Lab Report 2: Sensata Project

ME-114: Polymer Materials and Processing

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Part 1: Basic Characterization of Properties

I. Introduction

In a particular sensor developed by Sensata, the compressive force exerted by a resin-seal cannot drop below 20% of its original relaxation modulus. Over its lifetime, this seal will experience cyclic-stress load operations at 70 degre. In that time the material will experience stress relaxation, which is the decrease of stress at a constant strain. As this occurs the compressive force decreases and with that the equal and opposite force on the sensing element. A drop as significant as 20% would result in a shift to output levels that the sensor was not calibrated for. If the modulus were to drop further the seal would be compromised and the sensor would leak.

In this project we were tasked by Senstata to analyze Zytel, a nylon resin, and compare it with Celanex and Ryton to recommend the material best suited for the design problem. The best material will be the one whose stress relaxation modulus decreases the least and thus maintains the best seal at the operating temperature of 70°C. Our analysis consisted of an application of the Time Temperature Superposition Principle to develop a master curve for Zytel using stress relaxation data collected over the following temperatures: -40°C, 0°C, 22°C, and 77°C.

II. Material and Methods

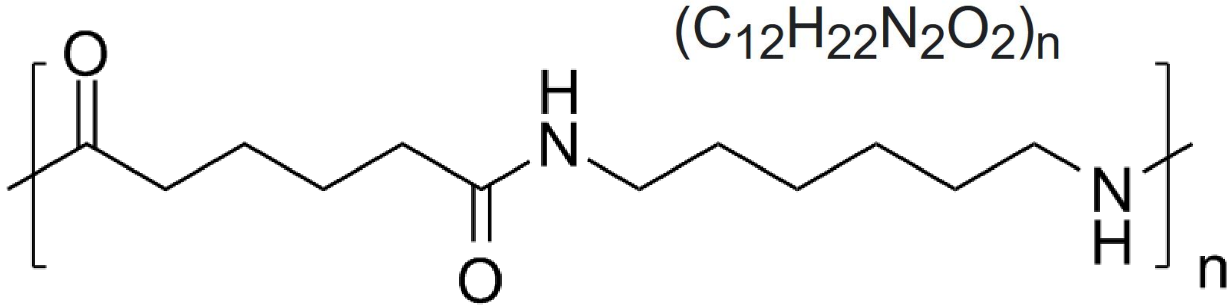
Zytel is a nylon resin created by Dupont also known as nylon-66, and comes with many advantages including heat resistance, high stiffness, high strength, and it’s easy to process. Because of the many advantages it offers, Zytel is widely used in many applications, some of which include automotive engine covers, cable insulation, electrical and electronic plastics, and many others. Overall, Zytel is a very useful material.

Many of these advantages are thanks to some of the properties of Zytel. The more important properties are listed here:

Table 1: Important Values for Testing

Glass Transition Temperature	80°C
Tensile Modulus	11000 MPa
Fillers	Glass Fiber, 33% Filler by Weight
Tensile Stress	200 MPa

Image 1: Chemical Formula and Structure of Zytel



Unfortunately for this lab we were not able to test any materials. The data sheet of each material, along with data already collected from last year's testing, was given to us for this analysis. This data included time, extension, load, strain, and tensile stress. This given data was collected by conducting tests on Zytel dog-bone sample on the Instron machine in Bray Lab.

To receive the data required, the dog-bone samples were tested at constant strain of 0.012 mm/mm, and the stress relaxation data were calculated at -40°C, 0°C, 22°C, and 77°C. From both the data sheets and the data (from a previous lab) that were provided, we were able to extract the values in Table 1 as well as graphs showing the change in elastic modulus over time at different temperatures.

