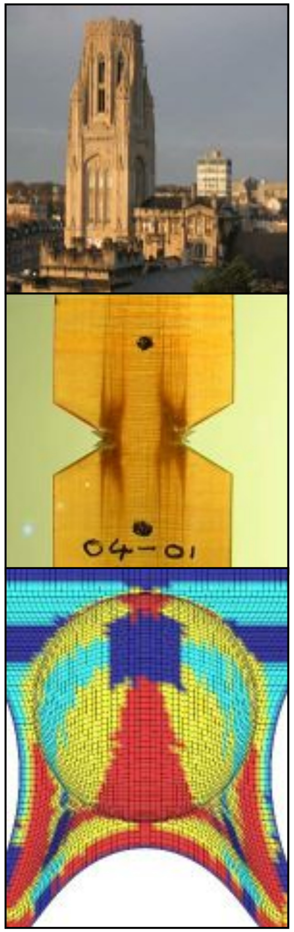

Self-Healing - Application in Engineering

Professor Ian Bond

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www.bris.ac.uk/composites

ADVANCED COMPOSITES CENTRE FOR INNOVATION & SCIENCE

HIPOCRATES: Self-healing polymers for concepts on self-repaired aeronautical composites

(36 months: Nov 2013 - Oct 2016)

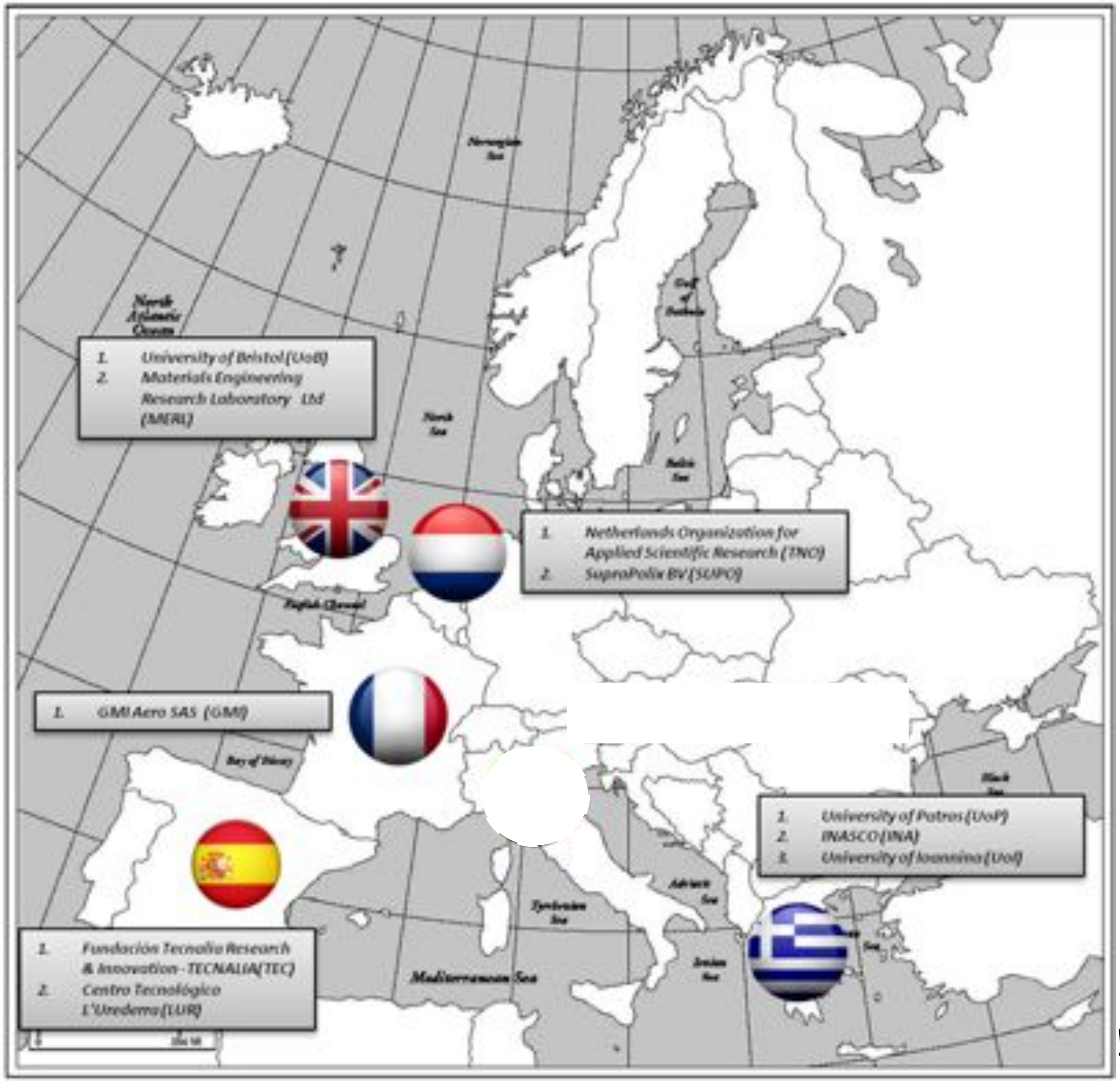
Professor Ian Bond

Dr Richard Trask, Prof Duncan Wass
Tim Coope, Rafael Luterbacher

http://hipocrates.drupal.pulsartecnalia.com/

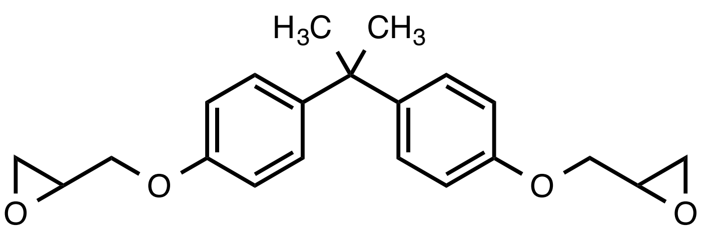
Consortium

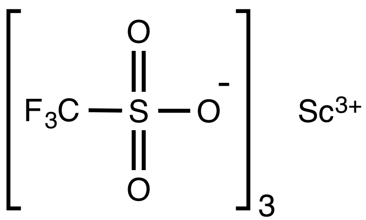
- **11 EU partners**

