National Aeronautics and Space Administration

Damage Mitigation: Recent Advances in Thermoplastic Puncture Healing Materials - Composites

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INTRODUCTION

One of the eight technology strategies of the NASA Aviation Safety Program is to continuously track, diagnose and restore the health of on-board systems, leading to self-healing and "refuse to crash" aircraft. An approach for the realization of self-healing and "refuse to crash" aircraft can be due in part to the incorporation and integration of self-healing materials into composite structures. Advanced structures in aero-vehicles can suffer from abrupt external impacts or extension of internal defects during service, potentially leading to catastrophic failure of aircraft without timely detection and repair. It is possible that self-healing materials on aircraft could have prevented the crash of American Airlines flight 587, the crash of Air France Concorde flight 4590 in France, and the explosion of space shuttle Columbia. [1, 2]

Materials that are capable of puncture healing upon impact provide a route for improved damage tolerance in load bearing structures and a means of self-mitigation or self-reliability towards overall vehicle health and aircraft durability. This type of material also shows great promise for cross-cutting space exploration applications where an internal breach caused by micrometeoroid impacts which would normally be considered catastrophic would be self-contained. Polymers such as Dupont's ® Surlyn have demonstrated healing capability following penetration of fast moving projectiles -- velocities that range from 9 mm bullets shot from a gun (~1100 ft/sec) to close to micrometeoroid debris velocities of 16000 ft/sec.

1. Ratner, D., Ratner, M., *Nanotechnology and Homeland Security: New Weapons for New Wars*, published by Prentice Hall PTR, **2004**.
2. Lin Ye, Ye Lu, Zhongqing Su, Guang Meng, *Functionalized composite structures for new generation airframes: a review*, Composites Science and Technology, 65, **2005**, 1436–1446.

MOTIVATION

- Develop self-healing polymeric materials to enable damage tolerant systems.
  - Tailor puncture healing for use temperatures and applications.
- Benefit in environments and conditions where access for manual repair is limited or impossible, or where damage may not be detected.

APPROACH

- Survey commercially available materials capable of puncture self-healing.
- Determine puncture healing mechanism.
- Understanding of mechanism guides design of new puncture self-healing materials.

BACKGROUND

- Self-healing behavior occurs upon projectile puncture when energy is transferred to the material during impact both elastically and inelastically thus establishing two requirements for puncture healing to occur:

  (1) The need for the puncture event to produce a local melt state in the polymer material and

  (2) The molten material has to have sufficient melt elasticity to snap back and close the hole

