Chapter 5: Material Selection

Contents

Introduction

The selection of composite materials for engineering applications requires a systematic evaluation that connects service requirements, material capabilities, manufacturing constraints, and economic factors into a coherent decision framework. This chapter presents the principal concepts and methods used in composite material selection, from defining functional requirements through multi-criteria evaluation to practical case studies and repair considerations [1], [3].

5.1 Service Properties and Functional Compatibility

The first step in material selection is to identify the properties the component needs during its operational life. These typically include [1], [3]:

- **Mechanical:** strength, stiffness, fatigue resistance, and impact tolerance.
- **Thermal:** thermal stability, conductivity, and resistance to elevated temperatures.
- **Chemical:** corrosion resistance and compatibility with the operating environment.
- **Physical:** density, dimensional stability, and surface finish.
- **Durability:** long-term performance under sustained loading, environmental exposure, and ageing.

Once these requirements are defined, the engineer matches them against available materials. This process asks four basic questions [1]:

- What is the component's primary function?
- What type of loading will it experience?
- What environment will it operate in? How long must it last?

Composites hold a particular advantage at this stage because their properties are not fixed they can be adjusted by changing the matrix, the reinforcement type, the fibre direction, or the layer stacking sequence to match the specific needs of the application [3].

5.2 Material–Process Compatibility

A material that meets all functional requirements may still be unsuitable if no manufacturing process can shape it into the required geometry at reasonable cost. Hand lay-up and VARI are suited to large simple shapes using thermoset matrices with glass or carbon fibres. RTM handles moderate-complexity parts with fibre preforms, while SMC/BMC injection moulding produces complex high-volume components using short-fibre reinforcement. Pultrusion is restricted to constant cross-section profiles with continuous fibres, and filament winding to axially symmetric geometries. AFP and prepreg processing accommodate large curved structures using either thermoset or thermoplastic matrices with continuous fibres. Additive manufacturing works with thermoplastic matrices and short or continuous fibres for complex low-volume parts [10], [11].

5.3 Multi-Criteria Selection

In practice, no material is best in every category. A material may be strong but expensive, or light but difficult to manufacture. Multi-criteria methods help engineers weigh these trade-offs systematically [1].

A. Ashby Charts

Ashby charts are graphs that plot one property against another for example, stiffness versus density. Each material occupies a region on the chart, and the engineer draws a selection line representing the design target. Materials above the line meet the requirement; those below do not. This visual approach makes it easy to compare dozens of materials at a glance and to identify which composites outperform metals for a given design objective [1].

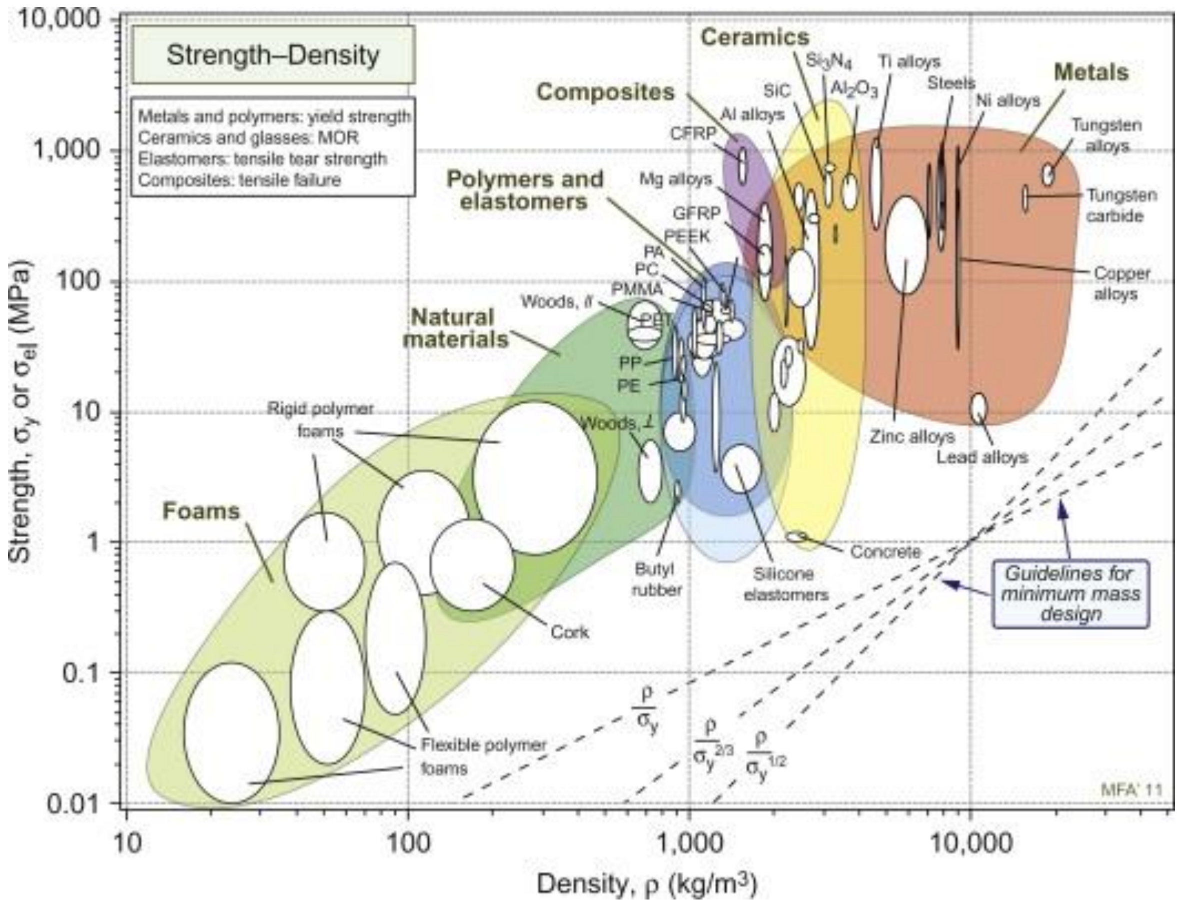

Figure 5.2 Ashby chart: strength-density, showing where composites, metals, and polymers fall.

