Low Cost Demonstrations to Teach Structure of Materials

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Abstract

Demonstrations and hands-on exercises have been used to enhance student learning in a materials science course for general engineering students. Using styrofoam balls, toothpicks, and simple organic chemistry models, students build crystal structures, polymer chains, and amorphous silica structures. These models are then used to illustrate slip in metal crystals, the origin of surface energy, and the interaction of polymer chains. This paper will focus on how these materials are used throughout the course both inside and outside the classroom. A second demonstration where students learn the differences between ductile and brittle fracture through the splitting of wood will be presented.

Introduction

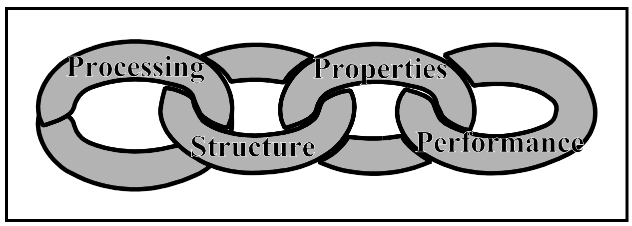

Figure 1: Chain Approach to Teaching Materials Science.

Most engineering students are required to complete a course in materials science and engineering. During the last several years an introductory course has been developed which is suitable for first year students[1]. The subject matter is organized according to the chain shown in Figure 1. That is, material properties are dependent on structure which in turn is dependent on processing. The course begins with a discussion of structure, follows with a discussion of processing, and then allows the students to apply these concepts when discussing properties.

The topics covered during the structure portion of the course are below.

- Cubic Crystal Structures
- Point Defects (Vacancies, Interstitials and Solute Atoms)
- Dislocations
- Surfaces and Interfaces
- Amorphous Materials
- Polymers, and
- Phase Diagrams

These are abstract concepts. While it is now possible to for one to view atomic arrangements in materials, it is not practical to do so in large undergraduate courses. To improve learning a series of low cost demonstrations and in class exercises have been developed to better illustrate these concepts.

Course Activities

Crystal Structure

While most engineers do not need to know about Miller Indices and other details, they do need to understand that the crystalline solid possesses long range order and represents the lowest energy state. They need to understand that different crystal structures behave differently. More importantly, an understanding of crystal structure is necessary if students are to understand dislocations, surfaces and phases.

Student groups built the simple cubic, body centered cubic and face centered cubic unit cell using a set of 14 2.5 inch styrofoam balls and toothpicks. With the completed models it was possible to show the relative densities and the different relationship between lattice parameter and particle size. During some semesters the students actually conducted an experiment where they verified the lattice parameter particle size relation. Using the 2.5 inch balls in conjunction with a set of 2 inch, 1.5 inch, and 1 inch styrofoam balls students built the CsCl, NaCl and ZnS crystal structure. This demonstrated the importance of the radius ratio rules. Using the 2.5 inch styrofoam balls the students built the diamond cubic crystal structure and compared it to the ZnS structure. The balls and other equipment are inexpensive and can be purchased at most craft stores.

Point Defects

Using pennies and graph paper students derived an expression for the equilibrium vacancy concentration. 25 pennies were placed on a grid. The students were asked to calculate the configurational entropy as pennies were removed. By approximating the enthalpy of vacancy formation as the number of broken bonds, the students were able to "derive" the appropriate equation.

$$X_v = Ce^{-\frac{\Delta H_v}{RT}} \tag{1}$$

Dislocations

In order to understand plastic deformation of metals and strengthening students need to be familiar with dislocations. Rather than emphasize the difference between edge and screw dislocations - the atomic nature of slip and dislocation motion is emphasized. Using the crystal structures built earlier students determine which planes and directions are most likely to slip. This demonstrates the concept that the slip system with the shortest burgers vector will be active, and that slip in ionic solids and diamond cubic is unlikely.

Surfaces

Most strengthening mechanisms involve placing surfaces or interfaces in to the material. When annealed the net surface area is reduced as these surfaces add energy to the material. Therefore it is vital that students understand surface energy so that they can understand the effect which structure has on properties and that which processing has on structure. Students combine several of the lattices built earlier and measure surface energy through the "broken bond" model. The broken bond model is then used to explain why dislocations are also unstable and eliminated during annealing.

Amorphous Materials

In order to understand the behavior of non-crystalline solids it is important to understand the structure of the material. After discussing the Lewis Structure of silica, students build a silica using an organic chemistry kit. The tetrahedral structure is identical. They are then challenged to arrange a random structure into a well organized crystal. They see that this is challenging and that it is very likely that silica will form a glass. This then serves as the basis for a discussion on glass forming and the structure of glasses.

Polymers

Using the same organic chemistry kits students build polymers from monomers. Once comfortable with the addition and condensation polymerization mechanisms the students build various materials. They compare the structure of polyethylene, polypropylene, polystryene and polyvinlychloride. This allows them to see that the apparently simple benzene ring is really a large side group. Polybutadiene is built with the ethyl group as a side group on the polymer chain to better illustrate crosslinking. Students slide polymer chains past each other to demonstrate the effect of side groups on strength. The teams also attempt to build crystals from polymer chains thus seeing that all polymers are amorphous to some extent.

Phase Diagrams

As shown in the phase diagram in Figure 2 Sn-Bi alloys are low melting materials. Sn-Bi alloys have been used to,

- demonstrate eutectic melting and diffusion in the solid and liquid states.
- validate the Sn-Bi phase diagram through determination of the amount of proeutectic constituent using image analysis software and the gridline technique,
- demonstrate coarsening of second phase particles,
- demonstrate sintering using Sn-Bi solder paste,
- demonstrate grain growth using Sn, and

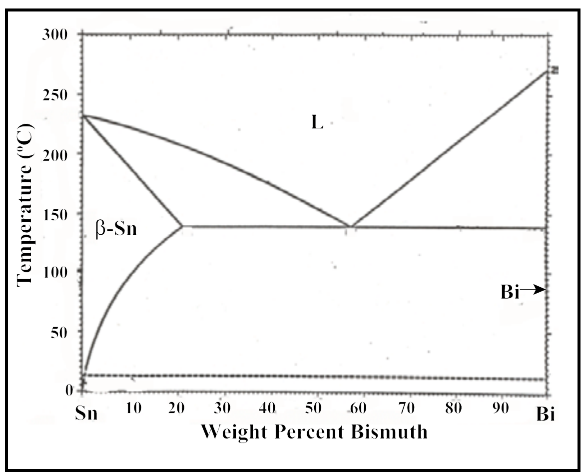

Figure 2: Sn-Bi Phase Diagram

- finally demonstrate how alloying and processing changes mechanical strength[2].

The alloys can be melted on a hot plate. Significant microstructural evolution occurs at temperatures which can be reached in a toaster oven. The metallographic preparation requires materials which can be purchased from boating supply houses and hardware stores.

Wood-Splitting Demonstration
To illustrate that strong materials can be brittle and that brittleness and strength are two different concepts, an axe is used to get the students' attention. Using thin pieces of pine and oak, it is shown that oak is stiffer than pine - less deflection. It is then shown that oak is stronger than pine, as striking the pine with the blunt end of the axe causes it to shatter. The instructor then shows that oak is easier to split. Thus oak has a lower fracture toughness than pine, but is stronger.

Conclusion

The activities presented in this paper are inexpensive and effective. Although it is not known to what degree they enhance learning, student comments on end of course evaluations indicate that students enjoy the demonstrations. End of course assessment shows that they have learned the concepts illustrated in the demonstrations.

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Biographical Information

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