# MAE 171A MECHANICAL ENGINEERING LABORATORY
## Materials Testing Laboratory
### Week 1 - LINEAR ELASTIC FRACTURE MECHANICS

*Objective:*

To gain an appreciation and understanding of the basic principles of fracture mechanics by determining the interrelationships of stress intensity, stress level, crack length, and crack tip radius using a series of specimen configurations.

*Materials:*

| Material | | Plane-Strain Fracture Toughness, $K_{IC}$ (MPa√m) | Tensile Yield Strength σ (MPa) |
|---|---|---|---|
| PMMA | Polymethylmethacrylate | 0.80 - 1.75 | 50-70 |
| PC | Polycarbonate | 2.75 - 3.30 | 55-69 |
| PP | Polypropylene | 1.70 - 2.00 | 33-36 |

*Example of Compact Tension Sample per ASTM D5045 -99*
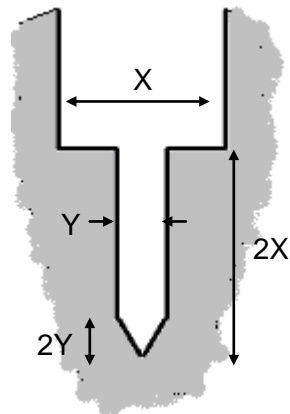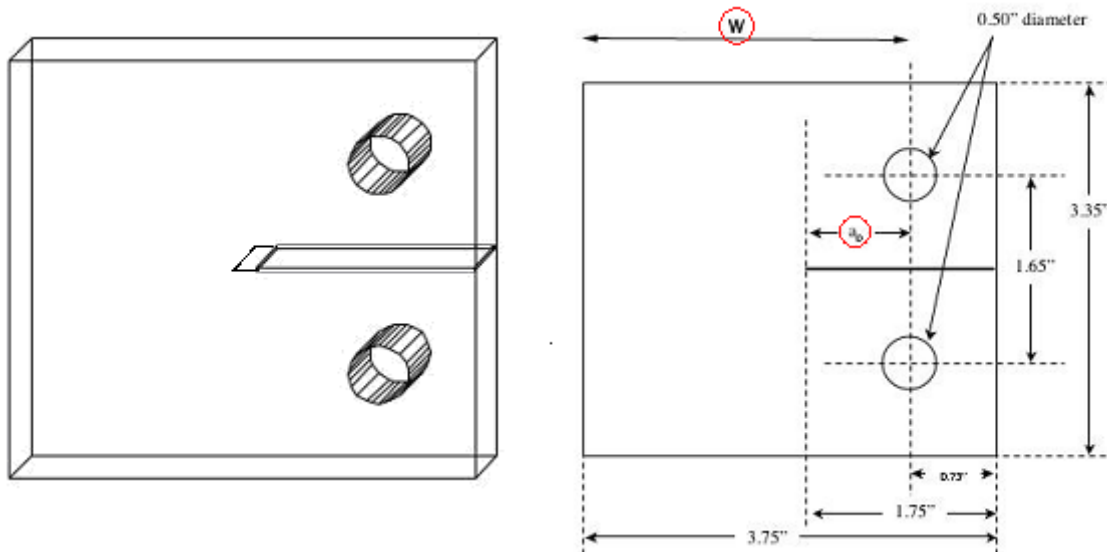




*Crack Tip Dimensions*

| Sample # | Material | Thickness B (inch) | Width W (inch) | Crack Length $a_o$ (inch) | Crack Tip Radius (inch) |
|----------|----------|--------------------|----------------|---------------------------|-------------------------|
| 1 | PMMA | 0.125 | 3.00 | 1.00 | ~0.005 |
| 2 | PMMA | 0.250 | 3.00 | 1.00 | ~0.005 |
| 3 | PMMA | 0.375 | 3.00 | 1.00 | ~0.005 |
| 4 | PMMA | 0.500 | 3.00 | 1.00 | ~0.005 |
| 5 | PMMA | 0.500 | 3.00 | 0.50 | ~0.005 |
| 6 | PMMA | 0.500 | 3.00 | 0.75 | ~0.005 |
| 7 | PMMA | 0.500 | 3.00 | 1.50 | ~0.005 |
| 8 | PMMA | 0.250 | 3.00 | 1.00 | ~0.016 |
| 9 | PMMA | 0.250 | 3.00 | 1.00 | ~0.031 |
| 10 | PMMA | 0.250 | 3.00 | 1.00 | ~0.047 |
| 11 | PMMA | 0.250 | 3.00 | 1.00 | ~0.075 |
| 12 | PC | 0.250 | 3.00 | 1.00 | ~0.005 |
| 13 | PP | 0.250 | 3.00 | 1.00 | ~0.005 |

## *Procedure:*

1. Measure each compact tension specimen (in *mm*) carefully with calipers prior to testing.
   a. The actual specimen thickness, specimen width (W), crack length ($a_o$), and crack-tip radius may differ from the chart.
   b. Measure the crack tip radius for each of the ~0.005 inch samples using the given microscope with micron measuring device.