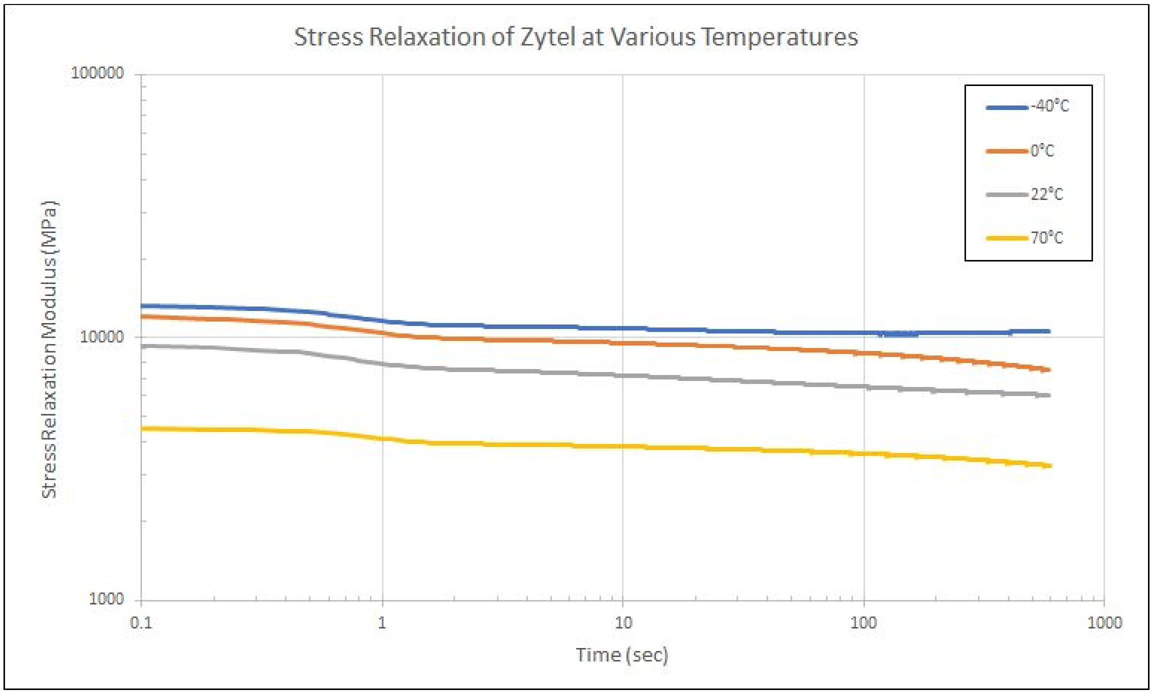
To see if our material (Zytel) is the optimal material to move forward with to use as a seal, we took a look at the other materials and their properties as well. These other materials are Celanex, PEI, and Ryton.

III. Results

The data from the stress relaxation tests was gathered, cleaned up, and analyzed to understand the material properties of Zytel. Figure 1 below shows a graph of Stress Relaxation Modulus vs Time for the four different temperatures tested.

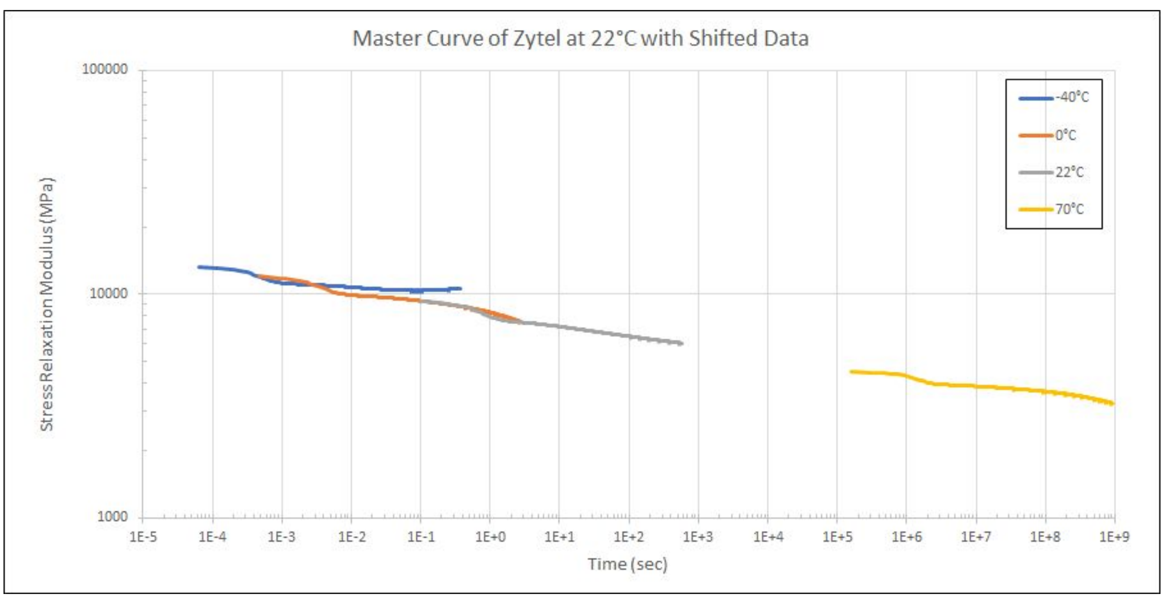
All but the first test at -40°C show that as time progresses, the stress on the material decreases due to stress relaxation. The test at 40°C decreased at first but then increased after about 30 seconds. This is an error, and it is most likely due to the fact that the material increased in temperature as the test occurred.

