Young's Modulus Investigation

AS Physics Coursework

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Introduction

This investigation aims to find the value of Young's Modulus for a specific material, in this case nylon fishing line.

Young's Modulus (E) is a measure of a material's stiffness, determined by the formula:

$$Young's\ Modulus\ (E)\ =\ Stress\ /\ Strain$$

The standard unit of measure for Young's Modulus is the pascal (Pa). 1 pascal is the same measure as 1 Nm^{-2} (Nm being Newton Metre).

A material always retains the same Young's Modulus value regardless of how much it is stretched or strained, and this should be revealed in this investigation by gathering a definite value of the modulus for nylon.

Hypothesis

Through research that I conducted before starting the investigation, I have determined that the correct Young's Modulus value of Nylon lies in the range 1-7GPa (the large range being due to different make-ups of Nylon with it being a compound). I should therefore be looking at achieving a final result within or very close to this range.

Since stress is proportionate to strain in the Young's Modulus formula, and the modulus value remains the same, I would expect the value of stress and strain to proportionally increase with each other.

Experiment Plan

In order to carry out this investigation into the value of Young's Modulus of nylon, I will conduct an experiment to gather the values of stress and strain when increasing force is added to the material, and will take readings as weight increases until the breaking point of the nylon is reached.

In order to calculate stress and strain, I will need to record each of the following variables throughout the experiment:

Force applied to the material (Newtons / N

Area of cross-section of the material (Metres-squared / m^2)

Original length also the material (Metres/m)

Also zero extension when the force is connected (Metres/m)

These variables will then allow the values of stress and strain to be calculated using the following formulas:

$$Stress \ = \ Force \ / \ Area \ (F/A)$$

$$Strain \ = \ Extension \ of \ Material \ / \ Original \ Length \ of \ Material \ (L/Lo)$$

This leads to a final Young's Modulus calculation formula of:

$$Young's \ Modulus \ = \ (Force \ / \ Area) \ / \ (Material \ Extension \ / \ Material \ Original \ Length)$$

$$E \ = \ (F/A) \ / \ (L/Lo)$$

The set-up I will be using to carry out this experiment consists of the nylon fishing line suspended from a stand using a clamp, and another clamp to ensure there is no movement in the stand itself. I will create a suitable loop at the bottom of the hanging material so that weights can be added but will need to ensure this loop does not weaken any area of the material and cause a drop in the breaking point value, as this would compromise the reliability of my experiment and result in premature breakage of the length of nylon.

At each stage of the experiment I will take readings of length using a standard 1m ruler, and will measure the area of a cross section by gathering the diameter value using a micrometer, halving this value to gather radius and then use the formula $Area = \pi r^2$

Before any weights are added, I will need to take a control measurement of the length and area of the nylon before any stress or strain is applied. Once this is done I will proceed to apply weight in intervals of 100g (0.981 N) and record the values of each variable stated at bottom of the previous page after each 100g weight is added, with the exception of original length which is a constant value and only needs to be recorded at the beginning of the experiment. I will continue to add weights until the material reaches its elastic limit and snaps, at which point I will record the force applied to break the object. In order to achieve an adequate number of results from each experiment to make a fair analysis and conclusion to the investigation, I will need to take a minimum of

eight readings (i.e the nylon should withstand at least 800g/7.849N). If this fails in the actual experiment then I will need to re-evaluate my plan and decide on a new method of conducting the experiment to meet this criteria.

To increase reliability, accuracy and to eliminate possible anomalous results, I will aim to repeat the entire experiment three times to gather average readings. If all three of these experiments were to be perfect then the final Young's Modulus value would be the same in each, so this will

be a good test of how much my investigation has suffered from error when I examine the range in the three values.

In my actual practical experiments, I have decided to measure Engineering Stress, as opposed to True Stress. As Engineering Stress does not take into account cross-sectional area changes, this will prevent me from damaging the nylon with repeated micrometer readings, and hence my values for area will always remain the same.

