Materials and Design 51 (2013) 484–492

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

Hybrid natural and glass fibers reinforced polymer composites material selection using Analytical Hierarchy Process for automotive brake lever design

M.R. Mansor [a,b], S.M. Sapuan [a,*], E.S. Zainudin [a], A.A. Nuraini [a], A. Hambali [c]

[a] Department of Mechanical and Manufacturing Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[b] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[c] Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

ARTICLE INFO

Article history:
Received 2 January 2013
Accepted 19 April 2013
Available online 28 April 2013

Keywords:
Hybrid polymer composites
Product design specifications
Material selection
Analytical Hierarchy Process
Automotive component design

ABSTRACT

Due to recent trend and increasing awareness towards sustainable product design, natural based fiber materials are gaining a revival popularity to replace synthetic based fiber in the formulation of composites especially for automotive structural and semi structural applications. In this paper, the Analytical Hierarchy Process (AHP) method was utilized in the selection of the most suitable natural fiber to be hybridized with glass fiber reinforced polymer composites for the design of a passenger vehicle center lever parking brake component. Thirteen (13) candidate natural based fiber materials for the hybridization process were selected and analyzed to determine their overall scores in three (3) main performance indices according to the component product design specifications. Using the AHP method, the kenaf bast fiber yields the highest scores and was selected as the best candidate material to formulate the hybrid polymer composites for the automotive component construction. Sensitivity analysis was also performed and results show that kenaf bast fiber emerged as the best candidate material in two out of three simulated scenarios, which further validates the results gained through the AHP method.

1. Introduction

Development of automotive components seldom requires the consideration of three major factors which are the component geometrical design selection, material selection and manufacturing process selection, most critically in the early product design stage. Designers faced many challenges to decide the optimum solution in all of the above cases especially where multiple factors and multiple choices or alternatives have to be considered simultaneously. However, the introduction of multi-criteria decision making (MCDM) technique such as Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and weighted property index method (WPIM) have enabled a systematic and quantitative selection method to be performed by designers to achieve the desired the optimum decision [1–4].

Among the above methods, Analytical Hierarchy Process (AHP) has been extensively applied in various scenarios involving multi-criteria decision making (MCDM) especially in automotive design application. The use of AHP in material selection of natural fiber polymer composites for automotive dashboard panel of passenger car was reported by Sapuan et al. where physical and mechanical properties of the candidate materials were used as the criteria in the selection process [5]. A part from that, Nepal et al. [6] demonstrated the used of fuzzy set theory based Analytic Hierarchy Process (fuzzy-AHP) framework for prioritizing subjective customer satisfaction (CS) attributes in target planning during the conceptual vehicle design stage. The subjective CS attributes were obtained from quality function deployment (QFD) analysis from customers. Through AHP, a broad range of strategic and tactical factors were given numerical weighting value and these weights are then incorporated into target planning by identifying the gap in the current CS level [6]. Hambali et al. [7] meanwhile reported the use of Analytical Hierarchy Process (AHP) method at the conceptual component design stage. The AHP method was embedded into a new concept selection model called concurrent design concept selection and material selection (CDCSMS) to assist designers in selecting the most appropriate design concepts and materials for automotive bumper beam composite components [7]. Ertay et al. [8] also showed similar application of AHP in the vehicle design stage. They studied the basic product planning stage of a car design using a new approach where analytic network process (ANP), the general form of the Analytic Hierarchy Process (AHP) is used to prioritize design requirements obtained through QFD by taking into account the degree of the interdependence between the customer

* Corresponding author. Tel.: +60 3 89466318; fax: +60 3 86567122.
E-mail address: sapuan@eng.upm.edu.my (S.M. Sapuan).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.04.072

needs and design requirements and the inner dependence among them [8].

A part from direct design application, AHP method are also widely used in other related activities such as manufacturing system, quality engineering and automotive supplier selection. Abdi and Labiba [9] demonstrated the use of AHP for structuring the decision making process for the selection of a manufacturing system among feasible alternatives based on the Reconfigurable Manufacturing System (RMS). The AHP model developed highlights manufacturing responsiveness as a new economic objective along with classical objectives such as low cost and high quality for the RMS [9]. Putri and Yusof [10] also reported the use of AHP in their proposed model for the implementation of quality engineering to automotive industries in general, and Malaysia and Indonesia in particular. In their model, a proposed conceptual model using AHP approach is established. They found that the AHP approach used in is a very useful technique in solving complicated and unstructured problems that may have interactions and correlations among different objectives [10]. Percin [11] in the other hand reported an integration of an Analytic Hierarchy Process (AHP) and multi-objective pre-emptive goal programming (PGP) to consider both quantitative and qualitative factors in selecting the best suppliers in automotive manufacturing industries in Turkey and allocating the optimum order quantities among them. Percin [11] findings demonstrate that the integrated AHP–PGP model can be useful to all firms in their supplier selection decisions.

