Fracture Toughness Testing
# Organization for Expts. 5 and 7 (weeks of 4/2 and 4/16)

## Experiment 5
- Lab in 127 Norris
- Can visit lab in advance Monday 4/2 and Monday 4/16 from 9am-12pm
- Submit logbook preparation to TA in advance as normal
- Two teams working together to test three samples. Lab is over when samples tested and logbooks complete (may not take full lab period).
- Your regular TA will be there.
- Each team submits their completed logbook to their TA before leaving lab

## Experiment 7
- Lab in Stability Tunnel
- Can visit in advance Friday 3/30 and Friday 4/13 from 8am to 12pm and 1pm to 5pm.
- Submit logbook preparation to TA in advance as normal
- First team* arrives at start of lab period. Has 75 mins to complete test. Second team arrives 90 minutes after start of lab, has 75 mins for test.
- Regular TA not there. Submit logbook to wind tunnel operator before leaving lab

* First team is the team with the lowest number on the experiment schedule

Don’t forget laptops
Organization for 5th Instrumentation Lab Period (week of 4/9)

- Lab in Randolph 25 (next to the open-jet tunnel)
- Apply digital data acquisition and processing, including your own LabView programs, to the dynamic beam structure of Experiment 6
- Works just like a regular experiment
  - Read manual (chapter 5 of instrumentation lab)
  - Meet with your team in advance
  - Visit the lab
  - Do a logbook preparation
  - Logbook submitted and end of lab is graded
- Note your logbook preparation should be submitted to Dustin Grissom (dgrissom@vt.edu) not your regular TA.

Don’t forget laptops
Fracture

- Breaking of structural components into two or more parts
- Brittle fracture - low energy absorption
- Ductile fracture - large energy absorption
Tanker SS Schenectady

(24 hours after launch)
Aloha Airlines
Aloha Airlines
Why does fracture occur?

- Load increases to a point where cracks grow catastrophically.
- There are always cracks
  - They form as part of the manufacturing
  - They develop over time as a result of fatigue
- The strength of materials in the presence of cracks is therefore critical in defining when they will fail.
F-111 Crack
The Ideal Crack

The Linear Elastic Fracture Mechanics (LEFM) Approach

Infinite flat plate

Plastic zone (radius $r_0$)

Even though the crack is embedded in a plastic zone, it is the elastic solution, in particular $K$ that determines the stress field through which the crack would advance.

Local stress $\sigma_x, \sigma_y$

Elastic solution

$$\sigma_x, \sigma_y = \frac{K}{\sqrt{2\pi x}}$$

where $K = \sigma \sqrt{\pi a}$

Plastic zone

Material yields

Distance from crack $x$
Stress Intensity Factor $K$

The Linear Elastic Fracture Mechanics (LEFM) Approach

- Scale of the elastic stress field generated by the crack
- Units of
  - Pa√m (usually MPa√m)
  - p.s.i.√in (usually k.s.i.√in)
- The stress intensity when the crack advances catastrophically is a measure of the strength of the material in the presence of a crack.
- This is called the Fracture Toughness $K_c$

Elastic solution

$$\sigma_x, \sigma_y = \frac{K}{\sqrt{2\pi x}}$$

where $K = \sigma \sqrt{\pi a}$
Effect of Thickness

Thin Plate

Deformation in z results in:
- stresses in only x and y - **Plane Stress**
- relief of some of the stress around crack
- a large fracture toughness, that depends on thickness
- ductile fracture takes place by tearing on 45° plane
Effect of Thickness

Thick Plate

$$\sigma (\text{uniform background stress})$$

$$\sigma_y$$

$$\sigma_z \neq 0 \text{ but } \varepsilon_z = 0$$

(Poisson contraction prevented by surrounding material)

Fracture by cleavage

Lack of deformation in z results in:

- strain in only x and y - **Plane Strain**
- no relief of stress around crack
- a lower fracture toughness, that is independent of thickness
- brittle fracture on horizontal plane
Effect of Thickness

Fracture toughness $K_c$

Plane Strain Fracture toughness $K_{Ic}$

$\text{Thickness } t$
$K_{Ic}$ for different materials

<table>
<thead>
<tr>
<th>material</th>
<th>yield</th>
<th>toughness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>2024-T851</td>
<td>455 MPa</td>
</tr>
<tr>
<td></td>
<td>7075-T651</td>
<td>495 MPa</td>
</tr>
<tr>
<td>Titanium</td>
<td>Ti-6Al-4V</td>
<td>910 MPa</td>
</tr>
<tr>
<td></td>
<td>*Ti-6Al-4V</td>
<td>1035 MPa</td>
</tr>
<tr>
<td>Steel</td>
<td>4340</td>
<td>860 MPa</td>
</tr>
<tr>
<td></td>
<td>*4340</td>
<td>1515 MPa</td>
</tr>
<tr>
<td></td>
<td>52100</td>
<td>2070 MPa</td>
</tr>
</tbody>
</table>

* heat treated for higher strength
Experiment 5

• Objective
  – To measure this material property, the plain strain fracture toughness, for Aluminum

• Approach
  – Break samples of different thickness using fracture toughness testing procedures specified in ASTM Standard No. E399

• Organization
  – Two teams of students have 3 samples between them

• Location
  – ESM Materials Lab, Norris 127
Samples

- Measure displacement vs. load until sample breaks.
- Identify load at fracture $P_Q$
- Use this to determine fracture toughness

Pre-crack generated by fatiguing the sample
Load and Displacement

**Extensometer**
(senses crack opening displacement)

Jaws fit in notches in side of sample

Clevis grips hold sample in machine

**Testing machine**
(applies displacement, senses force)

**Computer with LabView**
(reads and records load and displacement)

Controller and A/D
Broken Samples

Pre-crack

Pre-crack
Load at Fracture?

- Ductile or brittle?
- Elastic or plastic?
- Note that deciding when fracture occurs involves some choices.

Loadcell range 10 kips
Extensometer range 0.075"

Manufacturer gives:
Loadcell accuracy 10lbs
Extensometer accuracy 0.000075"
Fracture Toughness?

- Real sample is finite and applied stress is not uniform.
- However, if plastic zone is small enough then a region exists where stress field behaves as though sample is infinite.
- The stress intensity in this region is a function of the applied load and the sample geometry. This function is known in the form of a curve fit, derived from finite element analysis.

\[
K = \frac{P}{t \sqrt{w}} f\left(\frac{a_i}{w}\right)
\]

In $\infty$ case $K = \sigma \sqrt{\pi a}$
Ex. 5 Summary

• Pre-defined goal and procedures
• Two teams collaborate to break 3 samples
• Measure/photo samples before and after fracture
• Analyze the load vs displacement curves and the sample dimensions are analyzed to yield
  – The fracture toughness
  – The plastic zone size
  – Whether the sample is in plane stress or plane strain
• When you have completed all analysis, and have a plot of fracture toughness vs. sample thickness you are done.