Technical List of Apparatus

- Nylon Fishing Line
- Manual Micrometer (accurate to 0.01mm with a range of 25mm)
- Standard Wooden 1m Ruler (accurate to 1mm)
- Clamp stand with clamp
- Set of Weights with hanging hook (in 100g/0.981N intervals)
- G-Clamp

Variables

In this investigation the variable I intend to be changed is the amount of extension of the piece of nylon, required to calculate the value for strain. Other unintentional variables will also be present in the experiment, notably the cross-sectional area of the nylon wire, which will decrease as more strain is applied and the material stretched. By calculating engineering stress, the effect of this variable can be negated.

Safety

Whilst the practical side of this investigation does not include any particularly dangerous apparatus or methods, there are still some safety considerations to be taken.
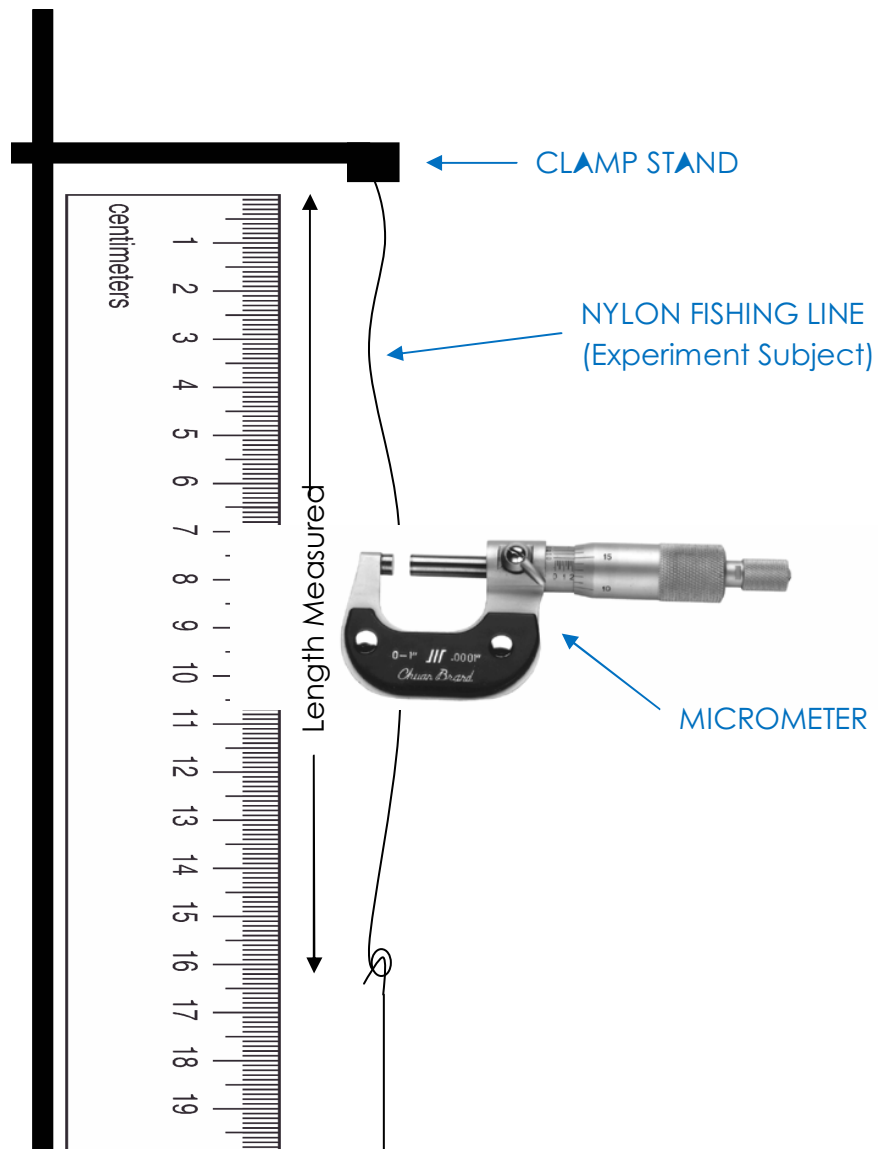
Eye protection will have to be worn whilst the nylon has stress and strain applied to it, as the material will be taken to breaking point, which could result in the material whipping back very quickly at this point, posing an eye damage hazard. It is also worth noting that at this point a substantial amount of weight will be dropping so arms and feet should be kept back from below the experiment and all persons in the vicinity should be on their feet to allow them to move back quickly if required.

