MLL100: Introduction to Materials Science and Engineering – Lab Session-Exp-11 **Three-point bend test on glass slide**

Lab Group: A

Name and Entry no:

Anup Nayak 2022CS51827

Rohit Agarwal 2022ES11332

Harsh Mittal 2022ES11796

23/25

Reading reference:

Section 12.2: Brittle fracture (pp. 300 – 304) and Section 12.6: Protection against fracture (pp. 308 – 310) of Chapter 12 in Material Science and Engineering book (5th Edtn.) by V. Raghavan.

Safety precautions:

- Handle the equipment, chemicals and related accessories safely and with utmost care.

- **Conducting three-point bend test on glass slide**
  - Experimental Procedure:
    - Measure all the required initial dimensions of the glass slide using Callipers.
    - Mount the adapter, on the tensometer, for applying the three-point bending load to the glass slide sample.
    - Apply tensile load gradually on the tensometer and record the fracture load (P_f). Record the corresponding maximum deflection (δ_f).
    - Etch another glass slide in dilute HF for about 15 *min* and repeat the test as given in Step 3.
    - Consider the distance between the supports of three-point bending fixture, L = 63.5 *mm*.

- Observation and Calculations:

[2 marks]

S. No	**Sample and Experiment details**		
		Unetched glass	**Etched glass**
1	Width (b), m	23.15	23.11
2	Thickness (d), m	1.27	1.19
3	Load at fracture (F_f), kg	38.1	30.3
4	Fracture stress (σ_f) = Nm^{-2}	~~85.2~~ 97.13	88.2
5	Deflection at fracture (δ_f), m	1.6×10^{-3}	1.2×10^{-3}

2

$$\sigma_f = \frac{3FL}{2bd^2}$$

$$Y = \frac{FL^3}{4bd^3\delta}$$

The above formulas can be used for calculation purpose.

Where

σ_f: Fracture stress (or flexural strength)
F: Load applied at the point of fracture
L: Distance between the two supports
b: Width of the specimen's cross-section
d: Thickness of the specimen's cross-section
Y: Young's modulus
δ: Defection

Answer the following based on your experimental observations and understanding:

1. Plot a graph of load F vs deflection δ for both unetched and etched glass. [3 marks]

2. A) Calculate the fracture strength of unetched and etched glass. [2 marks]

$\sigma = \sqrt{\frac{2\gamma Y}{\pi a}}$ (Griffith's Equation)

$a = \frac{2\gamma Y}{\sigma^2 \pi}$

$\sigma_f = \frac{3FL}{2bd^2}$

$Y = \frac{FL^3}{4bd^3\delta}$

2

etched		unetched	
F = 30.2 N	L = 6.35 cm	F = 38.1 N	L = 6.35 cm
b = 23.11 mm	d = 1.19 mm	b = 23.15 mm	d = 1.27 mm
So, $\sigma_f = \frac{3(30.3)(6.35\times10^{-2})}{2(23.11\times10^{-3})(1.19\times10^{-3})^2}$		So, $\sigma_f = \frac{3(38.1)(6.35\times10^{-2})}{2(23.15\times10^{-3})(1.27\times10^{-3})^2}$	
$\sigma_f = 88.3$ MN/m²		$\sigma_f = \cancel{85.2}$ 97.13 MN/m²	

B) Using the Griffith's equation with the standard values for Y and γ of the glass (Surface energy, $\gamma = 0.2$ J m^{-2}; Young's Modulus, Y = 70 G Nm^{-2}), calculate the surface crack size. Comment on your observation. [3 marks]

$\sigma = \sqrt{\frac{2\gamma Y}{\pi a}}$ (Griffith's Equation)

Unetched Glass :

$Y = \frac{FL^3}{4bd^3\delta} = 70$ GN/m² (Given)

$a = \frac{2\gamma Y}{\sigma^2 \pi} = \frac{2\times0.2\times70\times10^9\times7}{(97.13)^2\times10^{12}\times22} = 0.92\times10^{-6}$ m
$= 0.92\ \mu m$

Etched

$$a = \frac{2 \times 0.2 \times 70 \times 10^9 \times 7}{(88.3)^2 \times 10^{12} \times 22} = 1.14\ \mu m$$

3

3. What was the effect of etching on the fracture strength (σ_t) of glass? Give reason for your observations. **[5 marks]**

