THE INFLUENCE OF NONWOVEN INTERLEAF ARCHITECTURES ON THE IMPACT PERFORMANCE OF COMPOSITES

R. Archer[1],W.W. Sampson[2] and P. Potluri[3]

[1]School of Materials, University of Manchester, Manchester, UK
Email: rhys.archer@manchester.ac.uk
[2]School of Materials, University of Manchester, Manchester, UK
Email: william.sampson@manchester.ac.uk
[3]School of Materials, University of Manchester, Manchester, UK
Email: prasad.potluri@manchester.ac.uk

Keywords: Composites, Impact, Interleaf, Fracture, Carbon Fibre

Abstract

This paper presents preliminary results from the study of the influence of interleaf architecture on the damage tolerance of composite laminates. Areal density of the interleaves ($\mathrm{g\,m^{-2}}$) and the linear density of interleaf fibres have been identified as two paramters that influence the impact damage behavior. In this work, influence of interleaf area density on damage resistance and damage tolerance (residual strength) have been reported.

1. Introduction

Carbon fibre composites are increasingly important across sectors such as the automotive and aerospace industries [1]. Such composites provide an attractive materials system as the multilayered structure of fabrics bonded by a polymer matrix brings opportunities to control the properties for specific applications. As demand for a material increases, so does the need to understand how it performs under stress - often this is an understanding of mechanical behaviours eg. how the material can be strengthened. A particular challenge is to achieve this without a weight penalty. One method of improving the strength of composites is by introducing a veil between layers which acts as an interleaf layer within the laminate structure. It is only within the last 30 years that the potential advantages of interleaving on the interlaminar fracture toughness (IFT) [2] and damage tolerance [3] of carbon fibre composites has been investigated.

Polyester veil interleafs have been shown to improve the fundamental mechanical properties of composites. Kuwata et al. [4] found that polyester veil interleafs significantly improved mode I and mode II interlaminar toughness, and proposed that the primary mechanism was fibre bridging. Though this work identified that toughness can be increased through interleaving, the influence of the areal density of the veil on the properties of composites came with the work of Tsotis [5], who through testing a range of weights of polyamide and polyester veils meltbonded to plys of carbon fibre showed that the meltbonded veils provided reinforcement to the carbon fibres which improved the composite performce in compression after impact and decreased the damage area after impact. Tsotsis noted that although increasing the areal density of the polyamide interleafs had a positive affect on the compression performance of the composite, increasing the areal density of the polyester veil had the adverse affect. The observed effects were attributed to inherent relationship between the shear (MII) and tensile (MI) fracture toughness properties and impact damage mechanisms. A systematic study was presented by Ramirez et al. [6] who tested a range of veils of the same polymer with variable areal density and fibre diameter. They found that the interlaminar fracture toughness of the composite was dependant on the weight of the veil interleaved throughout, as the delamination that occurred was affected directly by fibre content of the crack tip. The grounding of this relationship is in stochastic fibre network theory [7]. Sampsons work using mathematical expressions to describe the structure of random fibre networks is applied to explain the structure of the interleaf veils, and therefore to interpret the resultant improvements in the IFT as a measure of these stochastic proprties.

Having understood the relationhip between MI and MII and impact, and following on from the work of Ramirez et al., we would expect that through systematically tested composites with veils of variable areal and linear densities, that a similar trend would be seen when the composites through impact and compression tests.

2. Method

2.1. Materials

Carbon fibre composites were manufactured using Vacuum Assisted Resin Infusion (VARI) method using facilities at the North West Composites Centre. For the infusion process, the ratio of 0.66 Araldite Epoxy Resin LY564 to 0.34 Aradur 2954 hardener was was used. The carbon fibre materials used were supplied by Sigmatex UK. Both a unidirectional (UD) and +/-45 orientation fabric was used. The fabric layers were interleaved with non woven PPS veils of varying linear density and areal densities provided by Technical Fibre Products Ltd. The properties of the fibre and the veil can be seen in Table. 1.

We tested composites specifically to compare the impact performance of the composite to the architecture of the veil interleaved throughout. In particular, comparisons were drawn to the coverage of the veil. Coverage is defined as a dimesionless density and will be used to determine whether the impact performance of the composite can be linked specific structural properties of the veil used. Coverage can be found using Eq.1 where $\bar{c}$ is coverage, $\bar{\beta}$ is the areal density ($\mathrm{kg\,m^{-2}}$), ω is the diameter of the constituent veil fibres (m), and δ is the linear density ($\mathrm{kg\,m}$). Note averages are used for coverage and areal density as these properties vary locally.

$$\bar{c} = \frac{\bar{\beta}\,\omega}{\delta} \tag{1}$$

.

