Effect of different types of electrospun polyamide 6 nanofibres on the mechanical properties of a carbon fibre/epoxy composites

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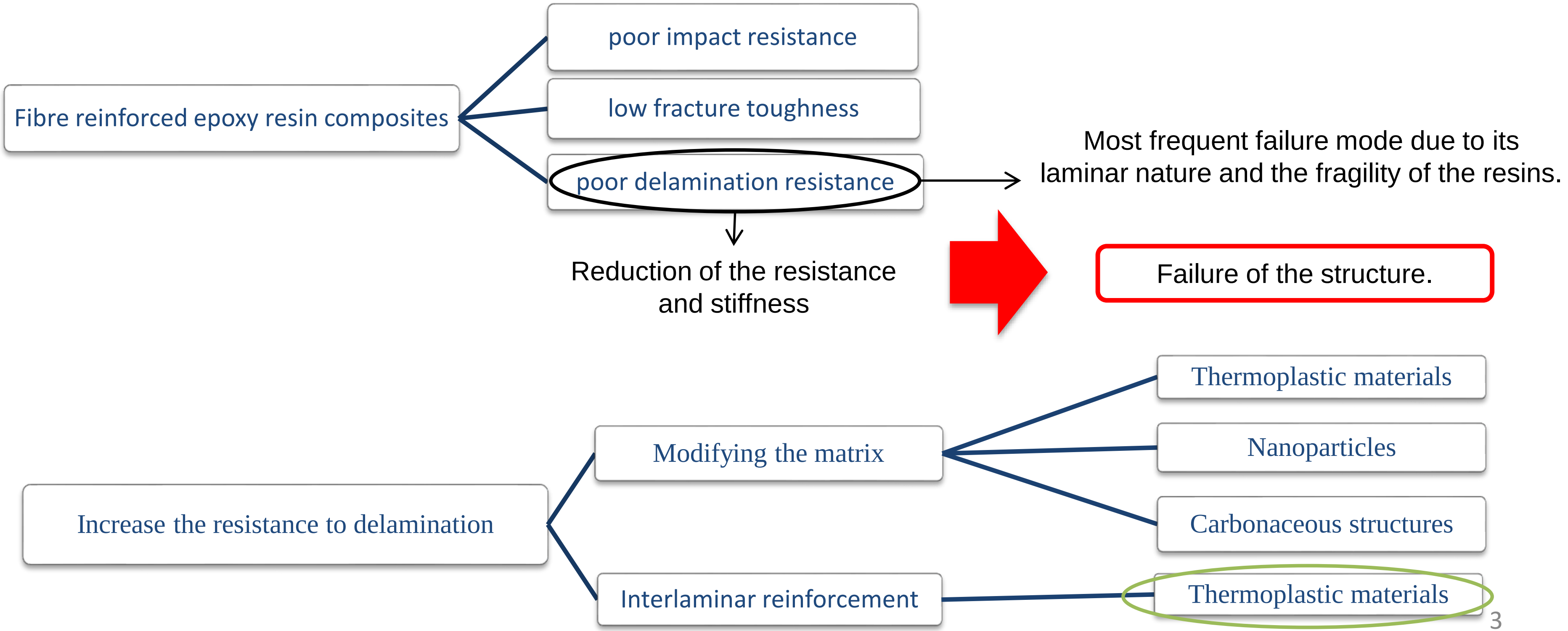
1. INTRODUCTION

- Fibre reinforced epoxy resin composites are widely used in industry, owing to their high strength and stiffness at low weight, and their good corrosion-resistance and fatigue properties.



1. INTRODUCTION

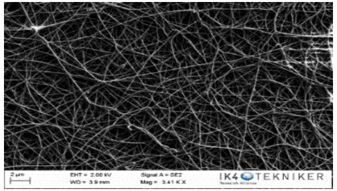
Electrospun thermoplastic nanofibres veils

Promising technique to toughen laminated composites without deteriorating the mechanical properties

Properties
- Great surface/volume ratio
- High porosity
- Low area density
- Adjustable pore size
- Nanoscale fiber diameter
- High mechanical resistance
- High permeability

Advantages

- ✓ Thin veils → Their presence do not affect the thickness and weight.
- ✓ No need to disperse →No viscosity increase or a non-homogeneous dispersion
- ✓ High porosity→ not impede the flow of resin



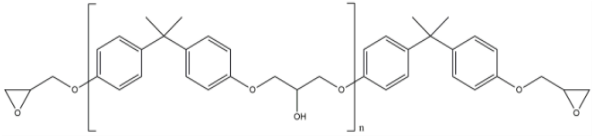
2. OBJECTIVE

The present work studies the effect of the incorporation of electrospun polyamide 6 nanofibre veils coming from two different type of pellets, in the final mechanical properties of carbon fibre epoxy composites with the objective to study the influence of the PA6 mechanical properties and nature in composite material.