3

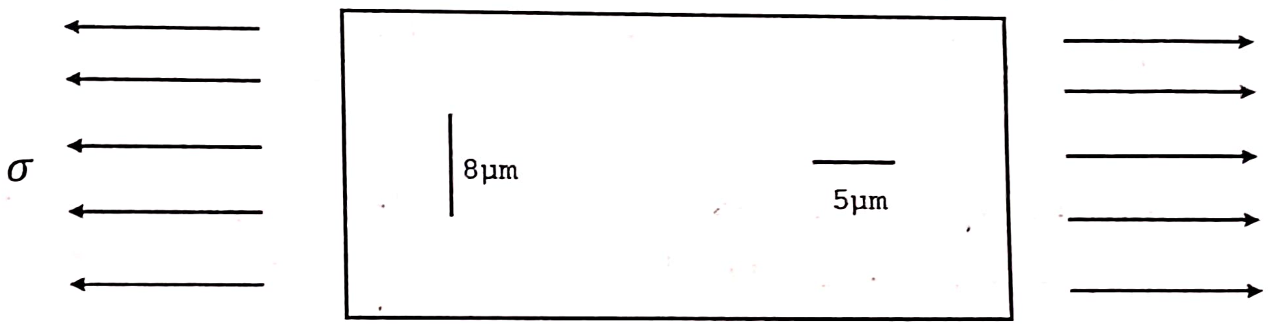
The fracture strength (σ_f) of ~~un~~etched glass is more than fracture strength (σ_f) of unetched glass. Theoretically since etching width HF acid removes the surface cracks. Etched glass has lesser number of surface crack deformations as compressed to unetched glass.

By griffith's equation $\sigma = \sqrt{\frac{2Y\gamma}{\pi a}}$, where a = half of crack length

∵ the no of cracks have reduced, as well the crack lengths (σ_f) etched > (σ_f) unetched as the crack propagation take larger load than before.

Explain observation ← But in our observation (σ_f) etched ~~= 67.68 GN/m²~~ < (σ_f) unetched ~~= 85.2 GN/m²~~

4. Which of the two cracks will propagate under the stress shown? Why? **[3marks]**



3

The crack of $L = 8\mu m$, perpendicular to the applied stress, will propagate under the stress shown as when a stress is applied parallel to the crack length (fibre length) the elongated cracks are ineffective, as there is no tensile stress perpendicular to the crack face

$$\sigma = \sqrt{\frac{2Y\gamma}{\pi a}}$$ (Griffith's equation)

for the crack of $l = 5\mu m$, $\gamma = 0$. Therefore, $\sigma = 0$ for the longitudinal crack.

5. Calculate the Young's modulus of the etched and unetched slide using the formula for three-point bending load. What is the effect of etching on the measure of Young's modulus of glass? Give reason for your observation. Estimate the maximum possible error in Y using the least counts of the variable involved in the expression to decide if there is a significant change in Y due to etching. **[5 marks]**

$Y = \frac{FL^3}{4bd^3\delta} = \frac{L^3}{4bd^3} \times \text{slope}$ ⇒ unetched glass, $Y = \frac{(28\,\cancel{\ldots})(5.35 \times 10^{-2})^3 \times 10^3}{4\,(23.15 \times 10^{-3})(1.29 \times 10^{-3})^3}$

~~etched glass, Y =~~

$\boxed{Y = 37.69\ GN/m^2}$

3

~~% error unetched =~~

% error of Y = $\left(\frac{\Delta F}{F} + \frac{\Delta b}{b} + \frac{3\Delta d}{d} + \frac{\Delta \delta}{\delta} + \frac{3\Delta L}{L}\right) \times 100$

For etched, % error Y = $\left(\frac{0.1}{38.1} + \frac{0.01}{23.15} + \frac{3\times 0.01}{1.29} + \frac{10^{-4}}{1.6\times 10^{-3}} + \frac{3\times 10^{-5}}{5.35\times 10^{-2}}\right) \times 100$

$= \boxed{8.97\%}$

etched glass, $Y = \frac{(30\,\cancel{\ldots})(5.35 \times 10^{-2})^3 \times 10^3}{4\,(27.11 \times 10^{-3})(1.19 \times 10^{-3})^3}$

$\boxed{Y = \cancel{28}\ 48.01\ GN/m^2}$ % error etched = $\boxed{11.27\%}$

6. Suggest methods for improving the fracture strength of glass. **[2 marks]**

1) Surface Treatment: When glass surface is etched with HF and the surface layers & the cracks in them are removed. This etched surface should be protected against further abrasion.

