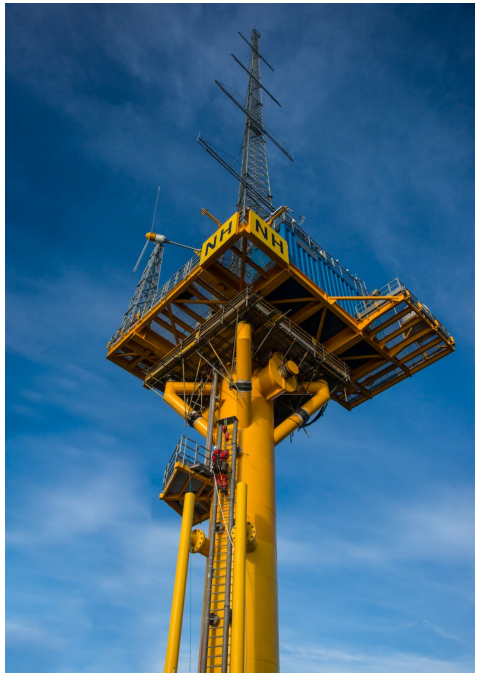

Alternative hybrid composites: A novel fibre metal laminate based on thermoplastic resin

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CATAPULT
Offshore Renewable Energy

Wind Industry Today

- The wind energy industry has grown consistently in the last decade, resulting in approximately 591 GW of installed wind capacity worldwide as of 2018 [1]. The blades of wind turbines are constructed primarily of composite materials, and with estimates of 9.6 metric tons of composite materials per megawatt of installed capacity [2].

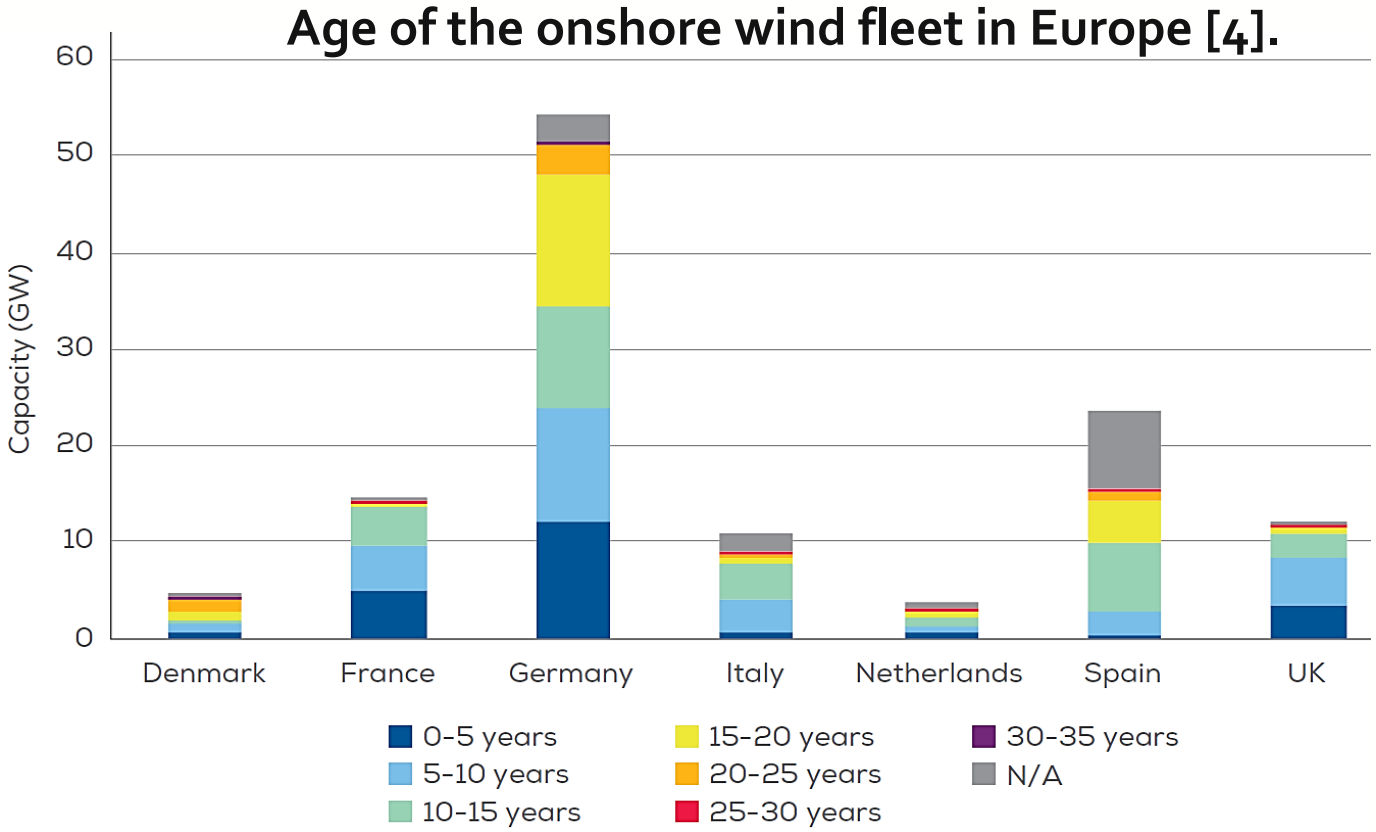
- With the currently used thermoset composite materials, the majority of these blade materials end up in landfills at the end of the blade's life, resulting in an immense amount of composite materials going to the waste stream.

