PHYSICS

Investigation of the Stress and Strain Properties of Copper, Thread, and Fishing Line

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Aim

To investigate the stress and strain properties, and therefore determine Young's Modulus, of three different materials, by comparing the effects of increasing load on these materials.

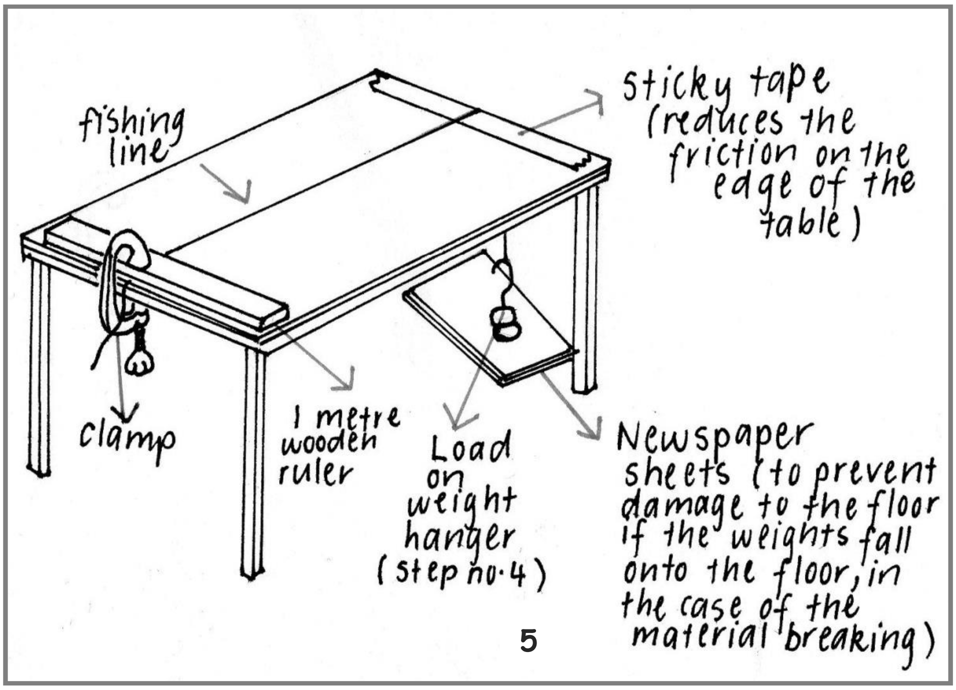
Method

Apparatus

- Clamp
- 1 metre wooden ruler
- Sticky tape
- 100 g weight hanger
- 40 cm plastic ruler
- 1 metre of fishing line (diameter – 0.34 mm)
- 1 metre of copper wire (diameter – 0.2 mm)
- 1 metre of thick cotton thread (diameter – 1.67 mm)
- 9 x 100 g masses
- A few newspaper sheets

Instructions

1. Set up the apparatus listed above, according to the image below, using the fishing line.



2. Tape the end of the fishing line to the hook of the weight hanger, ensuring that the fishing line is securely attached to the hook.

3. To measure the original length of the fishing line: gently extend the fishing line so that it is a straight line, and record this length (from the edge of the table to where it is taped on the hook) using the 40 cm plastic ruler.

4. Allow the fishing line to hang from the edge of the table; the 100 g (1 N) hanger will be the first load attached to the line.

5. Measure the distance between the floor and the end of the fishing line, using the 40 cm ruler (if the natural extension of the fishing line measures over 0cm on the ruler, record this number, then ensure that you subtract this value from the subsequent measurements for extension obtained).

6. One at a time, add a 100 g mass to the hanger, each time measuring the distance between the floor and the bottom of the fishing line. Do this until the line breaks, or all of the 9 x 100 g masses are on the hanger.

7. Repeat these steps using the thick thread and copper wire.

Hypothesis

- The fishing line will behave the most plastically, in comparison to the copper wire and thread. It will be the most flexible material, and therefore will have the smallest value of Young's Modulus.

- The thread will be the most brittle material. Also, it will be the stiffest material, and therefore will have the largest value for Young's Modulus.

