

NOTCHED BAR IMPACT TESTING OF MATERIALS

Background

Materials sometimes display brittleness which precludes their use in a given design. Brittleness is characterized by fracturing with low energy under impact. The fracture energy is proportional to the area under the tensile stress-strain curve and is called the **toughness**. Tough steel is generally **ductile** and requires 100 ft-lbs of energy to cause failure. **Brittle** steel does not deform very much during failure and requires less than 15 ft-lbs energy to cause failure.

Characterizing the toughness of a material is done in several ways. The most common method is the notched-bar impact test for which two types of specimens prevail, **Charpy** and **Izod**. By subjecting a specimen to an impact load, it will fail if the load exceeds the breaking strength of the material. By using a swinging pendulum to impart the load, the energy required to fracture the specimen can be calculated by observing the height the pendulum swings after fracture, as shown in **Figure 2-1**.

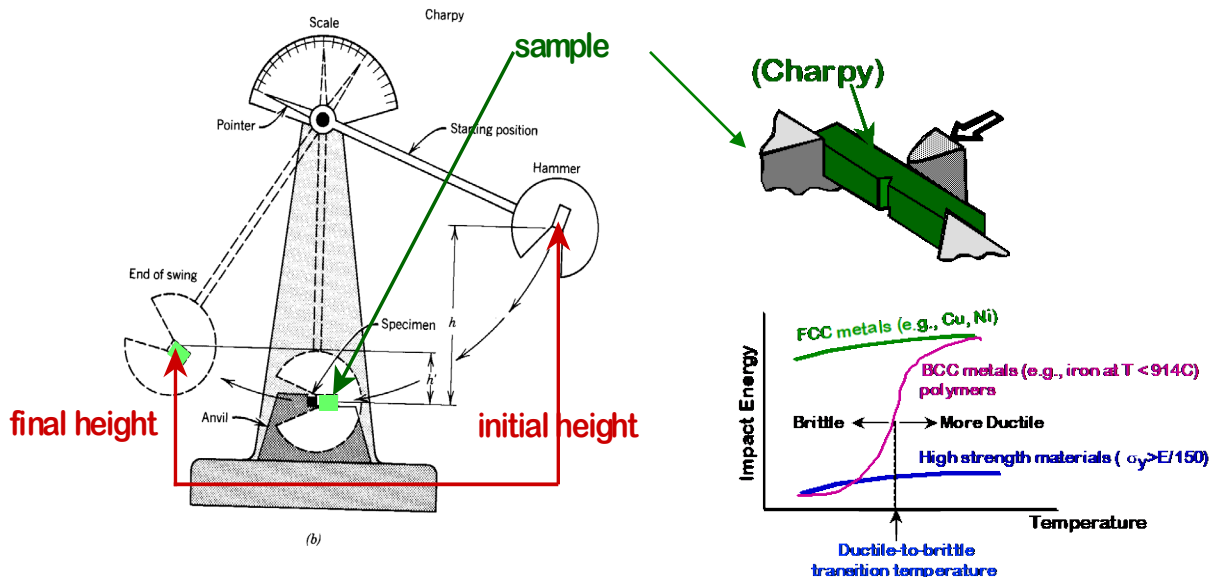


Figure 2-1: Charpy impact tester, sample positioned in anvil and general testing results.

This test has been used almost exclusively with **body-centered-cubic** (bcc) crystalline materials. These materials show a **transition** from ductile to brittle behavior with temperature (**Figure 2-2**). This means that at low temperature the fracture energy is low.

The mechanical behavior of materials often exhibits variations even for seemingly identical specimens and materials. The steel specimens for this experiment are manufactured from a single ingot of steel and are machined to a single drawing. Despite these precautions, the results from identical tests will not always be identical.

Variations in properties are often evaluated by means of statistics to establish the average value and the possible variance in the results. The amount of shear in the surface failure of steels can

be determined by looking at the fresh failure surface under low-power magnification (approx 3X). A smooth surface is characteristic of **shear**. A fine grained fracture surface is characteristic of **cleavage** and brittleness (**Figure 2-3**). Often failures are mixed (part shear and part cleavage).

