

University of Wales Trinity Saint David

School of Engineering

Rubber Properties

Kyle Edward Evans

2029909

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Material Properties and Introduction to Processing ACMA4000



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

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2 Introduction

Elastomers are polymers capable of stretching to great lengths before returning to their original form. I have been tasked with designing an experiment, exploring the material properties of an elastic band, and finding the stress-strain curve using the resulting data.

As implied by the materials name, the primary characteristic of an elastomer is its elasticity, and this is the result of the materials unique chemistry. Described in detail by (Callister Jr & Rethwisch, 2013), elastomers are composed of long cross-linked molecular chains that are twisted and coiled around one another. When the material is deformed due to a tensile load, these chains will partially uncoil and untwist in the direction of the stress, this can be witnessed by holding an elastic band and slowly stretching it outwards.

Common elastomers are known to have a low modulus, thus can experience a large and reversible strain in response to stress. However, “an elastomer under strain bond are not elongated and bond angles not deformed. Stretch of an elastomer depends upon rotation about bonds that is changes to dihedral angles.” (Shanks & Kong, 2013, p. 13). This suggests that the stretch of an elastic band relies on the molecular chains rotating and uncoiling as opposed to physically stretching and deforming, meaning that once fully uncoiled the material will reach its elastic limit and the chains will begin to stretch and eventually cause the material to fail.

This relates to the experiment as I will be incrementally stressing the elastic bands with a known weight until material failure, so it's important to understand the underlying chemistry and design the experiment with that in mind.

3 Experimental Method

Ultimately when designing the experimental method, I referred to a video of a similar experiment prepared by Chris Wyatt (2020). From the video I identified the main requirements for the experiment. First, method to attach and suspend the elastic band at a height, a way to apply tension to the band so that it will stretch, and finally a reliable measuring system.

Most of the materials used in the experiment were found around the house, and in the shed as leftovers from recent projects. As can be observed in figure 1, a length of wood was selected that was slightly longer than the width of the garden doorway, and an eye hook screwed into the centre of the length. Once lodged into the wall of in the garden, it provided a sturdy mounting point for the elastic band and the weights I intended to use.

The elastic band would then be slid onto the eye hook and attached directly to the 15-litre bucket by popping the handle free of the body and sliding the elastic band onto the handle. Given perfect weather conditions that would have been the entire setup, however on the day I decided to conduct this experiment it was raining heavily. To prevent the rain from affecting the experiment by adding additional unaccounted weight to the bucket, I lay a towel across the top of the wall and jammed an umbrella into the setup.



Figure 1 Budget Tensile Testing Setup (Kyle Evans, 2022)

Tension would be applied to the elastic band by adding weight to the bucket, I decided on using bottled water. It's what I had on hand at the time and provided an easy method to ensure I'm adding a consistent weight incrementally throughout the three samples.



Figure 2 Bottled Water Placed in Bucket (Kyle Evans, 2022)

One bottle of water would be added to the bucket at a time, and the length of the band measured using a measuring tape. This would then be typed directly into an Excel spreadsheet that I had opened on my phone to save some time, and this was repeated until the elastic band snapped. The experiment would then be repeated in its entirety to collect three sample data in total.

4 Results

4.1 Length/Tension Curve

Throughout the results I have combined the three samples into single graphs to save on room and to make it easier to compare the results against one another. Figure 3 is the length and tension curve, and it's clear that all the samples follow a similar pattern. The only real difference is the point of failure, with sample 1 failing at 9675 grams-force and sample 3 failing at 12825 grams-force. All three samples also exceed 450mm in length before snapping.