- The copper wire will be ductile, and therefore have a large plastic region on its stress vs strain graph. It will also have a relatively high Young's Modulus value.

Theory

- By adding weights to the end of the material as it hangs vertically off the table, the material will be under tension. Therefore, this pulling force causes the material to stretch, often resulting in an increase in the length of the material.

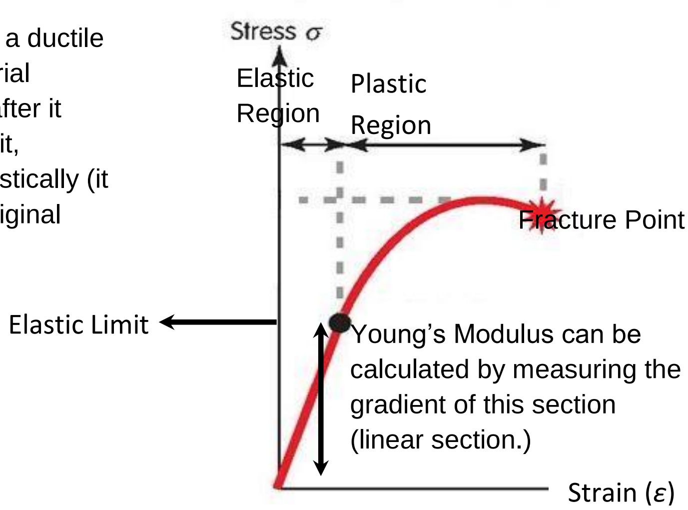
- Stress is the amount of force applied per unit area of the material. As the material is being pulled by the weights hanging off it, it will be under tensile stress $\Rightarrow \sigma = F/A$ (measured in N/m2 or Pa)

- Strain is the ratio of change in length over the original length of an object, when a force is applied to the object $\Rightarrow \varepsilon = \Delta l/L$ (no unit)

- Young's Modulus is a measure of the stiffness of a material. It is a ratio of stress per unit strain for the material $\Rightarrow E = \sigma/\varepsilon$ (measured in N/m2 or Pa). Materials with high values for Young's Modulus are stiff, as they require a large stress to achieve small deformations. Materials with low values for Young's Modulus are flexible, as they require a small stress to achieve large deformations.

- Plastic region of a stress vs. strain graph – where the graph no longer exhibits a linear line. The material will no longer return to its original length.
- Elastic limit – the maximum stress a material can be under before it permanently deforms and becomes plastic.
- Fracture point – the point on a stress vs. strain graph when the material breaks.
- A brittle material only displays elastic behaviour and will break at its elastic limit (the point where the line of a stress vs. strain graph is no longer constant. After this point, the material will not resume to its original length, and is therefore plastic)
- A ductile material can withstand stresses greater than its elastic limit and will undergo significant plastic deformation before failing.

This is an example of a ductile material, as the material continues to deform after it reaches its elastic limit, therefore deforms plastically (it will not return to its original shape).



Results

Refer to attached appendix.

