

Puncture Self-healing Polymers for Aerospace Applications

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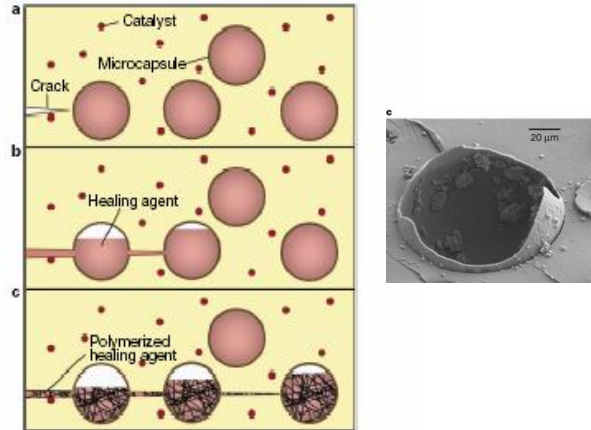


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Background

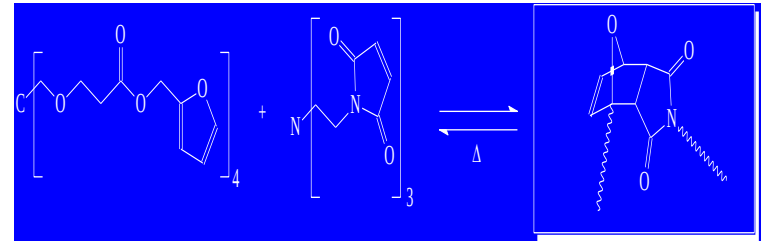


Autonomic Self healing Polymeric Composites University of Illinois



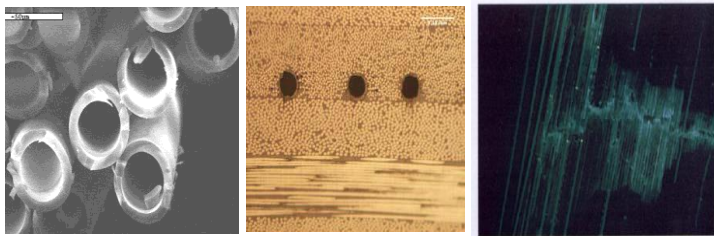
S.R. White, N.R. Sottos, J. Moore, P. Geubelle, M. Kessler, E. Brown, S. Suresh, S. Viswanathan, *Nature*, **409**, 2001, pp. 794-797

Thermally Re-mendable Polymers UCLA



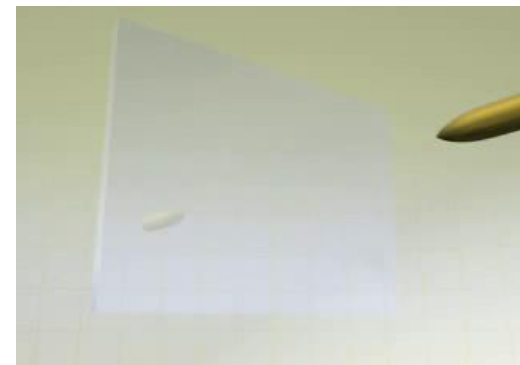
Chen et al., *Science*, 295, 1698 (2002).

Brittle glass fiber reinforced plastics containing hollow fibers filled with epoxy hardener and uncured resin in alternate layers, with fluorescent dye
University of Bristol



I. Bond and co-workers, *Composites A*, 32, (2001), 1767-1776.

Thermoplastic Puncture Healing Polymers NASA LaRC



Fall, R., Ward, T.C., *Puncture Reversal of Ethylene Ionomers-Mechanistic Studies*, Thesis, VA. Tech, **2001**.

Kalista, S.J., Ward, T.C., *Self-healing of Thermoplastic PEMA copolymers Following Projectile Puncture*, Thesis, VA Tech, **2003**.