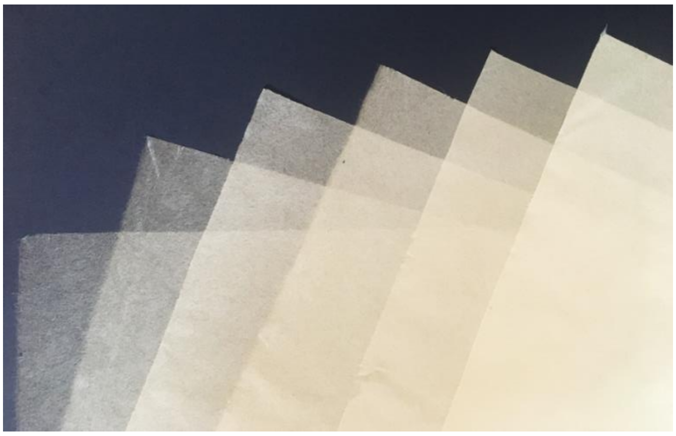

Figure 1. PPS Veils from 7 $\mathrm{g\,m^{-2}}$ (left) to 40 $\mathrm{g\,m^{-2}}$ (right)

Table 1. PPS Fibre/Veil Characteristics

		Veil		
Linear Density, δ ($\times 10^{-7}\mathrm{kg}^{-1}$)	Diameter, ω (μm)	Areal Density, $\bar{\beta}$ ($\mathrm{g\,m}^{-2}$)	Coverage, $\bar{c}$	Thickness (μm)
1	10	7	0.7	45
		10	1.0	54
		15	1.5	84
		40	4.0	173
2	14	7	0.5	53
		15	1.1	86
		20	1.4	109
		40	2.8	178

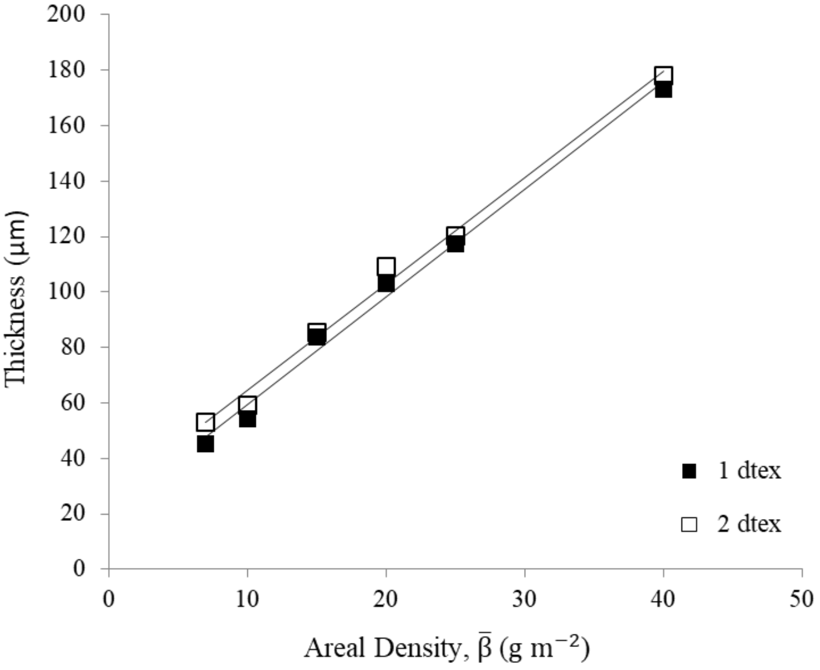

Figure 2. Areal Density and Thickness of veils

Figure 2 shows the relationship between thickness and areal density for the two families of veils. Both exhibit approximately a linear relationship with approximately the the same gradient, confirming that the porosity of the veils is constant, *i.e.* independent of their areal density and of fibre type.