Discussion

	Fishing Line	Copper Wire	Thread
Young's Modulus Value	1.4 x 103 N/mm^2 The fishing lines Young Modulus value is in between copper wire and thread. This differs from the hypothesis (fishing line will behave the most plastically and will be the most flexible), as it has the second largest Young's Modulus value. It is also difficult to conclude if it behaved the most plastically, as it did not reach its fracture point.	2.1 x 104 N/mm^2 As copper wire has the largest Young's Modulus value, it is the stiffest material out of the three materials. This is slightly in accordance with the hypothesis (copper wire will be ductile and have a relatively high Young's Modulus value). It has a high Young's Modulus value, and it did display ductile behaviour, through behaving plastically before fracturing.	8.2 N/mm^2 As the thread has the smallest Young's Modulus value, it is the most flexible out of the three materials. This greatly differs from the hypothesis (the thread will be the most brittle and stiff material), as it has the smallest Young's Modulus value. Therefore, it was the most flexible material.
Fracture Point	The fishing line did not reach its fracture point at a load of 10 N.	Copper wire reached its breaking point, which was at a stress of 254.3 N/mm^2. About 5 seconds after the load was placed on the end of the wire, it broke.	The thread did not reach its fracture point at a load of 10 N.
Elastic Limit	22 N/mm^2 Copper wire is subject to a stress in between copper wire and thread before it begins plastically deforming.	63.6 N/mm^2 Therefore, copper wire is subject to the greatest stress out of the three materials just before it begins plastically deforming.	0.5 N/mm^2 Thread is subject to the least stress out of the three materials before it begins plastically deforming.
Properties of the materials	According to the graph, the fishing line is more ductile than copper wire, as it has the larger plastic region. At 10 N, it was under the more strain (0.18) than the thread (0.13). However, as both the thread and fishing line did not reach their fracture point, it is difficult to assume which material is the most ductile.	According to the graph, copper wire deformed plastically until its fracture point. It is therefore not a brittle material, however, it is the most brittle material out of the three materials, as it fractured under a load of 8 N, whilst the other materials were yet to fracture under a load of 10 N.	According to the graph, thread has the largest elastic region out of the three materials, indicating that it is the most elastic material.

Safety Precautions
Safety goggles were worn, so that if one of the materials reached their fracture point and broke, the material wouldn't damage someone's eyes.
Closed toed shoes were worn, to prevent foot injury if the weights or heavy equipment (such as the clamp), were to fall on someone's foot.

Why standard units were not used in certain aspects of the experiment:
The standard unit of (m) was not used when measuring the extension of the materials, as the materials would only extend a length that could only be measured accurately through cm.
The standard unit of (m^2) was not used when determining the cross-sectional area of the materials, as the radii of the materials were too small to measure using a metre ruler. Therefore, stress is measured in N/mm^2

Random Errors
The copper wire was permanently bent in certain sections. This was due to the wire being wound in a circle. This would have created weak points in the wire, which consequently may have resulted in the wire fracturing. Therefore, the copper wire may have been able to undergo further stress.
Not waiting a certain amount of time after adding weights onto the material before measuring the change in length. Therefore, after measuring the change in length of a particular material, it may have stretched further before adding the next weight. This is also evident with the copper wire, as after 8N was attached to the wire, and the change in length measured, it broke. This inconsistency in time may have led to the outliers on the graphs of the materials.
Not reading the ruler at eye level. This may have led to uncertainties with the lengths and change in lengths of the materials obtained. Therefore, the last decimal place of the lengths measured may be questionable.
Determining the diameter of the thick piece of thread. Whilst this was done by using 6 pieces of the thread and dividing the total width of the pieces (1 ± 0.1 cm), incorrectly measuring the width by having too much or too little space in between the lengths may have an effect on the accuracy of this value.
As the thread was thick, the fibres composing it were intertwined to form a rope structure. While it was under increasing load, these fibres untwined and became straight, which contributed to the increase in length of the thread. Therefore, the lengths obtained for this material may be questionable, which led to the observation that the material was flexible.
Under a load of up to 2 N, the copper wire did not have a measurable change in length, as the ruler used only measures in cm. If the length was measured in a smaller unit, for example in micrometers, a change in length may have been observed, which would therefore impact on the strain values obtained when the copper wire was under a load of 1 N and 2 N.

Systematic Errors
Manufacturer's claims usually have a discrepancy of ±1%. Therefore, the 100 g weights may have a slight inaccuracy of ± 1 g, which would have an effect on the accuracy of the extension of the materials obtained.
Each of the diameters of the materials may have a discrepancy in the last decimal place of the value. This would lead to inaccuracies in the stress values obtained.

Conclusion

In conclusion, copper wire behaved the most brittle, whilst the thread and fishing line did not reach their fracture point, and displayed their flexible properties. The copper wire was the stiffest material, as its Young's Modulus value was 2.1 x 104 N/mm^2. It also displayed some ductile behaviour, which was mostly in accordance with the hypothesis. However, the results obtained for the fishing line and thread greatly differed from the hypothesis. The fishing lines Young's Modulus value was 1.4 x 103 N/mm^2, indicating its greater stiffness than the thread. The thread behaved the most flexibly, as it had the smallest Young's Modulus value of 8.2 N/mm^2.

