### What is a Shape Memory Polymer?

Shape memory polymers are an elite group of smart materials that have properties allowing them to, upon exposure to their Glass Transition Temperature (Tg), change their modulus to a rubbery state and be manually deformed and cooled [1]. The polymer keeps this temporary shape, until it is again exposed to its Tg, upon exposure to which causes it to automatically recover back to its original state.

### Review of Literature

Shape memory polymers are made from the crosslinking of multiple monomers. With the addition of a crosslinking agent to the solution of monomers, and the exposure to the correct amount of Ultra Violet light, the solution crosslinks and forms a new polymer. The purpose of crosslinking is often to obtain desirable traits from a group of monomers [2]. Studies have been done on Partial Polymerization, which involves partial synthesis of the polymer in the UV chamber, then deformation, and finishing the polymerization in this deformed state, therefore making the natural, and stable, stage of the polymer this shape [3].

## Objective: Shape Memory Polymer Helmet lining with Flexible Electronics

As opposed to trying to stop the problem head on, we have thought of a way to help scientists see which type of hits could be the most disastrous.

What we have come up with is a layer of SMP, that could either be layered into the helmet shell, or sit beneath it, that acts as a platform or substrate for flexible electronic pressure sensors. These sensors on the helmet will be able to measure the force and number of hits, their respective location on the helmet.

The sensors will all be wired (or somehow connected) to a battery powered chip located in the back of the helmet. This chip will store all of the information and data that is gathered throughout the game/practice. After the data is collected, the chip will be removed and uploaded to a computer where researchers can see all of the information about contact made during the event.

In an attempt to have the most accurate results, and have the least amount of problems possible, the polymer that acts as the platform will be partially polymerized. This polymer will be partially polymerized because it's better to have the polymer in its original state when in use, so it won't have the desire to recover back to any shape. Also the sensors won't have any strain or stress on them (as they would if they were on a polymer that was bent or deformed to a certain shape with the sensors on them).

### Material/Methods

#### Synthesis:

1. Add TCMDA and TATATO.
2. Add Photo Initiator (PI).
3. “Vortex” and “Sonicate” until dissolved.
4. Add TMICN in aluminum foil.
5. Vortex for 2 minutes.
6. Sonicate for 5 minutes.
7. Vortex for 2 minutes.
8. Sonicate until bubbles are gone (usually 4 sets of sonication).

This polymer was made from chemicals: Tricyclodecane dimethanol diacrylate (TCMDA), 1,3,5-triallyl-1,3,5-triazine-2,4,6(1H,3H,5H)-trione (TATATO), and Tris[2-(3-mercaptopropionyloxy)ethyl] isocyanurate (TMICN).

#### Crosslinking:

1. Crosslink in UV Chamber (365 nm) for 6 seconds.
2. Take polymer out, deform around/to different shape.
3. Hold in place (with tape or clips).
4. Crosslink for 15 minutes.

Partial Polymerization is used when one wants the original shape of their polymer to be something other than the usual flat sample. (Will add details in later)

The polymer is crosslinked in a UV chamber for 6 seconds. The polymer has solidified, but it is still very pliable and soft. When in this stage, the researcher will deform the polymer into the desired shape (ex. Wrapped around a vial). The polymer is secured in this shape (by tape of clips) and then is put back in the UV chamber for 15 minutes to finish its crosslinking.

After this the polymer is post-cured for 18 hours. Now the polymers original state will be in the deformed shape it was made into in-between crosslinking.

### Flexible Electronic Pressure Sensors

The purpose of the pressure sensors in this project is to read and collect data from collisions involving the head. There are many different approaches to finding the right type of sensor. There are industrial flexible sensors online, along with many possibilities that could be developed in the UTD lab. Whatever the sensors are, they will be connected to a series of wires or circuits that will lead into a computer chip located in the back of the helmet. This is the chip that will be used to store all of the data from the game or practice, and then put into a computer to analyze all of the data that was collected. The sensors should be able to detect force of the hit, location of the hit (on the helmet), and the frequency of the hits (how many hits one encounters).
Dynamic Mechanical Analysis (DMA) and Differential Scanning Calorimetry (DSC)

There were two different types of plastic tested for this. One was a thiol-ene composed of: 33 wt% TCMDA, 33 wt% TATATO, and 33 wt% TMICN; and the second was also a thiol-ene composed of: 25 wt% TCMDA, 50 wt% TATATO, 25 wt% TMICN.

Dynamic Mechanical Analysis (DMA) is a method used to find the viscosity of polymers. Stress was applied to the polymer and then strain was recorded. This allowed the researcher to determine the complex modulus of the polymer. This technique was used in this study to find the glass transition temperature of each sample.

Differential Scanning Calorimetry (DSC) is a thermoanalytical technique used to measure the difference in heat between a sample and a reference. The sample was put into a small metal container, and was placed next to an identical metal container with nothing in it. This empty container was used as a reference for the sample. The technique was used to measure the heat flow through the sample.

DMA Results

The graph above was created from the data from running SMP (33, 33, 33) and SMP (25, 50, 25) on a Dynamic Mechanical Analysis machine. This graph shows the relationship between Storage Modulus (MPa) and Temperature (°C). This information can be used to find the Glass Transition Temperature of the material tested.

DSC Results

The graph above demonstrates the data from both SMP (33, 33, 33) and SMP (25, 50, 25) on a Differential Scanning Calorimetry machine. The DSC shows the relationship between heat flow and temperature, and how heat flows throughout the sample in order to heat the sample. This method can be used to find polymer degradation.

References