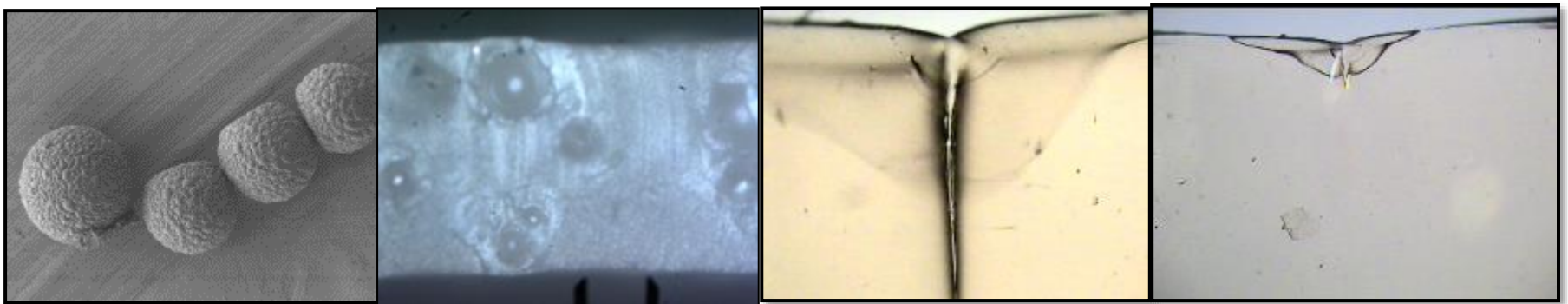
Self-Healing Technologies for Wiring and Surfaces in Aerospace and Deep Space Exploration Applications

Dr. Martha K. Williams[1], Dr. Tracy L. Gibson[2], Dr. Scott T. Jolley[3], and Anne Joan Caraccio-Meier[1]

1 – NASA John F. Kennedy Space Center (KSC)

2 – Engineering Services Contract, NASA KSC

Smart Coatings Conference, 2017
Orlando, FL
February 22-24, 2017

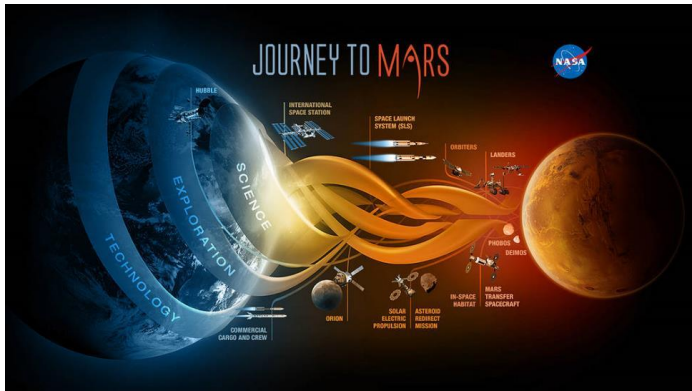


Self-Healing Technologies for Wiring & Surfaces in Aerospace & Deep Space Exploration Applications

Exploration Research and Technology Programs

Outline

- **Abstract reference**
- Why Self Healing Polymers for Wiring and Flat Surfaces
- Flexible Self Healing High Polymers Properties
- Synthesis and Preparation of Flexible, Self-Healing Films
- Early Attempts
- Microencapsulation Approaches
- Self-Sealing Matrices
- Self-Healing Laminates and Testing
- Summary
- Acknowledgments and Contacts



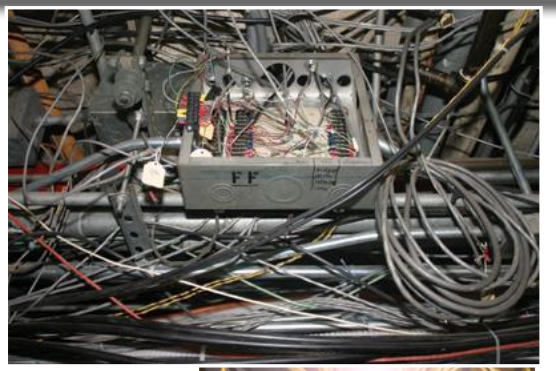
Abstract

Self-healing technologies have been identified as critical technology gaps for future exploration. NASA and KSC have been working in this area for multiple years with established intellectual property; however, there are many challenges that remain in this area of research.

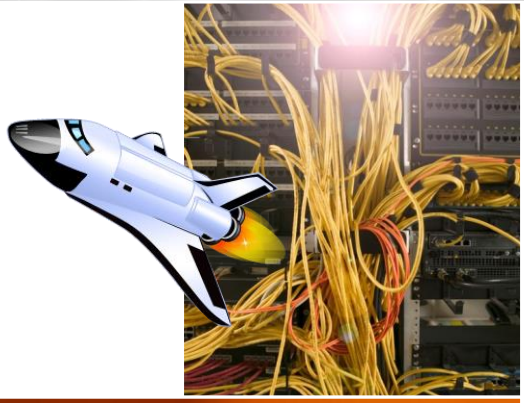
How do we mimic what the body does so naturally when we as NASA have unique requirements? We have been investigating several mechanisms for self-healing: microencapsulation with a healant core to fill in voids in the case of mechanical puncture and flowable (or sealable) systems that have inherent chemical properties that allow the materials to flow back together when cut or damaged.

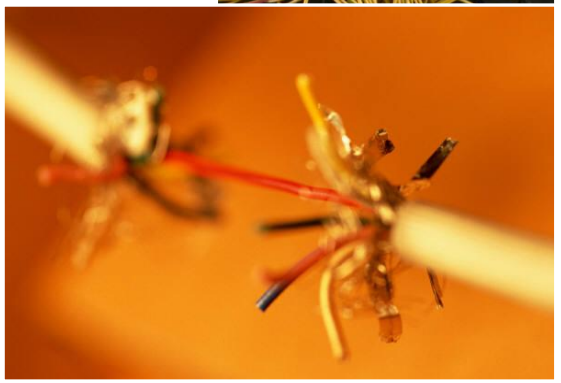
The microcapsules containing healant have to be durable and robust, must be able to take high temperatures to meet NASA unique requirements, provide good capillary flow of the healant, and be small in diameters to fill in damage voids in thin films or surfaces. Sealable systems have to flow in a range of temperatures and yet be light weight and chemically resistant. The systems currently being developed are based on polyimide and polyurethane matrices and have been studied for use in high performance wiring systems, inflatable systems, and habitation structures. Self-healing or self-sealing capability would significantly reduce maintenance requirements and increase the safety and reliability performance of critical systems. Advances in these self-healing technologies and some of the unique challenges needed to be overcome in order to incorporate a self-healing mechanism into wiring or thin films systems will be addressed.

