together to give the necessary mechanical strength or stiffness to the composite part. Today this definition usually refers to fibers as reinforcement in a resin matrix, but it can also include metal-skinned honeycomb panels, for example.

Reinforced concrete is a good example of a composite material. The steel and concrete retain their individual identities in the finished structure. However, because they work together, the steel carries the tension loads and the concrete carries the compression loads. Although not covered by this book, metal and ceramic matrix composites are being studied intensively. Composites in structural applications have the following characteristics:

- They generally consist of two or more physically distinct and mechanically separable materials.
- They are made by mixing the separate materials in such a way as to achieve controlled and uniform dispersion of the constituents.
- Mechanical properties of composites are superior to and in some cases uniquely different from the properties of their constituents. This is clearly seen with glass-reinforced plastics (GRP). In the case of GRP, the epoxy resin is a relatively weak, flexible, and brittle material, and although the glass fibers are strong and stiff, they can be loaded in tension only as a bare fiber. When combined, the resin and fiber give a strong, stiff composite with excellent toughness characteristics.

## 1.2 History of Composite Materials

A composite is, by definition, something made from two or more components—in our case here, a fiber and a resin. Composites are not a new idea. Moses floated down the Nile in a basket made from papyrus reeds coated with pitch. Papyrus is a form of paper with a visible fibrous reinforcement; therefore, it would not have been difficult to make a waterproof basket from it. From ancient times, it was known that bricks were stronger if filled with chopped straw. African "mud" huts were reinforced with grasses and thin sticks. The Butser Hill farm project shows that woven sticks, bonded with a mixture of cow dung and mud, were used to build house walls in England in 1500 B.C. It would be interesting to know how the correct mix ratio for the cow dung and the mud was determined! The lath and plaster walls in old English houses were a form of composite. Although the concept is old, the materials have changed. Carbon, aramid, and glass fibers are very expensive compared to straw, and epoxy resins are costly compared to a mixture of cow dung and mud! Fortunately, the performance for a given weight is much higher. There also are natural composites such as wood. The structure of a tree consists of long, strong cellulose fibers bonded together by a protein-like substance called lignin. The fibers that run up the trunk and along the branches are thus aligned by nature in the optimum way to resist the stresses experienced from gravity and wind forces. Large radii are provided at the trunk-to-branch and branch-to-branch joints to reduce stress concentrations at high-load points.





## 1.3 Advantages and Disadvantages of Composites

Composite parts have both advantages and disadvantages when compared to the metal parts they are being used to replace.

### 1.3.1 Advantages of Composites

1. A higher performance for a given weight leads to fuel savings. Excellent strength-to-weight and stiffness-to-weight ratios can be achieved by composite materials. This is usually expressed as strength divided by density and stiffness (modulus) divided by density. These are so-called "specific" strength and "specific" modulus characteristics.
2. Laminate patterns and ply buildup in a part can be tailored to give the required mechanical properties in various directions.
3. It is easier to achieve smooth aerodynamic profiles for drag reduction. Complex double-curvature parts with a smooth surface finish can be made in one manufacturing operation.
4. Part count is reduced.
5. Production cost is reduced. Composites may be made by a wide range of processes.
6. Composites offer excellent resistance to corrosion, chemical attack, and outdoor weathering; however, some chemicals are damaging to composites (e.g., paint stripper), and new types of paint and stripper are being developed to deal with this. Some thermoplastics are not very resistant to some solvents. Check the data sheets for each type.

### 1.3.2 Disadvantages of Composites

1. Composites are more brittle than wrought metals and thus are more easily damaged. Cast metals also tend to be brittle.
2. Repair introduces new problems, for the following reasons:
   - Materials require refrigerated transport and storage and have limited shelf lives.
   - Hot curing is necessary in many cases, requiring special equipment.
   - Curing either hot or cold takes time. The job is not finished when the last rivet has been installed.
3. If rivets have been used and must be removed, this presents problems of removal without causing further damage.
4. Repair at the original cure temperature requires tooling and pressure.

5. Composites must be thoroughly cleaned of all contamination before repair.
6. Composites must be dried before repair because all resin matrices and some fibers absorb moisture.

### 1.3.3 Advantages of Thermoset Resin Composites

Thermoset resin composites have advantages and disadvantages when compared to thermoplastic resin composites. The advantages of thermoset resin composites over thermoplastic resin composites include the following:

1. Thermosets will cure at lower temperatures than most thermoplastics will melt. Therefore, thermosets can be manufactured at lower temperatures than thermoplastics.
2. Two-part systems can be cured at room temperature, and their cure can be speeded by heating to approximately 80°C (176°F).
3. A range of curing temperatures, particularly with epoxy systems, allows repair at lower temperatures than the original cure.
4. Tooling can be used at lower temperatures than with thermoplastics.
5. Chemical resistance is generally good, but check for resistance to any chemicals that may come into contact with the part. For example, some epoxies are more resistant to chemicals than others.

### 1.3.4 Disadvantages of Thermoset Resin Composites

1. Slow to process (cold store/thaw/cure).
2. Relatively low toughness, environmental performance, and strength.
3. Can be health hazards.
4. Slow to repair.

### 1.3.5 Advantages of Thermoplastic Resin Composites

The advantages of thermoplastic resin composites over thermoset resin composites include the following:

1. Thermoplastic resin composites are much tougher than thermosets and offer fast processing times and good environmental performance, except against certain solvents in some cases. Again, check each material and its response to each solvent likely to be encountered.





2. No health hazards.
3. More closely match fiber performance.
4. Good fire/smoke performance (interiors and fuel tanks and engine parts).
5. Good fatigue performance.
6. Primary structure usage.
7. High temperature uses polyetheretherketone (PEEK) 250 to 300°C (482 to 572°F).
8. Commercial applications include helicopter rotor blades, some high-strength interior parts, and fairing panels on civil aircraft.
9. Future possibility of resin transfer molding (RTM) around reinforcing fiber or use in conventional application mode (i.e., pre-preg stacking). Single crystal growth versions could be used for engine parts.

### 1.3.6 Disadvantages of Thermoplastic Resin Composites

1. Cost.
2. New process methods.
3. Long-term fatigue characteristics unknown.
4. Temperature to melt for repairs is very high in some cases. This could cause serious problems for *in-situ* repairs to primary or secondary structures, especially if being done near fuel tanks or hydraulic systems.
5. Polyimides suffer microcracking (Ref. 1.1).

## 1.4 Applications of Composites to Modern Aircraft, Yachts, Cars, and Trains

### 1.4.1 Early Aircraft Structures

Early aircraft were composite-based structures because they were built from wood, which is a composite material comprising a cellulose/lignin mixture that gives wood its excellent strength-to-weight performance and properties of resilience and damage resistance. However, wood is subject to deterioration by moisture-induced decay and attack from fungal growths. By the 1930s, wooden aircraft structures began to be replaced by stressed-skin, monocoque aluminum alloy structures.