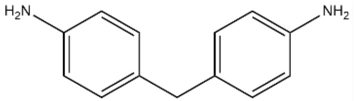
3. EXPERIMENTAL PART

Materials

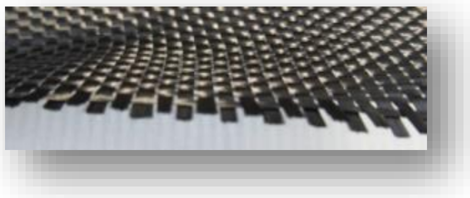
Matrix_Diglycidyl ether of bisphenol A (DGEBA)



Curing agent_4,4’-diaminodiphenylmethane (DDM)



Carbon fibre fabric HT3k

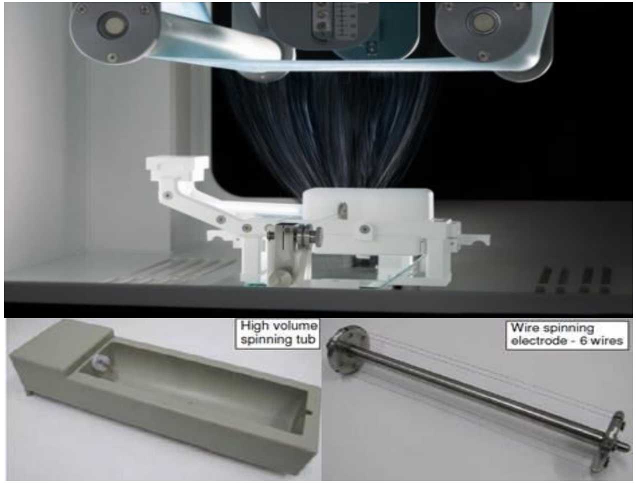


PA6 Ultramid B24 N 03 — Textile sector

PA6 Badamid B70 — Industrial sector

PA6 nanofibre veils preparation

- 12 wt% of both types of PA 6 pellets were dissolved in the mixture 2:1 acetic acid:formic acid by stirring during 2 hours at 80ºC.
- The nanofibres were produced using a multijet electrospinning setup Nanospider™, using a high volume spinning tub.
- The solution is poured into the feed unit and a cylindrical electrode formed by six wires is placed in the middle of the solution tank. The upward part has a second wire electrode, which has the opposite charge. The electrical field between the electrodes overcomes the surface tension of the polymer solution, forming thousands of jets than becomes fibres when the solvent is evaporated and they are deposited In the substrate.



PA6 Badamid

PA6 Ultramid

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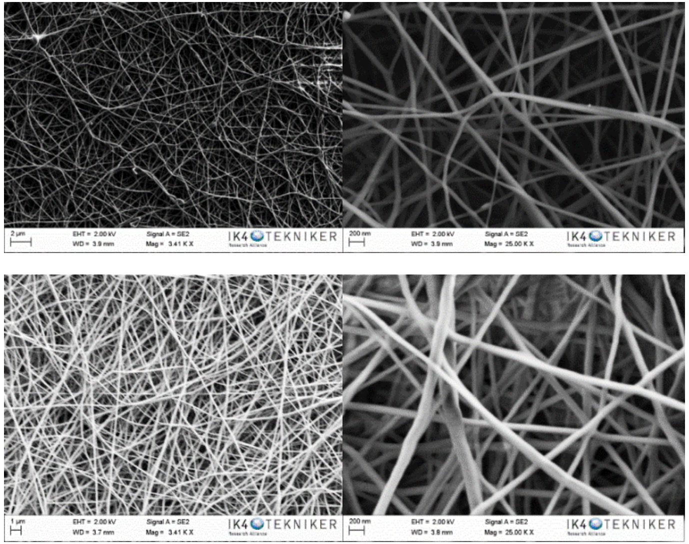
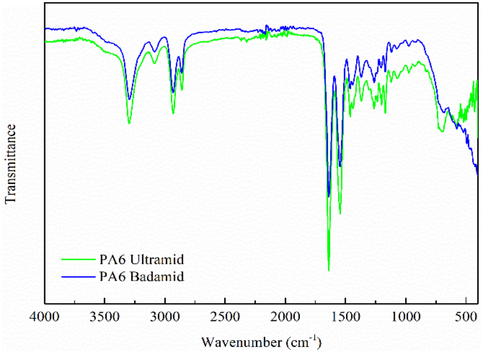
PA6 nanofibrous veils characterization

