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A COMPUTER-AIDED MATERIAL SELECTION FOR DESIGN OF AUTOMOTIVE SAFETY CRITICAL COMPONENTS WITH NOVEL MATERIALS

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ABSTRACT

An expert system for material selection for design of automotive component with fibre reinforced plastic materials has been developed. The expert-system shell KEE (Knowledge Engineering Environment) provides a tool to store and process expert knowledge. The system concentrates on selecting suitable materials for automotive components, in particular for major elements of pedal box system namely the mounting bracket, the accelerator, the clutch and the brake pedals. Data about the materials and their properties are stored in the frame-based system. The expert system enables material data to be accessed through user interface. Selection of the most suitable material is carried out through experience and expert knowledge (for instance, about manufacturing method for polymeric based composite materials) written in rule system. Factors like mechanical, physical and chemical properties, economic and manufacturing considerations were used in the material selection process. The material must satisfy all the above requirements in order to become a suitable candidate for a particular component.

Keywords: ***Computer-aided material selection, Expert system, Knowledge-based system, Automotive pedal, Polymeric-based composites, Fibre-reinforced plastics.***

1.0 INTRODUCTION

The use of computers in engineering design has become an acceptable route in most of engineering projects. It has long been the wish of design engineers to include design expertise in the CAD software, but conventional software systems have not been well suited to this task. Using the technology of expert system, it is possible to incorporate judgmental design knowledge within the CAD knowledge and environment. Expert systems or knowledge-based systems are particularly suitable for the processing of unstructured scattered knowledge for the solution of complex problems. One such problem is the selection of materials for design with novel materials (e.g. polymeric-based composite materials [1-3]).
The use of expert system in the fields of polymer or polymeric-based composite materials selection, has been reported in the literature [4-14]. Examples of computer packages on the materials selection of polymer materials that are currently gaining popularity include Plascams [4] and PERITUS [5,6]. Plascams is an expert system for plastic material selection, which works using two search routines, which enable the user to search material qualities from hundreds of materials. PERITUS [5, 6] contains expert system for selection of polymer as well as for metal and ceramic materials and processes for design. It performs manipulations of the data to assist with the preliminary selection of materials.

Bullinger et al [7], Bergamaschi et al [8], Nitsche et al [9] developed expert systems for the material selection of polymeric-based composite materials. In all the systems, data about the materials and their properties were processed and stored in database systems. Logical user interfaces between expert systems and database, were developed. Design and selection of the optimal materials were solved through experience and expert knowledge (for example about manufacturing method for fibre-reinforced composite materials) using rule-based reasoning facility.

Similar studies on the expert system of material selection were performed by Nielsen et al [10] and Hopgood [11], but the expert system served as consultants for selection of polymer materials. Nielsen et al [10] employed the reasoning using rule-based system while Hopgood [11] had been working based on two methods. These methods are:

- a method that utilizes point property data combined with weightings supplied by the user to rank candidates *and*
- the method that was concerned with the use of relationships between classes of material to produce more complete descriptions of material based on object oriented programming techniques.

Expert systems had also been used as material selection systems for specific applications. Boose [12] used it for selecting the best fibres for aircraft parts of Boeing such as rudders, spoilers, elevators and cowl component. Thurston and Crawford [13] used KBS in the selection of polymeric materials for automobile bumper. Fensenfeld et al [14] employed it in the selection of composite materials for automotive leaf springs. All the systems employed rule-based reasoning method of selection. Thurston and Crawford [13] also used the multiattribute utility analysis in their study. Fehsenfeld et al [14] had used frame-based representation for the data storage. In all the systems, different types of materials were selected by making trade off between design performance and cost of manufacture.

None of the above researchers used an expert system for selecting suitable materials for automotive pedal box system. In this study, data about the materials and their properties are processed and stored in the frame-based system. The developed expert system enables material data to be accessed through graphical user interface. Selection of the most suitable material is possible through experience and expert knowledge (for example, about manufacturing method for polymeric-based composite materials) written in the form of rules. The expert-system shell KEE (Knowledge Engineering Environment) serves as an excellent tool to process expert knowledge.

KEE is chosen because the rule-based system used for selecting materials is of pattern matchers. These pattern matchers are extremely flexible and powerful. They are more applicable for domains where the possible solutions are either unbounded or large in numbers, such as design, planning, and synthesis (Gonzales and Dankel [15]). Other KBS shells that have these characteristics include OPS-5, ART and CLIPS. It is in contrast with inference networks, where they are useful for domains where the number of different alternative solutions is limited, e.g. the classification of elements in the natural sciences and diagnostic problems.

