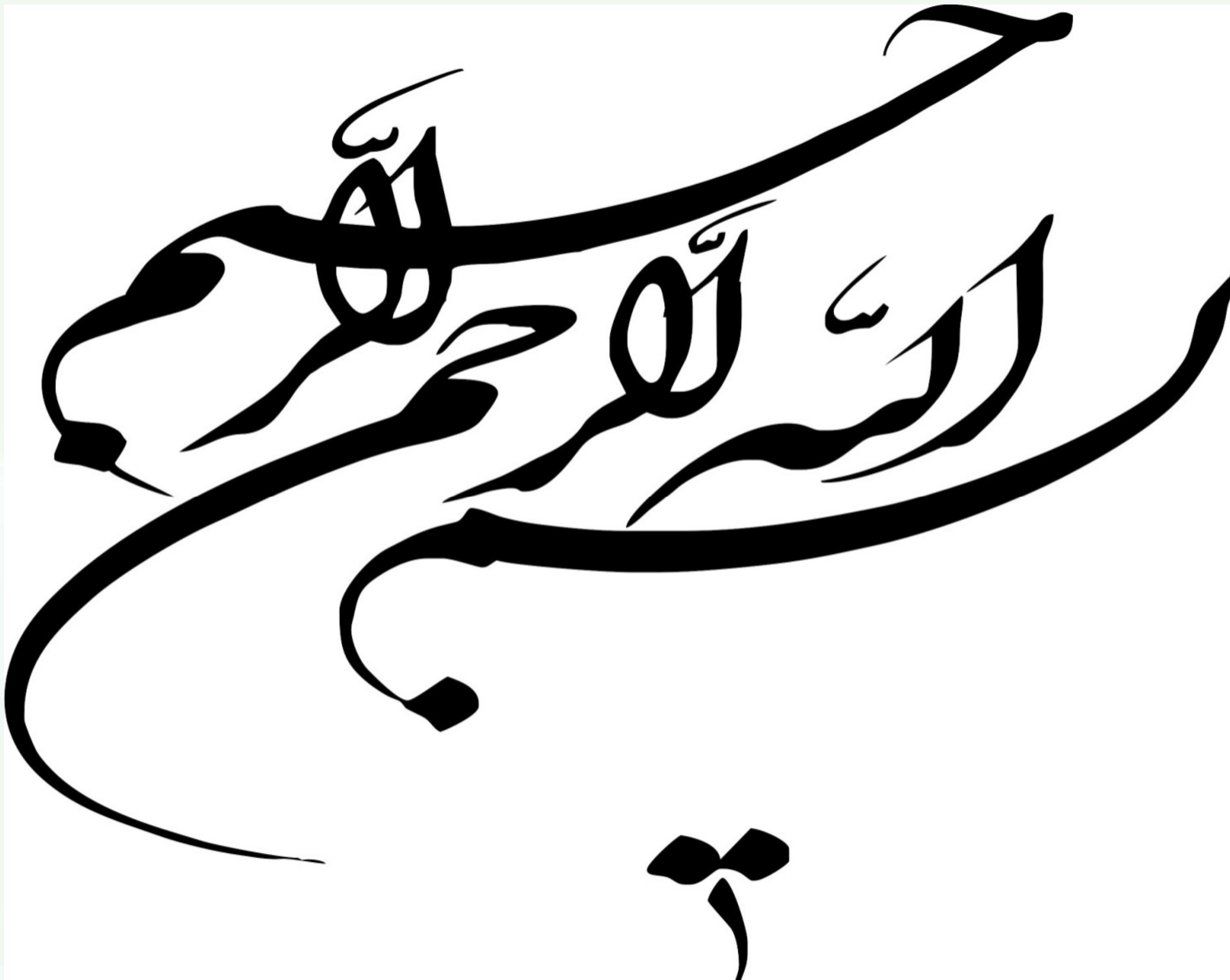

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K. N. Toosi University of Technology

Faculty of Materials Science and Engineering

Selection of Engineering Materials

Forth Session
(Materials Selection Process- 2)

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Classification of Materials Requirements

The next step in materials selection involves categorizing materials requirements into two major groups:

1- Hard Requirements (Go / No-Go Requirements)

2- Soft or Relative Requirements

Classification of Materials Requirements

Hard requirements are those that must be met for a material to be considered at all. These requirements are typically used in the initial screening of materials to eliminate unsuitable groups.

For example, when selecting a material for an insulating piece, all metallic materials are eliminated. If we want a flexible insulator, all ceramic materials are also eliminated.

Classification of Materials Requirements

Examples of Materials Hard Requirements Include:

- Stability in corrosive environments
- Formability
- Electrical conductivity or resistance
- Transparency to light or other waves
- Maintaining properties at high temperatures

Classification of Materials Requirements

Examples of Processes Hard Requirements Include:

- Production rate
- Size and shape of the product
- Surface finishing

Classification of Materials Requirements

- In many cases, the presence of specific equipment or experience of a production process in a workshop is also considered a hard requirement. Compatibility between the manufacturing process and the material is also an important variable. For example, sheet metal forming processes are not suitable for cast irons.

