Analysis of Linear & Viscoelastic Materials Using the Compression Test

submitted to
Amir Saeidi
Jack Ngo

by
Justin Couvrette
Kelsey Lawson
Liwen Yang
Xiangxi Yin

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Abstract: In this experiment, comparisons of the different behaviors between elastic and viscoelastic materials, alumina and nylon respectively, under compression are discussed. There are two nylon samples, one normal, the other soaked in water. Each sample has a constant load applied plotted on a stress-strain graph. The effect of strain rate regarding the deformation of elastic materials is unaffected whereas the deformation of viscoelastic materials is dependent on the changing strain rate. From the compression test, it can be concluded that the nylon samples are dependent on strain rate and can be classified under viscoelastic deformation unlike alumina not being affected by the strain rate making it deform elastically.

INTRODUCTION

Each material has a specific type of bonding that varies how the specimen will deform under applied loads. A material that can deform elastically, which allows the shape to be recovered after the stress is removed, allows the bonds to be stretched in the crystallographic planes. If the material has irreversible deformation, where the shape cannot return to its original form, it is known to be viscous. The deformation of viscous materials is time dependent unlike elastic materials. Materials can also behave in between these forms known as viscoelasticity. Throughout the experiment, comparisons between the elastic and viscoelastic behaviors of the materials are made.

Alumina, a ceramic known to show elastic behavior, and nylon, a polymer known to show viscoelastic behavior, are undergoing a compression test. The nylon sample has two various forms where one is classified as normal while the other has been soaked in water in order to determine if water has an effect on polymer viscoelasticity. Using the compression test machine, all of the samples underwent the same load in order to observe how each material behaves under constant strain under different strain rates. The effect of the strain rate on the deformation of elastic and viscoelastic materials were examined.

The alumina and the nylon samples had different strains with alumina at lower values and both of the nylon's above. These values of strain when plotted with stress confirms the behavior of deformation for each material with alumina showing elastic deformation due to the linear strain-stress line whereas both nylons showed viscoelastic deformation due to the curved stress-strain. When comparing just the two nylon samples, the water soaked nylon deformed more than the dry sample creating an assumption that water increases viscoelasticity. Two strain rates were used for each sample set yet, alumina showed little to no difference from the strain rates and both nylon samples had their data shifted depending on the strain rate.

BACKGROUND THEORY

Viscoelastic material exhibits both elastic and viscous properties when undergoing compression. The most extinct property of viscoelastic material is their time-dependent deformation. When viscoelastic material is compressed by an instant load, it deforms faster at the beginning and then gradually slows down. When the load is no longer applied, the material will not be able to retain its original shape. However, for elastic material, when applying an instant load, it deforms right away. When the load is no longer applied, they instantaneously retain their original shape. For polymers such as nylon, time-dependent deformation is due to the rearrangement of polymer chains which need time to break bonds and rearrange.

Viscoelastic property is also temperature-dependent. Nylon will behave elastically at low temperatures, viscoelastic at medium temperature, viscous at high temperatures. This is because the material's stiffness changes with temperature. In materials, an increase in temperature may increase the vibration of atoms, so the distance between atoms increases and reduces the force between atoms and the stability of bonds. This may cause the material's elastic modulus to decrease.[5]

Relaxation is the phenomenon in which the stress that develops in a body in constant distortion, temperature, and humidity conditions decreases over time.

THEORETICAL ANALYSIS

A stress–strain curve for a material gives the relationship between stress and strain. In this experiment, a total of two sets of experiments were set up. The first set was a compression test on three samples at a speed of 2mm / min, and the second set was a compression test on three samples at a speed of 4mm / min. In each set of experiments, there are three sets of samples, alumina, dry nylon, and wet nylon. The effect of water on polymer properties can be obtained by comparing the behavior between dry nylon and wet nylon. The comparison between alumina (elasticity) and nylon (viscoelasticity) can be used to find the difference between the behavior of elastic and viscoelastic materials under compression. Through the comparison of stress strain curves from these two groups of samples with different strain rates, the effect of different strains on different materials can be obtained.

