A

LAB NO 4
STRESS RELAXATION IN DUCTILE AND BRITTLE POLYMERS

Lab 5 Mechanical Properties of Ductile and Brittle Polymers

Group 2a
Lori Wiseman
Glenna Flynn
Roxanne Gleason

Oct. 20/98

Purpose: To study stress relaxation in a ductile polymer and a brittle polymer. To measure the elastic modulus, yield or fracture stress in a ductile polymer and a brittle polymer.

Theory:

Elastic Modulus (E): The ratio of stress to strain when deformation is totally elastic; also a measure of the stiffness of a material.

$$E = \frac{\sigma}{\epsilon}$$

Yield Stress (σ_y): The stress required to produce a very slight yet specified amount of plastic strain; a strain offset of 0.002 is commonly used.

Fracture Stress: The stress at fracture.

Stress Relaxation: The decrease in stress with time due to molecular relaxation processes within a polymer.

8.94

Ductile: A material is termed ductile if it experiences a large amount of plastic deformation upon fracture.

Brittle: A material is termed brittle if it experiences very little or no amount of plastic deformation upon fracture.

Q

Apparatus:
- Hounsfield tensometer (see fig. 1)
- load indication equipment (beam, strain gauges, power supply, and amplifier).
- (see fig. 2) Brittle clear specimen (2)
- Ductile Blue Specimen (2)
- Calipers (Vernier)
- meter stick
- Safety glasses

Procedure:

1. Measured the gauge length, width, and thickness of 4 specimens (2 ductile, 2 brittle).

2. Calibrated the extension ~~of the tensometer by measuring~~ (i.e. movement per turn), the distance the bar attached to the movable grip had moved after ~~100 turns of the fine adjustment wheel.~~ (8.40..) 100 turns ?

3. Gripped the ductile specimen (sample 2) in the ~~tensometer and~~ [illegible] increased the extension well beyond the yield point, recording the load every 10 turns of the fine adjustment wheel. ✓

4. Gripped the ductile specimen (sample 1) in the tensometer and in...

load reached a value that was ½ the yield load, then the extension remained constant (for approximately 20 minutes, while the load was recorded initially in one minute intervals, then in 5 minute intervals (when the load did not change rapidly).

5. Repeated step 3. with brittle specimen (sample 1).

6. Repeated step. 4. with brittle specimen (sample 2).

Table 1: Uncertainties

Parameters	Δl_0 (mm)	Δw_0 (mm)	Δt_0 (mm)	Δm (kg)	$\Delta(\Delta l)$ (mm)
Instrument	± 0.05	± 0.05	± 0.05	± 0.1	
Object	± 0.05	± 0.05	± 0.05	—	
Use	± 0.05	± 0.05	± 0.05	± 0.1	± 0.5
Total	± 0.05	± 0.05	± 0.05	± 0.1	± 0.5

fig. 1 Hounsfield Tensometer (top view)