[1] Association, A.W.E., *U.S. Wind Industry Annual Market Report 2018: Executive Summary Confirmation*. 2018.
[2] Arias, F., *Assessment of Present/Future Decommissioned Wind Blade Fiber-Reinforced Composite Material in the United States*. 2016, Department of Civil Engineering: City College of New York – City University of New York.

Wind Industry Today

- One alternative option to landfilling is to recycle the blades at the end of their lives , however, with the current thermoset resin technology, recycling is quite challenging.

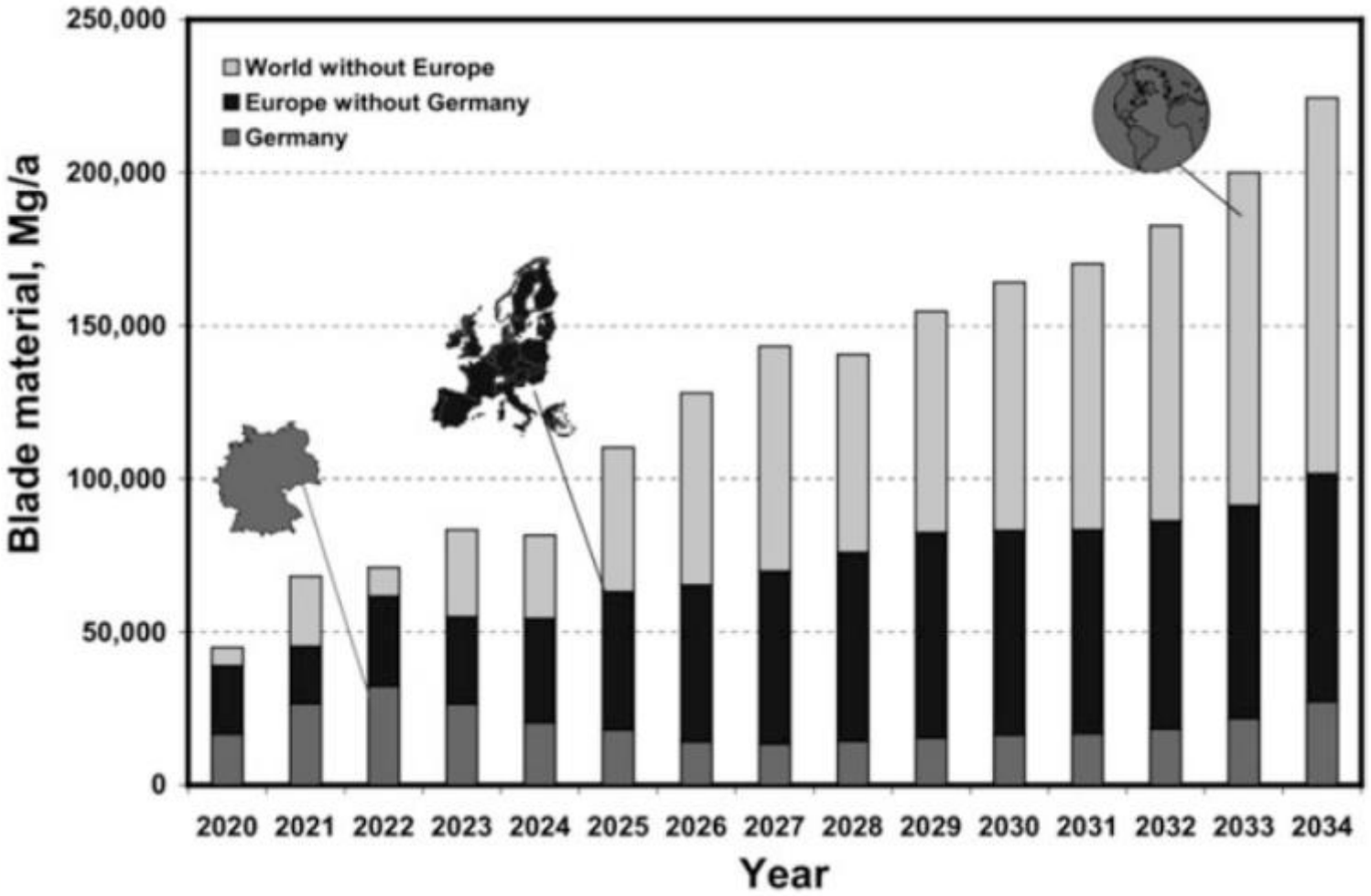
- By 2025 the annual composite waste from wind is estimated to be 66,000 tons [3].