Error Reduction

The practical side of this investigation is prone to errors through a number of factors. In order to attempt to reduce the number of errors that will affect the results of the investigation during the implementation of the practical, the following steps will be taken, in addition to the experiment being repeated three times as already mentioned above:

- Micrometer should be checked before each use to make sure it lies on the zero value when fully closed.
- Double-check all readings to be taken from the micrometer and ruler, and double-check the calculations for area on calculator.
- Nylon should not be interfered with once set-up on the clamp, in order to reduce added stress or weakening through factors not related to the intentional weights being added.
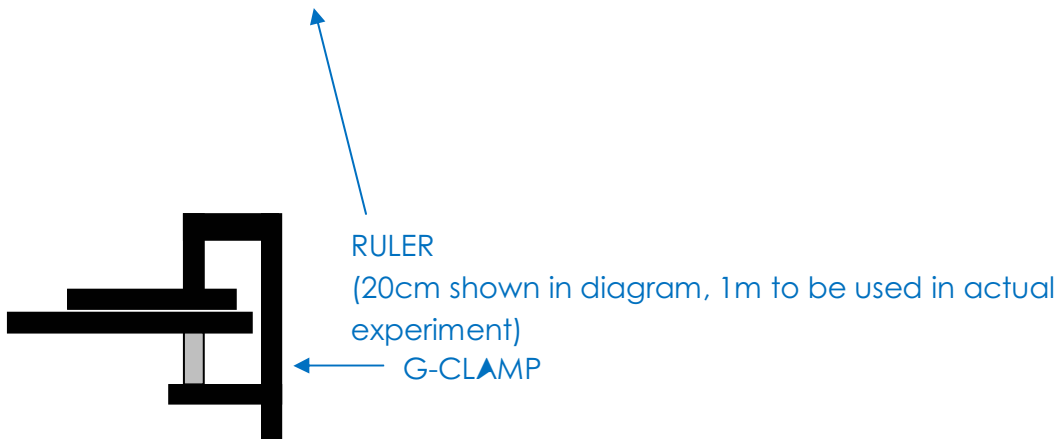
Apparatus Set-up Diagram

CLAMP STAND

NYLON FISHING LINE
(Experiment Subject)

MICROMETER

centimeters

Length Measured

RULER
(20cm shown in diagram, 1m to be used in actual experiment)
G-CLAMP

Table of Results – First Experiment

STRESS			STRAIN			YOUNG'S MODULUS (Pa) STRESS/STRAIN
Force (N)	Area (m^2)	STRESS (Pa)	L$_o$ (m)	Extension (m)	STRAIN	
0	2.69x10^{-8}	-	0.550	-	-	-
0.981	2.69x10^{-8}	**3.65x10^7**	0.550	0.011	**0.020**	**1.83x10^9**
1.962	2.69x10^{-8}	**7.29x10^7**	0.550	0.033	**0.060**	**1.22x10^9**
2.943	2.69x10^{-8}	**1.09x10^8**	0.550	0.047	**0.085**	**1.28 x10^9**
3.924	2.69x10^{-8}	**1.46x10^8**	0.550	0.059	**0.107**	**1.36 x10^9**
4.905	2.69x10^{-8}	**1.82x10^8**	0.550	0.064	**0.116**	**1.57 x10^9**
5.886	2.69x10^{-8}	**2.19x10^8**	0.550	0.075	**0.136**	**1.61 x10^9**
6.867	2.69x10^{-8}	**2.55x10^8**	0.550	0.084	**0.153**	**1.67 x10^9**
7.849	2.69x10^{-8}	**2.91x10^8**	0.550	0.089	**0.162**	**1.80 x10^9**
8.829	2.69x10^{-8}	**3.28x10^8**	0.550	0.102	**0.185**	**1.77 x10^9**
9.810	2.69x10^{-8}	**3.65x10^8**	0.550	0.106	**0.193**	**1.90 x10^9**
10.721	2.69x10^{-8}	**3.99x10^8**	0.550	0.110	**0.200**	**2.00 x10^9**
11.772	2.69x10^{-8}	**4.38x10^8**	0.550	0.115	**0.209**	**2.10 x10^9**
12.753	2.69x10^{-8}	**4.74x10^8**	0.550	0.121	**0.220**	**2.15 x10^9**
13.734	**BREAKING POINT**					

Region of Elasticity

Error and Uncertainty

Area: The micrometer used to measure the diameter of the nylon had an accuracy of 0.001mm, meaning there is an uncertainty of +/- 0.001mm to this measurement. With the measurement for the diameter being 0.185mm, this had a 0.54% level of uncertainty.