Why Self-Healing Wire?



- **Aged Wire**
  - Cracks/frays over time
  - Hard to detect damage
  - Extensive maintenance related damage during ground processing work – airline, military and Space Shuttle program
- **Space Shuttle Orbiter**
  - 183 miles of wiring buried deep within structure of vehicle
  - Difficult to manually inspect
  - Repair process is intrusive and often causes additional damage



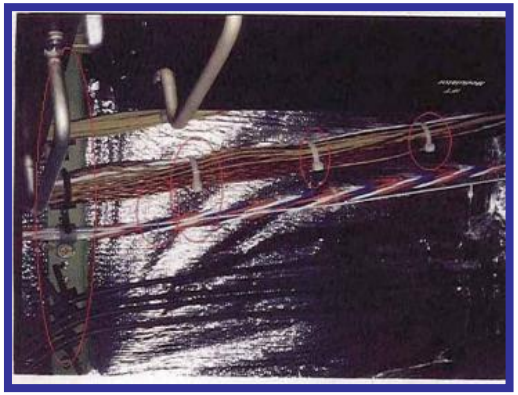


Why Self-Healing Wire?

Exploration Research and Technology Programs

BACKGROUND

- STS-93 (July 1999)
  - Short circuit in 14 AWG polyimide insulated wire
- TWA 800 (July 1996)
  - Frayed polyimide wire in center tank area
- SwissAir 111 (September 1998)
  - Damaged wire in plane's entertainment system
- AS-204 (Apollo 1, January 1967)
  - Electrical wire short



Why Self-Healing Wire?

Exploration Research and Technology Programs

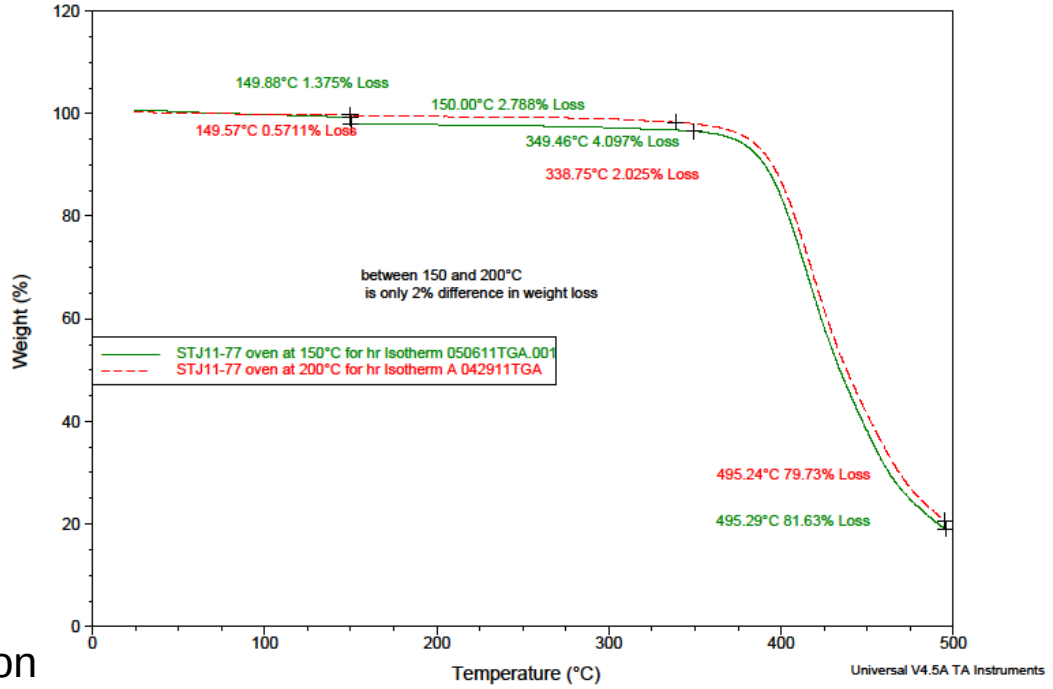
History

Mission	Cause	Result
Gemini 8	Electrical wiring short	Shortened mission-near loss of crew
Apollo 204	Damaged insulation, electrical spark, 100%) O_2	Fire, three astronauts lost
Apollo 13	Damaged insulation, short circuit/flawed design	Oxygen tank explosion, incomplete mission
STS-6	Abrasion of insulation/arc tracking	Wire insulation pyrolysis, 6 conductors melted
STS-28	Damaged insulation, arc tracking	Teleprinter cable insulation pyrolysis
Magellan	Wrong connection, wiring short	Wiring insulation pyrolysis
Spacelab	Damaged insulation, arc tracking	Wiring insulation pyrolysis during maintenance
Delta 178 / GOES-G	Mechanical or electromechanical insulation damage	Loss of vehicle
ESA-Olympus	Electrical wiring short	Loss of solar array

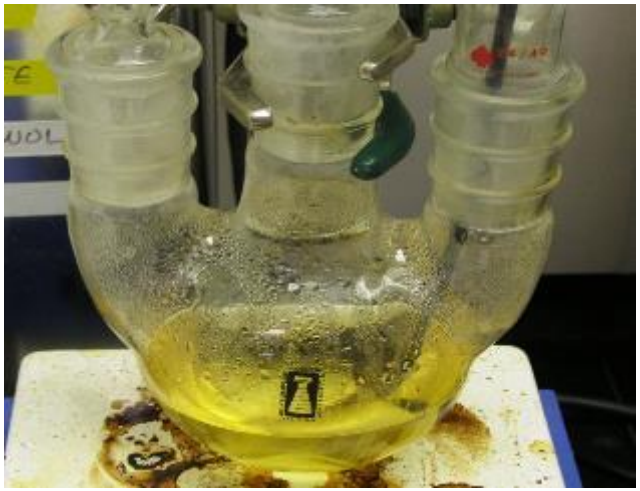
Flexible Self Healing High Polymers Properties

- **Flexible films (< 500 micron thick)**
- **High Thermal Stability (> 200C)**
- **Electrical Properties**
- **Flame Resistant**
- **Solvent Resistant**