[3] How wind is going circular | WindEurope n.d. https://windeurope.org/intelligence-platform/product/how-wind-is-going-circular/
[4] Wind Europe Accelerating wind turbine blade circularity. WindeuropeOrg 2020. https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Accelerating-wind-turbine-blade-circularity.pdf

Wind Industry Today

- Expected amount of End-of-Life blade material in Germany, in Europe and worldwide in the coming years; from 2020 to 2024 [5].



[5] Albers H, Greiner S, Seifert H et al (2009) Recycling of wind turbine rotor blades – fact or fiction? DEWI Mag 34:32–41

Thermoplastic resins

- The development of **infusible thermoplastic resins** for composite wind turbine blades, recycling has real potential. In addition to the recyclability aspect, thermoplastic resin can enable longer, lighter-weight, and lower-cost blades.

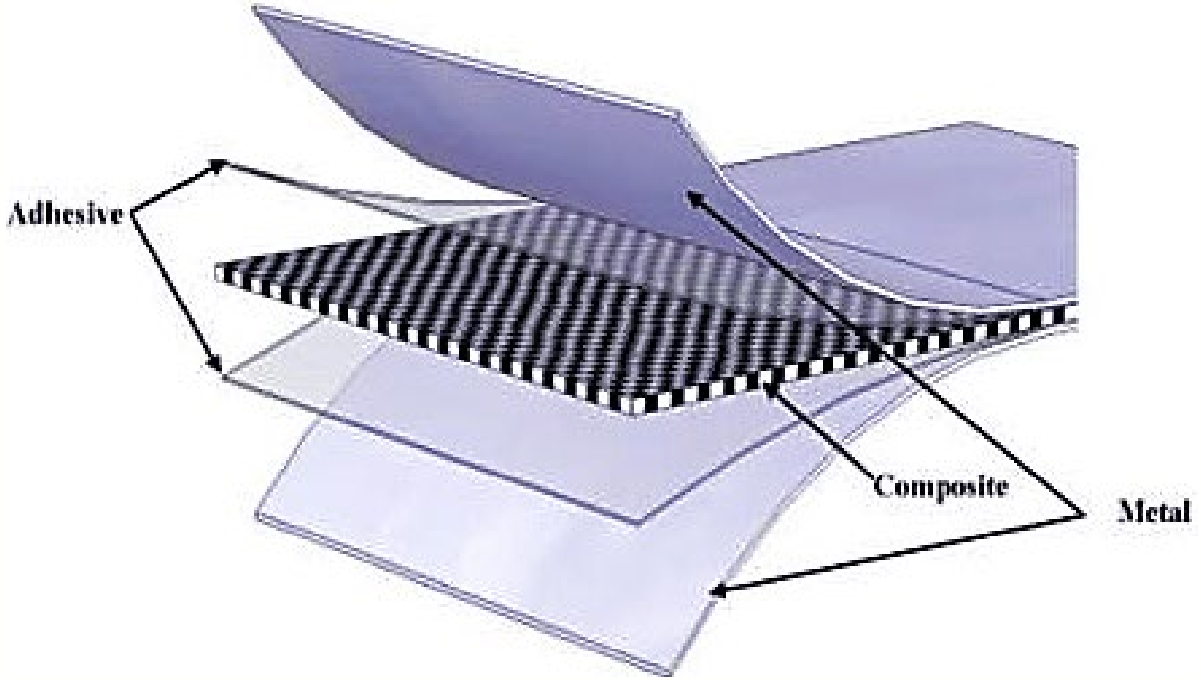
- Thermoplastic resin systems can polymerize at room temperature, eliminating the need for heated tooling and ovens for post-cure, resulting in manufacturing equipment cost and manufacturing time reductions.

- Infusible thermoplastic resins such as **Elium**, developed by Arkema Inc, can be used with existing thermoset manufacturing technology and methods for wind turbine blades.

Motivation

Fibre Metal Laminates (FML) vs Fibre Reinforced Plastics (FRP):

- Excellent fatigue and corrosion resistance properties
- Damage tolerance
- Impact resistance and strength
- Flame penetration resistance
- Lightweight hybrid materials for aerospace, renewable energy and automotive applications



Motivation

- **Thermoplastic FMLs advantages over conventional thermoset FMLs:**
  - Superior impact resistance
  - Higher fracture toughness
  - Extensive fatigue life
  - Thermoformability
  - Easier repairability and processability
  - High recycling potential
- **Applications of FMLs** in offshore structures; towers of wind/tidal turbine blades and leading-edge protection, ship construction; catamarans, high speed crafts, boat hulls etc.