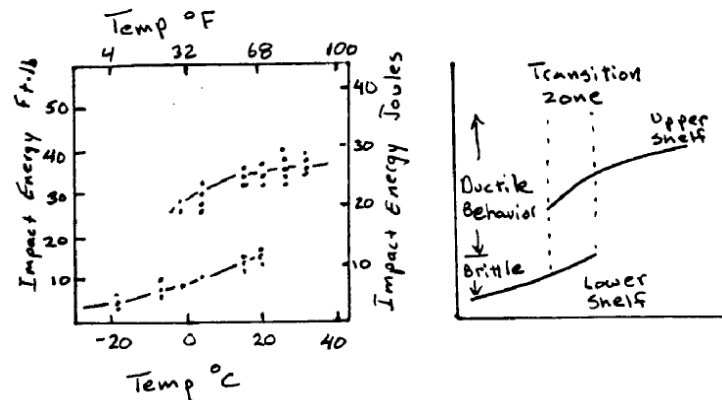


Figure 2-2: Impact Energy transition from ductile to brittle behavior.

If no plastic deformation accompanies fracture, it is generally a brittle fracture, i.e. cleavage. In the impact test the amount of plastic deformation is characterized by lateral expansion. **Lateral expansion** is a thickening of the specimen during fracturing. Looking at half the failed specimen, the lateral expansion is measured as shown in **Figure 2-3**.

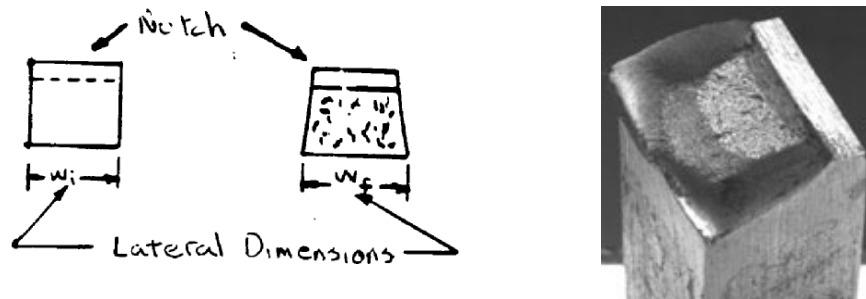


Figure 2-3: Lateral expansion of Charpy impact specimen.

where lateral expansion = $\Delta w = w_f - w_i$
 w_f = final lateral dimension
 w_i = initial lateral dimension

Technical Approach

The experiment consists of investigating the ductile-to-brittle transition in 1018-steel and the aluminum alloy (2024 or 6061) as a function of temperature. The Charpy impact specimens of each material are immersed in a bath for 10 minutes to reach thermal equilibrium at five separate temperatures ranging from -110°F (-79°C) to 212°F (100°C). The specimens are quickly transferred to the Charpy testing machine, fractured, and the impact energy is measured. After failure the fracture surfaces are examined for evidence of shear or cleavage failure and lateral expansion at the root of the notch.

Equipment

Thermocouple

Temperature Baths
 Charpy Impact Machine
 Tongs
 Digital caliper

<u>SAFETY INFORMATION</u>	
DURING THE COURSE OF THIS EXPERIMENT YOU WILL BE USING A DEWAR OF ACETONE WHICH HAS BEEN COOLED USING DRY ICE TO THE TEMPERATURE OF DRY ICE (-110°F or -79°C). CARE MUST BE TAKEN TO AVOID EXPOSURE TO SKIN OR EYES. THE EXPOSURE MAY CAUSE BURNS AND OTHER EFFECTS. STUDENTS ARE ADVISED TO TAKE THE FOLLOWING PRECAUTIONS:	
1.	Be careful to slowly insert specimens into the baths.
2.	Use tongs to insert and remove specimens.
3.	Do not drop specimens into bath. (Dewar will break).
4.	While transporting the Dewar, use the special cart set up for that purpose.

Procedure

1. Review safety considerations. **Label each specimen** using a hammer and punch.
2. Identify and measure the **initial lateral dimensions** of all specimens.
3. **Conduct impact tests** on 5 as received 1018-steel and five aluminum (2024 or 6061) specimens heated or cooled to dry ice, antifreeze bath with some dry ice, ice water, boiling water and room temperature. For consistent results, it is important that all specimens be positioned identically in the anvil of the Charpy impact tester; use the special tongs provided to correctly position the specimen. The notch on the specimen must face 180° opposite to the hammer.
4. **Measure lateral dimensions after impact.** Observe the nature of the fracture surface of steel specimens. The fracture specimens should all be carefully examined and particular attention should be paid to the type of fracture that is obtained in each particular case. Try to relate the type of fracture to the energy absorbed by the metal being fractured. A binocular microscope is available to study these fractures carefully. **Look for cleavage and shear and estimate the fraction area of each.**

<u>SAFETY INFORMATION</u>	
BEFORE USING THE IMPACT MACHINE, THE INSTRUCTOR WILL SHOW YOU EXACTLY HOW TO OPERATE IT. ALWAYS TAKE GREAT CARE IN HOW YOU HANDLE THE MACHINE TO AVOID ACCIDENTS.	

