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School of Engineering

‘Rubber Properties

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BEng (Hons) Mechanical and Manufacturing Engineering

14-11-2022

Materials & Introduction to Processing (ACMA4000)

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1.0 Introduction

Properties of Rubber Experiment

The purpose of this experiment was to prove the theory of how the properties of an elastomer (in this case a rubber band sample) affect its behaviour under tension and also achieve data that will allow the output of an engineering stress-strain curve and also a true stress-strain curve. Using the stress-strain-curve the young's modulus and ultimate tensile strength can also be determined.

In this instance the chosen specimen of material was a common elastic band, these are mostly manufactured from vulcanised natural rubber but sometimes can be made from synthetic rubber. The testing methods used were placing the rubber band sample under tension using weight and gravity as the force.

"173 years ago, on 17. March 1845, the London industrialist Stephen Perry was granted the patent for the production of elastic bands from vulcanised natural rubber. Since then, he has been considered the inventor of the rubber band sample, although he benefitted from the work done previously by one of his compatriots" (Apropos, n.d.)

Rubber has a low young's modulus which gives it the ability to deform greatly in size compared to its original state when placed under tensile stress before reaching its yield point, which then leaves the material permanently deformed.

"What makes elastomers unique materials for engineering purposes? They combine a very low young's modulus with a bulk modulus which is about two thousand times greater and with an ability to deform elastically by several hundred percent before failure. Large deformations occur because of a long chain molecular structure which forms a network able to respond to deformation by changes in chain configuration instead of the stretching of molecular bonds (as occurs in a normal rigid solid)" (De & White, 1996)

Vulcanised rubber is made up of long molecular chains these chains are coiled up tightly in random formations which are occasionally bonded by covalent bonds, the bonds are improved by the vulcanisation process by heating the base material with sulphur. As the long molecular chains are pulled apart, they straighten and uncoil allowing the material to stretch, as they straighten further, they reach their limit and the material will harden before reaching its yield point and enter plastic deformation.

“Crosslinking is a process of forming a three-dimensional network structure from a linear polymer by a chemical or physical method. In the present review, only chemical methods which produce covalently bonded networks, i.e. chemical gels, are surveyed. The formation of network structure is one of the essential conditions for generating the elastomeric properties of rubbers. The crosslinking technique, therefore, is significantly important to rubber industries. It should be noted, however, that physical methods for the formation of network structures are equally important, especially in the field of thermoplastic elastomers” (Akiba & Hashim, 1997)

To prove these properties, a number of experiments were performed to place the rubber band sample under tensile stress, and data was observed and recorded in a spreadsheet to create a stress-strain curve. Using the data and the stress-strain curve it was possible to obtain young's modulus, yield point, and Ultimate Tensile Strength for the rubber band sample.