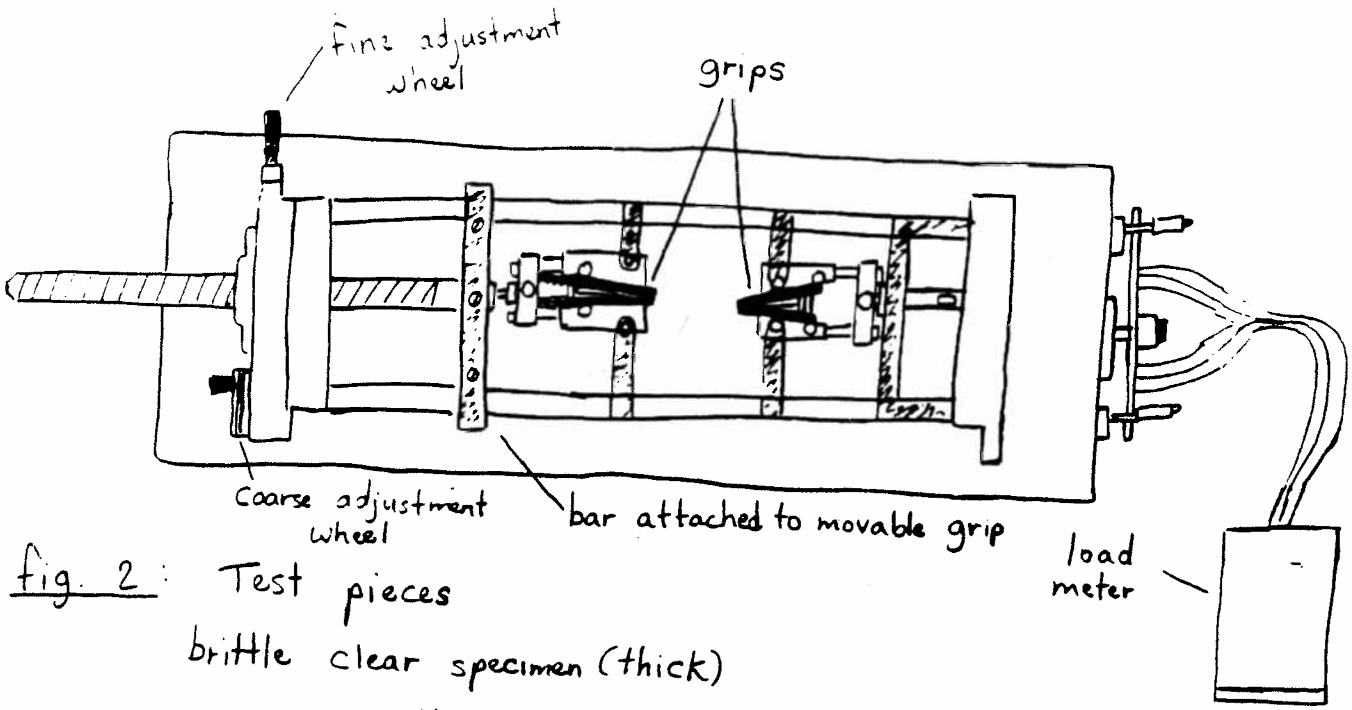
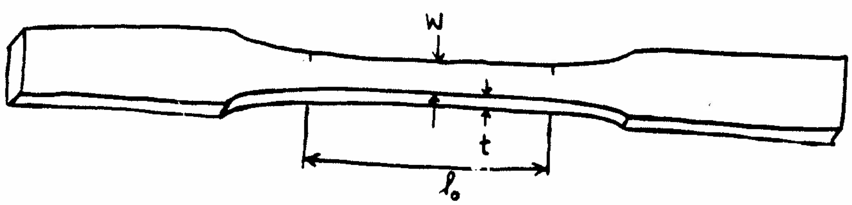
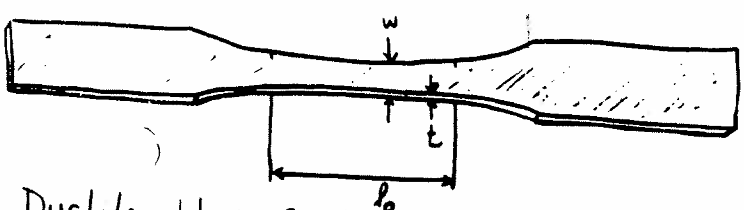


fig. 2: Test pieces

brittle clear specimen (thick)



ductile blue specimen (thin)



Ductile blue specimens

Sample 1

35.8

l_o = 29.35 mm 30.4

0.85

t = 0.80 mm 0.85

w = 12.30 mm 11.8

14.00

Sample 2

28.0

l_o = 30.20 mm

0.85

t = 0.80 mm 0.90

w = 12.35 mm 11.80

13.90

Brittle Clear specimens

Dirty

Sample 1

65.70

l_o = 66.35 mm 56.0

2.95

t = 2.90 mm

w = 12.50 mm 12.85

14.2

Clean

Sample 2

61.00

l_o = 61.90 mm 52.8

2.90

t = 2.95 mm 2.80

w = 12.30 mm 12.85

14.00

8.40 mm
9.50 mm

Results: (Note : extension calibration = 100 turns / 8.55 mm)

Table 2 : Measurements and Readings for Ductile specimen (sample 2)

load (kg) / 10 turns
0.2 (initial)
0.3
0.2
0.1
0.1
0.8
1.4
2.3
3.9
6.0
8.2
10.6
12.2
13.6
14.9
15.9
16.6
17.4
17.6
18.0
18.1
18.2
18.2
18.1

