الجامعة التكنولوجية
قسم هندسة المواد
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Selection of Engineering Materials
Lec-1

INTRODUCTION AND SYNOPSIS

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Introduction and synopsis

This chapter sets out the basic procedure for selection, establishing the link between material and function (Figure 2.1-1). A material has *attributes*: its density, strength, cost, resistance to corrosion, and so forth. A design demands a certain profile of these: a low density, a high strength, a modest cost and resistance to sea water, perhaps. It is important to start with the full menu of materials in mind; failure to do so may mean a missed opportunity. If an innovative choice is to be made, it must be identified early in the design process. Later, too many decisions have been taken and commitments made to

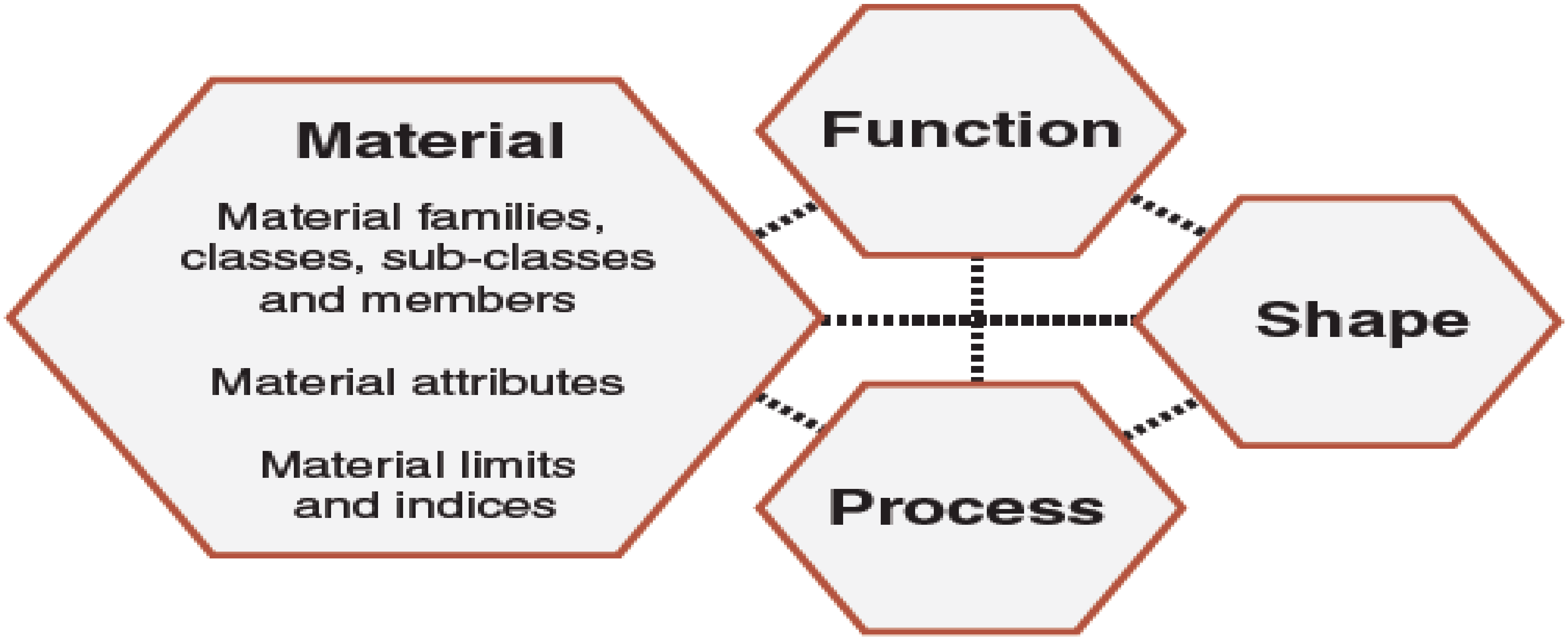

Figure 2.1-1 Material selection is determined by function. Shape sometimes influences the selection. This chapter and the next deal with materials selection when this is independent of shape.

allow radical change: it is now or never. The task, restated in two lines, is that of

(1) identifying the desired attribute profile and then

(2) comparing it with those of real engineering materials to find the best match.