B. Weighted Scoring Method

When several criteria matter at the same time, a scoring method can be used:

- List the criteria that matter (strength, density, cost, corrosion resistance, etc.).
- Give each criterion a weight reflecting how important it is for this particular application.
- Score each candidate material on every criterion.
- Multiply each score by its weight and add the results.
- The material with the highest total score is the best overall candidate.

This approach forces the engineer to make priorities explicit rather than relying on intuition [1], [7].

5.4 Aluminium Alloys versus CFRP Composites

The choice between aluminium and CFRP is one of the most common selection decisions in modern structural engineering. CFRP offers significantly lower density (~1.6 versus ~2.7 g/cm^3), higher specific strength and specific modulus, inherent corrosion resistance without surface treatment, and superior fatigue performance. Aluminium, however, retains advantages in manufacturing cost, recyclability, damage visibility surface damage in metals is immediately apparent whereas internal damage in composites may remain undetected and repairability through conventional techniques rather than the specialised methods composites require [1], [3], [7].

In aerospace, CFRP has progressively replaced aluminium in primary structures because the weight savings reduce fuel consumption significantly. The Boeing 787 and Airbus A350 are both over 50% composite by structural weight. Aluminium remains the better choice when cost, easy inspection, and simple repair are the priorities [1], [7].

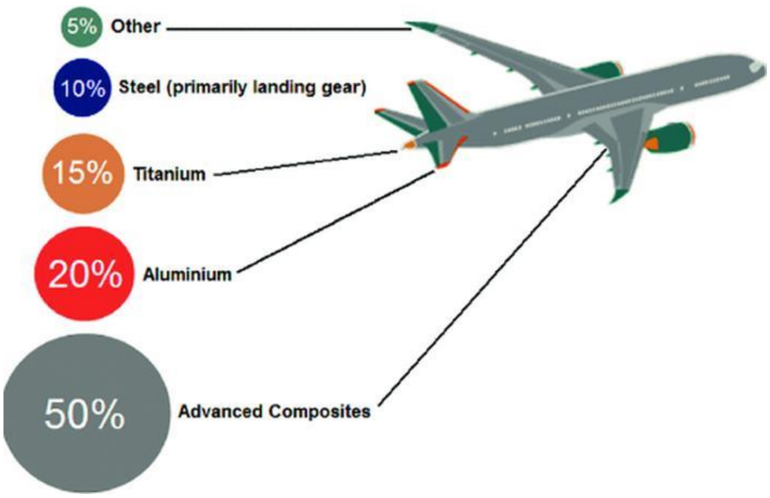

Figure 5.3 Composite content evolution in commercial aircraft structures.

5.5 Reinforcement and Repair of Damaged Structures

A. Structural Reinforcement

Composite patches and laminates (CFRP or GFRP) can be bonded onto the outside of existing structures concrete beams, bridge columns, metallic frames to restore or increase their load-carrying capacity. This technique is widely used for seismic retrofitting and for extending the life of ageing infrastructure [4], [15].

B. Repair of Composite Structures

When a composite component is damaged in service, three main repair methods are available:

- **Patch repair:** a composite patch is bonded over the damaged area simple and effective for surface damage.
- **Scarf repair:** the damaged zone is cut away at a tapered angle and replacement layers are bonded in this gives better load transfer and is used for structural repairs.
- **Injection repair:** resin is injected into delaminated zones to re-bond the separated layers used for internal damage that has not broken through the surface [3], [15].

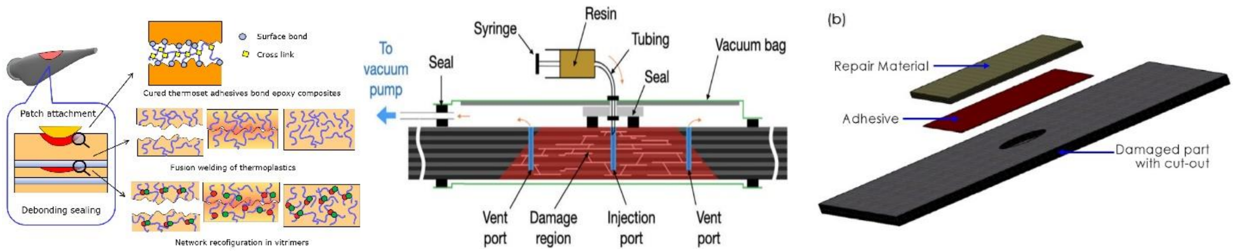

Figure 5.2 The three composite repair methods: patch, scarf, and injection.

The choice of method depends on how severe the damage is, whether the area is accessible, how critical the component is structurally, and how much strength needs to be restored [3], [15].

References

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