FML Project

EPSRC Centre for Advanced Materials for Renewable Energy Generation (CAMREG) funded project:

Thermoplastic fibre metal laminates for applications in renewable energy

PI-Prof Vasileios Koutsos (Edinburgh University)

CO-I Prof Conchúr M. Ó Brádaigh (Edinburgh University)

CO-I-Dr Dimitrios Mamalis (OREC)

RA-Dr James Maguire (Edinburgh University)

Published work:

-Mamalis D, Obande W, Koutsos V, Blackford JR, Ó Brádaigh CM, Ray D. Novel thermoplastic fibre-metal laminates manufactured by vacuum resin infusion: The effect of surface treatments on interfacial bonding. Mater Des 2019;162:331–44. doi:10.1016/J.MATDES.2018.11.048.

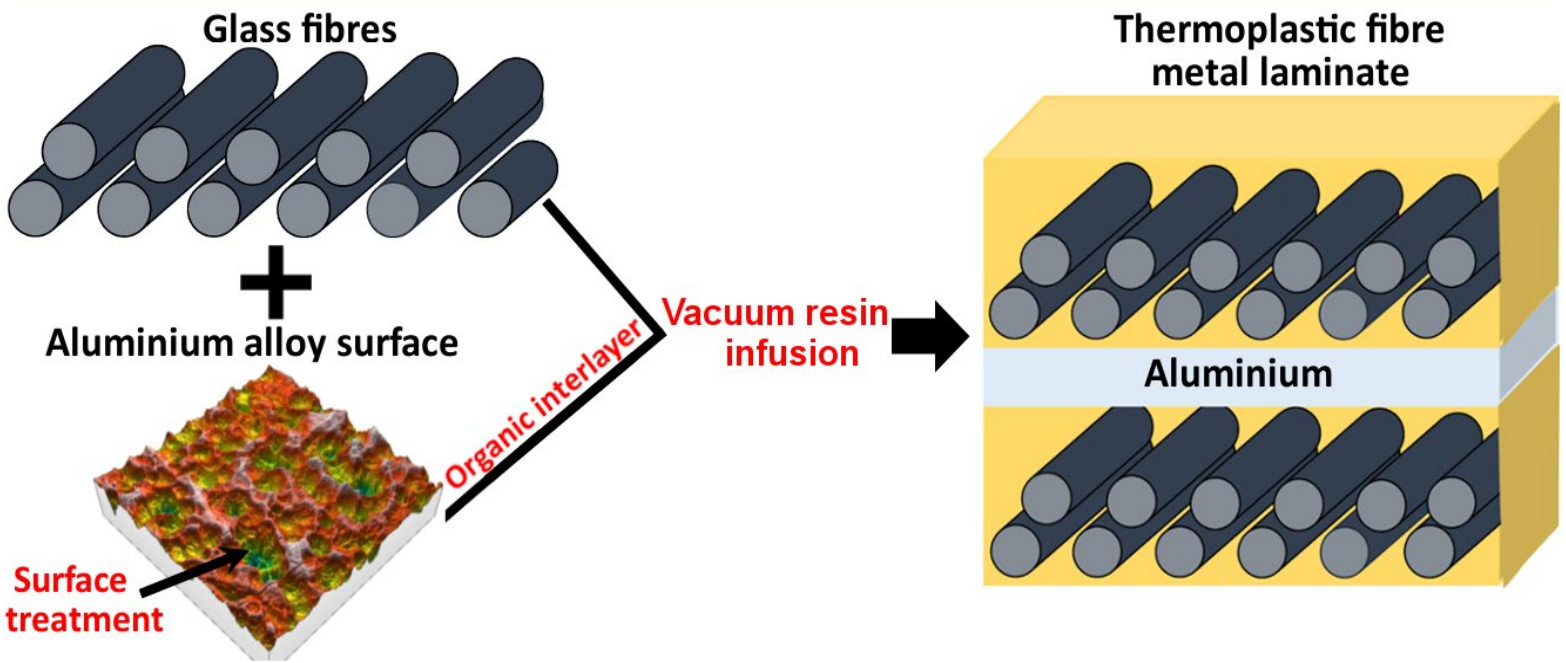
-Obande W, Mamalis D, Ray D, Yang L, Ó Brádaigh CM. Mechanical and thermomechanical characterisation of vacuum-infused thermoplastic- and thermoset-based composites. Mater Des 2019;175:107828. doi:10.1016/J.MATDES.2019.107828.

-Robert C, Mamalis D, Obande W, Koutsos V, Brádaigh CMÓ, Ray D. Interlayer bonding between thermoplastic composites and metals by in-situ polymerization technique. J Appl Polym Sci 2021;138:51188. doi:10.1002/APP.51188.

Thermoplastic FML concept

Objectives:

- Develop a new generation of **low cost**, **recyclable** hybrid FMLs based on a thermoplastic (TP) matrix.
- Manufacturability of TP-FMLs by the **in-situ polymerisation route** using VaRTM at room temperature.
- Establish an **acceptable level of bonding** between the metal and the thermoplastic.
- Investigate mechanical performance of the manufactured TP-FMLs



Schematic diagram of the FML composite based on Elium resin [6]

[6] Mamalis D, Obande W, Koutsos V, Blackford JR, Ó Brádaigh CM, Ray D. Novel thermoplastic fibre-metal laminates manufactured by vacuum resin infusion: The effect of surface treatments on interfacial bonding. Mater Des 2019;162:331–44. doi:10.1016/J.MATDES.2018.11.048.