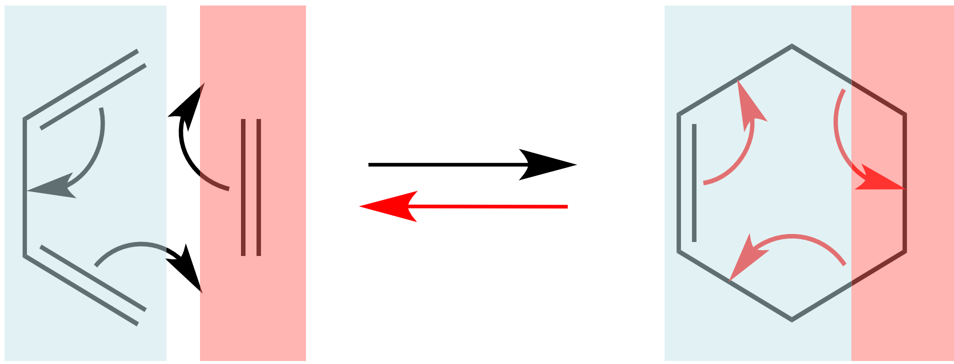


Aim & Objectives

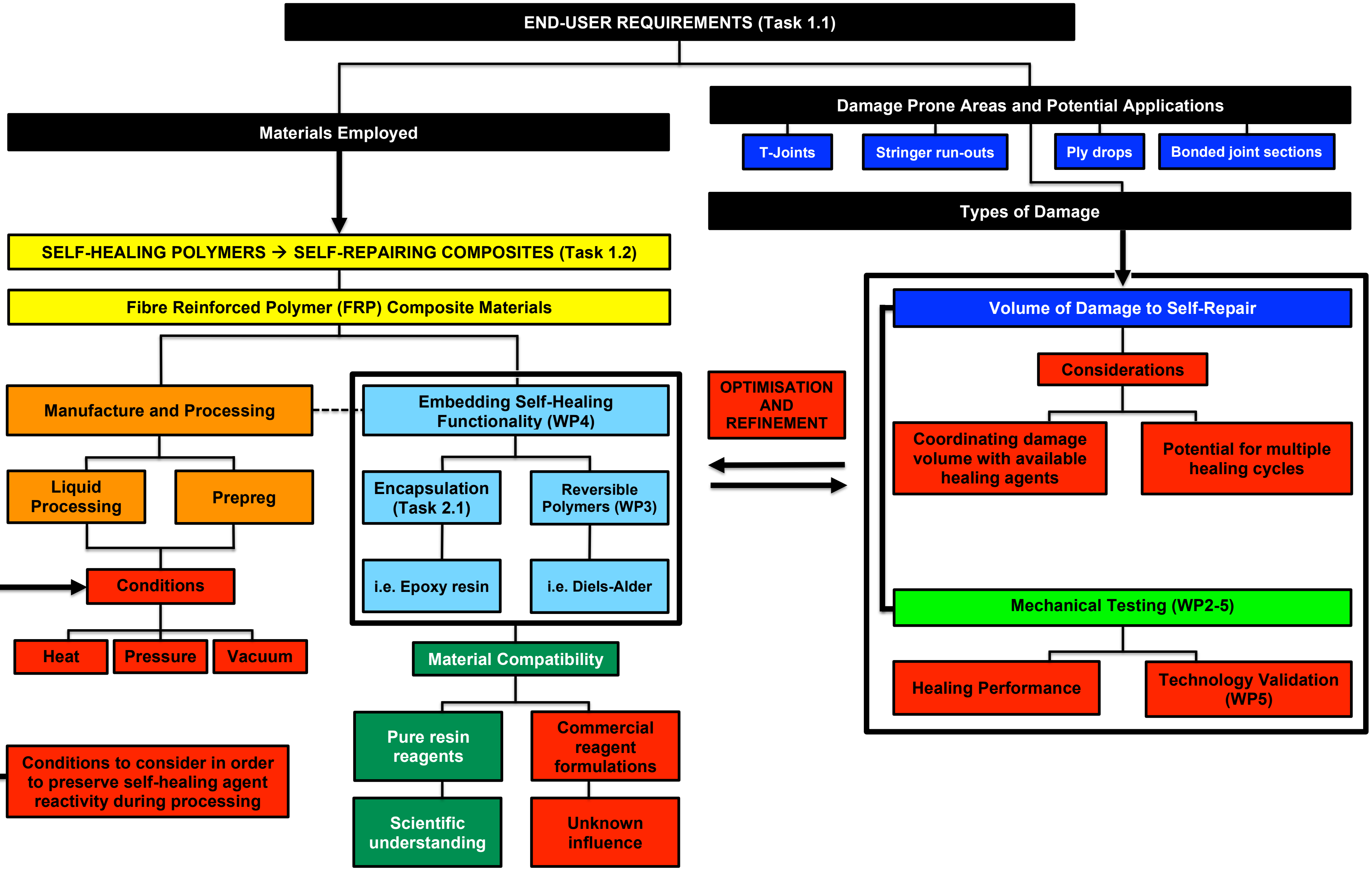
- To serve as a platform for developing the required knowledge, technologies, procedures and strategies to deliver self-repairing composites, while defining the roadmap to achieve the vision of self-repairing aero-composite structures.
- **Development of self-repair composites for aerospace industry**
  - Using conventional resin/prepreg systems
  - Targeted towards secondary structural composites
- **Combined self-healing systems (matched to damage size/type)**
  - Epoxy-based self-healing system (i.e. encapsulated, vascules) - **Bristol**
  - Diels-Alder thermo-mechanical activated system (polymer blend) - **TNO**







Technology Roadmap



Research focus

- **Material selection**
  - Wet layup (RTM, infusion etc)

    → ***Low temperature cure followed by elevated post-cure step***
  - Out of autoclave (OOA) prepreg

    → ***Preliminary studies with low T prepreg (cure cycle evaluation)***

Preserving self-healing agent reactivity post-manufacture

- **Preliminary test configurations**
  - Drilled holes → ***remediate damage generated during manufacture/ assembly***
  - Ply drops → **address premature failure, crack propagation**
  - Skin-Stiffener run-out→ **address premature failure, crack propagation**