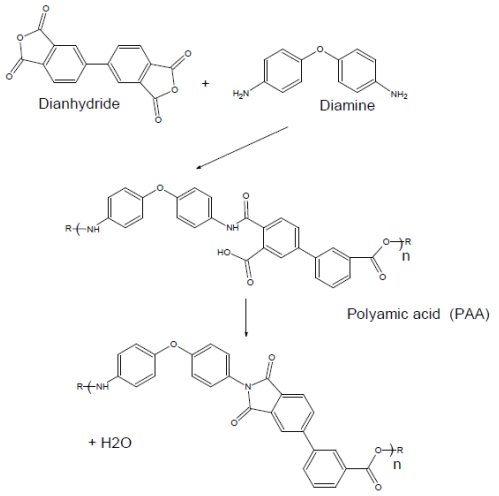
- **Applications**
  - Materials for Life Optimization
  - Life Sciences and Habitation
  - In-Situ Resource Utilization
  - Life Cycle Optimization of Products
  - Wiring for Aerospace and Exploration
  - Flat surfaces or laminate systems

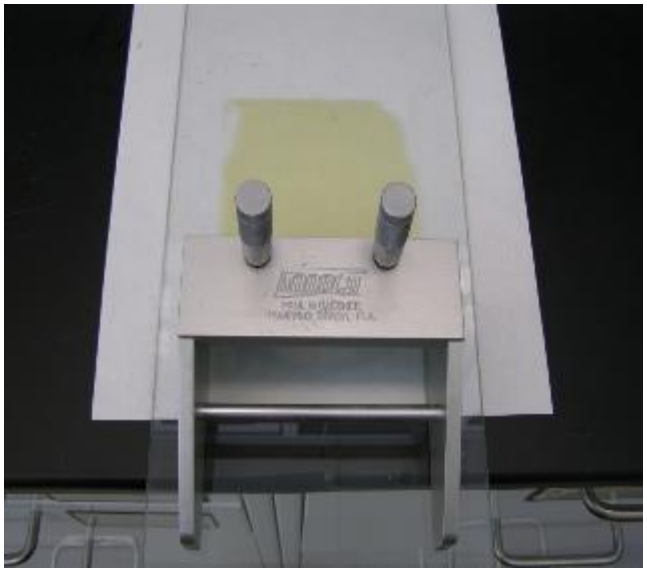


Synthesis and Film Preparation



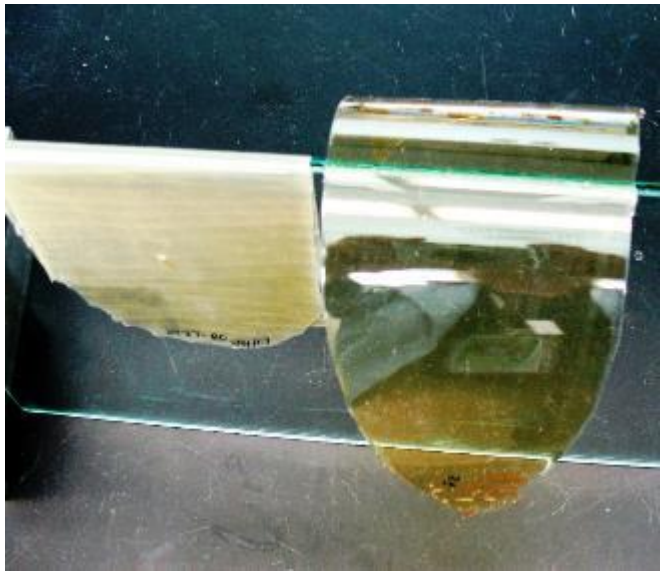
Polyimide synthesis





Film Drawdown (Left)

Example of variation in flexible films (right)