2.2 Design of Samples

Square composite panels of size 400 mm were manufactured. Each was cut to give 24 × (55 × 89 mm) specimens with thickness dependent on the areal density veil interleaved. The samples were sufficient for 6 repeat tests at three impact energies, 5 repeats for compression tests at each impact energy and 1 specimen for microscopy, allowing investigation of damage mechanisms. Two stacking seqences were used denoted as St.Sq. A $[0, \mathrm{V}, +45, \mathrm{V}, 0, \mathrm{V}, -45, \mathrm{V}, 0]_2$ or St.Sq. B $[0, \mathrm{V}, 0, +45, 0, \mathrm{V}, 0, -45, 0, \mathrm{V}]_2$. Both stacking sequences were used to compare the effect of the interleaf on impact performance. The properties of these composites can be seen in Table 2.

Table 2. Properties of composites tested

Interleaf	Stacking Sequence	Veil		Thickness (mm)	Thickness increase relative to no-veil (%)
		Linear Density, δ ($\times 10^{-7}$ kg m^{-1})	Areal Density (g m^{-2})		
None	B	-	-	4.28	-
	A	-	-	2.90	-
PPS	B	1	7	4.56	+ 6.5
			40	5.19	+ 21.2
	A	1	7	3.28	+ 13.1
			40	4.33	+ 49.3
		2	7	3.31	+ 14.1
			40	5.22	+ 80.0

2.3. Testing

After manufacture, to check that there were no defects in the panel, ultrasonic NDT scans were obtained using a Midas Water Jet C- Scan. The panel was marked, and specimens cut using a diamond saw; these were labelled and tested in a drop weight impact tower (Instron CEAST 9350) with a 16 mm hemispherical tup insert, following ASTM standards [8]; specimens were tested at 0 J, 8 J, 15 J, and 30 J. Indent depth was not readily recorded due to the already variable surface of the composite. Ultrasonic NDT scans were carried out on the specimens after impact, allowing analysis of the size and shape of the impacted area.

The residual compression strength of the composites was tested using an Instron 5982 electromechanical test frame fitted with 100 kN load cell, fixed compression platens and compression after impact fixture, which secured the specimen longitudinally, following ASTM standards [9]. Nominal strain was measured from crosshead displacement; the crosshead speed was 0.5 mm/min. Testing was carried out in ambient laboratory conditions. A comparison between the impacted specimens and non-impacted specimens was carried out to evaluate the loss of strength in each specimen due to impact.

3. Results and Discussion

Impact data was used to obtain the intial peak force (see Fig. 3) for all interleaved composites. Figures 4 and 5 present the intial and maximum peak force for composites manufactured with stacking sequence B, using the 1 dtex veil. It can be seen that when a veil is introduced, the intial max force increases by approximatley 1 kN, and increases again when a veil of a greater areal density is used. A similar relationship was observed for stacking sequence A (not shown) for both 1 dtex and 2 dtex, albeit with lower force values. The increase in thickness between the composites (Table 2. Pg 5) is not proportional to the force increase we see between the composite interleaved with no veil and with a 7 g m^{-2} veil, or that between the composites interleaved with 7 g m^{-2} and 40 g m^{-2}, indicating that the difference is due primarily to the change in areal density. A similar increase in force can be seen between the no-veil composite and the 7 g m^{-2} composite when comparing the max peak force graph (Fig. 5), however only a marginal difference can be seen between the composites with 7 g m^{-2} and 40 g m^{-2} veils. It is important to note that impacts at 30 J create an impact area that extends to the edges of the the size of the specimen, so these values, whilst indicative, should not be used to define the absolute performance of these composites.

