Chapter 2: Structure of Metals

Atomic structure. The **atomic structure** of metals is the arrangement of the atoms within metals. Understanding the structure of metals allows us to predict and evaluate their properties (such as **strength** and **stiffness**). In addition to atomic structure, several other factors also influence the properties and **behavior of metals**. They include the **composition** of the particular metal, **impurities** and **vacancies** in their atomic structure, **grain size**, **grain boundaries**, environment, size and surface condition of the metal, and the methods by which they are made into products.

Types of Atomic Bonds. All **matter** is made up of atoms consisting of a **nucleus** of protons and neutrons and surrounding clouds or **orbits** of electrons. The number of protons in the nucleus determines whether a particular atom will be metallic, **nonmetallic**, or **semimetallic**. An atom with a **balanced charge** has the same number of electrons as protons; when there are too many or too few electrons, the atom is called an **ion**. An excess of electrons results in a negatively charged atom, referred to as an **anion**, while too few electrons results in a positively charged atom, called a **cation**. The number of electrons in the outermost orbit of an atom determines the **chemical affinity** of that atom for other atoms.

Atoms can transfer or share electrons; in doing so, multiple atoms **combine** to form **molecules.** Molecules are held together by **attractive forces** called **bonds,** which act through electron **interaction**. The basic types of atomic attraction associated with electron transfer, called **primary bonds** or **strong bonds,** are: **Ionic bonds**, **Covalent bonds** and **Metallic bonds.** In addition to the strong attractive forces associated with electrons, **weak** or **secondary bonds**/attractions occur between molecules.

A. Fill in the blanks with the following words.

configurations, unit cell, molten, Face-centered cubic (FCC), Hexagonal close-packed (HCP), Body-centered cubic (BCC)

The Crystal Structure of Metals. When metals **solidify** from a **………………… state**, the atoms arrange themselves into various orderly **……………………..**, called **crystals;** this atomic arrangement is called **crystal structure** or **crystalline structure.** The smallest group of atoms showing the characteristic **lattice structure** of a particular metal is known as a **……………………**. The following are the three basic atomic arrangements in metals: 1. **………………………………………**; alpha iron, chromium, molybdenum, tantalum, tungsten, and vanadium, see Fig. 1. 2. **……………………………**; gamma iron, aluminum, copper, nickel, lead, silver, gold, and platinum, see Fig. 2. **3. ……………………………;** beryllium, cadmium, cobalt, magnesium, alpha titanium, zinc, and zirconium, see Fig. 3.

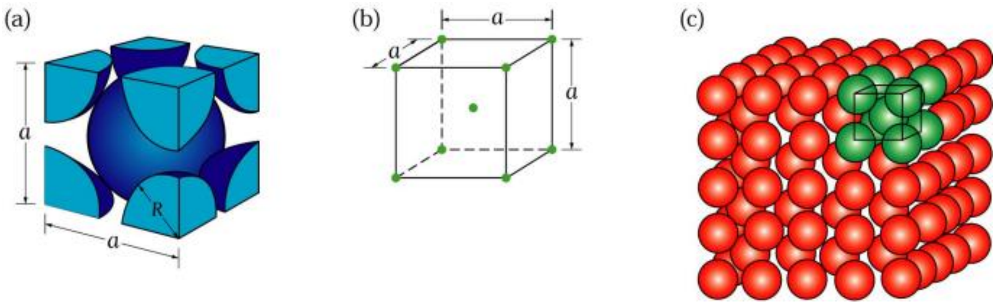

Fig. 1 The ………………………………. crystal structure: (a) **hard-ball model**; (b) unit cell; and (c) single crystal with many unit cells.

