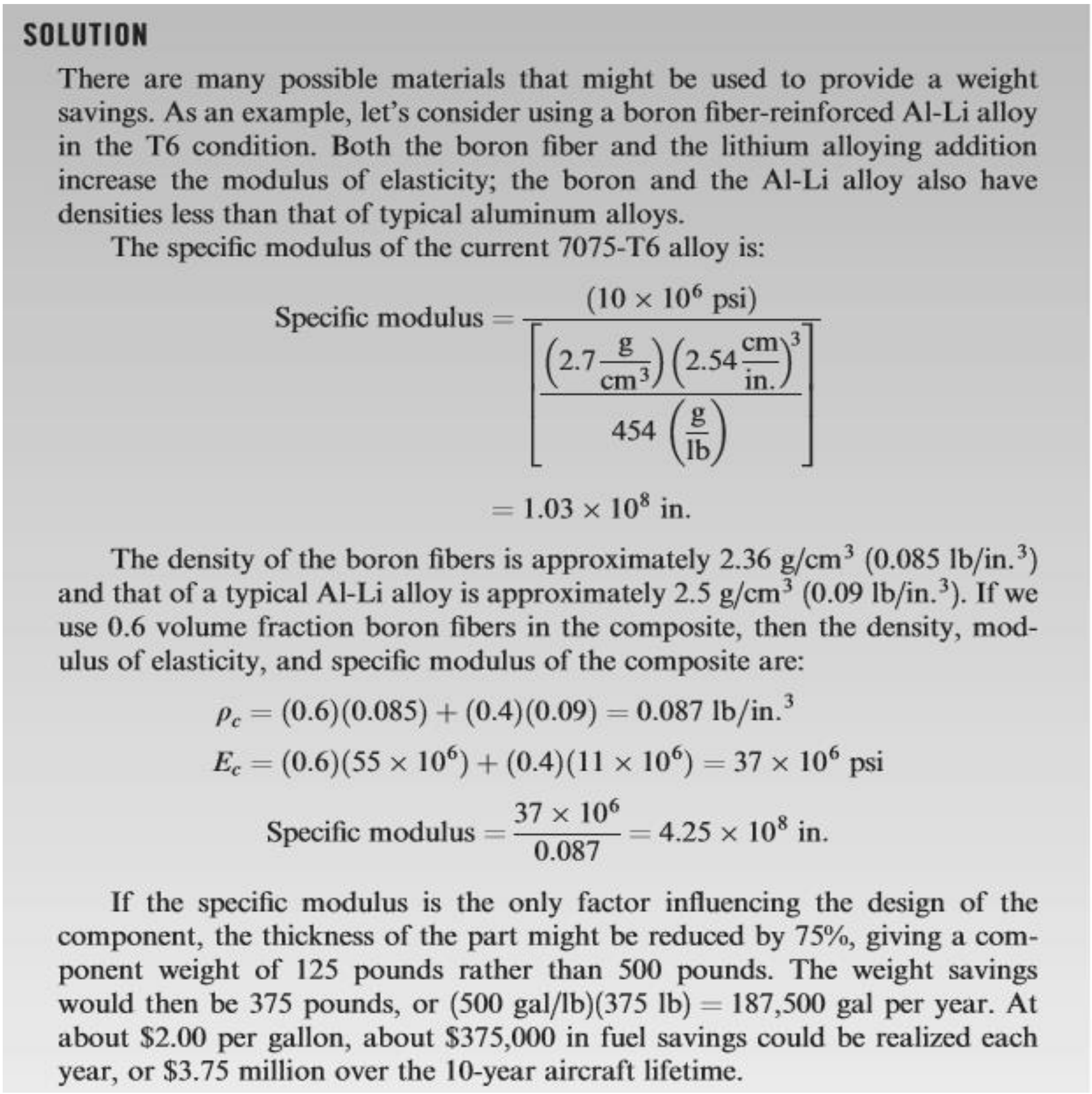
Lecture 5

EXAMPLE 17-9 Design of an Aerospace Composi

We are now using a 7075-T6 aluminum alloy (modulus of elasticity of ($10x10^6$ psi) to make a 500-pound panel on a commercial aircraft. Experience has shown that each pound reduction in weight on the aircraft reduces the fuel consumption by 500 gallons each year. Design a material for the panel that will reduce weight, yet maintain the same specific modulus, and will be economical over a 10-year life time of the aircraft.



