ME 354, MECHANICS OF MATERIALS LABORATORY

FRACTURE

01 January 2000 / mgj

PURPOSE

The purpose of this exercise is to study the effects of cracks in decreasing the load-carrying ability of structures and to determine the plane strain critical stress intensity factor, K_{Ic}, for single-edge notched specimens.

EQUIPMENT

- Single-edge notched tensile specimens of polymethyl methacrylate (PMMA) and polycarbonate (PC)
- Tensile test machine with grips, controller, and data acquisition system

PROCEDURE

- Measure the width and thicknss of the gage section for each specimen to 0.02 mm.
- Measure the notch length for each specimen to 0.02 mm.
- Zero the force output (balance).
- Activate force protect (~50 N) on the test machine to prevent overloading the specimen during installation.
- Install the top end of the tensile specimen in the top grip of the test machine while the test machine is in displacement control.
- Install the bottom end of the tensile specimen in the lower grip of the test machine.
- In displacement control adjust the actuator position of the test machine to achieve nearly zero force on the specimen.
- Deactivate force protect.
- Initiate the data acquistion and control program.
- Enter the correct file name and specimen information as required.
- Initiate the test sequence via the computer program.
- Continue the test until specimen fracture.
- Confirm the initial notch length for each specimen.
- Examine the fracture surface to note any evidence of subcritical crack growth. Note the appearance of the fracture surfaces.
- Examine the force versus displacement trace each test. Note the force at fracture initiation, P_Q, and maximum force, P_{max}, at fracture.

* REFERENCES

Annual Book or ASTM Standards, American Society for Testing and Materials, Vol. 3.01

E399 Standard Test Method for Plane Strain Fracture Toughness of Metallic Materials

RESULTS

Anticipated fracture forces will first be calculated for un-notched and notched specimens at yield and ultimate tensile strengths. These forces will be compared to anticipated fracture forces assuming single-edge notched tensile specimens such that:

$$K_Q = F(\alpha)\frac{P_Q}{WB}\sqrt{\pi a}$$

where $\alpha = a/W$ (1).

$$F(\alpha) = 0.265(1-\alpha)^4 + \frac{0.857+0.265\alpha}{(1-\alpha)^{3/2}} \quad \text{for } (h/W \geq 1)$$

where P_Q is the tentative fracture force, W is the gage section width, B is the gage section thickness, a is the notch/crack length, h is half the gage section length and K_Q is the tentative fracture toughness value.

Compare the relation of K_{Ic} versus yield strength for these alloys to that of other materials and comment on the susceptibility of these materials to fracture or yielding. Use your own sourses of information (e.g. tensile test laboratory results).

Silicon nitride (ceramic) alloys		6061-T6 Aluminum alloy		1018 HR Steel alloy	
E (GPa)	310	E (GPa)		E (GPa)	
σ_o (MPa)	$= S_{UTS}$ =500-1000	σ_o (MPa)		σ_o (MPa)	
S_{UTS} (MPa)	$= \sigma_o$ =500-1000	S_{UTS} (MPa)		S_{UTS} (MPa)	
% elongation	0.25-0.5	% elongation		% elongation	
K_{Ic} $(MPa\sqrt{m})$	5-10	K_{Ic} $(MPa\sqrt{m})$		K_{Ic} $(MPa\sqrt{m})$	

Design Concerns and Failure Criterion
(Fracture Mechanics, Maximum Normal Stress, or Yield Stress?)

PMMA polymer		PC polymer	
E (GPa)		E (GPa)	
σ_o (MPa)		σ_o (MPa)	
S_{UTS} (MPa)		S_{UTS} (MPa)	
% elongation		% elongation	
K_{Ic} $(MPa\sqrt{m})$		K_{Ic} $(MPa\sqrt{m})$	

Design Concerns and Failure Criterion
(Fracture Mechanics, Maximum Normal Stress, or Yield Stress?)

Show all work and answers on the Worksheet, turning this in as the In-class Laboratory report.

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WORK SHEET

NAME____**DATE**_____________

EQUIPMENT IDENTIFICATION____

1) Determine (look up) the following mechanical properties.

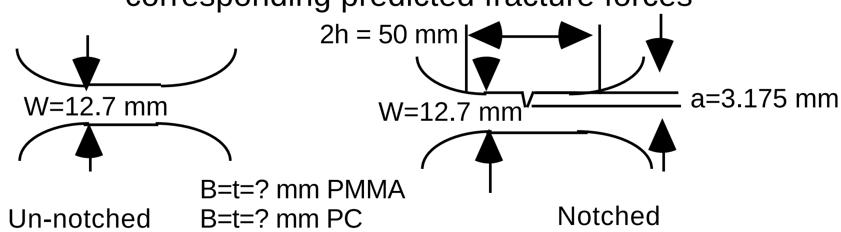
PMMA (acrylic)
Selected Mechanical Properties (R.T.)

E (GPa)	
σ_o (MPa)	estimate as S_{uts}
S_{UTS} (MPa)	
% elongation	
K_{Ic} $(MPa\sqrt{m})$	

PC (polycarbonate)
Selected Mechanical Properties (R.T.)