- Develop self-healing polymeric materials to enable damage tolerant systems
- Benefit in environments and conditions where access for manual repair is limited or impossible, or where damage may not be easily detectable
- Other applications

Cross Cutting Applications



Fuel Tanks



Space Structures



Approach



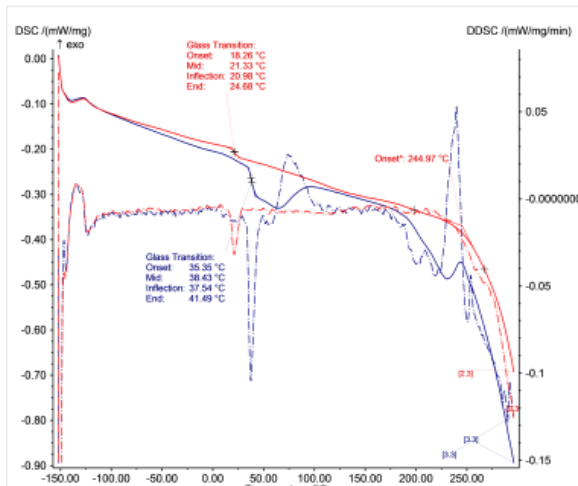
- Survey commercially available materials
- Determine puncture healing mechanism
- Understanding guides design of new puncture self-healing materials

Puncture Self-Healing Mechanism

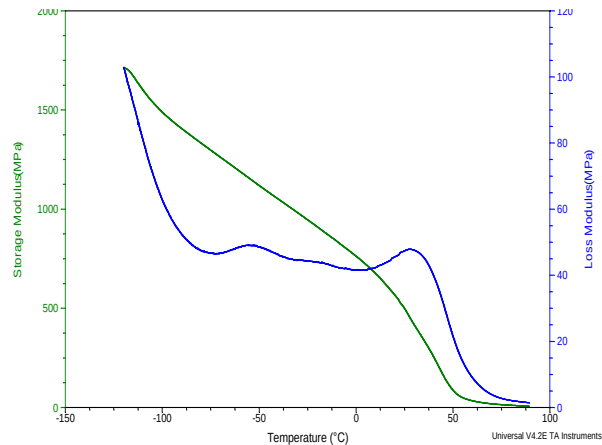


- Combination of viscoelastic properties determines puncture healing response of the material
- Requirements for self-healing following projectile penetration:
 - (1) Puncture event needs to produce a local melt state in the polymer material
 - (2) The molten material must have sufficient melt elasticity to snap back and close the hole

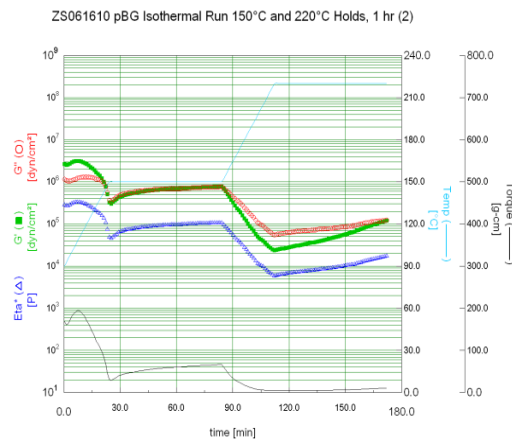
Puncture Healing Characterization Methods



Thermal Analysis



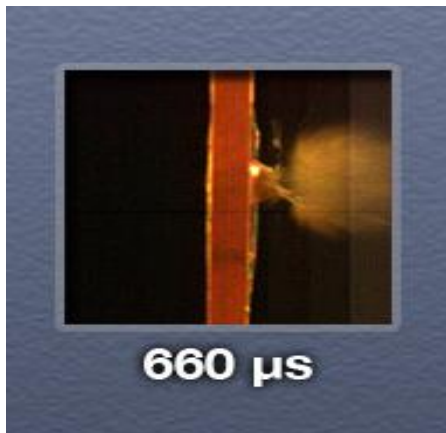
Dynamic Mechanical Analysis



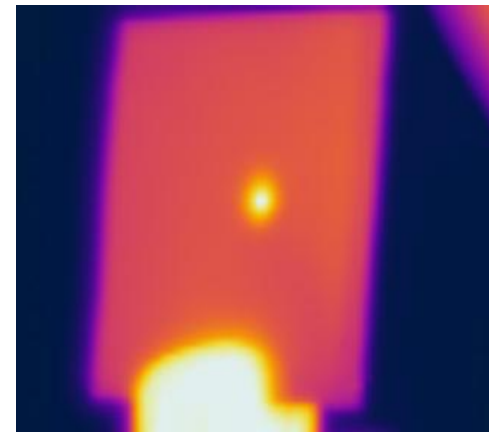
Rheology



Ballistic Testing



High Speed Video



High Speed Thermography

- 7.6 cm x 7.6 cm x 4.9 mm panels
- .223 caliber semiautomatic rifle from a distance of ca. 23 meters (.223 rounds)
- Remington full metal jacket (copper) 5.56 X 45 mm, 55 grain ammunition
- Panels were either mounted on a tripod or clamped inside an oven
- Chronographs were used to measure initial and final bullet velocity (avg. velocity 914 m/s)



