Materials Selection Using Knowledge-Based Techniques

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Declaration

All contributions to this work are acknowledged in the text of the thesis and referenced.

SUMMARY

A successful design is one of the most important elements for the commercial success of a product and the selection of appropriate materials is a key step within the product design process. The task is not easy; a large number of interacting factors, both technical and economic, need to be taken into consideration and a vast amount of data investigated.

Product designers can benefit from using computer systems which can emulate the reasoning processes of an expert in selecting materials and provide ready access to appropriate materials data. The knowledge based system developed, Plassel fulfils the key requirements identified for such a system. It can:

1. Emulate the reasoning processes of a plastics expert.
2. Allow a customised data search to be undertaken
3. Access a range of data sources covering both embodiment and detail data.
4. Convert component functional requirements into property requirements.
5. Allow knowledge and experience to be stored in the system
6. Allow cost to be fully considered

Professor Ashby in 1993 [1] stated *"A full expert system for materials selection is decades away. Success has been achieved in specialised highly focused applications"*. Plassel is not such an application, it provides access to a full set of selection facilities. Novel aspects of Plassel include its ability to select on multi-dimensional criteria, automatically 'rate' materials and to conduct customised searches. Professor Ashby concludes with " *It is only a question of time before more fully developed systems become available. They are something to keep informed about.* " Plassel is a *more fully developed* system for plastic materials selection than those currently available.

CHAPTER ONE

INTRODUCTION

Good design is crucial to commercial success, and a key design problem is in choosing the best material to utilise. It is estimated that there are between 40,000 and 80,000 [1] materials to choose from. The need to adequately survey the large number of possible material choices during the design process, places a premium on materials knowledge and experience. "*Material selection is the final, practical decision in the engineering design process and can determine that design's ultimate success or failure*" (James Shackelford [5]).

Computerisation can help by providing easy access to a vast amount of data and the information required to make good selection decisions. The proliferation of computerised materials data banks and selectors demonstrates this. Plastic materials selection is particularly difficult due to rapid development of new plastics, poor definition of their properties and the use of plastics as substitutes for more traditional materials in many industries.

1.1 The Importance of design

What is design? According to the Oxford English dictionary, " *Design is an outline from which something may be made.*" There are other definitions which add some 'flesh' to this, for example that by Crane & Charles [2];
"*Design is a complex process which sets out to specify everything that needs to be known in order that something may be made.*"
and by Dieter [3];
" *To design is to pull together something new or arrange existing things in a new way to satisfy the needs of society.*"

In the United States, it is surprising that, on average only one out of five new products that are put on the market proves to be successful. Bjorksten research laboratories [4] found that only about 5,400 out of 27,000 new products introduced in a given year by American companies proved successful.

Dr. John Bjorksten concluded that the principle reason for failure of new products was a lack of technical expertise related to the product. Major reductions in product cost can be achieved by decreasing the cost of product supply, this includes the costs of design , material , labour, machinery, overheads, etc...... and most often the decisions taken at design dominate the supply cost. According to Whitney [6], at General Motors, " *70% of the cost of manufacturing truck transmissions is determined at the design stage*" , and at Rolls Royce " *design determines 80% of the final production cost of 2000 components*".

1.2 The importance of Materials Selection

A major element within the design activity is the selection of appropriate materials for the proposed product. Crane and Charles [2], state:

"Materials selection should contribute to every part of the whole design process. This is because it is hardly possible to proceed very far with a genuinely innovative design without taking into account all the materials and manufacturing methods that are available for use".

The type of material data required at the different stages of the design process varies in breadth and precision. In the conceptual stage all materials (and options) may be considered though at low levels of data precision. Material requirements are then gradually defined in more detail and subsets of materials are selected and greater data precision is required. Each level of data requires its own data management scheme. Ashby [1] recognises "*the management is the skill: it must recognise the richness of the data and at the* *same time embrace the complex interaction between the material, its shape, the process by which it is given that shape, and the function it is required to perform."*

1.3 Criteria for Material Selection

Materials selection may be initiated when [2] :-

(1) *A new product or component is to be produced for the first time by the organisation.*

(2) *A desire to improve the existing product due to economic reasons or a desire to improve its performance.*

(3) *It is necessary to change material use owing to failure of the component in meeting customer specification, failure of material suppliers, etc.*

Material selection is a complex problem. The final decision is based upon a trade-off between technical and economic factors with full consideration of the interactions of materials, manufacturing processes and component geometry. In essence, the job of the designer is to visualise and understand the operation, use and function of the product in its environment, to translate this to product performance requirements and thence into the combination of materials properties and geometry that would satisfy such requirements. He must also take into account the influence of manufacturing process and shape on those properties and apply appropriate economic constraints. The product designer must understand how these factors fit together, what interactions are possible and what sort of trade-offs can and/or must be made. It is usually impossible for one individual to be thoroughly conversant with all of them. He must collaborate closely with specialists on different aspects of the overall problem. It is also difficult for the designer to handle and analyse such highly unstructured and scattered knowledge. The decision process relies very much on the designer's experience and knowledge. Past experience or heuristic rules of thumb are usually critical in the decision making process.

There are systematic methodologies proposed to ease this process, such as that by Kusy [7], but it is undoubtedly true that persons with knowledge and experience will usually arrive at a good solution more efficiently than those without, even with a methodology. However, previous experience of a similar application is by itself insufficient in the majority of applications. One of the biggest stumbling blocks in conducting a large-scale evaluation of materials and processes is the sheer amount of data that has to be processed. To ensure that all possibilities are considered, it is frequently necessary to evaluate a considerable number of materials and quite often a wide range of engineering properties. The task then, is to assemble all the data, analyse and classify it into useful terms.

Generally information about engineering materials can be divided into two broad categories; data, and knowledge. Data can be defined as the results of property measurements, knowledge represents the connections between items of data and is gained by instruction and experience. A range of sources for materials data and design advice have emerged to aid the designer in the process of evaluation and selection of materials. These range from the ubiquitous large and heavy data books, advisory departments of suppliers, salesmen, independent consultants, trade shows to conferences and not forgetting trade magazines. A survey by P.A Consulting [8] revealed the following usage rates of these sources among designers (figure 1.0).