The intelligent program of a knowledge-based system consists of an inference engine and a knowledge base. Closely associated with this intelligent program is a data or fact base. The inference engine manipulates the knowledge represented in the knowledge base to develop a solution to problem(s) described by the information in the database. The inference engine might attempt to work from the features to the solutions (called forward chaining), from the solutions to the features (backward chaining), or from both ends simultaneously (bi-directional reasoning) [15]. In KEE, all these three types of inference engines are available but for this particular case study, a forward chaining is implemented. The input to the KEE shell for selecting the materials include the material data from material database (CAMPUS), from the material handbook, and from the suppliers, product design specification (PDS) and other sources. The outputs from this selection process include the materials selected for a particular component after satisfying all the rules. These outputs were represented by a friendly user interface.

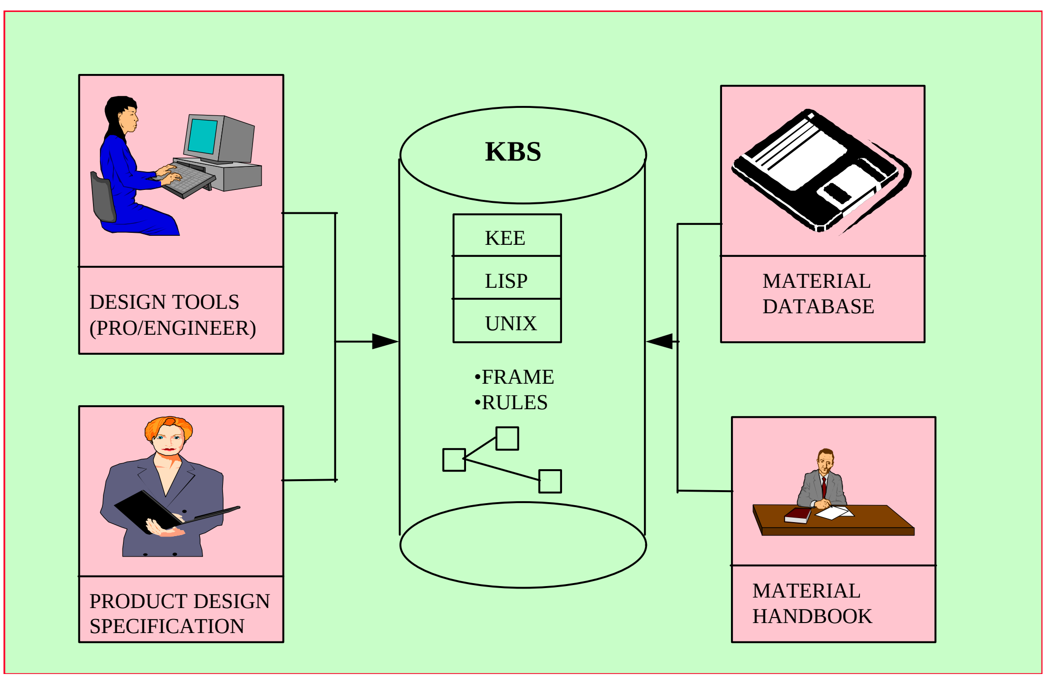

Fig. 1: Structure of system for material selection for design of pedal box system with polymeric-based composite materials

There are various means for representing knowledge in a knowledge base. In this case study, rules and frames are used. The inference engine supports the representation scheme using the forward chaining process.

2.0 STRUCTURE OF THE EXPERT SYSTEM FOR MATERIAL SELECTION

Fig. 1 shows the structure of the expert system for material selection for design of pedal box system with polymeric-based composite materials. It shows the relationship between the components, e.g. the knowledge base and other design tools. The expert system developed offers companies sufficient research potential to solve their practical problems. Such expert system can be extended further to other components within the automobiles, e.g. gear lever, air intake manifold, suspension system, connecting rod, disc brake, spoiler, drive-shaft etc.

The human-computer dialogue takes place with the help of selection menus in the user interface designed specially for the application. For instance, the designer first specifies the technical and other data required of a component. Then, he accesses the expert system. In this, a user is guided by the graphical user interface (See Fig. 2). The menus appear on the screen only on demand.

The definition of the requirements by the user is an important factor for the material selection. These requirements consist of quantitative characteristics (e.g. modulus of elasticity, yield stress) and qualitative properties (e.g. recyclability). These properties are collected in various groups.