PROCEDURE

In order to compare the difference between ceramics and polymers behavior during compression, compression tests were done on nylon and alumina samples. In order to find out the effect of water, 2 dry nylon and 2 wet nylon were prepared. Wet nylons were soaked in water for 3 days. In order to find out how strain rate could affect their behavior under compression, 2mm/min, and 4mm/min crosshead speeds were used.

There were 5 samples in total, 2 dry nylon, 2 wet nylon, and 1 Alumina. Since Alumina is elastic, it is reusable for both 4 mm/min and 2 mm/min compression tests. The aluminum sample had a height of 26.49 mm and 12.71 mm. Dry nylon samples had similar sizes around a height of 23.15 mm and 12.77 mm. Wet nylon samples had a similar size around a height of 24.03 mm and 12.73 mm.

The load limit of the machine was set to be 11 kN, and distance and load would be set to 0 at the beginning. After reaching this limit, the machine would stop.

RESULTS

Equations needed to calculate stress and strain:

$$\text{stress} = \frac{\text{applied force(N)}}{\text{cross-sectional area(m}^2\text{)}}$$

$$\text{strain} = \frac{\text{extension(m)}}{\text{original length(m)}}$$

Cross-sectional Area = πR^2

2 mm/ min compression test:

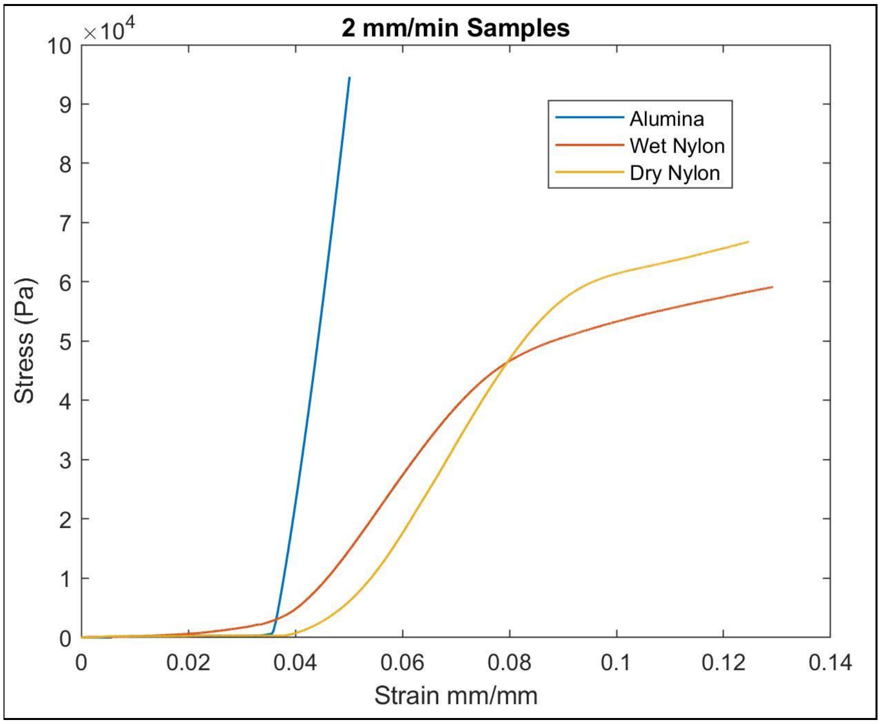


Figure 1: *It is a stress-strain curve for Alumina, dry nylon and nylon sample with crosshead speed 2mm/min*

- Sample Alumina:
  σ = load / 126.876e-6
  ε = displacement/ 26.49 mm
- Sample wet Nylon:
  σ = load / 128.68e-6
  ε = displacement/ 23.21 mm
- Sample dry Nylon:
  σ = load / 126.876e-6
  ε = displacement/ 24.05 mm

4 mm/ min compression test:

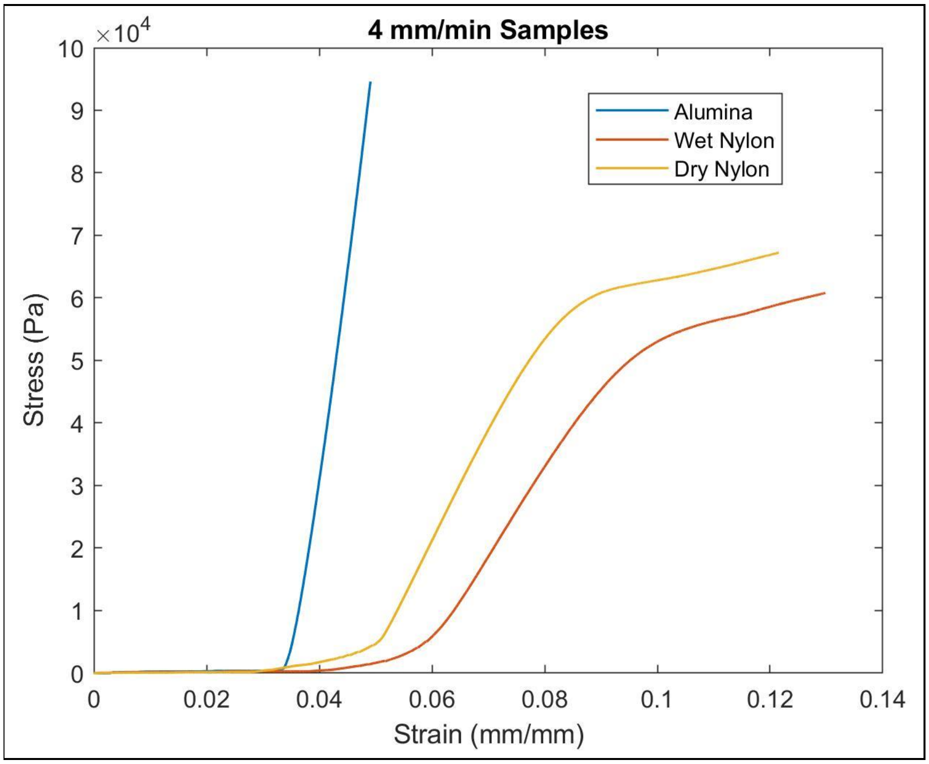


Figure 2: *It is a stress-strain curve for Alumina, dry nylon and nylon sample with crosshead speed 4mm/min*

- Sample Alumina:
  σ = load / 126.876e-6
  ε = displacement/ 26.48 mm
- Sample wet Nylon:
  σ = load / 127.676e-6
  ε = displacement/ 23.11 mm
- Sample dry Nylon:
  σ = load / 126.876e-6
  ε = displacement/ 24.68 mm

Dry nylons comparison:

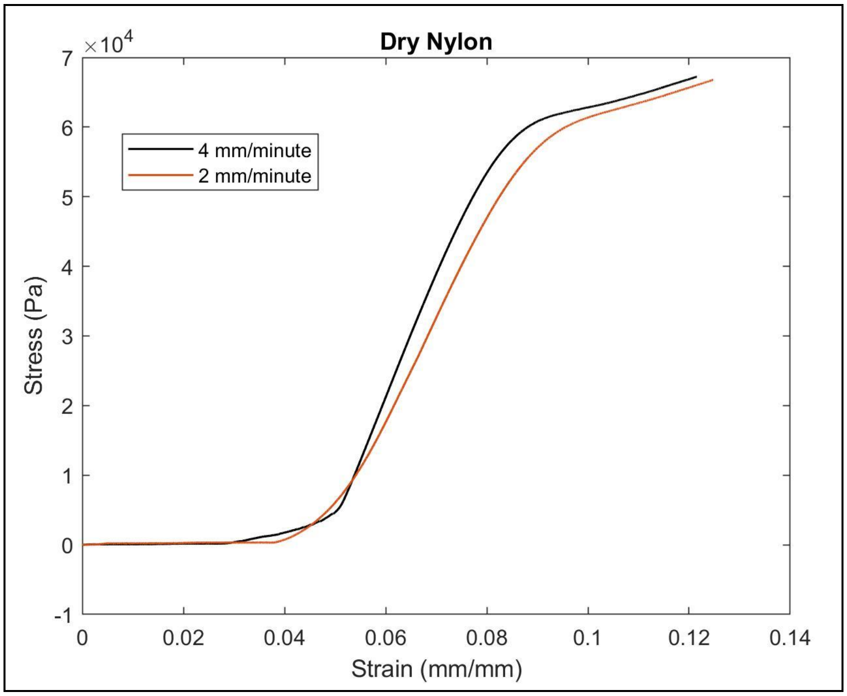


Figure 3: *It is a comparison of stress-strain curve of dry nylons at 4mm/min and 2mm/min strain rate*

