Self-Healing - Application in Engineering

Professor Ian Bond

I.P.Bond@bristol.ac.uk

www.bris.ac.uk/composites
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

END-USER REQUIREMENTS (Task 1.1)

Materials Employed

SELF-HEALING POLYMERS → SELF-REPARING COMPOSITES (Task 1.2)

Fibre Reinforced Polymer (FRP) Composite Materials

Manufacture and Processing

- Liquid Processing
- Prepreg

Conditions

- Heat
- Pressure
- Vacuum

Conditions to consider in order to preserve self-healing agent reactivity during processing

Optimisation and Refinement

Embedding Self-Healing Functionality (WP4)

- Encapsulation (Task 2.1)
- Reversible Polymers (WP3)

Material Compatibility

- Pure resin reagents
- Commercial reagent formulations
- Scientific understanding
- Unknown influence

Damage Prone Areas and Potential Applications

- T-Joints
- Stringer run-outs
- Ply drops
- Bonded joint sections

Types of Damage

Volume of Damage to Self-Repair

- Considerations

- Coordinating damage volume with available healing agents
- Potential for multiple healing cycles

Mechanical Testing (WP2-5)

Healing Performance

Technology Validation (WP5)
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)

- **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

Preserving self-healing agent reactivity post-manufacture
Self-Healing Approach & Integration

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

Microvascular channels (Bristol)
- Embedded vasculues (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

Possible tests for consideration:
Table 2. Proposed tests for ply drops

In order to be able to ascertain the healing capability, the propagation rate of damage has to be small, therefore mainly fatigue loading needed.

In this section an additional configuration is proposed where self-healing could easily be implemented into a structurally significant configuration.

3.1 Incorporation of self-healing features within a secondary bondline
As discussed previously in the 3M meeting in Brussels, the healing capability of self-healing fibre reinforced polymer (FRP) composites has to be adapted to a certain type of damage event. Adhesive bonding has the benefit of a better load transfer than bolted joints. However, issues can arise from the point of surface preparation, bonding conditions (moisture, temperature), inspection and damage monitoring (e.g. kissing joints).

Introducing a self-healing feature within a secondary bondline could potentially provide benefits to increase the reliability and usage of bonded structures. Examples of the suggested applications are listed below:

• Secondary bonded structures e.g. skin stiffened structure
• Sandwich structures
• Bonded repair
Marie-Curie ITN

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

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.

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

Crushed microcapsules bond glass slides
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

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

Crushed microcapsules bond glass slides
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
Self-Healing T-joints

**Vascular Recovery**

Stiffness Recovery: 94% – 99.84%
Strength Recovery: 80% – 130%

**EMAA Recovery**

Stiffness Recovery: 23% – 70%
Strength Recovery: 37 – 86%
Self-Healing - Application in Engineering

Professor Ian Bond
I.P.Bond@bristol.ac.uk

www.bris.ac.uk/composites