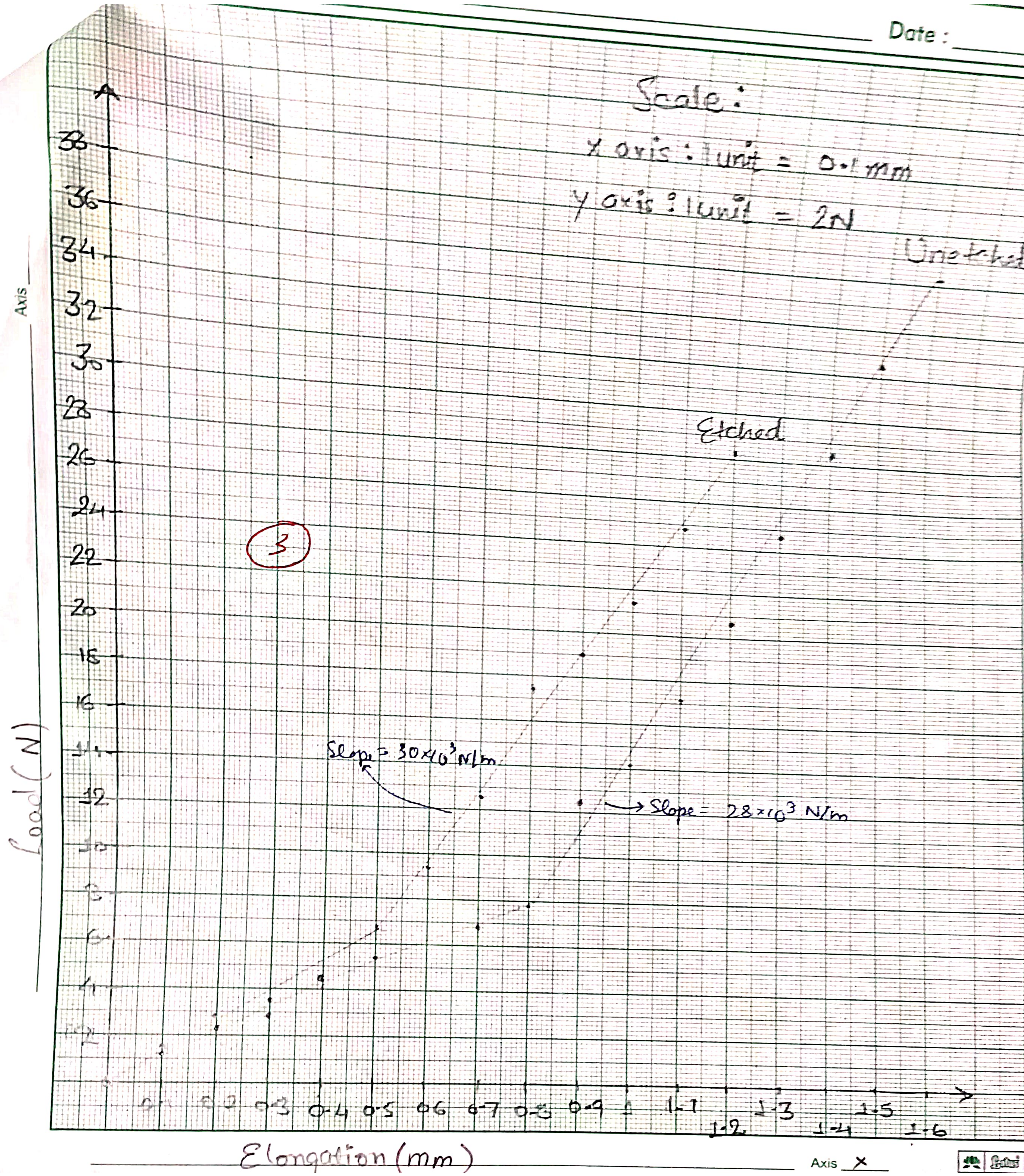
2) Introduction of compressive strength :- If a compressive ~~strength~~ stress is introduced at the surface, the tensile stress required to cause the surface cracks propagate is increased by a mag. eq. to the compressive stress.

2

3) Tempering :- Heat treatment which results in better resistance to crack propagation. Silicate glass is heated above its softening temperature & annealed long enough to remove all residual stresses. Then a contract become rigid. Eventually; the inside ~~of~~ is also resisted by the rigid outer layers & tensile stresses in the interior.

4) Ion-exchange method - compressive stresses are introduced in the surface layers by replacement of larger cations like K^+ by smaller cations like Na^+

Date :



Scale :
X axis : 1 unit = 0.1 mm
Y axis : 1 unit = 2N
Etched
Slope = 30×10³ N/m
Slope = 28×10³ N/m
3
Load (N)
Elongation (mm)

Axis X