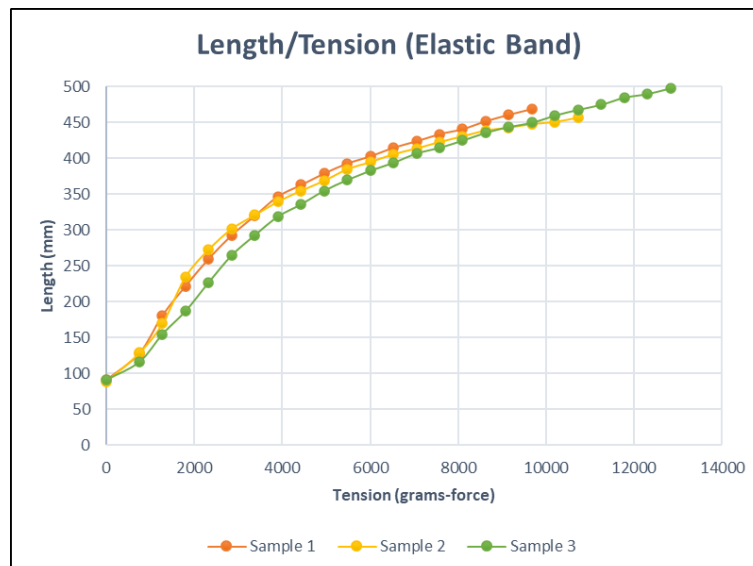


Figure 3 Length/Tension Curve (Kyle Evans, 2022)

4.2 Engineering Stress/Strain Curve

Looking at the engineering stress and strain curve in figure 4, it's clear that the curve starts off relatively straight until around 2.5 where it gradually morphs into a curve. The third sample was able to reach a stress level of 7.863 N/mm² and almost 4.5 times its original length, while the first sample fell short with 5.932 N/mm² and 4 times its length.

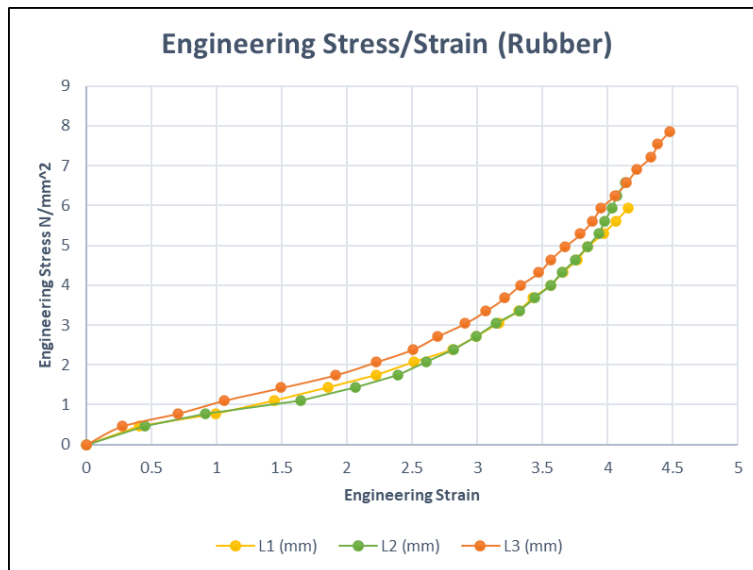


Figure 4 Engineering Stress/Strain Curve (Kyle Evans, 2022)

4.3 True Stress/Strain Curve

Compared to the previous curve, the true stress and strain curve reaches a much higher ultimate tensile stress with the third sample 43.032 N/mm^2 . The stress also increases quite gradually until it reaches a strain of 1 before rapidly increasing before the material fails between the 1.6 and 1.8 strain. Similarly, to the previous data, the largest disparity is between sample 1 and sample 2.