The first step in tackling it is that of *translation*, examining the design requirements to identify the constraints that they impose on material choice. The immensely wide choice is narrowed, first, by *screening-out* the materials that cannot meet the constraints. Further narrowing is achieved by *ranking* the candidates by their ability to maximize performance. Criteria for screening and ranking are derived from the design requirements for a component by an analysis of *function*, *constraints*, *objectives*, and *free variables*. This chapter explains how to do it.

constraints and material indices can be plotted onto them, isolating the subset of materials that are the best choice for the design. The whole procedure can be implemented in software as a design tool, allowing computer-aided selection. The procedure is fast, and makes for lateral thinking.

The selection strategy

Material attributes

Figure 2.1-2 illustrates how the kingdom of materials is divided into families, classes, sub-classes, and members. Each member is characterized by a set of *attributes:* its properties. As an example, the materials kingdom contains the family "metals", which in turn contains the class "aluminum alloys", the subclass "6000 series" and finally the particular member "Alloy 6061". It, and every other member of the kingdom, is characterized by a set of attributes that include its mechanical, thermal, electrical, optical, and chemical properties, its processing characteristics, its cost and availability, and the environmental consequences of its use. We call this its *property-profile*. Selection involves seeking the best match between the property-profiles of the materials in the kingdom and that required by the design.