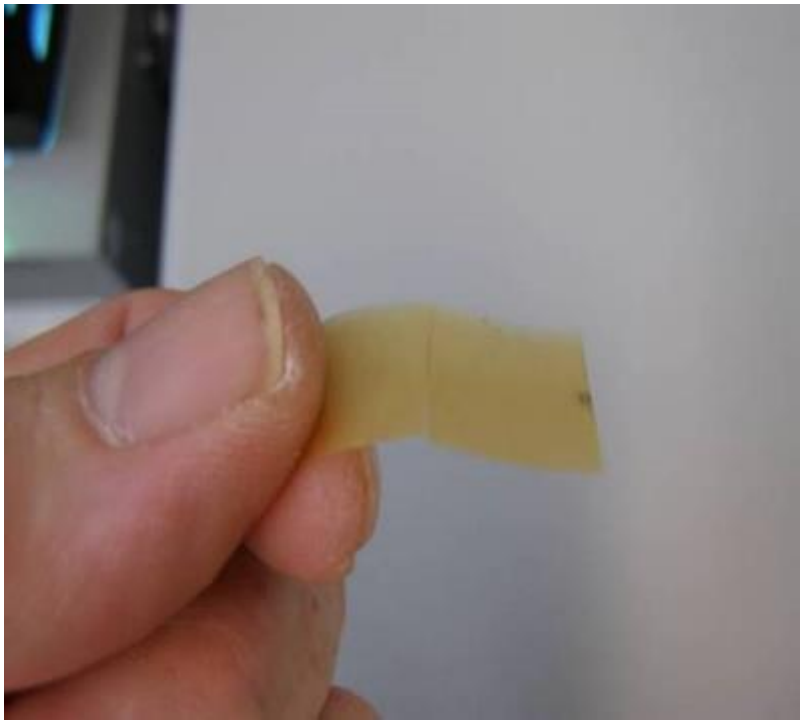


Examples of Chemistry and Film Properties

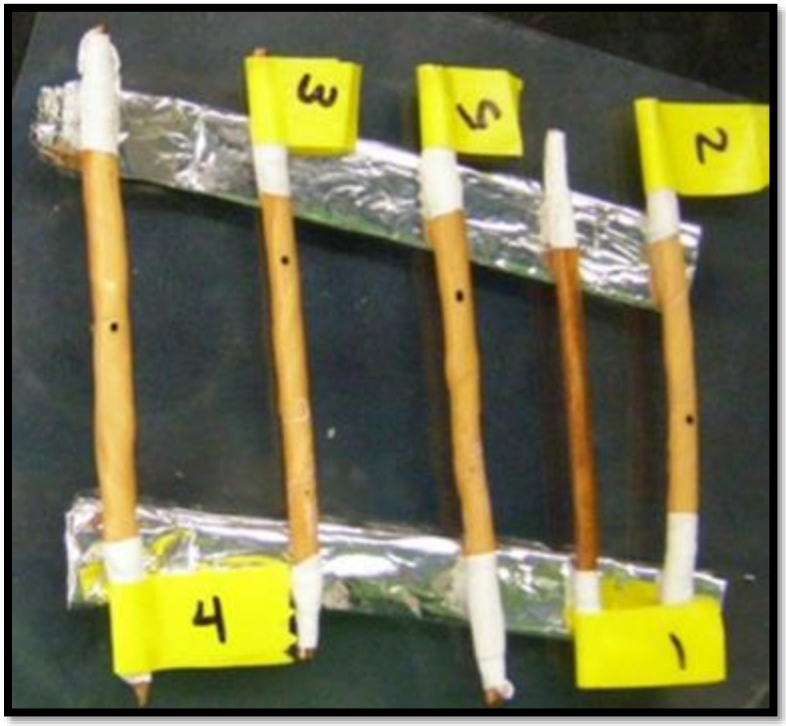
Item	Chemical Components (Appendix A)	Comments, Film Properties
1	BPADA/DAPS/ODA/MAA	SPIF
2 & 3	BPADA/XTJ-542/ODA/MAA	in NMP and DMF solvents
4	BPADA/XTJ-542/ODA	slow self-healing
5	BPADA/XTJ-542/ODA	ionomer
6	BPADA/XTJ-542/ODA/C8Succan	self-healing
7	BPADA/XTJ-542/DAD	self-healing
8	BPADA/XTJ-542/ODA/MAA	self-healing
9	BPADA/XTJ-542/ODA/MAA/Succan	self-healing
11	PMA/XTJ-542/ODA/MAA	Paste-like polyimide liquid
12	PMA/XTJ-542/ODA/MAA	Paste-like polyimide liquid
13	PMA/XTJ-542/ODA/MAA	Paste-like polyimide liquid
14	PMA/XTJ-542/ODA/succan	Paste-like polyimide liquid
15	BPDA/XTJ-542/ODA/succan	Paste-like polyimide liquid
16	BPDA/XTJ-542/ODA/succan	Hazy, weak film, no self-healing
17	BPADA/XTJ-542/TDA/succan	Similar properties to 3
18	BPADA/XTJ-542/DASO/succan	Less self-healing than TDA
19	BPADA/XTJ-542/DABA/succan	Weak film, no self-healing
20	TDI/XTJ-542	Polyurea – Fragile, no flow
21	TDI/DAPS	P-urea – Tougher, no flow
22	IPDI/XTJ-542	P-urea – self-sealing
23	IPDI/DAPS	P-urea – self-sealing
24	IPDI/Siloxane Diol	Polyurethane; self-sealing
25	IPDI/Terethane 1000	Polyurethane; no self-healing, liquid

Early Prototypes in Flexible and Curved Substrates

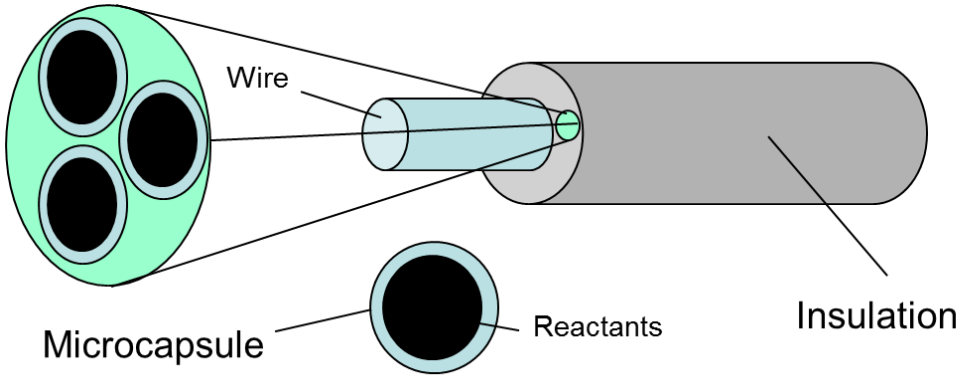
UV Cured Healant Microencapsulation

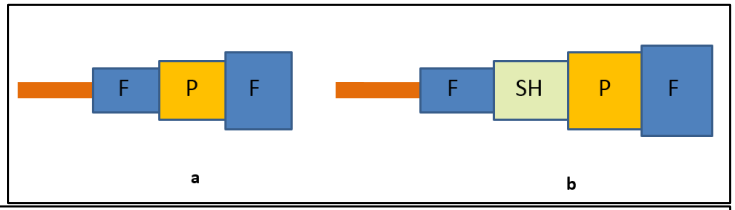


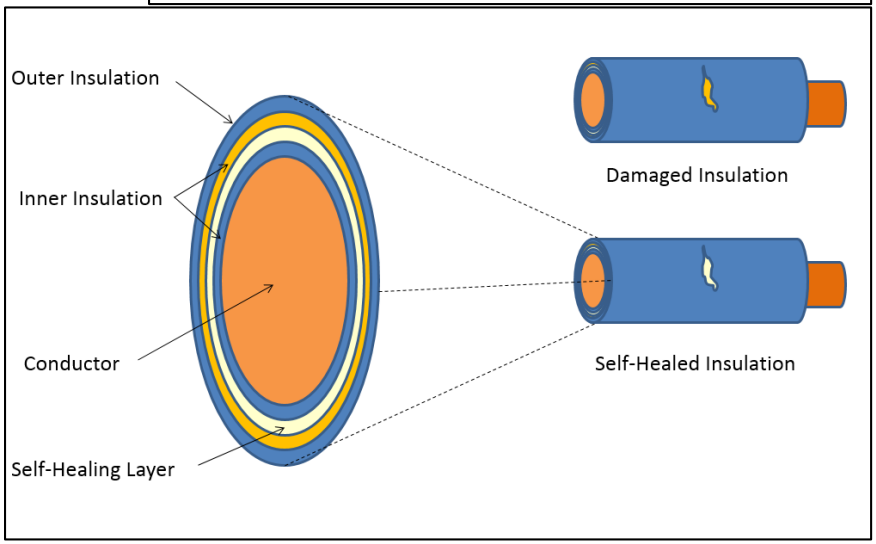
Epoxy Healant Microencapsulation
on curved substrates-wiring application



Self-Healing Wire Insulation Concepts







Self-Sealing Polyimide and Polyurethane Matrices

Polyurethane (L)and polyimide matrices ((R)

