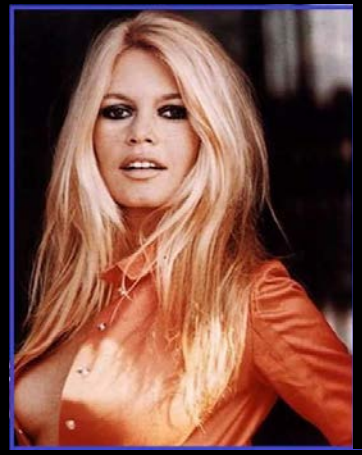
Self-Healing Materials

Dr. Ugo Lafont

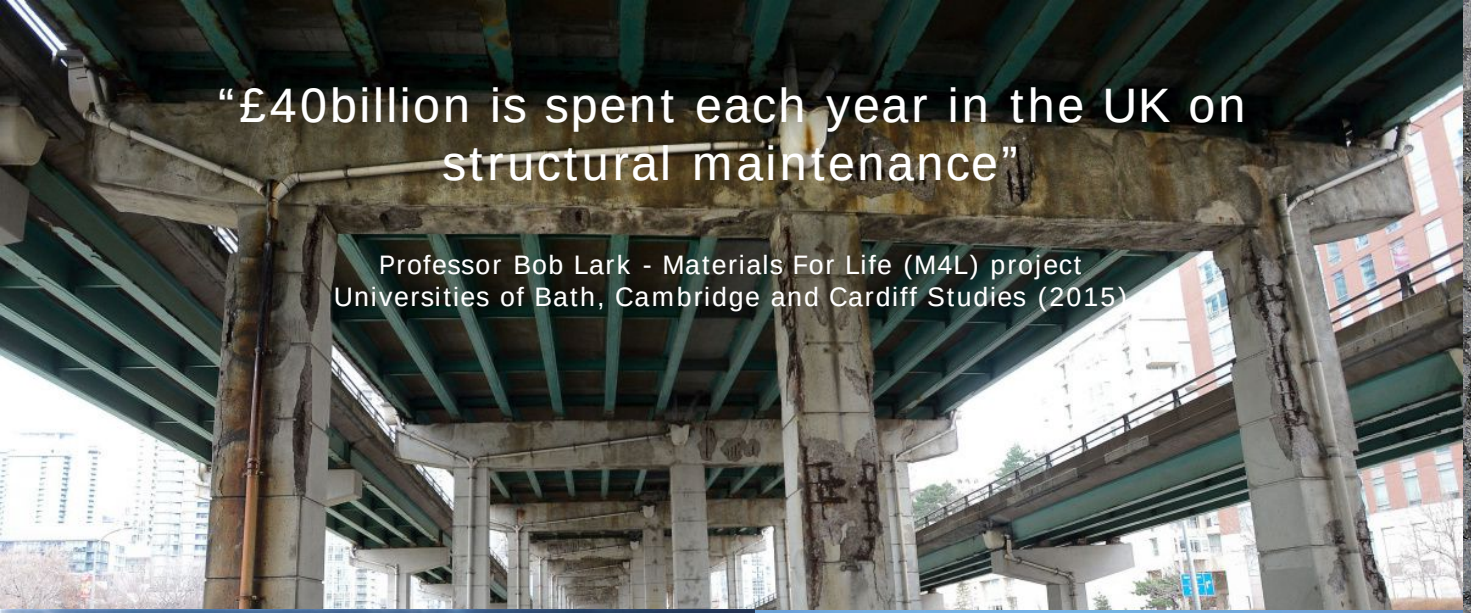
Image Credit: NASA/ESA and G. Bacon (STScI)

Interstellar Exploration Workshop – ESA-ESTEC 20-21 June 2019

ESA UNCLASSIFIED - For Official Use



2009



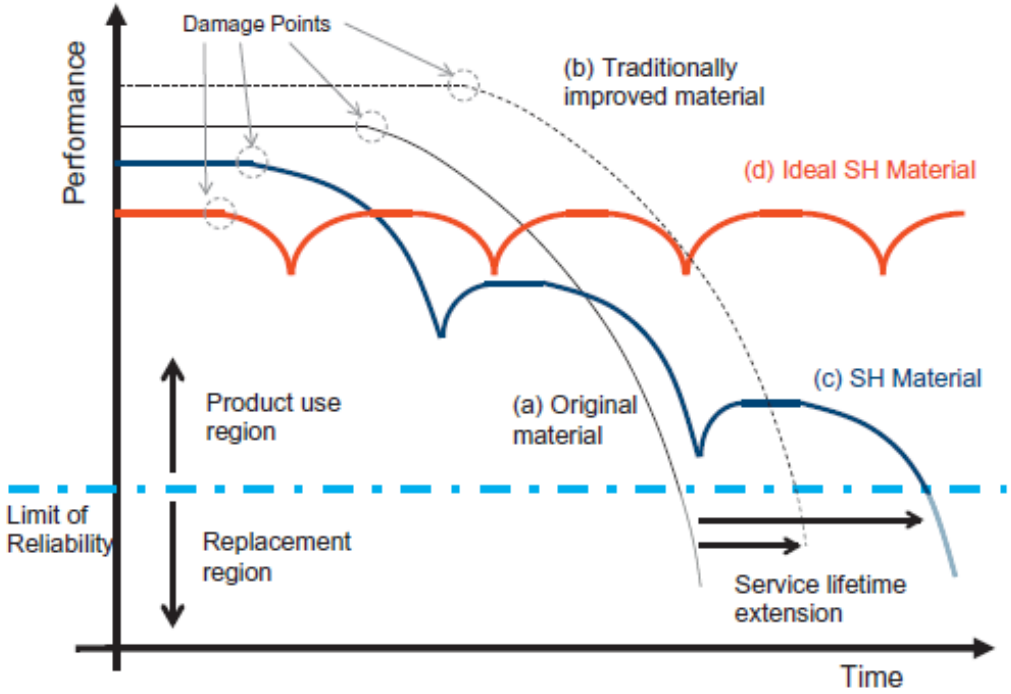
“£40billion is spent each year in the UK on structural maintenance”

Professor Bob Lark - Materials For Life (M4L) project
Universities of Bath, Cambridge and Cardiff Studies (2015)

Pont du Gard (South of France)
Roman Aqueduct - 1st Century

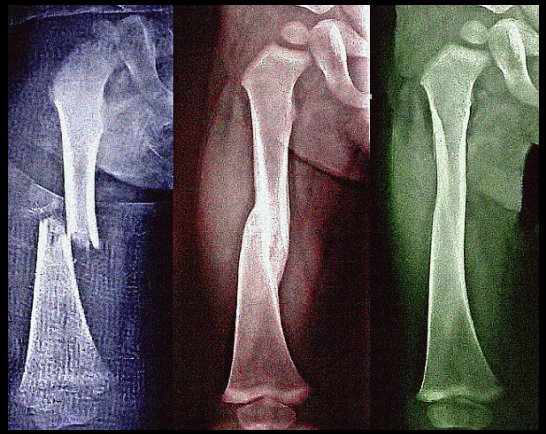
Mortar based on volcanic ashes and lime – “Self-healing”

Damage prevention VS Damage management



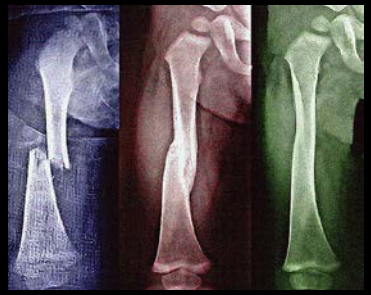
Garcia S.J., European Polymer Journal, 2014, 53, 118-125

Inspired by Nature
“Biomimicry”