To help alleviate some of these problems, a range of commercial computerised materials databases and selection packages have been made available.

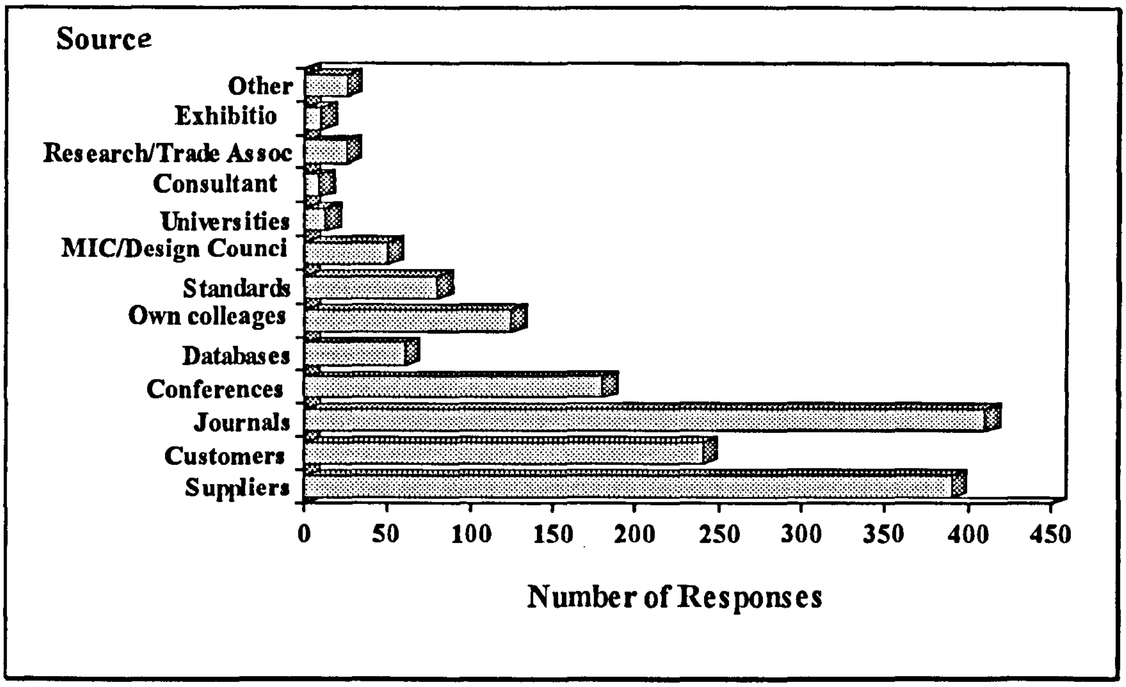

Fig 1.0 : Important Sources of Information on New Materials and Manufacturing Technologies (Adapted from Ref. 8)

With the vast number of available materials, it is likely that designers do not have adequate knowledge or time to evaluate them all in order to select the most appropriate material for their specific applications. Even when sufficient data is available from materials handbooks, materials suppliers or reports, it would be too time consuming to research all the literature for every new application. The problem of applying it still remains intractable unless the designers have assistance. This assistance needs to be "on-line", that is, constantly available.

On-line assistance could be interpreted as telephone support, but it is usually taken to mean computerised support. The storage of materials data in computers has two major theoretical advantages compared with printed matter :

- A greater quantity of data can be stored electronically, and
- Data can be retrieved more readily and transferred to other systems.

In addition, although a book may be revised in a new edition, an electronic data store can be brought up to date almost instantaneously. The increasing access to computers by designers has enabled a tremendous growth in the availability of computerised support. There are currently over one hundred and seventy [9] materials data and selection systems available. They range from simple personal computer based systems detailing the wares of a single supplier, to huge international on-line systems. There is a hierarchy among the systems. Some systems focus on selecting a generic material from the three basic groups, ceramics, metals and polymers, of materials options. Others focus on selection within these basic groups and also within the subsequent generic groups. Of all material classes, plastics (taken in this report to include both polymers and polymer-composites) is the one that has the greatest number of information systems.

1.4 Plastic Material Selection

The volume usage of plastics now comfortably exceeds that of other materials and engineering plastics demand has been continuously increasing for many years. Plastics are very open-ended in potential development, and new ones are being introduced at a rate of 750 per year [9]. The problems of materials selection are particularly acute in the area of plastics. Some of the reasons for this are:

(1) The rate of introduction for new plastics is higher than for other materials [10].

(2) The properties of plastics are less well understood by designers, and standards for property data less well established. Traditional materials education is more focused towards metallic materials.

(3) Plastic properties can be extensively modified by processing and the addition of fillers, and often a custom 'mix' can be created. This however is difficult to cater for when providing reference property data.

(4) Plastics are being applied in traditionally 'metallic' applications, such as vehicle inlet manifolds, and there is a lack of knowledge and experience about plastics in some of these industries.

Edward and Endean [10] provide a good practical example. It illustrates some of the benefits that can be gained by a change of material. The product, a digital multimeter, was made from sections of aluminium sheet formed into simple shapes and held together with aluminium extruded profiles, nuts and bolts, and other mechanical fasteners. The reason for the designers wanting to change was that a polymer would be easier to manufacture and assemble, and be more resistant to damage in use. Through a process of design analysis, the product was changed in order to provide the optimum utilisation of the new material. The resulting design has a reduced number of components and a shortened lead time. As a consequence, the cost of manufacturing of the 'new' product was about 15% of the aluminium version.

These properties and others such as ;

- low density,
- high strength to weight ratio,
- low elastic modulus,
- low thermal and electrical conductivity,
- high chemical and corrosion resistance,
- self lubrication,
- inherent colour,
- high coefficient of thermal expansion,
- low melting point,
- ease of manufacture into complex shapes.

have led to plastics becoming one of the most commonly used materials in our daily life, even though according to Fish [11], " *designing with plastics is often a more complex task than designing with metals. Engineering plastics, which are visco-elastic, do not respond to mechanical stress in the linear, elastic manner for which most designers have developed an intuitive feel. In many applications, engineering plastics exhibits a more complex property mix than do metals*".

