الجامعة التكنولوجية
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Selection of Engineering Materials (CousreII) Lec-6

WSM & WPM

By

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Introduction

Material selection is the bed rock of all engineering design and applications. This *selection* process can be described with respect to application requirements, possible *materials*, physical principles, and *selection*. The decision to select an alternative material among several available options is one of the challenges faced by designers. The selection process often involves several criteria that need to be enhanced effectively.

Product component material is regarded as one of the important parameters in the process of engineering product design. Charles (1989) has mentioned in his paper that in the materials selection plays an important role in the development of a product, as important as design and manufacturing and that all these activities are interrelated. The mechanical, physical, chemical, electrical, magnetic property requirements solely depend on the selected materials. Others which partly depend on component materials are product manufacturability; rigidity and stability of overall structure; safety, cost, and functionality. Consequently, material selection process appears to be one of the critical factors among the tasks that have to be accomplished in engineering design. Material selection is one of the most important activities for a product development process. In the modern design manufacturing environment such as newly-developed concurrent engineering methodology, material selection plays an important role in other activities in the total design model such as market investigation, product design specification, component design, design analysis, manufacture and assembly as shown in Figure 1.

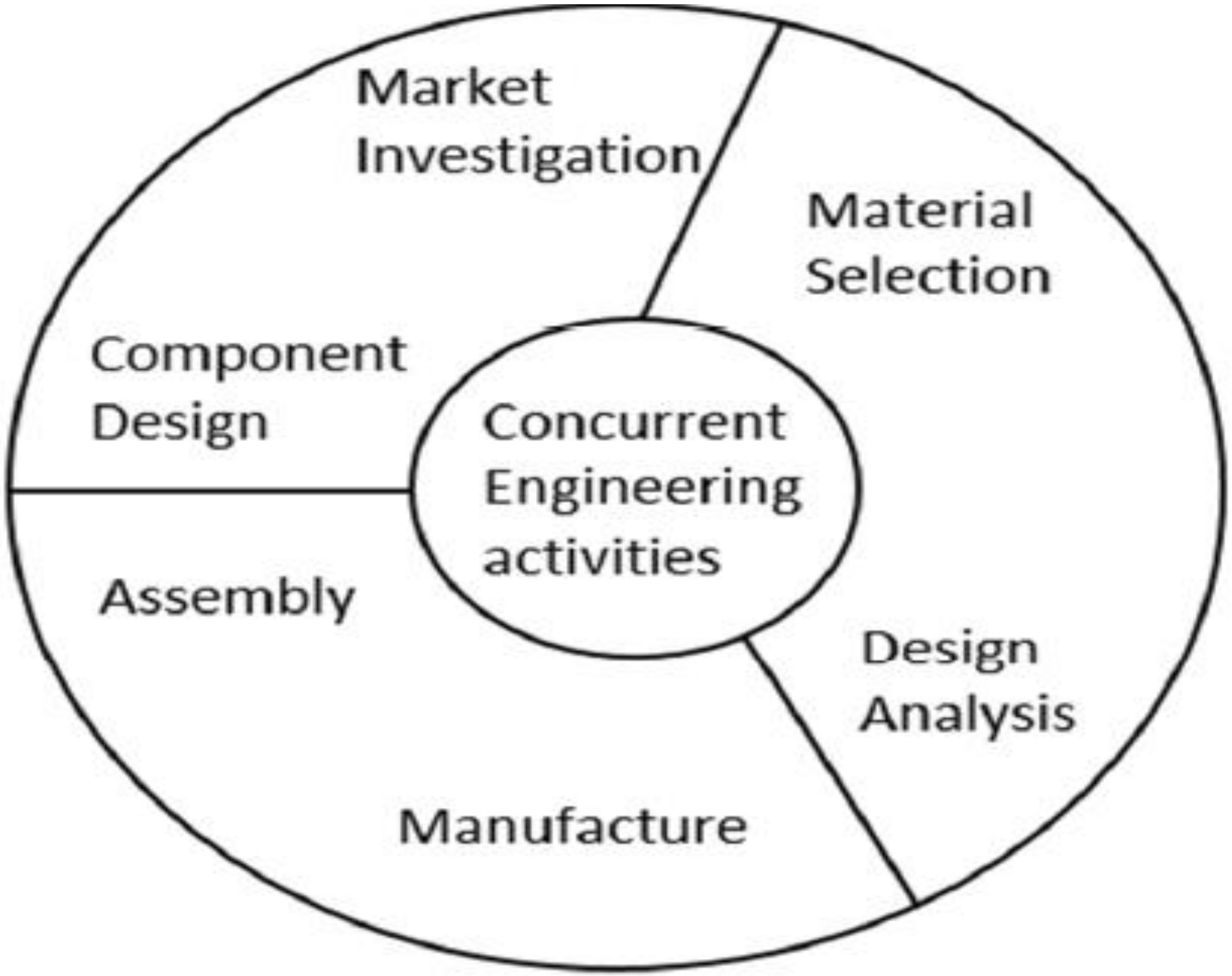

Fig.1 Material selection in production development

Materials selection methods have been in development for more than ten years. These methods typically aim to select the most appropriate solution for a given application (Haihong et al. 2010). However, the importance of materials selection in design has increased in recent years due to the range of materials available to the engineer is much larger than ever before. This represents the opportunity for innovation in design by utilizing these materials in products that provide greater performance at lower cost. To achieve this, it requires a more rational process for materials selection in deciding an appropriate optimization method that will help the decision maker to make the best choice of material for the product design.