Methodology

Materials:

- Commercially available unidirectional E-glass fabric (646 g/m²) supplied by Ahlstrom-Munksjö. The glass fabric consisted of 0° E-glass fibres (600 g/m²), 90° E-glass fibres (36 g/m²) and 90° polyester fibres (10 g/m²).
- Elium® 180 liquid thermoplastic resin supplied by ARKEMA.
- Alloy Aluminium (Al) 6082-T6, in the form of a sheet (0.71 mm thick), provided by Wilsons Ltd.

Methodology

Aluminium alloy modifications:

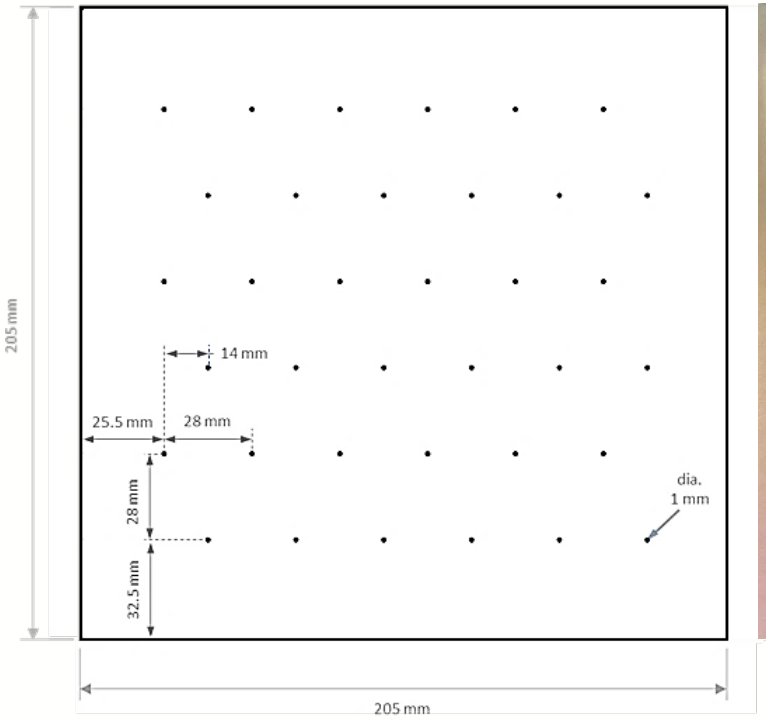
- Different chemical and physical surface treatments applied on the Al alloy sheets aiming to activate surface topography including alkaline and acid etching, anodising and atmospheric plasma treatments.
- Characterisation techniques of the Al treated surfaces: wettability/surface energy, surface topography and chemical composition (i.e. spectroscopy).

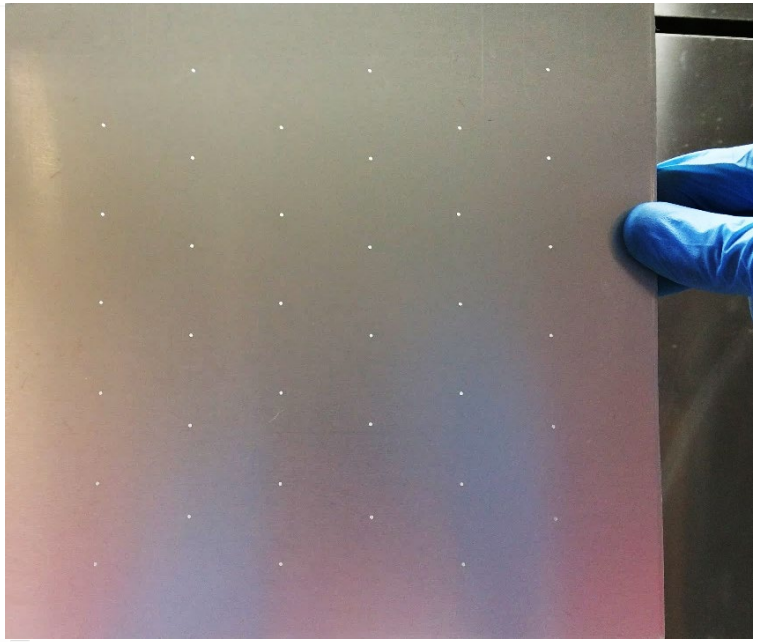
Fabrication of FMLs:

- All FMLs were manufactured using a hand lay-up VaRTM technique.
- Holes (flow paths) were drilled in the central zone of the Al sheets.
- FMLs were constructed with a 2/1 (UD glass-fabric-polymer/Al) configuration.

