

## NE 125 L

### Title Page

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## 1. Introduction

The purpose of this experiment is to learn how the basic mechanical properties of polymeric materials such as stress, strain, yield, elasticity, toughness, etc. are measured. In this experiment, we primarily focus on stress and strain. Stress is force applied per unit square of material and has units of  $\text{N/m}^2$  or Pa.

$$\sigma = \frac{F}{A} \quad (1.1)$$

Strain is the ratio between the change in length of the polymer sample and the initial length, that is:

$$\varepsilon = \frac{\Delta l}{l_0} \quad (1.2)$$

The concepts of stress and strain are key to the study of materials science and engineering because it helps us characterize different materials for different purposes. A tabulation of these stress/strain values for various industrial materials could provide us with valuable information when we seek a suitable material for a very specific application. For example, if we sought a material that had to be highly ductile for a particular industrial application, we could start with those materials that had an unusually high elongation at break. In other words, we could find out from our tabulated values which materials required a high amount of strain before they ruptured.

Tabulated values can depend on various other factors, namely temperature, humidity, cross-head speed, mechanism deformation, etc. In this experiment, we strive to determine if the cross-head speed at which the material is deformed has any relationship to the stress and strain parameters we're interested in.

The simplest way to measure basic mechanical properties such as stress and strain is to subject a uniform dogbone made of the desired sample—high density polyethylene, or HDPE in our case—to a load and to measure the corresponding increase in length. We then translate this data to stress and strain, which we then graph to determine the relationship between the two variables. During the course of this experiment, we assume the temperature to be constant at room temperature. We also assume the cross-sectional area of the dogbone to remain constant, although this is clearly not the case. Despite the fact that the individual dogbones could have had impurities in them, we assumed them to be identical and to have the same molecular weight and physical properties.

## 2. Materials and Equipment

1. Instron 3699 tensile testing system
2. Dogbone shaped polymeric material (HDPE)
3. Computer and data acquisition system
4. Precision calipers

## 3. Procedure

Prepare new dogbone samples using provided molds and pellets of high density polyethylene (HDPE). Measure the dimensions of each dogbone using the provided precision calipers. To decrease the effect of random error on the measurement, take the mean of 5 or more measurements. Label all dogbones and tabulate their dimensions beside their cross-head speeds. Insert the first dogbone into the Instron 3699 tensile testing system. Make sure the levers are fastened tightly and symmetrically across the dogbone neck. Feed the desired calibration requirements (eg. cross-head speed) into the data acquisition system. Begin the tensile test and record any observations until the dogbone breaks. Repeat the above steps for all remaining dogbones. Graph the data obtained from the acquisition system and discuss results.

## 4. Results

We imported the raw data from the computer-aided data acquisition system into Microsoft Excel for processing. The raw data provided us with the load and corresponding elongation that the polymer was subjected to. Our first task was to convert load and elongation to stress and strain respectively. We used equations (1.1) and (1.2) for this purpose.

For example, to calculate the stress and strain for dogbone 1 of dimensions  $12.8 \times 69.9 \times 3.0 \text{ mm}^3$  that was subjected to a load of 1.02 N and displayed a corresponding elongation of 16.7 mm, we proceed as follows:

$$\sigma = \frac{F}{A} = \frac{1.02}{12.8 \times 69.9} = 0.00114, \text{ and}$$
$$\varepsilon = \frac{\Delta l}{l} = \frac{16.77}{3.0} = 5.6$$

The results were plotted and the following graph (Figure 1 Relative Stress Strain Relationships) was obtained.

It is clear from the graph that there is an unambiguous relationship between the cross-head speed and the associated stress-strain graph. We discuss these relationships in the following section.