1- ACTIVATION PHASE 2- TRANSPORTATION PHASE 3- REPAIR PHASE

Mimicking nature self-healing properties

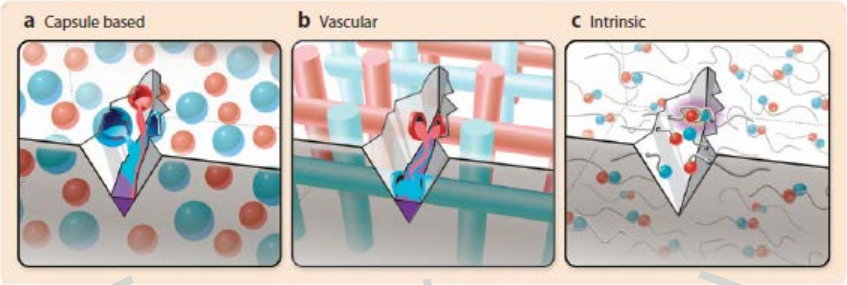


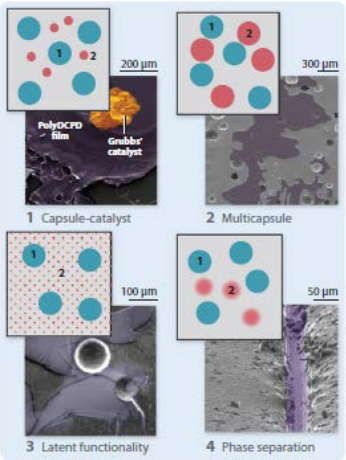
1st Generation of Self-Healing Materials

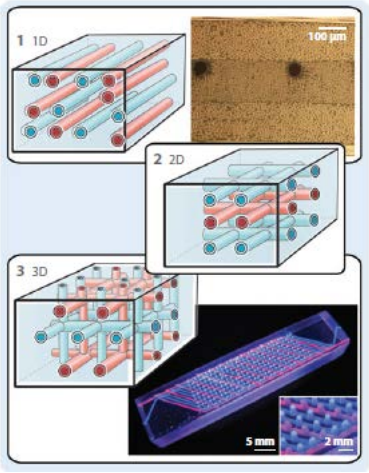
Structural integrity recovery

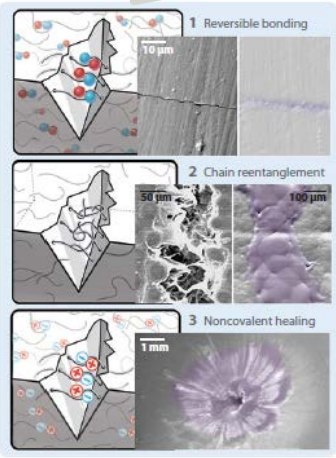
1 – Self-healing Concepts

Self healing approaches



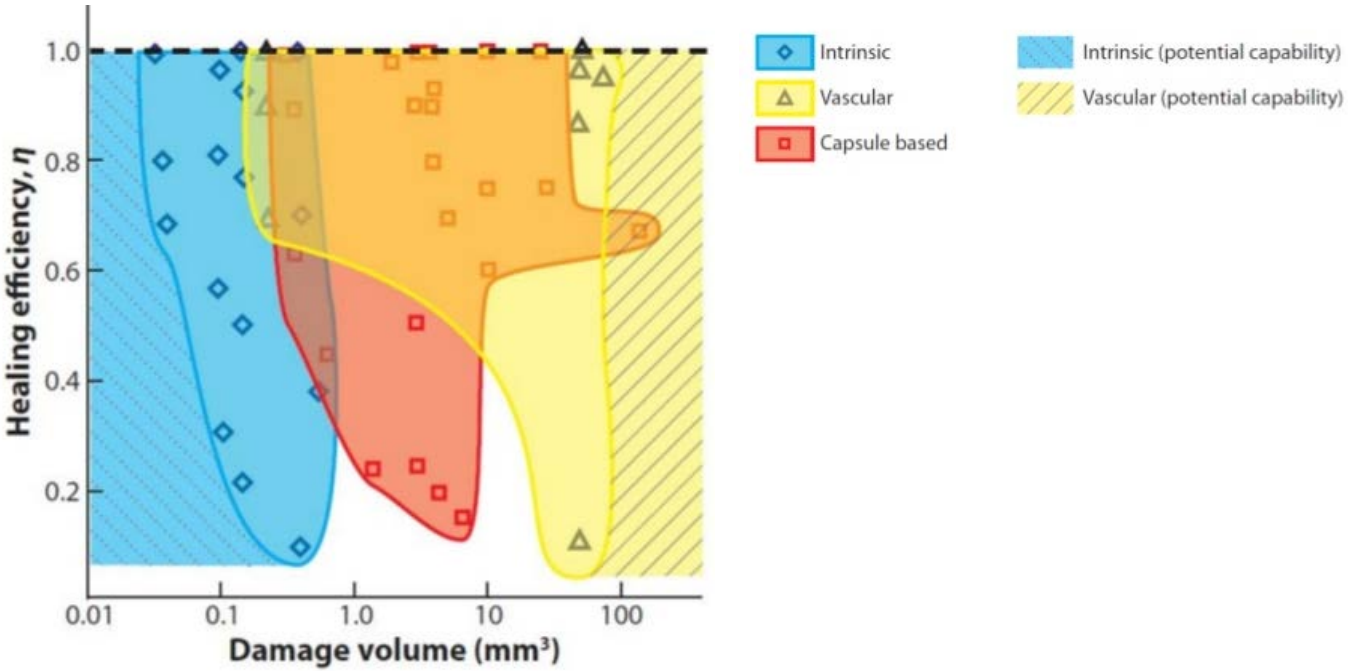






Blaiszik B. et al, Annual Review of Materials Research., 2010, 40, 179-211

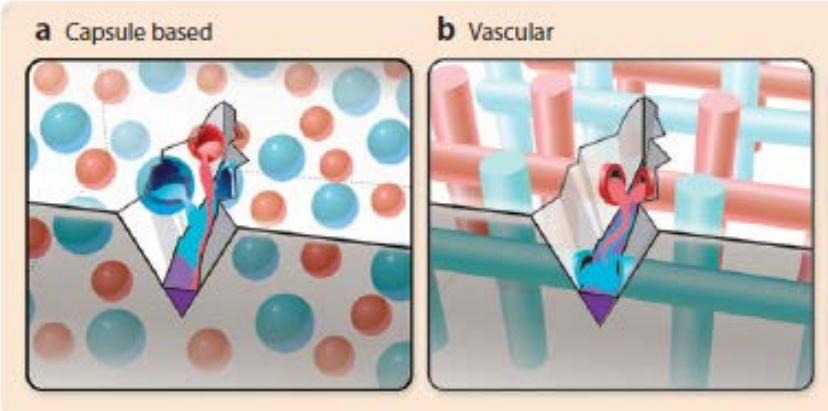
Healing vs Size of damage

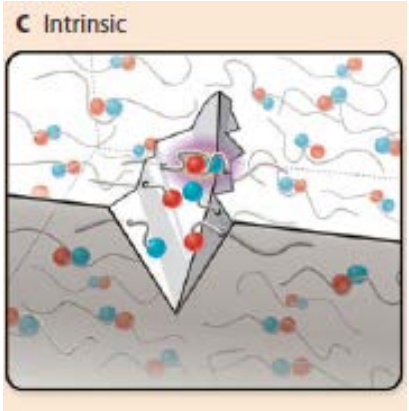


Blaiszik B. et al, Annual Review of Materials Research., 2010, 40, 179-211

B.J. Blaiszik et al, Self-Healing Polymers and Composites, Annual Review of Materials Research (2010) 40: 179-211

Autonomous vs Triggered





AUTONOMOUS Healing

TRIGGERED Healing
INTRINSIC Healing
(Thermal, Electrical, Mechanical)

