Investigation of the Mechanical and Shape Memory Properties of Polymer Fibers

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Abstract

In this study, we investigated mechanical and shape memory properties of different polymer fibers. In our experiment we tested three fishing line polymer fibers : Nylon 6 , Nylon 6,6 , and Polyethylene(PE). We tested the tensile strength of each of these fibers and found that Nylon 6 and Nylon 6,6 exhibited the greatest stress before break at around 800 MPa. We also conducted thermoanalytical tests to determine the glass transition temperatures (T_g) and melting temperatures (T_m) of our fibers. We then hot programmed our fibers to pre-determined strains, and proceeded to conduct free shape recovery tests on each of our programmed fibers. We found that Nylon 6,6 had the greatest shape recovery at strains above its yield point (35%). Test are currently being conducted to find the fixed stress recovery of our programmed fibers. We hope to use our results to improve the efficiency of the shape memory artificial muscles created in our lab.

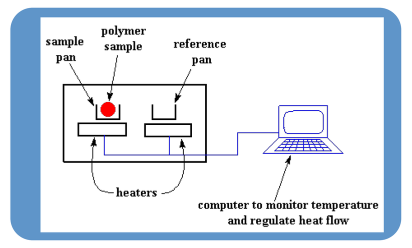
Introduction

In 2014 it was discovered [Haines *et al.*,2014, "Artificial Muscles from Fishing Line and Sewing Thread", *Science*, 343 (6173): 868-872] that inexpensive polymer fibers used for fishing line could easily be transformed ,by extreme twisting ,into coiled muscles that could contract by 49% and lift loads over 100 times heavier than can human muscle of the same length and weight. Utilizing this study , Pengfei Zhang and Dr.Guoqiang Li created a new polymer artificial muscle based healing-on-demand composite . This composite has the ability to self heal crack formations when external heat is applied. Their composite achieved over 54% healing efficiencies at fixed boundary conditions, even after repeated damage of the composite. Our goal is to improve the artificial (coiled) muscle used in this composite by finding a new polymer fiber with greater shape and stress recovery that will replace PE fiber used previously.

Methods

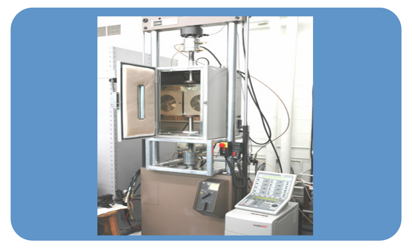
MTS Tensile testing

DSC Testing Schematic

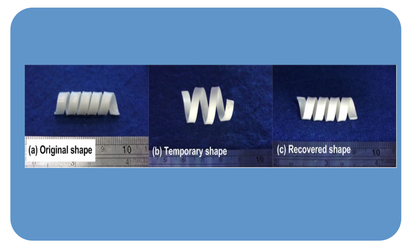


FTIR Spectral Analysis

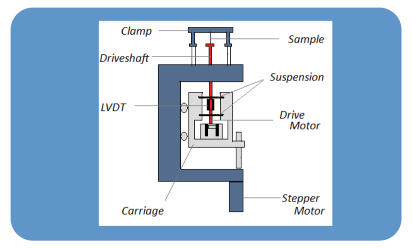
MTS Hot Programming



Free Shape Recovery



DMA Fixed Stress Recovery



Results

FTIR Spectra

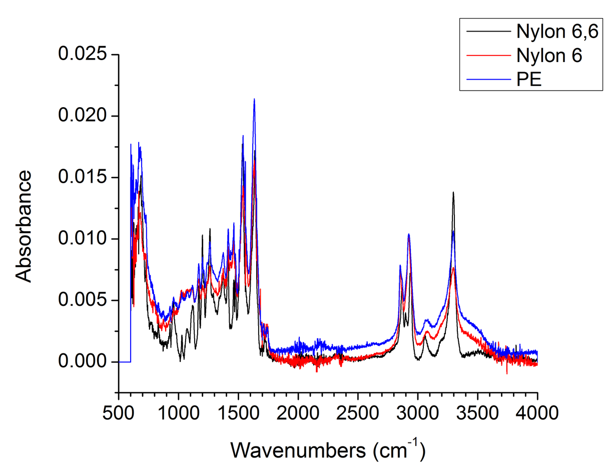
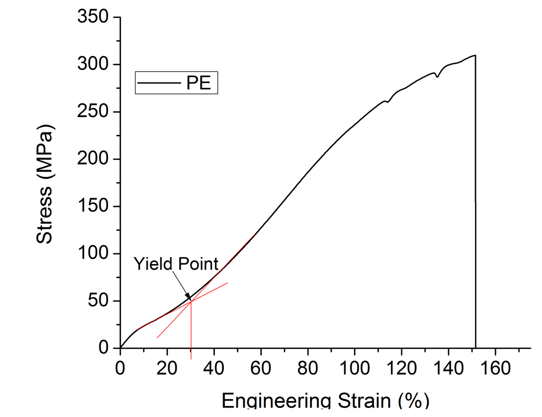