2.0 Experimental Procedure

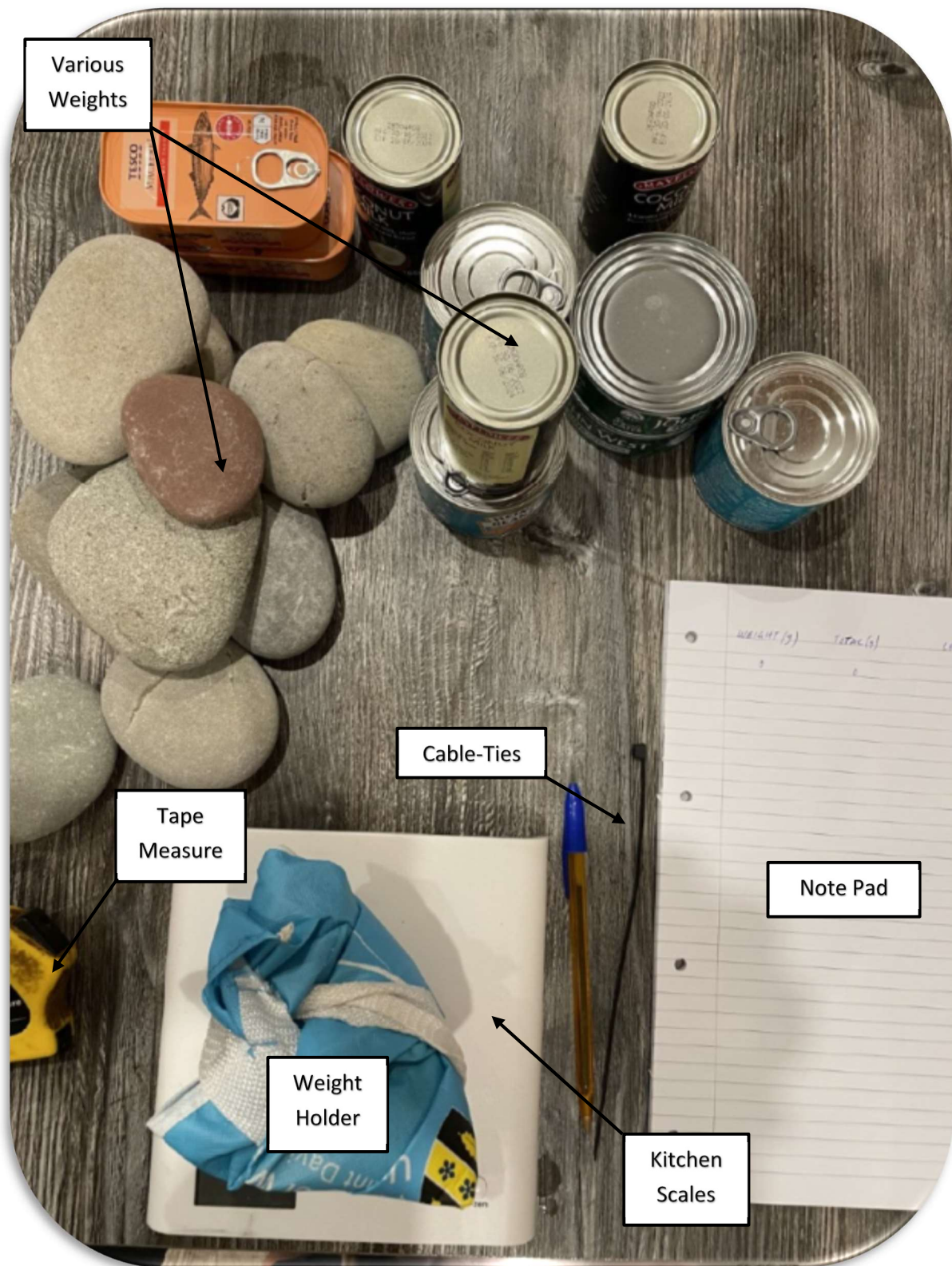


Figure 1

1. The length and cross-sectional area of the rubber band sample were taken and recorded using a tape measure (to achieve the cross-sectional area the sample was folded twice and measured, then divided by the number of sections).
2. Using a cable tie, the rubber band sample was fixed to an elevated chin-up bar located approximately 2.1m from ground level. (See figure 2)

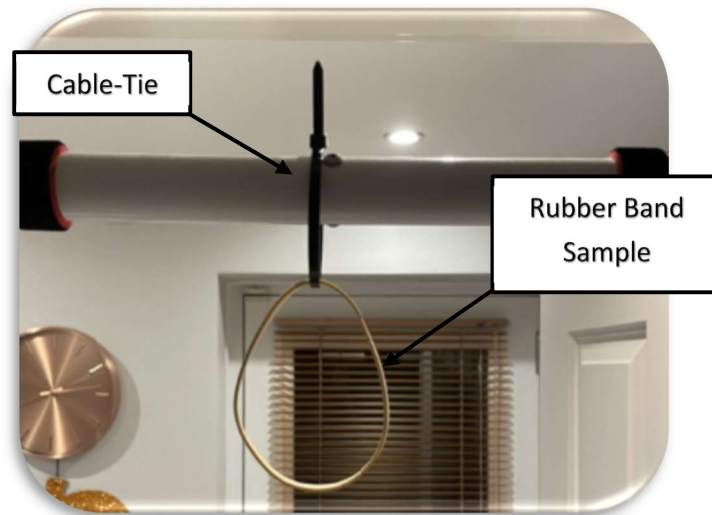


Figure 2

3. A weight holder was then weighed and recorded in a 2-column table of weight and length.
4. The weight holder was then attached to the rubber band sample using a cable tie. (See figure 3).

