

A PROTOTYPE OF KBS FOR MATERIAL SELECTION IN BUMPER BEAM DESIGN

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Abstract

This paper describes the development of the Knowledge Based System (KBS) for material selection in bumper beam design. The KBS is an expert system used to select the most suitable material by defining constraint values into the system. The aim of this project is to select the most suitable material for an automotive bumper beam. The selection method was based on the material selection requirements such as mechanical properties, physical properties and economic value. The constraint values were documented in the product design specification (PDS) derived from experimental work and design calculation. The KBS will rank the materials in the form of a hierarchical graph for the best five of the most suitable materials. The top ranking materials have the closest specification values to the user's defined value.

Keywords: Knowledge based system, material selection, bumper beam

Introduction

Computers science (CS) has become valuable technology nowadays and has shown its potential as a powerful tool for materials election. Some companies such as Furon, a manufacturer of structural bearings, has offered an expert system to its customers to select the products, which best meet the customers requirements including environmental consideration aspects and geometric compatibility. In the current demanding market, industry needs a tool to overcome certain problems effectively and rapidly. Therefore CS and Artificial Intelligence (AI) communities have to turn this demand into opportunity. The KBS or expert

system is one of the technology advantages available; by the combination of computers and programming languages it can be used to solve problems easily, cheaply and with lower risk particularly in the material selection process compared to former approaches.

Material selection process is an important activity in product development process because material plays an important role to ensure the product meets the product requirements such as lightweight, high specific strength, high specific stiffness etc. In automotive research KBS has been developed to select material for engine components such as the piston, connecting

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rod and piston ring (Sapuan *et al.*, 2002). Sapuan and Abdallah (1998) have developed an expert system for material selection of polymeric-based composite material for an automotive pedal box system. The system was developed to select a suitable material for major elements in the pedal box system such as accelerator, clutch, brake pedal and mounting bracket. However most of the KBS were developed specifically only to a particular component. To increase the number of KBS available in automotive applications this project is aimed to develop a KBS for material selection for an automotive bumper beam design. In the next sections the factors, rules and technique used for the KBS development will be described.

System Description

This system was developed based on heuristic rules and the experience of the designer. It is a

frame-based system, which acts as a database for material and contains all the required data properties. Classification and reasoning of material selection are carried out using a rule-based system approach. The frame-based system of the KBS is very flexible, expressive and accessible for interpretation to the rest of the system and it is used to describe the hierarchical relationship between the material and its attributes. Figure 1 and Figure 2 shows the flow chart of the material selection process and material selection hierarchy tree in the KBS respectively.

User Interface

User interface is an important part in the KBS system. It must be user-friendly for easy access to the system. The user interface was intended to allow the designer to work quickly in the KBS with a little familiarization. To interact with the

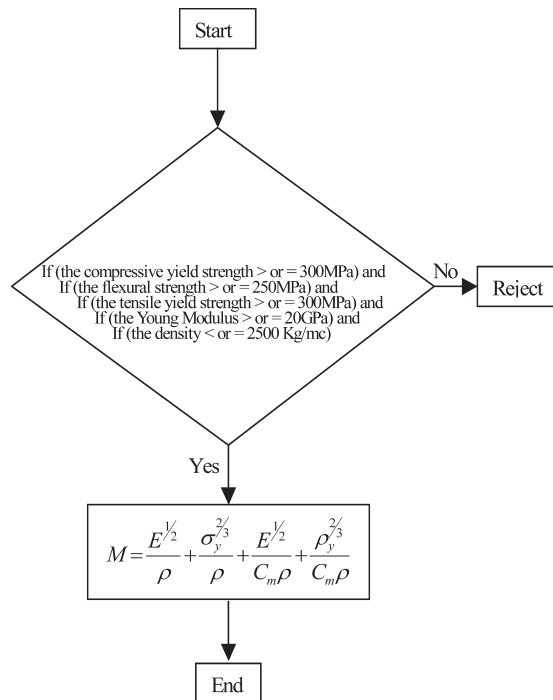


Figure 1. Flow chart of the material selection process

KBS the user just needs to use a mouse, menu, keyboard and a displayed window. The displayed window will show either information from a knowledge-based or user option.

The user interface was designed and formulated using images such as buttons, text, bitmaps and transcript. Figure 3 shows a user interface of the KBS for material selection in bumper beam design.

KBS Constraints

In this project, material properties are utilized as a rule to set the constraints in the KBS. Using the material properties rule, the designer will be able to examine whether the proposed materials are suitable as a candidate for the particular component. As an example, if the designer specifies the material with toughness value, T_d , the system will compare this toughness, with the pre-defined toughness limit, T_{max} . If the value of the defined constraint is in the limit, the system will proceed to the next constraint, and if not, this material will be eliminated for the next process.