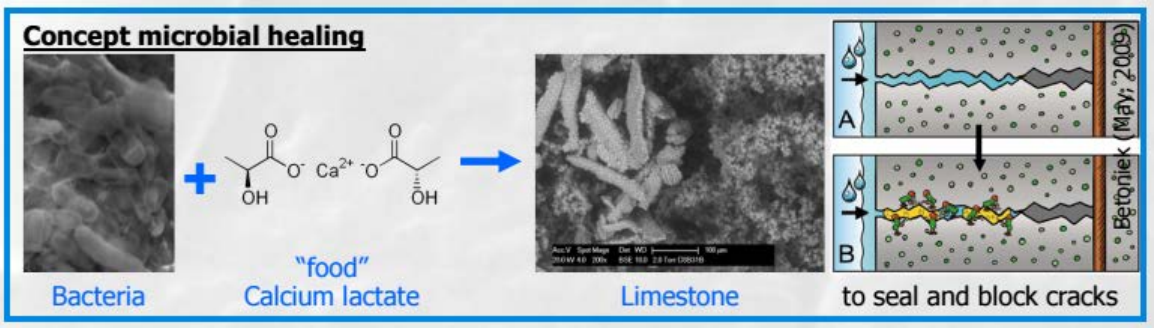
Multiple healing **not possible**

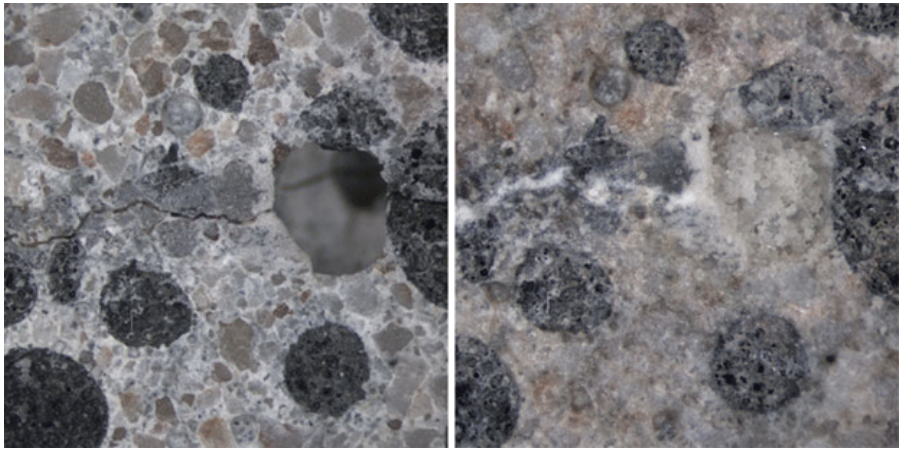
Multiple healing **possible**

Blaiszik B. et al, Annual Review of Materials Research., 2010, 40, 179-211

2 – Autonomous healing

Bio-Concrete



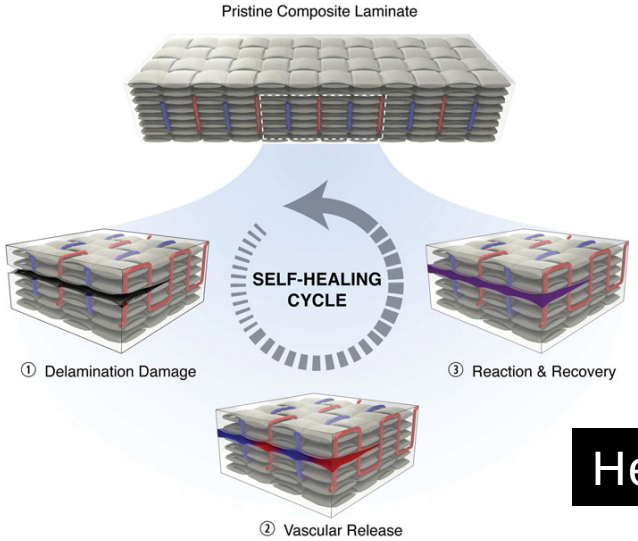


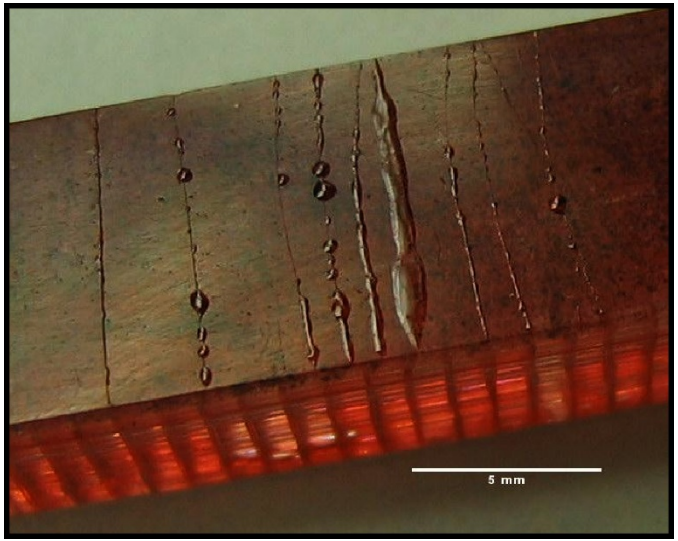
Healing by bacterial activities

2 – Autonomous healing

Composite / Resin / Coating

- Development of containers
- Strength reduction
- Shell life issue
- Multiple healing **not possible**

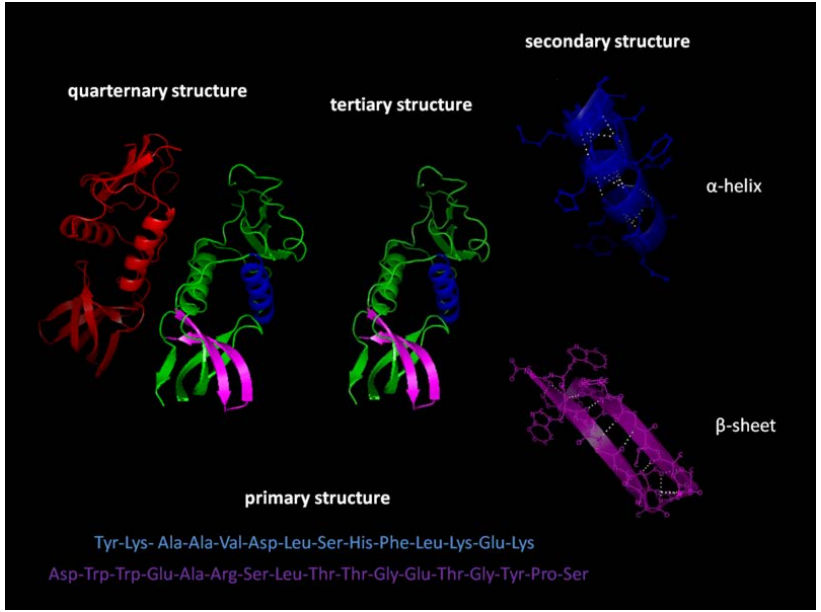


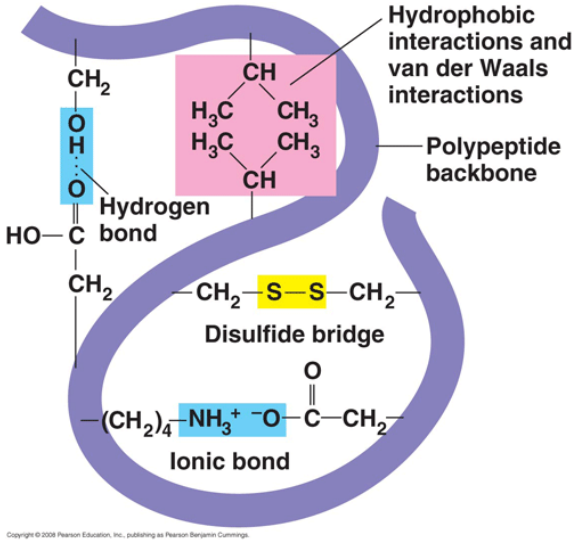


Healing liquid polymerized into damaged area

3 – Intrinsic Self-healing Materials

Dynamic bonding ability



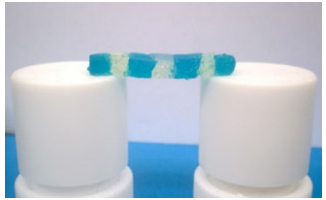


Molecular mobility by dynamic bonding ability
→ Trigger (Heat, pH, Radiation, Pressure…)

Dynamic bonding ability

Creation of reversible / dynamic bonding ability

Diels-Alder adduct [1]
Disulphide methatesis [2]
Transesterification [3]
Supramolecular network / H-Bonds [4]
Ionomers / Ionic interaction [5]
VdV interaction / inter-chain diffusion [6]



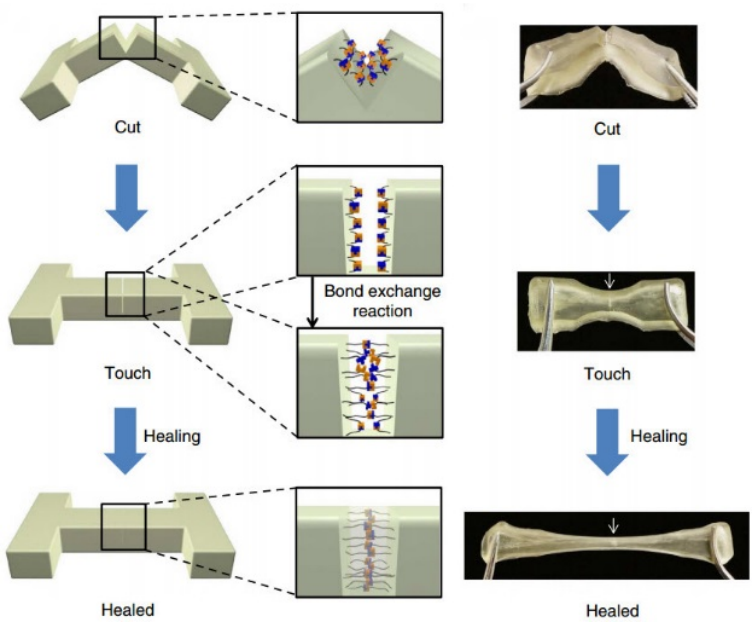
Advantages:

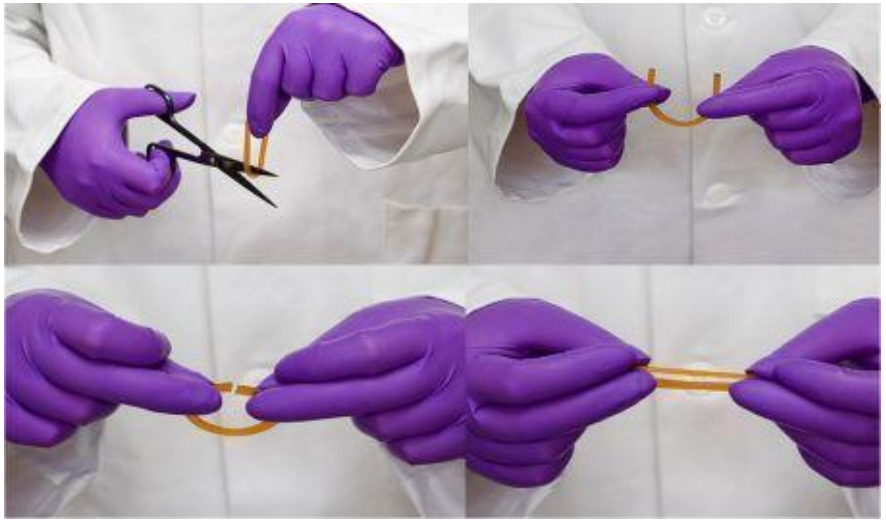
Triggered healing
Healing at the micrometer scale and below
Multiple healing possible
Healing of more than one functionality

[1] P. Reutenauer et al. Chemistry - A European Journal 2009, 15, (8), 1893-1900
[2] J. Canadell et al. Macromolecules 2011, 44, 2536-2541.
[3] D. Montarnal et al. Science 2011, 334, (6058), 965-968
[4] P. Cordier et al. Nature 2008, 451, (7181), 977-980
[5] J. Varley and S. van der Zwaag Polymer International 2010, 8, 1031-1038
[6] A. Susa et al. ACS Appl. Mat. Int. 2016, 8, 34068−34079

3 – Intrinsic Self-healing Materials

H-Bonding





ARKEMA
INNOVATIVE CHEMISTRY

Chemistry: H-bond
Stimulus: Pressure
Particularity: Moisture sensitive

Rubber / Elastomeric material

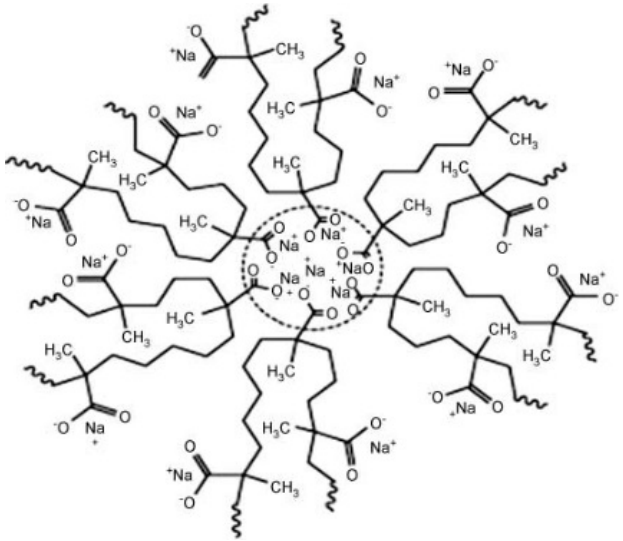
[1] Wenzhe Ying et al. Dynamic urea bond for the design of reversible and self-healing polymers. *Nature Communications*, 2014.

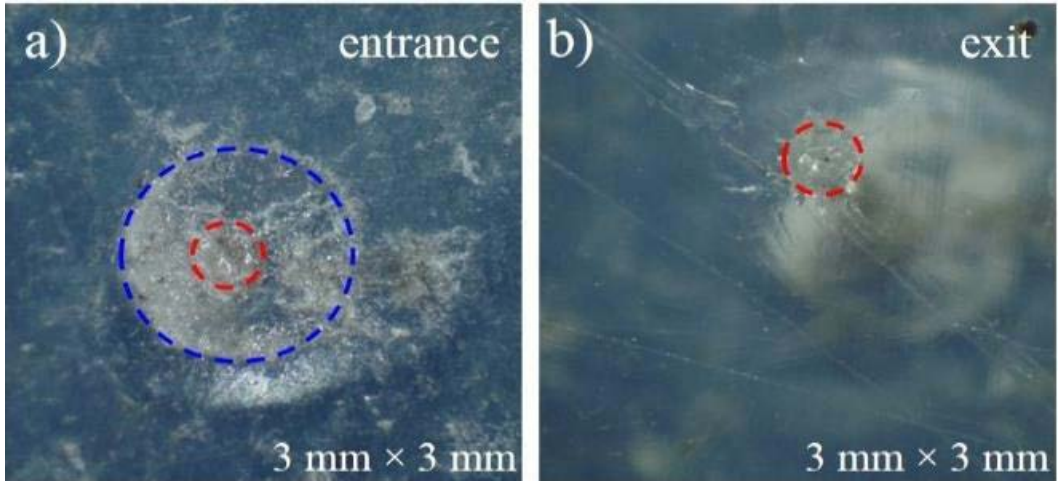
https://www.youtube.com/watch?v=F0ItKCH24ck

https://www.youtube.com/watch?v=0wDN6nMR4Tg

3 – Intrinsic Self-healing Materials

Ionic interaction





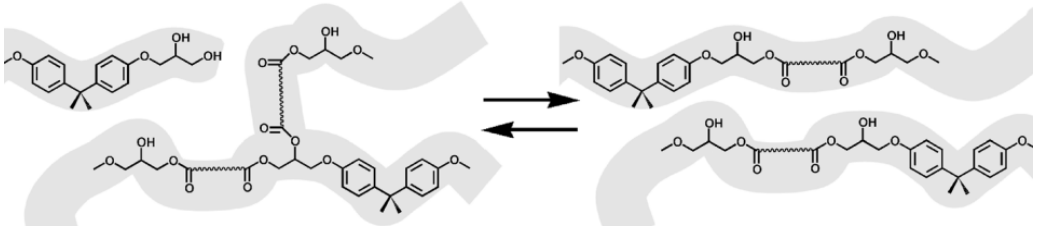
- Ionomers type of materials
- Ballistic application

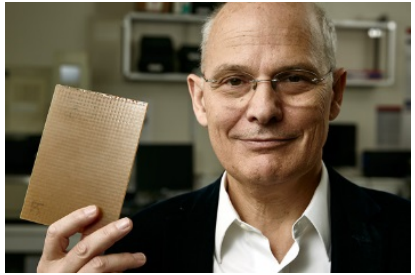
Stimulus: Energy of impact (Heat)

Thermoplastic material

3 – Intrinsic Self-healing Materials

Covalent bonding





- High Strength
- Recyclable
- Multiple healing
- **New class of material: VITRIMERS**