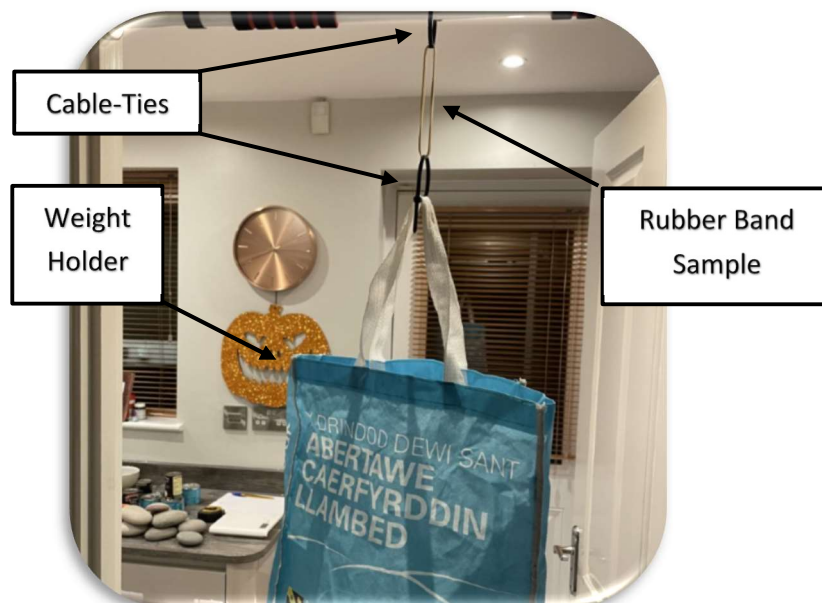


Figure 3

5. A crash mat was placed on the floor directly under the rubber band sample ready for the rupture point. (See figure 4)



Figure 4

6. The length of the rubber band sample was taken using the tape measure and recorded in the table adjacent to the weight of the bag.
7. A weighted object was weighed on the scales and recorded in the next row of the table, then placed in the weight holder.
8. The length of the rubber band sample was measured and recorded in the adjacent column to the weight of the last object placed in the bag.
9. Steps 7 to 8 were repeated until the rubber band sample ruptured.
10. Steps 1 to 9 were repeated twice more with 2 other rubber band samples similar in size to achieve mean and standard deviation from the 3 sets of results.

3.0 Results

Table 1 – Initial Raw data

Weight Added (g)	Total Weight (g)	Band 1 Length (mm)	Band 2 Length (mm)	Band 3 Length (mm)	Cross Sectional Area (mm) (ES)
0	0	125	118	116	15
70	70	127	120	118	15
200	270	133	128	127	15
200	470	145	146	138	15
200	670	155	163	154	15
165	835	168	181	168	15
165	1000	190	202	181	15
165	1165	211	222	197	15
125	1290	228	241	212	15
125	1415	241	255	226	15
132	1547	256	273	234	15
132	1679	272	291	248	15
295	1974	294	333	271	15
250	2224	301	357	293	15
322	2546	330	385	319	15
303	2849	352	423	354	15
376	3225	378	457	392	15
389	3614	405	480	412	15
459	4073	435	510	460	15
483	4556	477	533	480	15
556	5112	508	562	492	15
108	5220	513	568	512	15
476	5696	520	583	531	15
458	6154	536	593	552	15
457	6611	549	607	568	15
420	7031	Break	Break	580	15
830	7861			580	15

The initial results obtained were the raw data from the 3 identical experiments, these were the length of the rubber band sample alongside the weight added to the weight holder and the measurement of the cross-sectional area (this was achieved by folding the band over to give a thicker area to measure with the tape measure then divide by the number of sections) This data was tabulated in a spreadsheet using Microsoft excel. (Table 1)

Table 2 – Further data values

Weight Added (g)	Total Weight (g)	Force (N) (m*g)	Band 1 Length (mm)	Band 2 Length (mm)	Band 3 Length (mm)	Mean Length (mm)	STD Dev (mm)	Cross Sectional Area (mm) (ES)
0	0	0	125	118	116	119.67	3.858612	15
70	70	0.6867	127	120	118	121.67	3.858612	15
200	270	2.6487	133	128	127	129.33	2.624669	15
200	470	4.6107	145	146	138	143.00	3.559026	15
200	670	6.5727	155	163	154	157.33	4.027682	15
165	835	8.19135	168	181	168	172.33	6.128259	15
165	1000	9.81	190	202	181	191.00	8.602325	15
165	1165	11.42865	211	222	197	210.00	10.23067	15
125	1290	12.6549	228	241	212	227.00	11.8603	15
125	1415	13.88115	241	255	226	240.67	11.84155	15
132	1547	15.17607	256	273	234	254.33	15.96524	15
132	1679	16.47099	272	291	248	270.33	17.59419	15
295	1974	19.36494	294	333	271	299.33	25.5908	15
250	2224	21.81744	301	357	293	317.00	28.47221	15
322	2546	24.97626	330	385	319	344.67	28.87136	15
303	2849	27.94869	352	423	354	376.33	33.00842	15
376	3225	31.63725	378	457	392	409.00	34.41899	15
389	3614	35.45334	405	480	412	432.33	33.82635	15
459	4073	39.95613	435	510	460	468.33	31.18048	15
483	4556	44.69436	477	533	480	496.67	25.72072	15
556	5112	50.14872	508	562	492	520.67	29.9481	15
108	5220	51.2082	513	568	512	531.00	26.16614	15
476	5696	55.87776	520	583	531	544.67	27.47524	15
458	6154	60.37074	536	593	552	560.33	24.00463	15
457	6611	64.85391	549	607	568	574.67	24.14309	15
420	7031	68.97411	Break	Break	580	580.00	0	15
830	7861	77.11641			580	580.00	0	15

