Chapter 3: Mechanical Behavior and Testing

Introduction. In manufacturing operations, parts and components of products are formed into a wide variety of shapes by applying **external forces** to the workpiece, typically by means of various tools and dies. Common examples of such operations are **forging** of turbine disks, **drawing** wire for making nails, and **rolling** metal to make sheets for car bodies, **appliances**, and office equipment. Forming operations may be carried out at room **temperature** or **elevated temperatures** and at a low or a high **rate of deformation**. This chapter covers those aspects of mechanical properties and behavior of metals that are relevant to the design and manufacturing of products, and includes commonly used test methods employed in **assessing** various properties.

Tension. The **tension** test is the most commonly used method for determining the mechanical properties of materials, such as **strength**, **ductility**, **toughness**, **elastic modulus**, and strain-hardening capability.

The **engineering stress**, also called **nominal stress**, is defined as the ratio of the applied load, P, to the original **cross-sectional** area, A_0, of the specimen (P/A_0). **Permanent** (plastic) deformation occurs when the yield stress, Y, of the material is reached (see Fig. 1). The maximum engineering stress is called the **tensile strength** or **ultimate tensile strength** (**UTS**) of the material. If the specimen is loaded beyond its UTS, it begins to **neck**; the cross-sectional area of the specimen is no longer **uniform** along the **gage length** and is smaller in the necked region. As the test **progresses**, the engineering stress drops further and the specimen finally **fractures** at the necked region. The engineering stress at fracture is known as the **breaking** or **fracture stress**.

A. Define the following expressions (you can use Google search).

True (actual) stress: ………………………………………………………………………………………….……. .

Toughness: …… .

Strain rate: …… .

Fracture stress: …………………………………………………………………………………………..…… .

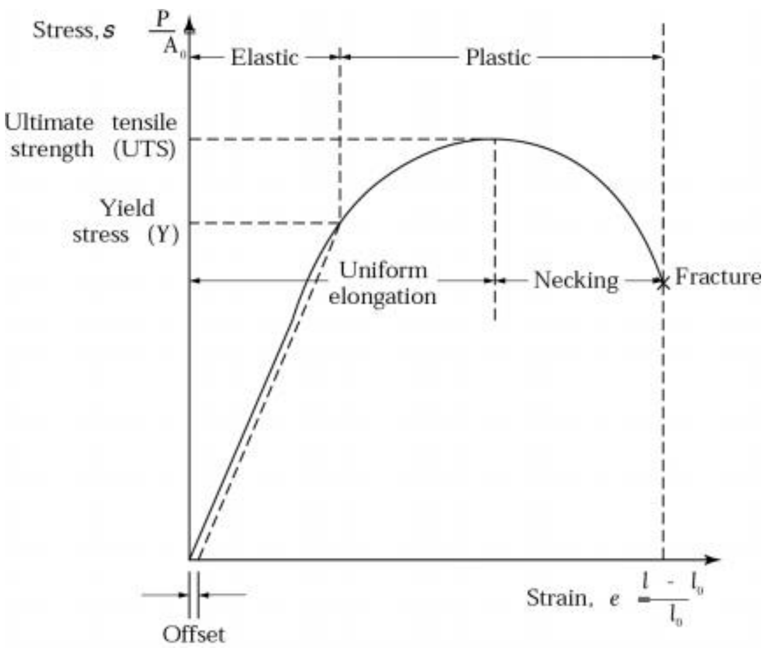

Fig. 1 A typical stress–strain curve obtained from a tension test, showing various features.

Compression. Numerous operations in manufacturing, such as forging and **rolling**, are performed with the workpiece subjected to **compressive** forces. The **compression test**, in which the specimen is subjected to a compressive load, gives information that is helpful in **estimating** forces and power requirements in these processes. This test is usually carried out by compressing a solid cylindrical specimen between two **well-lubricated** flat dies (**platens**). Because of **friction** between the specimen and the platens, the specimen's cylindrical surface **bulges**, called **barreling** (see Fig. 2).

Fig. 2 Barreling in compressing a round solid cylindrical specimen between flat dies.

Torsion. In addition to undergoing tensile and compressive forces, a workpiece may also be subjected to **shear** strains, such as in the punching of holes in sheet metals and machining. The method generally used to determine properties of materials in shear is the torsion test. The ratio of the shear stress to the shear strain in the elastic range is known as the **shear modulus**, or **modulus of rigidity**, *G*.

Bending (Flexure). A commonly used test method for **brittle** materials is the **bend** or **flexure test**, which typically involves a specimen that has a rectangular cross-section and is **supported** in a manner shown in Fig. 3. The load is applied vertically, at either one point or two points; consequently, these tests are referred to as three-point and four-point bending, **respectively**.

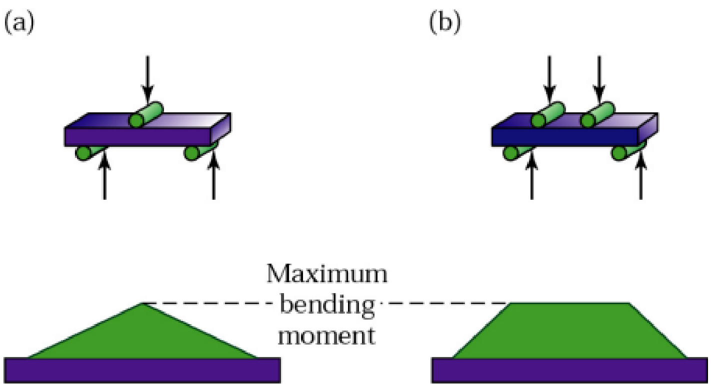

Fig. 3 Two bend-test methods for brittle materials: (a) three-point bending; (b) four-point bending.