These results are not entirely accurate, due to following errors which may have influenced the results:

- The copper wire having deformations.
- The varying length of time between measuring the change in length of the material after putting an extra load on it.
- Not reading the ruler at eye level.
- Inaccurately measuring the diameter of the thread.
- The unwinding of the thread which may have given the impression of an increase in length of the material.
- The accuracy of the manufacturers claims of the weights used and the diameters of copper and the fishing line.

Improvements to the experimental design include:

Use more weights to reach the fracture point of copper wire and the fishing line. This was a limitation of the experiment, as by not reaching these materials fracture points, their properties could not be accurately compared.

Use a micrometer or another suitable instrument to accurately measure the diameter of the thread, and the other materials, to test the manufacturer's claims. This would improve the accuracy of the values used, and therefore the accuracy of the results obtained for stress.

Use a scale to weigh the mass of the weights used. This is to ensure that the change in length of each material is due to an increase in the load attached by only 1 N, not by a load that is more or less than 1 N.

APPENDIX

Fishing Line –Cross-sectional area of 0.09 mm^2 ± 0.01 mm^2. Initial length – 38.4 cm ± 0.1 cm

Load (N) ± 1% (of individual weight)	Extension (cm) ± 0.1 cm	Stress (N/mm2)	Fractional Error (± x N/mm^2)	Strain	Fractional Error (± x)
1.00	0.3	11.0	0.2	0.008	0.003
2.00	0.6	22.0	0.5	0.017	0.003
3.00	1.7	33.0	0.7	0.044	0.003
4.00	2.8	44.0	0.9	0.073	0.003
5.00	3.7	55	1	0.096	0.003
6.00	4.2	66	1	0.110	0.003
7.00	5.2	77	2	0.140	0.003
8.00	5.9	88	2	0.150	0.003
9.00	6.2	99	2	0.160	0.003
10.00	7.0	110	2	0.180	0.003

Copper Wire – Cross-sectional area of 0.031 mm^2 ± 0.006 mm^2. Initial length – 32.2 cm ± 0.1cm

Load (N) ± 1% (of individual weight)	Extension (cm) ± 0.1 cm	Stress (N/mm2)	Fractional Error (± x N/mm^2)	Strain	Fractional Error (± x)
1.00	0.0	32.0	0.5	0.000	0.000
2.00	0.0	64	1	0.000	0.000
3.00	0.1	96	2	0.003	0.002
4.00	0.2	127	2	0.006	0.003
5.00	0.4	159	3	0.012	0.003
6.00	0.6	191	3	0.019	0.003
7.00	1.6	223	4	0.050	0.003
8.00	4.7 – fracture point	255	4	0.150	0.004

Thread – Cross-sectional area of 2.3 mm^2 ± 0.05 mm^2. Initial length – 33.8 ± 0.1 cm

Load (N) ± 1% (of individual weight)	Extension (cm) ± 0.1 cm	Stress (N/mm^2)	Fractional Error (± x N/mm^2)	Strain	Fractional Error (± x)
1.00	1.9	0.50	0.03	0.056	0.003
2.00	2.5	0.90	0.05	0.074	0.003
3.00	3.0	1.40	0.08	0.089	0.003
4.00	3.4	1.80	0.1	0.100	0.003
5.00	3.6	2.30	0.1	0.110	0.003
6.00	3.7	2.80	0.2	0.110	0.003
7.00	3.9	3.2	0.2	0.120	0.003
8.00	4.0	3.7	0.2	0.120	0.003
9.00	4.1	4.1	0.2	0.120	0.003
10.00	4.3	4.6	0.3	0.130	0.003

	Fishing Line	Copper Wire	Thread
Young's Modulus Value (N/mm^2)	1.4 x 103	2.1 x 104	8.2

Sample Calculation For Copper Wire, Under a Load of 6 N – Stress and Strain (Cross-Sectional Area of 0.031 mm^2. Initial length – 32.2 cm)