SOLUTION

There are many possible materials that might be used to provide a weight savings. As an example, let's consider using a boron fiber-reinforced Al-Li alloy in the T6 condition. Both the boron fiber and the lithium alloying addition increase the modulus of elasticity; the boron and the Al-Li alloy also have densities less than that of typical aluminum alloys.

The specific modulus of the current 7075-T6 alloy is:

$$\text{Specific modulus} = \frac{(10 \times 10^6 \text{ psi})}{\left[\dfrac{\left(2.7 \dfrac{\text{g}}{\text{cm}^3}\right)\left(2.54 \dfrac{\text{cm}}{\text{in.}}\right)^3}{454 \left(\dfrac{\text{g}}{\text{lb}}\right)}\right]}$$

$$= 1.03 \times 10^8 \text{ in.}$$

The density of the boron fibers is approximately 2.36 g/cm^3 (0.085 lb/in.^3) and that of a typical Al-Li alloy is approximately 2.5 g/cm^3 (0.09 lb/in.^3). If we use 0.6 volume fraction boron fibers in the composite, then the density, modulus of elasticity, and specific modulus of the composite are:

$$\rho_c = (0.6)(0.085) + (0.4)(0.09) = 0.087 \text{ lb/in.}^3$$

$$E_c = (0.6)(55 \times 10^6) + (0.4)(11 \times 10^6) = 37 \times 10^6 \text{ psi}$$

$$\text{Specific modulus} = \frac{37 \times 10^6}{0.087} = 4.25 \times 10^8 \text{ in.}$$

If the specific modulus is the only factor influencing the design of the component, the thickness of the part might be reduced by 75%, giving a component weight of 125 pounds rather than 500 pounds. The weight savings would then be 375 pounds, or (500 gal/lb)(375 lb) = 187,500 gal per year. At about $2.00 per gallon, about $375,000 in fuel savings could be realized each year, or $3.75 million over the 10-year aircraft lifetime.

This is certainly an optimistic comparison, since strength or fabrication factors may not permit the part to be made as thin as suggested. In addition, the high cost of boron fibers (over $300/lb) and higher manufacturing costs of the composite compared with those of 7075 aluminum would reduce cost savings. As mentioned before, Boeing has used 50% carbon-fiber-reinforced plastic in its latest 787 Dreamliner airplane to achieve 20% increase in fuel efficiency

Matrix Properties The matrix supports the fibers and keeps them in the proper position, transfers the load to the strong fibers, protects the fibers from damage during manufacture and use of the composite, and prevents cracks in the fiber from propagating throughout the entire composite. The matrix usually provides the major control over electrical properties, chemical behavior, and elevated-temperature use of the composite. Polymer matrices are particularly common. Most polymer materials—both thermoplastics and thermosets—are available in short glass fiber-reinforced grades. These composites are formed into useful shapes by the processes described in Chapter 16. Sheet-molding compounds (SMCs) and bulk-molding compounds (BMCs) are typical of this type of composite. Thermosetting aromatic polyimides are used for somewhat higher temperature applications. Metal-matrix composites include aluminum, magnesium, copper, nickel, and intermetallic compound alloys reinforced with ceramic and metal fibers. A variety of aerospace and automotive applications are satisfied by the MMCs. The metal matrix permits the composite to operate at high temperatures, but producing the composite is often more di‰cult and expensive than producing the polymer-matrix materials. The ceramic-matrix composites (CMCs) have good properties at elevated temperatures and are lighter in weight than the high-temperature metal-matrix composites. In a later section, we discuss how to develop toughness in CMCs.