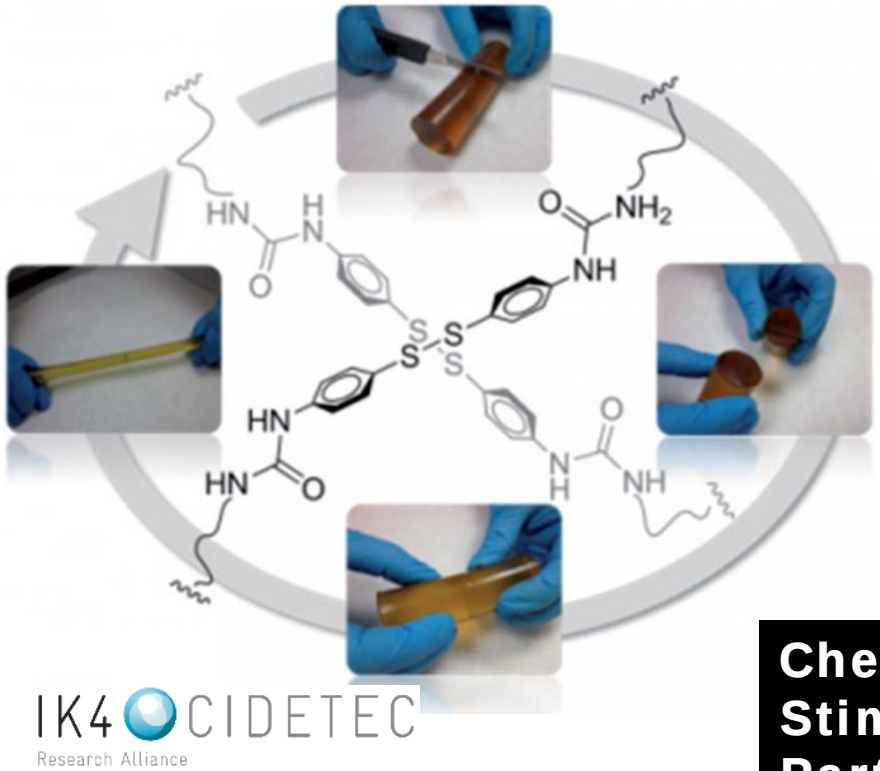
L. Liebler et al. Science (2011) 334, 965-968

Chemistry: Transesterification
Stimulus: Heat
Particularity: glass like behavior

Thermoset material

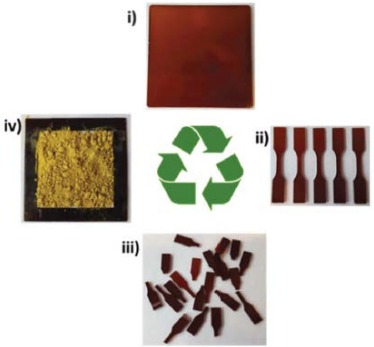
3 – Intrinsic Self-healing Materials

H-Bonding and Covalent



IK4 CIDETEC
Research Alliance

Odriozola et al, Mater. Horiz., 2016, 3, 241--247



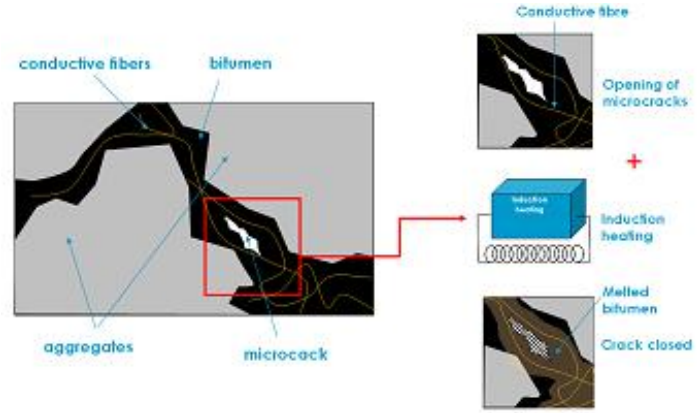
Full recycling

Elastomeric material

Chemistry: H-Bond / Disulfide metathesis
Stimulus: Pressure / heat
Particularity: double healing

4 – Self-healing Systems

Asphalt



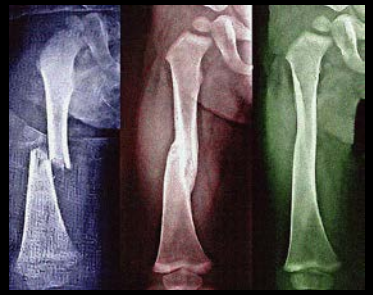
Highway A58 in NL: The first engineered self healing asphalt road

→Avoid raveling
→Increased service life
→Save maintenance time (money)
→First maintenance in 5 years

Healing by Magnetic Induction (HEAT) and pressure

Ballistic Application

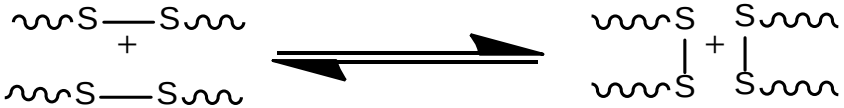
Mimicking nature self-healing properties

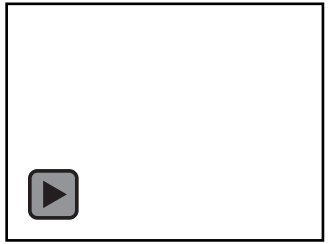


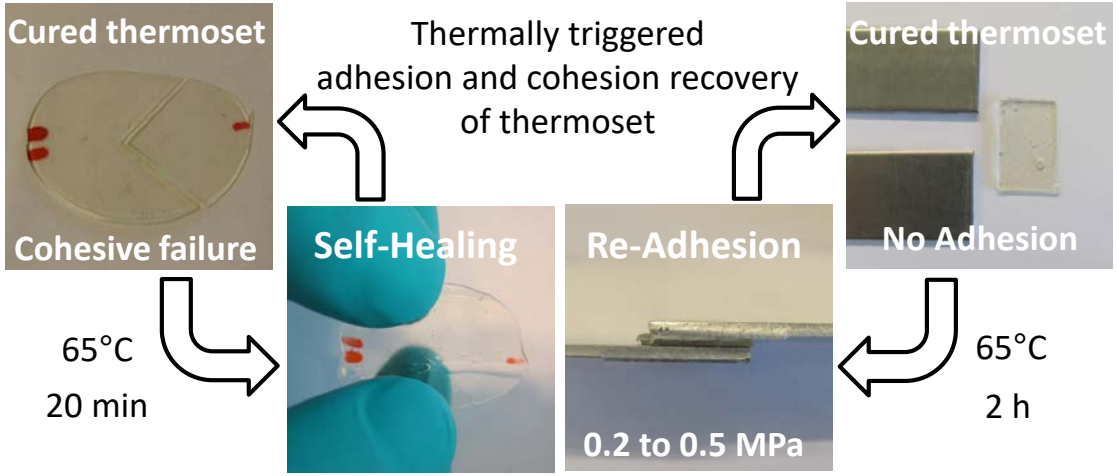
Next Generation of Self-Healing Materials:
Multifunctional self-healing materials

Can we develop material with multiple self-healing abilities / functionality?

5 – Multifunctional Self-healing Materials







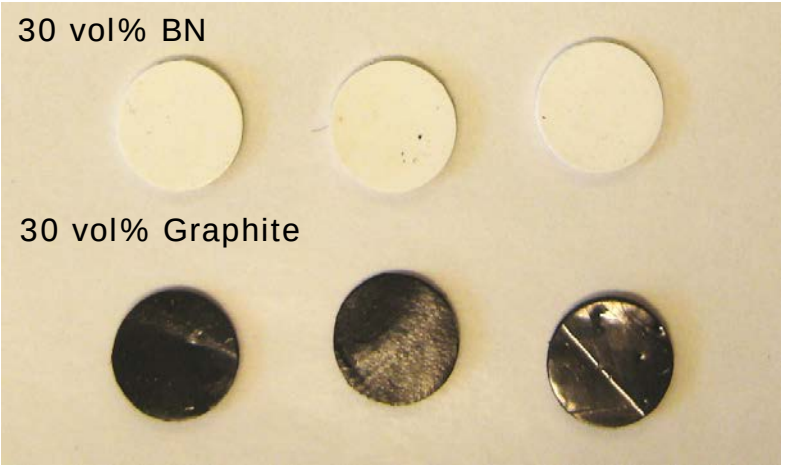
Polymer with self-healing adhesive and cohesive properties