Automotive pedal box system is a safety critical component within an automobile. It consists of the accelerator pedal, brake pedal, clutch pedal, mounting bracket, and other standard components like shaft, bolt, nut, springs, screws and light switch, as shown in Fig. 3. Currently, the majority of automobiles employ metallic materials for pedal box system. However, in this study, the alternative material (polymeric-based composite) is sought in order to reduce the weight.

Since the development of polymeric-based composite pedal box system is a new technology, the knowledge for material selection and design solutions were unstructured and scattered. The knowledge were pulled together from various sources such as through:

- detail study of metallic pedal box system
- investigation into other components within an automobile using polymeric-based composites
- data from material and component suppliers
- material database such as CAMPUS
- materials handbook
- patents
- trade literature
- standards
- conventional knowledge gathering techniques like textbook and internet.

Since pedal box system is one of the safety critical components in an automobile, the problem is very complex. Simply substituting the metallic component to polymeric-based composite one is not an appropriate approach because a lot of design rules for metals are not applicable to composites. Therefore, a thorough study on the performance of pedal box system especially on the stiffness and stress, was carried out. The addition of special features associated with composite components such as ribbing and unique cross-section was ensured.

KEE system successfully solved both problems of unstructured knowledge and complexity of the design associated with pedal box system through the rule- and frame-based system. All the information gathered were stored in the frame-based system, in the form of slots, attributes, units and arranged in hierarchical structure. The selection process was carried out using rule-based system and the inference engine called forward chaining system supported this selection process.

The product design specification (PDS) guides the user on what data to input when the system asks him. For instance, the PDS of accelerator pedal is shown in Table 1.

KEE Typescript Window

Reading KB PDS CLUTCH [17 units]
‘’|’’’’’’10’’’’’’’’|’’
‘’|’’’’’’10’’’’’’’’|’’

Knowledge base PDSCLUTCH in/research/home/jagk/pdsclutch loaded.

What is the CONSTRAINT.MATERIAL.COST.FOR.CLUTCH PEDAL of POLYMERIC.BASED.COMPOSITE? 4.6

What is the CONSTRAINT.DIRECT.LABOUR.COST.FOR. CLUTCH.PEDAL of POLYMERIC.BASED.COMPOSITE?2

What is the CONSTRAINT.YIELD.STRESS.FOR.CLUTCH .PEDAL of POLYMERIC.BASED.COMPOSITE? 211

What is the CONSTRAINT.MODULUS.OF.ELASTICITY. FOR.CLUTCH.PEDAL of POLYMERIC.BASED. COMPOSITE? 9000

What is the CONSTRAINT.CHARPY.IMPACT.STRENGTH. FOR.CLUTCH.PEDAL of POLYMERIC.BASED. COMPOSITE? 30

What is the CONSTRAINT.DENSITY.FOR.CLUTCH.PEDAL of POLYMERIC.BASED.COMPOSITE? 2.7

What is the CONSTRAINT.WATER.ABSORPTION.FOR. CLUTCH.PEDAL of POLYMERIC.BASED.COMPOSITE?8

Fig. 2: User interface in the system

Fig. 3: Metallic pedal box system

Table 1: Product design specification of accelerator pedal

PRODUCT DESIGN SPECIFICATION OF ACCELERATOR PEDAL

Modulus of elasticity > 888.6 MPa

Yield stress > 59.7 MPa

Charpy impact strength > 30 kJ/m^2

Creep resistance = High

Fatigue strength = High

Corrosion resistance = High

Density < 2.7 Mg/m^3

Water absorption < 8 %

The material must be recyclable

Ribbing structure can be made using the material

Manufacturing method associated with material must be high volume production

The component made from this material must be dimensionally stable

Tooling cost < £50, 000

Material cost < £4.6 per kg

Direct labour cost < £ 2 per component

3.0 STORAGE OF MATERIAL DATA

The material data are stored in the frame-based representation of the expert system. All properties categorized under cost, manufacturing issues, mechanical, physical and chemical properties are the slots for each material in the hierarchical graph in an expert system. In this study, there is no need to have a separate database management system to store the information as the frame-based system forms part of the expert system. Example of how the data is stored in the frame-based representation is shown in Fig. 4.

||| (Output) The GFR.THERMOPLASTICS Unit in PHD Knowledge Base

Unit: GFR.THERMOPLASTICS in knowledge.base PHD
Created by jagk on 4-10-96 16:17:19
Modified by jagk on 9-13-96 12:17:32
Superclass:GFRP
Subclass: GFR.ABS,GFR.PBT, GFR.POLYAMIDE12, GFR.POLYAMIDE66, GFR.POLYAMIDE6, GFR.POLYCARBONATE, GFR.PET, GFR.POLYPROPYLENE
Member of: CLASSES in GENERICUNITS