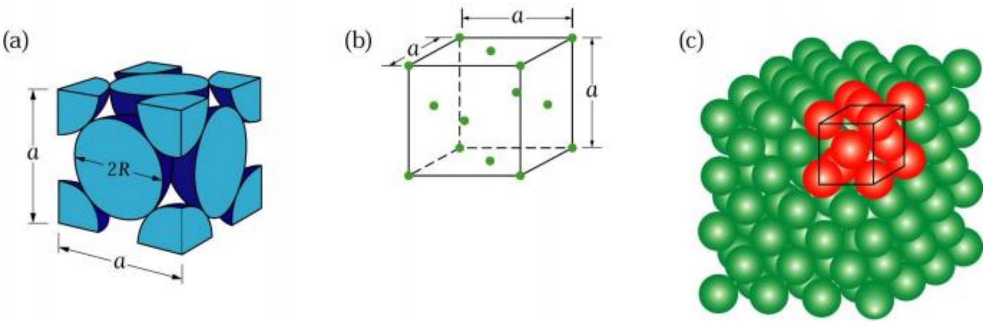

Fig. 2 The ………………………………. crystal structure: (a) hard-ball model; (b) unit cell; and (c) single crystal with many unit cells.

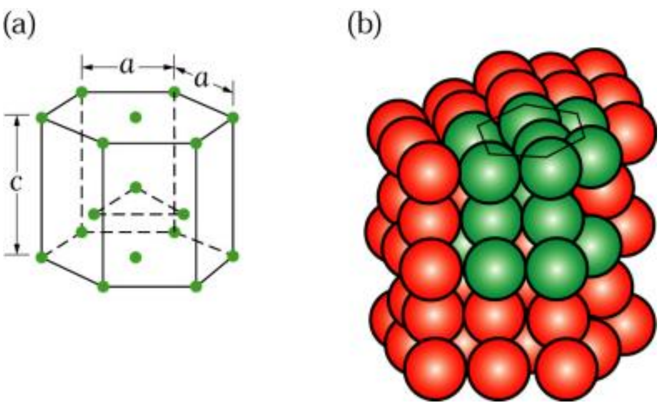

Fig. 3 The ……………………………………………. crystal structure: (a) unit cell; and (b) single crystal with many unit cells.

Deformation and Strength of Single Crystals. When a single crystal is subjected to an external force, it first undergoes **elastic** **deformation**; that is, it returns to its original shape when the force is removed. If the force is increased sufficiently, the crystal undergoes **plastic deformation** or **permanent deformation;** that is, it does not return to its original shape when the force is removed. There are two basic **mechanisms** by which plastic deformation takes place in crystal structures. One mechanism involves a plane of atoms **slipping** over an adjacent plane, called the **slip plane**, under a **shear stress**. The second, and less common, mechanism of plastic deformation in crystals is **twinning**, in which a portion of the crystal forms a mirror image of itself across the plane of twinning.

B. Fill in the blanks with the following words.

vacancy, imperfections, inclusions, dislocations

Imperfections in the Crystal Structure of Metals. The actual **strength** of metals is approximately one to two **orders of magnitude** lower than the strength levels obtained from **theoretical** calculations. This discrepancy is explained in terms of **defects** and ……………………… in the crystal structure. Unlike in **idealized** models described earlier, actual metal crystals contain a large number of defects and imperfections, which generally are categorized as: **1. Point defects**, such as a …………… (missing atom), an **interstitial atom** (extra atom in the lattice, see Fig. 4). **2.** Linear, or one-dimensional, defects, called …………………… (linear, screw). **3.** Planar, or two-dimensional, imperfections, such as grain **boundaries** and **phase boundaries**. **4.** Volume, or **bulk**, imperfections, such as **voids,** …………………… (**nonmetallic** elements such as **oxides**, sulfides, and silicates), other phases**,** or **cracks.**

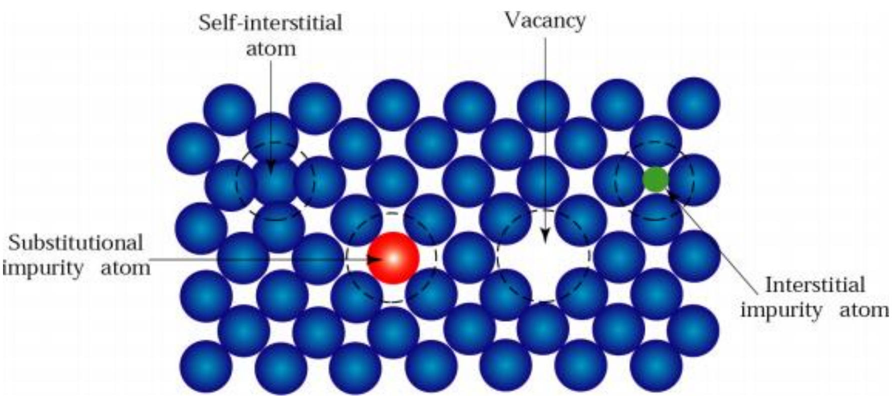

Fig. 4 **Schematic** **illustration** of types of defects in a single-crystal lattice: **selfinterstitial**, vacancy, interstitial, and **substitutional**.

