UNIVERSITI PUTRA MALAYSIA

SELECTION OF CONCEPTUAL DESIGN USING ANALYTICAL HIERARCHY PROCESS FOR AUTOMOTIVE BUMPER BEAM UNDER CONCURRENT ENGINEERING ENVIRONMENT

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

October 2009

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2009

HAMBALI BIN AREP@ARIFF **DOCTOR OF PHILOSOPHY** **2009**

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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Date: 2 February 2010

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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HAMBALI BIN AREP@ARIFF

October 2009

Chairman: Mohd Sapuan Salit, PhD, PEng

Faculty: Engineering

The main objective of this research is to consider and determine the most optimum decision on design concept, material and manufacturing process for the automotive composite bumper beam at the conceptual design stage. The objective was achieved by proposing two selection frameworks and the use of analytical hierarchy process under concurrent engineering environment. The research began by generating and developing eight new conceptual designs of automotive composite bumper beam and investigating various parameters or criteria and alternatives that normally used to manufacture automotive composite bumper beam by implementing total design approach. To determine the most optimum decisions on design concept, material and manufacturing process for the automotive composite bumper beam, analytical hierarchy process utilizing Expert Choice software was used. The research revealed that the glass fibre epoxy with a value of 0.257 (25.7%), design concept-6 with a value of 0.191 (19.1%) and injection moulding with a value of 0.228 (22.8%) are the most appropriate decisions on material, design concept and manufacturing process

respectively. It was also revealed that importance of addressing various design tools and considering the most optimum decisions on design concept, material and manufacturing process at the conceptual design stage in the design flow under concurrent engineering environment. Overall, it can be concluded that the proposed selection frameworks, analytical hierarchy process and concurrent engineering approach allow designers or decision makers to consider and determine the most optimum decision on design concept, material and manufacturing process at the conceptual design stage.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMILIHAN REKA BENTUK GAGASAN MENGGUNAKAN PROSES HIERARKI BERANALITIS UNTUK AUTOMOTIF RASUK BAMPER DALAM PERSEKITARAN KEJURUTERAAN SERENTAK

Oleh

HAMBALI BIN AREP@ARIFF

October 2009

Pengerusi: Mohd Sapuan Salit, PhD, PEng

Fakulti: Kejuruteraan

Objektif utama kajian ini ialah untuk mempertimbangkan dan menentukan keputusan yang paling optima terhadap konsep reka bentuk, bahan dan proses perkilangan untuk komposit automotif rasuk bamper. Objektif ini tercapai dengan mencadangkan dua kerangka pemilihan dan penggunaan proses hierarki beranalitis. Kajian ini bermula dengan menjanakan dan membangunkan lapan konsep reka bentuk baru komposit automotif rasuk bamper dan mengkaji pelbagai parameter atau kriteria dan alternatif di mana kebiasaannya digunakan untuk mengilang komposit automotif rasuk bamper dengan menggunakan kaedah keseluruhan reka bentuk. Untuk menentukan keputusan yang paling optima terhadap konsep reka bentuk, bahan dan proses perkilangan untuk komposit automotif rasuk bamper, proses hierarki beranalitis melalui penggunaan perisian ‘Expert Choice’ telah digunakan. Kajian ini mendedahkan bahawa gentian kaca epoksi dengan nilai 0.257 (25.7%), reka bentuk konsep 6 dengan nilai 0.191 (19.1%) dan pengacuan suntikan dengan nilai 0.228 (22.8%) adalah keputusan yang paling sesuai terhadap bahan, konsep reka bentuk

dan proses perkilangan masing-masing. Kajian ini juga mendedahkan bahawa kepentingan untuk menekankan pelbagai alat reka bentuk dan mempertimbangkan keputusan yang optima terhadap konsep reka bentuk, bahan dan proses perkilangan pada peringkat reka bentuk gagasan dalam persekitaran kejuruteraan serentak. Pada keseluruhannya, dapat disimpulkan bahawa cadangan kerangka pemilihan, proses hierarki beranalitis dan kaedah kejuruteraan serentak membenarkan pereka bentuk atau pembuat keputusan untuk mempertimbangan dan menentukan keputusan yang paling optima terhadapt reka bentuk konsep, bahan dan proses perkilangan pada peringkat reka bentuk gagasan.