B. Fill in the blanks with the following words.

indenter, scratching, resistance, wear, property

Hardness. **Hardness** is generally defined as ……………………… to permanent **indentation**; thus, steel is harder than aluminum and aluminum is harder than lead. Hardness, however, is not a fundamental ………………., because the resistance to indentation depends on the shape of the ……………………… and on the load applied. Hardness is a commonly used property; it gives a general indication of the strength of the material and of its resistance to ……………………… and …………………. . Several test methods, using different indenter materials and shapes, have been developed to **measure** the hardness of materials. The most commonly used hardness tests are: Brinell, Rockwell and Vickers.

Fatigue. Numerous components, such as tools, dies, **gears**, **cams**, **shafts**, and **springs**, are subjected to rapidly **fluctuating** (**cyclic** or **periodic**) loads, in addition to **static** loads. Under these loads, the component **fails** at a stress level below that at which **failure** would occur under static loading. Known as **fatigue** failure, this phenomenon is responsible for the majority of failures in mechanical components. Fatigue test methods involve testing specimens under various states of stress, usually in a combination of tension and bending. The test is carried out at various stress amplitudes (S), and the number of cycles (N) it takes to cause total failure of the specimen or part is then recorded.

Creep.**Creep** is the permanent deformation of a component under a static load maintained for a period of time. This phenomenon occurs in metals and some nonmetallic materials, such as thermoplastics and rubbers, and it can occur at any temperature; lead, for example, creeps under a constant tensile load at room temperature. Creep is especially important in high-temperature applications, such as gas-turbine blades and components in jet engines and rocket motors.

C. Fill in the blanks with the following words.

notched, dissipated, dynamic, metalworking, cantilever

Impact. In numerous machinery components and manufacturing operations, materials are subjected to **impact**, or **……………………**, loading; for example, in high-speed ………………………….. processes such as **heading** to shape nails and bolt heads.

A typical impact test for determining impact properties of materials consists of placing a **……………………** specimen in an impact tester and **breaking** the specimen with a **swinging pendulum**. In the **Charpy** test (after the French scientist G. Charpy), the specimen is supported at both ends, while in the **Izod** test (after the English engineer E.G. Izod), it is supported at one end like a **……………………** beam. From the swing of the pendulum, the energy **……………………** in breaking the specimen can be obtained; this energy is the impact toughness of the material.

Case study 1. **Brittle Fracture of Liberty Ships**

As part of the government project during World War II, United States planed continuous block **construction** of all-welded cargo vessels (*Liberty Ship*). The construction was started with outbreak of the Pacific war from 1942. 2708 Liberty Ships were **constructed** from 1939 to 1 945. 1031 **damages** or accidents due to **brittle fracture** were reported by April 1, 1946. More than 200 Liberty Ships were sink or damaged beyond all hope of repair. "Schenectady" is one of those, which broke in two with a large sound when it was moored at wharf (see Fig. 4).

The accident was caused by **occurrence** and **development** of brittle **crack**, which were due to the lack of fracture toughness of welded joint. The accident should be the most expensive and huge scale **experiments** of the century. The accident showed importance of fracture toughness, which marked the birth of the fracture mechanics.

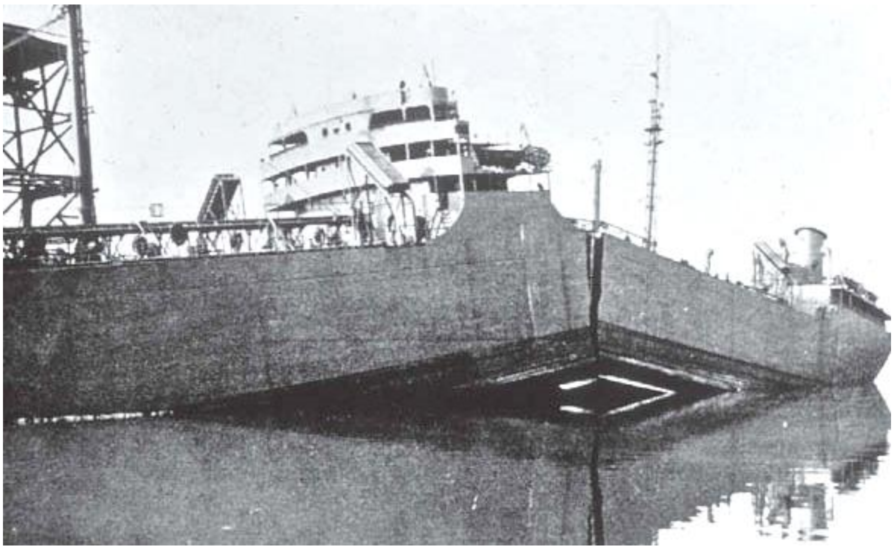

Fig. 4 Schenectady after breaking in two.

Case study 2. **Tensile Test** (Click this link).

D. Translate the following sentences into English.

۱. مدول الاستیک (مدول یانگ) شیب قسمت الاستیک منحنی تنش-کرنش است و میزان سفتی ماده را نشان می دهد.

۲. یکی از کاربردهای آزمایش سختی Knoop، اندازه گیری سختی دانه ها و اجزای سازنده یک آلیاژ فلزی است.

۳. موادی که مقاومت ضربه زیادی دارند، عموماً استحکام و انعطاف پذیری بالا و بنابراین چقرمگی بالایی دارند.