# turns ×10	load (kg)
10	
20	
30	

9.1
9.1
9.2
9.2
9.3
9.3
9.3
9.3
9.3
9.3
9.4
9.4
9.4

Table 2 Contiued

18.1
17.8
17.6
17.5
17.3
17.1
17.0
16.8
16.7
16.5
16.3
16.1
15.9
15.6
15.4
15.2
14.8
14.3
14.0
13.5
13.0
12.4
12.2
12.0
11.8
11.8
11.9
11.8

Table 2 continued

11.9
11.9
12.0
12.0
12.0
12.0
12.0
12.1
12.2
12.2
12.2
12.3
12.3
12.3
12.3
12.3
12.3
12.3
12.4
12.4
12.4
12.4
12.4
12.4
12.4 (failure)

Table 3 : Measurements and Readings for Ductile specimen (sample 1)

½ yield load = 9.1 kg (142 turns)

9.8 kg (

Intervals	load (kg)
1 min.	7.6
"	7.1
"	6.8
"	6.6
"	6.5
"	6.4
5 min.	6.1
"	5.8
"	5.8

Table 4 Measurements and Readings for Brittle specimen (sample 1)

Load (kg)/10 turns
0
0
0
0
0
0
0
0.3
0.1
0.1
0.3
0.6
0.9
1.6
2.8
4.7
11.5
20.3
38.3
58.5
88.8
117.6
148.5

Table 4 continued

239.4
260.5 fracture

Table 5: Measurements and Readings for Brittle specimen (sample 2).

117.1

$\frac{1}{2}$ yield load = 130.3 kg ($\approx$ 240 turns)

Intervals	load (kg)
1 min.	127.3
"	125.1
"	123.8
"	122.9
"	122.2
"	121.6
5 min.	119.7
"	118.4
"	117.6

112.5
110.7
109.5 } 1 MIN.
108.6
108.[illegible]
107.4
[illegible]
104.2
103.3

Calculations:

Ductile Specimens

Sample 1

$l_o = 29.35\,mm$

$A_o = t \times w$
$= (0.80\,mm) \times (12.30\,mm)$
$= 9.84\,mm^2$

Sample 2

$l_o = 30.20\,mm$

$A_o = t \times w$
$= (0.80\,mm) \times (12.35\,mm)$
$= 9.88\,mm^2$

Brittle Specimens

Sample 1

$l_o = 66.35\,mm$

$A_o = t \times w$
$= (2.90\,mm) \times (12.50\,mm)$
$= 36.25\,mm^2$

Sample 2

$l_o = 61.90\,mm$

$A_o = t \times w$
$= (2.95\,mm) \times (12.30\,mm)$
$= 36.285\,mm^2$

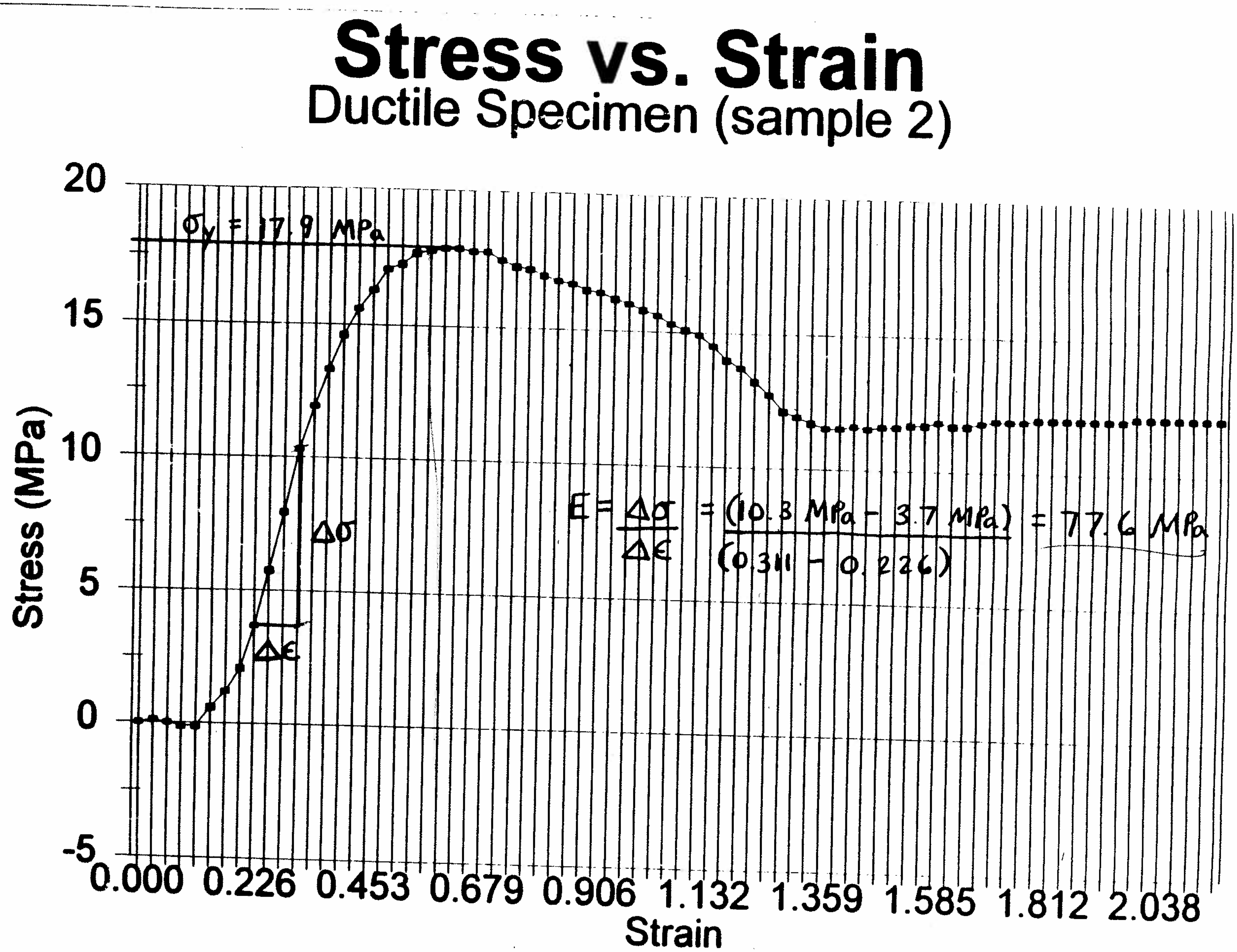

Stress vs. Strain
Ductile Specimen (sample 2)
Stress (MPa)
20
15
10
5
0
-5
0.000
0.226
0.453
0.679
0.906
1.132
1.359
1.585
1.812
2.038
Strain
σy = 17.9 MPa
Δσ
Δϵ
E = Δσ/Δϵ = (10.3 MPa − 3.7 MPa)/(0.311 − 0.226) = 77.6 MPa