Using the raw data, further data was calculated:

$$\text{Force (N/mm}^2\text{)} = \frac{\text{force} \times \text{gravtiy}}{1000}$$

$$\text{Mean Extension (mm)} = \frac{\text{Sum of 3 lengt}}{3}$$

$$\text{Standard deviation of extension lengths (mm)} = \sqrt{\frac{\sum (X - \mu)^2}{N}}$$

Σ = sum of

X = each value

μ = mean value

N = Number of values

(Using excel, this can be calculated by using the function =STDEV.P)

Table 3 – Stress-strain values

Cross Sectional Area (mm) (TS)	Engineering Strain	True Strain	Engineering Stress (N/mm2)	True Stress (N/mm2)
15	0	0	0	0
14.75342466	0.016713092	0.016574965	0.04578	0.046545125
13.87886598	0.080779944	0.077682951	0.17658	0.190844123
12.55244755	0.194986072	0.17813453	0.30738	0.367314819
11.40889831	0.314763231	0.273656597	0.43818	0.576102953
10.41586074	0.440111421	0.364720486	0.54609	0.786430446
9.397905759	0.596100279	0.467563328	0.654	1.043849582
8.547619048	0.754874652	0.562397431	0.76191	1.337056546
7.907488987	0.896935933	0.640239918	0.84366	1.600368969
7.458448753	1.011142061	0.69870275	0.92541	1.861130975
7.057667104	1.125348189	0.753935643	1.011738	2.150295526
6.639950678	1.259052925	0.814945666	1.098066	2.480589209
5.996659243	1.501392758	0.91684768	1.290996	3.229288045
5.662460568	1.64902507	0.974191674	1.454496	3.852996368
5.207930368	1.880222841	1.057867667	1.665084	4.795812969
4.769707706	2.144846797	1.145765176	1.863246	5.859623214
4.388753056	2.417827298	1.229005056	2.10915	7.208710446
4.151888975	2.61281337	1.284486796	2.363556	8.539086719
3.832740214	2.913649025	1.364470193	2.663742	10.42495128
3.61409396	3.150417827	1.42320901	2.979624	12.36668457
3.447503201	3.35097493	1.470399942	3.343248	14.54638823
3.380414313	3.437325905	1.490051921	3.41388	15.14849816
3.295593635	3.551532033	1.515463887	3.725184	16.95529431
3.203450327	3.682451253	1.543821745	4.024716	18.84553648
3.123549884	3.802228412	1.569080063	4.323594	20.76288595
3.094827586	3.846796657	1.578318004	4.598274	22.28689905
3.094827586	3.846796657	1.578318004	5.141094	24.91783721

Using our data for mean length it was then possible to calculate the following:

$$\text{Engineering strain} = \frac{(\text{current length} - \text{origin length})}{\text{original length}}$$

$$\text{Engineering stress (N/mm}^2\text{)} = \frac{\text{force}}{\text{cross sectional area}}$$

$$\text{True strain} = \ln * (\text{current length} \times \text{original length})$$

$$\text{True Stress - Cross Sectional Area} = \text{original area} * \frac{\text{original length}}{\text{current length}}$$

$$\text{True Stress (N/mm}^2\text{)} = \frac{\text{force}}{\text{current area}}$$