Wet nylons comparison:

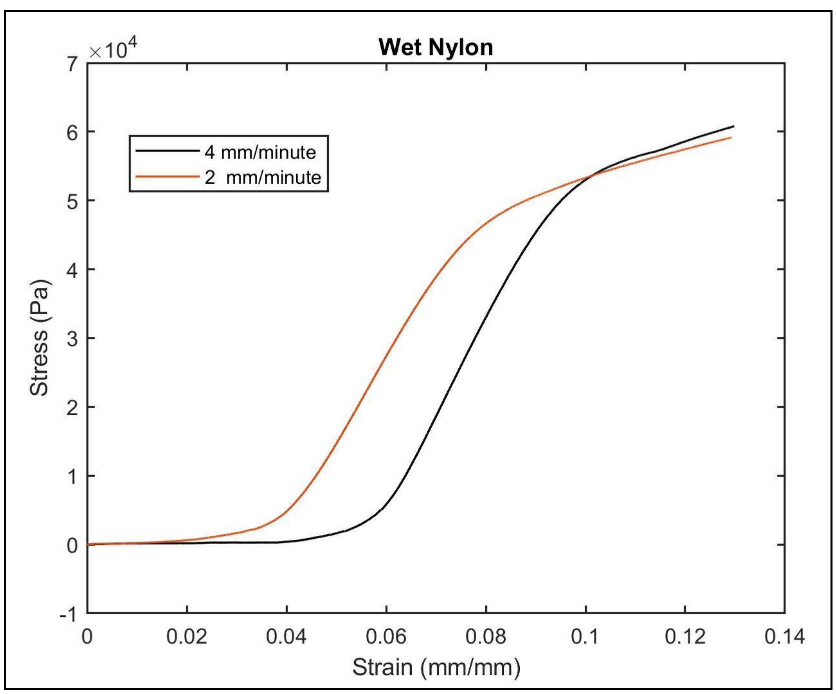


Figure 4: It is a comparison of stress-strain curve of wet nylons at 4mm/min and 2mm/min strain rate

Alumina comparison:

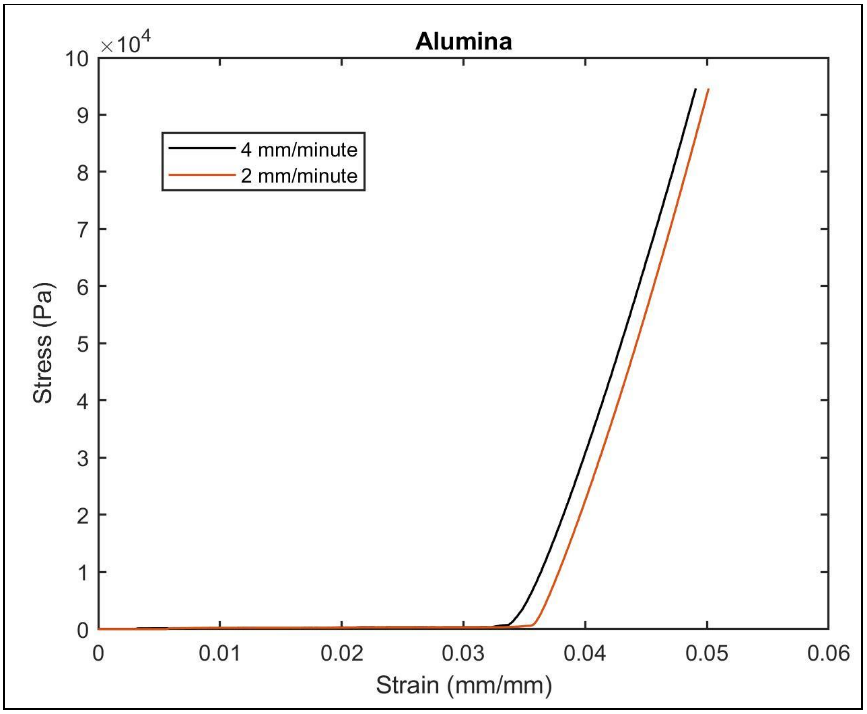


Figure 5: It is a comparison of stress-strain curve of alumina at 4mm/min and 2mm/min strain rate