Figure 1: This graph shows the stress relaxation of Zytel at four different temperatures.



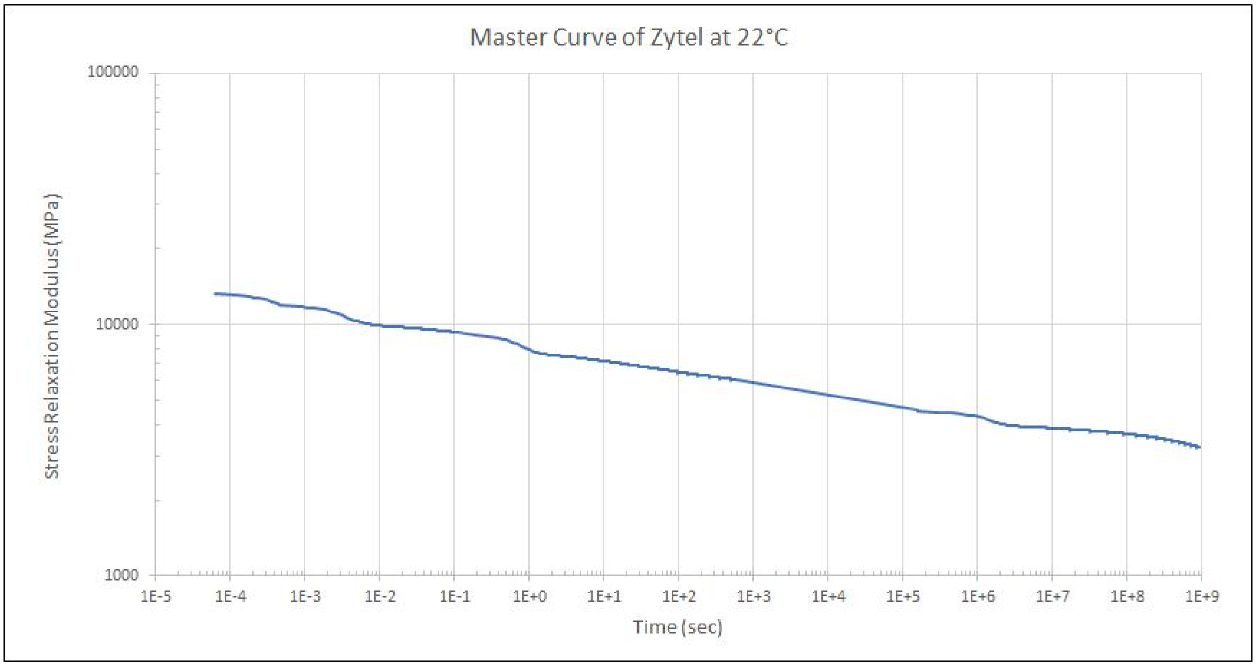
Nevertheless, we were able to successfully use the data to find a time shift at each temperature and combine them into a master curve. We decided to use the test at 22°C as the reference temperature since we did not test the material at the glass transition temperature and it was also the most stable one due to it being tested at room temperature. Figure 2 below shows the data from Figure 1 shifted to the corresponding spot on the master curve.