Determining Change in Length

Initial length ⇒ 0.5 cm

Results (Raw data from Log Book):

Load (N)	Extension (cm)
6	1.1

Calculating Change in Length:

Load (N)	Recorded length (cm) – initial length (cm)	Change in Length (cm)
6	1.1-0.5	0.6

Determining Strain: $\varepsilon = \Delta l / L$

Load (N)	Change in length (cm) / original length (cm)	Strain
6	0.6/32.2	0.019

Determining the Cross-Sectional Area of Copper Wire
Cross sectional area $=\pi$ x (diameter/2)2 $=\pi$ x (0.2/2)2 =0.031 mm^2

Calculating Stress: $\sigma = F/A$

Load (N)	Force (N) /Cross-Sectional Area of Copper Wire (mm^2)	Stress (N/mm^2)
6	6/0.03146	191

Determining Young's Modulus: $E=\sigma/\varepsilon$

Young's Modulus
$E = \sigma/\varepsilon$ – elastic region of graph – constant line E = 127.3/0.0062 E = 2.1 x 104 N/mm^2

Sample Calculation For Copper Wire, Under a Load of 6 N – Error Analysis

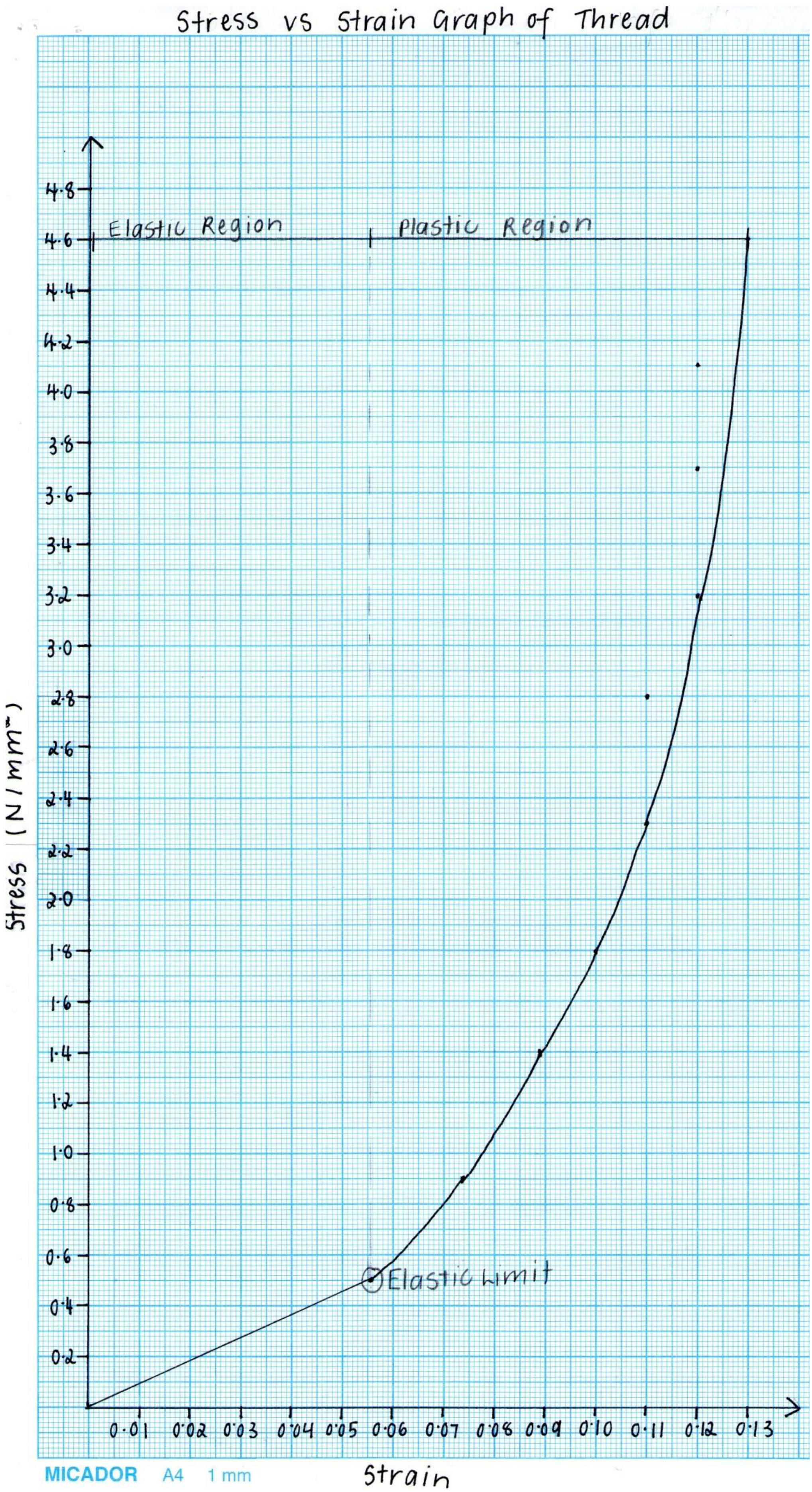
Fractional Error in Copper Wire, Under a Load of 6 N, for Stress