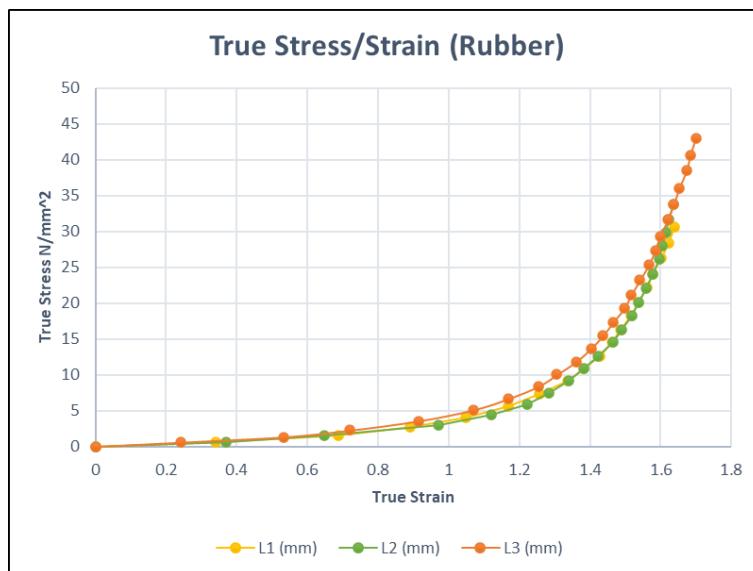


Figure 5 True Stress/Strain Curve (Kyle Evans, 2022)

4.4 Young's Modulus, Toughness, Mean, and Standard Deviation

The rest of the results have been combined into a single table for convenience, in table 1 the mean values and standard deviations for all the samples has been calculated along with the energy, volume, and toughness of the material.

As expected from the previous curves, the true ultimate tensile strength is much higher than that of the engineering strain stress curve. However, the standard deviation for the mean engineering UTS and the Young's modulus is significantly lower than the true UTS.

Toughness indicates how well a material can withstand impact without plastically deforming, therefore the higher the value the tougher the material. And considering the primary characteristics of elastomers, a high value is to be expected.

Total Energy	Total Volume	Toughness (N/m ²)
17.879	1456	12279.849
Mean Engineering UTS (N/mm ²)	Standard Deviation	Mean Stretch
6.790	0.983	4.25
Mean True UTS (N/mm ²)	Standard Deviation	
35.790	6.472	
Mean Young's Modulus (N/mm ²)	Standard Deviation	
2.348	0.134	

Table 1 Average Results (Kyle Evans, 2022)

5 Analysis of Results

5.1 Curve Analysis

Starting off with the length and tension curve, it's evident that as weight is added to the bucket the tension increases and so does the length of the elastic band. The material rapidly increases to 2.5 times its original length by the time it reaches 4000 grams-force worth of tension. After that the curve starts to level out as the molecular chains start to uncoil and untwist until they reach their linear limit and eventually causes the material to fail under the load.

Both stress and strain curves have behaved similarly to what was expected of an elastomer, they show that the material is capable of stretch many times their original length before breaking. And that the increase in stress is very gradual in response to a strain, there is no yield point to be observed in these graphs. Therefore, it can be assumed that if the elastic bands aren't stretched beyond ultimate tensile stress point, they will return to their original shape once unstressed.

The curves also exhibit behaviours of a highly elastic polymer when under stress, a brittle material would have suddenly fractured while deforming elastically. As mentioned by (Callister Jr & Rethwisch, 2013, p. 582), a plastic material would have entered a stage of elastic deformation before reaching a yield point and continuing to deform plastically before fracturing.

5.2 Table Analysis

To calculate the Young's Modulus, I first identified the linear region of the true stress and strain curve and isolated it to another graph. Then using the data points, a trendline can be formatted onto the graph to find the modulus, whilst I've used this technique in the past, I did have to remind myself by watching a video tutorial (The Complete Guide to Everything, 2021).

Since I repeated the experiment three times, I was able to find the mean and standard deviations from the results, for the former I used the built in excel function AVERAGE. This function will calculate the sum of the selected cells and divide the answer with the number of cells chosen. Then for the standard deviation I used the STDEV.S function, I chose sample variation of the function because I'm interested in characteristics of rubber not just these samples.

I was unsure of the differences between the two at first but according to (Statology, 2021) "You should calculate the sample standard deviation when the dataset you're working with represents a sample taken from a larger population of interest" which seems appropriate for this task.

The biggest benefit of setting up the Excel spreadsheet like this is that it is capable of automatically updating when cells are correctly referenced, so if I was to attempt this experiment in the future with a different setup then the same sheet can be used.

