

## Synthesis and Compression of Shape Memory Polymers

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### Introduction:

There exists an increased interest in smart materials and their applications. A shape memory polymer (SMP) is one that can be deformed to a temporary shape at low temperature, but recovers with heat or some other stimulus to its permanent shape. Shape memory is caused by a change of state from rubbery to glassy with heating and glassy to rubbery upon cooling. The temperature at which this transition usually occurs is the glass transition temperature<sup>1</sup>.

Shape memory polymers have potential for mass production for use in medicine and commercial applications because of the relative inexpensive materials and synthesis, a range of material tuning ability, and the potential for replacing other materials in common applications. For example, there has been some research into the use of SMPs for cardiovascular stents. Arguments exist that SMPs are better for this application because of the flexibility and compressibility that the shape memory effect provides<sup>2</sup>. Further investigation into the limitations of these materials is necessary to materialize a credible future.

### Procedure:

Cylindrical polymer samples were synthesized using 10% poly (ethylene glycol) dimethacrylate (PEGDMA) cross-linker in tert-butyl acrylate (tBA), with  $M_n=875$  and 550, respectively. The samples were polymerized in test tubes using UV polymerization for 30 minutes. Photoinitiator used was (2,2) dimethoxy-2-phenyl acetophenone, added at .1% of the total mixture. The glass test tubes were then removed, heated at 90C for 30 minutes, and samples were machined into cylinders of 8mm diameter and 16mm length.

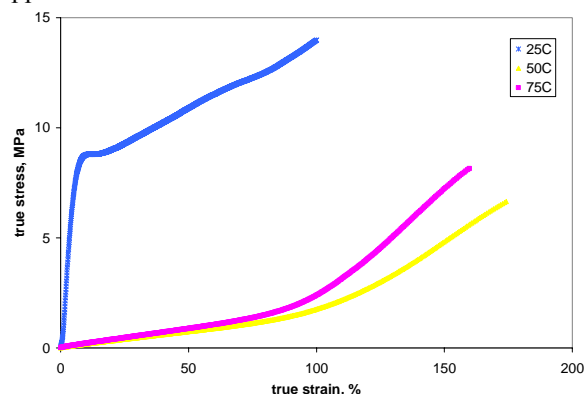
Finished samples were compressed using the Insight uniaxial mechanical test frame with a load cell capacity of 2 kN, at a rate of 3mm/min. The variable tested was environment temperature; tests were performed at 25C, 50C, 75C, and 100C. Data was recorded at 10.0 Hz. Among data recorded were stress, strain, extension, and load of each sample. This information was used to generate stress-strain data for the cylinders.

### Results/Discussion:

Using forces up to 1950N, samples in the glassy regime did not fail. At some points, true strains of up to 175% were experienced by PEGDMA-tBA without fracture. As seen in figure 1, true strain of up to 100% was experienced by the 25C (room temperature) compression. Cooling the cylinder to room temperature, the compressed shape maintained itself. Recovery tests were not performed. Tests at the glass transition temperature ( $T_g \approx 50C$ ) and closely above at 75C revealed quite the elastic behavior, with compression up to 175% true strain and full recovery upon removal from the platens. It is also important to note that none of the samples fractured with the 2kN force; it is difficult to know how much further they may have been compressed before fracture. The capacity of the load cell used was the limiting factor of the experiments.

It is unusual to see polymer have the resilience seen here. The elastic modulus measured ranged from 3-5MPa for the temperatures tested.

In figure 1, the results for 50C and 75C compression give insight to the actions of the polymer at the molecular level. The first stretch, seen to be quite horizontal, indicates a low elastic modulus. At this point, the heat is allowing some motion of the polymer chains to configure and minimize the height. At around 60-70% strain, there is no longer room for motions, and the chains no longer configure. Chain packing begins, which is evident by the great increase in stiffness. In the case of the room temperature samples, there is first some stiffness to compress the cylinder, but then it gives way and becomes more compressible with the applied load.



**Figure 1** Stress-strain measurements for cylindrical PEGDMA-tBA samples at temperatures of 25C, 50C, and 75C.

### Conclusion:

The compression tests of PEGDMA helped reinforce the idea that SMP's are a powerful material with the possibility for many applications. At different temperatures, various effects exist. At low temperature, the PEGDMA and tBA polymer has the highest elastic modulus, while barely over the glass transition temperature it is the most flexible, and at high temperatures the most likely to fracture. The most amazing part is the ability of the polymer to be compressed to true strains of up to 175%.

The demonstration of the versatility of this material should not go unnoticed; there is still much work to be accomplished in discovering what limitations exist.

### References:

1. J.Diani, Y. Liu, K. Gall; "Finite Strain 3D Thermoviscoelastic Constitutive Model for Shape Memory Polymers," 2006.
2. C. Yakacki, R. Shandas, C. Lanning, K.Gall; "Free Recovery Effects of Shape-Memory Polymers for Cardiovascular Stents," 2006.

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