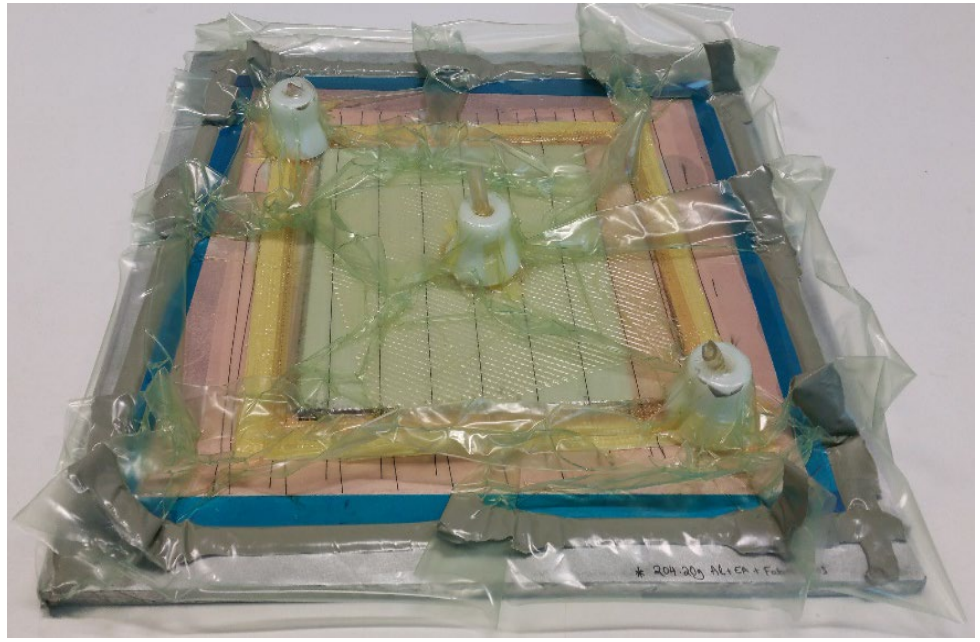
Methodology

Design of the Al hole-map



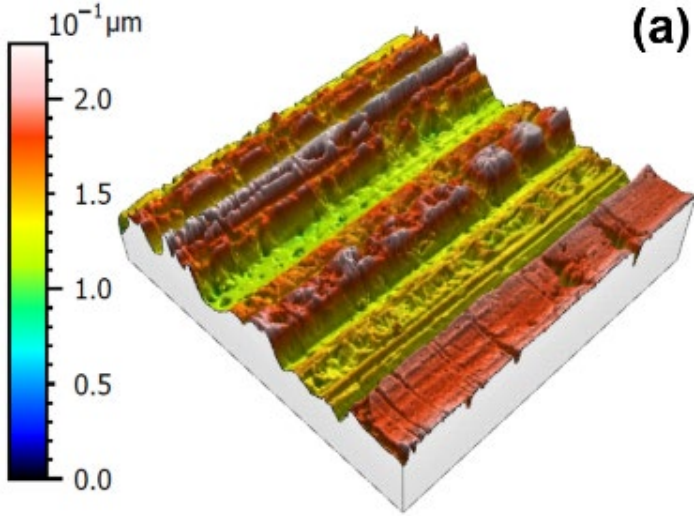


VaRTM (radial) set-up

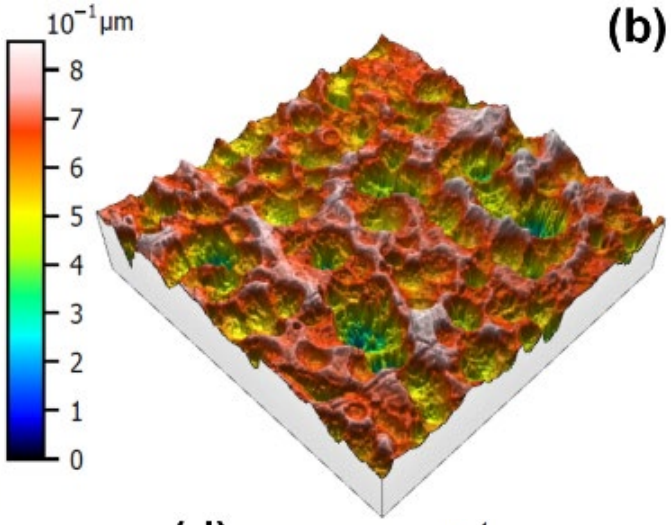


Results (3-D Microscopy)