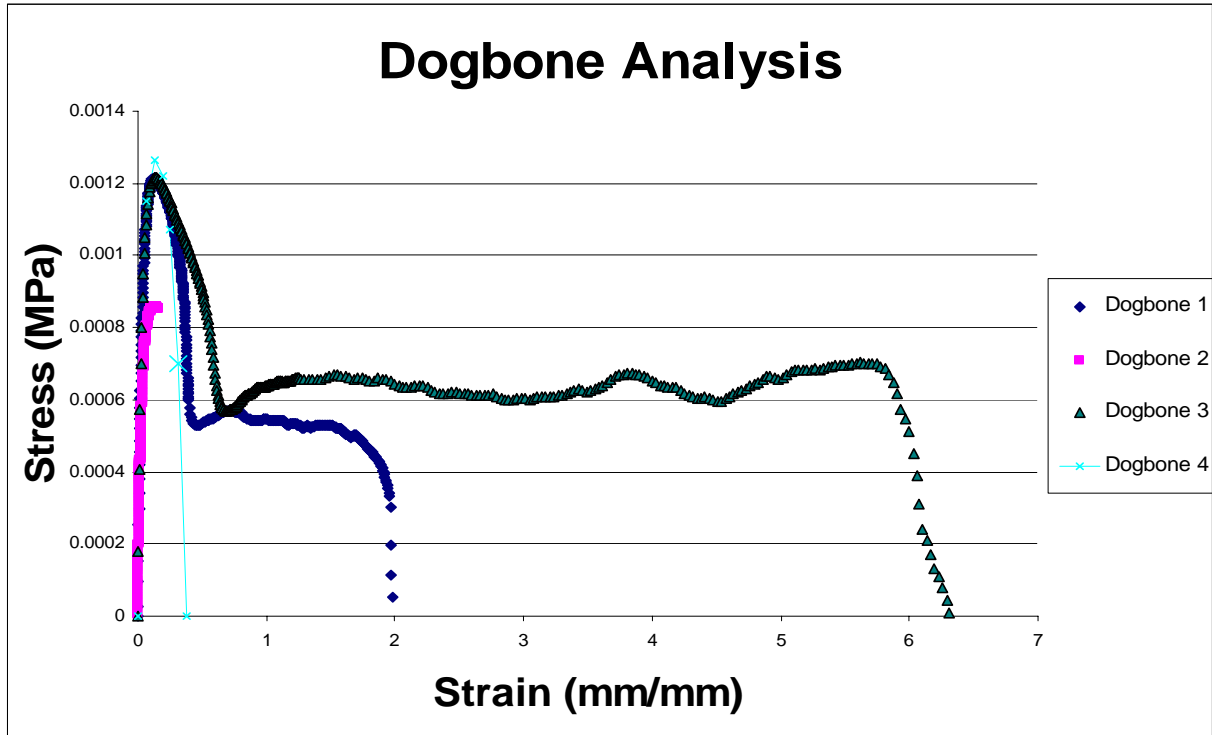


Figure 1 Relative Stress Strain Relationships

The cross-head speeds are summarized below.

Dogbone #	Cross-head speed (mm/min)
1	50.8
2	0.508
3	25.4
4	254

Table 1 Cross-head Speeds

## 5. Discussion

1. For the specimens tested, describe the stress-strain behavior, making use of the plots you prepared. Report all relevant parameters that you obtained from the tensile experiments.

For the specimens tested, different stress-strain behaviors were observed. The first dogbone was tested at 50.8 mm/min. The maximum stress observed by this dogbone was approximately 0.0012 MPa, which is comparable to the third dogbone (tested at 25.4 mm/min) where the maximum stress observed was also approximately 0.0012 MPa. In the second dogbone, there was a more striking proportionality observed between the stress and the strain. This observation can be used to conclude that since the molecules of the HDPE polymer had a more uniform deformation as they were given the opportunity to rearrange and realign themselves in the dogbone as it was being deformed. This phenomenon can be related to the cross-head speed of the tester (discussed in the following question). Lastly, the fourth dogbone underwent more rigorous deformation testing, and consequently experienced the maximum amount of stress out of all the four dogbones, but had the least elongation at break. We can thus conclude that HDPE has a very low resilience when subjected to high amounts of stress during a short interval of time.

