A Smart Sealant: Extending the Life of Roadways Using Shape Memory Polymers

Kira Kelley[1], Shane Lindeman[2], Dr. Harper Meng[3], Dr. Guoqiang Li[3]
[1]University of Vermont, [2]Louisiana State University, [3]Southern University and A&M College

LA-SiGMA
Louisiana Alliance for Simulation-Guided Materials Applications

Shape Memory Polymers: When submitted to external stress, these large molecules deform accordingly with the applied compression or tension. SMPs hold their new position until they have been heated past their "transition temperature," which is a range of temperatures specific to different types of shape memory polymers. At the transition temperature, the molecules reverse their deformation and assume their originally programmed shape.

Background

Damage to roadways occurs when water seeps into cracks and washes out the road from below the surface. The waterproof asphalt sealant used to prevent further damage soon separates from the crack and either the sealant or the entire road must be replaced immediately. By extending the life of the sealant, as is the goal of this research, Departments of Transportation would be able to save money, time, labor, and materials.

The increased lifespan of pavement sealant would be achieved by the addition of compressed SMPs. After the sealant has cured the sun would cause the temperature of the augmented sealant to surpass the transition temperature of the SMP powder. The particles' expansion would force the sealant deeper into the crack it occupies and would generate a tighter seal and more effectively inhibit water infiltration. The integrity of the sealant would be kept for longer than a sealant unadulterated by SMP particles.

Figure 2: Results of Test ii. The particles in isolation can be seen as having little to no expansive effect on the liquid matrix they were tested in when heated to their transition temperature.

Liquid	SMP Particle Size (µm)	Mass of Powder (g)	Total Initial Volume (mL)	Total Final Volume After Cooling (mL)	Max Observed Volume (mL)
none	600 uncompressed	1	5	5	5
C2H6O	600 uncompressed	0.8	6.6	6.6	7.8
H2O	600 uncompressed	1	8.7	8.7	8.7
H2O	600 compressed	1	9.4	8	9.5
H2O	300 compressed	1	7	7.1	7.2
C2H6O	300 compressed	2.9	7	7	7

The Tests:

Our tests used two separate batches of SMP, one of polyurethane and one of polystyrene. The former has a transition temperature of approximately 30-36°C and the latter has a range of 80-86°C. The deformation universally consisted of vertically compressing the SMP in its powdered form (at a rate of 0.25mm/min) and holding the strain constant for five to fifteen minutes, whereupon the stress relaxes. Three of the experiments we performed were:

i. **Outdoor Samples:** we have ten six-inch strips of cold-pour asphalt sealant in two locations outside and each segment has a separate ratio of compressed polyurethane powder (by weight) to sealant. An additional variable to the test is the particle size of the powder. One group is <300µm, and the other is <600µm.

ii. **Shape Recovery of Polystyrene Powder using Liquid Displacement:** to test the shape recovery of the polystyrene powder after compression we heated various samples (sorted by particle size and whether or not they had been heated past their transition temperature since their programming) in a glass graduated cylinder in a furnace heated to 80ºC.

iii. **Shape Recovery of Asphalt Cubes Using Liquid Displacement**: to test the capabilities of the powder to expand its asphalt matrix we repeated the previous test with the substitution of asphalt cubes in place of pure powder. The three specimens of cubes, (no powder, <300µm and <600µm particle size), cured indoors without approaching the range of their transition temperature after we had programmed them.

iv. **Compression Resistance Forces From Cubes at Varying Temperatures:** to test the stress needed to compress asphalt with and without SMP, asphalt cubes from the three specimens above were measured and compressed using the MTS machine inside a furnace to ascertain the effects of the powder (before and after triggering the shape memory capabilities) and noting the stress needed to compress cubes to a 50% strain rate.

Asphalt Sample:	Total Vol Initial (mL)	Total Vol Final (mL)	Total Max Vol (mL)	Cube Vol Initial (cm³)	Cube Vol Final (cm³)
None	5.0	5.0	5.2	NA	NA
Without SMP	5.5	5.5	5.7	0.5	0.5
<600µm SMP	5.5	5.6	5.9	0.5	0.6
<300µm SMP	5.5	5.6	5.9	0.5	0.6

Figure 3: Results of Test iii. Expansion of Asphalt Cube Samples in 5.0 mL of Water (from room temperature to 92°C, where the max volume was attained, back to room temp whereupon the final volume was measured).

The cubes expanded by 40% of their original size but retained only half of their original growth after the samples were allowed to completely cool back down. By setting the polystyrene particles in a solid matrix after their compressive deformation they were able to demonstrate visible expansion and to a certain extent retention of that expansion.

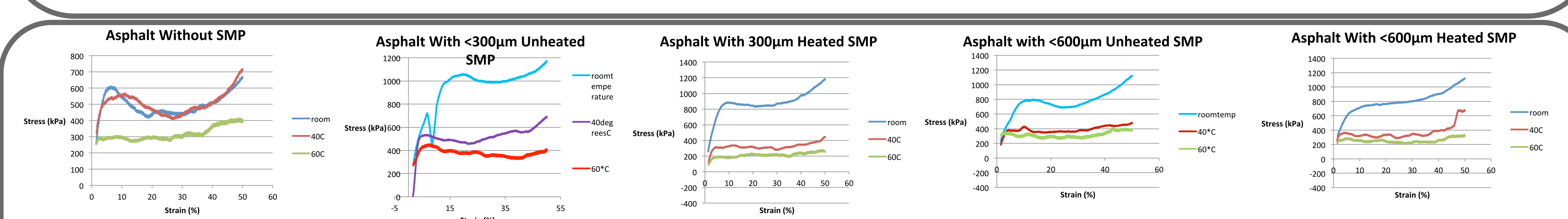

Figure 4: Results of Test iv. To see the direct effect of the resistance to compression generated by the powder, the stress on the unheated and heated (already recovered) cubes are shown. All cubes were compressed to 50% strain at a rate of 1mm/min. The warmer cubes offered much less resistance universally.

Figure 1: Outdoor samples. The weight ratio of the Polyurethene SMP to cold-pour sealant and the particle size accompany each image


Pure Asphalt, No SMP


10% <600µm SMP


20% <600µm SMP


20% <300µm SMP


40% <300µm SMP

Resulting Ideas and Conclusions:

- SMP with a low transition temperature might regain its shape before the sealant had time to cure outside.
- The SMP may not actually change size when compressed in powdered form; the particles may simply flatten but retain its total area.
- Despite this, the inclusion of powder in the asphalt may create expansive force as the molecules restructure and push opposite to the direction they were compressed
- The mixing process of the powder and asphalt gives the orientation of the potential forces of the compressed SMP a random distribution.
- When asphalt samples were heated they expanded much more with the SMP powder than without it.

Acknowledgments
This work was funded by the Louisiana Board of Regents, through LASIGMA [Award Nos. EPS-1003897, NSF (2010-15)-RII-SUBR, and HRD-1002541].

Southern University Agricultural & Mechanical College