4.0 Analysis

Analysis of Results

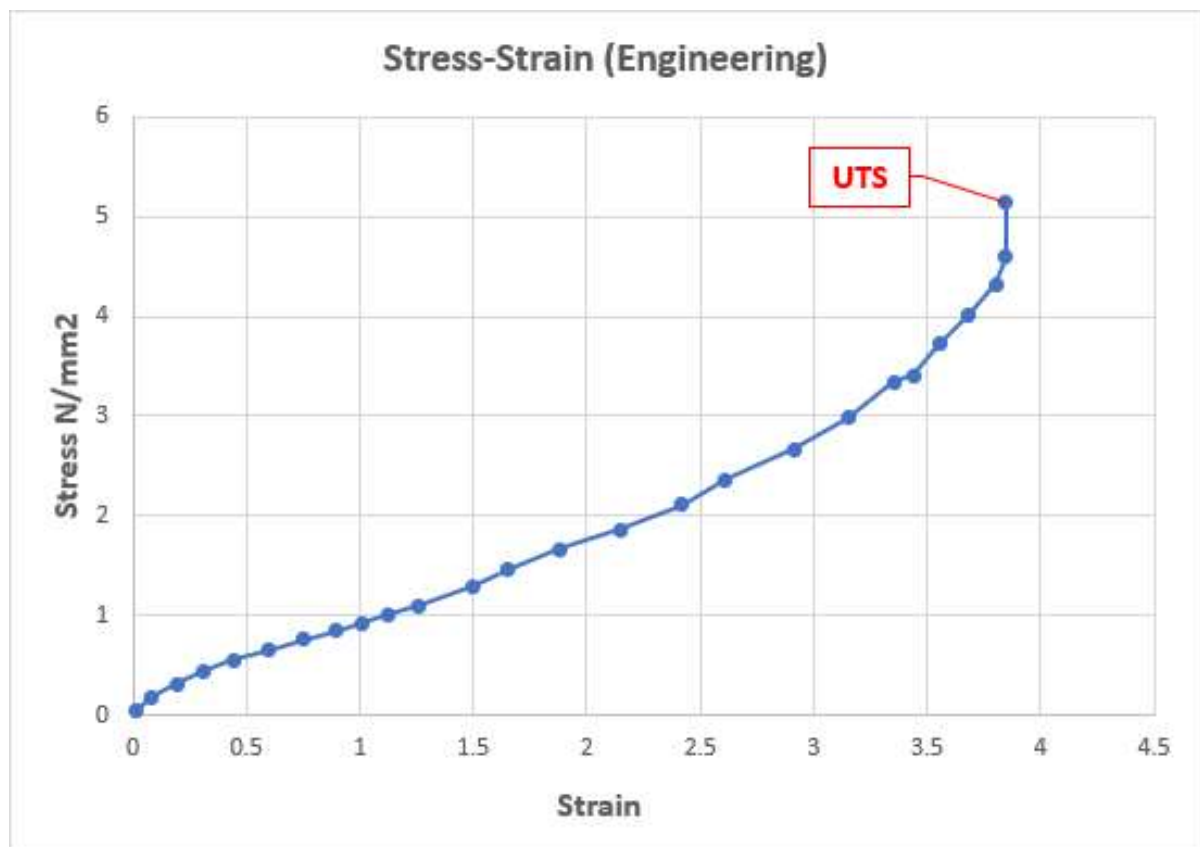


Figure 5

Analysing the engineering stress-strain graph (figure 5) we can see that the stress to strain ratio rises almost proportionally up to 3.41 N/mm², at this point the rubber band sample starts to tighten up as the stress goes up and the strain becomes less as more force is added, this can be seen as the trend line starts to steepen from 3.41 N/mm² up to the point of rupture at 5.14 N/mm², this is known as the UTS (ultimate tensile strength)

"If a material exhibits Hookean elasticity, it is said to obey Hooke's law, which states that the stress applied to an elastic material will be proportional to the strain produced in it" (Dunn, 2019)