Smart Coatings 2017

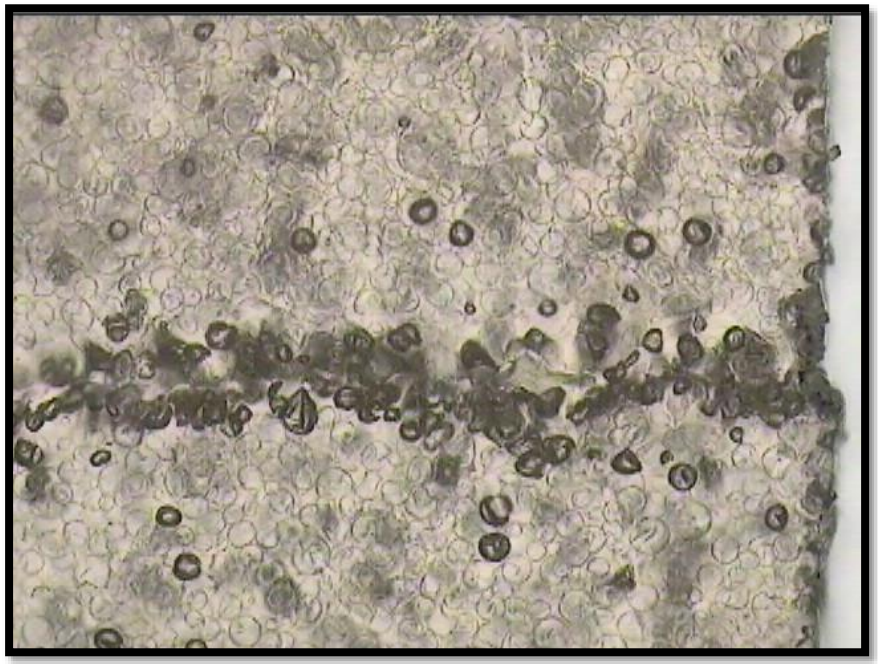
Self-Healing/Sealing Films with Microcapsules

Exploration Research and Technology Programs

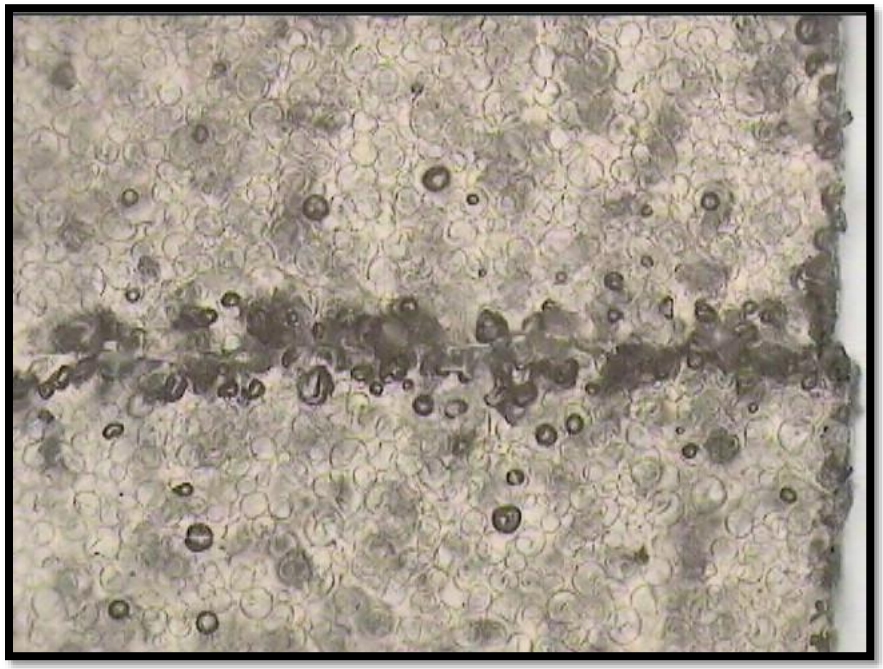
Examples

Results: *RazorTest*

CUT **2.5 seconds** 10x



CUT **2.5hrs** 10x

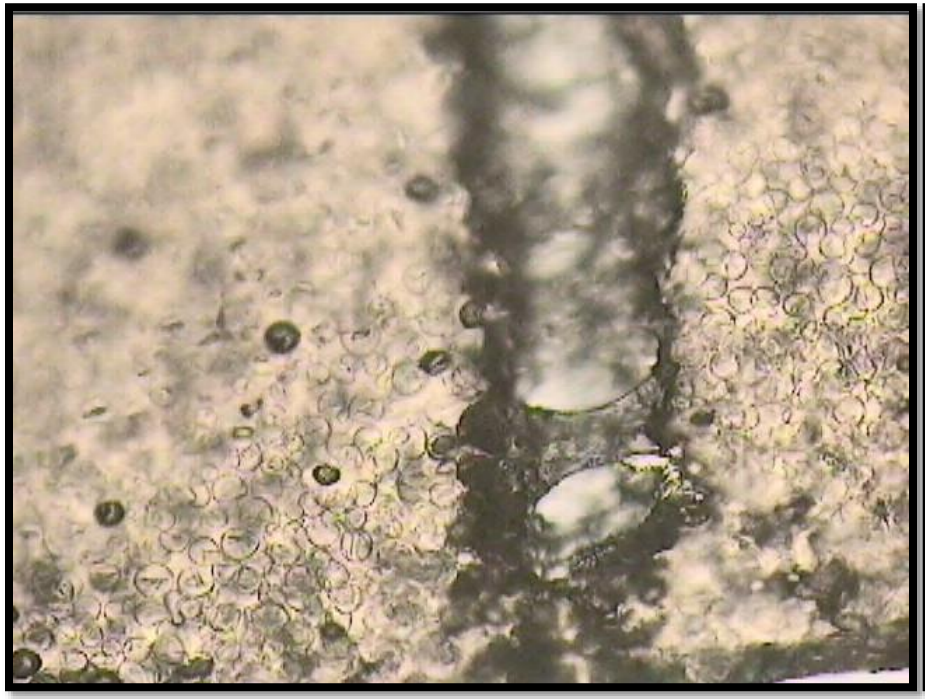


Darker colored microcapsules along cut indicate that the inner healant has been dispersed. These dark microcapsules are now mostly empty shells that have released their inner healant material.

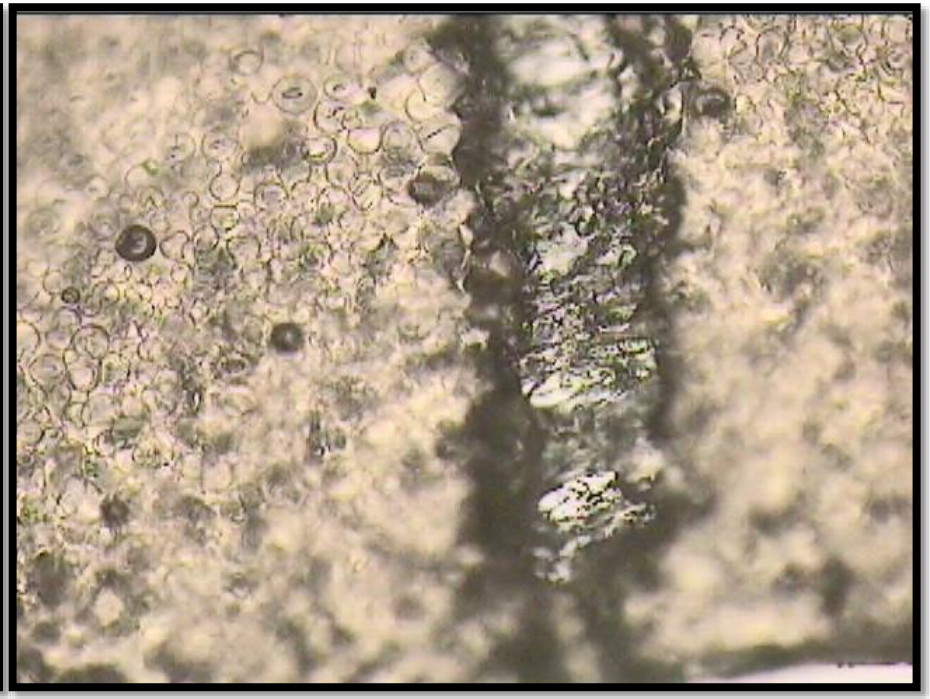
Self-Healing/Sealing Film with Microcapsules