Already there are many computerised polymer databases and material selection systems available for designers such as PLASCAMS 220 [12], CAMPUS [13] and EPOS [14] which have been designed to help engineers with the problem of plastic material selection.

1.5 Objectives

The difficulty in materials selection has been illustrated and the importance of knowledge and experience in the selection process introduced. Computerisation is of benefit in the design process to enable designers to access and manipulate the vast amounts data and information they need. Selection of polymer materials causes particular problems. If a system can be designed to cope with polymer material selection, it may be of even greater value for other types of materials. An effective system needs to combine knowledge about how to select plastics with easy access to data about the materials. Many knowledge-based and database systems exist, none, however, tackle the general problem of material selection. Existing systems either tackle aspects of material performance such as Corrosion [15] and provide design guidance, or use simple procedures to search materials data banks. The objectives of this thesis are:

1. Define the requirements for an ideal system for plastic material selection.
2. Describe the development of a knowledge-based system to satisfy them.

The definition of what is an ideal system is very closely linked with identifying and analysing likely users needs and their environment. A system can only be truly 'ideal' for a single (or a few) user(s) since each requirement is unique. This partly explains, why in the past, companies have often developed their own systems. The concept of an ideal system is in contradiction with the authors desire to build a general system, applicable in a wide range of situations and useful for a range of people. It may be better to use the term 'full', rather than 'ideal', though it again could be argued that a 'full' system, rather like an 'ideal' system is impossible to provide for all types of users and applications.

1.6 Thesis structure

In chapter one , some of the problems of material selection have been introduced. The issues raised are particularly relevant to the selection of polymer materials in manufacturing industry. The automobile industry is a good example, a wide range of polymer materials and technologies are being investigated and employed to meet increasing consumer and legislative demands. In chapter two, methods of selecting materials are described and discussed and the types of materials data analysed. Different commercial and experimental materials selection systems are investigated and assessed in chapter three. Knowledge as well as data is critical to good selection and Knowledge based systems techniques are introduced in chapter four with a view towards examining the application. of them to the selection of materials. In chapter five, polymer materials selection requirements are examined to identify the requirements for a material selection system. In chapter six the development of a system to meet the requirements identified, combining knowledge-based and database techniques is described. The system designed is evaluated in chapter seven and the important issues identified are discussed in chapter eight.

CHAPTER TWO

THE MATERIALS SELECTION PROCESS

The thorough evaluation and selection of materials for a specific application is a very difficult task. A number of approaches have been suggested to ease the task, the philosophy and details of which vary tremendously. The materials data available to support selection is also subject to a number of limitations. It is often incomplete, inconsistent or inappropriate.

2.1 Material Selection Approaches

There are two fundamental approaches to the selection of materials, non-systematic and systematic.

2.2.1 The Non-Systematic Approach to Material Selection

The non-systematic approach is based on past knowledge and experience. Although there are many tens of thousands of different materials available [1], the designer if possible, wants to reduce the risk of failure by using materials with whose properties he is thoroughly familiar. He also gets the benefit that heuristic selection can reduce the need for lengthy and detailed analysis, resulting in a shorter time to market. This is the predominant method in industry : "*Much material selection is based upon past experience. What worked before is obviously a solution, but not necessarily the optimum solution.*" (Dieter [2]). Obviously the quality of decisions based upon heuristic experience and knowledge is purely dependent upon the quality of that knowledge. Material selection on a historical basis may be unsatisfactory with the current trends and speed of development of newer and better materials [3]. Due to rapid developments in plastic materials, most materials used in the past have been replaced, frequently by newer, improved ones resulting in better performance and/or lower cost. To provide a fully optimised choice, the designer must also consider new or improved materials. For instance, in the automotive field, the drive to increase energy efficiency through weight reduction is revolutionising material selection [4]. Cooling fans, distributor caps, bumpers and many others are now made of plastic rather than metal. According to the British Plastics federation; " *out of 2730 parts from which a car is assembled, 771 are plastics*". Apart from the motivation for an optimum solution, pressure has also arisen from our entering an era of possible materials shortages and this often makes the selection of materials on a historical basis not viable because the desired materials may no longer be available. Consequently, there is a greater need than ever for material selection on a rational basis.

2.2 The systematic approach to materials selection.

Material selection, like any other aspect of engineering design, is a problem solving process. There is not any absolute procedure for material selection. According to Dieter [5] *"The selection of material on a purely rational basis is far from easy. The problem is not only often made difficult by insufficient or inaccurate property data but is typically one of decision making in the face of multiple constraints without a clear-cut objective function."*
Different companies may have their own approaches to selecting appropriate materials for their products. The steps in the selection process can generally however be divided into the four stages illustrated in figure 2.0:

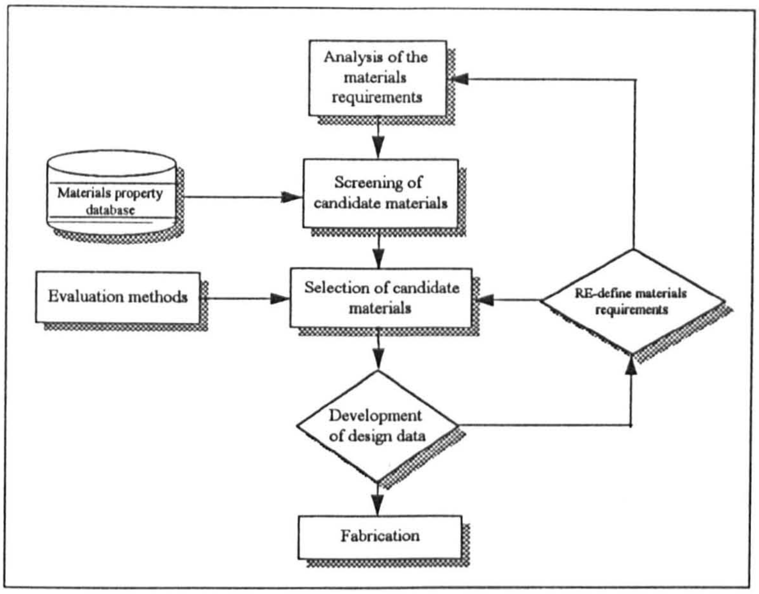

Figure 2.0 : The Material Selection Process

Step 1: Analysis of the materials requirements for the application

A crucial first step in rational material selection is preparing a complete performance specification, which delineates the basic functional requirements of the product and sets out the basic parameters from which the design can be developed [6]. Failure to do so can lead to costly errors. Based on the market needs, the designer is required to determine the demands the part will have to satisfy, with respect to for example, operating condition, appearance, fabrication (e.g.: weldability or machinability), safety aspects, environmental impact (storage and disposal), packaging requirements, ease of maintenance and regulatory requirements, etc.

Once the materials requirements have been fully specified, they can be translated into critical material properties. Usually, the functional requirements or performance of a material are expressed in terms of physical, mechanical, thermal, electrical, chemical, or fabrication properties. However, according to Crane & Charles [7], the material requirements fall into four major areas :

* Functionality

* Appearance

* Manufacturing Method

* Cost

In practice converting the performance specification into engineering terms is not always a straightforward task. For instance;

"if the component is required to pass UL 7J (5 ft * lbf) impact tests at 0°C, then, what is the requirement into terms normally used for evaluating impact strength of plastics, such as Izod impact strength. Since there is no well-defined correlation existing to relate these different impact tests, the designer must rely on engineering experience and intuition." (F. Fish [8])

Step 2: Screening of candidate materials (Preliminary Material Selection)

Subsequent to identification of the required material properties, a screening process is always required in order to narrow the field of choice from the huge number of available materials to a relative few which look promising for the application. This screening process can be done either by accessing computerised data bases, or by searching in material data books. In this stage, all the potential materials that can meet the performance specifications are identified on the basis of screening properties. A screening property is any material property for which an absolute lower (or upper) limit can be established for the application. No trade-off beyond that limit is tolerable. The aim of the screening process is to eliminate some obviously, unsatisfactory materials in order to speed up the selection process. Consequently it is often helpful to perform a first screening using the most restrictive design constraints which are not negotiable. Since environmental, appearance and chemical resistance design constraints are often very restrictive, they are usually used to narrow the list of candidate materials rapidly. Of course this mainly depends on the nature of the product. For instance,

"if a flame class of UL 94 5V is required for the application, the list of candidate materials can then be rapidly narrowed down to the few materials with this very high flame class rating." (F.A. Fish [8])

A Material Selection Chart is a very useful tool in preliminary material selection. On the materials selection chart, as shown in Figure 2.1 [9], primary constraints correspond to a horizontal or vertical line on the diagrams. All materials to one side can be rejected. This can narrow the choice to the materials with the most desirable performance properties which will maximise the performance of the component. Selection can be carried out quickly and simply by firstly specifying the requirements of both strength and temperature on the chart, then viewing the chart to find which balloon is specific for your requirements. However this method can only help the designer to select some appropriate subgroup or generic groups of materials (e.g. Metal, Wood, Plastic, HDPE, PVC, etc.), it cannot find exactly the most appropriate material for your requirements. Consequently, this method is nearly always used only for conceptual design or preliminary materials selection to identify a few candidate materials for the detailed design or optimal materials selection described later.

The qualified materials in the screening process will become the candidate materials for evaluation in the following step.

Step 3: Optimal selection of candidate materials

In this stage, the candidate materials in the shortlist are further evaluated and tested against a broader and more discriminating set of properties including the trade-off between performance, cost, fabricability, and availability in order to select the most appropriate materials for the specific application.

