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Materials selection using complex proportional assessment and evaluation of mixed data methods

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ABSTRACT

Material selection is a very fast growing multi-criteria decision-making (MCDM) problem involving a large number of factors influencing the selection process. Proper choice of material is a critical issue for the success and competitiveness of the manufacturing organizations in the global market. Selection of the most appropriate material for a particular engineering application is a time consuming and expensive process where several candidate materials available in the market are taken into consideration as the tentative alternatives. Although a large number of mathematical approaches is now available to evaluate, select and rank the alternative materials for a given engineering application, this paper explores the applicability and capability of two almost new MCDM methods, i.e. complex proportional assessment (COPRAS) and evaluation of mixed data (EVAMIX) methods for materials selection. These two methods are used to rank the alternative materials, for which several requirements are considered simultaneously. Two illustrative examples are cited which prove that these two MCDM methods can be effectively applied to solve the real time material selection problems. In each example, a list of all the possible choices from the best to the worst suitable materials is obtained which almost match with the rankings as derived by the past researchers.

1. Introduction

In recent years, many traditional materials are now being replaced by some 'advanced materials' to meet the demand of weight reduction and increase of their associated properties. It is estimated that there are more than 80,000 materials in the world including several types of metallic alloys and nonmetallic engineering materials. This large number of materials with complex relationships between different selection parameters often makes the evaluation and selection of materials for a given engineering application a difficult and challenging task to deal with [1]. The importance and criticality of material selection in engineering design is a well established conflicting issue as because selection of materials not only requires knowledge about various related physical, electrical, magnetic, mechanical, chemical and manufacturing properties, but also material cost, product shape, environmental effect, performance characteristics, availability, design considerations and other complex relationships between different selection criteria influencing the entire selection process. It is observed that mechanical properties, such as Young's modulus, strength, yield stress, elasticity, fatigue, creep resistance, ductility, hardness and toughness; physical properties, like crystal structure, density, melting point; magnetic properties; electrical properties, like resistivity, permittivity, dielectric strength; thermal properties, like specific heat, conductivity, expansivity, diffusivity, transmissivity and miscellaneous factors, like reliability, durability, recycleability, material's impact on environment etc. mainly influence the material selection problems. There are several existing methods to support the material selection decision-making problems, where the requirements and expectations from the materials are generally known. These approaches can be broadly classified as material screening and selection methods. Cost per unit property approach, chart method, questionnaire method, materials in products selection tools, artificial intelligence techniques are the examples of material screening methods. Various multi-criteria decision-making (MCDM) methods and different optimization tools have been proposed by the past researchers to aid the material selection process. Decision analysis is concerned with those situations where a decision maker has to choose the best alternative among several candidates while considering a set of conflicting criteria. In order to evaluate the overall effectiveness of the candidate alternatives and select the best material, the primary objective of

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an MCDM method-based material selection approach is to identify the relevant material selection criteria for a particular application, assess the information relating to those criteria and develop methodologies for evaluating those criteria in order to meet the designers' requirements. The MCDM methods can be broadly divided into two categories, i.e. (a) multi-attribute decision-making (MADM), and (b) multi-objective decision-making (MODM). There are also several methods in each of the above-mentioned categories. Priority-based, outranking, preferential ranking, distance-based and mixed methods are some of the popular MCDM methods as applied for evaluating and selecting the most suitable materials for diverse engineering applications.

