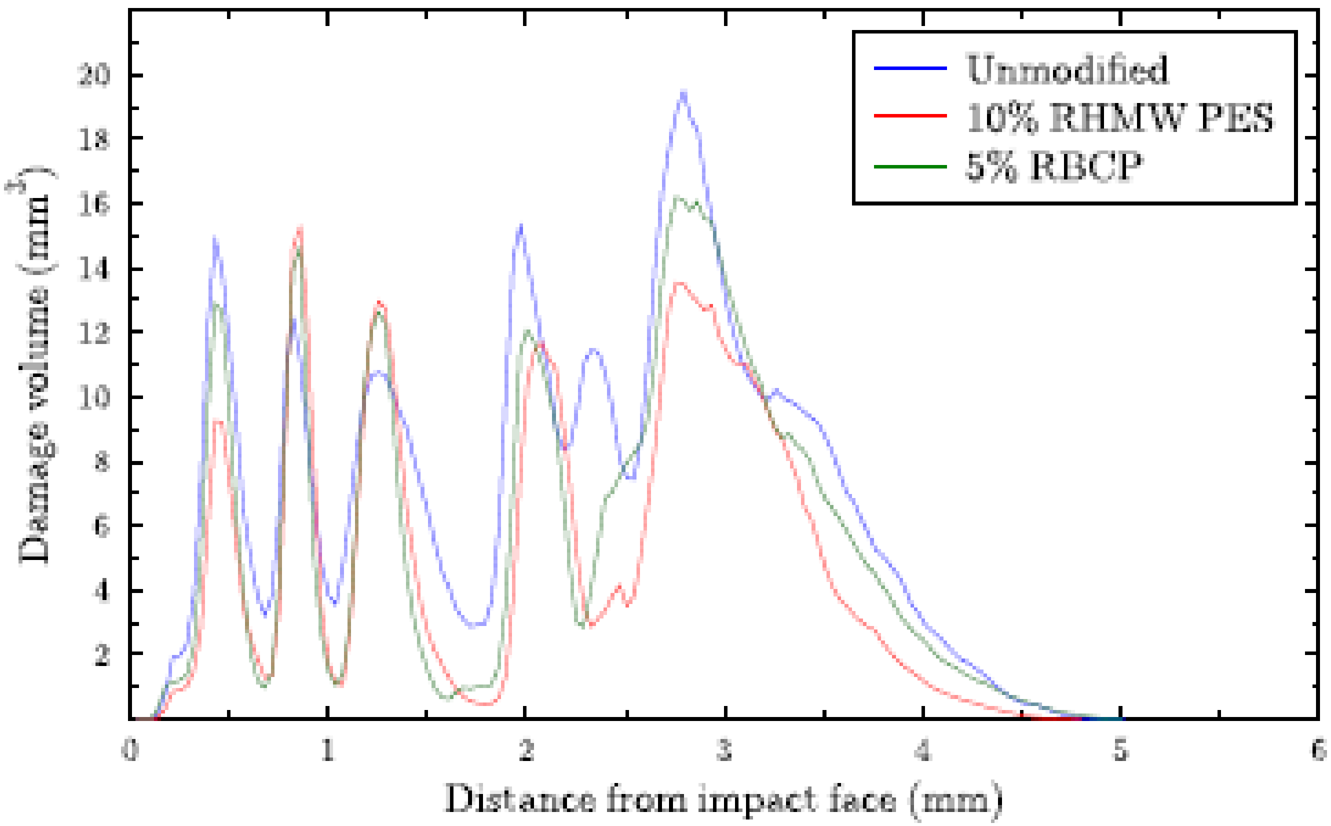
Impact



Damage volume vs. distance from impact face - unmodified resin 15J

Results

Impact



Damage volume vs. distance from impact face - different matrices 15J

Conclusions

- XCT can provide extension information on voids in as-prepared composites and on damage in impacted composites.
- In the bulk matrix systems, FBCP imparted superior toughness than PES.
- In interlaminar fracture and impact testing differences due to matrix fracture toughness become less clear.

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