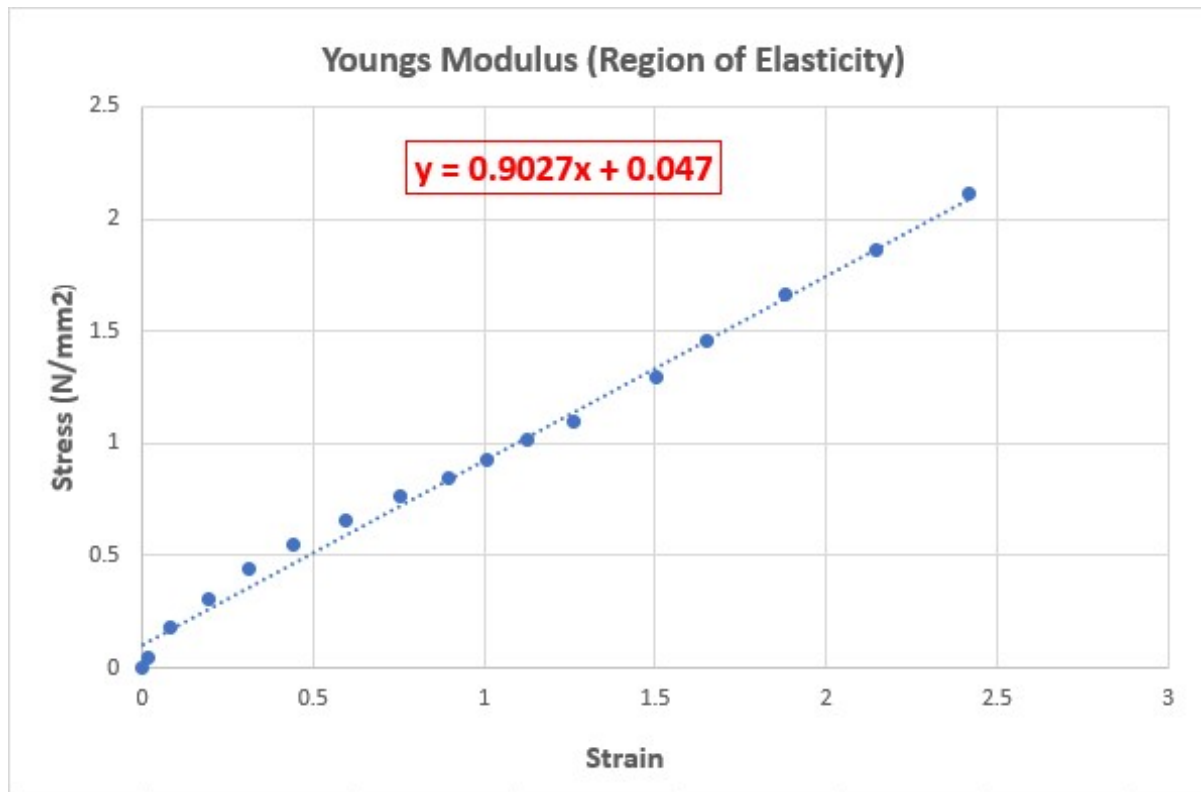


Figure 6

Using a graph of the initial apparent region of elasticity (Figure 6) a gradient of the results was added to the graph and the Youngs modulus could be determined at 0.9027 N/mm^2 ($0.9 \times 10^6 \text{ N/m}^2$)

This figure was obtained using Microsoft excel gradient line equation function. But can be calculated manually by using the formula $\frac{\text{stress}}{\text{strain}}$ in the gradient area of the graph.

Band 1 Increase %	Band 2 Increase %	Band 3 Increase %	Mean Increase %
439	514	490	481

Figure 7

Figure 7 shows the deformation percentage increase of the 3 rubber band samples and their mean extension figure of 481%

"Rubber has a low modulus of elasticity and is capable of sustaining a deformation of as much as 1000 percent. After such deformation, it quickly and forcibly retracts to its original dimensions" (Schaefer, /)

Standard Deviation

Looking at the standard deviation column in table 2, we observe that the 3 rubber band samples had varied reactions to the consistent forces applied, more so in the middle section of the table where the sample extension variation achieved up to 34mm from the mean value. This could be explained by a number of factors e.g., the bands had different levels of vulcanisation possibly coming from

different batches of material or possibly the bands being from an uncontrolled environment and may have been used/pre-stretched.