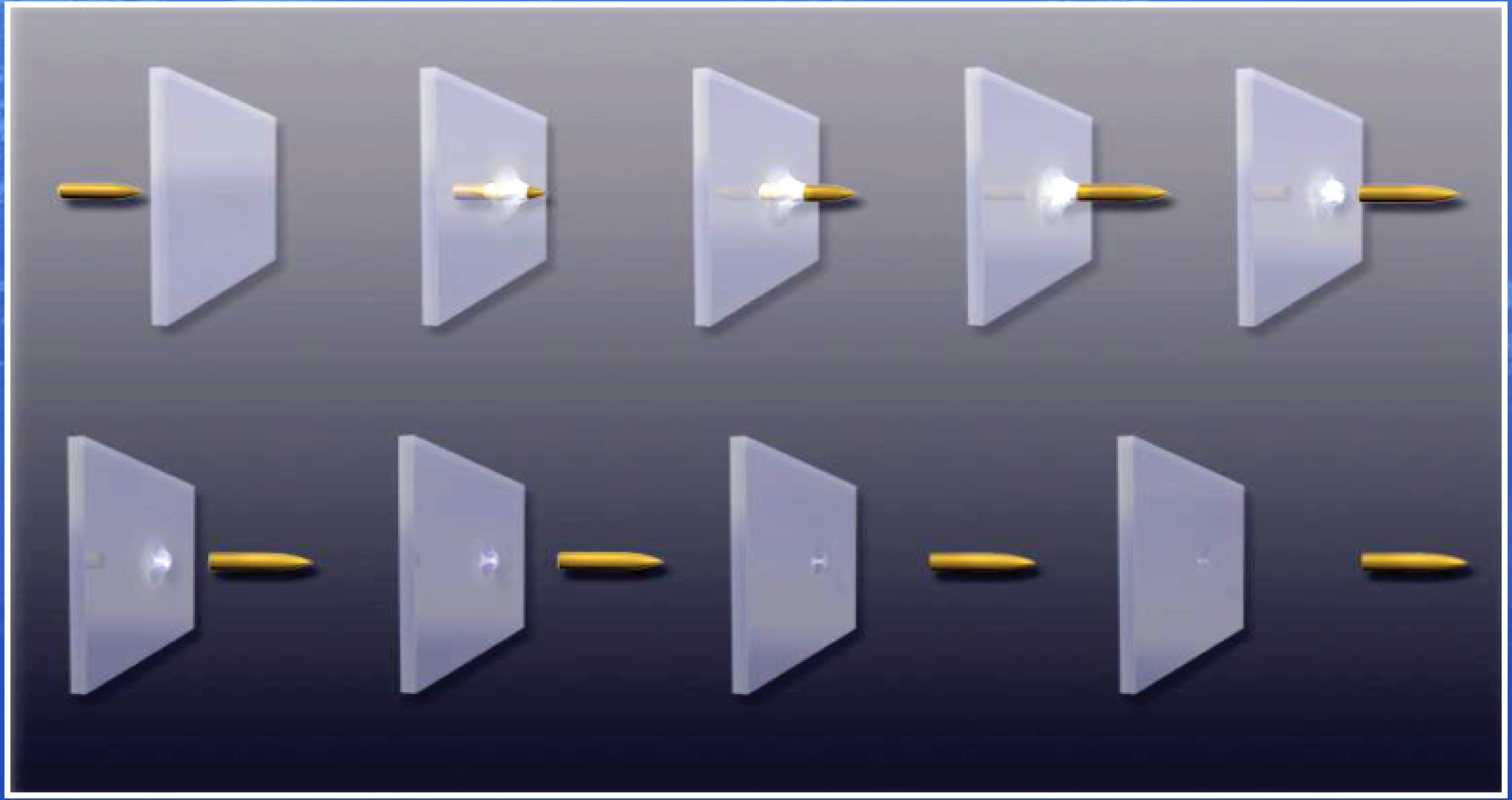
3. Fall, R., Ward, T.C., *Puncture Reversal of Ethylene Ionomers-Mechanistic Studies*, Thesis, VA. Tech, **2001**.
4. Kalista, S.J., Ward, T.C., *Self-healing of Thermoplastic PEMAA copolymers Following Projectile Puncture*, Thesis, VA Tech, **2003**.

Collaboration with Emilie Siochi, NASA-Langley Research Center

IMPACT OF GOALS of IVHM

Structures made of healing composite materials may:

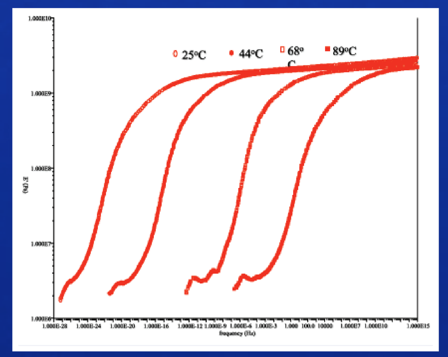
- Significantly prolong service life and improve safety and reliability in current and future aircraft.
- Support cross-cutting space exploration activities, such as enabling self-reliant systems necessary for long-duration requirements of future space structures and vehicles.