Self-Healing Approch & Integration

Self-healing films (Bristol/TNO)

- Epoxy-based, containing microencapsulated reagents (capsule) – Bristol
- Reversible Diels-Alder polymer (intrinsic) – TNO, NL

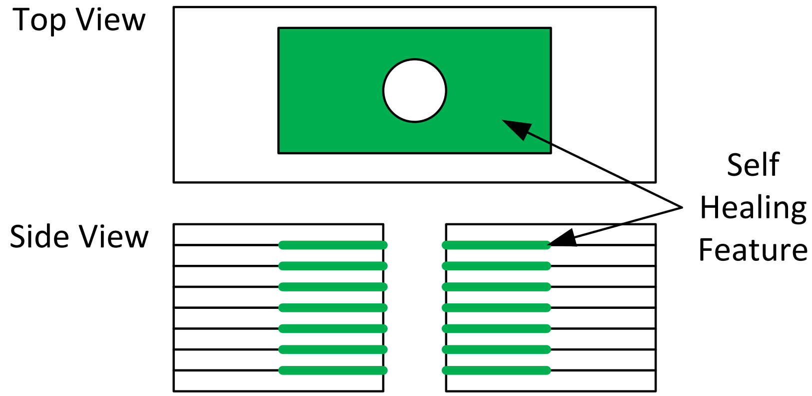
Microvascular channels (Bristol)

- Embedded vascules (ca. 500μm) deliver healing agent
- Connectivity between propagating damage and microvascular channels

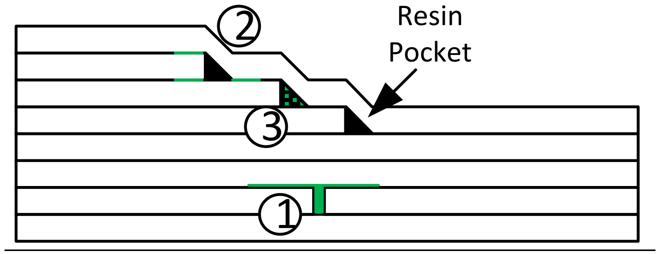
Structural Integration

1. *Open-hole tension (OHT) test coupon specimens*
   - Interleaved films in prepreg-based FRP composites, capsule and/or vascular approach(es)
   - To repair damage generated during machining and/or assembly
2. *Damage initiating at resin rich regions*
   - Ply drops, stringer run-outs, repair patches etc.
   - To repair in-service damage

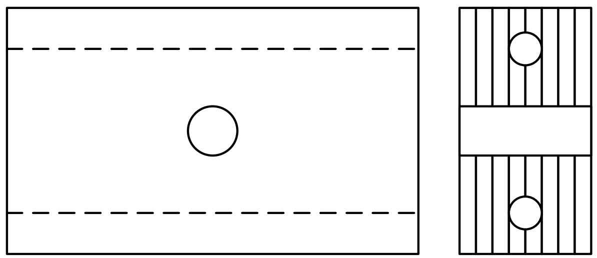
Capsule/Intrinsic



Ply drops



Vascular approach



Marie-Curie ITN

'SHeMat' - Training Network for **Self-Healing Materials: from Concepts to Market**

(48 months: Jan 2012 – Dec 2015)

[www.shemat.eu]

WP2: Self-Healing (Fibre Reinforced Polymer) Composites

Consortium

- 13 partners from 6 countries;
- Germany, UK, France, Netherlands, Switzerland, Belgium

Bristol Team

- Professor Ian Bond
- Professor Duncan Wass (Chemistry)
- Dr Richard Trask
- Patryk Jarzynk: *FRPs with a discrete self-healing function*
- Jack Cullinan: *FRPs with integrated vascular self-healing*

