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Introduction to Materials Science and Engineering

- 1–5 Iron is often coated with a thin layer of zinc if it is to be used outside. What characteristics do you think the zinc provides to this coated, or galvanized, steel? What precautions should be considered in producing this product? How will the recyclability of the product be affected?

Solution: The zinc provides corrosion resistance to the iron in two ways. If the iron is completely coated with zinc, the zinc provides a barrier between the iron and the surrounding environment, therefore protecting the underlying iron. If the zinc coating is scratched to expose the iron, the zinc continues to protect the iron because the zinc corrodes preferentially to the iron (see Chapter 22). To be effective, the zinc should bond well to the iron so that it does not permit reactions to occur at the interface with the iron and so that the zinc remains intact during any forming of the galvanized material. When the material is recycled, the zinc will be lost by oxidation and vaporization, often producing a “zinc dust” that may pose an environmental hazard. Special equipment may be required to collect and either recycle or dispose of the zinc dust.

- 1–6 We would like to produce a transparent canopy for an aircraft. If we were to use a ceramic (that is, traditional window glass) canopy, rocks or birds might cause it to shatter. Design a material that would minimize damage or at least keep the canopy from breaking into pieces.

Solution: We might sandwich a thin sheet of a transparent polymer between two layers of the glass. This approach, used for windshields of automobiles, will prevent the “safety” glass from completely disintegrating when it

fails, with the polymer holding the broken pieces of glass together until the canopy can be replaced.

Another approach might be to use a transparent, “glassy” polymer material such as polycarbonate. Some polymers have reasonably good impact properties and may resist failure. The polymers can also be toughened to resist impact by introducing tiny globules of a rubber, or elastomer, into the polymer; these globules improve the energy-absorbing ability of the composite polymer, while being too small to interfere with the optical properties of the material.

- 1–7 Coiled springs ought to be very strong and stiff. Si_3N_4 is a strong, stiff material. Would you select this material for a spring? Explain.

Solution: Springs are intended to resist high elastic forces, where only the atomic bonds are stretched when the force is applied. The silicon nitride would satisfy this requirement. However, we would like to also have good resistance to impact and at least some ductility (in case the spring is overloaded) to assure that the spring will not fail catastrophically. We also would like to be sure that all springs will perform satisfactorily. Ceramic materials such as silicon nitride have virtually no ductility, poor impact properties, and often are difficult to manufacture without introducing at least some small flaws that cause to fail even for relatively low forces. The silicon nitride is NOT recommended.

- 1–8 Temperature indicators are sometimes produced from a coiled metal strip that uncoils a specific amount when the temperature increases. How does this work; from what kind of material would the indicator be made; and what are the important properties that the material in the indicator must possess?

Solution: Bimetallic materials are produced by bonding two materials having different coefficients of thermal expansion to one another, forming a laminar composite. When the temperature changes, one of the materials will expand or contract more than the other material. This difference in expansion or contraction causes the bimetallic material to change shape; if the original shape is that of a coil, then the device will coil or uncoil, depending on the direction of the temperature change. In order for the material to perform well, the two materials must have very different coefficients of thermal expansion and should have high enough modulus of elasticity so that no permanent deformation of the material occurs.

- 1–9 You would like to design an aircraft that can be flown by human power nonstop for a distance of 30 km. What types of material properties would you recommend? What materials might be appropriate?

Solution: Such an aircraft must possess enough strength and stiffness to resist its own weight, the weight of the human “power source”, and any aerodynamic forces imposed on it. On the other hand, it must be as light as possible to assure that the human can generate enough work to operate the aircraft. Composite materials, particularly those based on a polymer matrix, might comprise the bulk of the aircraft. The polymers have a light weight (with densities of less than half that of aluminum) and can be strengthened by introducing strong, stiff fibers made of glass, carbon, or other polymers. Composites having the strength and stiffness

of steel, but with only a fraction of the weight, can be produced in this manner.

- 1–10** You would like to place a three-foot diameter microsatellite into orbit. The satellite will contain delicate electronic equipment that will send and receive radio signals from earth. Design the outer shell within which the electronic equipment is contained. What properties will be required and what kind of materials might be considered?

Solution: The shell of the microsatellite must satisfy several criteria. The material should have a low density, minimizing the satellite weight so that it can be lifted economically into its orbit; the material must be strong, hard, and impact resistant in order to assure that any “space dust” that might strike the satellite does not penetrate and damage the electronic equipment; the material must be transparent to the radio signals that provide communication between the satellite and earth; and the material must provide some thermal insulation to assure that solar heating does not damage the electronics.

One approach might be to use a composite shell of several materials. The outside surface might be a very thin reflective metal coating that would help reflect solar heat. The main body of the shell might be a light weight fiber-reinforced composite that would provide impact resistance (preventing penetration by dust particles) but would be transparent to radio signals.

- 1–11** What properties should the head of a carpenter’s hammer possess? How would you manufacture a hammer head?

Solution: The head for a carpenter’s hammer is produced by forging, a metal-working process; a simple steel shape is heated and formed in several steps while hot into the required shape. The head is then heat treated to produce the required mechanical and physical properties.

