Material Selection for a Given Engineering Application

5.1 Introduction

An ever increasing variety of materials is available today, each having its own characteristics, applications, advantages, and limitations. When selecting materials for engineering designs, a clear understanding of the functional requirements for each individual component is required, and various important criteria or attributes need to be considered. Material selection attribute is defined as a factor that influences the selection of a material for a given application. These attributes include: physical properties, electrical properties, magnetic properties, mechanical properties, chemical properties, manufacturing properties (machinability, formability, weldability, castability, heat treatability, etc.), material cost, product shape, material impact on environment, performance characteristics, availability, fashion, market trends, cultural aspects, esthetics, recycling, target group, etc.

The selection of an optimal material for an engineering design from among two or more alternative materials on the basis of two or more attributes is a multiple attribute decision-making problem. Various approaches have been proposed in the past to help address the issue of material selection. Liao (1996) presented a fuzzy multicriteria decision-making method for material selection. However, the method is complicated and requires much more computation. Farag (1997) proposed a simple mathematics-based weighted properties method that can be used when several properties should be taken into consideration. Giachetti (1998) described a prototype material and manufacturing process selection system that integrates a formal multiple attribute decision model with a relational database. The decision model enables the representation of the designer's preferences over the decision attributes. A compatibility rating between the product profile requirements and the alternatives stored in the database for each decision attribute was generated using possibility theory. The vectors of compatibility ratings were aggregated into a single rating of that alternative's compatibility. A ranked set of compatible material and manufacturing process alternatives was the output by the system.

review of the strategies or methods for materials selection, from which three types of materials selection methodology were identified: (i) free searching based on quantitative analysis, (ii) checklist/questionnaire based on expertise capture, and (iii) inductive reasoning and analog procedure. All of these methods use materials data in either a non-computerized or computerized form.

For the free-searching method, there are already a number of well-documented methods, the best known being the graphical engineering selection method or the ranking method (Ashby, 1992; Ashby and Johnson, 2002). A checklist/questionnaire method has been proposed by a number of researchers, the most recent described by Edwards (2005), where the author developed a structured set of questions to improve the likelihood of achieving an optimal design solution. The inductive reasoning and analog procedure resulted from the rapid development of information technology tools, and the application of artificial intelligence. Some of representative examples include a knowledge-based system for materials management that involves materials selection (Trethewey et al., 1998), a knowledge-based system for materials selection (Sapuan, 2001), integrated information technology approach (Jalham, 2006), fuzzy knowledge-based decision support system for selection of manufacturing processes and materials (Zha, 2005) and a case-based reasoning method (Amen and Vomacka, 2001). However, these systems and methods are complex and necessitate knowledge extensive.

A framework to represent and deal with the relationships between design variables of both materials parameters and system-level parameters was proposed by Raj (2000) and Raj et al. (2000). The idea of an integrated approach for materials selection and structural design had been advocated by Edwards (2002). The materials parameters could be material properties, or they could be parameters describing the micro/nanostructure of the materials. Ermolaeva et al. (2002) studied materials selection combined with structural optimization. However, the elaborate materials selection method proposed by these authors was limited to selecting from a limited number of specific materials. Lin and Lin (2003) discussed state-of-art research on environmentally conscious material selection methodologies. Ljungberg (2005) presented guidelines for sustainable product development with special regard to materials, design and ecology. Giudice et al. (2005) proposed a method to integrate mechanical and environmental performances for materials selection in the life-cycle design process. Kuo et al. (2006) presented an innovative method, namely, green fuzzy design analysis (GFDA), which involves simple and efficient procedures to evaluate product design alternatives based on environmental consideration using fuzzy logic. The hierarchical structure of environmentally conscious design indices was constructed using the analytical hierarchy process (AHP), which includes five aspects: (1) energy, (2) recycling, (3) toxicity, (4) cost, and (5) material. After weighting factors for the environmental attributes are determined, the most desirable design alternative can be selected using a fuzzy MADM method.

Edwards and Deng (2006) discussed the aspects of supporting design decision making when applying materials in combination. Deng and Edwards (2007) presented an overview of recent research in materials identification and materials selection. Shanian and Savadogo (2006a) had presented a material selection model using an MADM method known as ELECTRE. However, the ELECTRE method