$T_d > T_{max}$: operation system is stop and go to next material

$T_d < T_{max}$
 $T_d = T_{max}$: the system continues to next constraint

The most important thing in this part is to define the value of the constraints. The constraints' value is defined from the analysis or experiment result that has been done.

User Input Data

User input data is a dialogue platform between the system and the user. In this part, the system will ask a few questions to the user about the constraint values of the material properties. The following is the dialogue between the user and the KBS.

Dialogue between the system and the user:

What is the minimum value of compressive yield strength?

What is the maximum value of density?

What is the minimum value of flexural

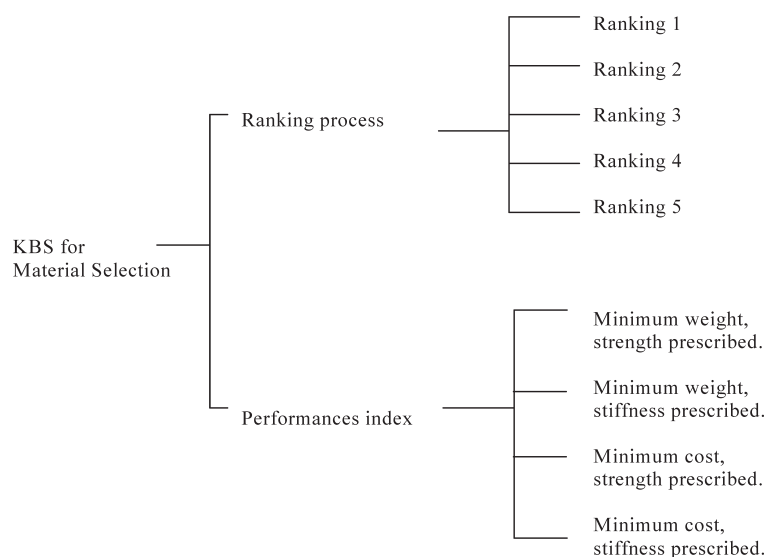


Figure 2. Material selection hierarchy tree

strength?

What is the minimum value of Young's Modulus?

What is the minimum value of tensile yield strength?

Database and Software to Develop KBS

First, a classification of material is defined and it will act as the main database for the KBS. This is a very important part of the KBS development, mainly to reduce project cost and to eliminate unwanted material at the early development stage. The material classification was defined through a pre-material selection process by considering the performance requirements of the automotive bumper beam.

Finding a good programming language is also important in developing the KBS. The language must be easy to use and able to create a simple graphic user interface as well as to develop fairly complex applications.

The knowledge contained in a product model will act as an object, that it belongs to a "class" in the KBS. This means that the KBS is object-oriented and it was developed using an object-oriented programming language. An

object-oriented programming (OOP) language offers flexibility, easing changes to programs and is widely used in a large-scale software engineering population. Furthermore, an OOP is easy to learn, simple to use and easy to maintain, lending itself to more direct analysis coding and also has more understanding of the complex situations than other programming methods. Today, there are many types of object-oriented programming such as C++, Java, Visual Basic, Kappa-PC, MS Access etc.

In this project, the Visual Basic (VB) programming language was employed as a language in the KBS development. VB is a simpler programming language and is easy to use, particularly to create a simple graphical user interface window and also for complex applications. It is a combination of visually arranging components in the form of a shape, specifying attributes and actions of components, and has the capability to write additional lines of codes for extra functions.

Material Selection Process

In this system, two processes have been employed to produce the relevant result for the bumper beam component. They are the

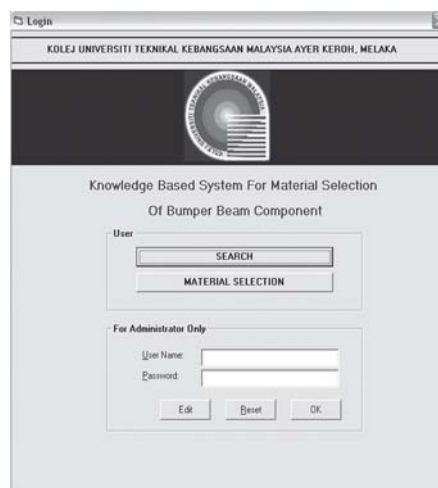


Figure 3. User interface of the KBS for material selection in bumper beam design

screening and ranking processes. The screening process purposely eliminates materials after considering the constraints. The ranking process ranks in order the admissible solutions using performance metrics based on the objective.