PA6 Ultramid

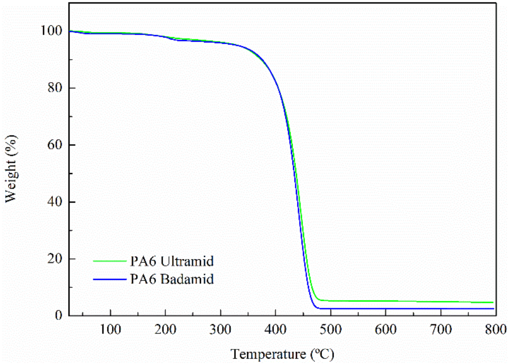
PA6 Badamid



continuous and uniform nanofibre network



FTIR

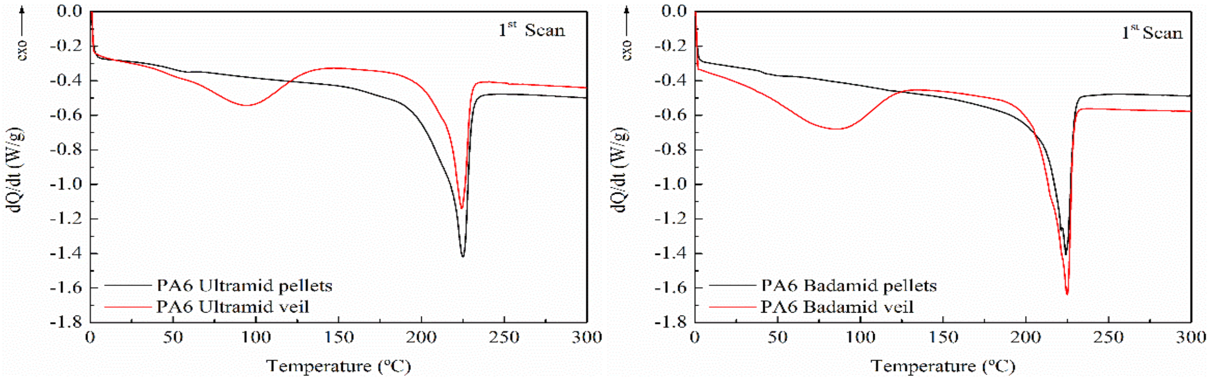


TGA

System	Fibre diameter (nm)	Areal weight density (g/m^2)
PA6 Ultramid	60-100	1,94
PA6 Badamid	60-130	2,23

No excess of solvent due to the electrospinning process

PA6 nanofibrous veils characterization



Thermal characterization (DSC)

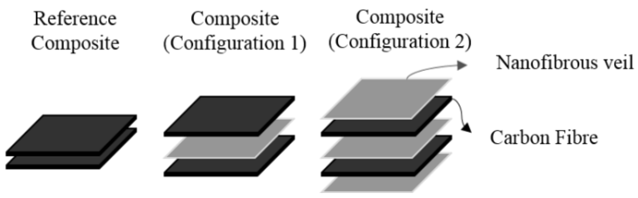
Material	T_f (°C)	ΔH_f (J/g)	X_c (%)
Ultramid pellets	225,1	107,1	46,5
Ultramid veil	224,3	61,2	26,6
Badamid pellets	224,1	95,4	41,5
Badamid veil	225,0	87,8	38,2

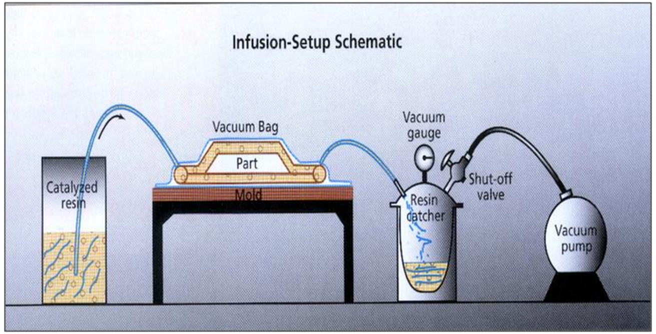
% Cristallinity pellets > Veils

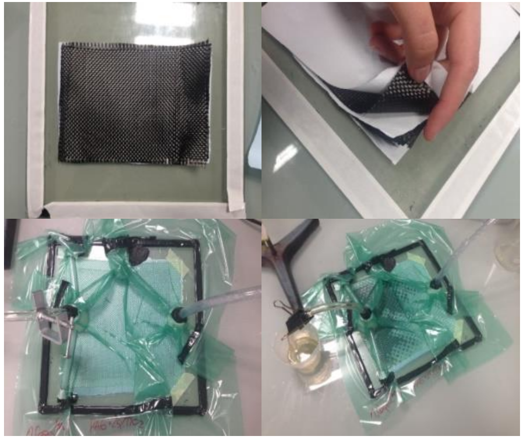
% Cristallinity PA6 Badamid > PA6 Ultramid

Composites manufacturing

Two carbon fibre plies interleaved with stand-alone nanofibrous veils were prepared