WP2: Self-Healing Composites

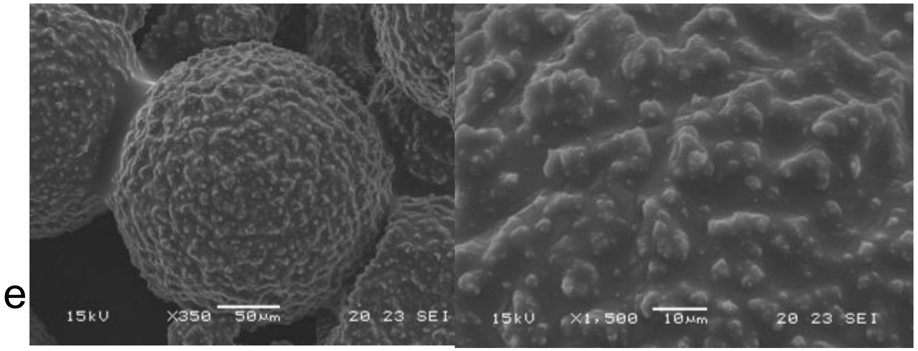
- Focus to equip FRP composites with self-healing function:
- Main objectives to develop:
  - structures that provide self-healing components,
  - vascular systems in natural and technical systems,
  - up-scaling self-healing composites to an industrial level.

Microcapsule Self-Healing of Fibre Reinforced Polymers

Patryk Jarzynka: *FRPs with a discrete self-healing function (Early Stage Researcher - PhD)*

Aim:

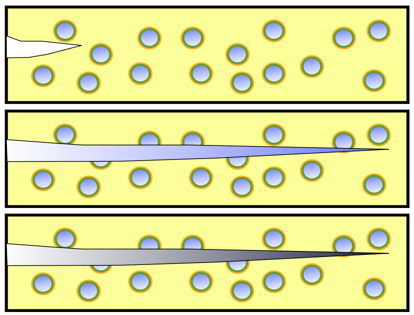
The overall aim is to develop a microcapsule based self-healing delivery system tailored for FRP composite materials.



SEM micrograph of microcapsules with UF/PU shell, liquid monomer core, catalyst coating.

Objectives:

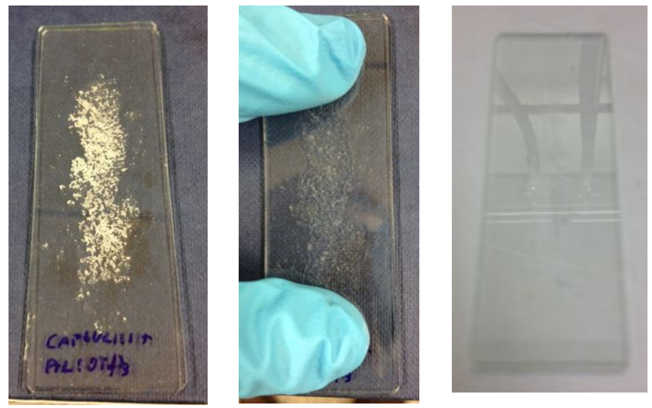
- Development of microencapsulation of active monomers in robust shell.
- Selection of suitable polymeriser (curing agents).
- Integration of healing functionality in FRPs.
- Mechanical testing of microcapsules in FRPs.
- Evaluation of healing functionality.



Dispersed, monomer filled microcapsules, decorated with catalyst:

a) Crack formed damage event.
b) Propagating crack ruptures microcapsules, releases monomer.
c) Healing agent polymerises after contact with catalyst coating and repairs damage.