Classification of Materials Requirements

- Also, in many cases, the automatic removal of a group of materials also leads to the elimination of a group of production processes. For example, if plastics are removed due to high ambient temperature, the injection molding method is also eliminated.

Classification of Materials Requirements

- **Soft requirements** are adjustable criteria that can be increased or decreased relative to each other.
- Mechanical properties, density, and price are examples of soft requirements.
- These types of requirements can be compared with each other based on their relative importance, which is a function of the application conditions.

Formulating and Evaluating Solutions

After determining and categorizing materials requirements, the rest of the selecting process is a search to identify a material that best meets the requirements.

- **Creating Solutions**

The starting point for material selection is the entire range of engineering materials. At this stage, creativity is essential to explore paths in all directions. At this stage, regardless of economic feasibility, possible options must be created (creating solutions).

Formulating and Evaluating Solutions

Screening Solutions

After proposing all possible solutions, inappropriate ones are eliminated, and attention is focused on options that seem practical. At the end of this stage, the number of candidate materials is reduced to a level where detailed evaluations can be carried out.

Selecting the Optimal Solution

- After narrowing down the possible materials options to those that do not violate any of the hard requirements, the search for materials that best meet the soft requirements begins.
- The goal of the evaluation stage is to weigh the nominated materials to meet the defined requirements in order to select the optimal one for that application.

Selecting the Optimal Solution

- In this process, we will not have only one correct answer, as materials selection process involves conflicting criteria and constraints that require some form of agreement and decision-making, thus multiple answers are possible. This is the reason why similar parts produced by different manufacturers with the same functions are made of different materials and with different methods.

Selecting the Optimal Solution

- There are several quantitative methods for optimizing selection, none of which is superior to the others, and one method is chosen based on different conditions. These methods include:

1. **Cost Per Unit Properties Method**
2. **Normalized (Weighted) Properties Method**
3. **Properties Constraint Method**

Cost Per Unit Property Method

- The cost per unit property method is used when one of the properties is identified as the most important functional requirement. In such simple cases, materials can be compared based on the cost of purchasing one unit of that important property.

- For example, in selecting suitable materials for a rod subjected to tensile force, the material with the lowest cost per unit strength is the optimal material. The material that has the lowest cost per unit of strength is the optimal material.

Cost Per Unit Property Method

- The minimum cost per unit strength means the minimum value of $C\rho/S$ is required.
- C represents the cost of material per unit mass, ρ indicates density, and S is the working stress of the material related to an appropriate safety factor to the material's yield stress.
- The concept of material cost (C) includes the total production cycle cost (including material price, lifespan, manufacturing cost, installation, maintenance, repair, and disposal).

Cost Per Unit Property Method

Since the applied force F and the length of the rod L are constant for a rod, the lower the Cρ, the better the material. For static loading, using yield stress is logical, but for dynamic loading or cyclic loading conditions, fatigue strength, and for conditions under creep, creep strength should be considered.

Cost Per Unit Property Method

- Example:

Consider a rod with length L to withstand a specified tensile force F. The cross-sectional area of the rod (A) is equal to

$$A = F/S$$

The cost of the rod (C') is calculated by multiplying the material mass by the cost of the material per unit mass:

$$(C') = C.\ \rho.\ A.\ L. = (\ C.\ \rho.\ F.\ L.) / S$$

C is the material cost per unit mass, ρ is the density of the material and ρ.A.L is the mass.

Cost Per Unit Property Method

When a material is introduced as a substitute for another material, two materials a and b are compared based on the relative cost per unit strength (RC').

$$RC' = (C')_a /(C')_b = C_a \rho_a S_b / C_b \rho_b S_a$$

Since S is related to yield stress with a coefficient, it is likely a constant coefficient and since the yield stress a and b are different, therefore S_a and S_b differ.

If RC' is less than one, material a is preferred over material b.

$$(C')_a < (C')_b$$

Cost Per Unit Property Method

The cost per unit property formulas under different loading conditions based on yield strength and stiffness

Unit cost of stiffness	Unit cost of strength	Cross-section and loading conditions
$C\rho/E$	$C\rho/S$	Cylindrical rod in tension or compression
$C\rho/E^{1/2}$	$C\rho/S^{2/3}$	Cylindrical rod in bending
$C\rho/G^{1/3}$	$C\rho/S^{2/3}$	Cylindrical rod in torsion
$C\rho/E^{1/2}$	------	Cylindrical rod as a beam
$C\rho/E^{1/3}$	$C\rho/S^{1/2}$	Rectangular cross-section in bending
-------	$C\rho/S$	Thin-walled cylinder pressure vessel

Cost Per Unit Property Method

- The cost per unit property method has the limitation of considering only one requirement as the most important and neglecting other requirements.

- However, in many applications, the situation is more complex and generally requires a material to exhibit more than one specific property as an important characteristic. In this case, the method of weighted properties is used.

Normalized (Weighted) Properties Method

- The normalized properties method can be used for optimizing material selection in situations where multiple properties need to be considered.