U. Lafont *et al.*, ACS App Mat and Int. (2012), 4, 6280-6288

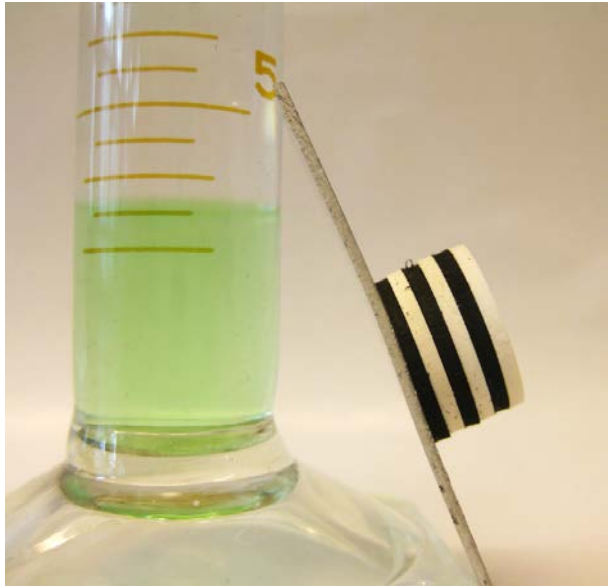
U. Lafont *et al.*, ACS Applied Materials & Interfaces, 4 (2012) 6280

5 – Multifunctional Self-healing Materials

Composites



1h @ 70 C



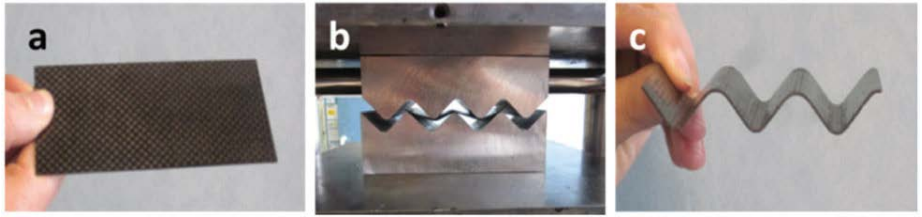
Recovery of adhesion, cohesion, thermal and / or electrical conductivity

U. Lafont *et al.*, J. Intelligent Material Systems and Structures (2013)

5 – Multifunctional Self-healing Materials

FRP with Vitrimers

RE-shaping



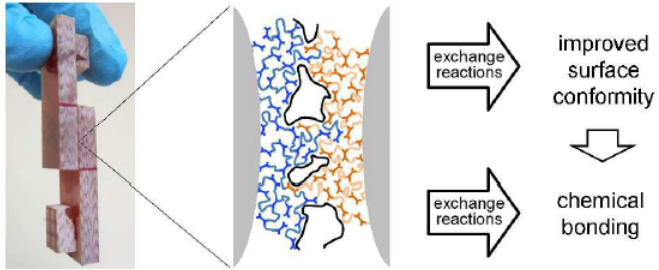
IK4 CIDETEC Research Alliance

Odriozola et al, Mater. Horiz., 2016

RE-cycling

RE-bonding

Glass fibers / epoxy vitrimer composites

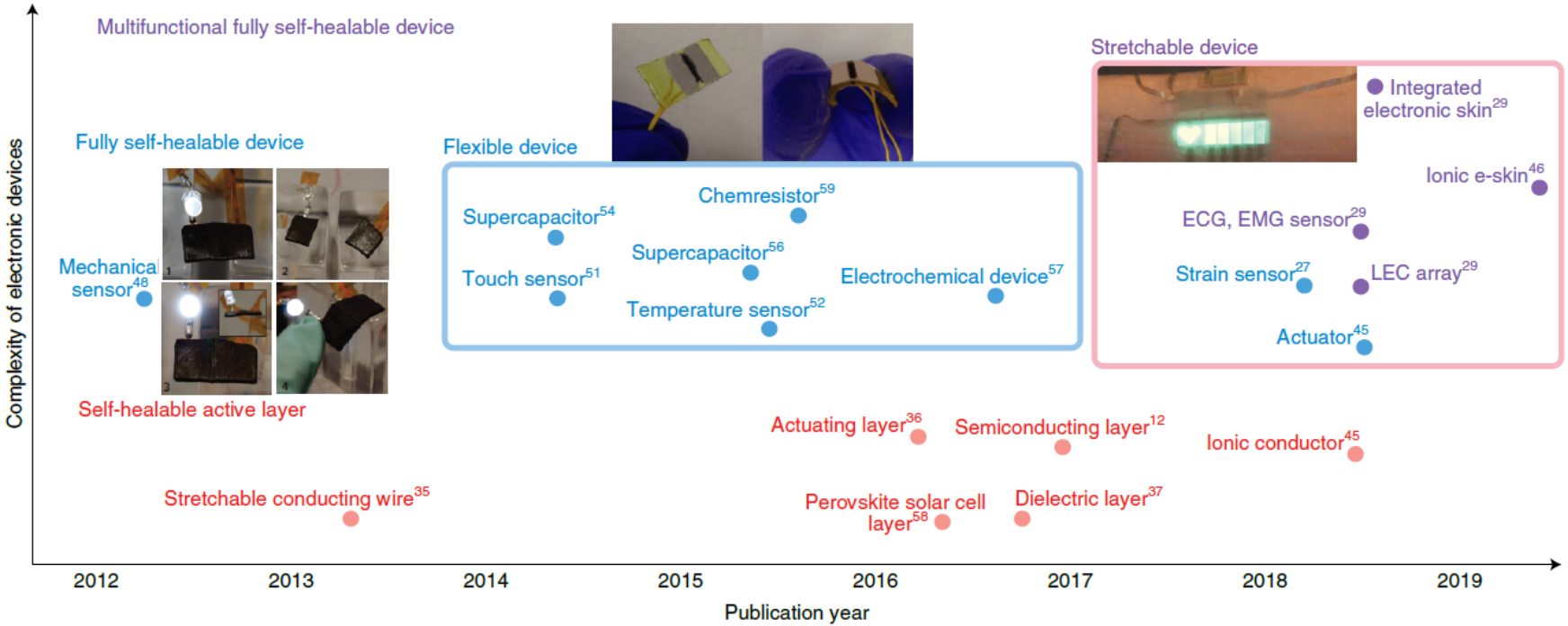


ESPCI PARIS
ÉCOLE SUPÉRIEURE DE PHYSIQUE ET DE CHIMIE INDUSTRIELLES DE LA VILLE DE PARIS

F. Tournilhac et al., *Soft Matter.* (2016)

5 – Multifunctional Self-healing Materials

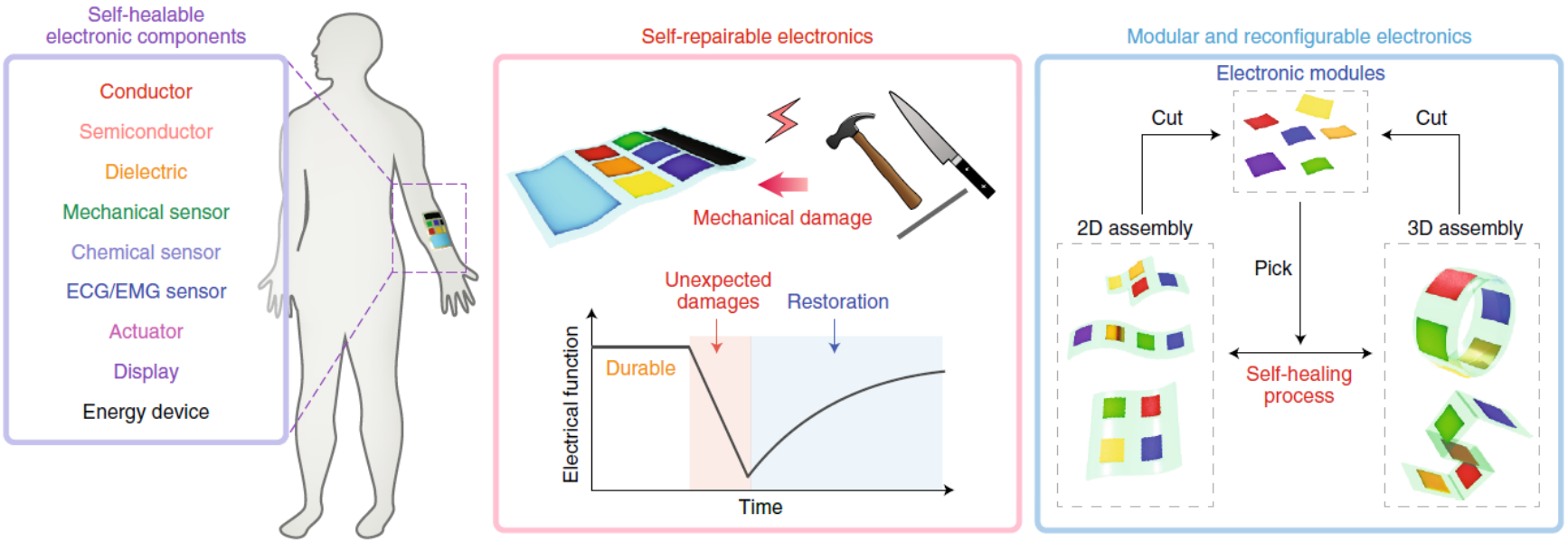
Self-Healing Electronic Devices



Kang J. *et al*, Nature Electronics (2019) 2, 144–150

5 – Multifunctional Self-healing Materials

Self-Healing Electronic Devices



Kang J. *et al*, Nature Electronics (2019) 2, 144–150

Self-healing concept for materials:

CREATE MOBILITY

1- ACTIVATION PHASE

2- TRANSPORTATION PHASE

3- REPAIR PHASE

AUTONOMOUS vs TRIGGERED

STIMULUS

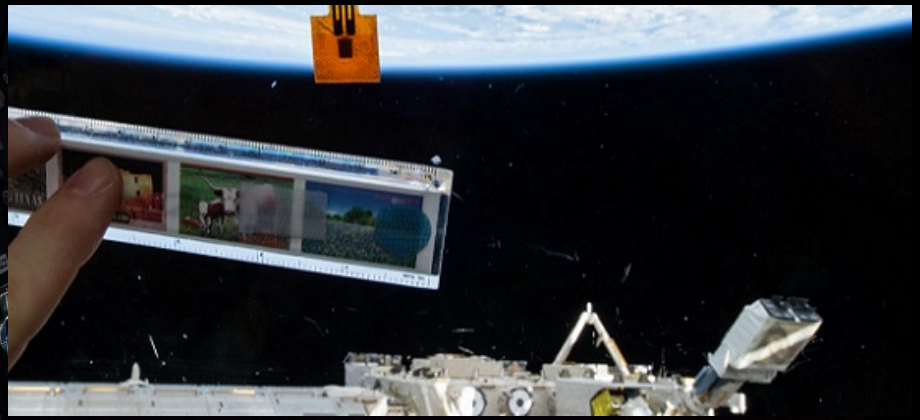
SCALE MATTER

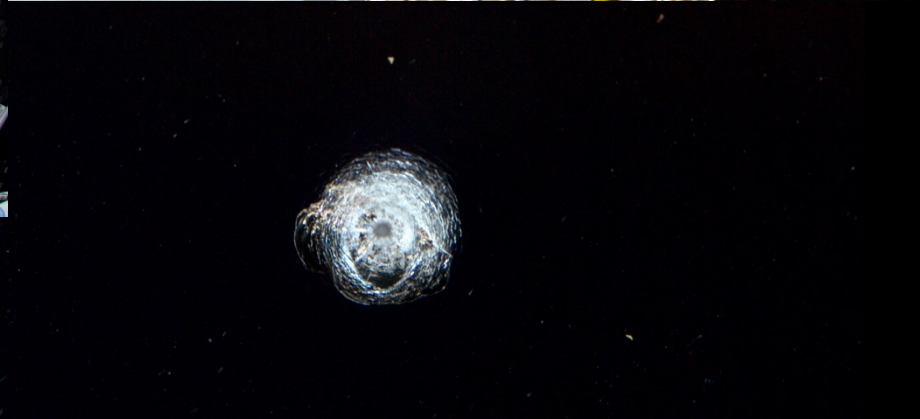
IS IT SUITABLE FOR INTERSTELLAR EXPLORATION APPLICATIONS ?

Image credit: 20thCenturey Fox

Glove of NASA Astronaut Rick Mastracchio

STS-118 3rd spacewalk - 15th Aug. 2007



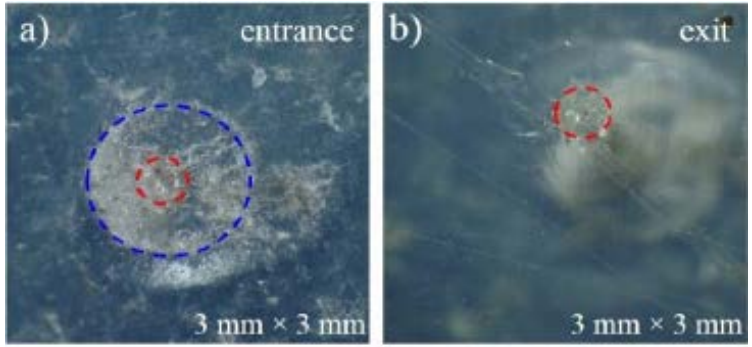


ISS Cupola impact revealed by ESA Astronaut Alexander Gerst in 2014

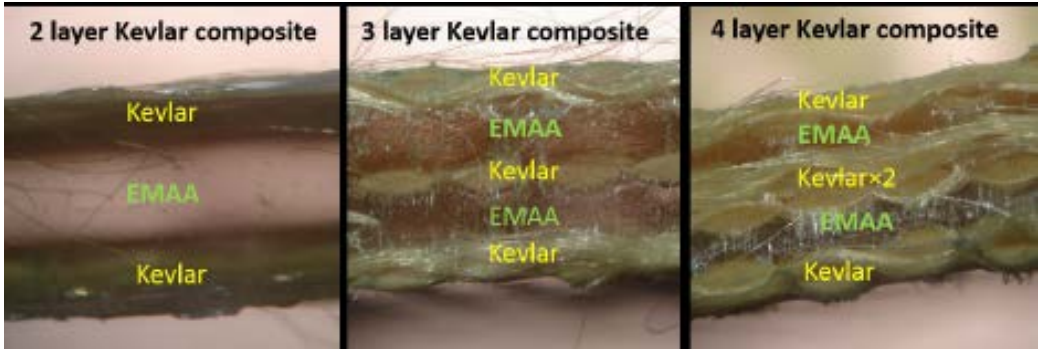
Impact protection

Mitigation of Small Debris (0.1-10 mm) Effect in Space - Monitored with Fiber Sensors and Self-Repairing Materials - Application to COPVs.

Goal: *Development of structural health monitoring / implementation of hyper velocity impact protection via self-healing*



Ballistic healing of EMMA



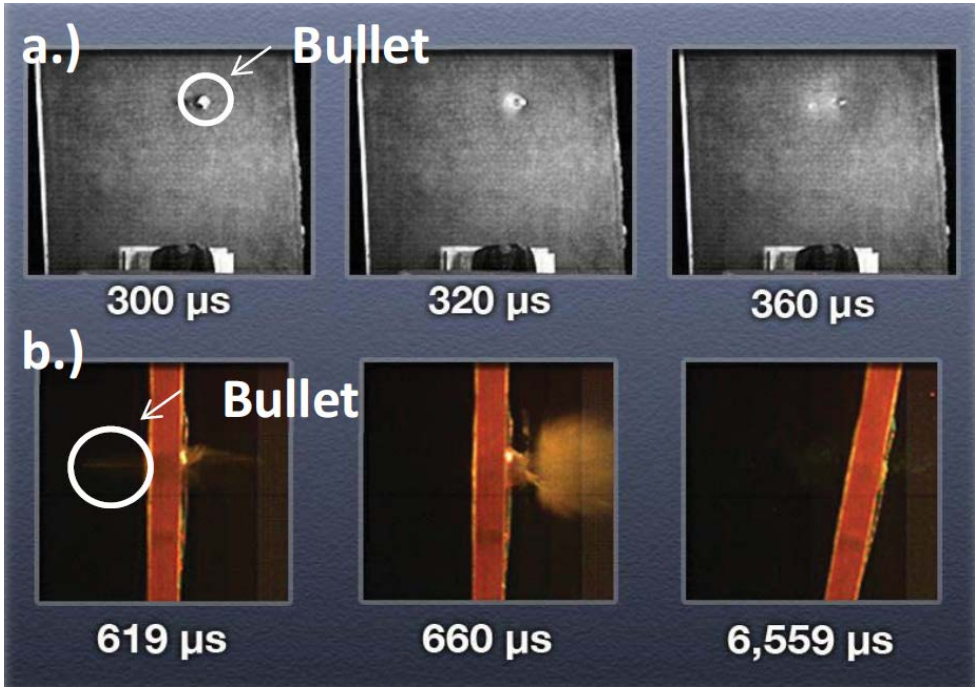
Example of protection strategy for COPVs

EMAA (polyethylene- co -methacrylic acid) shows ballistic healings
Damage recovery after puncture (2 mm SS bullet @ 1000 m/s)

