ME 354 MECHANICS OF MATERIALS LABORATORY

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# MECHANICAL PROPERTIES AND PERFORMANCE OF MATERIALS: Part a) Charpy V-Notch Impact

February 2004 PEL

## PURPOSE

The purpose of this exercise is to obtain a number of experimental results important for the characterization of the mechanical behavior of materials. The Charpy V-notch impact is a mechanical test for determining qualitative results for material properties and performance which are useful in engineering design, analysis of structures, and materials development.

## EQUIPMENT

- Charpy V-notch test specimens of 6061-T6 aluminum and 1018 (hot rolled) or A36 steel
- Charpy testing machine with 800-mm long pendulum arm and 22.6-kg impact head
- Type K thermocouple and digital readout unit
- Beakers of room-temperature water, warm water and boiling water
- Beakers of plain iced water
- Cryo-beakers of salted iced water and super cold liquids

## PROCEDURE

CAUTION: When using the Charpy testing machine, stand well clear of the swinging area of the pendulum both when the arm is cocked and for some time after the arm is released for a test while it is still swinging. Serious injury will result from a swinging pendulum arm.

For each material repeat the following steps

- Designate a person as the "operator" of the Charpy test machine: all other persons must stand clear during testing
- Designate a person as the "monitor and recorder" of temperatures and impact energies
- Designate a person as the "test specimen loader" who will remove test specimens from the liquid bath, quickly placing them on the test fixture of the Charpy testing machine
- Designate a person as the "test specimen retriever" who will retrieve the broken halves of the test specimens, will bind the halves together and will mark the test temperature on each pair of specimen halves for later examination and inspection. Use the following procedure to conduct tests in the order shown after exposure to the preconditions to give the approximate test temperatures indicated:

Room temperature water (20 to 25°C)
Warm water (50-60 °C)
Boiling water (95-100°C)
Ice water (0 to 4°C)
Salted ice water (-15 to -18°C)
Acetone with some dry ice (-50 to -57°C)
Acetone with much dry ice (-80 to -85°C)

- Place the thermocouple probe in the appropriate liquid being sure to allow both the test specimens and the thermocouple to equilibrate for at least five minutes prior to testing.
- Record the indicated temperature

• "Cock" the pendulum by activating the "raise" mechanism and stand clear while the pendulum is held in the "cocked" position.
• Using the tongs, quickly remove the test specimen from the bath and place it on the test fixture with the notch opening facing away from the direction of the cocked pendulum
• Stand clear
• Release the pendulum
• Secure the pendulum in its rest position (i.e., hanging vertically) and retrieve the fractured specimen halves.
• Record the impact energy (read directly from the dial on the Charpy testing machine)
• Repeat these steps for the each temperature and each material.

## BACKGROUND AND ANALYSIS

Static or quasi-static properties and performance of materials are very much a function of the processing of the material (heat treatments, cold working, etc.) in addition to design and service factors such as stress raisers and cracks. The behaviour of materials is also dependent on the rate at which the force is applied. For example, a polycarbonate tensile specimen which might show a relatively low yield point but up to 200% elongation at a low loading rate may show a much greater yield point but at only 5% elongation at an order of magnitude faster loading rate. Low carbon steels, such as 1018, may show considerable increases in yield strength and work hardening at high strain rates.

In quasi-static tests, the amount of energy required to deform a material is determined from the area under the tensile stress-strain curve and is know as the modulus of toughness. Under dynamic loading, stress-strain response is typically not recorded. Instead, the transfer of energy from a device such as a drop weight or a swinging specimen to the deforming or breaking specimen is equated to the "impact energy." The Charpy impact test uses a standard Charpy impact machine to evaluate this impact energy. The machine consists of a rigid specimen holder and a swinging pendulum hammer for striking the impact blow to a v-notched specimen as shown in Figs. 1 and 2. Unfortunately, while the test, including machine and specimen geometry, has been standardized, the test results do not provide definitive information about material properties and thus are not directly applicable to design (as for example might be a yield strength); however, the test is useful for comparing variations in the metallurgical structure of materials and in determining environmental effects, such as temperature on the dynamic response of the material. One of the most dramatic results of Charpy impact tests is in the form of plots of impact energy versus temperature in which sigmoidally-shaped curves (see Fig. 3) show substantial decreases in some materials' abilities to absorb energy below a certain transition temperature. This ductile to brittle transition is most apparent in materials with BCC and HCP crystalline structures as for example in steels and titanium. A classic and dramatic example of this ductile to brittle behaviour is the low carbon steel Victory ships of WWII cracking in half under even the mild conditions of sitting at anchor in a harbor. Materials with FCC structures (e.g., aluminum and copper) have many slip systems and are more resistant to brittle fracture at low temperatures.