The striking face and claws of the hammer should be hard—the metal should not dent or deform when driving or removing nails. Yet these portions must also possess some impact resistance, particularly so that chips do not flake off the striking face and cause injuries.

- 1–12** The hull of the space shuttle consists of ceramic tiles bonded to an aluminum skin. Discuss the design requirements of the shuttle hull that led to the use of this combination of materials. What problems in producing the hull might the designers and manufacturers have faced?

Solution: The space shuttle experiences extreme temperatures during re-entry into earth’s atmosphere; consequently a thermal protection system must be used to prevent damage to the structure of the shuttle (not to mention its contents!). The skin must therefore be composed of a material that has an exceptionally low thermal conductivity. The material must be capable of being firmly attached to the skin of the shuttle and to be easily repaired when damage occurs.

The tiles used on the space shuttle are composed of silica fibers bonded together to produce a very low density ceramic. The thermal conductivity is so low that a person can hold on to one side of the tile while the opposite surface is red hot. The tiles are attached to the shuttle

skin using a rubbery polymer that helps assure that the forces do not break the tile loose, which would then expose the underlying skin to high temperatures.

- 1–13** You would like to select a material for the electrical contacts in an electrical switching device which opens and closes frequently and forcefully. What properties should the contact material possess? What type of material might you recommend? Would Al_2O_3 be a good choice? Explain.

Solution: The material must have a high electrical conductivity to assure that no electrical heating or arcing occurs when the switch is closed. High purity (and therefore very soft) metals such as copper, aluminum, silver or gold provide the high conductivity. However the device must also have good wear resistance, requiring that the material be hard. Most hard, wear resistant materials have poor electrical conductivity.

One solution to this problem is to produce a particulate composite material composed of hard ceramic particles embedded in a continuous matrix of the electrical conductor. For example, silicon carbide particles could be introduced into pure aluminum; the silicon carbide particles provide wear resistance while aluminum provides conductivity. Other examples of these materials are described in Chapter 16.

Al_2O_3 by itself would not be a good choice—alumina is a ceramic material and is an electrical insulator. However alumina particles dispersed into a copper matrix might provide wear resistance to the composite.

- 1–14** Aluminum has a density of 2.7 g/cm^3 . Suppose you would like to produce a composite material based on aluminum having a density of 1.5 g/cm^3 . Design a material that would have this density. Would introducing beads of polyethylene, with a density of 0.95 g/cm^3 , into the aluminum be a likely possibility? Explain.

Solution: In order to produce an aluminum-matrix composite material with a density of 1.5 g/cm^3 , we would need to select a material having a density considerably less than 1.5 g/cm^3 . While polyethylene's density would make it a possibility, the polyethylene has a very low melting point compared to aluminum; this would make it very difficult to introduce the polyethylene into a solid aluminum matrix—processes such as casting or powder metallurgy would destroy the polyethylene. Therefore polyethylene would NOT be a likely possibility.

One approach, however, might be to introduce *hollow* glass beads. Although ceramic glasses have densities comparable to that of aluminum, a hollow bead will have a very low density. The glass also has a high melting temperature and could be introduced into liquid aluminum for processing as a casting.

- 1–15** You would like to be able to identify different materials without resorting to chemical analysis or lengthy testing procedures. Describe some possible testing and sorting techniques you might be able to use based on the physical properties of materials.

Solution: Some typical methods might include: measuring the density of the material (may help in separating metal groups such as aluminum, copper, steel, magnesium, etc.), determining the electrical conductivity

of the material (may help in separating ceramics and polymers from metallic alloys), measuring the hardness of the material (perhaps even just using a file), and determining whether the material is magnetic or nonmagnetic (may help separate iron from other metallic alloys).

- 1–16** You would like to be able to physically separate different materials in a scrap recycling plant. Describe some possible methods that might be used to separate materials such as polymers, aluminum alloys, and steels from one another.

Solution: Steels can be magnetically separated from the other materials; steel (or carbon-containing iron alloys) are ferromagnetic and will be attracted by magnets. Density differences could be used—polymers have a density near that of water; the specific gravity of aluminum alloys is around 2.7; that of steels is between 7.5 and 8. Electrical conductivity measurements could be used—polymers are insulators, aluminum has a particularly high electrical conductivity.

- 1–17** Some pistons for automobile engines might be produced from a composite material containing small, hard silicon carbide particles in an aluminum alloy matrix. Explain what benefits each material in the composite may provide to the overall part. What problems might the different properties of the two materials cause in producing the part?

Solution: Aluminum provides good heat transfer due to its high thermal conductivity. It has good ductility and toughness, reasonably good strength, and is easy to cast and process. The silicon carbide, a ceramic, is hard and strong, providing good wear resistance, and also has a high melting temperature. It provides good strength to the aluminum, even at elevated temperatures. However there may be problems producing the material—for example, the silicon carbide may not be uniformly distributed in the aluminum matrix if the pistons are produced by casting. We need to assure good bonding between the particles and the aluminum—the surface chemistry must therefore be understood. Differences in expansion and contraction with temperature changes may cause debonding and even cracking in the composite.