If the specimens are transferred rapidly to the machine, it can be assumed that the temperatures at which they are broken are those of the baths in which they have been held. Desired bath temperatures are:

dry ice/acetone bath	- 110 °F	(- 79 °C)
antifreeze/water mix with some dry ice	- 40 °F	(- 40 °C)
ice/pure water	32 °F	(0 °C)
room temperature	72 °F	(23 °C)
boiling water	212 °F	(100 °C)

Write up and discussion

Prepare a memo report. Relate the type of fracture observed to the energy absorbed by the metal. Try to relate the type of fractures observed (shear or cleavage) to the test temperatures. Report the fraction area

of cleavage and shear to nearest 20%. Compare the variation of impact energy with temperature observed for steel and aluminum.

Plot the results obtained **using Excel**; graphs should compare (**overlay**) the 1018-steel and aluminum (2024 or 6061) samples:

- 1) impact energies vs temperature
- 2) changes in width vs temperature
- 3) shear % vs temperature

Using the attached data from Tables 1 and 2 **and the data you collected from testing**, calculate the **average value** of the fracture energy at each temperature. Graph the **average fracture energy versus temperature for steel and for aluminum**. Overlay this with **the standard deviation for 13 data points**. **The average and standard deviation can be calculated using Excel.**

Table 1: temperature and impact energy values for steel.

steel	Temp °C				
	-70	-44	0	25	100
Impact energy (ft-lbs)	5	35	57	78	65
	7	32	48	69	83
	18	26	55	67	94
	14	39	54	68	80
	10	27	67	75	95
	10	30	63	76	90
	5	16	35	76	94
	6	16	34	76	103
	5	16	61	76	94
	6	17	47	66	73
	13	19	54	70	85
	8	19	41	66	108

Table 2: temperature and impact energy values for aluminum.

Aluminum	Temp °C				
	-70	-44	0	25	100
Impact energy (ft-lbs)	9	10	9	8	8
	8	9	8	9	8
	9	8	9	8	9
	9	8	8	8	9
	10	10	10	10	10
	9	10	11	10	8
	8	7	9	11	11
	8	8	7	8	8
	11	7	8	7	9
	8	7	7	8	7
	6	7	7	8	8
	7	8	8	8	8

The Standard Deviation is given by:

$$SD = \sqrt{\frac{(x_i - \bar{x})^2}{(n - 1)}}$$

where: x_i = individual fracture energy value

$$\bar{x} = \frac{x_i}{n}$$

n = number of values (data points)

Plot the upper and lower values of the standard deviation versus temperature on the chart with the average value of the fracture energy (one graph for steel, one graph for aluminum). The additional data from other groups is used to make these calculations.

Glossary of Terms

Understanding the following terms will aid in understanding this experiment:

Body-centered cubic. Common atomic arrangement for metals consisting of eight atoms sitting on the corners of a cube and a ninth atom at the cubes center.

Brittle. Lacking in deformability.

Cleavage. Brittle fracture along particular crystallographic planes in the grains of the material.

Ductile fracture. Fracture of a material with significant deformation required.

Ductility. The ability of a material to be permanently deformed without breaking when a force is applied.

Face-centered cubic. Common atomic arrangement for metals consisting of eight atoms sitting on the corners of a cube and six additional atoms sitting in the center of each face of the cube.

Fracture. Failure or breakage of a material.

Impact energy. The energy required to fracture a standard specimen when the load is suddenly applied.

Impact test. Measures the ability of a material to absorb a sudden application of a load without breaking. The Charpy test is a commonly used impact test.

Lateral expansion. The lateral change in dimension of a Charpy impact specimen due to fracture. The dimension measured is the width opposite the v-notch (see Fig. 1-3).

Plastic deformation. Permanent deformation of the material when a load is applied, then removed.

Shear. Deformation due to parallel crystallographic planes.

Shear lip. The surface formed by ductile fracture that is at a 45° angle to the direction of the applied stress.

Toughness. A qualitative measure of the impact properties of a material. A material that resists failure by impact is said to be tough (also given as the total area under the stress-strain curve).

Transition temperature. The temperature below which a material behaves in a brittle manner in an impact test.