Results: *Pull Test*

4.6.10 10x top side pull 3 **upper focus**



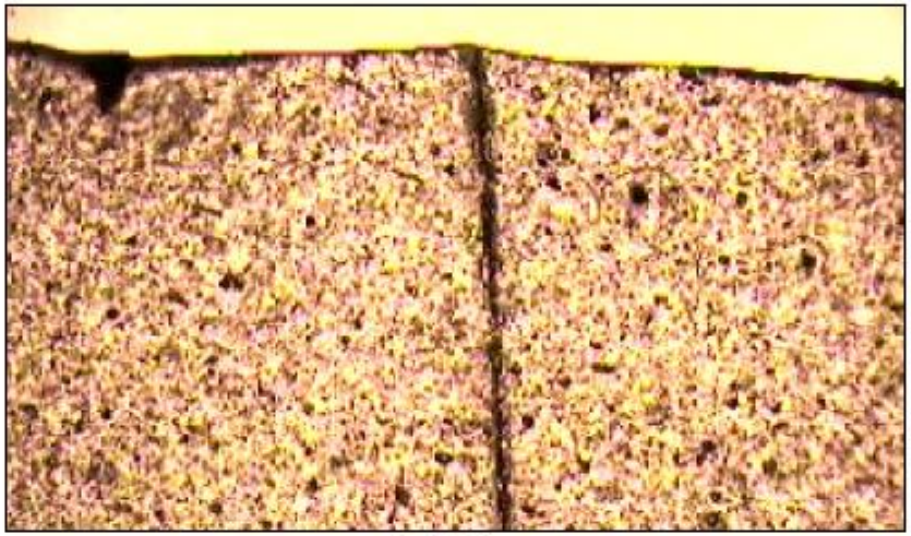
4.6.10 10x top side pull 3 **deeper focus**



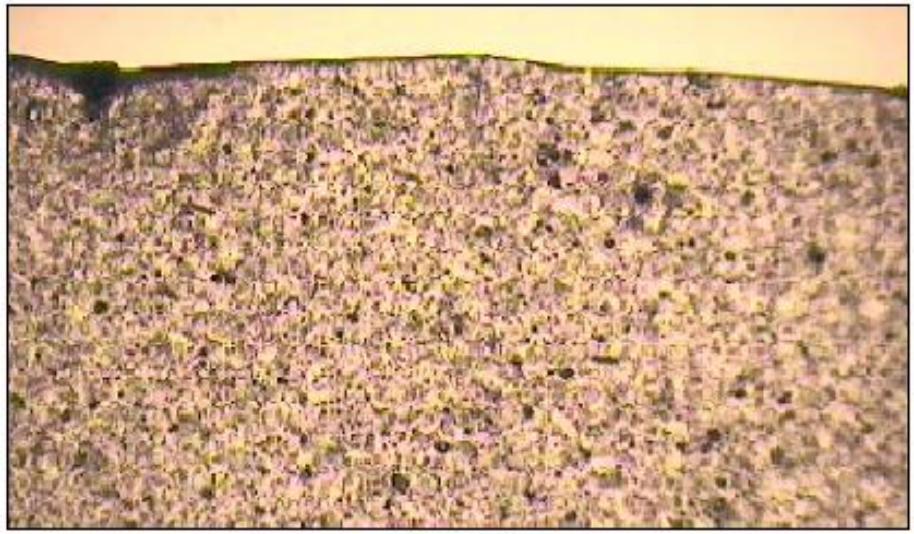
Images of a “healed” film, now pulled apart, display the visual flow that has occurred from the microcapsules and matrix.

How to measure the strength of the healed area/bonds that have formed between the tear of the newly healed film are being addressed.

Self-Healing/Sealing Film



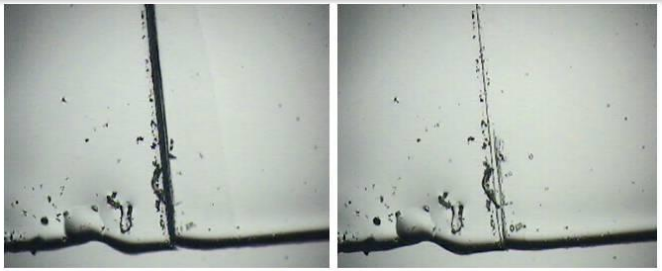
DAY 1

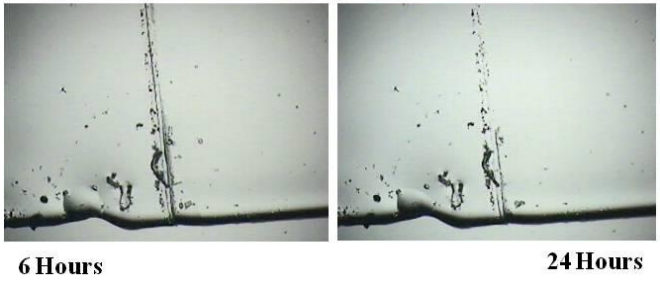


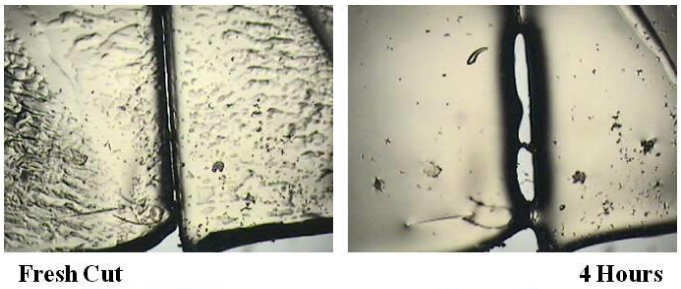
DAY 2

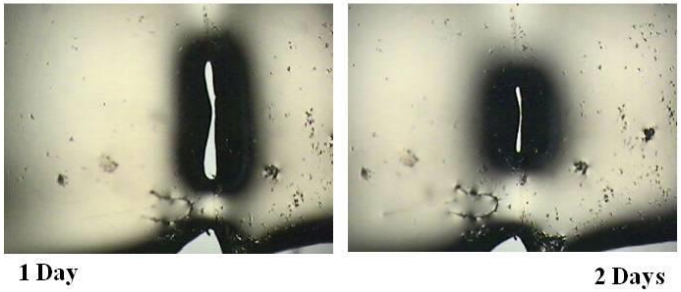
Other films heal without an apparent “scar”. Indicating that the novel polyimide film matrix alone also has self healing /sealing properties.

