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DOI: 10.6084/m9.figshare.902203

Link to publication record in Manchester Research Explorer

Citation for published version (APA):

Wilkinson, A., Stein, J., Withers, P., & Leonard, F. (2013). Fracture behaviour and damage characterisation in composite impact panels by laboratory X-ray computed tomography. In *Thermosets 2013: From Monomers to Components* (pp. 69-71) https://doi.org/10.6084/m9.figshare.902203

Published in:

Thermosets 2013

Citing this paper

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

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Thermosets 2013 September 18th – 20th , Berlin







Engineering and Physical Sciences Research Council

Outline	Introduction O	Experimental procedures	$\begin{array}{c} {}_{Results} \\ \bigcirc \bigcirc$	Conclusion O
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



Outline O	Introduction O	Experimental procedures	Conclusion O
Materials			
_			

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)





Outline O	Introduction O	Experimental procedures	$\begin{array}{c} \text{Results} \\ \bigcirc $	Conclusion O
Materials				
Toughenir	ng 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





Outline O	Introduction O	Experimental procedures $\bigcirc igodot$	Conclusion O
Manufacturing			

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 \approx 6 mm intervals



Outline O	Introduction O	Experimental procedures $\bigcirc \bigcirc \bigcirc$	$\begin{array}{c} \text{Results} \\ \bigcirc $	Conclusion O
Characterisation				

Techniques

- XCT
 - Nikon Metrology 225/320 kV Custom Bay (see <u>www.mxif.manchester.ac.uk</u>)
- Impact
 - Instron Ceast 9350 Drop Tower
 - 89 mm x 55 mm, energies 5,10,15, 20 J
- Plane-Strain Fracture Toughness -K_{lc}
 - 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





Outline O	Introduction O	Experimental procedures $\bigcirc \bigcirc \bigcirc$	Results	Conclusion O
Results				

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				
a) all labels		b) Glass v Yarns and	veft voids	c) Void
10 mm) 10 mm		,

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

composites

Outline O	Introduction O	Experimental procedures	$\bigcirc \bigcirc $	Conclusion O
Results				

XCT statistical analysis of void positions





XUI

Outline O	Introduction O	Experimental procedures	Conclusion	
VCT				

Outline	Introduction	Experimental procedures	Results	Conclusion
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Comparative Rheology



Outline O	Introduction O	Experimental procedures	$\begin{array}{c} \text{Results} \\ \bigcirc $	Conclusion O
Results				

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





Outline O	Introduction O	Experimental procedures	$\bigcirc \bigcirc $	Conclusion O	
Results					

Mode I Interlaminar Fracture





Outline O	Introduction O	Experimental procedures	$\bigcirc \bigcirc $	Conclusion O	
Results					

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



Outline O	Introduction O	Experimental procedures	$\bigcirc \bigcirc $	Conclusion O
Results				

Impact



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



Outline O	Introduction O	Experimental procedures	Results	Conclusion O
Results				

Impact



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



Outline O	Int	croduction	Exper O C	imental procedures O	$\begin{array}{c} \text{Results} \\ \bigcirc $	Conclusion
Results						
Impact						
			1		0	no est to popular all construction of prior.
	(a) 5 J unmodifie	ed	(b)	5 J $+5wt\%$ RBCP	2	
in a second s		1. S. 1.			â	
2.9 193	(c) 10 J unmodifi	ed	(d)	10 J + 5wt% RBCP	5.	A Provide Law
Transf.		the state of the second			23	
55 -	(e) 15 J unmodifi	ed	(f)	15 J + 5wt% RBCP	(e) Front +5wt% RBCP
-		5				15J
tion -			-11-m ²			
	(g) 20 J unmodifi	ied	(h)	20 J + 5wt% RBCP	÷ ; ;	
Unm	odified resi	า	FBCP I	modified resin		
30				1		
20				AND I		D Back +5wt% BBCP
ล้		22	151	and the second		
ndy.		· ·				

(a) Front unmodified

(b) Back unmodified



Outline O	Introduction O	Experimental procedures	Results	Conclusion O
Results				

Impact



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



Outline O	Introduction O	Experimental procedures	$\bigcirc \bigcirc $	Conclusion O
Results				

Impact



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



Outline O	Introduction O	Experimental procedures	$\bigcirc \bigcirc $	Conclusion O
Results				
Impact				



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



Outline	Introduction	Experimental procedures	Results	Conclusion
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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.



Outline O	Introduction O	Experimental procedures	Conclusion

Acknowledgements

• EPSRC – funding



Engineering and Physical Sciences Research Council

• NWCC / NCCEF – facilities

• Alan Nesbitt – technical support



northwest composites

• Huntsman, Solvay, Sigmatex, Arkema – supply of materials

