Journal of Cleaner Production 107 (2015) 557–567

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Implementation of the expert decision system for environmental assessment in composite materials selection for automotive components

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ARTICLE INFO

Article history:
Received 7 May 2014
Received in revised form
25 February 2015
Accepted 1 May 2015
Available online 29 May 2015

Keywords:
Expert system
Decision method
Materials selection
Analytical hierarchy process
Environmental factor
Natural fiber composites

ABSTRACT

Conventional materials selection system was replaced with sophisticated software tools by rapid changing technology. The growing environmental concerns and regulations widely among the industry, especially in automobiles, force us to explore the natural fiber materials as a replacement for synthetic materials which is in common use. As a result of extensive research and development, new natural fiber reinforced composite materials are emerging and the database of materials growing exponentially. The decision of selecting optimized materials was complicated, as it involves diversified choice of materials, coupled with various influencing criteria for the selection process. To abstain from deciding inappropriate materials, the technology of expert system software tools can help us in the appropriate materials selection. The objective of this research was to explore the implementation of Analytical Hierarchy Process (AHP) using the expert choice software tool for deciding optimum natural fiber reinforced composite materials by considering main criteria and sub-criteria in the hierarchical model. The final judgement was performed with different scenarios of sensitivity analysis, giving priority to the environmental factors and sustainability. The result shows that the natural fiber composite material hemp and polypropylene gained the higher rank in the selection process and almost compliant with the requirements of industrial product design specification and can be recommended to automotive component manufacturers to enforce green technology.

1. Introduction

Traditionally, materials are selected mostly based on the experience of product design engineers and the materials readily available for common use. However, computer based material selection has gained popular attention in recent decades. As the computerized system is reputed for its fast processing, accuracy and huge volume of data storage, this technology was implemented particularly for selection system. The use of printed handbooks and datasheets in the manufacturing process with limited choice are considered as outdated technology (Djassemi, 2009; Sapuan, 2001).

A comprehensive review denotes that the strategy of materials selection facilitates implementation of digital logic method, chart method, checklist and questionnaire. Later they developed material selector software with database, widely in use, was Cambridge Engineering Selector (CES) software (Ashby and Johnson, 2002; Ashby, 2001; Jahan et al., 2010).

Expert or knowledge-based system was a computer software system originally from Artificial Intelligence (AI). Sapuan et al. (2002) developed a knowledge-based system for materials selection using a PC tool kit with object-oriented programming and rule based reasoning. The system selects the most suitable ceramic matrix composite materials for three engine components with few modules such as a knowledge acquisition module, inference engine module and user interface module. The IF-THEN rule was applied to the materials in the database and the system can assist in ranking for selection of the suitable material according to the properties of each component. Jalham (2006) proposed a decision making

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http://dx.doi.org/10.1016/j.jclepro.2015.05.084
0959-6526/

system with integrated information technology (IIT) approach by screening the property of material and eliminating the unneeded materials. Three selection phases were applied by considering techno-economic factors and environment factor like recyclability and health hazards. Finally, this approach was translated into a computer program to select the optimum material for washing machine agitator. Sapuan and Abdalla (1998) developed a system for material selection of polymer-based composites using rule-based reasoning for automotive components, in particular for the pedal box system. The package uses the Knowledge Engineering Environment (KEE) software tool kit.

Usually, more than one material satisfies the product constraints and various criteria of each material influence the selection process. So, the selection of optimal material for engineering design was also considered as Multiple Criteria Decision Making (MCDM) problem. Jahan et al. (2010) lists out the different methods of material selection in engineering design for multiple criteria decision making methods. The methods include AHP, Elimination and choice expressing reality (ELECTRE), Simple additive weighting method, Technique of ranking Preferences by Similarity to the ideal Solution (TOPSIS), limits on properties method, multi-attribute utility analysis, genetic algorithm, neural network, goal programming and fuzzy technique. Shanian and Savadogo (2006) used ELECTRE method and entropy weights to solve multiple criteria decision making problem while selecting a suitable material for non-heat treatable cylindrical materials. Jee and Kang (2000) proposed an expert system to help design engineers to select optimal material for a flywheel using the Technique of ranking Preferences by Similarity to the ideal Solution (TOPSIS) as a tool in computer aided engineering (CAE).

