Mechanical Activation of the Shape-Memory Effect in Polymers for Biomedical Applications

Christopher M. Yakacki PhD[1,2], Roxanne Likos[3], Robert Lamell[1,3], Daniel Guigou[1,4], Ken Gall PhD[1,2,4]
[1]Research and Development, MedShape Solutions Inc, Atlanta, GA 30318
[2]School of Materials Science and Engineering, The Georgia Institute of Technology, Atlanta, GA 30332
[3]W. H. Coulter School of Biomedical Engineering The Georgia Institute of Technology, Atlanta, GA 30332
[4]George Woodruff School of Mechanical Engineering, The Georgia Institute of Technology, Atlanta, GA 30332

Statement of Purpose: Shape-memory polymers (SMPs) are defined as a class of "smart" materials that are able to adapt and respond to a stimulus. SMPs can be activated via heat, light, alternating magnetic fields, and solvents; however, these techniques are mostly based on *thermal* activations.(*1*) Many research groups are exploiting SMPs for biomedical applications.(*1*)

This study proposes a new method of *mechanically* activating the shape-memory effect to allow for temperature-independent and near-instantaneous recovery. Shape-memory recovery is driven by entropy elasticity and relies on the temperature to reach a critical value to overcome intermolecular frictional forces. Rather than solely relying on temperature, mechanical energy can be added into the system to overcome these frictional forces and drive shape recovery. The purpose of this study was to investigate if mechanical forces could be used to activate SMP acrylate networks with respect to temperature and crosslinking density.

Methods: SMP networks were photo-polymerized from tert-butyl acrylate (tBA) and poly(ethylene glycol) dimethacrylate (PEGDMA). The molecular weight of crosslinker (PEGDMA) was controlled such that networks with 10, 20, and 40wt% crosslinking maintained a glass transition temperature (T_g) of ~50ºC. Cylindrical-tube samples were machined from polymerized rod stock and programmed for shape-memory above T_g using a three-piece sabot (Figure 1). This process axially strained the samples 26%. A second set of samples was machined to the same dimensions of the programmed SMP samples. Both sets of samples were compressed at 0.1mm/s to deform the samples to the original shape of the programmed SMP samples at 20, 27, 34, and 41ºC.

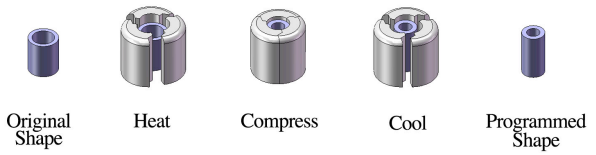

Figure 1: Process for programming shape-memory effect.

Lastly, SMP bone plugs were tested in a mock tenodesis setup. The SMP plugs were activated to fixate a nylon tendon in a synthetic bone hole. Samples were activated either by compression (mechanical) or temperature (thermal) and tested for fixation strength over time.

Results: Samples programmed with shape-memory showed a substantial drop in modulus, strength, and energy required to deform to samples compared to identical shaped samples not programmed for shape memory at corresponding temperatures. Figure 2 compares the response for the 10wt% crosslinked samples, which is representative of the remaining networks. On average, the SMP samples showed a 50-70% reduction in energy required for deformation compared to non-SMP group, which is summarized for all the networks and temperatures in Figure 3.

In the tenodesis model, mechanically activated SMP samples initially held 225N of fixation compared to 100N of fixation by thermally activated samples. After 30 minutes, the mechanically activated samples showed a slight drop in fixation strength to 200N, while thermally activated samples increased to 155N.

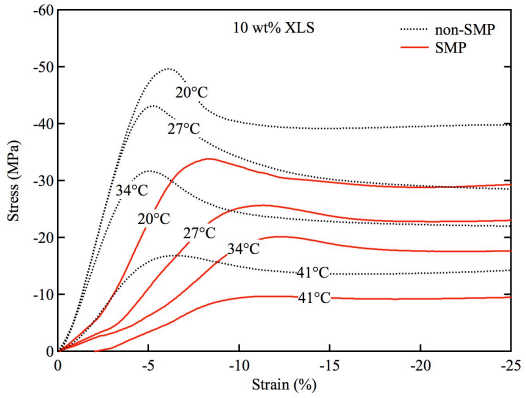

Figure 2: Stress-strain behavior of samples programmed as a SMP compared to identically machined samples not programmed with shape-memory (non-SMP).

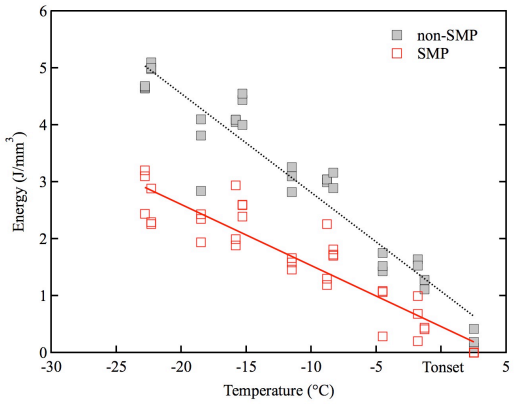

Figure 3: Energy required to deform SMP and non-SMP samples for all networks and testing temperatures.

Conclusions: These results show forces/energy can be used to supplement thermal energy to activate the shape-memory effect. Furthermore, the force required to activate strain recovery is substantially less than identical samples not programmed for shape memeory.

References:

1. C. Yakacki, K. Gall, in *Advances in Polymer Science*. 2010; vol. Shape Memory Polymers: 147-175.