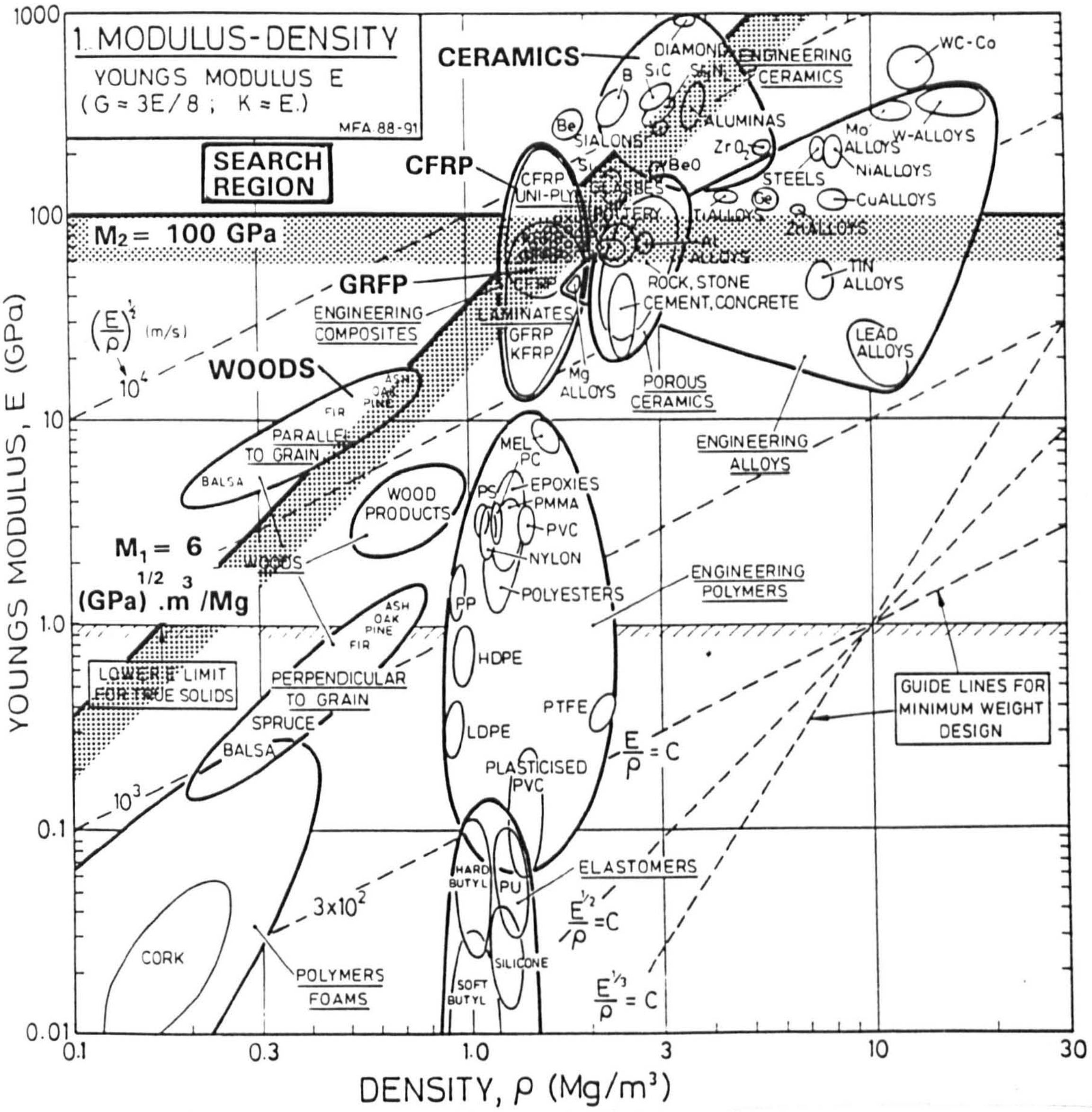

Figure 2.1 Materials Selection Chart (Source : [1])

It is necessary at this point to select a processing method for manufacturing the part, based on material choice, part configuration and economics. There are several evaluation methods, listed below, commonly used in this stage. All of them are discussed in section 2.3.

- * Cost Vs Performance Indices
- * Value Analysis
- * Failure Analysis
- * Benefit-Cost Analysis
- * Weighted Property Indices

Step 4: Prototyping and Verification Tests

Finally and most importantly, before finalising any material selection, testing the component under real or simulated in-service conditions is required. Due to the possible influence of manufacturing processes on critical design properties or inappropriate selection, testing is required in order to verify that the component (with selected material) works properly under specific conditions. Consequently the key material properties for the selected material are determined experimentally through prototypes in order to obtain statistically reliable measures of the material performance under the specific operating conditions. Prototypes can be prepared by a number of different methods. A major goal is to obtain prototypes for testing that are as similar as possible to production parts. The basic trade-off is prototype cost versus the reliability of the data obtained during part testing. Oberholtzer [10] said that *"usually, more expensive prototypes provide less-reliable test data."* If the component cannot fulfil the specific requirements and fails the verification tests, it indicates that the material selection and/or design was faulty. The designer is required to re-consider the materials requirements and repeat the selection process again. Fish [8] concludes;

"The expense of plastics tooling and the uncertainties inherent in plastic part design contribute to the extensive use of prototyping and testing sequences while developing plastics application. Engineering tests are performed on a sufficient number of prototypes to qualify the design."

2.3 Evaluation Methods for Material Selection

The possible complexity of comparisons and trade-offs means that there is no one method that is suitable for all circumstances. According to George Dieter [11] ,*"there is not a well-developed methodology for materials selection. Partly, that is due to the complexity of the comparisons and trade-offs that must be made. Often the properties we are comparing cannot be placed on comparable terms so a clear decision can be made. Partly it is due to the fact that little research and scholarly effort have been devoted to the problem."*

A range of evaluation methods have evolved. In this section some important evaluation methods for material selection are described. They are: Cost Vs Performance Indices, Value Analysis, Failure Analysis, Benefit-Cost Analysis and Weighted Property Indices.

2.3.1 Cost Vs. Performance Indices

It is logical and reasonable to consider cost at the outset of the material selection process. A cost-performance index is used to determine the relative weight (cost) of each material for equal property performance (e.g. equal stiffness or equal strength). This index can be a useful parameter for optimising the material selection but it is not easy to construct meaningful indices of performance for the complex situations found in many designs. Often, the material cost is directly related to the weight (or volume) of material. The determination of cost vs. performance (per property) relationships becomes a question of determining the structural equivalency of different materials. For example suppose polyethylene costs 0.6 £/kg and polyester costs 2 £/kg, what is the cost of a unit strength of these materials to support a load, of lets say 11kN in a bar of 100mm thickness. In developing the cost-performance index for this problem, a mathematical expression is needed to determine the relationship between strength, material cost, and weight. After the cost vs. performance index has been calculated it can be used for optimising the selection of materials.

According to Dieter [3], cost is the most important criterion in materials selection, and is used as a factor in the initial screening process. This seems a limiting view to the author, often the designer is interested in satisfying the performance requirements first, and then cost can be used as a selection criterion among the materials satisfying the performance criterion. Hence it can be important in the final screening process, not the first as suggested by Dieter.

The idea of using indices, not necessarily versus cost, is an important concept in selecting materials and is utilised in several systems such as Ashby's [1] balloon charts (figure 2.1) and as provided by the graph plotting facility in CAMPUS.

2.3.2 Value Analysis

Value analysis applies a rational approach to identifying and reducing unnecessary costs and hence maximising 'value'.

"Value analysis is an organised system of techniques for identifying and removing unnecessary costs without compromising the quality and reliability of the design. The field this technique is usually applied to is much broader than just material selection, but its framework applies admirably to the problem of

material selection." (Dieter [3])

The analysis process can be divided into four main stages:

(1) Defining the functions of the design.

(2) To assess the value of each function

$$\text{value of function} = \frac{\text{importance of function}}{\text{cost of providing function}}$$

(3) Compare value of each function

(4) Identify the unsatisfactory functions and make corrections.