Original Length: Using a 1m ruler accurate to 1mm, and therefore an uncertainty of +/- 0.001m, the original length measurement of 0.550m has a 0.18% level of uncertainty.

Extension: This was measured with the same instrument as original length, meaning an uncertainty of +/- 0.001m. As the value for each extension differ, so will the percentage uncertainty. This ranges from 9% on the first measurement, to 0.83% on the final measurement of the extension.

Table of Results – Second Experiment

STRESS			STRAIN			YOUNG'S MODULUS (Pa) STRESS/STRAIN
Force (N)	Area (m^2)	STRESS (Pa)	L$_o$ (m)	Extension (m)	STRAIN	
0	3.00x10^{-8}	-	0.542	-	**-**	**-**
0.981	3.00x10^{-8}	**3.27x10^7**	0.542	0.009	**0.017**	**1.97x10^9**
1.962	3.00x10^{-8}	**6.45x10^7**	0.542	0.024	**0.044**	**1.48 x10^9**
2.943	3.00x10^{-8}	**9.81x10^7**	0.542	0.040	**0.074**	**1.33 x10^9**
3.924	3.00x10^{-8}	**1.31x10^8**	0.542	0.059	**0.109**	**1.20 x10^9**
4.905	3.00x10^{-8}	**1.64x10^8**	0.542	0.067	**0.124**	**1.32 x10^9**
5.886	3.00x10^{-8}	**1.96x10^8**	0.542	0.073	**0.135**	**1.46 x10^9**
6.867	3.00x10^{-8}	**2.29x10^8**	0.542	0.079	**0.146**	**1.57 x10^9**
7.849	3.00x10^{-8}	**2.62x10^8**	0.542	0.088	**0.162**	**1.61 x10^9**
8.829	3.00x10^{-8}	**2.94x10^8**	0.542	0.094	**0.173**	**1.70 x10^9**
9.810	3.00x10^{-8}	**3.27x10^8**	0.542	0.120	**0.221**	**1.48 x10^9**
10.721	3.00x10^{-8}	**3.57x10^8**	0.542	0.123	**0.227**	**1.57 x10^9**

Region of

11.772	3.00x10⁻⁸	**3.92x10⁸**	0.542	0.125	**0.231**	**1.70 x10⁹**
12.753	3.00x10⁻⁸	**4.25x10⁸**	0.542	0.129	**0.238**	**1.79 x10⁹**
13.734	**BREAKING POINT**					

Error and Uncertainty

See ~~Miscellaneous~~ section of explanation.

~~Area:~~ Uncertainty of ⁺/₋ 0.001mm. Diameter of 0.195mm, so uncertainty percentage is 0.5%.

~~Original Length:~~ Uncertainty of ⁺/₋ 0.001m. Length was 0.542m, so uncertainty is 0.18%.

~~Extension:~~ Uncertainty of ⁺/₋ 0.001m. Ranges from a length of 0.009m with 11% uncertainty, to a length of 0.129m with 0.78% uncertainty.

Table of Results – Third Experiment

STRESS			STRAIN			YOUNG'S MODULUS (Pa) STRESS/STRAIN
Force (N)	Area (m²)	STRESS	L₀ (m)	Extension (m)	STRAIN	
0	2.84x10⁻⁸	-	0.459	-	**-**	**-**
0.981	2.84x10⁻⁸	**3.45x10⁷**	0.459	0.013	**0.028**	**1.22x10⁹**
1.962	2.84x10⁻⁸	**6.91x10⁷**	0.459	0.02	**0.044**	**1.59 x10⁹**
2.943	2.84x10⁻⁸	**1.04x10⁸**	0.459	0.026	**0.057**	**1.83 x10⁹**
3.924	2.84x10⁻⁸	**1.38 x10⁸**	0.459	0.032	**0.070**	**1.98 x10⁹**
4.905	2.84x10⁻⁸	**1.73 x10⁸**	0.459	0.041	**0.089**	**1.93 x10⁹**
5.886	2.84x10⁻⁸	**2.07 x10⁸**	0.459	0.048	**0.105**	**1.98 x10⁹**
6.867	2.84x10⁻⁸	**2.42 x10⁸**	0.459	0.054	**0.118**	**2.06 x10⁹**
7.849	2.84x10⁻⁸	**2.76 x10⁸**	0.459	0.058	**0.126**	**2.19 x10⁹**
8.829	2.84x10⁻⁸	**3.11 x10⁸**	0.459	0.062	**0.135**	**2.30 x10⁹**