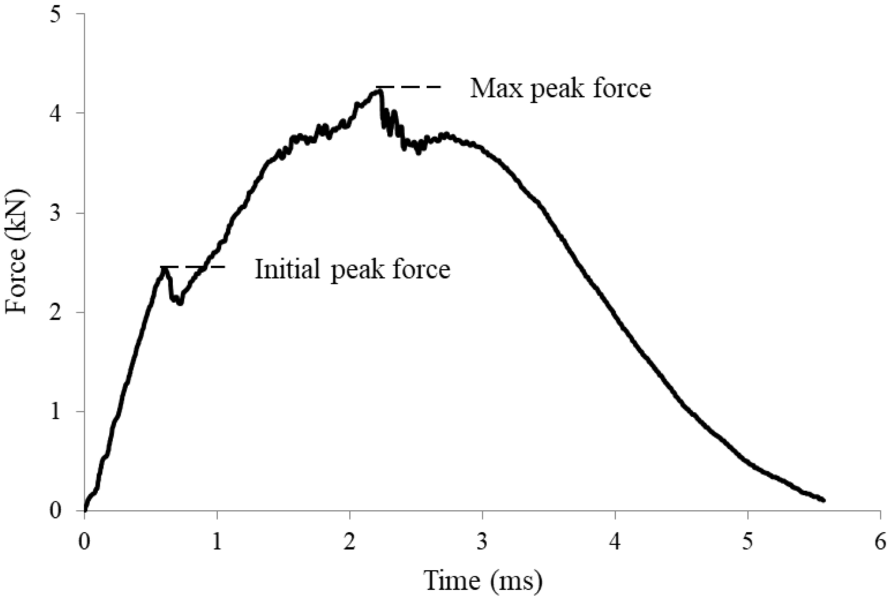

Figure 3. Typical Time Force graph of St. Sq. A, 1 dtex, 7 g m^{-2}

The impact area (Fig. 6) and energy absorbed through compression after impact testing (Fig. 7) are consistent with the impact data. They show that the introduction of a 40 g m^{-2} veil reduces the impact area and increases residual compressive strength. Although the composite interleaved with a 7 g m^{-2} veil exhibited greater impact resistance than those with no veils, there was no significant increase in the energy absorption or decrease in impact area. The composites interleaved using sequence A showed a similar trend, with a greater increase between the 7 g m^{-2} and 40 g m^{-2} composites. This indicates that the heavier veils limit the compression damage within the composite more than the lighter ones. Note the large error bars for the non impacted specimens due to the variablility in failure position and buckling during testing.