Infusion process

Curing
4 h at 90 ºC

Reference Composite

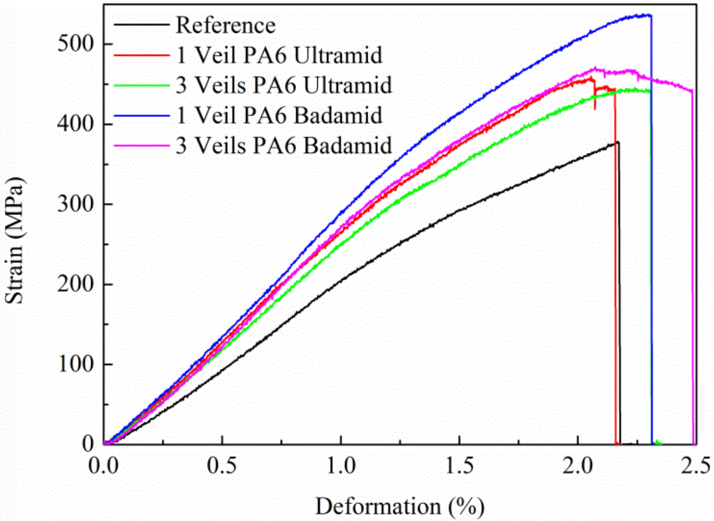
(thickness between 0.6-0.7 mm)

For the fracture test (mode I, mode II), composites with 14 layer of carbon fibre and an interlaminar veil in the central axis have been developed also using vacuum infusion technique.

4. RESULTS AND DISCUSSION

Composites characterization

Flexure test



Sample	σmax (MPa)	Δσmax %	δmax (%)
Reference	375.5±33.2		2.2±0.2
1 veil PA6 Ultramid	449.5±10.8	19.7	2.1±0.0
3 veil PA6 Ultramid	415.4±23.8	10.6	2.1±0.2
1 veil PA6 Badamid	534.6±28.9	42.4	2.3±0.0
3 veil PA6 Badamid	502.3±48.5	33.8	2.1±0.1

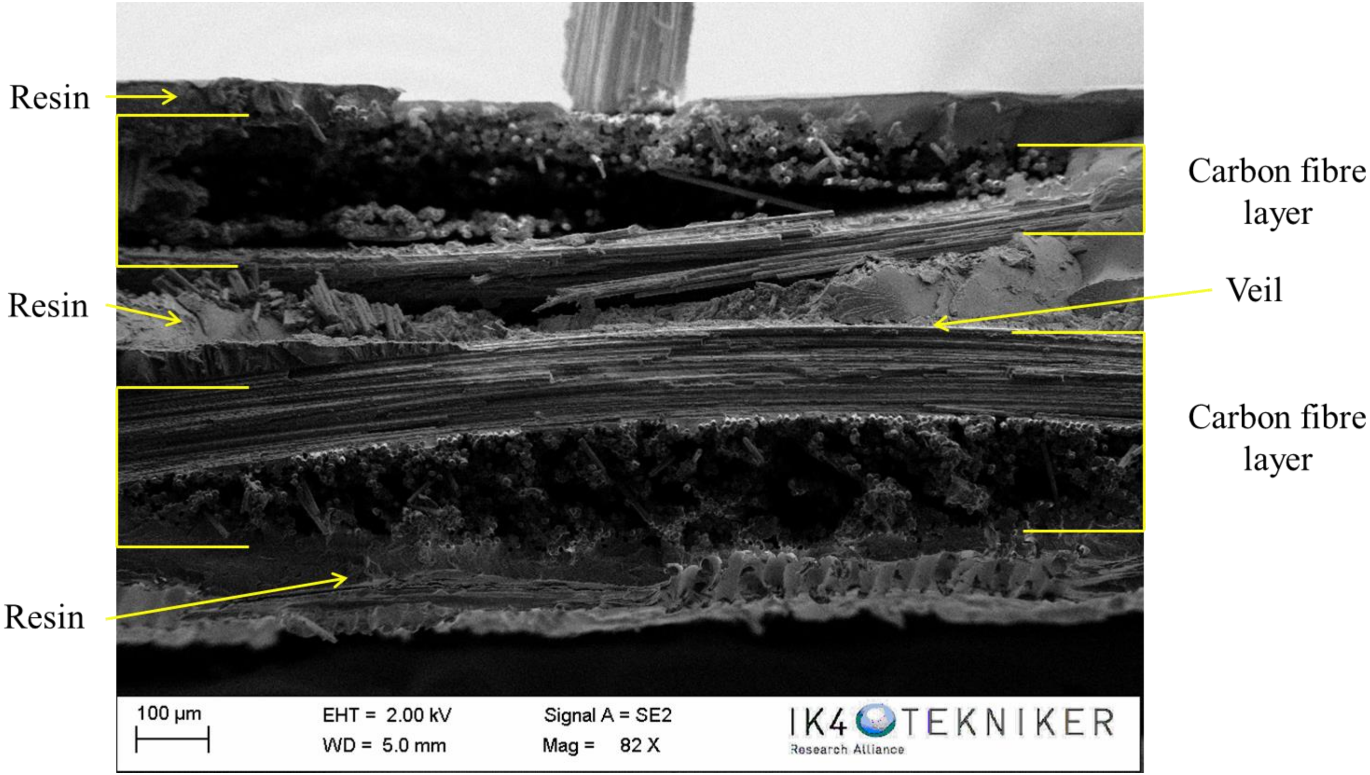
Both, PA6 Ultramid and PA6 Badamid nanofibrous veils, toughen composite laminates considerably