- Each material requirement or property is weighted based on its importance. The weight of each property is the product of its numerical value by the weight coefficient (α).

Normalized (Weighted) Properties Method

- The individual values of normalized properties for each material are summed to obtain a comparative performance index of materials (γ). The material with the highest performance index γ is the optimal material for that application.

- The problem with this method is in its simple form that requires combining heterogeneous units, which can lead to illogical results.

Normalized (Weighted) Properties Method

When different physical, chemical, and mechanical properties are combined with significantly different numerical values, this issue becomes noticeable. In this case, the property with a higher numerical value will have a greater impact regardless of its weight coefficient. This problem is resolved by introducing scaling coefficients (normalization).

Normalized (Weighted) Properties Method

Each property is scaled in such a way that its maximum value does not exceed 100. When evaluating a list of candidate materials, each property is examined one at a time, and the best value in the list is assigned a score of 100, with other values given proportionally. The weight coefficient is then multiplied by the resulting number (a number between 0 and 100).

Normalized (Weighted) Properties Method

Introducing normalization coefficients facilitates converting the typical values of material properties to dimensionless normalized values. For a specific material, the normalized value β for a property is equal to:

$$\boldsymbol{\beta} = \frac{numerical\ value\ of\ the\ property * 100}{Highest\ value\ in\ list}$$

For properties such as cost, weight reduction due to corrosion or wear, weight increase due to oxidation, etc., a smaller number is desirable. Therefore:

$$\boldsymbol{\beta} = \frac{Numerical\ value\ of\ the\ property * 100}{Lowest\ value\ in\ list}$$

Normalized (Weighted) Properties Method

For properties of materials that are rarely defined with numerical values (such as corrosion resistance, abrasion resistance, machinability, weldability, etc.), terms like excellent, very good, good, fair, and poor are commonly used. In these cases, a grading scale is used to convert qualitative ratings to numerical values.

Normalized (Weighted) Properties Method

For example, to such terms are assigned numbers 1, 2, 3, 4, and 5, respectively, and the material performance index (γ) is determined using the following method:

$$\gamma = \sum_{i=1}^{n} \beta_i \alpha_i$$

α: Relative importance coefficient

β: Normalized property

i: All values from 1 to n for relevant properties

Normalized (Weighted) Properties Method

This method can be considered for the case where a new material is chosen to replace the existing material. In this case, the relative merit score (RM) is obtained as follows:

$$RM = M_n / M_e$$

M_n and M_e are the respective superiority number of the new and current materials. If RM is greater than one, the new material is better.

For a large number of materials with multiple properties, the mentioned method requires a lot of calculations and is time-consuming, so it is better to use a computer.

Properties Constraint Method

In the properties constraint method, functional requirements are divided into the following three groups:

- **Properties with Minimum Constraints**
- **Properties with Maximum Constraints**
- **Properties with Target Values**

Properties Constraint Method

- For example, if a material is desired to be strong and light, a minimum limit for strength and a maximum limit for density are determined.

- When compatibility between materials is important, a target value is set for them. For example, the coefficient of thermal expansion and the position of the material in galvanic series are controlled to respectively manage thermal stresses and galvanic corrosion.

Properties Constraint Method

- Defining an upper or lower limit for a property is a function of the component's application. For instance, electrical conductivity for a power cable, a lower limit for the conductor and an upper limit for the insulation are defined.

- The method of properties constraints is used to optimize material and process when there are relatively many possible options available. In this case, the specified limits for different properties can be used to eliminate unsuitable materials.

Properties Constraint Method

- ✓ Remaining materials are those whose properties are above the lower limit, below the upper limit, and within the target range for defined requirements.
- ✓ After the screening stage, the method of properties constraints can be used to optimize the selection among the remaining materials.

Properties Constraint Method

- ✓ Similar to the method of weighted properties, a weighting factor (Q) is assigned to each of the requirements or properties. Then, according to the following equation, a superiority number (m) is calculated for each material:

$$m = \left[\sum_{i=1}^{nl} ai \frac{yi}{xi} \right]_l + \left[\sum_{j=1}^{nu} aj \frac{xj}{yj} \right]_u + \left[\sum_{k=1}^{nt} ak \, |xk/yk - 1| \right]$$

Properties Constraint Method

- l, u, and t, respectively represent the lower limit, upper limit, and target value of properties.
- n_l, n_u, and n_t represent the number of properties with lower limit, upper limit, and target value.
- X_i, X_j, and X_K are the weighting factors of properties with lower limit, upper limit, and target value.
- y_i, y_j, and y_k are the specified values of lower limit, upper limit, and target size.
- The smaller the numerical value of superiority number (m), the better the material is.

Properties Constraint Method

Cost can be considered in two ways:

1. It can be considered as a property with an upper limit and an appropriate weight assigned to it.

2. It can be entered as a corrective factor in the superiority number calculation as follows:

$$m' = (C_x / C_y)\, m$$

Where C_x and C_y are the cost of the candidate material and the specified upper limit for cost, respectively.

In this case, the lower the corrected superiority number (m') is, material associated with it is the optimal material.