Region of Elastic

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9.810	2.84×10^{-8}	**3.45×10^{8}**	0.459	0.069	**0.150**	**2.30×10^{9}**
10.721	2.84×10^{-8}	**3.78×10^{8}**	0.459	0.072	**0.157**	**2.41×10^{9}**
11.772	2.84×10^{-8}	**4.15×10^{8}**	0.459	0.076	**0.166**	**2.50×10^{9}**
12.753	2.84×10^{-8}	**4.49×10^{8}**	0.459	0.082	**0.179**	**2.51×10^{9}**
13.734	2.84×10^{-8}	**4.84×10^{8}**	0.459	0.085	**0.185**	**2.61×10^{9}**
14.715	2.84×10^{-8}	**5.18×10^{8}**	0.459	0.096	**0.209**	**2.48×10^{9}**
15.696	2.84×10^{-8}	**5.53×10^{8}**	0.459	0.106	**0.231**	**2.39×10^{9}**
16.667	2.84×10^{-8}	**5.87×10^{8}**	0.459	0.114	**0.248**	**2.36×10^{9}**
17.658	**BREAKING POINT**					

Error and Uncertainty

See ~~previous values as or explanation.~~

~~Area:~~ Uncertainty of ⁺/₋ 0.001mm. Diameter of 0.19mm, so uncertainty percentage is 0.53%.

~~Original Length:~~ Uncertainty of ⁺/₋ 0.001m. Length was 0.459m, so uncertainty is 0.22%.

~~Extension:~~ Uncertainty of ⁺/₋ 0.001m. Ranges from a length of 0.013m with 7.7% uncertainty, to a length of 0.129m with 0.88% uncertainty.

Average values for Young's Modulus (GPa)

~~Calculated from region of elasticity only~~

First Experiment	1.42
Second Experiment	1.50
Third Experiment	1.66

Overall Average Value	**1.53**

Breaking point of the nylon (force in Newtons/N)

First Experiment	13.734
Second Experiment	13.734
Third Experiment	17.658

Mode Breaking Force	**13.734**
Mean Breaking Force	**15.042**

Graphs of Results from Experiments 1 – 3

To analyse my data and begin interpreting my findings from the experiments, I decided to plot of stress against strain values for each one.

The graph of each experiment can be found on the next three pages. Through research earlier in my project I am able to identify different areas of the graphs. These are identified in red on the graphs and a description of each is provided below.

Region of elasticity
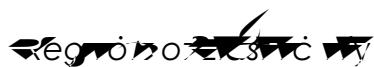
This region of the graph is identified as the part where the points most closely appear to form a straight line. This straight line (which I have plotted through 'line of best fit' method) represents Young's Modulus. Any force applied in this area will have a non-permanent stretching effect on the material, and the material will return to its original state when the force is released. This is the only part of the graph suitable for gathering the Young's Modulus value.

Strain-Hardening Curve

This region of the graph begins to form after the region of elasticity. At this point the material has begun to permanently deform and will no-longer return to its original point, however its strength is now increasing, as displayed by the reducing positive gradient of the curve plot. Again, due to inaccuracies and anomalies, this curve has been plotted through a 'best fit' method.

Maximum Strength

This is the point at which the strain-hardening curve reaches its peak point. It displays the maximum possible strength of the material. After this point the curve will begin to drop, representing the necking region and the approach to breaking point.

Breaking Point

This is the point at which the material has weakened to rupturing point and displays the stress required to break the material.