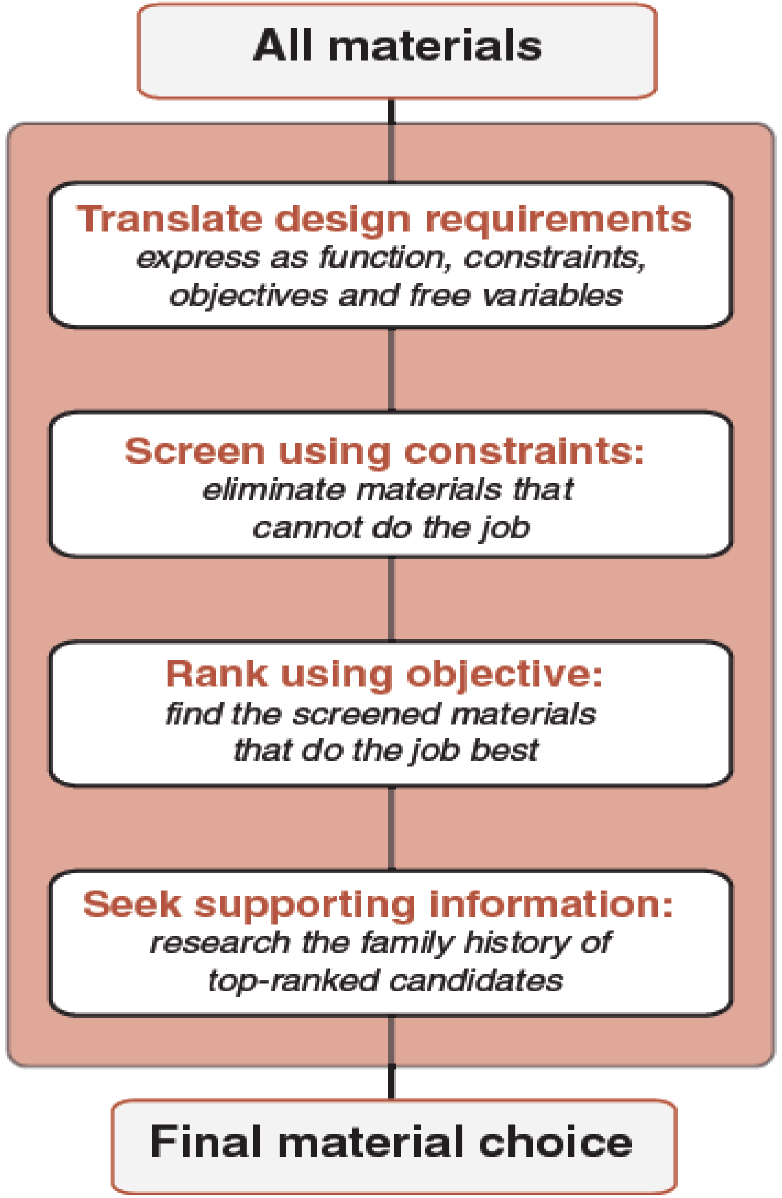

Figure 2.1-3 The strategy for material selection. The four main steps—translation, screening, ranking, and supporting information—are shown here.

There are four main steps, which we here *call translation, screening, ranking, and supporting information* (Figure 2.1-3). The steps can be likened to those in selecting a candidate for a job. The job is first analyzed and advertised, identifying essential skills and experience required of the candidate ("translation"). Some of these are simple go/no go criteria like the requirement that the applicant "must have a valid driving license", or "a degree in computer science", eliminating anyone who does not ("screening"). Others imply a criterion of excellence, such as "typing speed and accuracy are priorities", or "preference will be given to candidates with a substantial publication list", implying that applicants will be ranked by these criteria ("ranking"). Finally references and interviews are sought for the top ranked candidates, building a file of supporting information—an opportunity to probe deeply into character and potential.

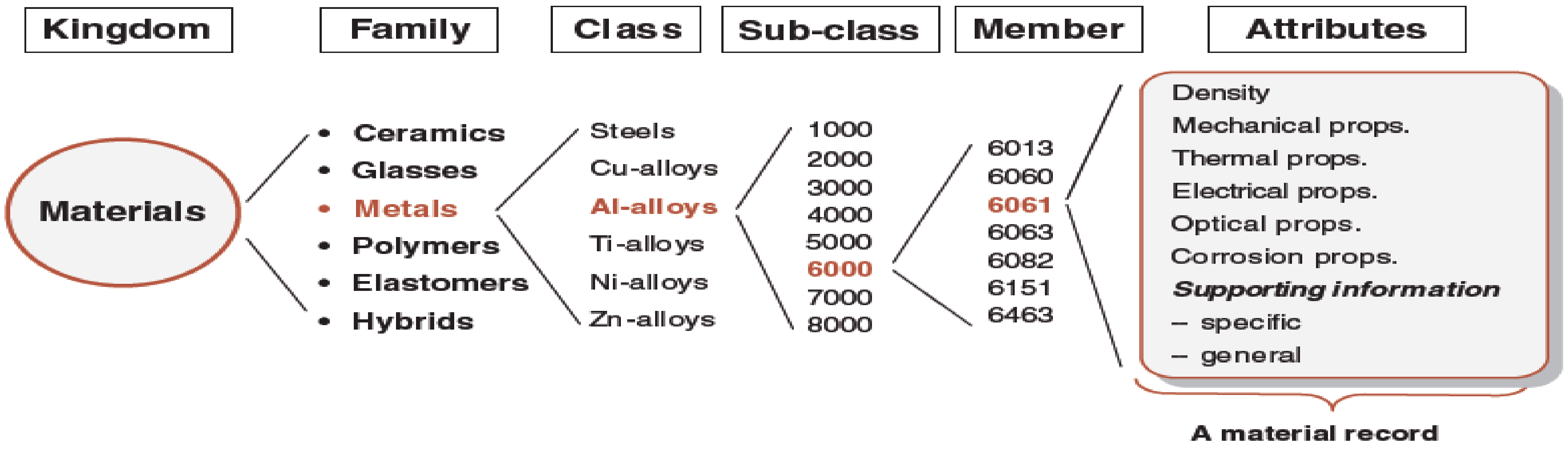

Figure 2.1-2 The taxonomy of the kingdom of materials and their attributes. Computer-based selection software stores data in a hierarchical structure like this.