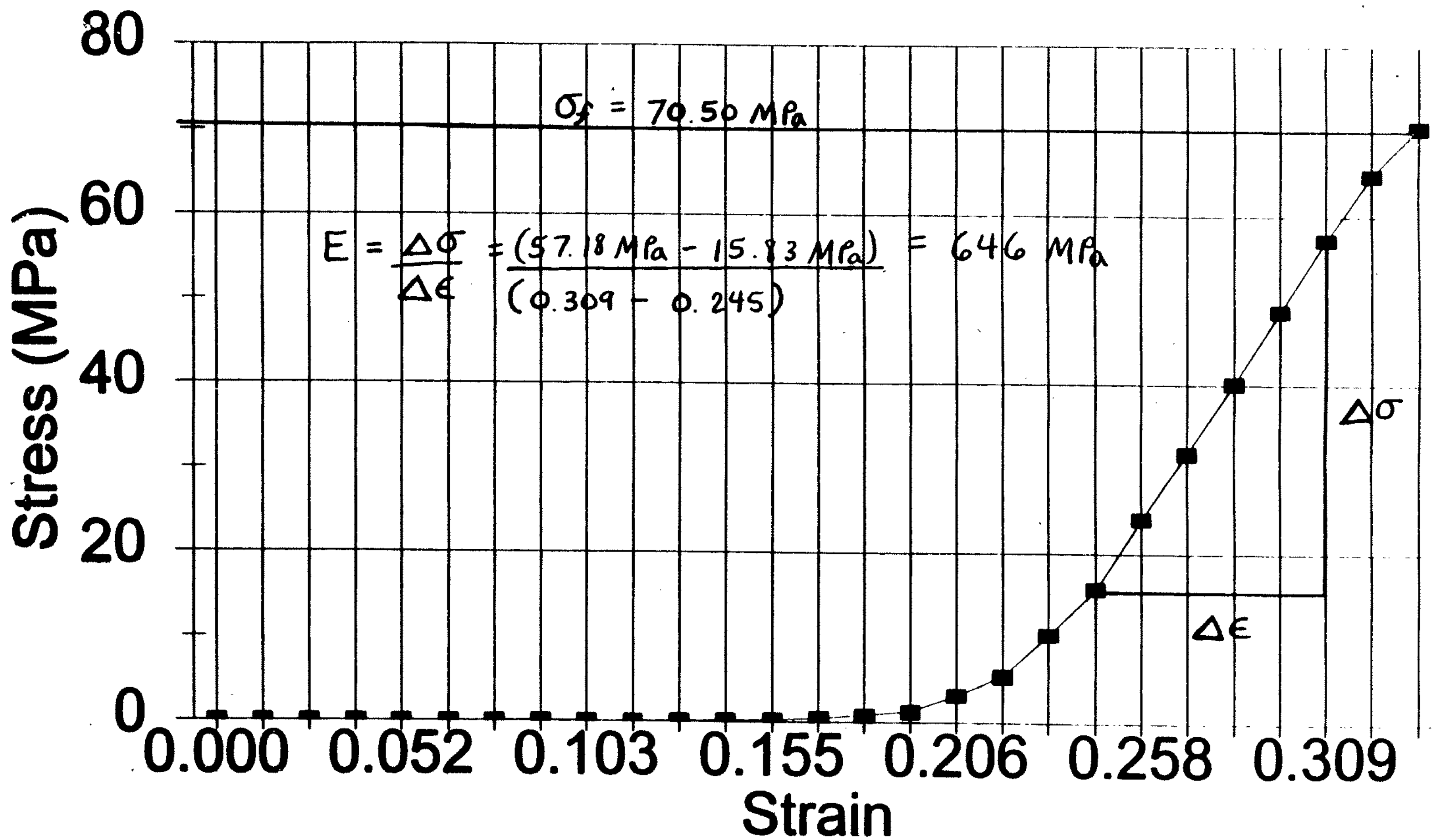
Table 6:

Ductile Specimen (Sample 2)

# of Turns	Load (kg)	Deformation (mm)	Stress (MPa)	Strain
10	0.0	0.000	0.0	0.000
20	0.1	0.855	0.1	0.028
30	0.0	1.710	0.0	0.057
40	-0.1	2.565	-0.1	0.085
50	-0.1	3.420	-0.1	0.113
60	0.6	4.275	0.6	0.142
70	1.2	5.130	1.2	0.170
80	2.1	5.985	2.1	0.198
90	3.7	6.840	3.7	0.226
100	5.8	7.695	5.8	0.255
110	8.0	8.550	7.9	0.283
120	10.4	9.405	10.3	0.311
130	12.0	10.260	11.9	0.340
140	13.4	11.115	13.3	0.368
150	14.7	11.970	14.6	0.396
160	15.7	12.825	15.6	0.425
170	16.4	13.680	16.3	0.453
180	17.2	14.535	17.1	0.481
190	17.4	15.390	17.3	0.510
200	17.8	16.245	17.7	0.538
210	17.9	17.100	17.8	0.566
220	18.0	17.955	17.9	0.595
230	18.0	18.810	17.9	0.623
240	17.9	19.665	17.8	0.651
250	17.9	20.520	17.8	0.679
260	17.6	21.375	17.5	0.708
270	17.4	22.230	17.3	0.736
280	17.3	23.085	17.2	0.764
290	17.1	23.940	17.0	0.793
300	16.9	24.795	16.8	0.821
310	16.8	25.650	16.7	0.849
320	16.6	26.505	16.5	0.878
330	16.5	27.360	16.4	0.906
340	16.3	28.215	16.2	0.934
350	16.1	29.070	16.0	0.963
360	15.9	29.925	15.8	0.991
370	15.7	30.780	15.6	1.019
380	15.4	31.635	15.3	1.048
390	15.2	32.490	15.1	1.076
400	15.0	33.345	14.9	1.104
410	14.6	34.200	14.5	1.132
420	14.1	35.055	14.0	1.161
430	13.8	35.910	13.7	1.189
440	13.3	36.765	13.2	1.217
450	12.8	37.620	12.7	1.246
460	12.2	38.475	12.1	1.274
470	12.0	39.330	11.9	1.302
480	11.8	40.185	11.7	1.331
490	11.6	41.040	11.5	1.359
500	11.6	41.895	11.5	1.387
510	11.7	42.750	11.6	1.416
520	11.6	43.605	11.5	1.444
530	11.7	44.460	11.6	1.472
540	11.7	45.315	11.6	1.500
550	11.8	46.170	11.7	1.529
560	11.8	47.025	11.7	1.557
570	11.9	47.880	11.8	1.585
580	11.8	48.735	11.7	1.614
590	11.8	49.590	11.7	1.642