In this project, the AHP method is implemented for material selection purpose of hybrid natural fiber/glass fiber reinforced polymer composites for automotive component application during the initial conceptual product design stage. The aim is to identify the most appropriate candidate natural fiber material to be hybridized with glass fiber reinforced polymer composites for the automotive component construction based on multiple performance requirements such as functional performance, weight and product cost. The product design specifications of the automotive parking brake lever component were first formulated based on the functional performance and sustainability requirements. Introduction of ecodesign criteria into the product development stage is performed to cater both user satisfaction and environmental needs all in the same time. Thus, the new product design specification will be more holistic in nature, a part from complying with various sustainability related standards imposed to automotive manufactures recently.

In the later material selection stage, thirteen (13) types of natural fiber materials were identified as the alternative materials to be incorporated with the component design. The alternative materials were compared and rated in term of preference to each other with respect to the given design requirements using pair-wise comparison technique introduced in the AHP method. The comparison data were later synthesized to obtain the overall rank between the candidate materials using the priority vector values. Finally, the consistency ratio values were calculated to measure the degree of consistency for the judgments made to increase the accuracy and confidence level of the obtained results. Sensitivity analysis was also performed later on using the AHP tools to simulate what-if scenario for validating the proposed solution obtained at the end of the material selection process.

2. Product design specifications

A new product design specification (PDS) as proposed by Pugh [12] was first developed for the parking brake lever component using hybrid kenaf/glass fiber reinforced polypropylene composites. The PDS document was formulated based on market research on various automotive related components available in the literature review such as bumper beam, clutch pedal and instrument panel. A part from that, design for sustainability requirements was also incorporated to the PDS document to strike a balance between environmental needs with the product functional performance that will benefit both the product user and the environment in the same time throughout the whole product life-cycle [13]. Based upon ecodesign or design for sustainability tools currently available such as the Ecodesign Strategies Wheel by Brezet and Van Hemel [14] and the Ten Golden Rules for ecodesign by Luttropp and Lagerstedt [15], several ecodesign strategies were considered such as the application of low impact materials through the selection of non-hazardous, non-exhaustible and recyclable materials for the component construction [16].

Market research was conducted based on journals, websites and patents for various automotive products. The main objectives are to study what are the key elements embodied in the automotive product design as well as to identify the similarities in the product design specification elements for automotive applications. Among the automotive product designs identified are interior body components such as interior panel and pedal [17–19] and exterior body components such as bumper beam and bonnet [20–23].

The market research results show that various PDS elements are involved in automotive product design depending many factors such the nature of operation for the component (type of loading condition subjected to the component) [24], structural performances [25–27], design standard and regulations [28,29], and the interaction between the component and its environment based on the location of the component (either at the interior or exterior of the vehicle) [30–32]. A part from that, market research results also revealed the several PDS element associated with recent trend in automotive design such as design for sustainability as indicated through weight reduction [33–35], product disposal consideration to meet the vehicle end-of-life targets [36–38] and reducing cost [39,40].

2.1. Product design specification for automotive parking brake lever

Based on the information gathered from market research, the PDS for automotive parking brake lever is formulated. A part from that, several automotive design standards associated with the parking brake design were also included which are ECE 74/60 (Clause 5.3) and ECE-R21 (Clause 5.3) for parking lever's hip point location with respect to the front seat hop point and EEC 78/632 (Clause 5.3.2) for parking brake lever edge radius and cut section area, EU DIRECTIVE 2000/53/EC (Article 2) for EU vehicle end-of-life requirements of percentage of components to be reuse or recycled and safe for disposal, and US National Highway Traffic Safety Administration (NHTSA) Federal Motor Vehicle Safety Standards (FMVSS) No. 571.135 for light vehicle brake system [41–43]. In total, for the automotive parking brake lever design, six (6) major elements were selected which are performance, weight, standard, disposal, environment and cost. The major elements are then categorized into eleven (11) sub-elements for more specific description which are strength, stiffness, density, parking brake lever testing standard, reuse and recyclability, safe for disposal, corrosion resistance, water absorption, raw material cost and manufacturing cost. Summary of the parking brake lever product design specifications is shown in Fig. 1.

3. Material selection of hybrid natural and glass fibers reinforced polymer composites using AHP: a case study on automotive parking brake lever component

Parking brake system a secondary braking system used to hold a parked vehicle in position safely. In general, there are three types