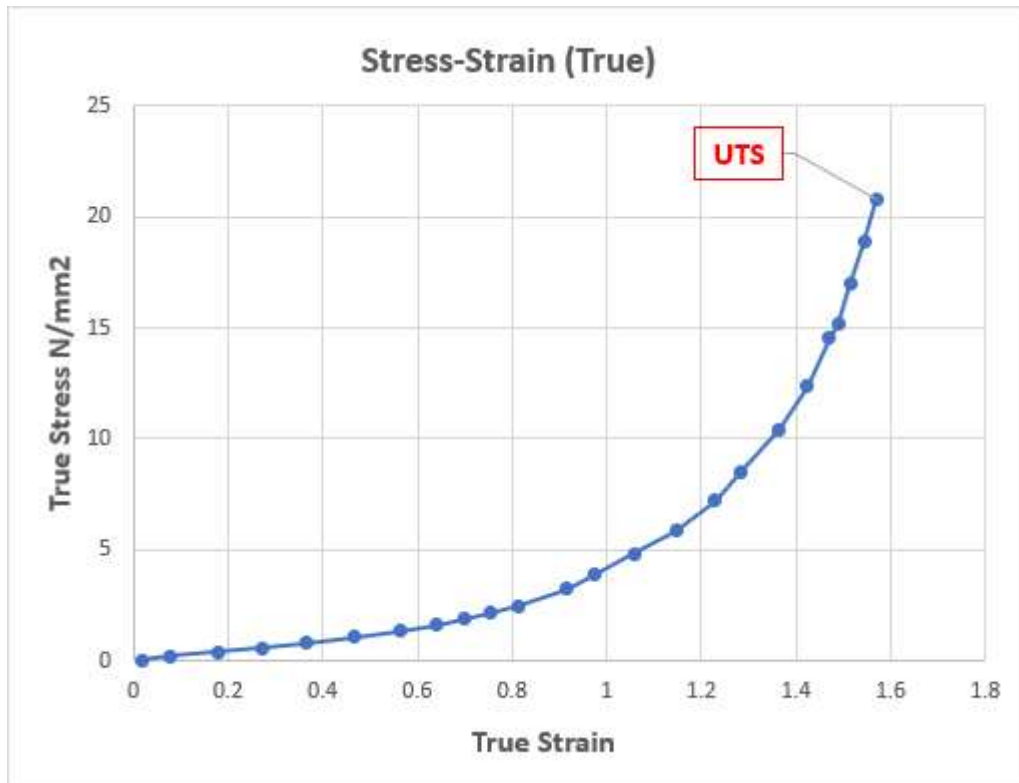


Figure 8

Along with the engineering stress-strain data, the values for true stress and true strain were calculated and a graph was produced to visualise the results (figure 8)

A true stress-strain curve is different to the engineering stress-strain curve, the cross-sectional area for engineering stress-strain curve is calculated using the nominal cross-sectional area of the sample at the start of the experiment, whereas the true stress-strain curve uses the current cross-sectional area of the sample as it narrows while strain is applied. Due to the difficulty of measuring the sample as it narrows the method for finding the cross-sectional area is to use the formula **original area** * $\frac{\text{original length}}{\text{current length}}$ this allows us to calculate the area based on the length extension ratio.

Comparing the graphs in figure 5 and figure 8, we can see the true stress-strain curve is much smoother, this is due to the area becoming smaller in proportion with the strain gradually until the material starts to harden and the strain becomes less as the stress goes up.

This can be attributed to the long chain molecules being closely coiled up at the start of the stretching and slowly untangling until they have straightened up and start becoming tighter due to cross linking of the long chain molecules.

A rubber band sample is commonly made from vulcanised natural rubber, this is where the original natural material has been cross linked using sulphur increasing the number of crosslinks adding to the strength of the material

“Vulcanization is the process by which the elastomer molecules become chemically cross-linked to form three-dimensional structures having dimensional stability” (Schaefer, /)

Another notable comparison can be made between the graphs in figure 5 and 8 is the UTS, this is considerably higher in the true stress-strain graph, this is because the engineering stress-strain graph does not take into account the decreasing cross-sectional area. Overall, there isn't a great deal of difference in the curves of both graphs for this type of material.

Analysis of Experimental Accuracy

On reflection the experiment was a low budget attempt, where quality was sacrificed for cost using all items that were on hand around the home, there are clearly a number of areas where the experiment setup would have slightly skewed the results even though it gave us a fairly accurate representation of both stress/strain graphs for the samples used.

Areas For Concern:

Cable Ties

The cable ties were not a suitable method for fixing the band to the elevated bar due to their shape, they created an area where the band was sat over a square edge on both sides on both ends of the sample and this would most likely create a cutting/shearing action or stress point on the band when the tension was increased. Also, they would have an element of flexibility in their material taking up a small portion of the load. This could have attributed to the sample rupturing before reaching its natural UTS

Weight Holder

For holding the weighted items, a recyclable bag for life was used, this was cumbersome to place weights in and out of and it was difficult to not pull the band into un-intentional tension or drop the weight into the bag creating momentum and stretching the band a little more than it would have, causing slightly more stress on the sample than in a controlled setting.

Rubber band sample

As the bands were found at home there was no way of knowing if any of the bands had been pre-stretched, suffered trauma or tampered with. Manufacturing defects could also be hidden in the sample.

Measurement

For measurement, a tape measure was used, this was only accurate to the millimetre and how accurate the observer's vision was, it would be easy to view the measurement from an angle and be slightly out of skew with the measurement.