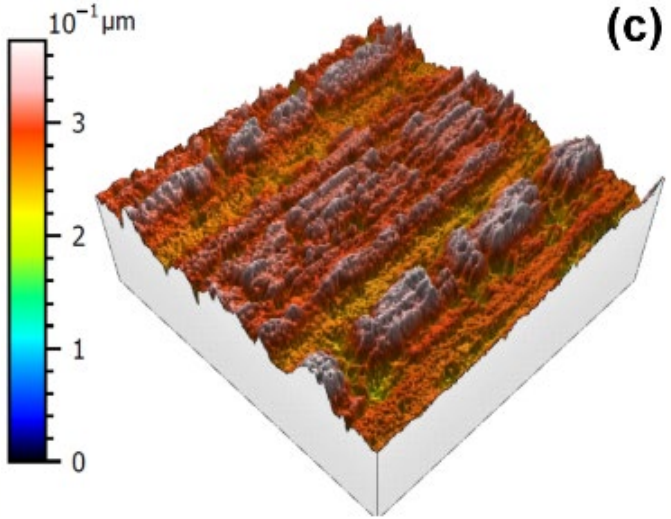
Degreased-only



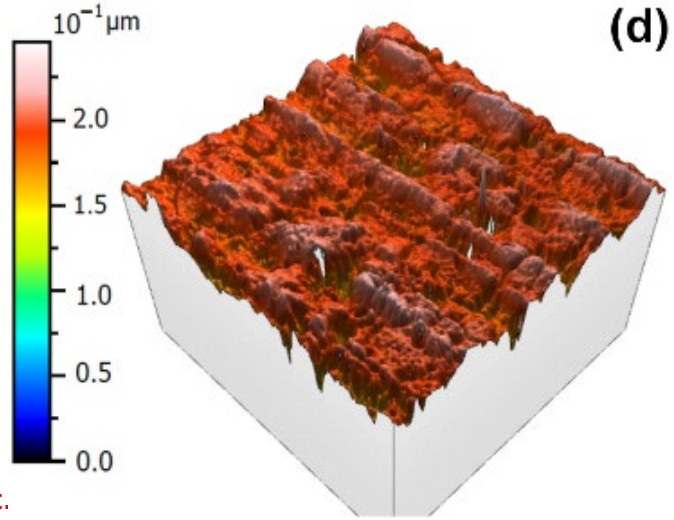
Alkali (20 min)

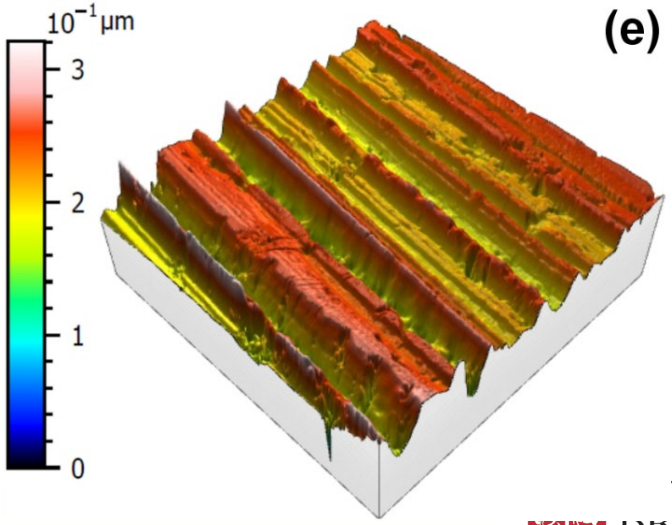


Acid (20 min)



Anodised (Def Stan 2003-25/4)

