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WEB-BASED EXPERT SYSTEM FOR MATERIAL SELECTION OF NATURAL FIBER- REINFORCED POLYMER COMPOSITES

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By

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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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Chairman : Mohd Sapuan Salit PhD, P.Eng
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Conventional material selections are mostly based on the experience of product design engineers and the materials in common use. An inappropriate selection of materials for engineering component would result in entire product failure which ultimately has a negative impact on the society. Several algorithms, methods and spreadsheets are being proposed by various researchers in this field to improve materials selection. But, the computer oriented materials selection and knowledge-based expert systems are the robust approach in materials selection to handle huge amount of materials of choice. The decision of selecting optimised materials was complicated, as it involves diversified choice of materials, coupled with various influencing criteria for the selection. Usually more than one material satisfies the product constraints. In the exponentially growing material database, selection of optimal material for engineering design is Multi Criteria Decision Making (MCDM) problem as many properties of each material influence the selection process.

In this research, first the implementation of Analytical Hierarchy Process (AHP) computational tool was explored for deciding optimum material for automotive components. The final judgement was performed with different scenarios of sensitivity analysis with prioritising the environmental factors and sustainability. The result shows that the selected alternative materials for synthetic polymer was in compliance with the industrial Product Design Specification (PDS) and can be recommended to automotive component manufacturers to enforce green technology.

Secondly, an expert system using Java programming technology with two tiers of search engine was developed to perform a fast selection of candidate materials in huge volume. The weighted-range method (WRM) was introduced to identify the range value and to scrutinize the candidate materials in the selection process. The expert system performance was tested with automotive component as a case study with high, medium and low precision criteria and the result sets generated by the expert system comply with industry benchmarks.

In the third stage, hybrids of expert system with neural network technology was desired to narrow down the selection. So, the integration of Artificial Neural Network (ANN) with an Expert System for material classification was explored. The computational tool, Matlab was proposed for classification with Levenberg-Marquardt training algorithm, which provided faster rate of convergence for feed forward network. The system proved to be consistent with 93.3% classification accuracy with 15 neurons in

the hidden layer. Finally, the developed expert system was deployed over the internet with central interactive interface from the server as a web-based application. As Java is platform independent and easy to be deployed in web based application and accessible through the World Wide Web (www), this expert system can be one stop application for materials selection.

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

SISTEM PAKAR BERASASKAN SESAWANG UNTUK PEMILIHAN BAHAN BAGI KOMPOSIT POLIMER DIPERKUAT GENTIAN ASLI

Oleh

BASHEER AHMED AHMED ALI

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Pilihan bahan konvensional kebanyakannya berdasarkan pengalaman jurutera reka bentuk produk dan bahan-bahan yang biasa digunakan. Pilihan tidak sesuai bahan untuk komponen kejuruteraan akan mengakibatkan kegagalan produk keseluruhan yang akhirnya mempunyai kesan negatif kepada masyarakat. Beberapa algoritma, kaedah dan *spreadsheet* adalah dicadangkan oleh pelbagai penyelidik dalam bidang ini untuk meningkatkan pemilihan bahan. Namun, pemilihan bahan-bahan yang berorientasikan komputer dan sistem pakar berasaskan pengetahuan adalah pendekatan yang teguh dalam pemilihan bahan-bahan yang mengendalikan bahan-bahan pilihan berkuantiti besar. Sebagai sistem berkomputer yang dimaksudkan untuk pemprosesan yang cepat, tepat dan jumlah penyimpanan data yang besar, teknologi ini adalah sangat membantu terutamanya bagi sistem pemilihan. Biasanya lebih daripada satu bahan memuaskan kekangan produk. Pemilihan bahan yang optimum untuk reka bentuk kejuruteraan adalah mengenai Kriteria Membuat Keputusan Pelbagai (MCDM) kerana banyak ciri-ciri setiap bahan mempengaruhi proses pemilihan.