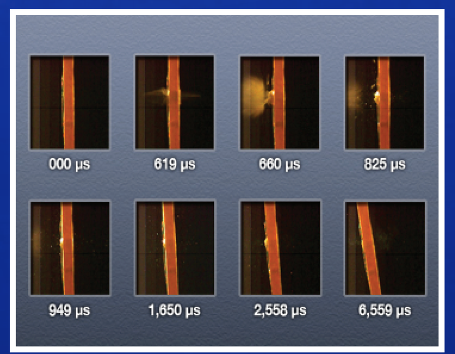
Bullet penetration schematic diagram of puncture healing mechanism

METHODS

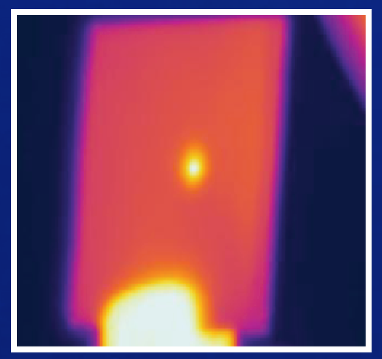
- Thermal and mechanical analysis of polymers.
- Mid-velocity projectile tests on various commercially available polymers at various temperatures.
- Measured initial and final bullet velocities with chronographs.
- Measured site of impact temperatures with thermal imaging cameras.
- Dynamic Mechanical Analysis - Time Temperature Superposition (TTS) master curve.
- High speed video



Master Curve: PB-g-PMA-co-PAN



High Speed Video

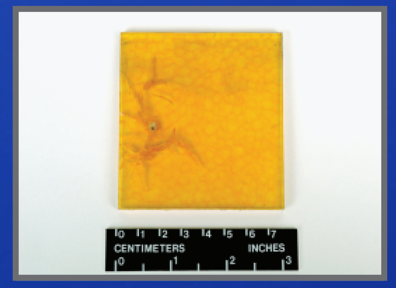


Ballistics Testing Facility

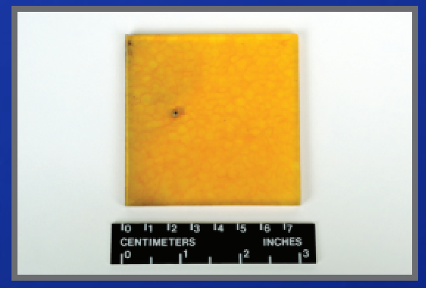
BALLISTIC TESTING RESULTS

Polymer	Tg (°C)	Tm (°C)	Elongation (%)	Tensile Strength (MPa)	Tensile Modulus (MPa)
Surlyn	-100	54,95	309	27.2	308.5
Affinity EG 8200	-68	46,66	947	9.3	5.9
PB-g-PMA-co-PAN	85	-	7.5	37.3	2472.5
Lexan	150	-	2.0	59.0	2900
PBT	70	210	250	50.0	2000
PBT-co-PAGT	66	180	500	6.9	188

Polymer	Test Temp (°C)	Site of Impact Temp (T_f) (°C)	Tg (°C)	Tm (°C)	Hole Diameter (mm)	Self healing (Y or N)
Surlyn	25	127	-100	54,95	--	Y
Affinity EG 8200	25	77	-68	46,66	--	Y
PB-g-PMA-co-PAN	25 50	133 127	85	-	.5 --	N Y
Lexan	25 100	--	150	-	-- 4.0	N N
PBT	25 100	--	70	210	-- 3.0	N N
PBT-co-PAGT	28 100	--	66	180	-- 1.0	N N



Test temperature: (25ºC)



Test temperature: (50ºC)

CONCLUSIONS and FUTURE WORK

- Several commercially available polymers possessing unique puncture self-healing functionality at low to mid range temperatures have been identified.
- Puncture self-healing improved with increasing temperature for the commercially available polymer, PB-g-PMA-co-PAN.
- Puncture self-healing was more effective when site of impact temperatures were above glass transition temperatures and melting temperatures of respective polymers.
- High speed video confirmed puncture healing mechanism in Surlyn and PB-g-PMA-co-PAN.
- Incorporate computational methods in the design of new compositions.

CROSS CUTTING APPLICATIONS

Space Structures

Fuel Tanks

Integrated Vehicle Health Management Project

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