Member slot: CHARPY.IMPACT.STRENGTH from POLYMER.BASED.COMPOSITE
***Inheritance*: OVERRIDE.VALUE**
***Comment*:"The unit is kJ/meter.squared"**
Values: UNKNOWN

Member slot: CORROSION.RESISTANCE from POLYMERIC.BASED.COMPOSITE
***Inheritance*: OVERRIDE.VALUE**
***ValueClass*:(ONE.OF.HIGH.MEDIUM.LOW)**
Values: UNKNOWN

Member slot: CREEP.RESISTANCE from POLYMERIC.BASED.COMPOSITE
***Inheritance*: OVERRIDE.VALUE**
***ValueClass*: (ONE.OF.GOOD.FAIR.POOR)**
Values: UNKNOWN

Member slot: DENSITY from POLYMERIC.BASED.COMPOSITE
***Inheritance*: OVERRIDE.VALUE**
***Comment*:"The unit is Mg/meter.cube"**
Values: UNKNOWN

Member slot: DIRECT.LABOUR.COST from POLYMERIC.BASED.COMPOSITE
***Inheritance*: OVERRIDE.VALUE**
***Comment*:"The unit is Pounds/hour"**
Values: UNKNOWN

Member slot: FATIGUE.STRENGTH from POLYMERIC.BASED.COMPOSITE
***Inheritance*: OVERRIDE.VALUE**
***ValueClass*: (ONE.OF.HIGH.MEDIUM.LOW)**
Values: UNKNOWN

Member slot: MANUFACTURING.METHOD from POLYMER.BASED.COMPOSITE
***Inheritance*: OVERRIDE.VALUE**
***ValueClass*:(ONE.OF.GOOD.FAIR.POOR)**

Fig. 4: A unit with slots in frame-based system showing the material properties

4.0 THE MATERIAL SELECTION PROCESS

The expert system uses the knowledge and ability of experts. Problems are not only solved by mathematically provable solutions, but can also be resolved with the help of vague knowledge, rules and chains of deductions. For example, experience, i.e. diffuse expert knowledge that cannot be algorithmized, is entered into the expert system in the form of a collection of rules and facts. All the information about a special field of knowledge, acquired via the interrogation of experts, suitable for handling problems in this field of knowledge, is stored in knowledge bases. Expert knowledge is presented in simple if-then relations. For example, if the designer intends to choose a material with low material cost, the expert system offers only glass fibre reinforced plastic material as a solution. A section of the content of a knowledge base is shown in Fig. 5.

After the user inputs, the material selection can be started. This is done by initiating the inference mechanism (i.e. the part of the controlling the rule processing) in the expert-system shell KEE.

5.0 MULTI-ATTRIBUTE PROBLEM FOR SELECTING A FINAL MATERIAL

When polymeric-based composites are selected, more than one candidates are obtained and not all the properties of these materials are of equal importance. Table 2 shows the comparative weightings of the materials based on four main properties. The designer can specify the importance of the individual properties (e.g. scores with values from 1 to 4). The total score of the component will rank the material as high, medium or low. Material that has high rank is chosen as the most suitable material for a component.

```
(accelerator.pedal.physical.property.rules)
(if
(the density of ?material is ?density)
((lisp (< ?density 2.7))
(the water.absorption of ?material is ?water.absorption)
((lisp (> ?water.absorption 8))
then
(the selection.for.accelerator.pedal of ?material is OK5)))
```

Fig. 5: Physical property rules for selecting material for accelerator pedal

Table 2: The comparative scores of materials for clutch pedal based on four properties

MATERIAL	DENSITY (mG/m^3)	SCORE5	MATERIAL COST (£/kg)	SCORE6	MODULUS OF ELASTICITY (MPa)	SCORE7	YIELD STRESS (MPa)	SCORE8	TOTAL SCORE	RANK2
ZYTEL73G 30.NC-10^	1.8	1	4.1	2	9600	1	180	2	6	low
ZYTEL70G 43LNC-10^	1.49	3	4.02	3	14200	4	221	4	14	high
ARNITE.AV 2360S	1.73	2	3.8	4	13000	3	165	1	10	medium
ULTRAMID B4300G6	1.43	4	4.5	1	11500	2	190	3	10	medium