Thermal and Mechanical Property Characterization Results



Polymer	Tg (°C)	Tm (°C)	Elongation (%)	Tensile Strength (MPa)	Tensile Modulus (MPa)
Surlyn [®] 8940	-100	54,95	309	27	309
Affinity [™] EG 8200G	-68	46,66	947	9	5.9
PB-g-PMA-co-PAN	85	-	7.5	37	2473
Lexan [®]	150	-	2.0	59	2900
PBT	70	210	250	50	2000
PBT-co-PAGT	66	180	500	6.9	188

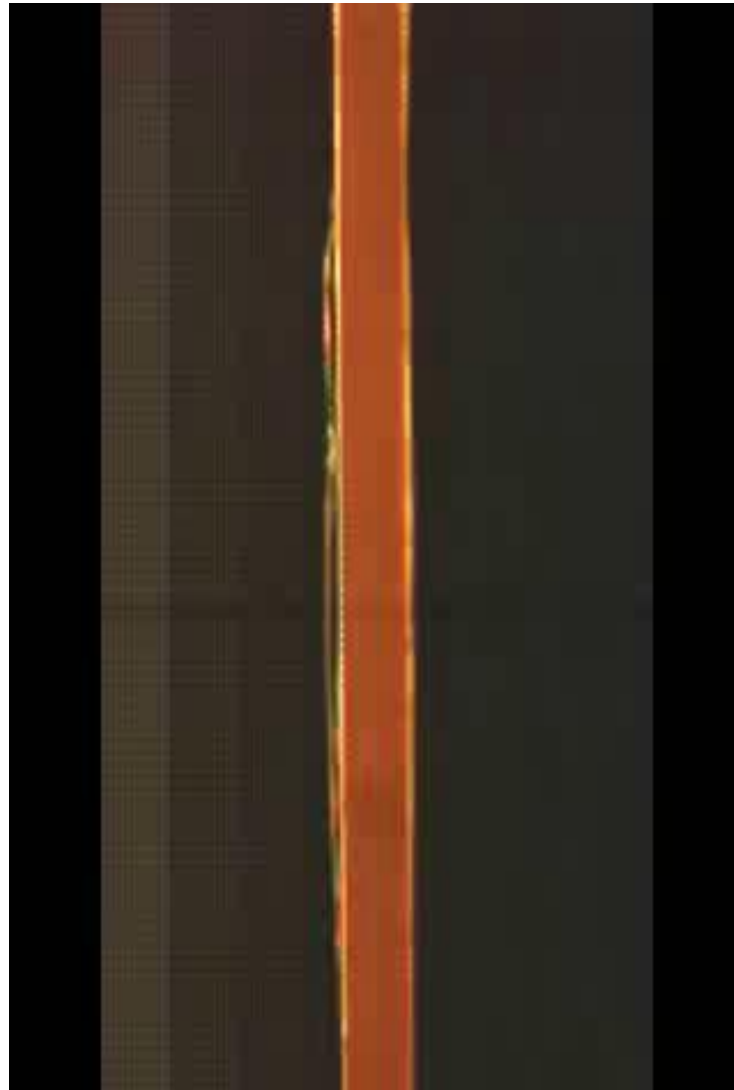
1. Dupont - Surlyn[®] 8940
2. Dow - Affinity[™]EG 8200G
3. GE – Lexan[®]