For the cross-sectional area measurement, the sample had to be folded over twice to be measured then divided by the number of sections to get the most accurate measurement with a tape, leading to an approximate cross-sectional area rather than an accurate measurement.

During the experiment it became apparent that the band was still extending very gradually after the measurement was taken, this would have led to premature results for the strain

There were some variations in the results of the 3 different rubber band samples as shown in table 4:

Table 4 – Sample Variations

Force (N) (m*g)	Band 1 Length (mm)	Band 2 Length (mm)	Band 3 Length (mm)
0	125	118	116
0.6867	127	120	118
2.6487	133	128	127
4.6107	145	146	138
6.5727	155	163	154
8.19135	168	181	168
9.81	190	202	181
11.42865	211	222	197
12.6549	228	241	212
13.88115	241	255	226
15.17607	256	273	234
16.47099	272	291	248
19.36494	294	333	271
21.81744	301	357	293
24.97626	330	385	319
27.94869	352	423	354
31.63725	378	457	392
35.45334	405	480	412
39.95613	435	510	460
44.69436	477	533	480
50.14872	508	562	492
51.2082	513	568	512
55.87776	520	583	531
60.37074	536	593	552
64.85391	549	607	568
68.97411	Break	Break	580
77.11641			580

Even though the force added was consistent for each band, the bands extended to different lengths and band 3 withstood more force before rupture. These results confirm to us that although on the eye the bands look identical to the naked eye there are variations in the band properties at a molecular level.

Cost and Time

The time taken for the stress-strain graph experiment to be conducted 3 times in total was approximately 2 hours. There were no immediate costs associated with the experiment as all items used were already at home. Below is an approximate costing of the items if they were to be purchased outright:

Weights - Pebbles and tins of food products = £15.00

Rubber band samples - Selection Box of elastic bands = £2.00

rubber band sample fixing - Cable ties = £ 3.00

Weight holder - A bag for life = £ 1.50

Crash mat - household pillow = £10.00

Experiment improvements

With extra time and no boundary on budget, this experiment could have a number of improvements as outlined below:

Force Method

The most desired improvements would be the use of a dedicated tensile testing machine and purpose made samples. The samples could be put under strain in a controlled environment, where the strain/extension is controlled by the tensile machine. This would allow smaller increments of extension which in turn would lead to more accurate measurements and also measurements closer to the point of rupture. This method would result in the stress/strain graph to be flipped where the strain would change to the x axis, as this would now be the controlled unit.

Rubber Band Sample

Purpose made samples are already in use today, these have

dedicated fixing points at both ends with enough material to be able to clamp it in place, the middle section is a uniform width and thickness but smaller between the clamped areas to focus the stress in that area. These samples would ideally have been manufactured from the same batch of source material to minimise differences.



Figure 9 – Current Test Sample already in use for testing.

Image reference - [How to Test the Quality of Rubber? \(testing-instruments.com\)](https://www.testing-instruments.com/how-to-test-the-quality-of-rubber/)

Experiment Numbers

At a larger scale the experiment could be completed in higher numbers to gain a bigger range of average results accounting for any small variations found between the samples.

5.0 Conclusion

The principal task for this experiment was to produce 2 types of stress-strain graph for a chosen rubber sample. The final engineering and true stress-strain graphs produced gave insight into a number of properties of the samples used.

The samples displayed a low long modulus of **$0.9 \times 10^6 \text{ N/m}^2$** , this would be considered in line with the theoretical data for this type of material. The samples had an almost proportional stress-strain ratio allowing the material to deform largely in comparison to its original size.

The engineering stress-strain graph also showed us the rupture point of the material, also known as Ultimate Tensile Strength (UTS) the outcome for this value was **$5.14 \times 10^6 \text{ N/m}^2$** . It would be hard to standardise on this value, due to unknown variables in the samples used, these include size and chemical make-up. In comparison to the true stress-strain graph this was considerably lower due to the cross-sectional area used being the initial area compared to the length ratio based cross-sectional area of a true stress-strain graph.

The stress-strain graph method of displaying the properties of a material is useful for engineers and designers to choose materials for a particular part where yield strength, toughness, ductility & UTS would be factors in final choice of material.

The experiment method was crude and displayed limitations in many areas including measuring methods, facilities to add force to the band in a controlled manner and also human error. Utilising purpose made samples and a tensile testing machine would result in more accurate results and remove a large amount of the variation in data.

6.0 Acknowledgments

Evie-May Harris & Millie Harris assistance with raw data recording.

Maria Harris, use of kitchen area and food items for experiment.

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