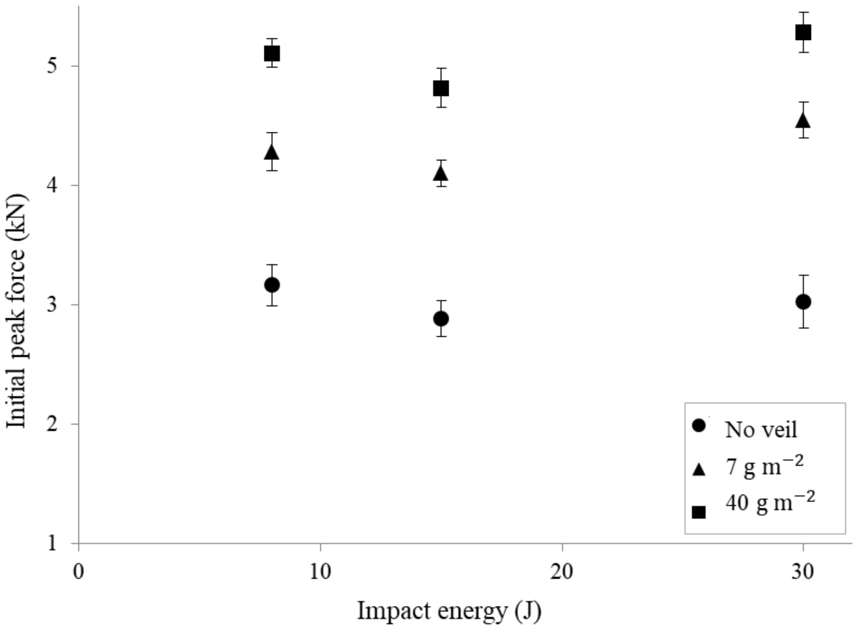

Figure 4. Initial Peak force during impact testing St. Sq. B, 1 dtex

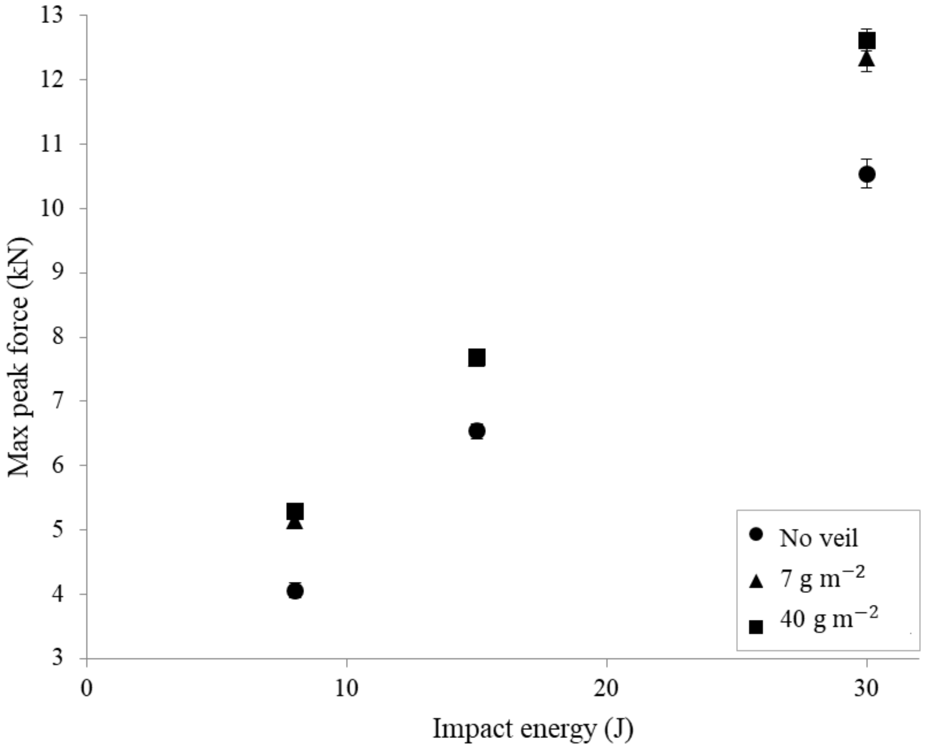

Figure 5. Max Peak Force during impact testing St. Sq. B, 1 dtex

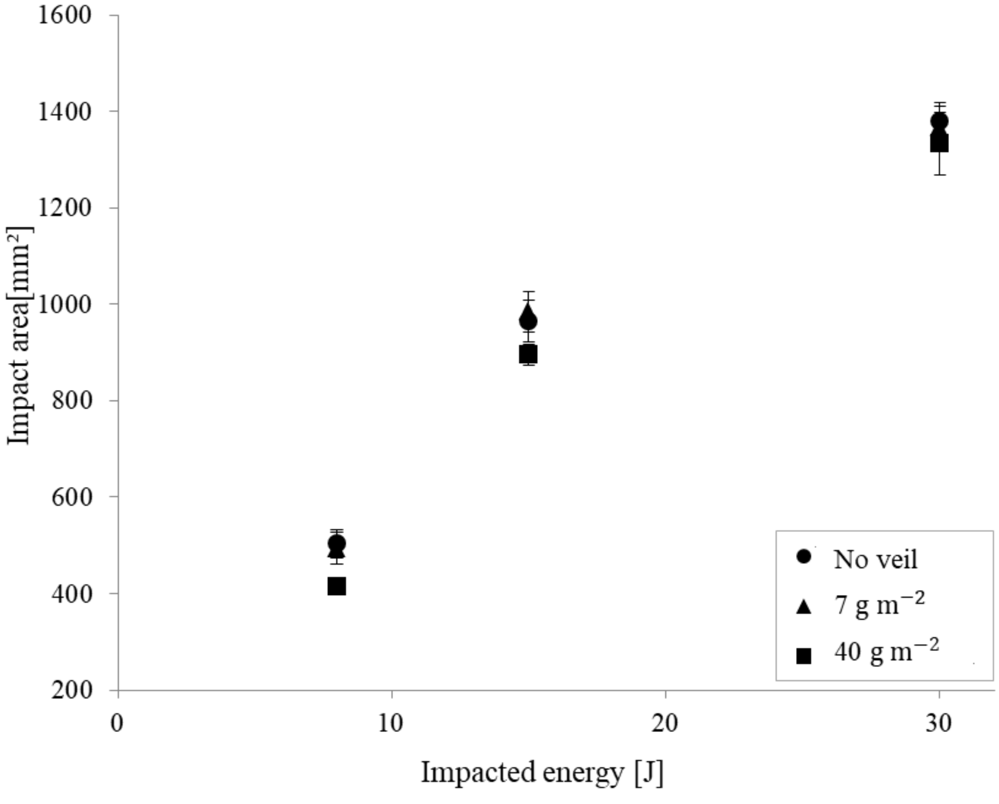

Figure 6. Impact Area from Impact testing St. Sq. B, 1 dtex

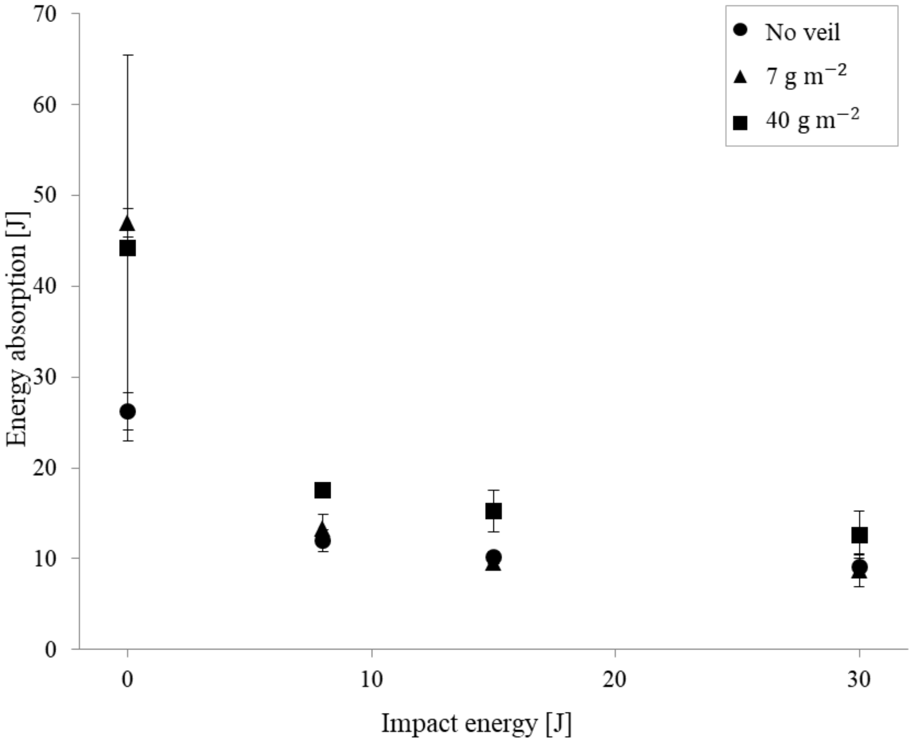

Figure 7. Energy Absorption through Compression testing St. Sq. B, 1 dtex