σ_{max} 1 Veil > σ_{max} 3 Veils

The outer veils do not contribute positively to the improvement flexural mechanical properties

Composites characterization

Fractographic SEM analysis

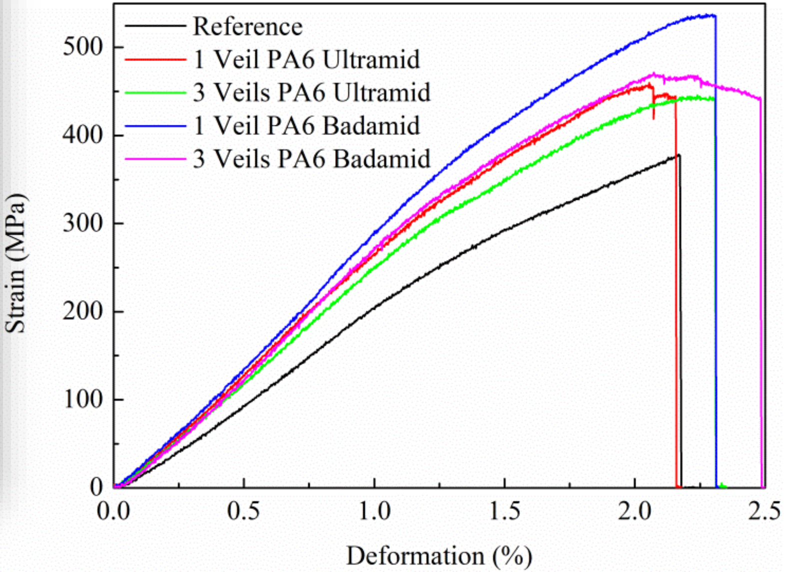


1 Veil PA6 Ultramid

4. RESULTS AND DISCUSSION

Composites characterization

Flexure test



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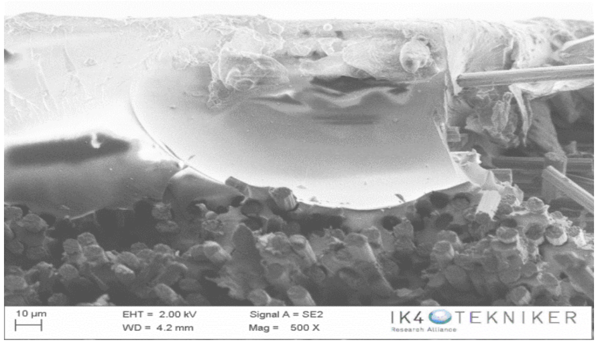
3 veil PA6 Badamid	502.3±48.5	33.8	2.1±0.1

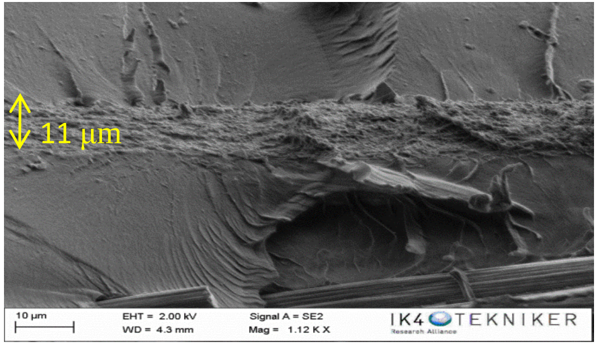
σ_{max} Badamid veil > σ_{max} Ultramid Veil

Composites characterization

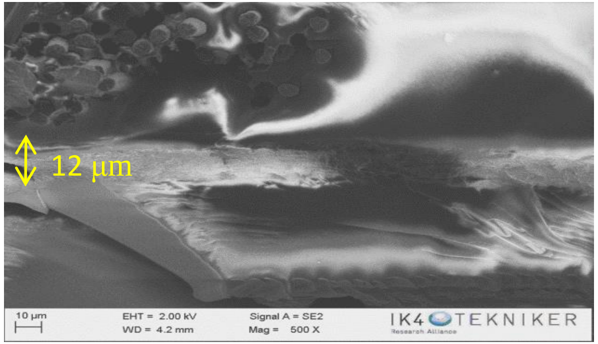
Fracture waves of the resin end in the veil
The veils prevent the propagation of the crack through the polymeric matrix



