As in the tension test, the Modulus of Resilience is the area under the elastic portion of the τ - γ curve such that

$$U_r = \int_o^{\gamma_o} \tau \, d\gamma \qquad (5.55)$$

Similarly, the Modulus of Toughness is the area under the total τ - γ curve such that

$$U_t = \int_o^{\gamma_f} \tau \, d\gamma \qquad (5.56)$$

The Modulus of Rigidity (or Shear Modulus), G, is the slope of the τ - γ curve in the elastic region and is comparable to Young's Modulus, E, found in tension. Recall that the relation between E and G is $G = \frac{\Delta\tau}{\Delta\gamma} = \frac{E}{2(1+\upsilon)}$.

The true shear stress-strain curve can be compared to the tensile true stress-strain curve by converting the normal values to shear values. The conversion is as follows:

Elastic range: τ equivalent = $\frac{\sigma}{2}$; γ equivalent = 1.25ε (5.57)

Plastic range: τ equivalent = $\frac{\sigma}{2}$; γ equivalent = 1.5ε (5.58)

That these values are correct can be seen from Mohr's circle of stress and of strain for the elastic and plastic ranges (Fig. 5.15). Knowledge of Poisson's ratio, υ, is needed for Mohr's circles of strain for the tensile test. For mild steel in the elastic range, υ = .0.30; in the plastic range, υ =0.5 as a result of the constant volume assumption.

Impact

The static properties of materials and their attendant mechanical behavior are very much functions of factors such as the heat treatment the material may have received as well as design factors such as stress concentrations.

The behavior of a material is also dependent on the rate at which the load is applied. Polymeric materials and metals which show delayed yielding are most sensitive to load application rate. Low-carbon steel, for example, shows a considerable increase in yield strength with increasing rate of strain. In addition, increased work hardening occurs at high-strain rates. This results in reduced local necking, hence, a greater overall material ductility occurs. A practical application of these effects is apparent in the fabrication of parts by high-strain rate methods such as explosive forming. This method results in larger amounts of plastic deformation than conventional forming methods and, at the same time, imparts increased strength and dimensional stability to the part.

In design applications, impact situations are frequently encountered, such as cylinder head bolts, in which it is necessary for the part to absorb a certain amount of energy without failure. In the static test, this energy absorption ability is called "toughness" and is indicated by the modulus of rupture. A similar "toughness" measurement is required for dynamic loadings; this measurement is made with a standard ASTM impact test known as the Izod or Charpy test. When using one of these impact tests, a small notched specimen is broken in flexure by a single blow from a swinging pendulum. With the Charpy test, the specimen is supported as a simple beam, while in the Izod it is held as a cantilever. Figure 5.16 shows standard configurations for Izod (cantilever) and Charpy (three-point) impact tests.

A standard Charpy impact machine is used. This machine consists essentially of a rigid specimen holder and a swinging pendulum hammer for striking the impact blow (see Fig. 5.17). Impact energy is simply the difference in potential energies of the pendulum before and after striking the specimen. The machine is calibrated to read the fracture energy in N-m or J directly from a pointer which indicates the angular rotation of the pendulum after the specimen has been fractured.