Stress vs. Strain

Brittle Specimen (sample 1)



Error Calculations:

Ductile Specimen (Sample 1), Error in elastic modulus:

$$\frac{\Delta\sigma_E}{\sigma_E} = \frac{\Delta F_E}{F_E} + \frac{\Delta A_o}{A_o} = \frac{\Delta m_E}{m_E} + \frac{\Delta t_o}{t_o} + \frac{\Delta W_o}{W_o}$$

0.1 0.05 0.06

$$\rightarrow \frac{\Delta\sigma_E}{\sigma_E} = \frac{0.1\ \text{kg}}{6.6\ \text{kg}} + \frac{0.05\ \text{mm}}{0.80\ \text{mm}} + \frac{0.05\ \text{mm}}{12.35\ \text{mm}} = \underline{0.082}$$

0.75 11.95

$$\frac{\Delta\epsilon_E}{\epsilon_E} = \frac{\Delta(\Delta l)_E}{\Delta l_E} + \frac{\Delta l_o}{l_o} = \frac{0.5\ \text{mm}}{2.567\ \text{mm}} + \frac{0.05\ \text{mm}}{30.20\ \text{mm}} = 0.20$$

$$\frac{\Delta E}{E} = \frac{\Delta\sigma_E}{\sigma_E} + \frac{\Delta\epsilon_E}{\epsilon_E} = 0.082 + 0.20 = 0.28$$

$$\Delta E = 0.28\,(E) = 0.28\,(77.6\ \text{MPa}) = \pm 21.7\ \text{MPa}$$

Ductile Specimen (Sample 1), Error in yield stress:

$$\frac{\Delta\sigma_y}{\sigma_y} = \frac{\Delta m_y}{m_y} + \frac{\Delta t_o}{t_o} + \frac{\Delta W_o}{W_o} = \frac{0.1\ \text{kg}}{18.0\ \text{kg}} + \frac{0.05\ \text{mm}}{0.80\ \text{mm}} + \frac{0.05\ \text{mm}}{12.35\ \text{mm}}$$

0.00134
0.0179
0.00397

$$\frac{\Delta\sigma_y}{\sigma_y} = 0.072$$

$$\Delta\sigma_y = 0.072\,(\sigma_y) = 0.072\,(17.9\ \text{MPa}) = \pm 1.3\ \text{MPa}$$

0.00548
0.0357
0.004

from Figs.

0.0051

Table 7:

Brittle Specimen (Sample 1)

# of Turns	Load (kg)	Deformation (mm)	Stress (MPa)	Strain
10	0	0.000	0.00	0.000
20	0	0.855	0.00	0.013
30	0	1.710	0.00	0.026
40	0	2.565	0.00	0.039
50	0	3.420	0.00	0.052
60	0	4.275	0.00	0.064
70	0	5.130	0.00	0.077
80	0.3	5.985	0.08	0.090
90	0.1	6.840	0.03	0.103
100	0.1	7.695	0.03	0.116
110	0.3	8.550	0.08	0.129
120	0.6	9.405	0.16	0.142
130	0.9	10.260	0.24	0.155
140	1.6	11.115	0.43	0.168
150	2.8	11.970	0.76	0.180
160	4.7	12.825	1.27	0.193
170	11.5	13.680	3.11	0.206
180	20.3	14.535	5.49	0.219
190	38.3	15.390	10.36	0.232
200	58.5	16.245	15.83	0.245
210	88.8	17.100	24.03	0.258
220	117.6	17.955	31.82	0.271
230	148.5	18.810	40.19	0.283
240	180.3	19.665	48.79	0.296
250	211.3	20.520	57.18	0.309
260	239.4	21.375	64.79	0.322
270	260.5	22.230	70.50	0.335 ← fracture