Figure 2: This graph shows the shifted data from Figure1 with respect to the test at 22°C.



As seen in figures above, the data for the test at -40°C started to curve upwards, so we removed that data to make it look smoother. Some data was missing so we interpolated between the results and combined the rest to create the final master curve shown below in Figure 3.

Figure 3: This graph shows the master curve of Zytel after combining the data and interpolating for the missing data.



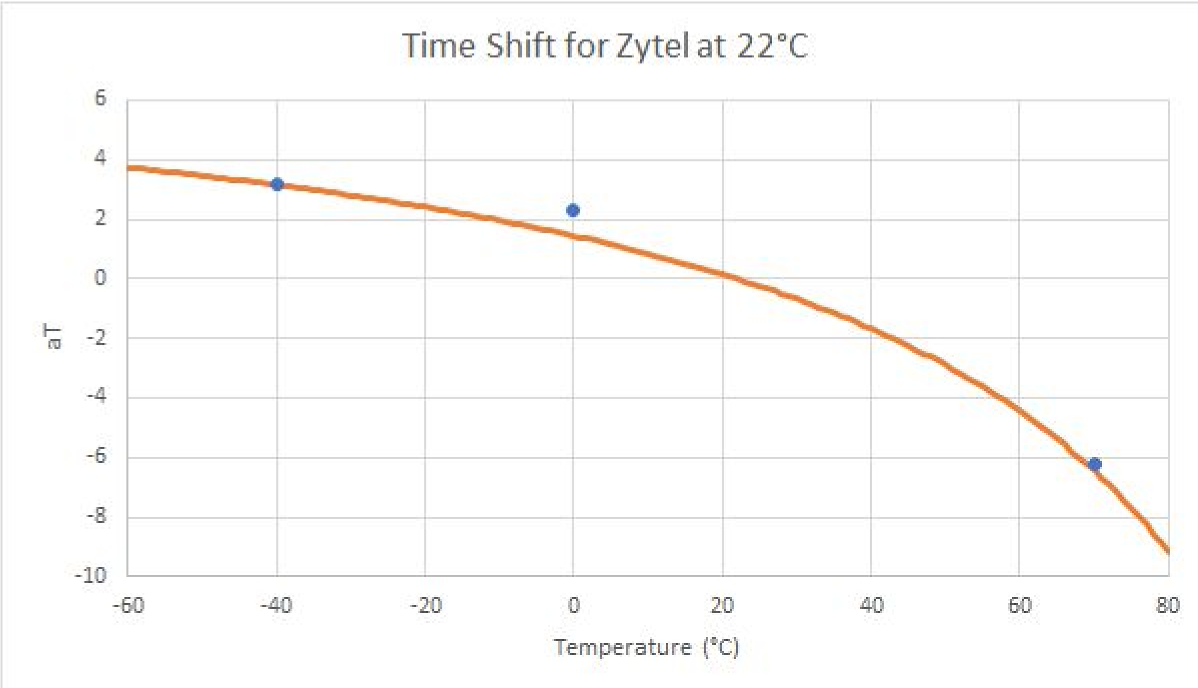
The table below shows the shift factor for the tests at -40°C, 0°C , and 70°C. As one can see, the shift factor for the first two tests, which were below the reference temperature, are positive and shifted to the left on the master curve. The opposite is true with the test at 70°C , which is negative and shifted to the right.

Table 2: Shift Factor for Each Temperature

Temperature (°C)	a_T at 22°C
-40	3.2
0	2.33
70	-6.19

With the shift factors calculated, we plotted the values and found the best fit for the data. Figure 4 shown below demonstrates the shift factor values we calculated for the three temperatures, as well as the line of best fit for the data.

Figure 4: This graph shows the time shift for Zytel at 22°C



The line of best fit for the data follows the WLF Equation which is shown below.

WLF Equation: $$log(a_T) = \frac{C_1(T - T_{ref})}{C_2 + (T - T_{ref})}$$

Our reference temperature was 22°C, and the best fit to our data resulted in C_1 = 9°C and C_2 = -115°C. The final modified equation to the best fit to our data is shown below.