Bonding and Failure Particularly in polymer and metal-matrix composites, good bonding must be obtained between the various constituents. The fibers must be firmly bonded to the matrix material if the load is to be properly transmitted from the matrix to the fibers. In addition, the fibers may pull out of the matrix during loading, reducing the strength and fracture resistance of the composite if bonding is poor. Figure 17-16 on the next page illustrates poor bonding of carbon fibers in a copper matrix. In some cases, special coatings may be used to improve bonding. Glass fibers are coated with a silane coupling or ‘‘keying’’ agent (called sizing) to improve bonding and moisture resistance in fiberglass composites. Carbon fibers are similarly coated with an organic material to improve bonding. Boron fibers have been coated with silicon carbide or boron nitride to improve bonding with an aluminum matrix; in fact, these fibers have been called Borsic fibers to reflect the presence of the silicon carbide (SiC) coating. Another property that must be considered when combining fibers into a matrix is the similarity between the coefficients of thermal expansion for the two materials. If the fiber expands and contracts at a rate much different from that of the matrix, fibers may break or bonding can be disrupted, causing premature failure.

In many composites, individual plies or layers of fabric are joined. Bonding between these layers must also be good or another problem—delamination—may occur. Delamination has been suspected to be a cause in some accidents involving airplanes using composite-based structures. The layers may tear apart under load and cause failure. Using composites with a three-dimensional weave will help prevent delamination.

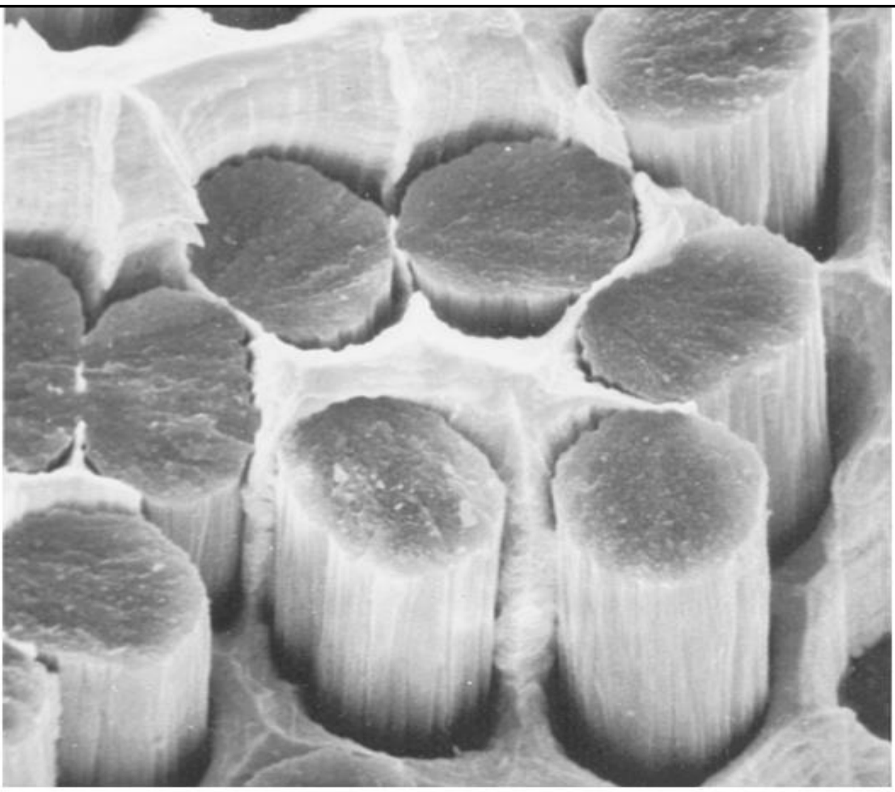


Figure 17-16 Scanning electron micrograph of the fracture surface of a silver-copper alloy reinforced with carbon fibers. Poor bonding causes much of the fracture surface to follow the interface between the metal matrix and the carbon tows (×3000). (*From* Metals Handbook, *American Society for Metals, Vol. 9, 9th Ed., 1985.*)