2. Load all samples in the servohydraulic frame in tension at a nominal crosshead speed of 2 mm/min until fracture and store the load displacement record for each test.
   Output Units: Force        - N,              Stress - MPa
                      Displacement - mm,        K - MPa*m$^{1/2}$ [*It is calculated using N, m, MPa]

## *Analysis:*
## *Stress Intensity Factor, K*

1. Compare the stress intensity factors calculated using the crack length/load-at-fracture data for each of the specimens (1-13).

2. Are the values of *K* for each PMMA specimen the same? If so, is this a valid $K_{IC}$ value for the material? If not, explain why the values are different.

$$K = \frac{P}{B \cdot W^{1/2}} f\left(\frac{a}{W}\right)$$

$P$ = applied load at fracture (N)    $a$ = crack length (m)
$W$ = specimen width, (m)    $B$ = specimen thickness (m)

$$f\left(\frac{a}{W}\right) = \frac{2 + \left(\frac{a}{W}\right)}{\left[1 - \left(\frac{a}{W}\right)\right]^{3/2}} \left[0.886 + 4.64\left(\frac{a}{W}\right) - 13.32\left(\frac{a}{W}\right)^2 + 14.72\left(\frac{a}{W}\right)^3 - 5.6\left(\frac{a}{W}\right)^4\right]$$

3. Discuss the trends and plot the nominal stress at fracture ($P/BW$) for PMMA vs:
   a. Thickness          - Specimens 1-4
   b. Crack Length       - Specimens 4-7
   c. Crack Tip Radius   - Specimens 8-11

4. Plot the calculated fracture toughness ($K_{IC}$) vs. $a^{1/2}$ for each of the sharp-tip PMMA (r ~ 0.005) specimens on the same graph. It may help to plot Specimens 1-4, 5-7 with different colors.
   a. Is $K_{IC}$ a constant for all the specimens? Why or why not?
   b. Compare the values to the published data for PMMA
   c. What effect does the PMMA sample thickness have on the calculated fracture toughness?

5. How does the specimen thickness affect the conditions of plane strain versus plane stress? If the sample thickness does not appear to affect the calculated fracture toughness, explain why not in this case.

6. What are the main assumptions of linear elastic fracture mechanics and how do they affect the validity of the experiments conducted here?

7. What are the fracture toughness values determined for the PC and PP samples? How does the PC value compare to the published value for this material?

8. Discuss the molecular structure of the three materials (PMMA, PC, and PP) and relate the observed fracture behaviors and properties to the underlying structure of each polymer.

## Stress Concentration

1. Using the data from the specimens with the enlarged crack tips (r > 0.005), calculate the crack tip radius for each of the "sharp" machined crack PMMA specimens.

# MAE 171A MECHANICAL ENGINEERING LABORATORY

## Materials Testing Laboratory
## Week 2 - TIME-DEPENDENT DEFORMATION OF POLYMERS

### *Objective:*

The main objective is to gain an appreciation and understanding of *creep* and *stress relaxation* behaviors in various polymers. Polymers experience considerable time dependent deformation behavior, unlike metals and ceramics, and these behaviors must be accounted for in engineering designs that utilize polymers. This lab will demonstrate these time-dependent deformation behaviors and analyze the behaviors using some simple material models.