For example, suppose a value analysis is conducted on a electric toaster design. The first step is to define the functions of the product, such as:

(A) Convert electricity to heat

(B) connect to electricity supply

(C) disconnect from supply if element overheats

(D) switch off when the toast is done

In order to assess the value of each function, the following steps need to be performed;

Step 1 - Pair the functions, and make comparisons.

i.e. AB BC CD AC BD AD

Step 2 - Underline the most important member of each pair.

i.e. $\mathrm{A\underline{B}\ \underline{B}C\ C\underline{D}\ \underline{A}C\ \underline{B}D\ \underline{A}D}$

Step 3 - Count the underlined functions and use this as an 'importance' score.

function	importance score
A	2
B	3
C	0
D	1

Step 4 - Construct a table of function against component cost.

Component	Function A	Function B	Function C	Function D
Electronics			85p	150p
Element	15p	5p		
Connector		20p		
Lead		50p		
Wiring		10p	20p	70p
Fasteners		10p	2p	5p
Cost of function	15p	95p	107p	225p
% of total cost	3	22	24	51
Score	1	2	2	4

The score that is given is based on a scale from one for the lowest cost up to a maximum score equal to the number of functions.

Step 5 - Use value function expression to obtain value score.

$$\text{Value of function} = \frac{\text{importance of function}}{\text{cost of providing function}}$$

Function	Importance score	Cost Score	Value score
A	2	1	2
B	3	2	1.5
C	0	2	0
D	1	4	0.25

Having followed the steps, a comparison is made between these functions. Attention is required when the function value score is low

The previous example only illustrates how a value analysis is performed in the design domain. Although this technique can help the designer to decide whether the product made from the selected material is worthwhile or at the lowest cost, it mainly focuses on economic factors and has insufficient consideration on the engineering aspects. In addition considerable skill, knowledge and judgement are required to determine worth in terms of money. One way to determine the worth of a function is to ask yourself "what would be a reasonable amount to pay for the function". The decision-making process is very subjective. Birley, Heath, and Scott [17] state value analysis is usually not incorporated into a systematic approach to materials selection. It is used rather subjectively and employs a decision making technique to define the required functions of a product, especially when a design review on a new product is being conducted or an existing product redesigned.

2.3.3 Failure Analysis

This method is based on predicting and determining the ways in which the product may fail in service, so that materials that are unlikely to fail are selected. Failure analysis is a rational way for selecting materials by identifying the causes of the failure. It determines all of the ways in which the products, or parts similar to a new design, fail in service. Then, with respect to that knowledge, appropriate materials that are unlikely to fail can be selected. Failure analysis commonly requires the combined detective work of various experts who must systematically consider each alternative and any other plausible cause of the failure. It may be very time consuming. In addition, this technique is a systematic approach to the measurement, control and improvement of reliability. So, it is especially useful if reliability is the most important goal of the product, such as in aerospace applications. However, for most general engineering applications, economic factors cannot be overlooked and, so, other methods may be more suitable for material evaluation.

2.3.4 Benefit-Cost Analysis

The process of benefit-cost analysis is based on the following expression [3]

$$\text{Benefit/cost ratio (BCR)} = \frac{\text{Benefits - Disadvantages (to owner)}}{\text{Costs}}$$

Profit is usually the primary goal of an organisation. In the selection of alternative materials for specific applications, although the performance of the component can be improved by using other materials, the profit may be reduced due to increased material costs. In order to deal with this problem, benefit/cost ratio's can be used to help the designer to consider profit in material selection. The ratio relates the capital investment required to produce the desired benefit.

Generally, only the alternatives for which BCR > 1 are acceptable. First, the alternatives are ranked with respect to cost, and the lowest-cost situation is taken as the initial reference. The mechanism of this technique is to compare the reference with the next higher cost alternative by the incremental benefit and the incremental cost. If B/C < 1 for the second, costs will not be covered, and the first alternative is the superior one. This is then compared with alternative three. This evaluation continues until all the alternatives have been considered. The final superior alternative is the best one, though it may not have the largest overall benefit/cost ratio.

2.3.5 Weighted Property Index

In most applications, a selected material is required to satisfy more than one performance requirement. Performance requirements may adversely interact, e.g. cost v stiffness. This means that compromises among different properties are inevitable in materials selection [3]. The designer is required to determine the overall performance of the materials with respect to the various requirements.

The Weighted Property Index (WPI) is a useful systematic method of evaluating the overall combined performance of materials [3,17]. Each material property is assigned a certain weight depending on its importance to the required service performance. WPI_j for the property j is determined by multiplying the scaled property value, S_j (or rating, R_j) by the corresponding weighting factor, W_j. Since different properties have widely different numerical values, each property must be scaled within a range, i.e. 0-100.

Evaluation of material by WPI (Equation 1):

$$WPI_i = \sum_{j=1}^{n} (W_j S_j) \qquad \text{(Equation 1)}$$

where WPI_i = Weighted Property Index for material i

W_j = weighting factor for property j

n = number of material characteristics specified

S_j = Scaled property

= (value of property/max. value in list)*scale

if a high value for the property is desirable

or = (min. value in list/value of property)*scale

if a low value for the property is desirable

For properties that are not readily expressed in numerical values, e.g., weldability, S_j can be replaced by some kind of subjective ratings, R_j.

The higher the material performance index, the more appropriate may be the material for the specific requirements. This weighted property technique is the best tool for choosing between the competing property requirements in a general engineering situation [3]. It can also consider the trade-off of performance and economic factor by considering cost as one of the properties, usually with a high weighting factor. This systematic method of evaluating materials in the selection process is used in one of the best computerised materials database selection systems (Plascams [12]).

2.4 Discussion on material selection approaches

There is no blueprint for correct materials selection. No correct complete set of procedures can be followed. Different situations may require different approaches in selecting materials for specific applications. The approach may depend on market needs, the nature of the product and the nature of the company. However, there are some general points that can be summarised.