From figures 8 and 9, it may be observed that composite laminates with 40 g m^{-2} veils have smaller and more uniform impact damage area in comparison to laminates with 7 g m^{-2} veils. This results in higher residual compression strength (CAI) for 40 g m^{-2} samples.

.

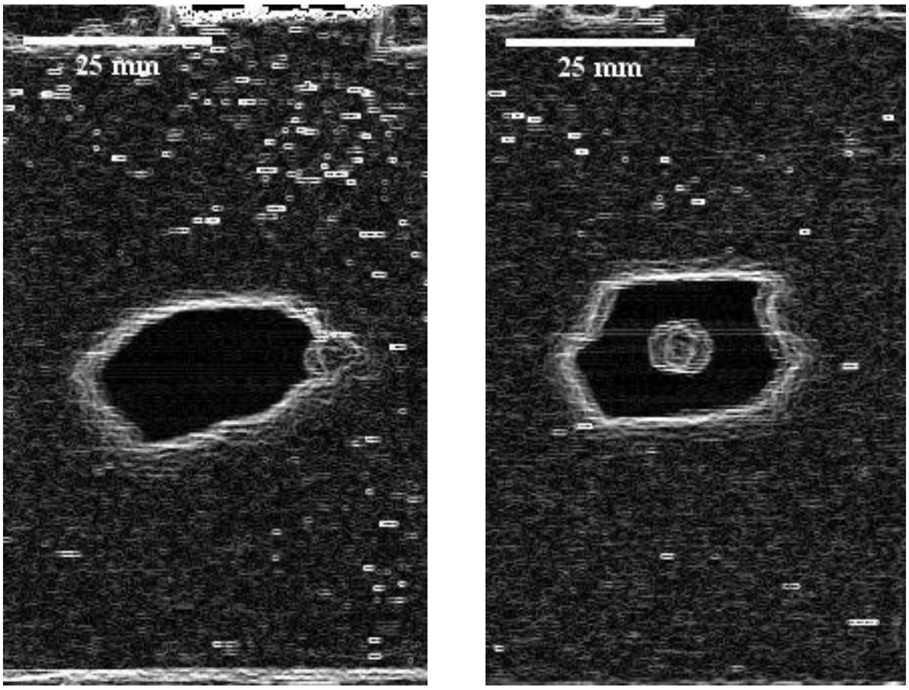

Figure 8. Typical C-scan of 8 J impact area across compoites interleaved with 1 dtex veils, 7gm^{-2} (left) and 40gm^{-2}(right),