ESA Contract 4000109225 - NPI 316

6 – Self-Healing for Space Application

Impact protection



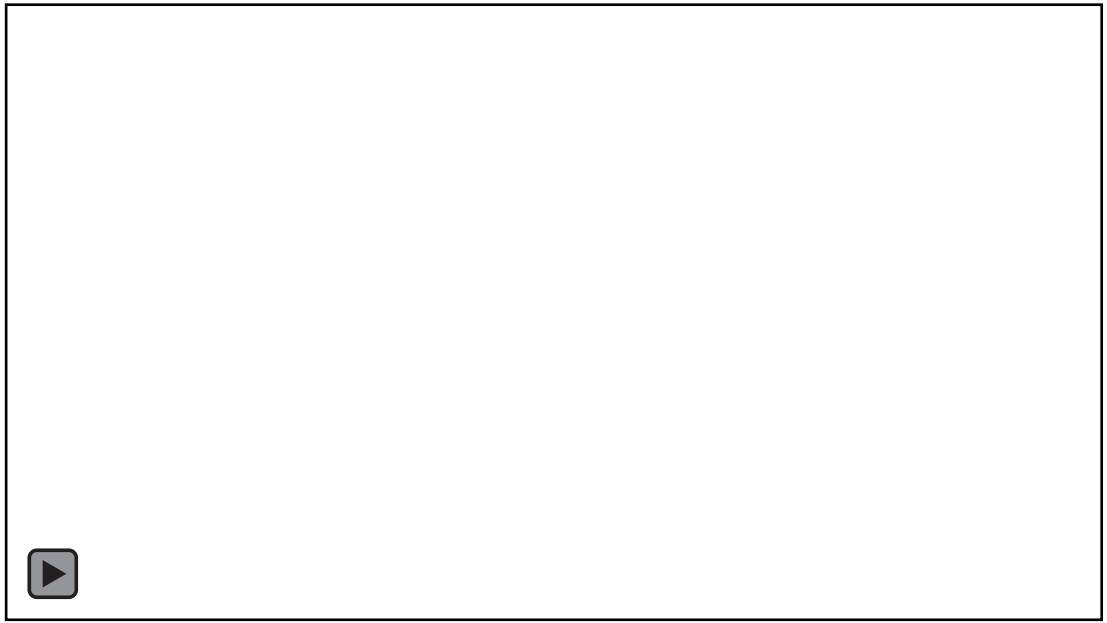
Ballistic healing of EMMA

Ballistic healing PB-g-PMA-co-A

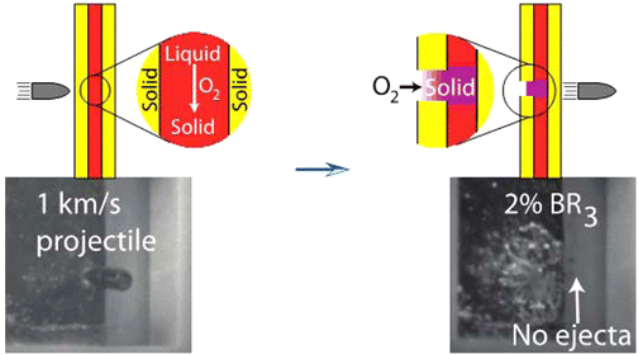
Gordon, K. L., Ballistic Puncture Self-healing Polymeric Materials, NASA/TM–2017-219642

6 – Self-Healing for Space Application

Impact protection



https://www.youtube.com/watch?v=CnITwYrFj-M



Thiolenetrialkyl borane resin

Zavada, S. R. et al, *ACS Macro Lett.*, 2015, 48, 819-824

6 – Self-Healing for Space Application

ESA Activity

TRP Study – Effect of Space environment on vitrimer based CFRP
Goal: *Development of vitrimer based resin that are suitable for space environment – Manufacturing of CFRP strucrture and assembly without any adhesive – Recycling*

TRP Study – Dust repellant coating for EVA suit
Goal: *Development of coating to prevent dust accumulation on astronaut suit – Self-repelant coating*

Study Idea – Large area flexible self-healing impact detector
Goal: *Development of piezoelectric based flexible material to create large area impact detector with self-heling capabilities*

SELF-HEALING MATERIALS AS ENABLER FOR

Increased system/habitat reliability – Maintenance strategy – Damage management
Ballistic impact protection

Structural heath monitoring + Impact protection

Functional coating life time increase / rejuvenation

Radiation protection + **source of raw material**

Out of earth Manufacturing
Habitat Maintenance
Autonomy

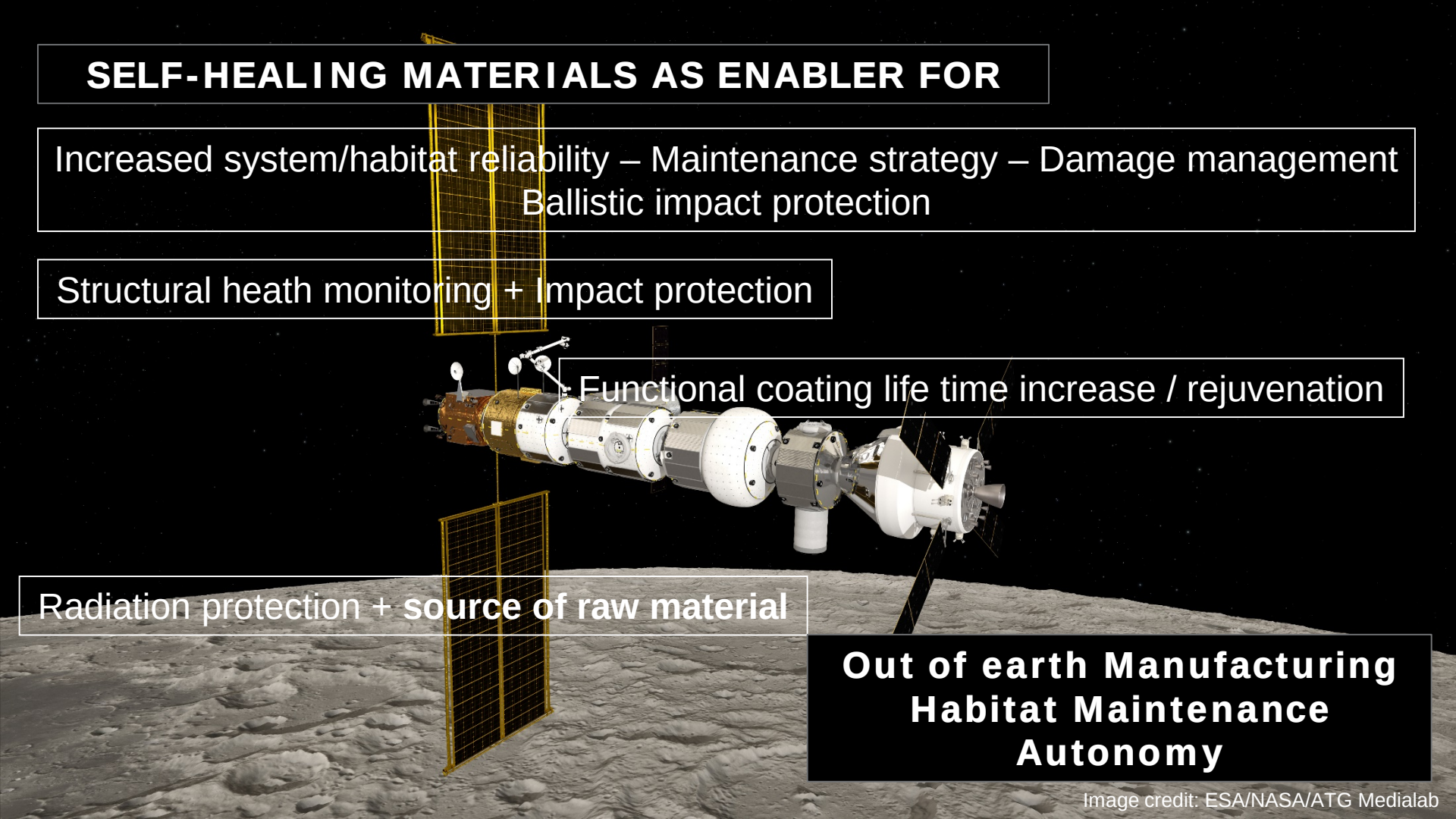


Image credit: ESA/NASA/ATG Medialab