### *Materials:*

| | | |
|---|---|---|
| LDPE | - | Low-density polyethylene |
| HDPE | - | High-density polyethylene |
| UHDPE | - | Ultra-high density polyethylene |
| PP | - | Polypropylene. |
| Teflon | | |

Sample Geometry: Right regular compression cylinders

| Test | Sample Number | Material | Height and Width Pre – Test (mm) | Height and Width (mm) every 5 min for an hour | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | 0 min | 5 min | 10 min | ….. | 60 min |
| *Creep* | 1 | LDPE | | | | | | |
| | 2 | HDPE | | | | | | |
| | 3 | UHDPE | | | | | | |
| | 4 | PP | | | | | | |
| | 5 | Teflon | | | | | | |
| *Stress Relaxation* | 6 | LDPE | | | | | | |
| | 7 | HDPE | | | | | | |
| | 8 | UHDPE | | | | | | |
| | 9 | PP | | | | | | |
| | 10 | Teflon | | | | | | |

## *Procedure:*

1. Label and lightly sand the edges of 2 specimens of each of the 5 materials so that they are burr-free and parallel.

2. Measure the width (at the center), and height of each specimen in mm carefully prior to testing.

3. Using the *Creep Test* procedures in the load frame control system, conduct one creep test on a specimen of each material, recording the stress and strain as a function of time.

> 3.1 After the sample is removed from the load frame, measure its length and diameter:
> a) Immediately
> b) Every minute for the $1^{st}$ 5 minutes
> c) Every 5 minutes thereafter for the next hour.
> ** You may want to run 5 simultaneous stopwatches online, to track the measuring times of each of the samples as they exit the load frame)

> 3.2 Plot:
> a) Creep modulus as a function of time for all the materials in the same plot.
> b) Sample stress and strain as a function of time and best fit of the data to the *Voight or 4 Element Model*, whichever fits better, for creep deformation for each material in a separate plot.
> c) Specimen dimension data recorded after removing the creep samples from the test frame.

> 3.5 Compute the strain in the sample from both the length data and the diameter data as a function of time and plot this data for each material. Comment on the trends in this data and relate these results to the previous creep and stress relaxation test data.

> 3.4 Report the values for the relaxation times ($\tau$) for each material, and discuss the trends in the data between the various materials, and specifically for the variation in the values for the different molecular weight polyethylene materials.

4. Using the *Stress Relaxation Test* procedure in the load frame control system, conduct one stress relaxation test on a specimen of each material, recording the stress and strain as a function of time (you do not need to measure these samples after testing).

4.1  Plot:
   a)  Relaxation modulus as a function of time for all the materials in the same plot.
   b)  Sample stress and strain as a function of time for each material in a separate plot. In the same plot, do a best fit of the data to the ***Maxwell model*** or ***Standard Liner Solid model (three elements or Kelvin model),*** whichever fits better, for stress relaxation.

4.3  Report the values for the relaxation time, $\tau$, and the viscosity, $\eta$, for each material.  Discuss the trends in the data between the various materials, and specifically for the variation in the values for the different molecular weight polyethylene materials.

5.  Compare the values of the relaxation time, $\tau$, obtained from the stress relaxation experiment and the creep experiment.  Are they similar for the same material?  Do they vary in a similar manner as a function of molecular weight for the 3 polyethylene materials?

6. Look up the molecular and physical characteristics of each polymer tested in this lab such as: formula, molecular weight, glass transition temperature, elastic modulus, etc., and discuss how these characteristic relate to your observed material behaviors.

# MAE 171A MECHANICAL ENGINEERING LABORATORY
## Materials Testing Laboratory
## Week 3 - EFFECT OF TEMPERATURE ON FRACTURE MECHANICS OF POLYMERS

## *Objective:*
Determine the effect of the temperature on the fracture mechanics of polymers.

## *Materials:*

| Material | | Plane-Strain Fracture Toughness (room temperature) $K_{IC}$ (MPa√m) | Tensile Yield Strength σ (MPa) |
|---|---|---|---|
| PMMA | Polymethylmethacrylate | 0.8 - 1.75 | 50-70 |
| PC | Polycarbonate | 2.75 - 3.3 | 55-69 |
| PP | Polypropylene | 1.70 – 2.00 | 33-36 |