In this laboratory exercise the primary outcome will be plots of impact energy versus temperature for two materials (FCC-606-T6 aluminum and BCC-1018 steel). Note the effects of temperature and material type on the levels and shapes of the curves. Examine the fracture surfaces of specimens and compare the type and degree of deformation to the impact energy and the corresponding temperature. Consider not only the type of material, but also the effect of notches and temperature in making design decisions.

REFERENCE:

Annual Book or ASTM Standards, American Society for Testing and Materials, Vol. 3.01
E23 Standard Test Methods for Notched Bar Impact Testing of Metallic Materials

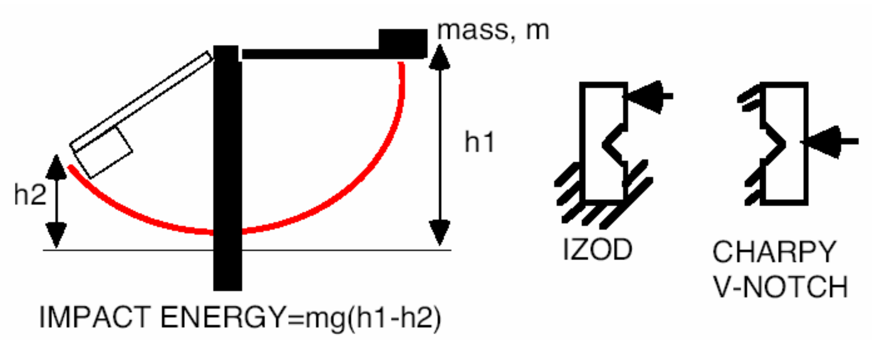



Figure 1. Schematic of Charpy Impact Testing and Izod and Charpy V-notch specimens

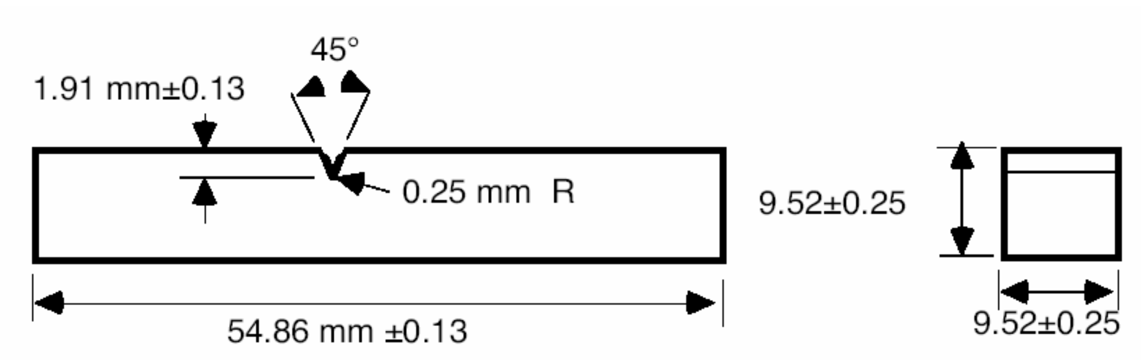



Figure 2 Charpy V-notch specimen used in this laboratory showing dimensions

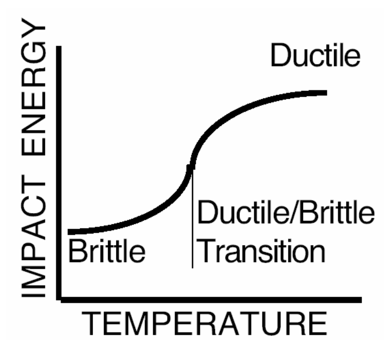



Figure 3. Schematic of plot of impact energy versus temperature showing sigmoidal curve

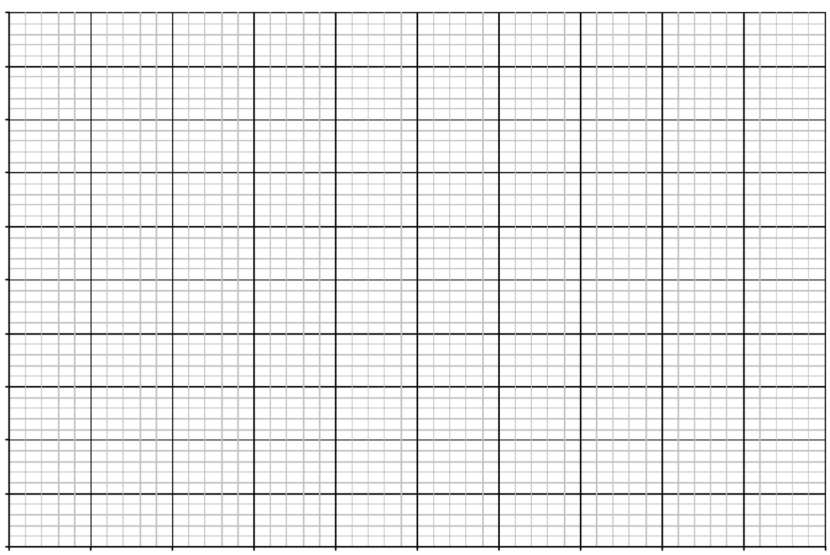
<u>DATA</u>

Fill in the following table:

| | Impact Energy (J) | |
|---|---|---|
| | 6061 T6 Aluminum | 1018 (HR) or A26 steel |
| Boiling hot temperature ( $^{o}$C) | | |
| Warm temperature ( $^{o}$C) | | |
| Room temperature ( $^{o}$C) | | |
| Freezing temperature ( $^{o}$C) | | |
| Cold temperature ( $^{o}$C) | | |
| Very cold temperature ( $^{o}$C) | | |

<u>RESULTS AND DISCUSSION</u>

Plot the impact energy versus temperature for each material on the same graph.



Compare these impact results for each metal to tabulated values from a source such as the ASM Metals Handbook. Comment on differences and similarities.

Examine the type and degree of deformation of each fracture surface. Correlate this information with the corresponding impact energies. Comment on the correlations.

ME 354 MECHANICS OF MATERIALS LABORATORY

# MECHANICAL PROPERTIES AND PERFORMANCE OF MATERIALS: Part b) Stress Intensity Factors

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## PURPOSE

To measure the plane strain critical stress intensity factor ($K_{Ic}$) of polycarbonate and acrylic, using the single edge-notch specimen geometry.

## PROCEDURE:

(a) Measure the following dimensions for both the polycarbonate and acrylic specimens:

- gage width
- gage thickness
- notch length

Record these measurements in Table 1

Perform the following steps for the acrylic specimen, with the Instron in displacement control:

(b) Zero the load cell by initiating the "calibrate" routine

(c) Check to make sure both grips are open, so that the specimen slides freely between the grips. Then use the actuator controls to position the grips so that the specimen ends will be fully clamped.

(d) Install the specimen: tighten the upper grip first, subsequently tighten the bottom grip

(e) Initiate the data acquisition and control program…stop the test after specimen failure

(f) Examine the fracture surfaces. In particular, note any evidence of subcritical crack growth. Describe your observations in the space provided on the following page.

(g) Examine the force versus displacement curves. Record the force applied at the moment of fracture initiation, $P_Q$, and the maximum force applied, $P_{max}$, in Table 1.

Repeat steps (b)-(g) for the polycarbonate specimen.

## DATA REDUCTION

For this specimen geometry the mode I stress intensity factor is given by:

$$K_{Ic} = F(a)\frac{P_Q}{W\,t}\sqrt{p\,a}$$

where: $$F(a) = 0.265(1-a)^4 + \frac{0.857 - 0.265a}{(1-a)^{3/2}} \qquad a = \frac{a}{w}$$

and the measure value of $K_{Ic}$ is valid if:

$$\frac{P_{\max}}{P_Q} < 1.10 \quad \text{and} \quad t > 2.5\left(\frac{K_{Ic}}{s_o}\right)^2$$

## DATA

Fill in the following table:

| | Acrylic (PMMA) | | Polycarbonate | |
|---|---|---|---|---|
| | Test #1 | Test #2 | Test#1 | Test #2 |
| Gage Width *w* (mm) | | | | |
| Gage Thickness *t* (mm) | | | | |
| Initial Notch Length *a* (mm) | | | | |
| $P_Q$ (N) | | | | |
| $P_{max}$ (N) | | | | |

## RESULTS AND DISCUSSION

Fill in the following table:

| | Acrylic (PMMA) | | Polycarbonate | |
|---|---|---|---|---|
| | Test #1 | Test #2 | Test #1 | Test #2 |
| $K_{Ic}$ (measured) | | | | |
| $P_{max} / P_Q$ (measured) | | | | |
| $2.5 (K_{Ic} / s_o)^2$ (measured) | | | | |
| Test Valid (yes/no)? | | | | |
| $K_{Ic}$ (handbook-textbook) | | | | |

Description of the failure surfaces:

(a) For the acrylic specimen:

(b) For the polycarbonate specimen:

Recall that the stress-strain response of acrylic and polycarbonate was measured during lab 2. Based on the single-edge notch tests conducted today, are cracks (or crack-like notches) important concerns to the design engineer? Were the measured and handbook values of $K_{Ic}$ for acrylic and polycarbonate similar? If not, what factors caused the differences?