ACKNOWLEDGEMENTS

Firstly, I would like to express my sincere gratitude, appreciation and thanks to my research supervisor and the chairman of my supervisory committee Professor Dr. Ir. Hj Mohd Sapuan Salit. I am also thankful to the members of the supervisory committee Associate Professor Dr. Datin Napsiah Ismail and Dr. Nukman Yusoff for their support in this research work and entire preparation of this doctoral dissertation.

I would like to convey my thanks to Mr. Ahmad Saifuddin Ismail, senior technician for his kind assistance and support during the entire period of my project. I would like to convey my thanks to Mr. Mohd Fauzi Mohamed Noor and Mr. Khairul Azmi Md Rezali both from PROTON Sdn Bhd for getting information on automotive bumper beam.

I would like to express my sincere thanks and gratitude to my beloved wife Mrs. Suhila Mohd Salleh who has supported and encouraged me to work on this PhD research project.

I would especially like to thank my parents and family who have always prayed for me and without their support I would not have accomplished anything. Finally, I would to thank all staff at Universiti Putra Malaysia for their help and support.

I certify that a Thesis Examination Committee has met on 2 October 2009 to conduct the final examination of Hambali Arep@Ariff on his Doctor of Philosophy thesis entitled "Selection of Conceptual Design using Analytical Hierarchy Process for Automotive Bumper Beam under Concurrent Engineering Environment" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Doctor of Philosophy.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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CHAPTER 1

INTRODUCTION

1.1 Background

Nowadays, concurrent engineering (CE) is considered as a key factor in determining the success of a company. CE is an important approach in the world of new product development process (Veness et al., 1996). CE principles have been cited as the main keys for the rapid new product development process and it was introduced by Japanese companies (Bowonder and Miyake, 1993). Using this approach, Japanese companies are able to produce products much more quickly without compromising the quality than their competitors. In many industries, their products are the benchmarks. This is due to the use of improved methods (CE approach) to develop products (Hartley, 1992). However, employing CE has not always been proven easy. As the popularity of CE grows and its applications have become more diverse, the core principles which define CE have become increasingly vague. CE approach is sometimes viewed as expensive in the short term, requiring resources and levels of commitment that may not be available. However, when appropriately used, CE can bring organizational benefits that far exceed the profits associated with any single product (Swink, 1998).

In the automotive industry, the principles of CE have to be seriously implemented in order to reduce product development time, improve product quality, reduce costs and

fulfil customers' requirements. For example, a key factor behind the success of Japanese automakers is their shorter time required to develop a new model without compromising the quality (Izuchukwu, 1992). There are many activities involved in the development of automotive components such as design concept selection, materials selection and manufacturing process selection. These selection activities are normally performed by cooperating between design, material and production engineers. Generally, the main goal of these selection activities is to identify the most optimum decision options.

Composites have been a part of the automotive industry for several decades, with early applications in the 1953 (Das, 2001). The use of composites has increased dramatically because of their properties such as low density which offer low weight material, high stiffness, high strength, high corrosion resistance, etc. Unlike metallic materials, many different considerations have to be taken into account before composite materials can be used to make automotive components. Various factors need to be considered before producing composite automotive components such as the type of matrix used and fibre properties, etc. Most of the products generally failed due to inappropriate decision during selection of design concept, material and manufacturing process (Dowlatshahi, 2000). Therefore, design concept selection, materials selection and manufacturing process selection are very important in manufacturing automotive components. They should be considered at the early stage of product development process in order to determine that the product can be manufactured at lower cost but higher quality.