Crushed microcapsules bond glass slides



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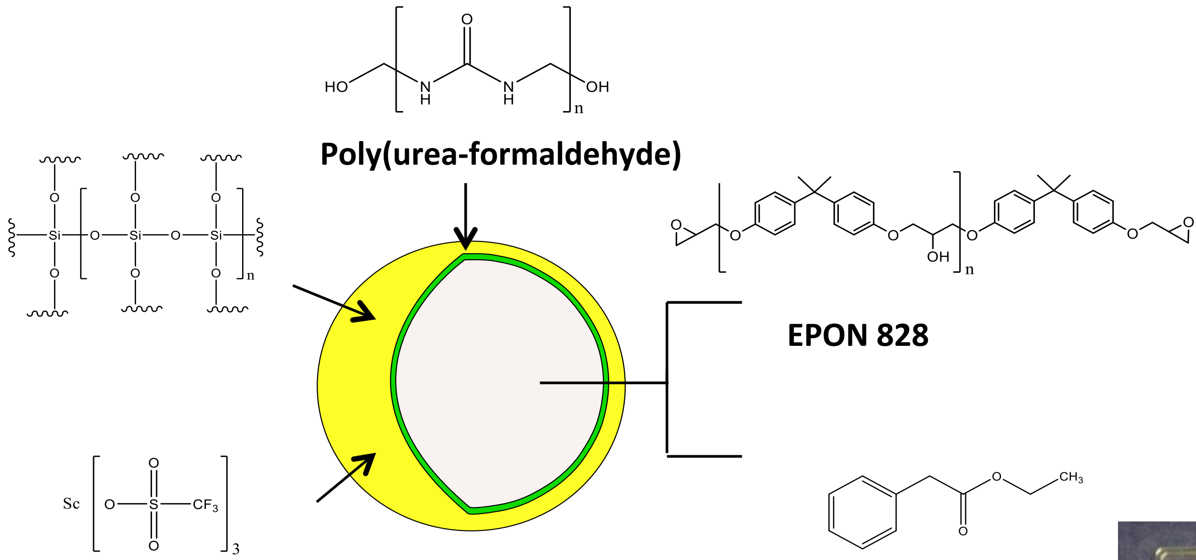
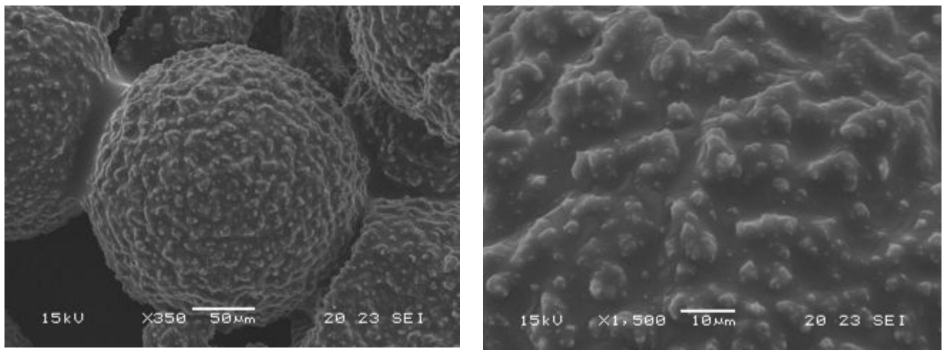
Integrated Self-Healing Microcapsules

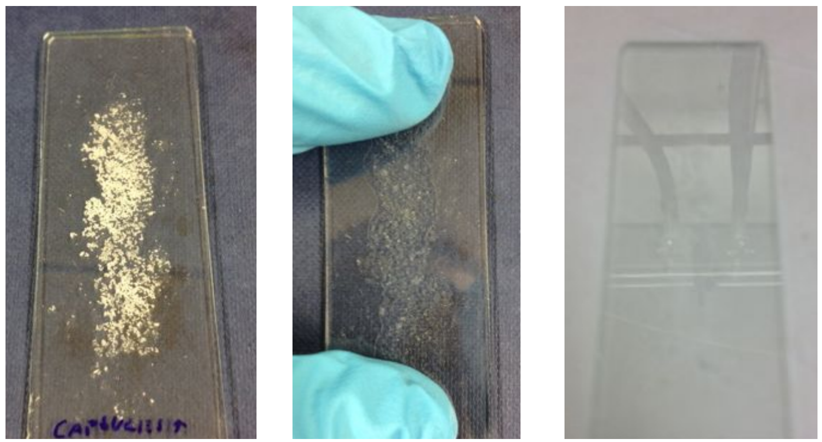
- Fully-functioning SH microcapsule system
- Epoxy/solvent filled microcapsules reinforced with Silica outer shell and decorated with $Sc(OTf)_3$ catalyst molecules



Scandium (III) Triflate



Capsules impregnated with $Sc(OTf)_3$ at variable concentration and crushed between two microscopic slides. Room Temperature



Crushed microcapsules bond glass slides

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Damage Tolerant T-Joints: *Damage Manipulation & Self-Healing*