* *The material selected must fulfil the performance specification of the product.*

* *Although cost must be a prime adjunct to the technical considerations in selecting materials, materials selection must not be based solely on cost. Quality and reliability are always very important factors.*

* *For the safety reasons, the effects of changes in operating conditions outside the normal limits due to uncertainty should be taken into account.*

* *To select an appropriate material, first screening for a list of possible materials by the most restrictive design constraints and then evaluating the qualified materials by making the trade-offs with cost and processing methods, etc. is common. Finally, several tests or failure analysis are performed to verify the selection.*

* *The correlation between the performance requirements and the material properties must be accurate.*

* *The availability of materials must be considered.*

The different evaluation methods for materials selection have their own advantages and disadvantages. They evaluate materials by focusing on different criteria such as cost and performance in Cost vs. Performance Index, profit and cost in Benefit-Cost Analysis, and overall performance for competing property requirements in Weighted Property Index, etc.. Different situations may require particular methods for optimum effectiveness. For instance, failure analysis is very useful to material selection when a design is modified. Material selection also depends on the overall objectives of the designer or the nature of the product, e.g. cost-oriented or performance-oriented. However, for general engineering situations, overall performance of materials is always of interest and is considered. The weighted property technique is a systematic and appropriate tool for choosing between the competing property requirements. It can take both technical and economic factors into account successfully and directly. In addition, due to its simplicity, this systematic method of evaluating materials in the selection process is very appropriate for computerisation. Obviously the quality and applicability of data used within a selection approach and particularly with computerised materials selection is of critical importance.

2.5 Computerised Material Selection

Computers greatly enhance man's ability to organise and present data. They can have a large storage capacity, and software database systems can provide easy access to available relevant material data. Even so, there is often far too much information for an individual or group of individuals to assimilate. Computers can also assist the assimilation of data. They achieve this by requesting data for a material selection problem, such as the material specification and processing requirements. This data is then processed in relation to corresponding data bank values, either by comparison or calculation, and the user may be presented with an optimal or near optimal solution. If the problem has been clearly defined by the answers to computerised questions , the information received by the user will be 'most' relevant to the problem, and the volume greatly reduced.

2.5.1 Types of Materials Data

A report by the National Materials Advisory board [16] classifies the information in a materials property database according to three categories :

(1) Test Data

A materials suppliers specification data sheet lists the properties of new and enhanced materials determined in standard tests. The processing and interpretation of data is often complicated by the absence of sufficient information to properly characterise materials and the lack of standard format in the presentation. There are a number of testing bodies (ASTM, BSI, DIN etc.)[1] specifying different standards which require test results to be expressed in a variety of units and this further complicates direct numerical comparison between material properties. The validation of data is not straightforward. Due to experimental variability, any quoted datum will probably be a mean value. For a number of different samples taken from a population , a judgement must be made on the statistical significance of any difference in sample parameters.

(2) Variable Data

This data relates to specification requirements, material costs, fabrication costs, maintenance procedures, etc. It may be expressed in numerical form but, since it is not invariant, it must frequently be up-dated as economic conditions, available materials, production processes, etc. change.

(3) Instructive Data

This is data that cannot be reduced to numerical form, such as the conclusions derived from laboratory tests and performance feedback regarding

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[1] ASTM : American Society for Testing and Materials
BSI : British Standards Institution
DIN : German Standards

precautions to be taken in the production, fabrication or application of a given material.

2.6 Ordering of Data

The most simple form of data organisation is an information library providing access to material property data. To further exploit computer capabilities this basic form has progressed to allow the comparison of relevant data and accept or reject materials for presentation to the user. Various 'optimisation' methodologies have been suggested for dealing with the large amount of test and variable quantitative data :

2.6.1 Direct Comparison Approach

This methodology requires a data input of selected ideal material properties, either as single values or a range of acceptable values, for any one property. These are then compared with corresponding databank values for materials known to the computer, and if the databank values are found to match a material is accepted, or if they differ a material is rejected.

Problems arise when the set of material property data for any one material is incomplete, which is frequently the case. Some programs overcome this by including a candidate material only if data supporting its inclusion is available. Others will include a material even if data is unknown.

2.6.2 Combined Weightings Approach

This methodology makes use of 'value judgements'. A value judgement is a number, usually between 0 and 9, corresponding to a quantitative or qualitative material property. As examples : weldability can be a qualitative property, and very poor weldability may be represented by value judgement 1 ; operating temperature is a quantitative property and a high operating temperature of, for example, 290°C may be represented by value judgement 9.

A data input of selected ideal material properties as a single value judgement for each property is required. For each material, ideal value judgements are multiplied by corresponding databank value judgements and the results are added together to give a total value. Total values are ranked in decreasing order, and the materials corresponding to totals near the top of the list are most suitable for the application.

2.6.3 Geometrical Approach

An ideal material for a specific application may be geometrically represented in the form of a regular polygon with various properties plotted along radials from the polygon centre to each vertex. Values for each property are defined as Y1,Y2,.....Yn, which are represented as equal distance radials. A candidate material for the application may then be considered with its respective properties, designated X1,X2,...Xn, plotted along each radial. The suitability of a candidate material is rated according to three factors :

(a) The size of the polygon and its closeness to the ideal.

A 'Mean Weighted Characteristic' (MWC) may be defined as,

$$\mathrm{MWC} = \frac{\sum_{i=1}^{n} \frac{a_i X_i}{Y_i}}{\sum_{i=1}^{n} a_i} \qquad \text{Equation 2}$$

where n is the number of properties and ai is a weighting coefficient arbitrarily chosen from 0 to 1 according to the relative importance of a particular property, zero being unimportant and unity being a critical property.

The computer can rapidly calculate a MWC for all materials supplied to its databank. The closer the MWC is to one, the closer the overall properties meet the requirements, i.e., the polygons are nearly the same size.

(b) The shape of the polygon and its closeness to the ideal.

A 'Balance Factor' (BF) may be defined as a root-mean-square deviation given by,

$$BF = \sqrt{\sum_{i=1}^{n} \left[\frac{Xi}{Yi} - MWC \right]^2} \qquad \text{Equation 3}$$

The closer the BF is to zero, the more nearly in concept is the shape of the candidate material polygon to that desired.