Relevant parameters that affected the experiment, besides the applied stress (load) and strain were the orientation of the dogbone in the tensile tester and the temperature at which the experiment was carried out at. If the dogbones were not symmetrically inserted into the tester, the load would not be evenly distributed along the dogbone. The temperature parameter was controlled in the experiment (i.e., all dogbones were tested at room temperature). However, it must be noted that stress-strain relationships for identical materials with identical cross-head speeds would exhibit different characteristics at different temperatures.

Realistically speaking, random parameters such as air-bubbles and impurities in the solid will affect the tensile strengths; however, these parameters were not taken into consideration as they are difficult to quantify and investigate. Also, the assumption that the cross-sectional area of the dogbone remained constant throughout the experiment affects the results as this is not the actual case, but a mere simplification of the testing scenario. The graph obtained in Figure 1 Relative Stress Strain Relationships is thus the *engineering* strain curve and not the true strain curve.

2. *Compare the data for the HDPE at the different crosshead-speeds. Explain any trends that you observe.*

The crosshead-speed is elongation per unit time. This parameter is kept constant by varying the load applied to the specimen. This is achieved through a complex feedback loop that is implemented by the Instron Tensile Tester itself. Now, each HDPE dogbone was tested at different crosshead-speeds, resulting in different stress-strain data. The first dogbone had twice as fast crosshead-speed as the third one. This fact is reflected in our graph. Although both of them had the same tensile strength in the elastic region, the first dogbone displayed a catastrophic deformation at less than half of the strain as that of the third one. We consequently conclude that the maximum strain for deformation is inversely proportional to the crosshead speed.

In this experiment, there were some technical problems experienced with the second dogbone, because of which the testing procedure had to be altered. As a result, the data was not exactly as expected; however, the trial still revealed an insightful relationship between the crosshead speed and the stress-strain curve. The slow crosshead speed of 0.5 mm/min displayed no trail of fracture as displayed by dogbone one, three or four. However, this cannot be used to conclude any relationship between the stress-strain and the crosshead-speed because of the aforementioned technical error. Lastly, the fourth dogbone with the fastest crosshead-speed displayed the minimum strain and maximum stress. As emphasized previously, dogbone 4 had minimal resilience and hence broke the fastest.

## **6. Conclusion**

From the above results and following discussion, we have seen that the faster the cross-head speed, the less strain it takes to rupture the polymer. The resilience of the material, i.e. the energy required to move out from the elastic portion of the stress-strain curve is remarkably low with high cross-head speeds. Nonetheless, HDPE dogbones subjected to high cross-head speeds still displayed a slightly higher tensile strength. In other words, the quicker the polymer is stretched, the greater the force, but lower the energy required to move away from the elastic into the visco-elastic region.

More results were apparent upon further examination. The region of relaxation is strongly time-dependent (i.e. the cross-head speed). The smaller the cross-head speed, the more prevalent the relaxation period on the stress/strain curve.

Further analysis revealed that there was always a quick decrease in stress levels just before the material was about to rupture for all four dogbones. This could prove useful in industrial applications: sensors could be implemented to monitor stress levels. If the sensors detected sharp negative gradient in stress, it might be an indication that the material is about to rupture. Consequently, special precautionary measures can be taken in a timely manner.

We also noted that the stress/strain curves obtained above were only the engineering strains and not the true strains. We also assumed the cross-sectional area of the dogbones to be constant, which we know is not the case, especially for polymers subjected to slow cross-head speeds. In addition, this experiment did not allow us to test the effects of temperature, impurity or density on stress-strain curves. For instance, we could have used materials of different density, such as LDPE, polystyrene (PS) or ethylene-propylene-rubber (EPR) running at same cross-head speeds to observe the relationship between density and stress/strain.

Overall, the experiment was a success. We were able to discover new relationships between basic mechanical properties, in particular stress and strain. This helped reinforce our knowledge on mechanical properties and also provided insight into how scientific experimentation and testing was to be carried out.