Dalam kajian ini, pelaksanaan alat pengiraan Proses Analisis Hierarki (AHP) telah diterokai untuk menentukan bahan yang optimum. Penilaian akhir telah dilakukan dengan senario yang berbeza analisis sensitiviti dengan mengutamakan faktor persekitaran dan kemampanan. Hasilnya menunjukkan bahawa bahan-bahan alternatif dipilih untuk polimer sintetik mematuhi Spesifikasi Rekabentuk Produk (PDS) industri dan boleh disyorkan untuk pengeluar komponen automotif untuk memperkuatkan agenda teknologi hijau.

Yang kedua, sistem pakar menggunakan teknologi pengaturcaraan Java yang telah dibangunkan untuk melaksanakan pemilihan yang cepat untuk banyak calon bahan dengan dua peringkat enjin carian. Kaedah jarak wajaran (WRM) diperkenalkan untuk mengenal pasti nilai dan kepelbagaian untuk meneliti bahan-bahan calon dalam proses pemilihan. Prestasi sistem pakar diuji dengan komponen automotif sebagai kajian kes tinggi, sederhana dan kriteria ketepatan yang rendah dan set hasil yang dijana oleh sistem pakar mematuhi tanda aras industri.

Pada peringkat ketiga, didapati bahawa pelaksanaan satu sistem pakar sahaja menjadikannya sukar untuk meneliti bahan-bahan yang dipilih. Kacukan sistem pakar dengan teknologi rangkaian neural kini sangat dikehendaki untuk menghalusi pemilihan. Maka dengan ini, integrasi Rangkaian Neural Buatan (ANN) dengan Sistem

pakar untuk pengelasan bahan telah diterokai. Alat pengiraan, Matlab adalah dicadangkan untuk pengelasan dengan algoritma latihan Levenberg-Marquardt, yang menyediakan kadar yang lebih cepat daripada penumpuan untuk rangkaian suapan *forward*. Sistem ini terbukti menjadi konsisten dengan 93.3% ketepatan pengkelasan dengan 15 neuron pada lapisan tersembunyi. Akhirnya, sistem saraf pakar maju diatur dalam *internet* dengan pusat interaktif antara muka dari pelayan sebagai aplikasi berasaskan web. Sebagaimana Java adalah platform bebas dan mudah untuk digunakan dalam aplikasi berasaskan web dan boleh diakses melalui World Wide Web (www), sistem pakar ini juga boleh menjadi salah satu aplikasi sehenti bagi pemilihan bahan bahan polimer.

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

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile-butadiene styrene
AHP	Analytical hierarchy process
AI	Artificial intelligence
ANC	Average of normalized column
ANFIS	Adaptive neural fuzzy inference system
ANN	Artificial neural network
API	Application program interface
CAD	Computer aided design
CAE	Computer aided engineering
CES	Cambridge engineering selector
CI	Consistency index
CIM	Computer integrated manufacturing
CMS	Cambridge material selector
CNC	Computer numerical control
CR	Consistency ratio
DBMS	Database management system
DPF	Date palm fibre
EC	Expert choice
EE	Enterprise edition
EFB	Empty fruit bunch
ELECTRE	Elimination and choice expressing reality
GFRP	Glass fibre reinforced plastic
GNA	Guass newton algorithm
GNU	General public license
GUI	Graphical user interface
HTML	Hypertext markup language
HTTP	Hypertext transfer protocol
IDE	Integrated development environment
IE	Internet Explorer
IIT	Integrated information technology
JDBC	Java database connectivity
JDK	Java development kit
KBMS	Knowledge based management system
KBS	Knowledge based system
KEE	knowledge engineering environment
KG	Kilogram
LMA	Levenberg marquardt algorithm
MARS	Multipoint approximation method
MCDM	Multi criteria decision making
MLP	Multilayer perceptron
MLPNN	Multilayer perceptron neural network
MPa/GPa	Megapascal/Gigapascal
MSE	Mean squared error
NFC	Natural fibre composite
ODBC	open database connectivity
PC	Personal computer
PDS	Product design specification

PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
PVC	Poly vinyl chloride
RDBMS	Relational database management system
RI	Random index
TFT-LCD	Thin film transistor-liquid crystal display
TOPSIS	Technique of ranking preferences by similarity to the ideal solution
URL	Universal resource locator
VIKOR	VIseKriterijumska Optimizacija I Kompromisno Resenje (in Serbian)
WRM	Weighted- range method
WWW	World wide web

CHAPTER 1

INTRODUCTION

1.1 Background of study

The innovation in material science and technology reveals more materials than ever before and the selection menu become countless for the engineers. Ashby (2005) described the available materials for the engineers are vast and expected to something over 120,000 materials of choice. Materials selection is an important criterion for engineering applications. The explosion all over the world is increasingly using the computing power to solve a complex engineering problem that offers the optimum solution.

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 Multi Criteria Decision Making (MCDM) problem. 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 automotive manufacturers are on the brink of revolution, initially focused to replace the metal components with plastics. Now their concern was to reduce the usage of plastics and substitute the same with bio-composites to protect the global environmental consciousness (Stewart, 2010; Park and Dang, 2011; Mohanty et al., 2005; Shen et al., 2010). The high fibre content of natural fibre composites reduces the amount of pollution base polymers. In automotive interior components like door panels, seat backs, headliners, dashboards, instrument panel, spare wheel tray, rear panel and trunk liners the substitute of natural fibre reinforced composites results in lower weight of components and thereby improves the fuel efficiency and also reduces emissions. At the end of cycle natural fibres results in added energy and carbon credits.

The natural fibre composites with different fibre orientations, matrices and constitutions would result in different mechanical properties and characteristics. These different attributes of natural fibres would increase the challenges for the material selection process. Thus, this causes a very difficult task for an engineer to select the right and the most appropriate material for a particular design. Therefore, a systematic software system has to be developed to help design engineers to choose the optimum material in the selection process.

1.2 Problem statements

Conventional materials selection systems are mostly based on the experience of product design engineers with the materials of common use and they are hardly prepared to take risks with new materials and systems. In the field of material selection, the use of printed handbooks and datasheets with limited choice are considered as outdated technology (Djassemi, 2009; Sapuan, 2001). As a result of extensive research and development, new fibre reinforced composite materials are emerging and the database of materials is growing exponentially. Lower material price

cannot guarantee to achieve the optimum material. The decision of selecting optimized materials was complicated, as it involves diversified choice of materials, coupled with various influencing criteria for the selection process. The selection of inappropriate materials affects the efficiency of the final product, customer satisfaction and also raises environmental issues.

Earlier research works concluded their judgement of optimum material with few numbers of alternate materials and apply traditionally analytical calculations rather than computational software tools (Jahan et al., 2010). Some studies also shows that existing expert material selection system selects the materials with the screening or ranking orders (Lan et al., 2011), which deals with human assumption. Furthermore, some existing research work used commercial software tools for material selection process and focused on synthetic fibre composites with few candidate materials (Hambali et al., 2010). The mostly used CES material selector divides the selection into stages that lacks with user-friendly features. The multi-step procedure used to select optimum materials complicates the multi criteria selection. Moreover, the Asbhy's chart used to screen the materials in CES software raises the possibility of material elimination from the selection list. To overcome this problem, there is a need for intensive research to develop an open source free licensed user friendly expert system for material selections that can handle a large volume of candidate materials.

Research has been conducted in the field of materials selection for manufacturing process and design of metal and polymer composite materials (Hambali et al., 2010; Lan et al., 2011; Mansor et al., 2013). However, least consideration has been given to material selection of natural fibre reinforced composites. As several research being carried out to use natural fibres as alternative materials for petrochemical based synthetic materials to enforce global green technology (Ishak et al., 2011; Bachtiar, 2008; Wirawan et al., 2011; El-Shekeil et al., 2012). Moreover, motivated by potential advantages of weight saving, lower raw material price and ecological advantages of using these green resources which are renewable and biodegradable (Jawaid and Khalil, 2011). Lucintel (2008) estimates by 2016 the natural fibre composite market is expected to reach US$ 3.8 billion. Therefore, a deep research in materials selection for natural fibre composites that prioritize the environmental factors is a timely need of the globe.