Jack Cullinan: *FRPs with integrated vascular self-healing (Early Stage Researcher - PhD)*

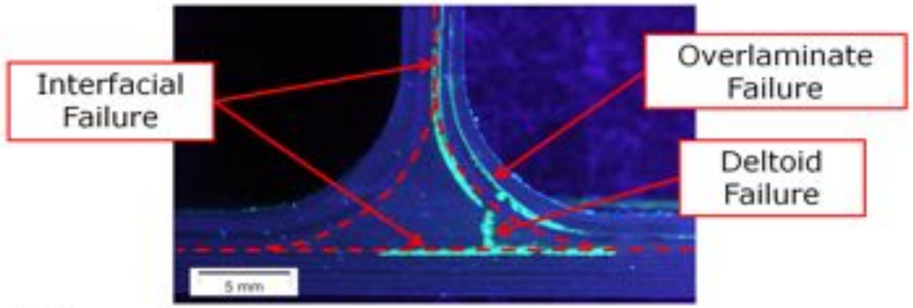
Aim:

The successful implementation of established self-healing technologies in industrially relevant, complex composite structures

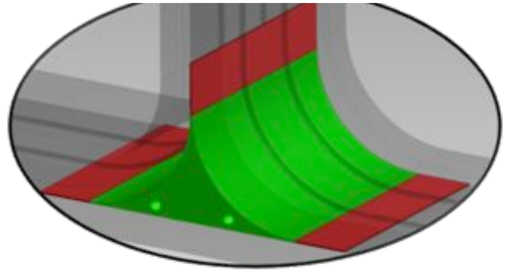
Objectives:

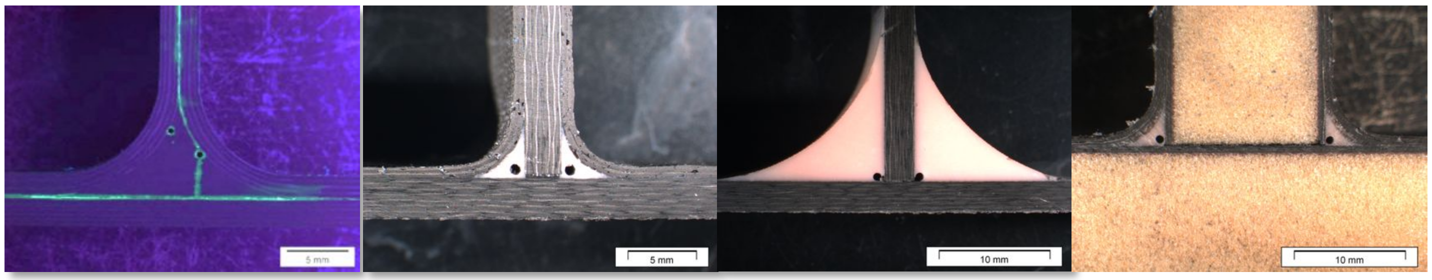
- Development, characterisation and optimisation of representative structural configurations for SH.
- Mechanical testing of components
- Evaluation of healing functionality.
- Evaluate industrial implementation

Failure modes in T – joints



Healing strategy: Vascular SH (green) + EMAA crack arrestors (red)





Various T - joint configurations:

- *Large deltoid ideal for SH infrastructure*
- *Z-pinning, stitching & tufting all ineffective in improving onset of damage*