Brittle Specimen (sample 1), Error in elastic modulus:

$$\frac{\Delta\sigma_E}{\sigma_E} = \frac{\Delta m_E}{m_E} + \frac{\Delta t_o}{t_o} + \frac{\Delta W_o}{W_o} = \frac{0.1\ kg}{152.8\ kg} + \frac{0.05mm}{2.90mm} + \frac{0.05mm}{12.50mm}$$

2.65

$$\frac{\Delta\sigma_E}{\sigma_E} = 0.022$$

$$\frac{\Delta\epsilon_E}{\epsilon_E} = \frac{\Delta(\Delta l)_E}{\Delta l_E} + \frac{\Delta l_o}{l_o} = \frac{0.5\ mm}{4.246mm} + \frac{0.05\ mm}{66.\ \ mm}$$

$$\frac{\Delta\epsilon_E}{\epsilon_E} = 0.12$$

$$\frac{\Delta E}{E} = \frac{\Delta\sigma_E}{\sigma_E} + \frac{\Delta\epsilon_E}{\epsilon_E} = 0.022 + 0.12 = 0.14$$

$$\Delta E = 0.14\,(E) = 0.14\,(646\ MPa) = \pm 90.4\ MPa$$

Brittle Specimen (sample 1), Error in fracture stress:

$$\frac{\Delta\sigma_f}{\sigma_f} = \frac{\Delta m_f}{m_f} + \frac{\Delta t_o}{t_o} + \frac{\Delta W_o}{W_o} = \frac{0.1kg}{\cancel{260.5}kg} + \frac{0.05mm}{2.90\ mm} + \frac{0.05mm}{12.50mm}$$

$$\frac{\Delta\sigma_f}{\sigma_f} = 0.022$$

$$\Delta\sigma_f = 0.022\,(\sigma_f) = 0.022\,(\cancel{70.58}\ MPa) = \pm 1.5\ MPa$$

0.0301
0.0333
0.004

0.151

Discussion of Uncertainties:

Instrument Uncertainties:

The instrument errors are uncertainties caused by limitations in the calibration of the instruments used in this experiment. The vernier calipers created an error in the thickness and width of each specimen of ± 0.05 mm. The original lengths (gauge lengths) of each specimen also had an error of ± 0.05 mm created by using the calipers. The load indicator created an error of ± 0.1 kg.

Object Uncertainties:

The dimensions of each of the specimens measured may not have been uniform throughout, thus creating errors of ± 0.05 mm.

Use Uncertainties:

Not using a constant grip each time when measuring the dimensions of the specimens with the Vernier calipers may create errors of ± 0.05 mm. Not reading the load indicator at precisely the right time may create errors of ± 0.1 kg. Not calibrating the movement per turn precisely may create errors of ± 0.5 mm.