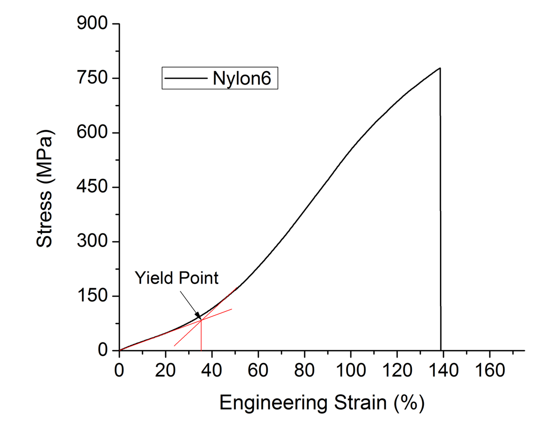
Figure 1: Infrared spectra of our materials .Peaks distinguish molecular bonds , while intensities distinguish abundance of these bonds.

Tensile Test Plots

A)



B)



C)

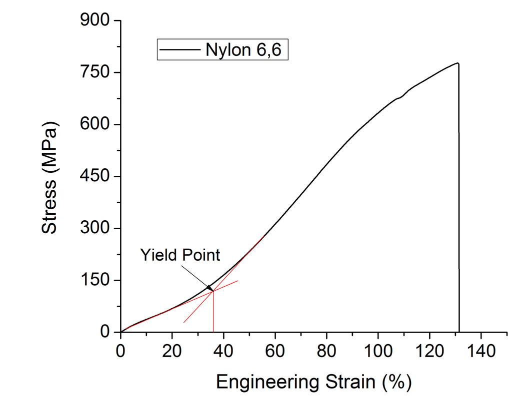
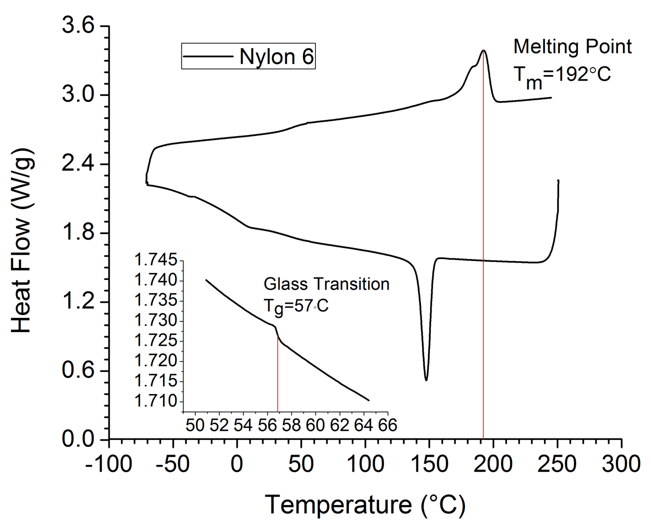


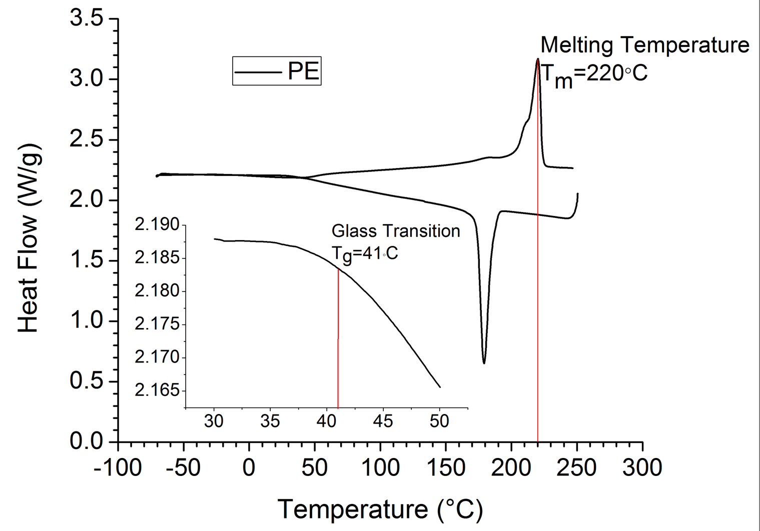
Figure 2: Stress vs Strain plots displaying the tensile strengths of our materials: PE (A), Nylon 6 (B), Nylon 6,6 (C) . All fibers were tested until break. Yield points were determined after data collection using tangent analysis.