6 Analysis of Experiment

Overall, I believe that the experiment was a success, however it was not without its fair share of flaws and inaccuracies. Some of the problems I was able to identify during the experiment while others didn't occur to me until I began analysing the results and methods.

6.1 Health and Safety Considerations

Whilst planning and setting up the experiment I also took health and safety into consideration since the experiment would result in highly tensioned elastic bands snapping as well as a heavy bucket falling to the ground. The two main risks I identified was the bucket falling and impacting my feet, and the elastic band snapping and potentially hitting me in the eyes.

To minimise these risks, I attached a length of braided cord to the bucket, looped through the wooden bar and attached to the garden decking to stop the bucket crashing into the ground. Also, as can be seen in figure 6, the proper PPE was worn throughout the experiment, including a pair of safety glasses and steel toe capped boots that I use at work in the workshop.



Figure 6 Safety Glasses (Kyle Evans, 2022)

6.2 Performing the Experiment

During the experiment it occurred to me that the points of contact where the rubber band was mounted to the eye hook and bucket could be stress points, and upon inspecting the samples I noticed slight discolouration where they made contact and that's also where they eventually failed under tension.

I believe that the sample could be improved by better selecting a more appropriate form, and according to (TestResources, 2013), the most appropriate shape for tensile testing is that of a dog-bone as it promotes failure to occur in the mid-section. The bag of elastic bands I used included two distinct types, one that was taut and circular when unstressed while the other misshapen and clearly much larger than the first as can be seen side by side in figure 7. I made sure to only use one type of band during the experiment, namely the circular type as it seemed to be the most consistent.



Figure 7 Two Types of Elastic Bands (Kyle Evans, 2022)

6.3 Cost Versus Quality

This experiment was incredibly cheap to perform as I already had most of the materials and tools required on hand either in the home or in the garden shed. Overall cost of the project was £4.98, and that was for the 15-litre bucket and a bag of elastic bands. It was also quick to set up, disassemble, and easily stored away at the end since it only consisted of a length of wood and a bucket.

After completing the experiment, I realised that I never checked the elastic bands for dimensional consistency and doubted that they would be. Upon checking with a vernier calliper my suspicions were correct. There was upwards of almost half a millimetre difference between the widths and most certainly would have had an affect on the results, however I'm unsure as to whether it has had a large enough affect to warrant a change in product and could have been compensated if known beforehand.

7 Discussion

Given more time and money I would revisit both the sample selection, and the setup as a whole and aim for a more reliable, repeatable, and accurate experiment. Starting with the material, I would look at emulating the dog-bone specimen style used in professional tensile testing machines and fabricate jaws to securely clamp it into place during the experiments. According to (TestResources, 2013) these specimens are often manufactured using a cutting die, failing that I would investigate other methods like laser cutting and 3d printing.

As for the setup itself, I would most certainly investigate a better method of measuring the change in length rather than using a measuring tape. I would start off by looking at a way to constrain the bucket linearly and mounting a fixed rule to the assembly like how milling and drilling machines can be equipped with a depth feed scale. I believe this would be quicker to measure, more accurate, and potentially safer as there would be no need to get close to the elastic itself to take the measurement.

8 Conclusion

In conclusion, the results have shown a consistent similarity to the already established theory despite several flaws during the set up and conduction of the experiment. While the experiment could be improved, it was still capable of producing useful results and demonstrating properties of elastomers at a very advantageous price point that just about anyone could do for themselves at home without spending too much money or adapt to whatever they might have on hand.

9 Acknowledgements

First, I would like to thank my parents for allowing me to use the garden despite the wall being in dismay, and some concern over it surviving the experiment. And for lending me some of the materials and tools, like the bottled water to use as weights to tension the elastic band, and the kitchen scales used to weight the bucket and water.

I'd also like to thank my colleagues and employer for covering me in work and giving me the time and opportunity to pursue higher education, if it wasn't for them then I wouldn't be able to do this.

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