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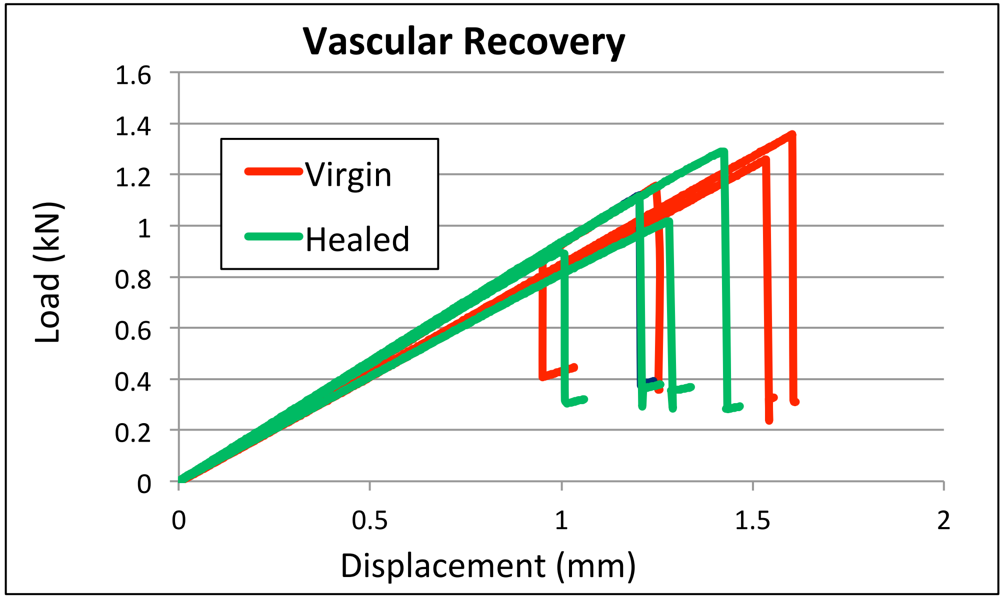
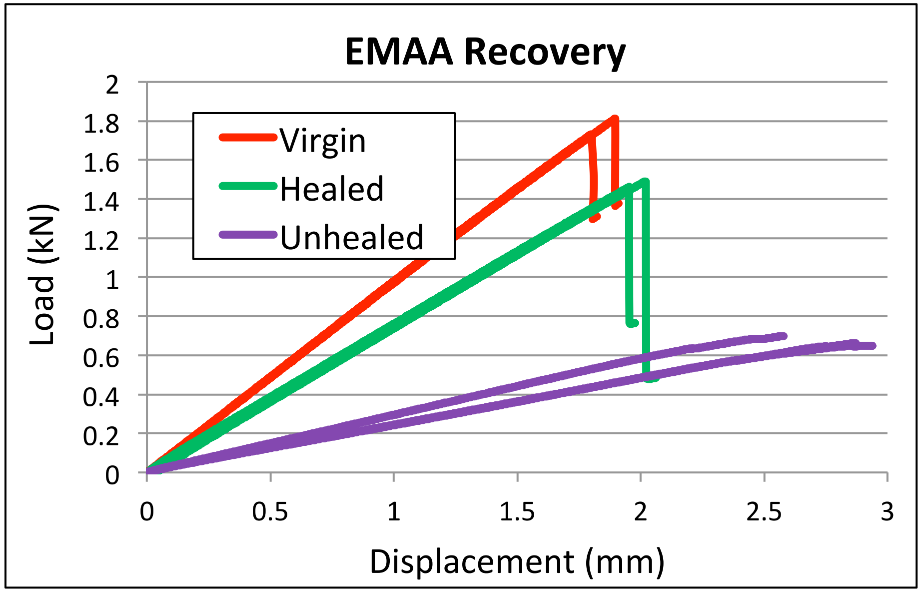
SHeMat

Self-Healing T-joints





Stiffness Recovery:

94% – 99.84%

Strength Recovery:

80% – 130%

Stiffness Recovery:

23% – 70%

Strength Recovery:

37 – 86%

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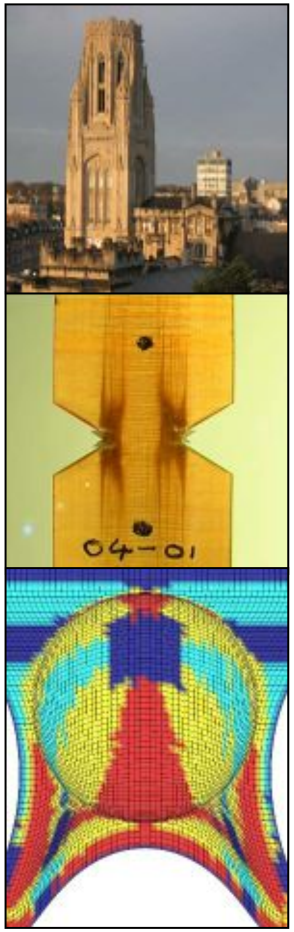

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