CANDIDATE MATERIALS FOR POLYMERIC BASED COMPOSITE PEDAL BOX									
ZYTEL.70G43LNC-10^		GRILAMIDE.LV-3H		SCOLEFIN.PP340G1		DURATHEN.AKV.30.GIT.H2^		TWARON.1488	
ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE
OK5	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET
UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
ARNITE.AV2360S		ULTRAMID.A3WC4^		VESTOLEN.P7052G		ULTRAPEK.A1000C6		ULTRADUR.B4300.G6	
ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE
OK5	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN		OK5	
CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET
UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
VESTAMID.L-CF15SW~		FIBREDUX920-CX-793-42%		XANTAR.G623B		VESTAMID.L-GFNF^		ULTRAMID.B3ZG8^	
ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE
UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN		OK5	UNKNOWN	OK5	UNKNOWN
CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET
UNKNOWN	. UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
FIBREDUX920-KX-285-52%		NOVADUR.P2HGV		MF.1206		EP.8460S		PF.6507	
ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE
UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET
UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
UP.802P		TERLURAN.KR.2810.G3		ARNITE.TV4.440KL.BLACK		ZYTEL.73G30.NC-10^		MAKROLON.8035	
ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE
UNKNOWN	UNKNOWN	UNKNOWN		OK5	UNKNOWN	OK5	UNKNOWN	OK5	UNKNOWN
CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET
UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
ULTRAMID.TKR.4370C6^		RYNITE.430.NC-10		EP.841		TWARON.1010		UP.3420S	
ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE	ACCELERATOR	BRAKE
UNKNOWN		OK5	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	
CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET	CLUTCH	BRACKET
UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	

Fig. 6: Output of data sheets of selected materials through graphics display from the first stage of selection

6.0 PRESENTATION OF THE MATERIAL SELECTED

The presentation of the results of the material selection is shown to the user, in a clearly arranged format. For this reason, the data was prepared graphically in a suitable form:

- A listing of the input requirements (PDS) for the material as specified by the user in the user interface (See Table 1)
- Output of selected materials through graphic display from the first stage of selection is shown in Fig. 6
- A table, listing all the candidate materials after the first stage of material selection (see Table 2)
- Output of finally selected material from the second stage of selection via graphics display. The data sheets contain all characteristic values (See Fig. 7).

7.0 CONCLUSIONS

The method described above is a way of assisting design engineers in selecting the appropriate materials for polymeric-based composite automotive pedal box system with the help of a comfortable graphical user interface. The system enables the user to automatically retrieve the optimal material from the database system and has been proven to be faster and more efficient than selecting using conventional methods.

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BIOGRAPHY

S. M. Sapuan earned his B.Eng. degree in Mechanical Engineering in 1990 from University of Newcastle, N.S.W., Australia and MSc. in Engineering Design in 1994 from Loughborough University, UK. He completed his Ph.D. in Concurrent Engineering in 1998 from De Montfort University, UK. He worked as a researcher in Faculty of Engineering, Universiti Malaya from 1990 to 1993 in the areas of sterilization process in palm oil mill, energy conservation in industries and biofuels. He then joined Proton Berhad as a Design Engineer in Chassis Section, R & D Department. Currently he is lecturing at the Universiti Putra Malaysia. He is a member of the Society of Automotive Engineers, USA. He has published over 50 articles in various international conferences and refereed journals.

FINAL MATERIAL FOR ACCELERATOR, BRAKE AND CLUTCH PEDALS IS ZYTEL70G43LNC-10^	**FINAL MATERIAL FOR MOUNTING BRACKET IS ARNITE. AV2360S**
Material type = glass fibre reinforced polyamide66	Material type = glass fibre reinforced PET
Material supplier = Du Pont De Nemours	Material supplier = DSM
Percentage by volume = 43 %	Percentage by volume = 33 %
Modulus of elasticity = 14200 MPa	Modulus of elasticity = 13000 MPa
Yield stress = 221 MPa	Yield stress = 165 MPa
Good creep resistance	Good creep resistance
Charpy impact strength = 100 kJ/m^2	Charpy impact strength = 40 kJ/m^2
Good corrosion resistance	Good corrosion resistance
Water absorption = 4.7 %	Water absorption = 0.4 %
Manufacturing method = injection moulding	Manufacturing method = injection moulding
Density = 1.49 Mg/m^3	Density = 1.73 Mg/m^3
Material cost = RM 24.12/kg	Material cost = RM 22.8/kg
Direct labour cost = RM 3.00/component	Direct labour cost = RM 3.00/component
High production volume and recyclable	High production volume and recyclable

Fig. 7: Output of data sheet of finally selected materials for pedal box system