Force Applied to Copper Wire	Copper Wire Cross-Sectional Area
Force $\Rightarrow$ 6 N Error $\Rightarrow$ 1% Therefore = 1/100 x 6 =0.06 (6.00 ± 0.06 N) F(A) = 0.06/6 F(A) = 0.01 (6.00 ± 0.01 N)	Diameter $\Rightarrow$ 0.20 ± 0.01 mm Radius $\Rightarrow$ 0.10 ± 0.01 mm Area = πr2 $=\pi$ x (0.10)2 = 0.031 mm^2 F(A)=(0.01/0.10)x2 =2/10 Multiply this value by the actual copper wire cross-sectional area = 2/10 x 0.031 = 0.006 mm^2 (0.031 ± 0.006 mm^2)
Error in Stress	
F(A) = (Error in Force + Error in Cross-Sectional Area) x Actual Stress Value Obtained = (0.01 + 0.006) x 191 = 3 N/mm^2 Stress of Copper Wire under a load of 6 N $\Rightarrow$ 191 ± 3 N/mm^2	

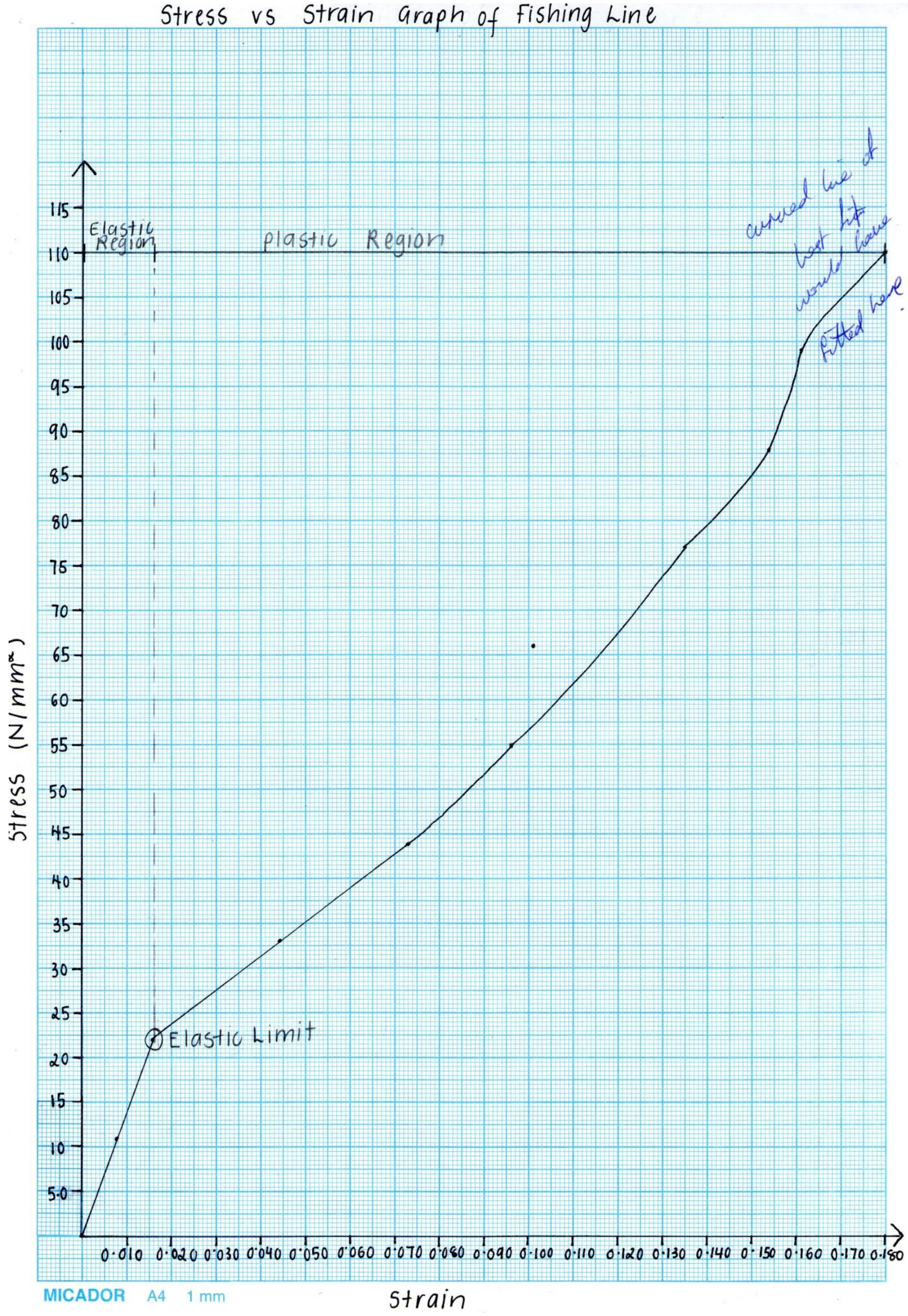
Fractional Error in Copper Wire, Under a Load of 6 N, for Strain

