



Fourth lecture

***CHARACTERIZATION
OF MATERIALS —1***

Fourth Stage

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2023 -2024

1.2.c. Friction and wear failure

Wear properties of an implant material are important, especially for various joint replacements. Wear cannot be discussed without some understanding of friction between two materials. When two solid materials contact, they touch only at the tips of their highest asperities (microscopic protuberances). Therefore, the real contact area is much smaller than the apparent surface area. It is found that the true area of contact increases with applied load (P) for ductile materials. Ductile materials can be pressure welded due to the formation of plastic junctions, the plastic junctions are the main source of an adhesive friction when two materials are sliding over each other with or without a lubricating film.

1.3. Viscoelasticity

1.3.a. Viscoelastic material behavior

Viscoelastic materials are those for which the relationship between stress and strain depends on time. In such materials the stiffness will depend on the rate of application of the load. In addition, mechanical energy is dissipated by conversion to heat in the deformation of viscoelastic materials. All materials exhibit some viscoelastic response. In metals such as steel or aluminum at room temperature, as well as in quartz, the response at small deformation is almost purely elastic, Metals can behave

plastically at large deformation, but ideally plastic deformation is independent of time. Also, plastic deformation occurs only if a threshold stress is exceeded. By contrast, materials such as synthetic polymers, wood, and human tissue display significant viscoelastic effects, and these effects occur at small or large stress.

1.3.b. Characterization of viscoelastic materials

1.3.c. Prediction of the response

1.3.d. Mechanical models

1.3.e. Behavior of viscoelastic materials

1.3.f. Applications

There are a variety of consequences of viscoelastic behaviors that influence the application of viscoelastic materials. For example, in those applications for which a steady-state stress is applied, the creep behavior is of greatest importance. The expected service life of implant materials may be very long; consequently, attention to the long-term creep behavior is in order.

2. Thermal Properties

The most familiar thermal properties are the melting and freezing (solidification) temperatures. These are phase transformations that occur at specific temperatures, these transformation temperatures depend on the

bond energy, e.g., the higher the bonding strength, the higher the melting temperature. If the material is made of different elements or compounds, then it may have a range of melting or solidification temperatures, that is, the liquid coexists with solid over a range of temperatures, unlike a pure material. The thermal energy spent on converting one gram of material from solid to liquid is called the heat of fusion. The unit is Joules per gram, where one Joule is equivalent to one Newton meter. The heat of fusion is closely related to the melting temperature (T) The thermal energy spent on changing the temperature of a material by 1°C per unit mass is called specific heat. Traditionally, water is usually chosen as a standard substance, and 1calorie is the heat required to raise 1 gram of water from 15 to 16°C, but now the standard unit of energy including energy associated with heat is the Joule. Thus, the specific heat is in units of J/g. (1 calorie is equivalent to 4.187 J. The calorie used to represent food or metabolic energy is actually a kilocalorie, or 1000 calories.) The change in length ΔL for a unit length (L_0), per unit temperature is called the linear coefficient of expansion (α), which can be expressed as

$$\alpha = \frac{\Delta L}{L_0 \Delta T}$$

The thermal expansion may depend on the direction in a single crystal or composite, and it may depend on temperature. If the material is

homogeneous and isotropic, then the volumetric thermal expansion coefficient (V_{exp}) can be approximated:

$$V_{exp} = 3\sigma$$

3. Phase Diagrams

When two or more metallic elements are melted and cooled they form an intermetallic compound or a solid solution or, more commonly, a mixture thereof. Such combinations are called "alloys." The alloys can exist as either a single phase or a blend of multiple phases depending on temperature and composition. A phase is defined as a physically homogeneous part of a material system. Thus, a liquid and gas are both single phase, but there can be more than one phase for a solid, such as fcc iron and bcc iron, depending on pressure and temperature. Among multiphase metals, steels are iron-based alloys containing various amounts of a carbide (usually Fe_3C) phase. In this case, the carbon atoms occupy the interstitial sites of the iron atoms, this is called an interstitial solid solution. Most metal atoms are too large to exist in the interstitial sites. If the two metal atoms are roughly the same size, have the same bonding tendencies, and tend to crystallize in the same types of crystal structure, then a substitutional solid solution may form. This structure is composed of a random mixture of two different atoms, as shown in Figure 4. Unless the elements are very similar in properties, such a solution will exhibit a

limited solubility, i.e., as more substitutional atoms are added into the matrix, the lattice will be more and more distorted until phase separation occurs at the solubility limit. In some systems, such as Cu-Ni, as shown in Figure, complete solid solubility exists.

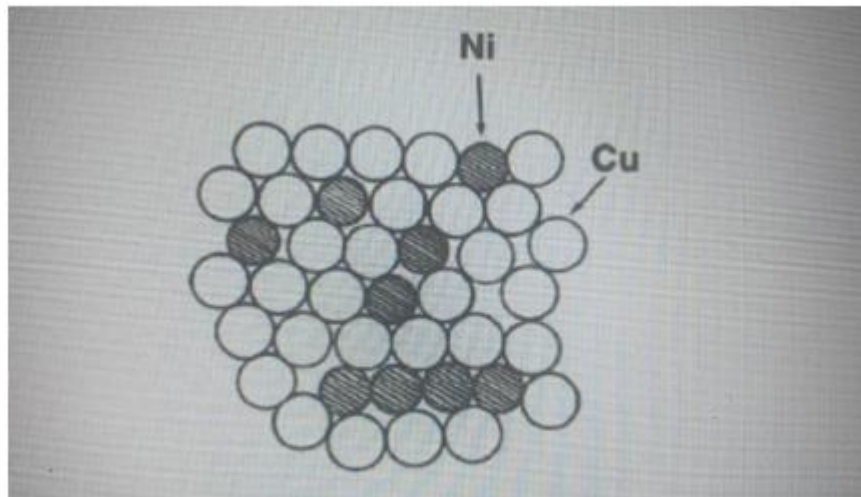


Figure 4. Substitutional solid solution of a Cu-Ni system.

4. STRENGTHENING BY HEAT TREATMENTS

4.1. Metals

One of the strengthening processes is precipitation (or age) hardening of alloys by heat treatments. This is accomplished by rapidly cooling (quenching) a solid solution of decreasing solubility. If quenching is done properly, there will not be enough time for the second phase (B) to form. Hence, a quasi-thermal equilibrium exists, but depending on the amount of

thermal energy (related to temperature) and time, the second phase (B) will form (precipitation).

If the B phase particles are small and uniformly dispersed throughout the matrix, their presence can increase the strength greatly. It is important that they be dispersed within a grain as well as at

grain boundaries, so that the dislocations can be impeded during the deformation process, as in the case of cold-working.

4.2. ceramics and glasses

As mentioned earlier, ceramics and glasses are hard and brittle due to their non-yielding character during deformation, which in turn is due to their bonding characteristics. Because of this brittleness they are subject to stress concentration effect at the microcracks present in the material when in tensile deformation