High Speed Video



Surlyn[®] 8940

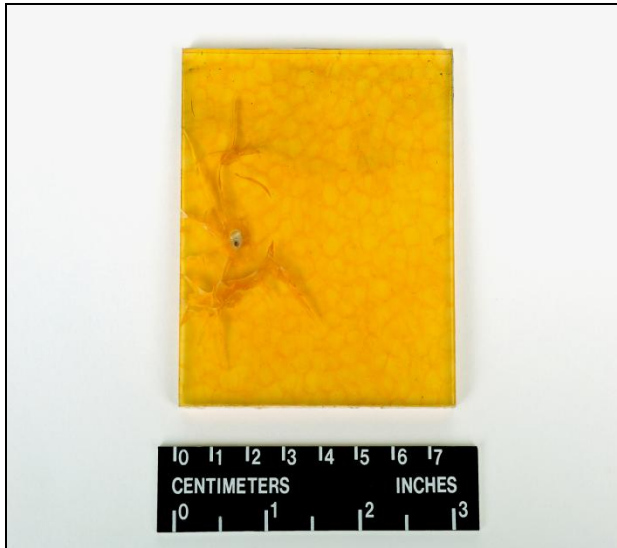
High Speed Video



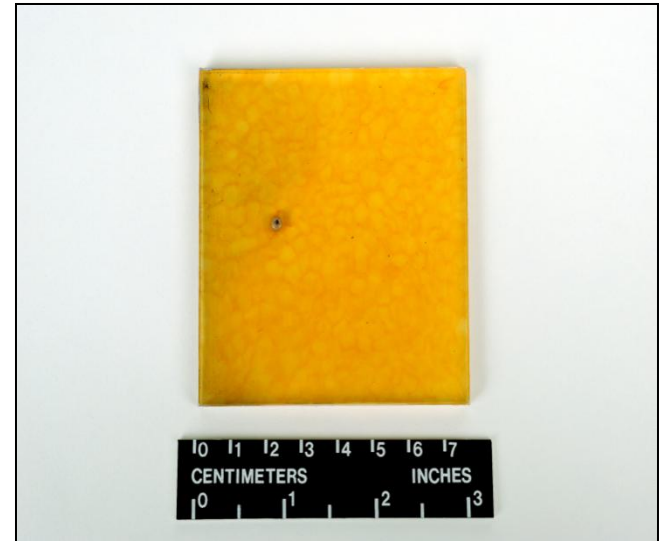
PB-g-PMA-co-A

Ballistic Testing Results

(PB-g-PMA-co-PAN)

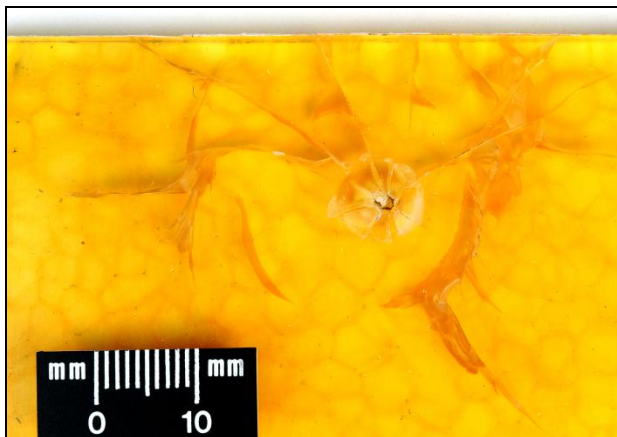


Front

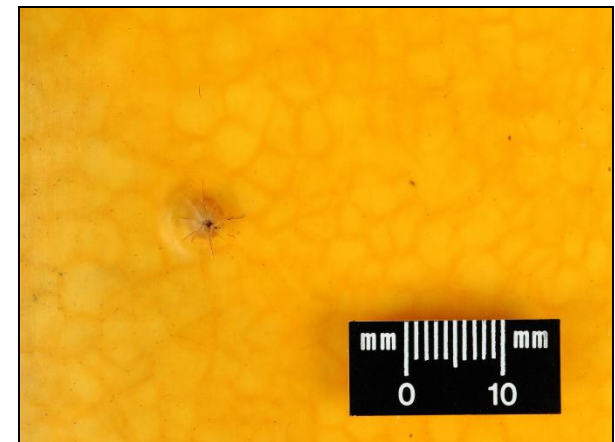


Test temperature: (25°C)

Test temperature: (50°C)