<u>Work Hardening</u> (<u>Strain Hardening</u>) Although the presence of a dislocation lowers the shear stress required to cause slip, dislocations can be **1. <u>Entangled</u>** and **<u>interfere</u>** with each other **2. <u>Impeded</u>** by **<u>barriers</u>**, such as grain boundaries, **<u>impurities</u>**, and **<u>inclusions</u>** in the material The higher shear stress required to overcome **<u>entanglements</u>** and **<u>impediments</u>** results in an increase in the overall strength and **<u>hardness</u>** of the metal, and is known as work hardening or strain hardening. The greater the deformation, the greater is the number of entanglements and hence the higher the increase in the metal's strength.

Grains and Grain Boundaries. When a mass of **<u>molten</u>** metal begins to **<u>solidify</u>**, crystals form independently of each other at various locations within the liquid mass, and thus have random and unrelated **<u>orientations</u>**. Each of these crystals eventually grows into a crystalline structure, or **<u>grain</u>**; each grain consists of either a single crystal (for pure metals) or a **<u>polycrystalline</u> <u>aggregate</u>** (for alloys). The number and size of the grains developed in a unit volume of the metal depends on the rate at which **<u>nucleation</u>** (the initial stage of crystal formation) takes place. The interfaces that separate the individual grains are called **<u>grain boundaries</u>.**

C. Fill in the blanks with the following words.

phenomenon, orange peel, annealing, recrystallization, distortion, forging

Recovery, Recrystallization, and Grain Growth. Plastic deformation at room temperature causes (a) **……………………….** of the grains and grain boundaries; (b) a general increase in strength; and (c) a decrease in **<u>ductility</u>**. These effects can be reversed, and the properties of the metal can be brought back to their original levels, by heating the metal to a specific temperature range for a given period of time—a process called **……………………….** . Three events take place consecutively during the annealing process: **1. <u>Recovery</u>**. During recovery, which occurs at a certain temperature range below the recrystallization temperature of the metal, the stresses in the highly deformed regions of the metal are relieved. **<u>Subgrain</u>** boundaries begin to form (called **<u>polygonization</u>**), with no significant change in mechanical properties such as hardness and strength. **2. ……………………….** This is the process in which, within a certain temperature range, new **<u>equiaxed</u>** and strain-free grains are formed, replacing the older grains. **3. Grain Growth.** If the temperature is raised further, the grains begin to grow and their size may eventually exceed the original grain size; called **grain growth**, this **……………………** adversely affects mechanical properties. Large grains also produce a **rough** surface **appearance** on sheet metals, called **……………..**, when they are **stretched** to form a part, or on the surfaces of a piece of metal when subjected to **bulk deformation**, such as **compression** in **…………..** .

Cold, Warm, and Hot Working. **Cold working** (T/T_m < 0.3) refers to plastic deformation that is usually carried out at room temperature; when deformation occurs above the recrystallization temperature, it is called **hot working** (T/T_m > 0.6). "Cold" and "hot" are relative terms, as can be seen from the fact that deforming **lead** at room temperature is a hot-working process, because the recrystallization temperature of lead is about room temperature. As the name implies, **warm working** is carried out at **intermediate** (0.3 < T/T_m < 0.6) temperatures; thus, warm working is a compromise between cold and hot working.

Case study 1. In a jet **engine** (as shown in Fig. 5), the gas **stream** leaving the **combustion** **chamber** where **fuel** and air are mixed and **ignited** can be 3000 degrees Fahrenheit. The problem that arises is that the metal that **turbine** **blades** are made from, nickel-based **superalloys**, can begin to melt between 2300 degrees Fahrenheit and 2500 degrees Fahrenheit. So to allow the blades to operate above their melting point, they are made with special materials using a special process to produce an **intricate** **pattern** of internal **cooling passages** and then **coated** with ceramics for **thermal protection**. The blades also have to be immensely strong because they endure tremendous stress, spinning at thousands of **rpms**. The **centrifugal** forces across the **span** of a blade can reach 20,000 times the force of gravity. Think of it this way — each blade individually is working as hard and producing as much power as a high-performance race car engine. A typical commercial engine uses 100-200 single crystal blades.