Even though the ELECTRE and TOPSIS methods were widely applied to MCDM problems, it has the following limitations. The principle of TOPSIS method uses the Euclidean distance algorithm and affected with more diverse sets of weights (Olson, 2004). The correlation of attributes was not taken into consideration in this algorithm. Moreover, if more attributes were used, it was difficult to keep the consistency of judgement matrix. The ELECTRE methods intelligently determine only the rank of each material and the differences between alternatives are not given in numerical values, for better understanding. Furthermore, if the number of alternatives increases, the computational procedures in this method would rapidly increase with complicated calculations (Jahan et al., 2010).

1.1. Analytical hierarchy process (AHP): a material selection tool

The AHP provides a methodology for multi-criteria analysis and decision making technique. It can be implemented in almost all applications related to decision making. It was widely used in many fields, such as planning, resource allocations, operational management, selecting alternatives, decision support system, supply-demand chain, project delivery analysis and management planning (Vaidya and Kumar, 2006). Hambali et al. (2010) used Expert Choice commercial software for implementing analytical hierarchy process (AHP) in their material selection for automotive composite bumper beam. They selected optimum material by prioritizing the candidate materials and applying multiple sensitivity analysis.

AHP technique also applied as a combined method with fuzzy logic and goal programming. Tseng et al. (2009) claimed that the human decision-making process inherent with uncertainty and imprecision, hence proclaims the necessity to handle the decision priorities with flexibility and robustness, they proposed a decision system based on the concept of Fuzzy-AHP model for the decision makers. Mustafa (2004) develops a combined model of analytical hierarchy process and goal programming to study the investment behavior of companies in computer-integrated manufacturing (CIM). It includes both the qualitative and quantitative factors in deciding the multi-attribute problem. ZongXiao et al. (2008) developed a web based decision support application for industrialized process safety assessments with an AHP-based safely assessment decision analysis system (SADAS) with connection to oracle9i database. The program uses model view control programming of Java technology with JSP, JavaBean and Servlet. The system was made available on the World Wide Web (WWW) and cross-platform capabilities. Mayyas et al. (2011) presented material selection for automotive Body-In-White (BiW) panels using Quality Function Deployment (QFD) and AHP method. The method analyzed ten different engineering materials and selects steel as most appropriate material for BiW panels.

The technique of AHP was also applied to select the optimum material for automotive dashboard component from 29 different types of natural fiber composite materials. The physical and mechanical properties are taken as the main criteria for selection process (Sapuan et al., 2011). Hambali et al. (2009) proposed a concept selection model to assist designer engineers in selecting the most appropriate design concepts and materials for automotive composite components using the AHP technique. Eight design concepts of automotive composite bumper beam were considered in that study and the most appropriate one was ultimately identified using the AHP process.

The decision making factor in AHP was very prevalently applied because of its straightforwardness in the decision process. Therefore, in this study, AHP was selected as a decision making tool as it has greater flexibility and the methodology facilitates understanding and implementation. But AHP has its own limitations, like the influence of user's inputs on the final score results and secondly, it can only compare a very limited number of decision alternatives, when more number of alternatives are compared, the pair wise comparison provided by the traditional AHP is obviously infeasible.

1.2. Materials for automotive component: environmental basis

The automotive manufacturers are on the brink of revolution, initially focused to replace the metal components with plastics (Mayyas et al., 2012). Now their concern was to reduce the usage of plastics and substitute the same with bio-composites to protect the global environmental consciousness (Karana, 2012). Al-Oqla and Sapuan (2014) studied the feasibility of using the date palm fiber (DPF) for sustainable product in the automotive industry. The adoption of DPF also has a significant effect on environmentally waste problem issues. Zhao et al. (2012) determined the material selection with the criteria of environmental evaluation for cleaner production. They proposed simplified computational calculation tool, spreadsheet using binary dominance matrix and gray relational analysis to select most sustainable material using Poly vinyl chloride (PVC) materials. Djassemi (2009) exemplified Cambridge Engineering Selector (CES) software tool for material selection with a focus on sustainability and ecological issues. The best material for medical diagnostic equipment was selected by considering aluminum and magnesium alloys. The selection criteria include the factors on recycled content, energy consumption and polluting emissions. Yoshida et al. (2006) elaborated the contamination in the cabin air of the car and examined that a total of 275 organic compounds were identified in 101 types of Japanese cars. The interior temperature was tested between 17 °C to 36 °C. The result shows formaldehyde as the organic compounds most affecting indoor air quality. It was related to plastics, rubbers and resins used abundantly in the interior parts of automobiles.

Even though many polymers are available with different characteristics for manufacturing, 13 different polymers are used in the