Reference



1 Veil PA6 Ultramid
Interlaminar Veil



1 Veil PA6 Badamid
Interlaminar Veil

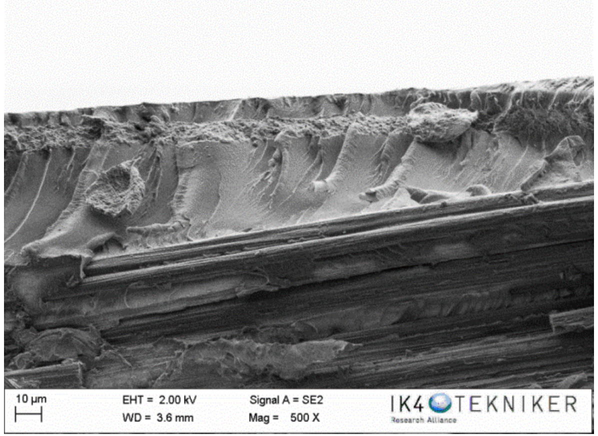
PA6 Badamid

- Better integration of the veil
- Better intrinsic properties
- Greater crystallinity

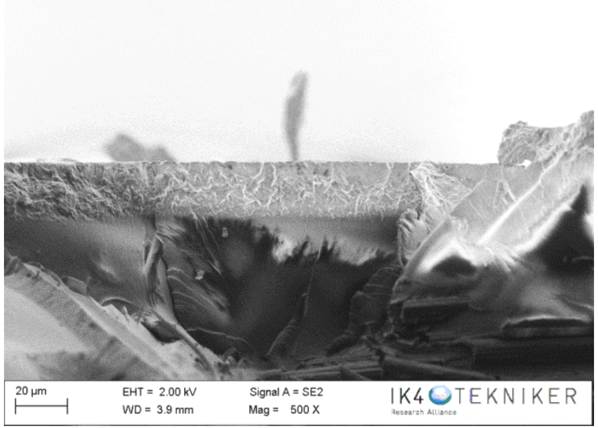
Composites characterization

While the interlaminar veil clearly stops the crack propagation, the outer veils do not seem to contribute to avoid it

3 Veils PA6 Ultramid (Outer Veil)



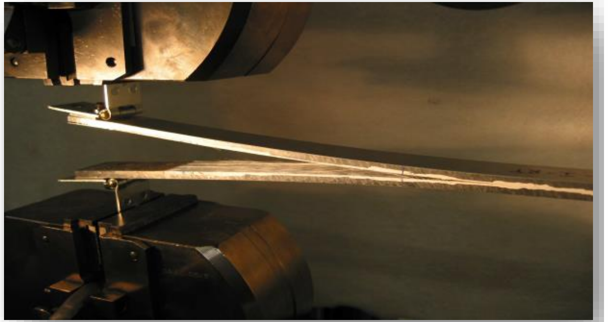
3 Veils PA6 Badamid (Outer veil)

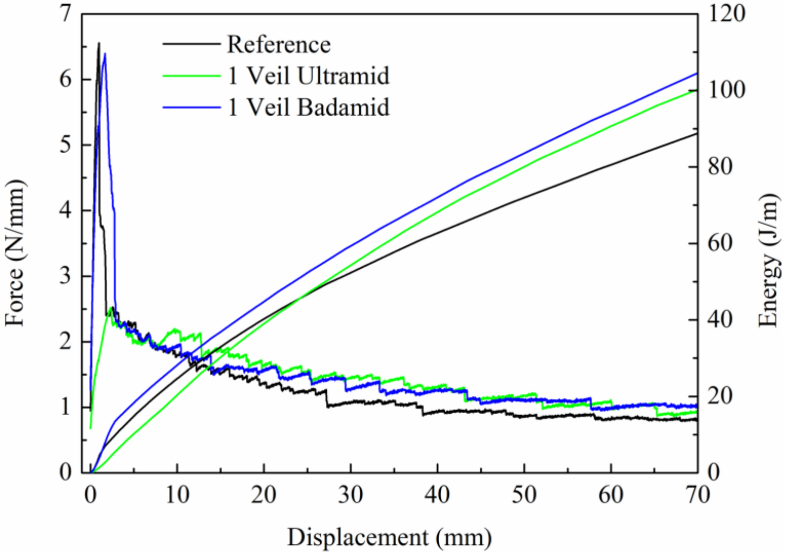


- A difference in the position of the outerveils is appreciated
- The infusion process can result in composite materials with a very thin external face of resin or an outer face formed by the resin impregnated veil