Modified WLF Equation: $$log(a_T) = \frac{9\,(T - 22)}{-115 + (T - 22)}$$

With this equation, we can make predictions about the stress relaxation of the material at different temperatures. We will also be able to compare it to the other materials to choose the best fit to the design problem.

Part 2: Designing a Plastic Part Subjected to Stress Relaxation Conditions

IV. Discussion

Table 3: Table showing the percent relaxation of materials at four different temperatures.

Zytel	Temperature (°C)	-40	0	22	70
	% Relaxation	+2.18%	-13.95%	-7.29%	-10.20%
Celanex	Temperature (°C)	-80	0	40	65
	% Relaxation	0%	+3%	-23%	-26%
Ryton	Temperature (°C)	20	36	72	88
	% Relaxation	-3.6%	-33%	-34%	-63%

From the provided data and previous lab reports, we compared the stress relaxation values at different temperatures for the Zytel, Celanex, and Ryton materials. In general, as the materials approached their respective glass transition temperatures, the percent relaxation increased as the material deformed back to its original shape.

Table 4: Comparison of glass transition temperatures and modulus for all the materials tested.

Material	Tg (°C)	Modulus (MPa)
Zytel	80	11000
Ryton	88	186-190
Ultem	217	3580
Celanex	60.0	9200

If we did not know the time-dependent stress relaxation, we'd be looking for values with a high Tg and a high modulus. However, this is not enough to make a comprehensive decision, so further analysis is necessary.

Table 5: Maximum operating temperature for each material, so that modulus will not decrease 20% .

Material	Zytel	Ryton	Ultem	Celanex
Max. Operating Temp for 20% Modulus Decrease, (°C)	>70	27	20	~30-40

We hope to select the material with the best properties available, in this case the highest operating temperature such that there is no more than a 20% decrease in modulus. In general, these seem to be well below every material's glass transition temperature. These values were estimated through the percent relaxation values observed in table 3

In consideration of all the design choices of this problem, we believe Zytel is the best choice given its stress and strain properties, as well as its minimal stress-relaxation at operating temperature. Based on our discussions...

V. Conclusion

Under constant strain at 70°C, the material that would work best is Zytel. This conclusion was reached by comparing time dependent deformation, involving decreasing stress over time. From the project description of the resin-seal design problem, we required a material that is able to maintain its shape through cyclic operations at a certain temperature. In other words, we wanted to identify the material with the lowest percent stress relaxation (high percent would mean the seal, upon losing compressive force, changes shape and renders the seal useless.) and the highest modulus.

Though we were not able to physically conduct the material testing due to the unique circumstances of the 2020 Fall semester, dealing with lab data from previous years was useful in helping us carry out this analysis. Overall, this class served as a strong introduction into the vast world of polymers as well as enhancing our understanding of the material property choices that are made for various design problems. With these skills we have a solid launching-off point for more in-depth knowledge on polymers.