### *Example of Compact Tension Sample per ASTM D5045 -99*



Sample Identification and Approximate Dimensions
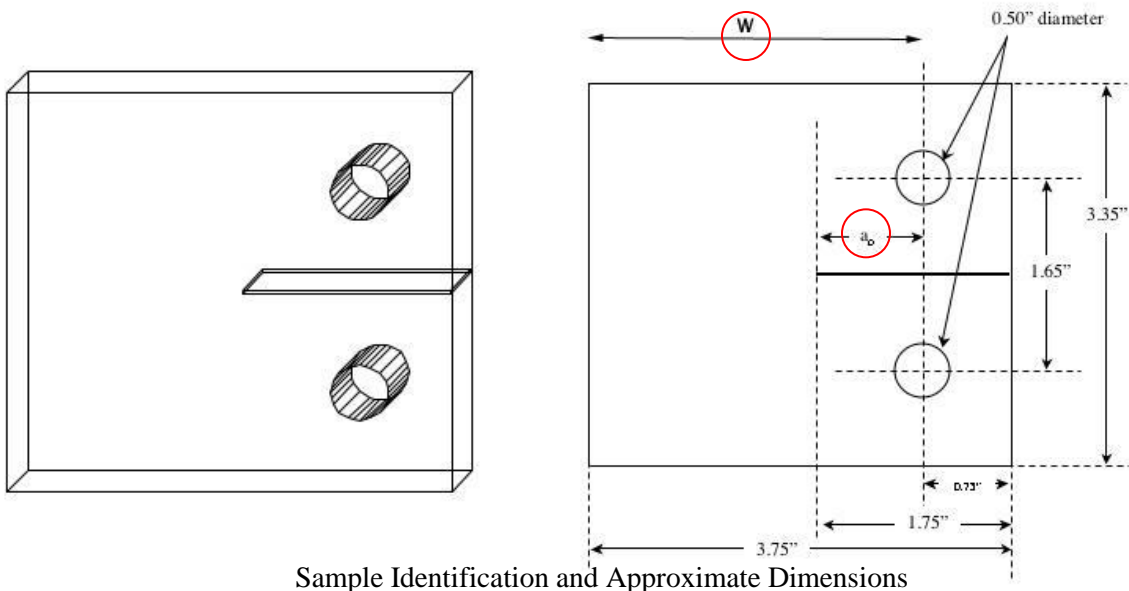
| Sample #'s (cold, room, hot) | Material | Thickness | Width | Crack Length, $a_o$ | Crack Tip Radius |
|---|---|---|---|---|---|
| 1 – 3 | PMMA | 0.500 inch | 3.75 inch | 1 inch | ~0.005 inch |
| 4 - 6 | PC | 0.500 inch | 3.75 inch | 1 inch | ~0.005 inch |
| 7 - 9 | PP | 0.500 inch | 3.75 inch | 1 inch | ~0.005 inch |

**Cold and room temperatures samples are translucent, hot samples are painted black

*Test Temperatures:* The tensile tests will be conducted at 3 different temperatures:
~0°C (cold) , ~25°C (room) and ~70°C(hot).

## *Procedure (refer to ASME standard how to read load-deflection curve, follow 5% rule)*

*Stress Intensity Factor, K*

1. Measure the width (w) and crack length ($a_o$) with the calipers as done in Week 1. The crack tip radii will be assumed to be equal to those of the similar samples in week 1.
2. Place one translucent specimen of each material on the ice bath and wait until their temperatures become uniform.
3. Perform the heated sample test
   a. Place a painted sample in the load frame with the painted side facing away
   b. Attach a thermocouple to the back of the sample, close to the crack tip, using the accompanying clip.
   c. Place a 120-watt IR bulb at a short distance from the crack tip.
   d. Wait for the sample to reach a steady temperature - A feedback controller connected to the lamp and thermocouple will cause the lamp to blink once a steady a state temperature of 70°C is reached.
   e. Perform tension tests as done in Week 1.
4. Test the room temperature samples, and then the cold samples in the load frame
5. Store the load displacement record for each test conducted at the 3 temperatures.

## *Analysis:*

1. Compare the stress intensity factors calculated using the crack length/load-at-fracture data for each of the specimens. Is K equal to $K_{IC}$?

$$K = \frac{P}{BW^{1/2}} f\left(\frac{a}{W}\right)$$

$$f\left(\frac{a}{W}\right) = \frac{2 + \left(\frac{a}{W}\right)}{\left[1 - \left(\frac{a}{W}\right)\right]^{3/2}} \left[0.886 + 4.64\left(\frac{a}{W}\right) - 13.32\left(\frac{a}{W}\right)^2 + 14.72\left(\frac{a}{W}\right)^3 - 5.6\left(\frac{a}{W}\right)^4\right]$$

$P$ = applied load at fracture,      $a$ = crack length,
$W$ = specimen width,                $B$ = specimen thickness..

2. Plot the calculated fracture toughness $K_{IC}$ vs $T$ (temperature) for each material. What effect does the temperature have on the calculated fracture toughness?

3. In the lab of week 2, you have looked up the molecular and physical characteristics of each polymer tested in this lab such as: formula, molecular weight, glass transition temperature, elastic modulus, etc. Discuss how these characteristics relate to your observed material behaviors.

4. Discuss the possible strengthening effect of the temperature.