Composites characterization

Fracture Mode I test



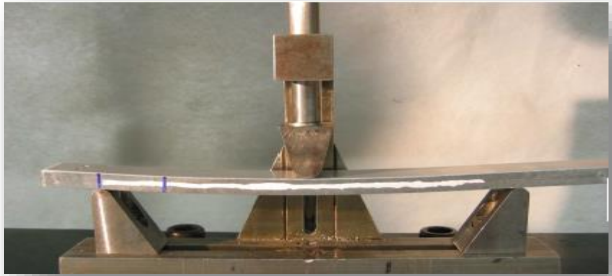


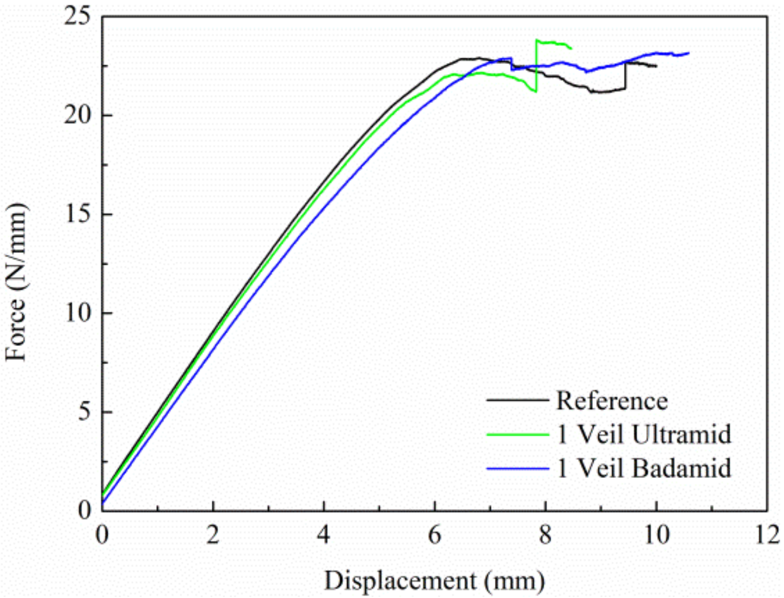
Sample	Load (N/mm)	Δ%	Energy (J/m)	Δ%	G_{IC} (J/m^2)	Δ%
Reference	6.6±0.8		62.7		389±12.8	
PA6 Ultramid	2.5±0.1	62.9	68.1	8.6	466±73.0	20.0
PA6 Badamid	6.4±0.1	2.6	72.0	14.8	560±72.3	44.0

The presence of the veil tends to impede the propagation of the crack

Composites characterization

Fracture Mode II test



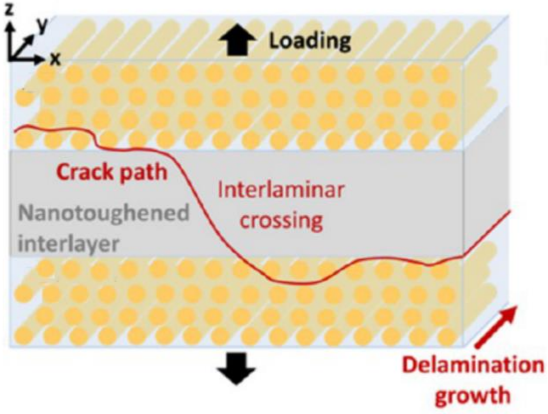


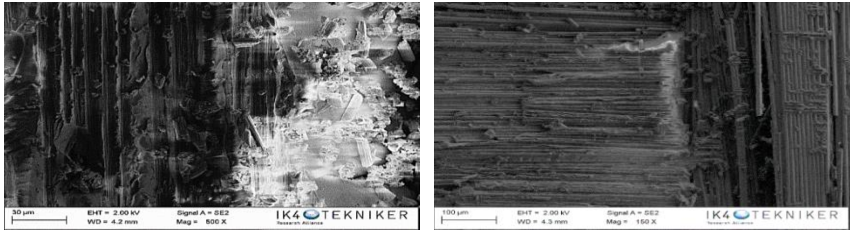
Sample	Load (N/mm)	Δ%	G_{IIC} (J/m^2)	Δ%
Reference	22.7±2.7		2536.8±257.7	
PA6 Ultramid	22.1±1.4	2.6	2544.0±304.0	0.3
PA6 Badamid	22.6±0.4	0.4	2970.9±526.0	16.8

The maximum load reached is similar
No significant improvement is reached

Composites characterization

The surface of the veils remains in both sides of the composite specimen and the crack propagates partially between the carbon fibre and the veil