Chen [2] developed a method to solve the tool steel material selection problems under fuzzy environment, where the importance weights of different criteria and the ratings of various alternatives under different criteria were assessed in linguistic terms using fuzzy numbers. Jee and Kang [3] utilized two theories of decision-making, i.e. (a) entropy method to determine the weight for each material property, and (b) TOPSIS (technique for order preference by similarity to ideal solution) method to rank the candidate materials while selecting the optimal material for a flywheel. Rajan and Narasimhan [4] used weighted performance index values for material selection for the design and development of rocket motors. Ermolaeva et al. [5] applied a structural optimization method for the optimal choice of foams as a core material for sandwiches with aluminum alloy faces, for the use as floor panels in the bottom structure of a concept car. The corresponding minimization problem was formulated and solved for each material application while assessing an environmental impact of materials–candidates during the entire life cycle of the structure. Rao [6] presented a methodology for material selection for a given engineering component using graph theory and matrix approach (GTMA). A digraph was developed taking into account several material selection criteria and their relative importance for the application considered. Shanian and Savadogo [7] applied ELECTRE (ELimination and Choice Expressing the REality) method which would provide a more precise selection of material for a particular application while producing a material selection decision matrix and criteria sensitivity analysis. Shanian and Savadogo [8] applied a non-compensatory compromised approach (ELECTRE IV) for selecting material for a bipolar plate used in a polymer electrolyte fuel cell. The individual effect of the components of the performance indices on the ranking change in each possible candidate material was also studied. Manshadi et al. [9] proposed a weighting factor approach while combining non-linear normalization with a modified digital logic method for materials selection and compared the results of two case studies with those obtained from the classical weighted property method. Chan and Tong [10] presented an integrated methodology of performing an order pair of materials and end-of-life product strategy for the purpose of material selection using grey relational analysis. Rao [11] applied an improved compromise ranking technique (VIKOR method) while incorporating analytic hierarchy process (AHP) for assigning weights or relative importance to various criteria affecting the material selection decision-making problems. Thakker et al. [12] proposed a novel approach for optimal selection of wave energy extraction impulse turbine blade material while combining three methods, e.g. the Cambridge Material Selector based method, the adapted value engineering technique and TOPSIS method. The sensitivity analysis showed the robustness of the proposed approach. Shanian and Milani [13] applied a revised Simos' method with ELECTRE III model in an attempt to provide a decision aid framework that would account for the separations in design preferences and uncertainties in expressing individual's opinion over the design criteria in group material selection decision. Farag [14] presented two quantitative methods of materials substitution, i.e. (a) performance/cost analysis which would allow the designer to either look for a substitute material of similar performance at a lower cost or for a material with better performance but at a higher cost, and (b) compound objective function which would help the designer to develop different substitution scenarios based on the relative weights allocated to various performance requirements. Rao and Davim [15] used a logical procedure of material selection for a given engineering design while combining TOPSIS and AHP methods. The proposed material selection index would help the decision maker to evaluate and rank the alternative materials. Chatterjee et al. [16] attempted to solve two material selection problems using VIKOR (Vlse Kriterijumska Optimizacija Kompromisno Resenje) and ELECTRE II methods, and compared their relative performance for a given material selection application. Khabbaz et al. [17] introduced a simplified fuzzy logic approach to easily deal with the qualitative properties of materials and the corresponding fuzzy space. The proposed approach would considerably reduce the volume of mathematics as involved with the conventional methods. Shanian and Savadogo [18] applied the compensatory models to solve a multi-criteria material selection problem for a thermal loaded conductor and then using different versions of the non-compensatory methods, examined the outranking approach to solve the same problem. Maniya and Bhatt [19] examined three different material selection problems using preference selection index (PSI) method and validated the ranking results with those of GTMA and TOPSIS method. Jahan et al. [20] reviewed the quantitative procedures that have been developed to solve the material selection problems for various engineering components. The details of those methods, their application modalities, merits and inadequacies were mainly addressed. Jahan et al. [21] proposed a linear assignment method to rank materials for a given engineering component with respect to several criteria. The proposed material selection procedure was relatively simple and could solve material selection problems having qualitative properties or user-interactions.

Although a good amount of research work has already been carried out by the past researchers on materials selection using different MCDM methods, there is still a need to employ a simple and systematic mathematical approach to guide the decision maker in taking an appropriate material selection decision for a specific engineering application. In this paper, an attempt is made to explore the applicability and capability of two almost new MCDM methods, i.e. (a) complex proportional assessment (COPRAS), and (b) evaluation of mixed data (EVAMIX) methods for selection of the most appropriate material for a given engineering application. Till date, both these MCDM methods have very limited applications in the engineering domain. Two examples are illustrated to demonstrate their applicability and compare their ranking performance while solving those material selection problems under given environments. It is observed that in both the cases, the top-ranked alternative materials exactly match with those obtained by the past researchers.

2. Complex proportional assessment method

This preference ranking method of complex proportional assessment (COPRAS), mainly developed by Zavadskas et al. [22], assumes direct and proportional dependences of the significance and utility degree of the available alternatives under the presence of mutually conflicting criteria. It takes into account the performance of the alternatives with respect to different criteria and the corresponding criteria weights. This method selects the best decision considering both the ideal and the ideal-worst solutions. The COPRAS method which is used here for evaluating and selecting the alternative materials for the given engineering prob-