DSC Results

A)



B)



C)

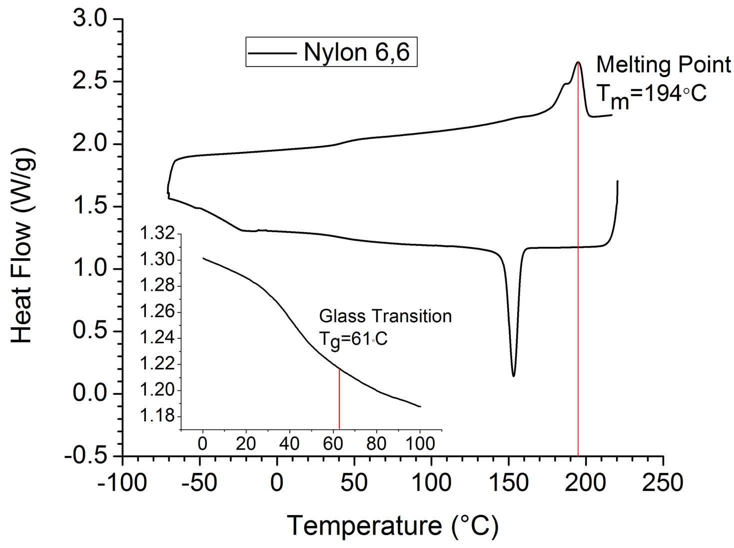


Figure 3: Heat flow cycles of our materials: Nylon 6 (A), PE (B), Nylon 6,6 (C). Used to determine the melting and glass transition temperatures of each material.

Shape Recovery Results

Material	Programmed Strain	Shape Fixity Ratio (%)	Shape Recovery Ratio (%)
Nylon 6,6	40%	62.5	31.25
	60%	59.0	31.65
	80%	67.7	17.86
	100%	70.8	15.24
Nylon 6	20%	52.1	34.72
	40%	52.1	18.38
	60%	55.5	25
PE	20%	41.7	39.06
	40%	67.7	14.88
	60%	69.4	21.55

Figure 4: Chart displaying the different strain percentages that each material was hot programmed to. Calculated shape fixity and shape recovery ratios are also shown. These ratios determine how well a material can hold its temporary shape, and how well it can recovery its original shape.

Stress Recovery Results

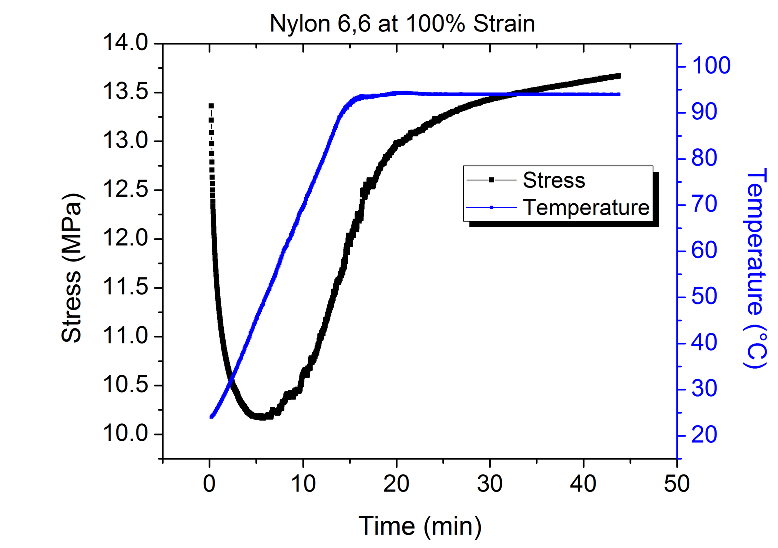


Figure 5: Fixed Stress recovery result for Nylon 6,6 (100% Strain). The blue data shows the temperature ramp rate (T_{set}=94°C), and the black data shows the stress recovery as time progresses. The stress recovery strength of this sample peaks around 13.75Mpa

Conclusion

In this study was set out to find the mechanical and shape memory properties of the fibers Nylon 6, Nylon 6,6, and Polyethylene (PE). We characterized our materials using infrared spectroscopy and found that our materials had similar chemical compositions. This may be attributed to the manufacturing process of our fishing line fibers; many companies use polymer mixtures comprising of some percentage of Nylon 6. Through tensile testing, we found that both Nylon 6 and Nylon 6,6 had greater tensile strength than the PE fiber (≈800MPa each). Using our tensile results, we found the yield points of our fibers to be at 30%, 35%, and 37% strain for PE, Nylon 6,6 , Nylon 6, respectively. We also characterized the thermal properties of our materials using DSC tests, and found the T_g and T_m values of each fiber. Based on our strain at yield point ,we determined strains for which each material would be programmed to. After programming, we conducted free shape recovery tests and found that Nylon 6,6 had the greatest shape fixity and shape recovery at strains above its yield point (35%). We are also in the process of conducting fixed stress recovery test on our materials which will give us a better understanding of each materials viability as effective artificial muscles. In the future, we hope to use the results from these test to create coiled muscles from our different materials, and conduct further test on those coiled muscles to see if the healing efficiency of our muscle composites can be improved upon.

Acknowledgements

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