Translation

How are the design requirements for a component (defining what it must do) translated into a prescription for a material? Any engineering component has one or more *functions*: to support a load, to contain a pressure, to transmit heat, and so forth. This must be achieved subject to *constraints*: that certain dimensions are fixed, that the component must carry the design loads or pressures without failure, that it insulates or conducts, that it can function in a certain range of temperature and in a given environment, and many more. In designing the component, the designer has an *objective*: to make it as cheap as possible, perhaps, or as light, or as safe, or perhaps some combination of these. Certain parameters can be adjusted in order to optimize the objective—the designer is free to vary dimensions that have not been constrained by design requirements and, most importantly, free to choose the material for the component. We refer to these as *free variables*. Function and constraints, objective and free variables (Table 2.1-1) define the boundary conditions for selecting a material and—in the case of load-bearing components—a shape for its cross-section. The first step in relating design requirements to material properties is a clear statement of function, constraints, objective, and free variables.

Screening: attribute limits

Unbiased selection requires that all materials are considered to be candidates until shown to be otherwise, using the steps in the boxes below "translate" in Figure 2.1-3. The first of these, *screening*, eliminates candidates that cannot do the job at all because one or more of their attributes lies outside the limits set by the constraints. As examples, the requirement that "the component must function in boiling water", or that "the component must be transparent" imposes obvious limits on the attributes of *maximum service temperature* and *optical transparency* that successful candidates must meet. We refer to these as *attribute limits*.

Table 2.1-1 Function, constraints, objectives and free variables

Function	What does component do?
Constraints*	What non-negotiable conditions must be met? What negotiable but desirable conditions ...?
Objective	What is to be maximized or minimized?
Free variables	What parameters of the problem is the designer free to change?

* It is sometimes useful to distinguish between "hard" and "soft" constraints. Stiffness and strength might be absolute requirements (hard constraints); cost might be negotiable (a soft constraint).

Ranking: material indices

Attribute limits do not, however, help with ordering the candidates that remain. To do this we need optimization criteria. They are found in the material indices, developed below, which measure how well a candidate that has passed the screening step can do the job. Performance is sometimes limited by a single property, sometimes by a combination of them. Thus the best materials for buoyancy are those with the lowest density, ρ; those best for thermal insulation the ones with the smallest values of the thermal conductivity, λ. Here maximizing or minimizing a single property maximizes performance. But—as we shall see–the best materials for a light stiff tie-rod are those with the greatest value of the specific stiffness, E/ρ, where E is Young's modulus. The best materials for a spring are those with the greatest value of σ_f^2/E where σ_f is the failure stress. The property or property-group that maximizes performance for a given design is called its *material index*. There are many such indices, each associated with maximizing some aspect of performance.[1] They provide *criteria of excellence* that allow ranking of materials by their ability to perform well in the given application.

To summarize: screening isolate candidates that are capable of doing the job; ranking identifies those among them that can do the job best.

Supporting information

The outcome of the steps so far is a ranked short-list of candidates that meet the constraints and that maximize or minimize the criterion of excellence, whichever is required. You could just choose the top-ranked candidate, but what bad secrets might it hide? What are its strengths and weaknesses? Does it have a good reputation? What, in a word, is its credit-rating? To proceed further we seek a detailed profile of each: its *supporting information* (Figure 2.1-3, bottom).

Supporting information differs greatly from the structured property data used for screening. Typically, it is descriptive, graphical or pictorial: case studies of previous uses of the material, details of its corrosion behavior in particular environments, information of availability and pricing, experience of its environmental impact. Such information is found in handbooks, suppliers' data sheets, CD-based data sources and the world-wide web. Supporting information helps narrow the short-list to a final choice, allowing a definitive match to be made between design requirements and material attributes.

Why are all these steps necessary? Without screening and ranking, the candidate-pool is enormous and the volume of supporting information overwhelming. Dipping into it, hoping to stumble on a good material, gets you nowhere. But once a small number of potential candidates have been identified by the screening–ranking steps, detailed supporting information can be sought for these few alone, and the task becomes viable.