Back

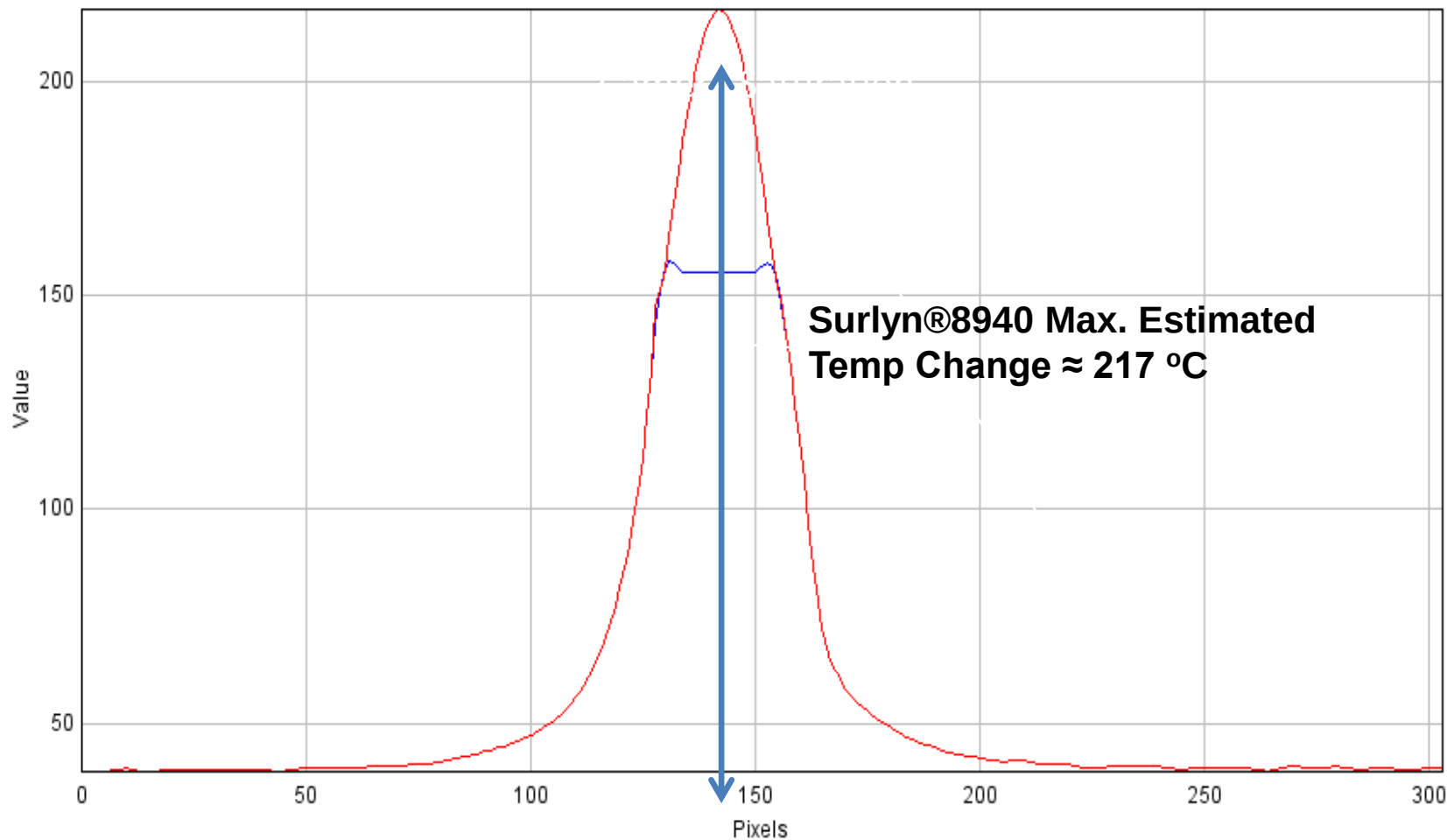


Ballistic Testing Results



Polymer	Test Temp (°C)	Tg (°C)	Tm (°C)	Hole Diameter (mm)	Self healing (Y or N)
Surlyn®8940	25	-100	54,95	--	Y
Affinity™ EG 8200G	25	-68	46,66	--	Y
PB-g-PMA-co-PAN	25	85	-	.5	N
	50			--	Y
Lexan®	25	150	-	--	N
	100			4.0	N
PBT	25	70	210	--	N
	100			3.0	N
PBT-co-PAGT	28	66	180	--	N
	100			1.0	N