Table 1.1: Limitations of earlier similar research works

Earlier similar research works	Limitations
Hambali et al., 2010	• Material selection only for bumper beam. • Not support multi component selection, • Applied commercial software tools for material selection process • Limited to only six candidate materials • Selection only for synthetic polymer composites • Not focus on environmentally friendly material

Lan et al., 2011	• Selects the materials with the screening and ranking orders • Limited to only twelve candidate materials • Interface in Chinese language and focused only to Chinese community • Use only metals as candidate materials • Not use environmentally friendly material

However, compared to other commercial materials like metals and plastics, the database of emerging natural fibre composites does not convene the advanced industrial need. As a requirement, the compilation of knowledge-base for natural fibre composites would be an added advantage to the designers' community. Secondly, if the result set of the expert system increases than the implementation of expert system alone makes it difficult to scrutinize these vast selected materials. Then hybrid of expert systems with neural network technology is a desirable solution. Classification of materials through neural network under various influencing criteria would significantly narrows down the selection.

Despite the commercial success, the conventional stand-alone expert systems experience some limitations. These expert systems have availability constrain and accessible only on installed desktop computers. As these expert systems are not distributed applications, the knowledge sharing among expertise is not possible in these systems. The software upgradation or updating the system with newer version will also be inconvenient in these systems.

1.3 Aim and Objectives of study

The aim of this research work is to develop a web based expert system that handles a large number of material database and can be implemented for the selection of optimum material in the manufacturing process.

The specific objectives of this research are as follows:

1. To explore the implementation of AHP concept for deciding optimum materials selection in natural fibre reinforced composite by prioritizing the environmental factors and sustainability.
2. To develop a standalone open source rule-based expert material selection system using Java programming technology.
3. To integrate the ANN with the expert system output and to classify the NFC materials in accordance with the range specified in the PDS.
4. To enhance the expert system with web-based applications using Java applet programming and conveniently available for the engineers at the point of need nevertheless anytime and anywhere.

1.4 Scope of study

In this research work, the expert system was developed in open source software Java programming language under free software license from Sun Microsystems. Java technologies are licensed under GNU General Public License (GNU GPL) and the system developed can be distributed under the same license terms.

In the vast material family the focus in this research was given to natural fibre composites materials for potential usage in automotive interior components. The natural fibre composites was considered as the materials of choice for automotive components like door panels, seat backs, headliners, dashboards, instrument panel, spare wheel tray and trunk liners. In this study, the consideration was given to three interior components i.e dashboard, door panel and rear panel. These case studies were tested with the values from the renowned industrial product design specification (PDS).

In material selection for automotive components, the design engineers have to consider many properties influencing the selection. In this study, the physical and mechanical properties considered for automotive components were density, tensile strength and Young's modulus. The database of natural fibre composites materials were not experimentally obtained, rather they were gathered from the published literature.

1.5 Organization of the thesis

The chapter 1 of this thesis starts with an introduction, problem statement, objectives of study and ends with the scope of study. Chapter 2 presents a detailed review of literature related to expert systems and its application for materials selection. This chapter also covers the importance of natural fibre reinforced composites as an alternative material for synthetic fibres and its application in automotive industries. Chapter 3 presents the implementation of Analytical Hierarchy Process (AHP) as an expert decision system in selection of optimum composite materials for automotive components on the basis of environmental factors. Chapter 4 details about the development of Java based expert system for selection of natural fibre composite materials. Also introduces Weighted-range method (WRM) with rule-based decision criteria for selection of materials with three precisions. Chapter 5 presents a framework for integration of Artificial Neural Network (ANN) and expert system for material classification of natural fibre composites. Chapter 6 proposes a web-based expert system for material selection. Summary of conclusions and recommendation of future works are suggested in chapter 7.

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