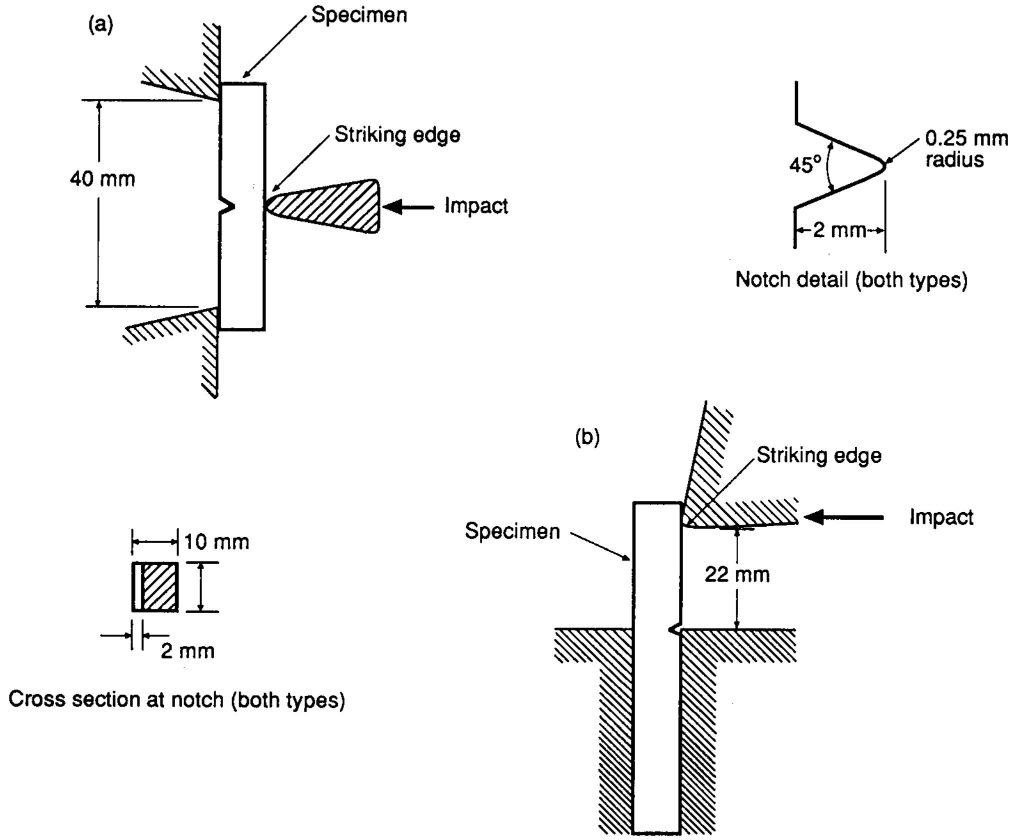
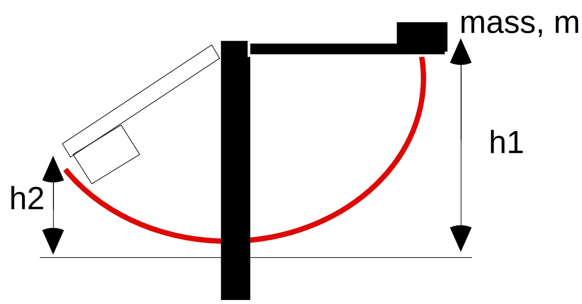


Figure 5.16 Charpy and Izod impact specimens and test configurations



IMPACT ENERGY=mg(h1-h2)

Figure 5.17 Charpy and Izod impact specimens and test configurations

The Charpy test does not simulate any particular design situation and data obtained from this test are not directly applicable to design work as are data such as yield strength. The test is useful, however, in comparing variations in the metallurgical structure of the metal and in determining environmental effects such as temperature. It is often used in acceptance specifications for materials used in impact situations, such as gears, shafts, or bolts. It can have useful applications to design when a correlation can be found between Charpy values and impact failures of actual parts.

Curves as shown in Fig. 5.18 showing the energy to fracture as measured by a Charpy test indicate a transition temperature, at which the ability of the material to absorb energy changes drastically. The transition temperature is that temperature at which, under impact conditions, the material's behavior changes from ductile to brittle. This change in the behavior is effected by many variables. Metals that have a face-centered cubic crystalline structure such as aluminum and copper have many slip systems and are the most resistant to low-energy fracture at low-temperature. Most metals with body-centered cubic structures (like steel) and some hexagonal crystal structures show a sharp transition temperature and are brittle at low temperatures.

Considering steel; coarse grain size, strain hardening, and certain minor impurities can raise the transition temperature whereas fine grain size and certain alloying elements will increase the low temperature toughness. Figure 5.18 shows the effect of heat treatment on alloy steel 3140 and 2340. Note that a transition temperature as high as about 25°C is shown. This material, then should not be in service below temperature of 25°C when impact conditions are likely to exist.