Gutteridge and Water-man (1986) described the aim of materials selection as the identification of materials, and with appropriate manufacturing operations, and with the right dimensions, shape and properties necessary for the product or component to demonstrate its required function at the lowest cost. Selecting the best material for a part involves more than selecting a material that has properties to provide the necessary performance in service; it is also connected with the processing of the material into the finished part. A poorly chosen material can contribute to the manufacturing cost of a part and increase its price. Also, the properties of the material can be changed by processing (beneficially or detrimentally), and that may affect the service performance of the component.

The choice of a material is frequently the result of several compromises. For example, the technical appraisal of an alloy will generally be a compromise between corrosion resistance and several other properties such as strength and weldability. The objective of any material selection procedure is to identify appropriate selection criteria or material properties that may be associated with the design product or component. Knowing fully well that the performance of an engineering component is limited by the properties of the material of which it is made, and by the shapes to which this material can be formed. Thus, an attempt to identify these criteria that influences material selection for a given engineering design need to be considered so as to eliminate unsuitable alternative, and to select the most suitable alternative using simple and logical methods such as multi-criteria methods

Formulation of the Weighted-sum Method

The weighted sum model is probably the most commonly used approach in solving multi-criteria optimization problem as presented by Odu and Charles-Owaba (2013). The weighted-sum method involves selecting scalar weights w_k and optimizing an objective function with non-negative weightings ($w_k \geq 0, k = 1, n$). The weighting method consists of solving a sequence of scalar problems where the objective is defined by a linear combination of all objective functions (Zhang and Yang 2001).

Let f_j be the objective function expressing the behaviour of material property j with respect to some known quantities. For a particular material selection situation, j = 1, 2, 3, . . ., N representing n different types of mechanical, electrical, chemical, thermal, economic, manufacturing, magnetic, etc. properties. In order to select materials which simultaneously combine the best of the requirements of each property, let F_i be an expression for a performance index combining the set of n objective functions into a single function as follows:

$$F_i = \beta_1 f_1(x_{i1}) + \beta_2 f_2(x_{i2}) + \ldots + \beta_j f_j(x_{ij}) + \ldots + \beta_n f_n(x_{in}) \qquad (1)$$

where

$\{\beta_j / j = 1,2,3,\ldots,n\}$; set of normalizing factors which allows dimensional consistency in expression (1).

x_{ij}: the value of material *i* for property *j*

Usually, one normalizes measurements so as to present relative deviation between

0 and 1. Normalization aims at transferring dimension into dimensionless quantity by providing a considerable format for combining set of objective functions into s single entity. Normally, in multi-criteria optimization problems, there are two major normalization functions. These include linear normalization and vector normalization.

In the case of linear normalization, the maximum value of a certain criterion j is defined, such that the normalized value p_{ij} for beneficial criteria and non-beneficial criteria (cost attribute) are evaluated.

For beneficial criteria (maximum value more preferable)

$$p_{ij}^{\ b} = \frac{x_{ij}}{x_j^{\max}} \tag{2}$$

For non-beneficial criteria (cost attribute) (minimum value more preferable)

$$p_{ij}^{\ c} = 1 - \frac{x_{ij}}{x_j^{\max}} \tag{3}$$

Where $x_j^{\max}$ is the maximum value of criterion *j*

$p_{ij}^{\ b}$ is the values of the beneficial criterion of alternative *i*

Weighted product model (WPM)

Weighted product model (WPM) (Bridgman, 1922; Miller & Starr, 1969; Triantaphyllou & Mann, 1989) is the extension of the weighted sum model (WSM) (Fishburn, 1967; MacCrimon, 1968; Triantaphyllou & Mann, 1989; Triantaphyllou, 2000). Each alternative is compared with the other alternatives by multiplying a number of ratios, one for each decision criterion. Each ratio is raised to the power equivalent to the weights of the corresponding criterion (Bridgman, 1922; Miller & Starr, 1969; Triantaphyllou & Mann, 1989; Triantaphyllou, 2000; Tofallis, 2014).

Step 1: Forming an evaluation matrix ($m_i \times n_j$) shown by equation 9 according to Hwang and Yoon (1981) comparison scale. Where, m is the number of alternatives and n is the number of criteria. Hwang and Yoon comparison scale are shown in Table 3. Where, $m_i = n_j$ or $m_i \neq n_j$.

$$R(m_i \times n_j) = \begin{bmatrix} r_{11} & r_{12} & r_{13} & \dots r_{1n} \\ r_{21} & r_{22} & r_{23} & \dots r_{2n} \\ r_{31} & r_{32} & r_{33} & \dots r_{3n} \\ \dots & \dots & \dots & \dots \dots \\ r_{m1} & r_{m2} & r_{m3} & \dots r_{mn} \end{bmatrix} \quad (9)$$

Step 2: The evaluation or the decision matrix is normalized by using Equation 10 or Equation 11 according to the requirements and thus creating the normalization matrix.

a) For positive criteria, (whose larger values is desired)

$$n_{ij} = \frac{r_{ij}}{r_j^{max}} \tag{10}$$

Where, *i = 1, 2, 3.... m*

j = 1, 2, 3.... n

b) For negative or cost criteria, (whose smaller values is desired)

$$n_{ij} = \frac{r_j^{min}}{r_{ij}} \tag{11}$$

Where, *i = 1, 2, 3.... m*

j = 1, 2, 3.... n

r_j^{max} = Largest number in the column of j

r_j^{min} = Smallest number in the column of j

Step 3: The ratio or the relative weightages is calculated comparing each alternative over another by using Equation 12.

$$P(\frac{A_k}{A_l}) = \prod_{j=1}^{n} (\frac{n_{kj}}{n_{lj}})^{w_j} \tag{12}$$

k, l = 1, 2, 3.... m