In recent years, the use of composite has been more focused on automotive components such as automotive bumper system. The bumper system consists of four main components namely, bumper fascia, energy absorber, bumper beam and bumper stay (Yim et al., 2005 and, Lee and Bang, 2006). However, bumper beam has been selected in this research in order to illustrate the use of CE at the conceptual design stage of product development process. The main research is concerned with the determination of the most optimum decision on design concept, material and manufacturing process for automotive bumper beam at the conceptual design stage. Techniques and tools used in this research are total design approach, analytical hierarchy process (AHP), Expert Choice and SolidWorks.

In summary, determining the most optimum design concept, material, and manufacturing process at the early stage of product development process are very important. The use of CE approach encourages and assists designers to evaluate and determine the most appropriate decision at the conceptual design stage of product development process.

1.2 Problem statements

The automotive industry has always been known to be very competitive, as far as its design, material and process usage are concerned. The automotive industry was selected due to its facing greater market pressure to develop high quality products more quickly at lower cost. One of the automotive components that has recently been addressed by researchers and car makers to improve its design, material and process

is a bumper beam (Bernert et al., 2006 and Thatcham, 2007). Today's designers are facing a big challenge in determining the most optimum selection of design concept, material and manufacturing process during development of automotive bumper beam. Determining the most optimum decisions on design concept, material and manufacturing process during selection process of product development is a difficult task. It is because selection process involved many factors which need careful considerations. Inaccurate decision of selection in product development process may cause the need for the product to be redesigned or remanufactured. These reprocessing activities will increase development time and cost of the product. A more critical issue here is how much the requirements and designs have been modified in order to be finally accepted for manufacturing and production. Even though a good number of research work has been carried out in the past in determining the most optimum decisions on design concept, material and manufacturing process. There is a need for a simple, easy and systematic method to guide designers in taking a proper decision particularly in determining the most optimum decisions on design concept, material and manufacturing process for the polymeric composite automotive components. One of the methods that can be employed to assist designers in determining the best decision after considering numerous factors is analytical hierarchy process or AHP. AHP (Saaty, 1980) provides a comprehensive framework for solving such problems. So far, there is no researchers have employed analytical hierarchy process (AHP) to determine the most optimum decision on design concept, material and manufacturing process for the automotive bumper beam.

Generally, to determine the most optimum decision on design concept, material and manufacturing are performed at the latter stage of product development process such as embodiment stage or detail stage. It means that critical issues related to development of product such as design concept selection, materials selection, manufacturing process selection are frequently not identified until these stages. It is clear that the embodiment stage or detail design stage is too late a point in the product development cycle to identify the constraints imposed during selection process. This scenario may contribute to the increase in the time and cost involved in the product development process. Moreover, most the existing product development processes are lacking in terms of addressing the concurrent engineering (CE) tools, which is a key factor to a successful development of a new product in the CE environment. To overcome these circumstances, concurrent engineering approach must be implemented at the early stage of product development process. Therefore, the development of automotive bumper beam at the conceptual design stage of product development process is explored in this research. Considering the most optimum decision on design concept, material and manufacturing process using AHP at the conceptual design stage is also explored in this research.

1.3 Research aim and objectives

The aim of this research is to determine the most optimum decisions on design concept, material and manufacturing process during the conceptual design stage of product development process for the automotive composite bumper beam.

To accomplish this, the following objectives have been carried out:

a) To determine the input parameters for design concept selection in the development of a polymeric based composite bumper beam.

b) To determine the input parameters for materials selection in the development of a polymeric based composite bumper beam.

c) To determine the input parameters for manufacturing process selection in the development of a polymeric based composite bumper beam

d) To validate the process selection procedure developed using sensitivity analysis

1.4 The scope and limitation of the research

The scope of the present research includes development of a concept selection model, development of product through market investigation, product design specification (PDS), concept generation and concept selection, determination of the most optimum decision on design concept, material and manufacturing process using analytical hierarchy process (AHP) and verification by conducting various scenarios of sensitivity analysis using Expert Choice software.