In this section, rules have been implemented in the KBS for the selection of the suitable material for the automotive bumper beam. For instance, when the conditions of a rule are satisfied then the conditions are valid. Therefore, to select the material for the automotive bumper beam, the following approach has been applied:

If <X> Then <Y>

where X are the constraints defined by the user and Y is the conclusion. Meaning that this material fulfilled all constraints defined by the user. The process of material selection for the automotive bumper beam has been defined through the following rules:

Rules:-

If (the compressive yield strength $\geq$ or $=$ 300 MPa) and

If (the flexural strength $\geq$ or $=$ 250 MPa) and

If (the tensile yield strength $\geq$ or $=$ 300 MPa)

and

If (the Young Modulus $\geq$ or $=$ 20 GPa) and

If (the density $\leq$ or $=$ 2500 Kg/m³)

Then

(This material is a candidate for the bumper beam component and goes to the next section)

Figure 4 shows the graph of the Young Modulus (GPa) versus Density (Mg/m³). After the screening process the materials in the shaded area, that are Aluminum Alloys, GFRP, KFRP, Glasses, Magnesium Alloys and others have been chosen as candidates for the automotive bumper beam. These materials will proceed to the next process or ranking process for the

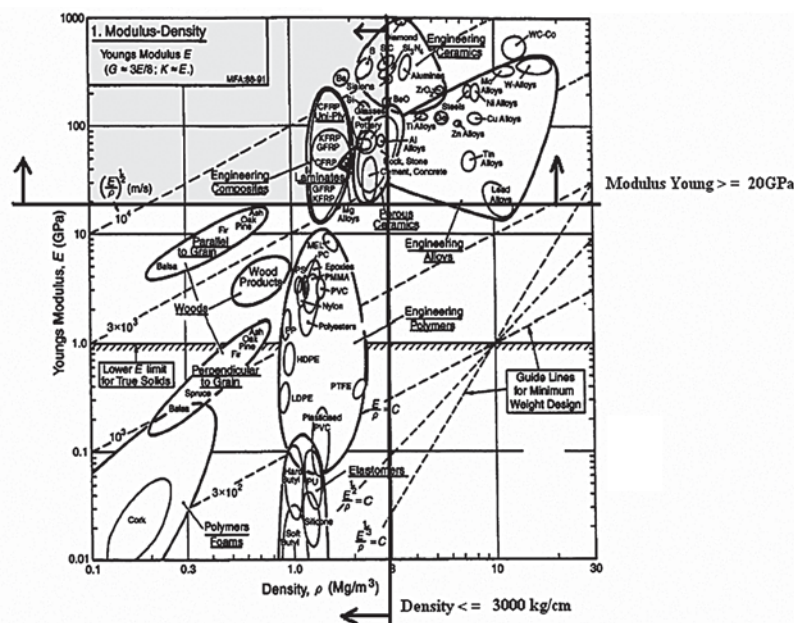


Figure 4. Graph of the Young Modulus versus Density (Ashby and Cebon, 1993a)

second stage in the selection process. The shaded area in the graph indicated that all materials satisfied all selection criteria defined by the user and were considered as 'passed' the screening process.

The material that has passed the screening process is stored in the database for every selection process and it can be examined at any time. It is also possible to modify any selection process to ensure the performance criteria are confirmed or unconfirmed until the most suitable materials are found. The materials that pass the screening process will be stored in a disc file and compiled as the package. This enables users continually to do a selection process and re-evaluate the selection criteria based on the input from other design information. It also forms a document in the selection process

Formulating Material Selection Process

Based on the formulation developed by Ashby (1993), the performance index that is a combination of different material properties has been employed in this system to select the material for the bumper beam in automotive application. The detail of the performance index is shown in Table 1.

In this project each performance index is computed and summed, to produce the total performance index M as in equation (1). This total performance index is important to enable the KBS to process material in the database and select the material with the highest strength and stiffness. This material also has shown a good result in terms of cost and weight.

$$M = \frac{E^{1/2}}{\rho} + \frac{\sigma_y^{2/3}}{\rho} + \frac{E^{1/2}}{C_m \rho} + \frac{\rho_y^{2/3}}{C_m \rho} \quad (1)$$