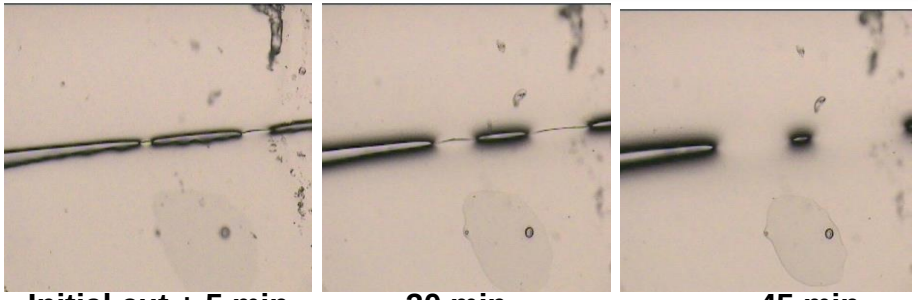
Self-Healing/Sealing Films – Healing Times

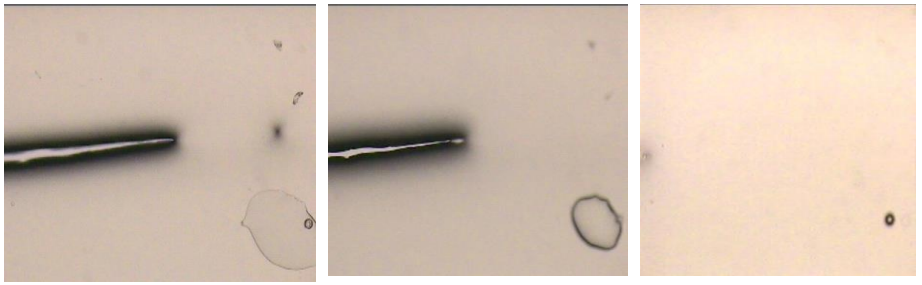


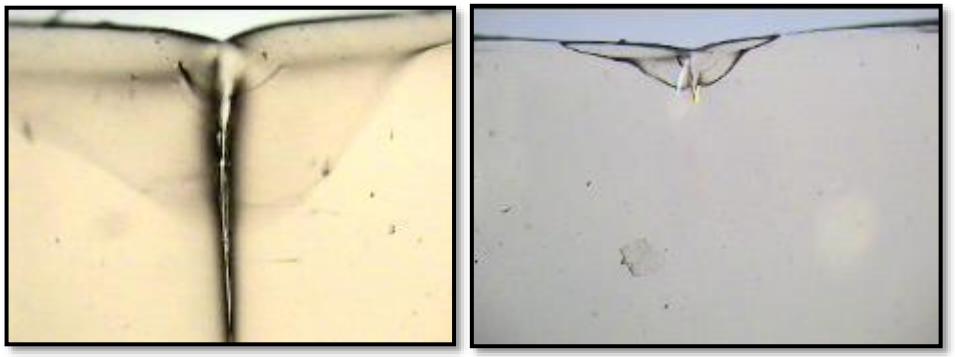






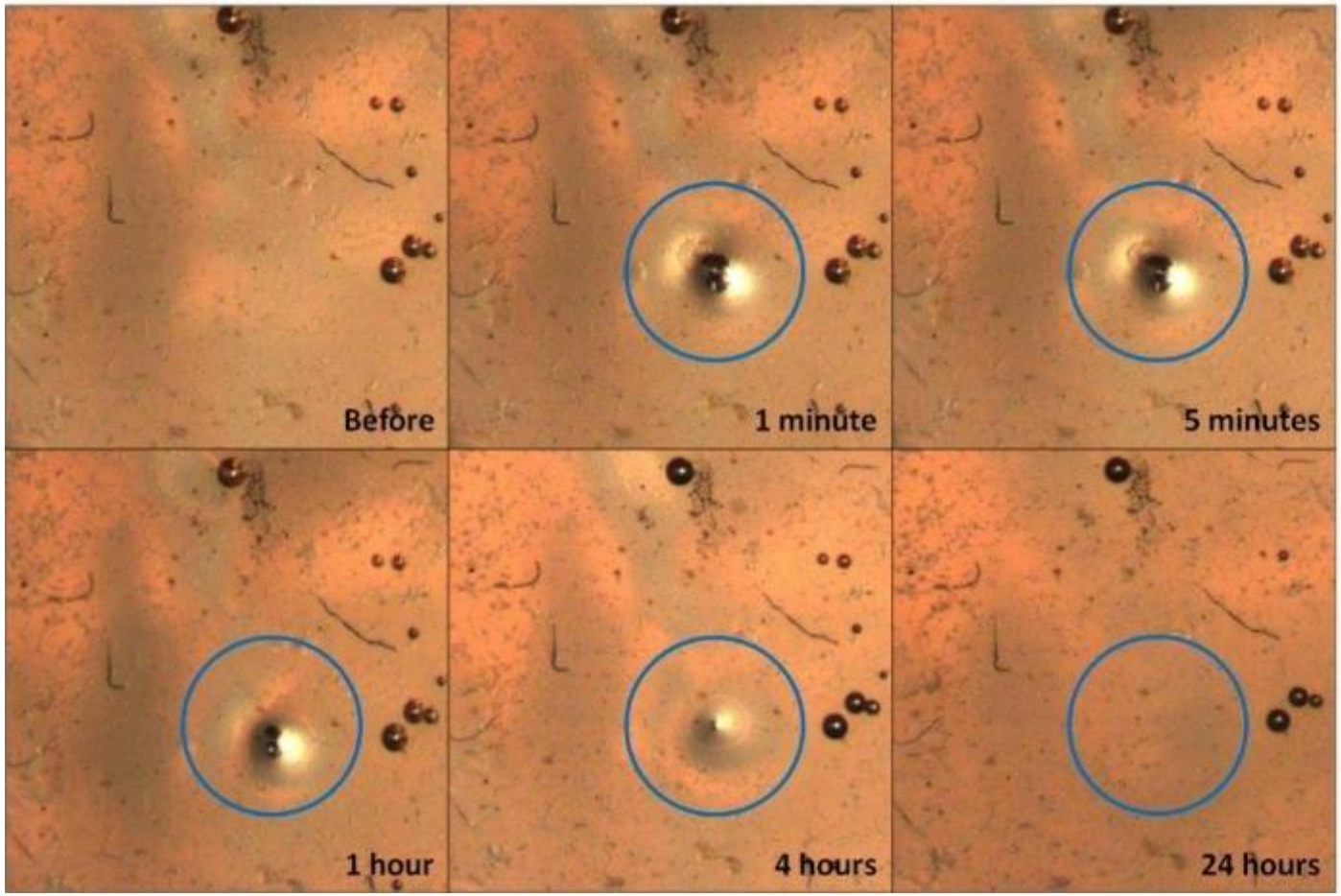






initial cut and less than 20 sec later

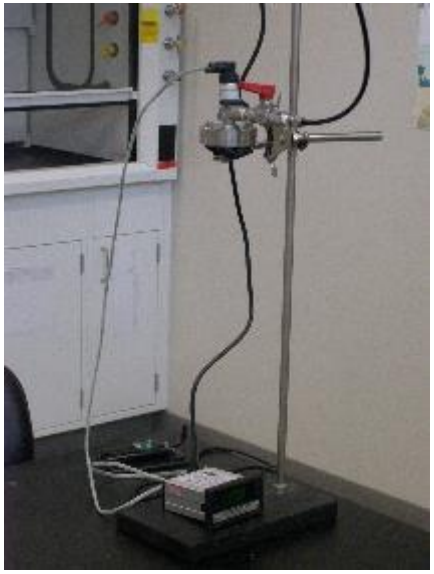
Self Healing Laminates
Puncture and Healing activity



24 hour time lapse photos of puncture evaluation in a self healing laminate system as shown in drawing (right below)

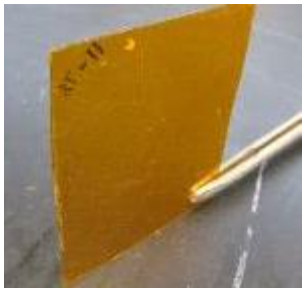
Smart Coatings 2017

Self-Sealing Laminates Testing Results



Testing conditions

- 45 mm test specimens of 3 layered laminates (e.g. right)
- Pressurized to 19.5 psia
- Initial test without damage



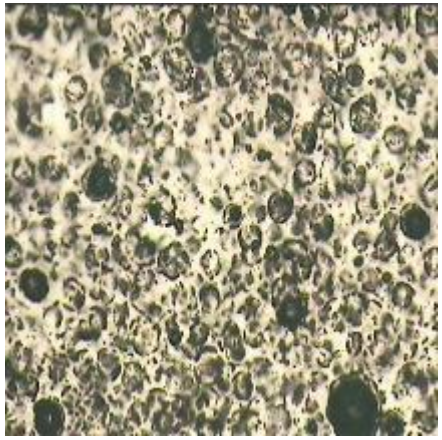
Follow-on test after puncture with a 0.50 mm needle

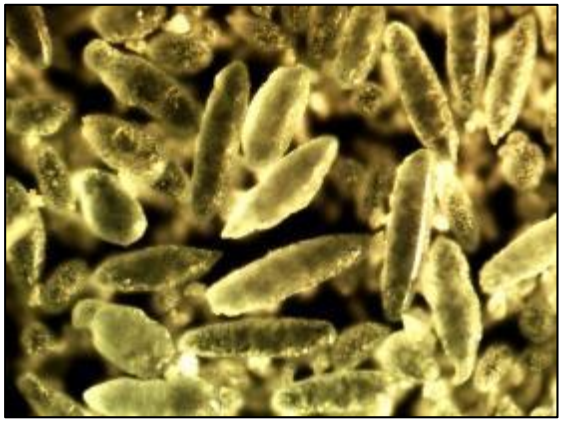
- Specimen were damaged and allowed to stand at room temperature/pressure, followed by testing after 2hrs
- Testing under continuous pressure was not conducted

Item	Top & Bottom Layer	Central Layer	Results
1	Kapton (2 mil)	STJ11-78	Sealing occurred after 24 hours
2	SPIF	STJ11-77 (150C)	Sealing occurred after 4 hours
3	SPIF	STJ17-10b	Film failed during evaluation
4	SPIF	STJ11-75	Sealing occurred after 2 hours
5	Mylar	STJ11-80	No sealing after 24 hours
6	Kevlar®	Polyimide	No sealing after 24 hours
7	SPIF	739 RTV	Slow leak after 5 minutes (0.2 psia), does not completely seal
8	SPIF	3140 RTV	Slow leak after 5 minutes (0.1 psia), does not completely seal