E (GPa)	
σ_o (MPa)	estimate as $S_{uts}/2$
S_{UTS} (MPa)	
% elongation	
K_{Ic} $(MPa\sqrt{m})$	

2) For the following NOMINAL specimen dimensions, determine the corresponding predicted fracture forces



Un-notched (PMMA)
B=t=______mm
Yield: $P_m = \sigma_o A_W = \sigma_o WB =$ __________N
Ultimate: $P_m = S_{UTS} A_W = S_{UTS} WB =$ __________N

Un-notched (PC)
B=t=______mm
Yield: $P_m = \sigma_o A_W = \sigma_o WB =$ __________N
Ultimate: $P_m = S_{UTS} A_W = S_{UTS} WB =$ __________N

Notched (PMMA) [Net cross section]
Yield: $P_m = \sigma_o A_{W-a} = \sigma_o (W-a)B =$ _______N
Ultimate: $P_m = S_{UTS} A_{W-a} = S_{UTS}(W-a)B =$ ______N

Notched (PC) [Net cross section]
Yield: $P_m = \sigma_o A_{W-a} = \sigma_o (W-a)B =$ ______N
Ultimate: $P_m = S_{UTS} A_{W-a} = S_{UTS}(W-a)B =$ ___N

Fracture (PMMA)
a = ______m for K_{Ic} but a = _____mm for a/W
W = _____________ mm
a/W = α = _____________
B = _____________ mm
K_{Ic}= _____________ $MPa\sqrt{m}$

$$F(\alpha) = 0.265(1-\alpha)^4 + \frac{0.857+0.265\alpha}{(1-\alpha)^{3/2}}$$ = ________

for($h/W \geq 1$) where $\alpha = a/W$

$$P_f = \frac{K_{Ic} WB}{F(\alpha)\sqrt{\pi a}}$$ = _____________N

Fracture (PC)
a = ______m for K_{Ic} but a = _____mm for a/W
W = _____________ mm
a/W = α = _____________
B = _____________ mm
K_{Ic}= _____________ $MPa\sqrt{m}$

$$F(\alpha) = 0.265(1-\alpha)^4 + \frac{0.857+0.265\alpha}{(1-\alpha)^{3/2}}$$ = ________

for($h/W \geq 1$) where $\alpha = a/W$

$$P_f = \frac{K_{Ic} WB}{F(\alpha)\sqrt{\pi a}}$$ = _____________N

3) Determine the fracture initiation force, P_Q and the maximum force, Pmax from the force vs displacment test results. Measure the actual width, W, actual thickness, B, and actual notch/crack length, a.

PMMA
Fracture Test Results

W (mm) (measured)	
B=t (mm) (measured)	
a (mm) (measured)	
P_Q (N) (measured)	
P_{max} (N) (measured)	

PC
Fracture Test Results

W (mm) (measured)	
B=t (mm) (measured)	
a (mm) (measured)	
P_Q (N) (measured)	
P_{max} (N) (measured)	

4) Compare the measured fracture initiation force, P_Q, , to the predicted forces, P_m and P_f, calculated above. Which approach (Un-notched or Notched (yield and ultimate) or Fracture) is closer to the measured fracture force? Is this what you expected? If so, why or why not?

Note: Do the 'fracture' tests meet the requirements of ASTM E399?

i) Valid specimen with pre-crack and known S.I.F., **ii)** $\frac{P_{max}}{P_Q} < 1.10$ and **iii)** $B > 2.5\left(\frac{K_{Ic}}{\sigma_o}\right)^2$

Based on these results, are cracks or crack-like notches important concerns to a designer? How would you design to account for these features?

5) Calculate a tentative plane strain fracture toughness value, K_Q, from the fracture force and compare this to the 'book' value of the plane strain fracture toughness, K_{Ic} .

PMMA

$$F(\alpha) = 0.265(1-\alpha)^4 + \frac{0.857+0.265\alpha}{(1-\alpha)^{3/2}} = \_\_\_\_\_\_\_\_$$

for(h/W $\geq$1) where α = a/W

a = ____________ m

$$K_Q = F(\alpha)\frac{P_Q}{WB}\sqrt{\pi a} = \_\_\_\_\_\_\_ \left(MPa\sqrt{m}\right)$$

PC

$$F(\alpha) = 0.265(1-\alpha)^4 + \frac{0.857+0.265\alpha}{(1-\alpha)^{3/2}} = \_\_\_\_\_\_\_\_$$

for(h/W $\geq$1) where α = a/W

a = ____________ m

$$K_Q = F(\alpha)\frac{P_Q}{WB}\sqrt{\pi a} = \_\_\_\_\_\_\_ \left(MPa\sqrt{m}\right)$$

PMMA
Fracture Test Results

K_Q $\left(MPa\sqrt{m}\right)$	
K_{Ic} $\left(MPa\sqrt{m}\right)$	

PC
Fracture Test Results

K_Q $\left(MPa\sqrt{m}\right)$	
K_{Ic} $\left(MPa\sqrt{m}\right)$	

Are K_Q and K_{Ic} similar? If not, what factors (e.g. simulated crack, ductility, test rate, material properties, etc.) might account for these differences? Are these valid fracture tests or more notch sensitivity tests? Do these tests indicate a susceptibility of components comprised of certain materials to brittle fracture from crack or crack-like notches, even though they normally display moderate ductility?