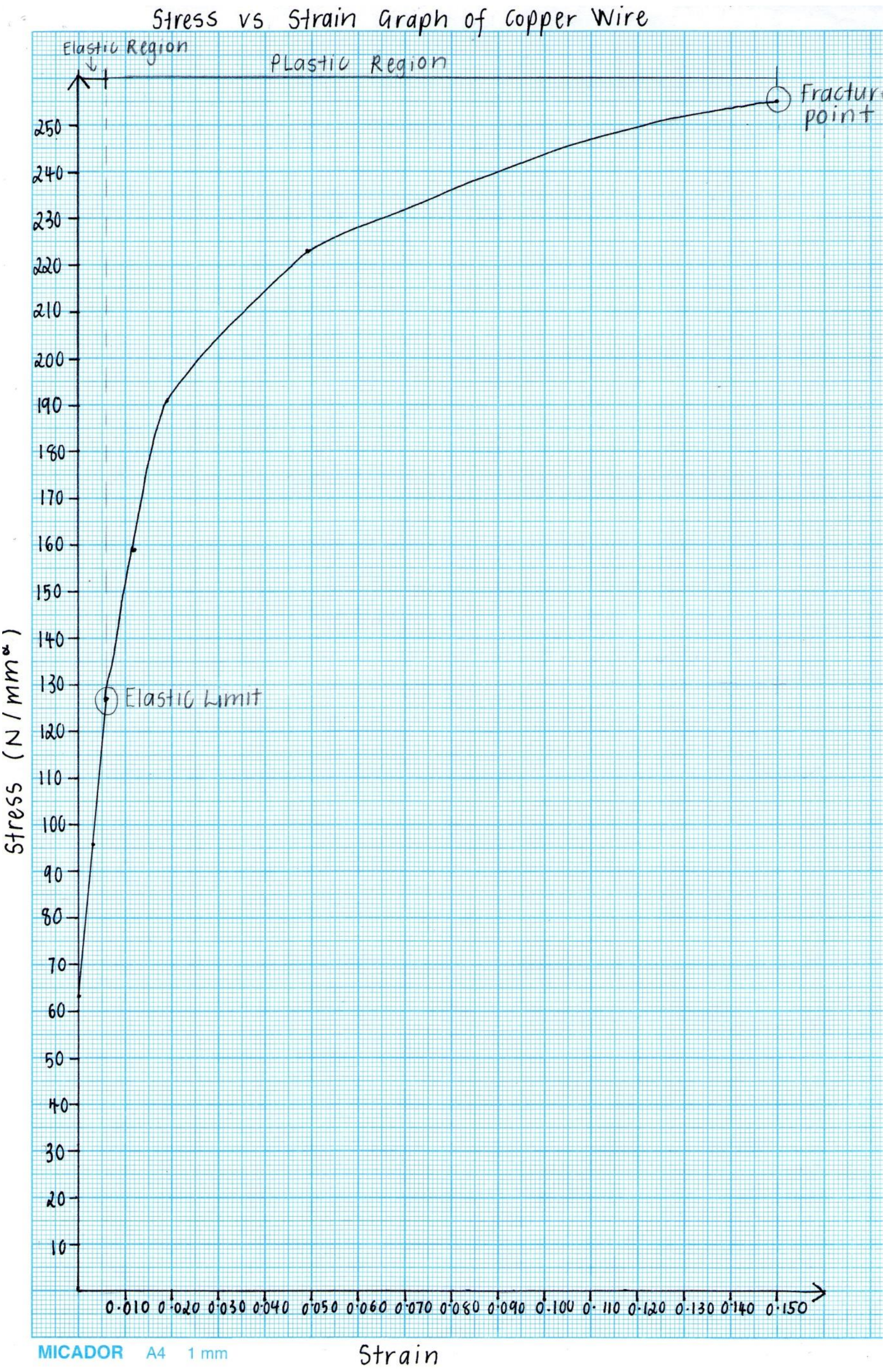
<table>
<tr><th>Error in the Original Length Recorded of the Copper Wire</th><th>Error in the Change of Length of Copper Wire</th></tr>
<tr><td>Initial length = 32.2 ± 0.1 cm
F(A) = 0.1/32.2
= 1/322 cm (32.200 ± 0.003 cm)</td><td>Length recorded for 6 N = 0.6 ± 0.1 cm
F(A) = 0.1/0.6
F(A) = 1/6 cm (0.6 ± 0.2 cm)</td></tr>
<tr><td colspan="2">Error in Strain</td></tr>
<tr><td colspan="2">F(A) = (Error in Original Length + Error In the change of Length) x Actual Strain Value Obtained
= ((1/322) +(1/6)) x 0.019
=0.003

Strain of Copper Wire under a load of 6 N ⇒ 0.019 ± 0.003</td></tr>
</table>


Stress vs Strain Graph of Thread
Elastic Region
Plastic Region
Elastic Limit
Stress (N/mm²)
Strain
4·8
4·6
4·4
4·2
4·0
3·8
3·6
3·4
3·2
3·0
2·8
2·6
2·4
2·2
2·0
1·8
1·6
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0·01
0·02
0·03
0·04
0·05
0·06
0·07
0·08
0·09
0·10
0·11
0·12
0·13
MICADOR A4 1 mm

Stress vs Strain Graph of Fishing Line




Stress vs Strain Graph of Copper Wire
Elastic Region
Plastic Region
Fracture point
Elastic Limit
Stress (N / mm²)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0·010 0·020 0·030 0·040 0·050 0·060 0·070 0·080 0·090 0·100 0·110 0·120 0·130 0·140 0·150
MICADOR A4 1 mm
Strain

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Champion, Neil. Dediwalage, Ranjith. Mundy, Megan. Plant, Barry. 2009. Nelson Physics Units 3 + 4. Australia: Cengage Learning Australia Pty Limited.

Handouts from class: Errors and Accuracy, Summary of Practical Investigation Booklet
Experiment 44: Load-Extension Graphs