Analysis of the Graphs

The graph from the first experiment corresponded to what my research had told me that I should expect to find. There is a clear elastic region at the start of the graph followed by a strain-hardening region. I am lead to believe that in this experiment, the nylon ruptured early, as the curve appears to not quite make it to its true peak (the maximum strength of the material), and there is no visible necking region before the breaking point, which I would have expected to find.

There are many possible reasons for the premature breakage and it most likely lies down to a random error where the cause could not be documented, possibly a knock that the nylon received pushing it beyond its true rupturing point. The graph shows that the Young's Modulus region of the material occurs up to a force of around 3.924N (400g of weight).

In the first graph, most points have remained very close to the line of best fit, with the only anomalous result seeming to be the drop in a point at 2.91×10^8 Pa of stress, as the strain value seems too low for the trend of the graph. This was most probably a reading error, as no other results appear to be affected in this way.

The graph of the second experiment appears to show a very obvious error that has occurred after 2.94×10^8 Pa of stress was added, and this error has affected all further readings taken, as there is a large and unexplained jump in stress values from this point. The most likely reason I can predict for the error is a slight slip at the point where the nylon was clamped onto the apparatus, but there is no way to be certain why this happened. Nevertheless, there are similarities to the first graph, especially in the area which is of most importance to me, the elastic region. This again forms a clear straight line up to a weight of 400g was added before the trend line begins to curve, though not quite so obviously as with the first graph.

Since the jump in results was clearly an error, I have split my line of best fit to show a continuation of the curve through the four points that were affected by the error. With this practice applied to the curve, it is clear that it does in fact follow the same sort of trend as the first graph. Since the nylon also ruptured at 13.734N, as with the first experiment, and the lack of rupturing point, I can probably conclude that this experiment also ruptured early and the material failed to reach its maximum strength.

The graph of the third experiment again seems to present points towards the end which go against the research I had conducted earlier, displaying an increasing gradient at the end of the curve rather than the levelling off and necking region that I had expected. However, with the exception of these results, a very normal graph can be plotted that again clearly shows a region of elasticity where Young's Modulus is valid, followed by a strain-hardening region.

In this experiment, the nylon withstood a greater amount of stress before rupturing, however with still no necking region visible, I have to declare the results for breaking point inconclusive.

Closer Investigation of the Region of Elasticity

My graphs from the first three experiments have helped me to identify the region of elasticity of the nylon. This is the region from which I will be able to deduce my conclusions to this investigation by calculating the Young's Modulus value of the material.

The problem now encountered is that the straight line portion of my graphs contains only four point plots. To calculate Young's Modulus from just four plots could prove extremely inaccurate.

I have therefore decided to carry out one further experiment in which I will more closely examine the area of elasticity to get more points to plot and therefore greater accuracy in my final investigation conclusions.

My graphs indicate that the elastic region lies up to a force of 3.924N. I am therefore going to conduct an experiment very similar to that of the original ones, but applying weights in intervals of 10g (0.0981N) up until the end of the region of elasticity at 400g. This will allow me to the plot a final straight-line graph to calculate Young's Modulus with 40 points, allowing for much more accurate results and greater room for mitigating the effects of anomalous results.