DISCUSSION

The smaller strain a material obtains under a certain load, the less it deforms. This can be explained by the equation of strain which is equal to the change of length over initial length. The less the length change, the less it deforms. According to figure 1 and figure 2, when loading reaches its maximum value 11 kN, the alumina sample always has the lowest strain. Dry nylon always has a slightly lower strain than wet nylon. The reason why Alumina has a much lower strain among nylons is because the ionic bond in alumina has higher stability than the covalent bond and van der Waals force in nylon. When encountering a force, Alumina tends to stretch bonds along crystallographic planes. However, for nylons, polymer chains inside tend to break and diffuse to the sides. That also explains why at room temperature, Alumina is elastic material while nylons are viscoelastic material. Because the essence of viscoelasticity is because of rearrangement of atoms or molecules inside an amorphous material while the essence of elasticity is a result of bond stretching.

In addition, the reason why wet nylon deforms more than dry nylon under the same load is because the water content enhances the viscoelasticity of nylon. It is a result of water molecules forming new hydrogen bonds with the polymer which weakens the original van der Waals force. As a result, the stability of nylon decreases and the viscoelasticity increases.[3]

According to figure 3 and 4, samples compressed under crosshead speed 4mm/min always have a slightly larger deformation than samples with crosshead speed 2mm/min. The difference is very slight and seems not to affect the degree of deformation among nylons too much. While for elastic material Alumina, according to figure 5, the trend is completely the opposite. The 2mm/min strain rate caused a slightly higher deformation among the alumina sample. In order to find out what exactly causes the difference, more experiments are expected to be done.

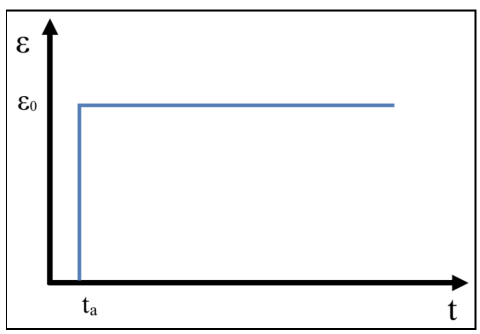
In the next experiment, an experimental group that can design strain rates with greater differences has verified whether the deformation behavior of dry nylon is affected by strain rate.

DISCUSSION QUESTIONS

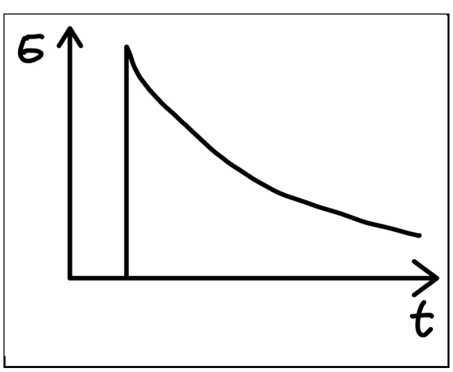
1. What is the effect of temperature on viscoelastic material?

The higher the temperature, the more viscous property the material will have. However, at low temperatures, the material shows more elastic property due to the increase in material stiffness.

2. In this experiment, we did a constant strain test, as shown in the figure below. Draw a σ- t curve that corresponds to this condition for a viscoelastic material.



The solution is drawn below:



3. How do you expect a nylon sample with a lower degree of polymerization, i.e. smaller polymer chains, behave under compression?

The smaller the polymer chain, the easier to break their arrangement of chains so the more viscous the material will be, and the faster it deforms.

CONCLUSION

According to the chart, under the same force, the elastic alumina sample has the lowest strain. An important feature to notice is that there is no stress relaxation in the alumina sample. This shows us that alumina is not a viscoelastic material. Nylon with viscoelasticity has higher strain than alumina under the same compression force. At the same time, wet nylon has a higher strain than dry nylon under the same load. The deformation of the polymer is affected by the strain rate, and the lower the strain rate, the higher the viscoelasticity. The deformation of elastic materials is not affected by the strain rate. Experimental results agree with assumptions.

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