9	SPIF	3145 RTV	Slow leak after 5 minutes (0.2 psia), does not completely seal

Summary of Self-Healing Options

- Microencapsulation of healants for self-healing damages – addressed the potential for increased volume delivery of healant by changing morphology of microcapsules, including elongated microcapsules architecture
- Addressed thermal, electrical, and chemical stability of matrices and microcapsules
- Self-sealing flowable systems – utilizes novel low-melting polyimide chemistry polymers
- Systems can be utilized individually or together – as stand-alone materials or laminates
- Self-healing has been demonstrated in a laboratory environment but has not been scaled-up to produce usable quantities for production





Thank you for your attention!

Dr. Martha K. Williams
Lead Polymer Scientist,
Sr. Principal Investigator, UB-R3
1.321.867.4554
Martha.K.Williams@nasa.gov
Exploration Research and Technology
NASA Kennedy Space Center, FL 32899 USA

Dr. Tracy L. Gibson
Senior Scientist
Vencore (ESC),
Kennedy Space Center
1.321.867.7572
Tracy.L.Gibson@nasa.gov

Questions on technology transfer or commercial licensing opportunities? Please contact:

Lewis Parrish
lewis.m.parrish@nasa.gov
1.321.867.
Jeff Kohler
jeffrey.a.kohler@nasa.gov
1.321.861.7158

Acknowledgement of other, additional Inventors and team members:
Trent Smith (NASA inventor, Dr. Wendy Li, ESC inventor), Lilliana Fitzpatrick, ESC, Clara Wright (NASA), Sarah Snyder and Jamie Palou

Funded by NASA and FAA


QUESTIONS?