VI. Appendix

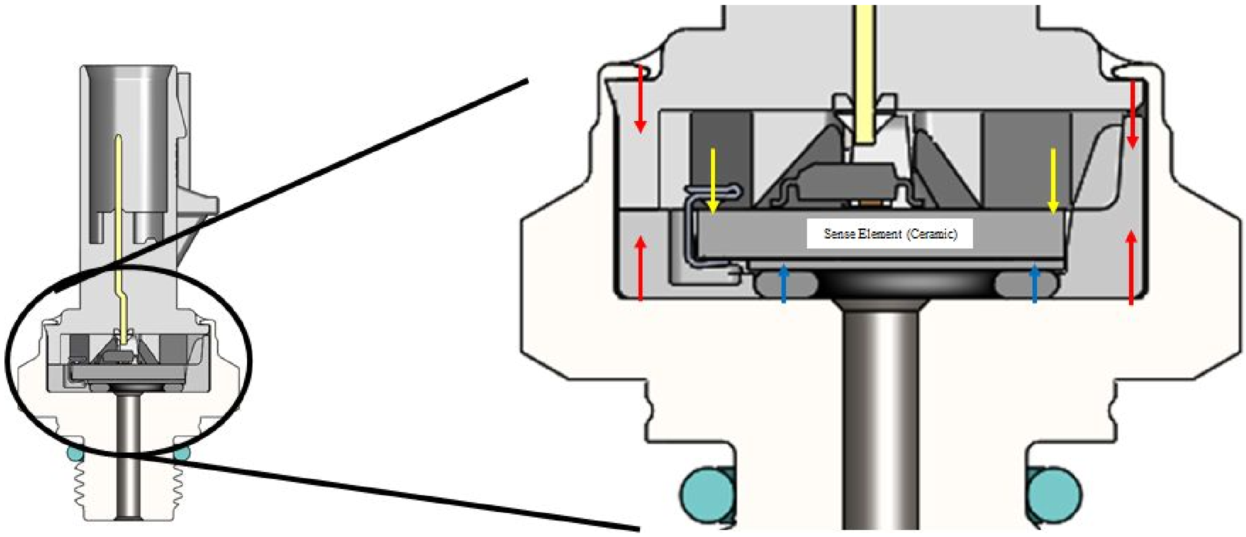


Figure 5: Crimped Stack Up for the Design Problem

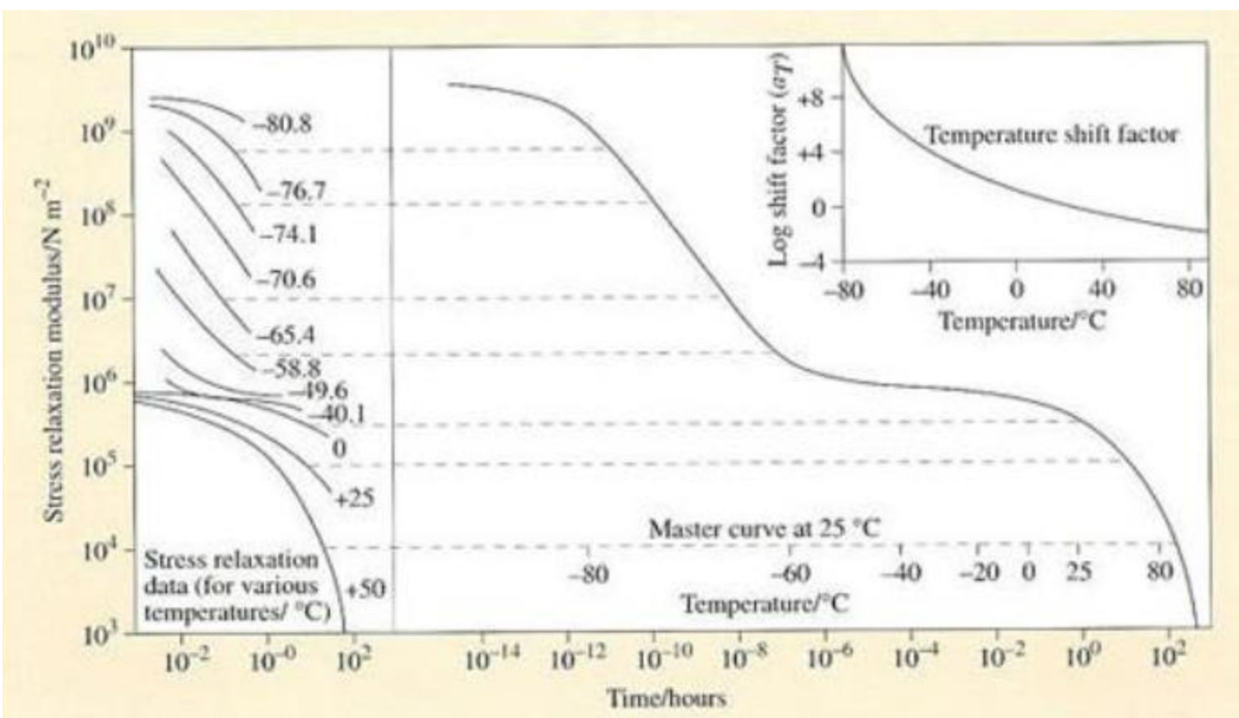


Figure 6: Example of a completed master curve as well as the shift factor.