Stress Relaxation Over Time for a Brittle and Ductile Specimen

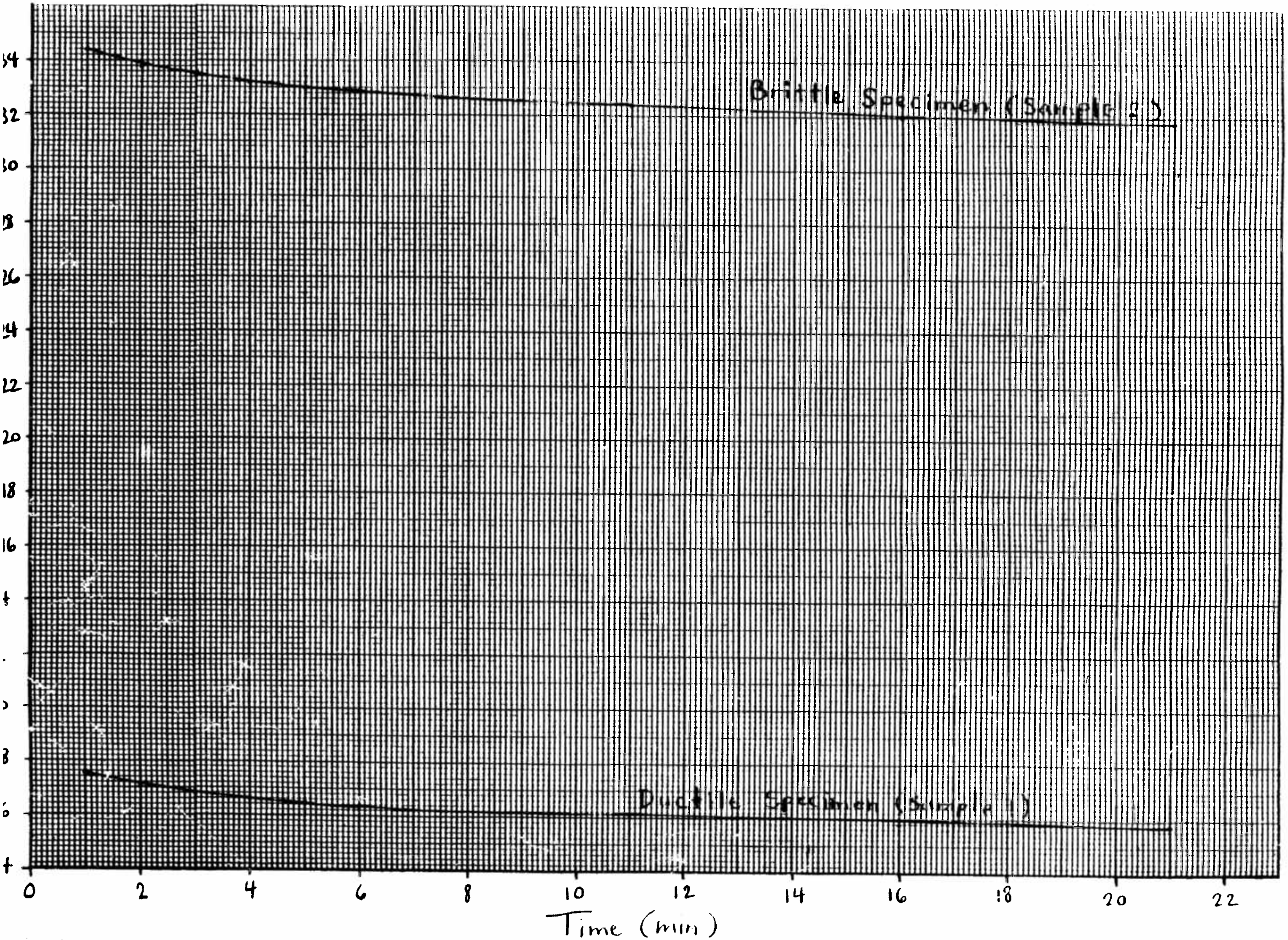


Table 8 : Stress relaxation for Ductile Specimen (Sample 1)

Time (min.)	Stress (MPa)
1	7.6
2	7.1
3	6.8
4	6.6
5	6.5
6	6.4
11	6.1
16	5.8
21	5.8

Table 9 : Stress relaxation for Brittle Specimen (Sample 2)

Time (min.)	Stress (MPa)
1	34.4
2	33.8
3	33.5
4	33.2
5	33.0
6	32.9
11	32.4
16	32.0
21	31.8

Conclusions:

Table 10: Elastic Moduli, yield stress, and fracture stress for Ductile and Brittle Specimens

	Ductile	Brittle
E (MPa)	77.6 ± 21.7	646 ± 90.4
σ_y (MPa)	17.9 ± 1.3	—
σ_f (MPa)	—	70.50 ± 1.6

→ 629.3 ± 88.10

→ 79.81 ± 1.94

263.74 ± 73.85

27.71 ± 3.0481

Thus, ~~it can~~ be concluded that the brittle specimen was stiffer than the ductile specimen (i.e. E was larger for brittle specimen than for ductile specimen). However, the brittle specimen was not as tough as the ductile specimen, resulting in fracture at a much lower strain as compared to the strain carried by the ductile specimen. The ductile specimen yielded at approximately 60% strain, whereas, the brittle specimen did not yield and fractured without warning at approximately 34% strain.

The brittle specimen displayed the greatest stress relaxation over time when compared to the ductile specimen.