1.5 Structure of the thesis

This thesis has been structured into 9 chapters. The first chapter is an introduction. Chapter 2 presents the literature review related to various areas associated with this research. The methodology of the research work is presented in chapter 3. It is composed of proposed structure of research works, proposed selection frameworks at the conceptual design stage and analytical hierarchy process methodology. The conceptual design of automotive composite bumper beam and discussion are presented in chapter 4. Chapter 5 presents the first article entitled 'Application of analytical hierarchy process (AHP) and sensitivity analysis for selecting the best design concepts during conceptual design stage'. This first article reported the use of analytical hierarchy process and the validation of the selection process using sensitivity analysis.

Chapter 6 presents the second article entitled 'Material selection of the polymeric composite automotive bumper beam using analytical hierarchy process'. This second article reported the development of materials selection by determining various input parameters that influence the selection process in development of polymeric based composite automotive bumper beam. The validation of the selection process using sensitivity analysis is also discussed in this chapter.

Chapter 7 presents the third article entitled 'Application of analytical hierarchy process in the design concept selection of automotive composite bumper beam during the conceptual design stage'. This third article reported the development of design concept selection by determining various input parameters that influence the

selection process in development of polymeric based composite automotive bumper beam. The validation of the selection process using sensitivity analysis is also discussed in this chapter.

Chapter 8 presents the fourth article entitled ‘Composite manufacturing process selection using analytical hierarchy process’. This fourth article reported the development of manufacturing process selection by determining various input parameters that influence the selection process in development of polymeric based composite automotive bumper beam. The validation of the selection process using sensitivity analysis is also discussed in this chapter.

Chapter 9 presents the overall conclusions and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concurrent engineering (CE) principles are very important in product development process. One of its principles is an early decision making (Prasad, 1996). Most of the products that failed are generally due to inappropriate decision making made on design concept, material and manufacturing process at the early stage of product development process (Dowlatshahi, 2000). The use of traditional method such as sequential engineering process in product development also contributes to the failure of the product in the marketplace. The traditional approaches to the development of products are now considered to be inefficient, time consuming and incapable of giving the levels of performance required. In an attempt to rectify the problems associated with traditional approaches, CE approach needs to be employed in the product development process (Young and Allen, 1996).

The automotive industry has always been known to be competitive and even now the industry is facing greater market pressure to develop high quality components more quickly at lower cost. That is why CE approach and the use of composite materials are playing a major role in the development of the automotive components (Sapuan, 2005). To illustrate the importance of CE principles such as early decision making, and the use of composite materials at the early stage of product development process, automotive composite bumper beam has been selected in this study.

In general, the use of polymeric based composite in the development of automotive bumper beam was reviewed in this chapter. The importance of using CE concept in solving design problems, the importance of design concept selection, materials selection, manufacturing process selection and the use of analytical hierarchy process (AHP) at the conceptual design stage are also included in this chapter.

2.2 Composite

Composite materials are not new. They have been widely used in marine applications for the military since World War II in the late 1940s to early 1950s (Mazumdar, 2002). Nowadays, composite materials are widely used in various industries such as aerospace, automotive, marine, boating, sporting goods, consumer goods and infrastructure. Basically, a composite material can be defined as any materials consisting of two or more components with different properties and distinct boundaries between the components (Vassiliev and Morozov, 2001).

2.2.1 Application of composites in automotive industry

Composite materials have been utilized in various industries including automotive, aerospace, civil infrastructure, marine and consumer goods. The automotive industries earliest introduction to the composite materials began in 1953 and it is still evolving until today. Composites were first used in the body of the Chevrolet Corvette in 1953. Its body was made from fiberglass (Mangino et al., 2007).