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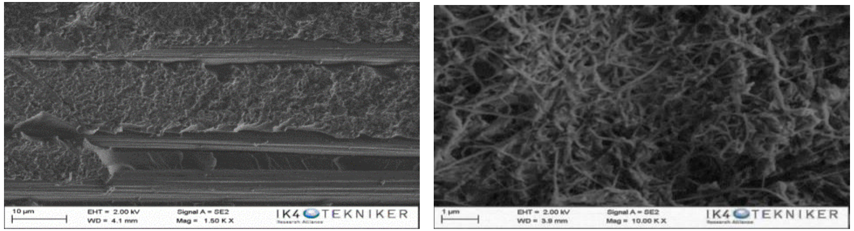
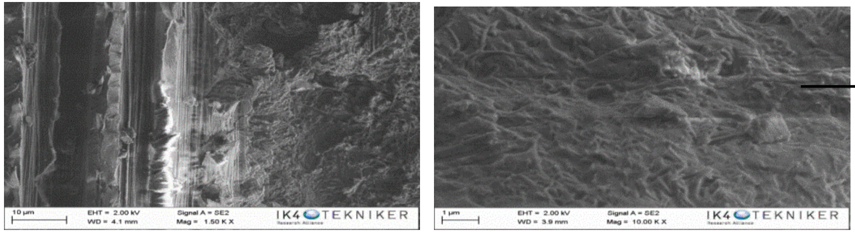


1 veil PA6 Ultramid

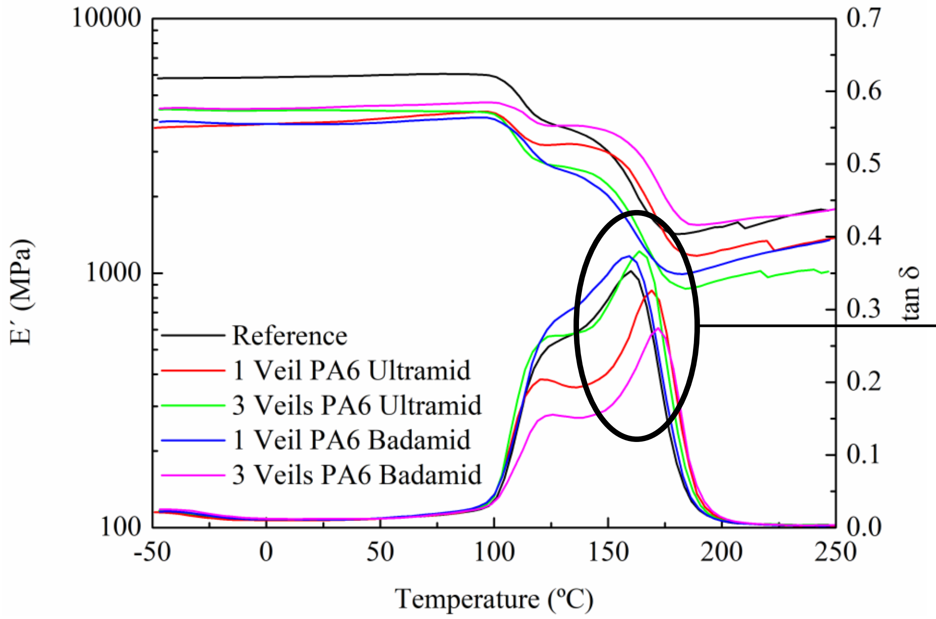


→ more integrated in the resin

1 veil PA6 Badamid

Composites characterization

Dynamic mechanical thermal analysis (DMTA)



Tg_{∞} Increase

5. CONCLUSIONS

- The incorporation of polyamide nanofibre veils increase their mechanical properties.

- For composites with one PA6 nanofibre veil between the carbon fibre plies, the stress at failure during the flexural mechanical tests increased 19.7% and 42.4 % for composites modified with PA6 Ultramid and PA6 Badamid, respectively.

- The analysis of the fractured surfaces, carried out by SEM, indicated that the veil hindered the crack propagation in the composites.

- The veils from Badamid, with higher crystallinity, conduct to better results than the veils from Ultramid.

- The fracture toughness analysis showed that G_{IC} value increased 20 and 44% for composites modified with a veil of PA6 Ultramid and PA6 Badamid, respectively, whereas G_{IIC} values only increase slightly for the composite modified with the veil of PA6 Badamid. This increment is due to the crack propagation across the PA6 veil, which result in a high energy absorption of the veil.

The inclusion of electrospun polyamide 6 nanofibre veils on the carbon fibre/epoxy composites resulted in a significant improvement in mechanical properties, both flexural and fracture toughness, without an increase in laminate thickness, weight and maintaining or slightly increasing the glass transition temperature of the composite.

AKNOWLEDGMENTS

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THANK YOU FOR YOUR ATTENTION

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