In the programming language, the new performance index is seen as follows:

```
tempResult1 = ymRS ^ (1 / 2) / dRS
tempResult2 = tsRS ^ (2 / 3) / dRS
tempResult3 = (ymRS ^ (1 / 2)) / (cRS * dRS)
tempResult4 = (tsRS ^ (2 / 3)) / (cRS * dRS)
M = tempResult1 + tempResult2 + tempResult3 + tempResult4
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Once the performance index of each material in the database was computed, the system will sort the material in rank based on the score in the performance index. The material with the highest score in performance index will be ranked as the first and so on. The score is to indicate the properties of the material closest to the material properties that have been defined by the user in the system. These materials become the most suitable materials for the automotive bumper beam component.

Results and Discussion

The KBS for material selection has the capability to select the most suitable material for the automotive bumper beam. To select the most suitable material for the automotive bumper beam the user needs to define the constraint value in the user dialogue box. Variations results will be produced if the user varies the constraint values in the system. This revealed that the system was intelligent enough to manipulate a variation of input that has been

Table 1. Performance index

Function	Objective	Constraints	Performance index
Beam	Minimum weight	Stiffness prescribed	$E / \rho^{1/2}$
Beam	Minimum weight	Strength prescribed	$\sigma_y^{2/3} / \rho$
Beam	Minimum cost	Stiffness prescribed	$E^{1/2} / C_m \rho$
Beam	Minimum cost	Strength prescribed	$\sigma_y^{2/3} / C_m \rho$

defined by the user in the system.

The material selection result in this system has been represented in Figure 5. In this system, 5 types of materials have been selected to be the material candidates for the automotive bumper beam. If there are any changes of the defined constraint values, the material candidates and the rankings will be varied respectively. In this system if the user constraint value cannot be found, the result will be presented as "NULL" in commands.

The result as shown in Figure 4 reveals that Norplex NP130HF Glass Fabric material is selected as the first rank, second is Aluminum 7178-T6; 7178-T651, third Aluminum 7178-T76; 7178-T7651, fourth Aluminum 2048, and the last is Aluminum 7475-T7351.

The result has shown that the system has the capability to choose the best material candidates for the automotive bumper beam. Norplex NP130HF Glass Fabric is the new material and the authors have yet found its application in the automotive industry since this system was developed. The user may select another material from the top five-listed material because this system intends to reduce the huge number of material candidates to a

smaller number of material candidates. From the top five ranks of material have been chosen 4, which are aluminum alloys and could be the best material for automotive bumper beam.

During the past decade, aluminum alloy especially in 7xxx series has been used for specific applications in the automotive industry, such as hoods of the vehicles. Aluminum alloys were selected as the materials for the automotive bumper beam because they are a light-weight material which is 40 - 60% lighter than steel. This may reduce vehicle weight and consequently reduce fuel consumption. The low elastic modulus of aluminum alloys is an asset when a structure is subjected to shock-loading conditions. The aluminum alloys are able to absorb energy three times higher than steel before permanent damage occurs for an equal moment of inertia and strength. Besides that the aluminum alloys material has many advantages to make it suitable for automotive application, such as:

- Strong. The entire vehicle body can be aluminum.
- Durable. Good resistance to corrosion and fatigue.
- Nontoxic.

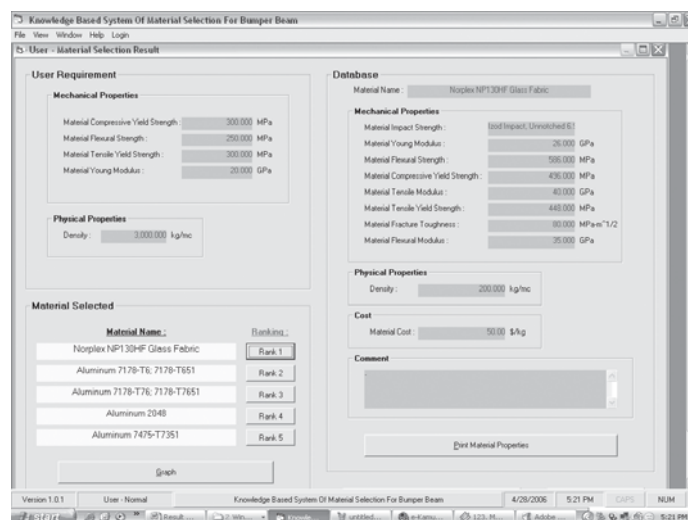


Figure 5. Material selection result

- Workable. It uses well-understood metal working processes.
- Recyclable. It is important to save energy and be a benefit to the environment.
- Conductive.

Conclusion

This project showed that the Knowledge-Based System for material selection of the bumper beam is a new system that has been developed to help design engineers to select the most suitable materials. The results have shown that the KBS in material selection gives a significant impact in the material selection process. The selection process is based on the selection criteria, which in turn is based upon the defined constraint values from material engineers. If the constraint values are satisfied, then those particular materials are selected as the best materials. This revealed that the system was capable enough to manipulate the variation of input. Visual Basic (VB) supported by object-oriented programming and rule-based reasoning was used to develop KBS for material selection and was reliable and easy to use. The KBS works in full interactive mode and gives feedback information to the user to follow the design procedures.

The development of the KBS for material selection enables designers to choose the best material candidate for the bumper beam

component with minimum effort and time. With 100 materials and 6 rules for each material to select the best material in manual selection, it would take a longer time. By adopting the KBS as the material selection tool the process takes less time compared to the manual method. The developed KBS supported the designer in selecting the best material for the bumper beam component.

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