CHARACTERIZATION AND TESTING OF SPIDER-SILK-LIKE SHAPE MEMORY POLYURETHANE FIBER

Qianxi Yang
Ph.D. Candidate
Faculty Advisor: Dr. Guoqiang Li

ABSTRACT

The spider dragline silks possess the extraordinary combination of high strength, low weight, high damping and super-contracting capability [1-6]. These remarkable properties of spider dragline are determined by its unique molecular structure [1, 7]: It is now well accepted that spider dragline is a semicrystalline material made of amorphous flexible chains reinforced by strong and stiff crystals. It is the perfect balance between the high stiffness of crystalline and the high ductility of the amorphous phase that gives the spider silk excellent mechanical properties. In spite of this, the extreme complicated and expensive spider breeding and silk harvesting processes made the commercially available spider silk dragline almost impossible. Therefore, seeking an alternative low-cost polymeric fiber has become one of the hot topics in recent polymer research. The key to the solution is the well-known idea of ‘structure determines properties’.

Shape memory polymer is a class of smart materials that can be deformed and fixed in a temporary shape at a certain condition and recovers the original shape when exposed to a suitable stimulus [8-12]. Foremost among all the shape memory polymer systems, polyurethane based shape memory polymer (SMPU) draws the most attention due to its unique properties, such as the wide range of shape recovery temperatures (from -30 to 70°C), high shape recoverability, good process ability and excellent biocompatibility [13-15]. Recently, scientists have imparted the shape memory properties of SMPUs to fibers to enhance their mechanical properties [16-20]. Due to their similarities in the micro-structures, it is envisioned that SMPU fiber may have similar properties with the spider dragline silk. This study seeks to better understand the working mechanism of SMPU fiber in multi-scales and multi-aspects [21, 22].

The meso-scale morphology of SMPU fibers were first characterized using differential scanning calorimetry (DSC), Fourier transform infrared spectrometry (FTIR) and X-ray diffraction (XRD). It is found that SMPU experiences different phase transitions and phase separations under different programming and stress recovery conditions. A morphological model was proposed based on the results to illustrate the phase evolution during different thermomechanical treatments (See Figure 1).

![Figure 1. Schematic representation of the morphological model proposed for our SMPU fiber (Replot from [21]).](image)

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The macro-scale mechanical, dynamical and shape memory properties of SMPU fiber are tested and compared to those of spider dragline silk [refs]. From the testing results, although the polymeric fiber has a lower strength compared to spider dragline silks (0.2-0.3GPa versus 1.1GPa), it possesses much higher toughness (276-289MJ/m³ versus 160MJ/m³), due to its excellent extensibility. The dynamic mechanical tests reveal that SMPU fiber has a high damping capacity (tanδ=0.10~0.35) which is comparable to or even higher than that of spider silks (tanδ=0.15). The shape memory property is characterized by the fully constrained recovery stress. Compared to SMPU fiber (4~7MPa), spider
dragline silk can generate remarkably higher super-contraction stresses, ranging from 10MPa to 140MPa. In addition, different programming procedures and recovery conditions result in different behaviors.

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REFERENCES