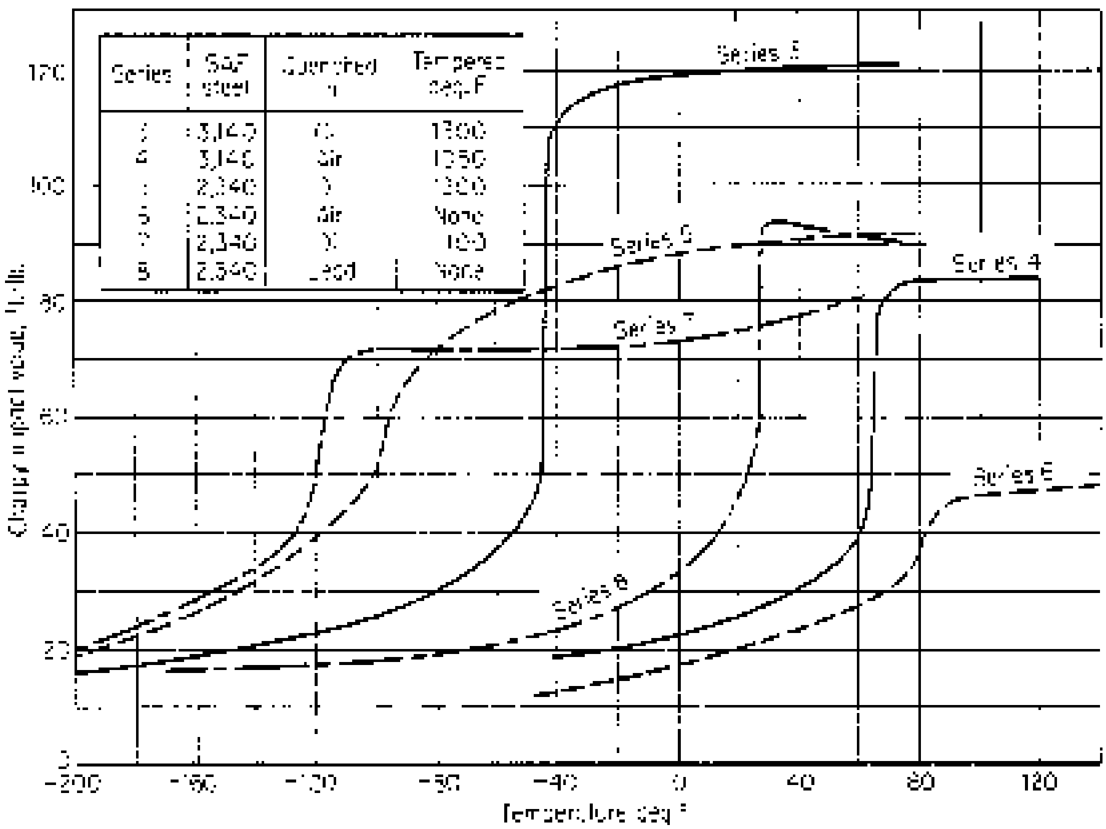


Figure 5.18 Variation in transition-temperature range for steel in the Charpy test

In defining notch "toughness", a number of criteria have been proposed to define the transition temperature. These include:

a. some critical energy level

b. a measure of ductility such as lateral contraction of the specimen after fracture

c. fracture surface appearance - the brittle fracture surface has a crystalline appearance, while the portion of the specimen which fracture in a ductile manner will have a so-called fibrous appearance.

Any of these criteria are usable. Perhaps the most direct criteria for a particular metal is to define the transition temperature as that temperature at which some minimum amount of energy is required to fracture. During World War II, allied Victory ships literally broke in two in conditions as mild as standing at the dock because of the use of steel with a high-transition temperature, coupled with high-stress concentrations. It was found that specimens cut from plates of these ships averaged only 9 J. Charpy energy absorption at the service temperature. Ship plates were resistant to failure if the energy absorption value was raised to 20 J at the service temperature by proper control of impurities.