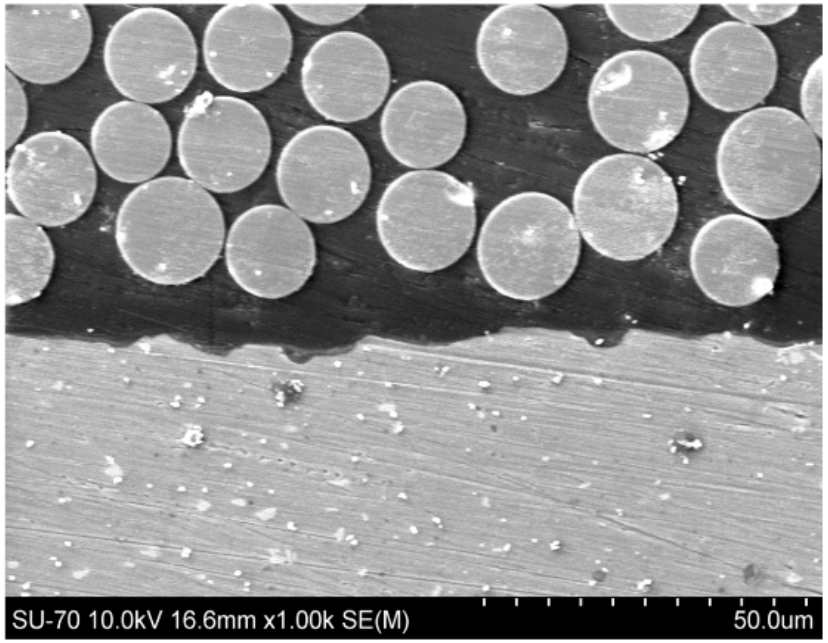




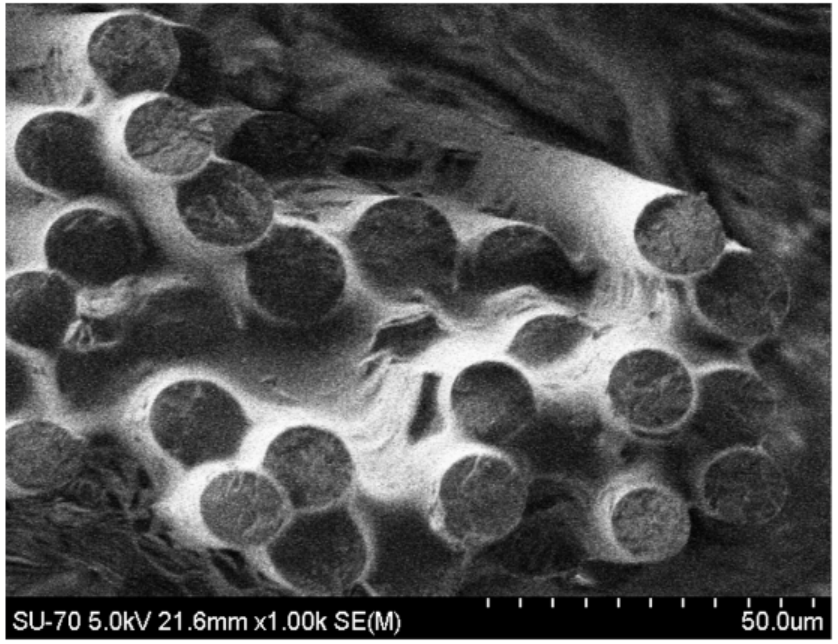
Atmospheric plasma (1mm/s 1 scan)

Results (SEM)

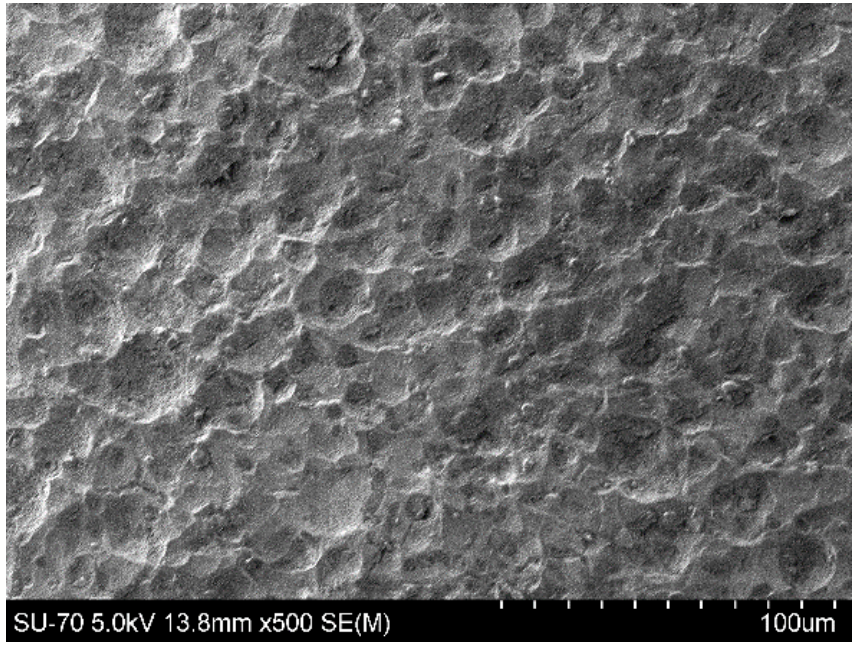
FML metal-composite interface



GFRP fracture surface



Debonded Al surface after flexure test



Concluding remarks

- Suitable surface treatment conditions were identified for the Al alloy sheets ; 10%wt. NaOH for 20 min, in term of surface roughness and chemical activity.
- VaRTM manufacturing of the FMLs was successfully carried out using Elium® liquid thermoplastic resin.
- Flexural and ILSS performance of GFRP and FML were examined. The measured properties were in comparable range with published literatures.
- Mode-I Interlaminar fracture toughness of the FML was found to be significantly higher (410 J/m^2) than the reported value of epoxy based FML (131 J/m^2) [7].
- A novel way of bonding Al alloy sheets and thermoplastic composite layers through the in-situ polymerisation technique was found to be successful.

[7] Laban O, Mahdi E. Enhancing mode I inter-laminar fracture toughness of aluminum/fiberglass fiber-metal laminates by combining surface pre-treatments 2017.

Future Work

- Achieving optimised metal-composite bond strength by a suitable technique which is industrially viable such as plasma activation.
- Optimisation of the FML manufacturing with minimum processing defects and deep understanding of the infusion mechanism.
- Manufacturing FMLs with consistent and high consolidation quality.
- Generating mechanical property data with thorough investigation of the damage and failure mechanism.

Future Work

- Exploring the feasibility of press-forming of FMLs.
- Investigating and developing predictive models relate to the fatigue and creep behaviour of the FMLs.
- Investigating the chemical (hydrocarbon) and water resistance.
- Preliminary investigations of the recyclability, weldability and repairability of the FMLs.
- Evaluating the commercial viability of the technology along with our industrial partners

Thank you! ☺