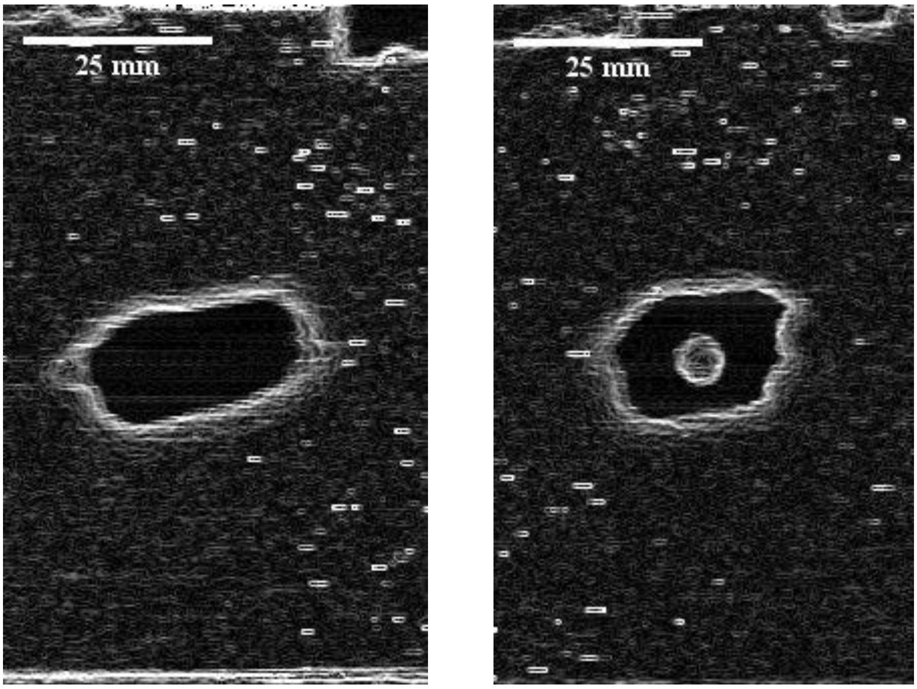

Figure 9. Typical C-scan of 8 J impact area across compoites interleaved with 2 dtex veils, 7gm^{-2} (left) and 40gm^{-2}(right),

4. Concluding remarks

From the data collected, it can be seen that for both stacking sequences studied, introducing the PPS interleafreduces impact damage and and the energy absorbed in compression after impact. From the c-scans, it can be seen that increasing the areal density of the veil changes the shape of the impact damage area in a manner consistent with the composites absorbing more energy in compression.

To see the full effect of the areal density of interleaved veils on the performance of the composites, and to further probe the relationship with the coverage of the veil, we have in hand testing of samples made using veils with areal densities between 7 g m^{-2} and 40 g m^{-2}.

References

[1] Claunch, E. C., 2015. Forecasting on Composites – Markets, Products, and Demands. *J..Text. Apparel, Tech.and Man.*, **9**(2):1-6.

[2] Ishai, O., Rosenthal, H., Sela, N. & Drukker, E., 1988. Effect of selective adhesive interleaving on interlaminar fracture toughness of graphite/epoxy composite laminates. Composites, **19**(1), pp. 49 - 54.

[3] Masters, J.E. & Evans, R.E., 1987. A new Generation of Epoxy Composites for Primary Structural Applications: Materials and Mechanics. In: Toughened Composites, ASTM STP 937. Philidelphia: American Society for Testing and Materials, p. 413.

[4] Kuwata, M. & Hogg, P.J., 2011. *Compos. A: Appl.Sci.Manuf.*, **42**(10): 1551-1570.

[5] Tsotsis, T. K., 2009. *Polym.Compos.*, **30**(1):71-86.

[6] Ramirez, V.A., Hogg, P.J. & Sampson, W.W., 2015. Compos. Sci. Tech., **110**:103 - 110.

[7] Sampson, W.W. (2009). Modelling Stochastic Fibrous Materials with *Mathematica*.Springer-Verlag, London, 2009.

[8] ASTM International 2007. Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop - Weight Impact Event. D 7136/D7136M - 07.

[9] ASTM International 2007. Standard Test Method for Compressive Residual Strength Properties of Damaged Polymer Matrix Composite Plates. D 7137/D7137M - 07.