In 1970, a **research** team found that **introducing** and **solidifying** the molten **superalloy** directionally through a **smooth** bent structure creates a filter that admits only one crystal into the mold. Using these technique, a single crystal blade where all the atoms are **aligned** in a repeating arrangement with no boundaries could be built. The structure eventually took the shape of a helix.

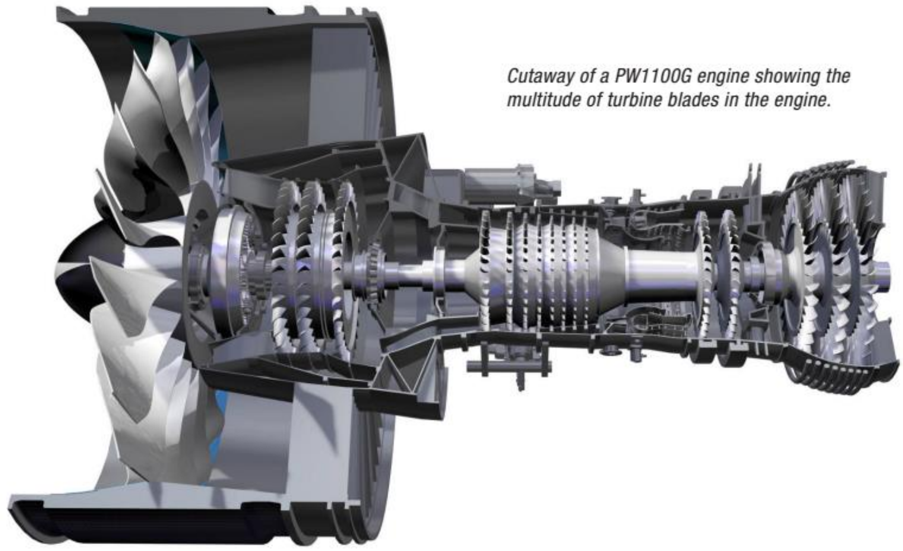

Fig. 5 Cutaway of a PW1100G engine showing the multitude of turbine blades in the engine.

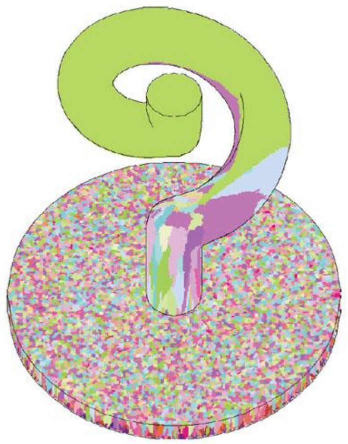

Fig. 6 Single crystal formation in the "starter" chamber

By the early 1980s, single crystal turbine components began to have practical applications. In 1980, the JT9D-7R4 engine used for the Boeing 747, McDonnell Douglas DC-10, and the Airbus A300 was the first commercial application. Single crystal components were key to the success of the TF30 engine used on the F-111 and F-14 jet fighters and the F100 engine used on the F-15 and F-16 fighters.

Case study 2. Top 5 strongest metals

Ch02 Top 5 strongest metals.mp4 (Command Line)

D. Translate the following sentences into English.

۱. فلزاتی که شبکه کریستالی مکعبی با وجوه مرکز پر دارند (مانند آلومینیوم، طلا، مس و نقره) معمولاً استحکام متوسط و انعطاف پذیری خوب دارند.

۲. از آنجایی که اتم های موجود در مرز دانه ها بی نظمی بیشتر و فشردگی کمتری دارند، مرز دانه نسبت به خود دانه بسیار فعال تر است.

۳. اندازه دانه تأثیر قابل توجهی در استحکام فلزات دارد: هر چه اندازه کوچکتر، فلز قوی تر است و هرچه اندازه بزرگتر باشد فلز انعطاف پذیر تر است.