## 7. Questions

1. The initial linear region of the stress-strain curve indicates the elastic deformation region. The slope of this linear region, called the modulus of elasticity or Young's modulus, is given by Hooke's Law [4]:

$$E = \frac{\sigma}{\epsilon} \quad (1.3)$$

2. Upon examination of Figure 2 Nominal Stress and Strain, we find that the modulus of elasticity isn't very high, the material ruptures just about the tensile strength, and the material exhibits a recognizable period of relaxation (curve in region 3). It is therefore quite evident that the curve belongs to a low density polymer such as low density polyethylene, or LDPE.

The total area under the curve represents the total energy absorbed by the polymer before rupture. The temperature of the polymer affects the behavior of the material under stress, dependant on what it is relative to the glass transition temperature ( $T_g$ ). Region number 1 represents the amount of strain that the polymer can withstand elastically, i.e. the polymer will return to its original orientation should the stress be removed.

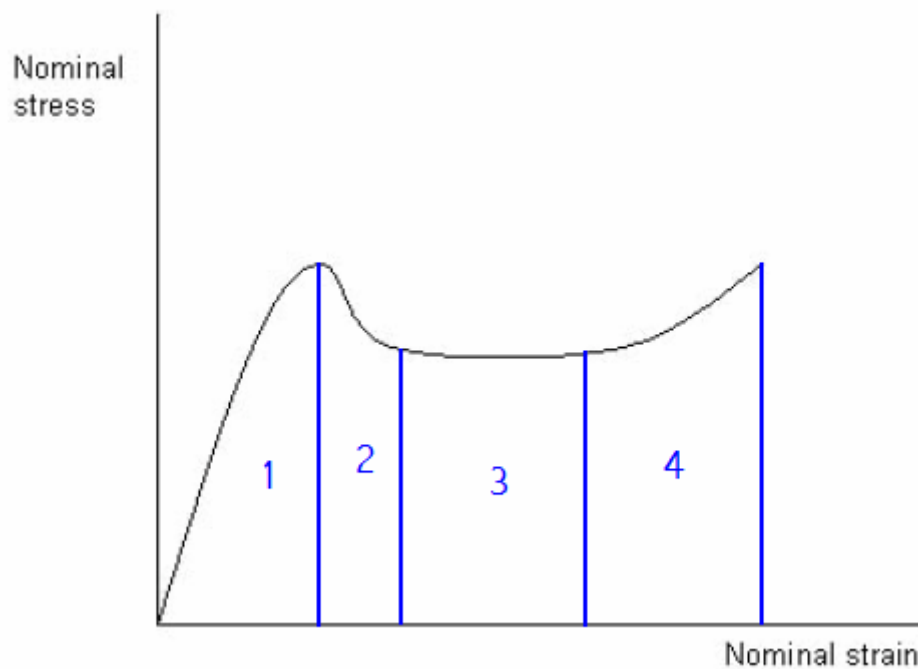


Figure 2 Nominal Stress and Strain

The first maximum of the curve represents the tensile strength of the polymer, between regions 1 and 2 of the curve. Here, the derivative of the curve would be zero, and the tensile strength would be equal to the y-value at this point. Region 2 is the visco-elastic region. Here, the polymer chains no longer possess any restoring forces. Region 3 could be where the polymer chains are rearranging themselves in order to brace for further stress.

The temperature of the polyethylene has some effect on the stress/strain data; in this case, it was above the glass transition temperature. When the temperature is high, there is more vibration among the molecules, and so it is harder to achieve van der Waals bonding. Van der Waals bonds are those which occur between two atoms when a temporary dipole is induced between them. This happens because the electrons surrounding each atom get attracted to the protons in the nucleus of the other atoms, and an momentary induced dipole moment is produced. When the polymer is above its glass transition temperature, the van der Waals forces are minimal (or less than they would be if the temperature were below the glass transition temperature). This gives the polymer chains the ability to rearrange themselves as per region 3.

A possible reason why there is a second rise in the curve could be that the sample is prepared to handle more stress after the rearrangement of the molecules in segment 3 of the graph. This newfound elastic property is displayed in segment 4. The end-point of the curve is where the polymer ruptures.

## 8. References

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