Results – Closer Investigation of Region of Elasticity

STRESS			STRAIN			YOUNG'S MODULUS (GPa)
Force (N)	Area (m²)	Stress (Pa)	L_0 (m)	Extension (m)	Strain	
0	2.84×10^{-8}	-	0.340	-	-	-
0.098	2.84×10^{-8}	3.45×10^6	0.340	0.001	0.003	1.17
0.196	2.84×10^{-8}	6.90×10^6	0.340	0.003	0.009	0.78
0.294	2.84×10^{-8}	1.04×10^7	0.340	0.004	0.012	0.88
0.392	2.84×10^{-8}	1.38×10^7	0.340	0.004	0.012	1.17
0.490	2.84×10^{-8}	1.73×10^7	0.340	0.005	0.015	1.17
0.588	2.84×10^{-8}	2.07×10^7	0.340	0.005	0.015	1.41
0.686	2.84×10^{-8}	2.42×10^7	0.340	0.006	0.018	1.37
0.784	2.84×10^{-8}	2.76×10^7	0.340	0.007	0.021	1.34
0.882	2.84×10^{-8}	3.11×10^7	0.340	0.008	0.024	1.32
0.98	2.84×10^{-8}	3.45×10^7	0.340	0.009	0.026	1.30
1.078	2.84×10^{-8}	3.80×10^7	0.340	0.013	0.038	0.99
1.176	2.84×10^{-8}	4.14×10^7	0.340	0.015	0.044	0.94
1.274	2.84×10^{-8}	4.49×10^7	0.340	0.016	0.047	0.95
1.372	2.84×10^{-8}	4.83×10^7	0.340	0.017	0.050	0.97
1.470	2.84×10^{-8}	5.18×10^7	0.340	0.020	0.059	0.88
1.568	2.84×10^{-8}	5.52×10^7	0.340	0.022	0.065	0.85
1.666	2.84×10^{-8}	5.87×10^7	0.340	0.024	0.071	0.83
1.764	2.84×10^{-8}	6.21×10^7	0.340	0.024	0.071	0.88
1.862	2.84×10^{-8}	6.56×10^7	0.340	0.024	0.071	0.93
1.960	2.84×10^{-8}	6.90×10^7	0.340	0.025	0.074	0.94
2.058	2.84×10^{-8}	7.25×10^7	0.340	0.026	0.076	0.95
2.156	2.84×10^{-8}	7.59×10^7	0.340	0.029	0.085	0.89
2.254	2.84×10^{-8}	7.94×10^7	0.340	0.031	0.091	0.87
2.352	2.84×10^{-8}	8.28×10^7	0.340	0.032	0.094	0.88
2.450	2.84×10^{-8}	8.63×10^7	0.340	0.033	0.097	0.90
2.548	2.84×10^{-8}	8.97×10^7	0.340	0.033	0.097	0.92
2.646	2.84×10^{-8}	9.32×10^7	0.340	0.034	0.100	0.93
2.744	2.84×10^{-8}	9.66×10^7	0.340	0.037	0.109	0.89
2.842	2.84×10^{-8}	1.00×10^8	0.340	0.038	0.112	0.90
2.940	2.84×10^{-8}	1.04×10^8	0.340	0.039	0.115	0.90
3.038	2.84×10^{-8}	1.07×10^8	0.340	0.041	0.121	0.89
3.136	2.84×10^{-8}	1.10×10^8	0.340	0.043	0.126	0.87

3.234	2.84x10⁻⁸	1.14x10⁸	0.340	0.043	0.126	0.90
3.332	2.84x10⁻⁸	1.17x10⁸	0.340	0.044	0.129	0.91
3.430	2.84x10⁻⁸	1.21x10⁸	0.340	0.046	0.135	0.89
3.528	2.84x10⁻⁸	1.24x10⁸	0.340	0.050	0.147	0.85
3.626	2.84x10⁻⁸	1.28x10⁸	0.340	0.051	0.150	0.85
3.724	2.84x10⁻⁸	1.31x10⁸	0.340	0.052	0.153	0.86
3.822	2.84x10⁻⁸	1.35x10⁸	0.340	0.053	0.156	0.86
3.920	2.84x10⁻⁸	1.38x10⁸	0.340	0.054	0.159	0.87

Analysis of the Graph

As this experiment was conducted solely within the region of elasticity, the results taken form a straight line with constant gradient. This straight line represents the Young's Modulus value of the material.

By calculating a triangle of Δx and Δy, I can determine the Young's Modulus value of nylon from my graph. Δx represents a value for stress and Δy represents a value for strain.

The triangle of Δx and Δy, along with their measurements are shown on the graph. My calculations for the Young's Modulus value are shown below:

Stress:

$$\Delta x = (12 \times 10^7) - (3.55 \times 10^7) = 8.45 \times 10^7 \text{ Pa}$$

Strain:

$$\Delta y = 0.134 - 0.04 = 0.094$$

Young's Modulus:

$$\Delta x / \Delta y = (8.45 \times 10^7) / 0.094$$

$$= 9.0 \times 10^8 \text{ Pa}$$

$$= 0.9 \text{ GPa}$$

My calculated final value for Young's Modulus is therefore 0.9 GPa. This is the value that I would obtain by plotting any size of $\Delta x / \Delta y$ triangle on my straight line graph as it is a constant value.