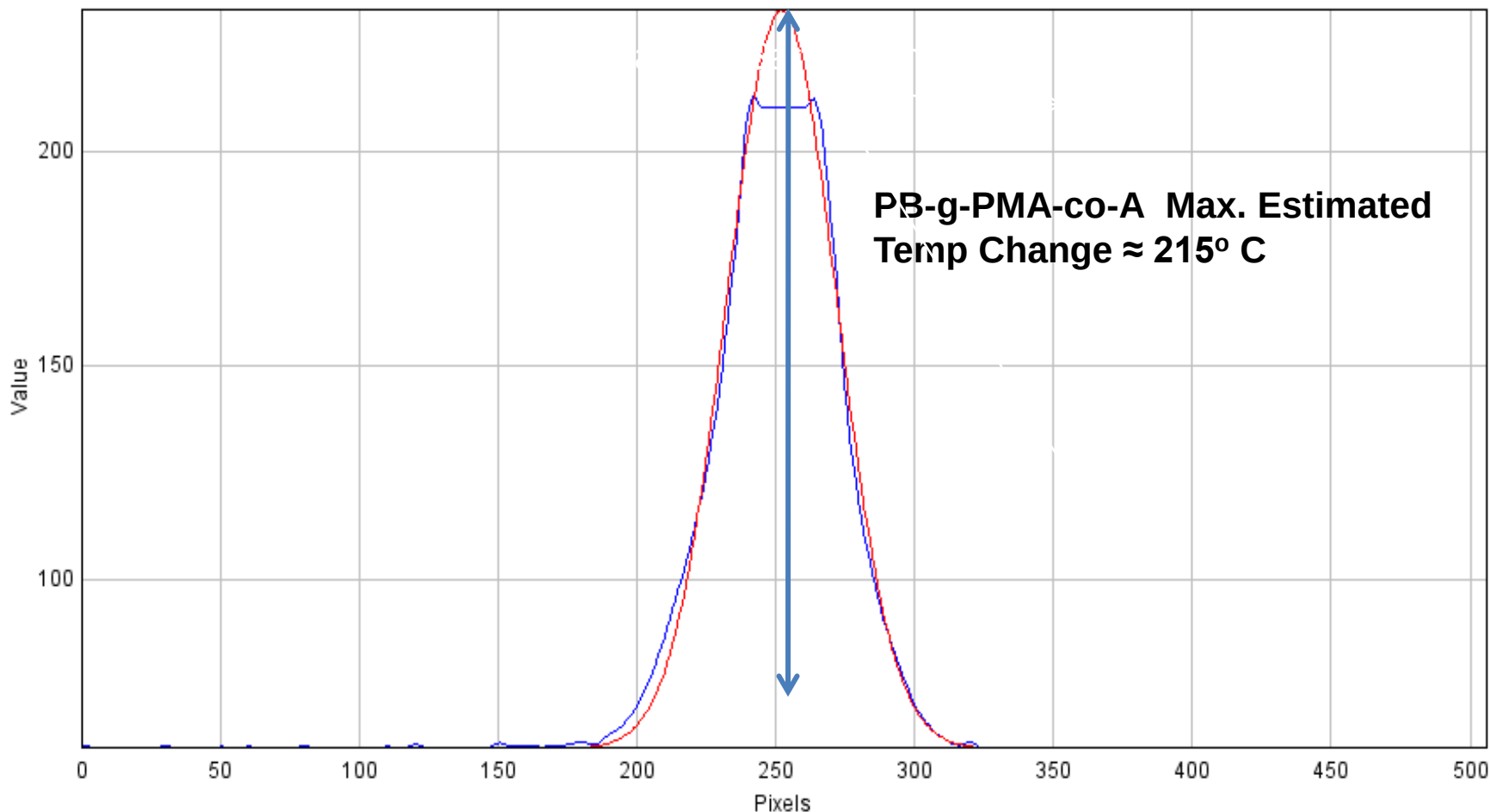
Temperature Profile across Bullet Penetration Region



1.0 pixel = 0.2646 millimeters

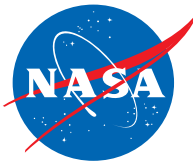
Blue : Experimental data, Red : Best Fit Gaussian

Temperature Profile across Bullet Penetration Region



1.0 pixel = 0.2646 millimeters

Blue : Experimental data, Red : Best Fit Gaussian



Polymer	$T_g(^{\circ}\text{C})$	$T_m(^{\circ}\text{C})$	$T(^{\circ}\text{C})$ at site of impact	Viscosity at $T(^{\circ}\text{C}), \eta$, (Poise)
Surlyn®8940	-100	95	240	3282
PB-g-PMA-co-A	19, 85	--	265	4333



- Commercially available polymers possessing unique puncture self-healing functionality at low to mid-range temperatures were identified
- Puncture self-healing was enabled when temperatures at site of impact were above glass transition and melting temperatures of the polymers
- High speed thermography revealed a $\Delta T = 215^{\circ}\text{C}$ at the site of impact for both Surlyn and PB-g-PMA-co-A polymers
- Melt viscosities of both Surlyn and PB-g-PMA-co-A measured at temperatures comparable to those observed at the site of impact following bullet penetration indicate melt flow
- Investigate routes for self-healing systems such as integration of puncture-healing materials into lightweight composite structures