Conclusion

I have determined through this investigation that the nylon tested in my closer experiment of the elastic region had a Young's Modulus value of 0.90GPa. This is however a disputable result, as my original three experiments showed an average Young's Modulus value in the elastic region of 1.53GPa, and my hypothesis predicted that the value should at least have been around the 2GPa region.

Having fully examined my results and techniques I am still unable to provide an explanation for this strangely low value for Young's Modulus, and as such would have to say that this is an inconclusive result. I cannot for certain say that there has been an error, as any error appears to have been random and untraceable, but I am also in no position to fully confirm that this value is the true correct Young's Modulus of the nylon that I tested.

I have also determined through this investigation that the mean breaking point of the nylon was at a force of 15.042N. It should however be noted that my graphs all seem to suggest earlier breaking points occurred than should perhaps have been expected, and also that the modal average breaking point was much lower at 13.734 due to two premature breakages.

Evaluation

This investigation has successfully provided me with the values I aimed to obtain at the outset, however there are some questionable results and values that may have been the result of errors in my experiments, meaning that this is an essentially inconclusive investigation that will require further work to confirm my conclusions and obtain more reliable results.

Errors, Anomalies and Technique

- ~~Accuracy~~

    Since this experiment relied mostly on human eyesight for the reading of values there is a good chance that inaccurate values and errors have at some point been recorded. The naked eye is very vulnerable to mistakes in readings and misperceptions of values.
    The experiment also relied heavily on human involvement when applying weights to the nylon and keeping the nylon from being interfered with. If weights were to be applied too aggressively and/or the nylon accidentally knocked, there is a chance of the readings from that point suffering from error. This is especially important when considering the point at which the nylon ruptured on each occasion, as it may have been weakened through human intervention at some point in the experiment.

- *Significant crossovers*
    These are points in the investigation that, should an error occur at this point, would seriously affect the entire outcome of the investigation or experiment.

Probably the most significant point where an error could have been made was the measurement of cross-section area. Not only was this a very small reading for diameter, but having this value then reduced further when converted to radius in meters, and then squared, means that the final value for area could suffer significantly from error.

Also notable here is the reading for original area, which is only measured once, and therefore if read wrong, would seriously affect the entire set of values for strain in that particular experiment's results with a systematic and repetitive mistake.

- Variation in recordings

The breaking point of the nylon should always have been the same value. Whilst the first two experiments broke at the same point, the third experiment took much more weight before breaking. This clearly highlights an error in one set of results. It would seem to suggest that the two experiments with low breaking points suffered from error and therefore means that my results for the value of breaking point suffer from a very high level of uncertainty.

- Anomalous results

In general, the effect of anomalous results on this experiment was very limited. Enough readings were taken in each experiment to clearly highlight where anomalies had appeared, allowing these values to be discounted and therefore not influence any results or averages where applicable. Any anomalies that were found tended to be small and insignificant, with no huge deviations from the trend of results.

- Experimental technique

Using a manual wooden ruler, accurate only to 1mm, left large room for error when taking readings in the experiments. The layout of my apparatus in general also created reliability problems, as I had to make sure I was perfectly level with the bottom of the nylon thread to take an accurate reading, and with the amount of readings being taken it is likely that there was a mistake made during this process at some point.

Some parts of the experiment however used better technique, for example the micrometer which was accurate to 0.001mm provided very accurate results of the reading for diameter which means my cross-section area values are of good reliability.

Suggestions for Improvement and Further Work

Since my values for Young's Modulus proved to be questionable, I would suggest that further investigation needs to be carried out in order to achieve a more conclusive result.

It would be a good idea to repeat the investigation of the elastic region two more times so that greater accuracy can be achieved by calculating an average final value from the three experiments.

The experiments all seemed very vulnerable to sources of human error and so in future investigations I believe the set-up and technique needs to be adjusted to reduce the reliance on human measurements and contact with the nylon.

Upon obtaining a more reliable conclusion for the nylon investigation, I would also suggest expanding the investigation to new types of material so that the behaviours and values of different types of material can be analysed. A good proposal for this would be to see how polymers, such as nylon, react differently to metals or brittle materials when stress is applied.