(c) The subjective assessment of the importance of deviations from ideal.

The rating procedure or criteria with regards selecting a material is to choose those having minimum values of the expression,

$$d = \sqrt{(1 - MWC)^2 + (BF)^2} \qquad \text{Equation 4}$$

The previous equation represents a distance 'd' on a plot of MWC versus BF values for various materials. It is possible to rate materials on a MWC-BF plot according to good, fair or poor overall characteristic and according to good or poor balance.

2.6.4 Algebraic Approach

'This approach bases the selection process on minimising the sum of the per unit deviations of the properties of candidate materials from the ideal properties. If the ideal properties are designated Yi and the properties of candidate materials are Xi, then the criterion is expressed algebraically as follows :

$$\text{Min } Z = \sum a_i \left| \frac{X_i}{Y_i} - 1 \right| \qquad \text{Equation 5}$$

where a_i is a subjective weighting coefficient between zero and unity.

If a range of values are acceptable for any one property, then upper, lower and target values must be input to the program. The following constraints are introduced in addition to the above algorithm :

$$\frac{X_i}{Y_i} > 1 \text{ for upper limit on property } i$$

$$\frac{X_i}{Y_i} < 1 \text{ for lower limit on property } i$$

$$\frac{X_i}{Y_i} = 1 \text{ for target property } i$$

2.6.5 Application

Many commercially available databanks, such as Epos, Plascams and Campus, make use of the direct comparison approach to assist materials selection. Plascams also makes use of the combined weightings approach.

There are only two reported applications of the geometric and algebraic approaches being used. A program developed by D.P.Hanley and E.Hobson incorporates both [18]. The Polygon module in PERITUS [20] uses the geometric approach.

2.7 Searching Methods

The choice of search methods crucially affects the user interface. Many so called 'intelligent' material selection programmes (not to be confused with Artificial Intelligence) have been designed and , together with a databank and one or more optimisation methodologies, constitute a material selection package.

'Intelligent' programmes, such as those in the EPOS [14], PLASCAMS [12], MATUS [19], and PERITUS [20] packages, use a combination of searching strategies. (EPOS and PLASCAMS are reviewed in detail in chapter three). Generally, these attempt to mimic the material selection procedure of an expert by a series of question and answer routines, which guide the user into accessing relevant information. A variety of routines are used to adapt the system for use by different people seeking information for different requirements.

2.8 Present Applications

Currently available systems have limitations, which are examined in the discussion in chapter three, and this has restricted their applicability and use. Material selection packages tend to fall into two categories [21]:

(a) Detailed Reviews

These packages review a small number of materials. They tend to be used for the later stages of design and for the development of manufacturing procedures. Their databases are often developed, maintained and used by individual companies, and are specific to their purposes.

(b) Overviews

This second category of databases give overviews of the full range of materials. Their purpose is usually to make engineers aware of the variety of materials available early in the design cycle so that the trade-offs between design configuration and material properties can be optimised.

Epos and Plascams are both examples of packages falling within the second category.

In the back of the minds of most designers is the idea that information is a resource which can be exploited as a commodity by means of the appropriate system. Yet no systems have so far been totally successful. Various explanations for the causes of failure and suggestions to overcome the problems have been put forward. These are summarised briefly in the next section .

2.9 Recent Developments and the Future

There are four main areas for consideration :

2.9.1 The Broader Concept of Materials Selection

Plevy [22] believes that the current approach to material selection is too narrowly-based. The problem of selecting the right material for a given application cannot be solved by reference to optimum required physical properties and a few quantifiable variable properties alone. A material or process can rarely be chosen or changed without regard for the full implications of the action. Less quantifiable factors of a socio-economic nature must be considered. He gives as examples :

(a) Sociological.

A sociological factor, difficult to predict or assess quantitatively, is the response of the workforce to changes of materials and associated processing which may effect their working conditions or the security of their employment.

(b) Socio-economic.

Legislation concerned with, for example, health and safety at work, product liability , environmental pollution and energy conservation has had a significant impact on materials and process selection.

Economic aspects have become more prominent in the intensely competitive climate of recent years, involving not only the cost and availability of competitive materials but also requiring a more detailed study of the associated processing energy and labour charges.

Plevy suggests that a broad methodology is needed that is suitable for the whole range of problems associated with materials and process selection. It must allow for consideration of the wider implications of changing a material and/or process and for new product areas where the overall objectives are not well defined and the means of attaining them is less certain. The starting point should be the origin of the problem. In this, he draws on Gillam's discussion [23] which suggests that for each material or process selection this will be unique. Plevy indicates that the way forward is by application of a 'systems approach'. This approach to problem solving focuses on systems taken as a whole, not on their constituent parts, and is concerned with the 'total-system' performance, (manufacturing - marketing - consuming), even when a change in only one of its areas is contemplated.

The term for this approach is 'holistic '. Holism envisages that all systems - technical, economic, sociological - consist of interrelated sub-systems which can be examined or explained only as a totality, since it is the relationships between the sub-systems that are frequently the factors of paramount importance.

N.Swindells and R.J.Swindells [24] have adopted Plevy's approach but believe that the scope of his concept is too broad to achieve a practical working method. They narrow this down by considering only the requirements for the innovation stage of design. They suggest that the problems of selecting a material for an application at this stage can be overcome by resolving four alternative situations which arise from the interaction between the variables.

These four situations relate to :

* the duty or function required of the component;
* the material properties;
* the manufacturing route; and
* the shape, dimensions and failure mode of the component.

They describe the Peritus system [20] which is designed around this concept . Peritus is currently unavailable, ownership having recently passed from Matsel systems to Elsevier, Amsterdam. It may be that other systems can now better perform the functions in Peritus.

2.9.2 Systems Management

G.Ostberg [25] suggests that the systems failure may be due to :

(a) Lack of understanding of user perspective and requirements.

Information cannot be extracted from the system in a form that is useful. This implies :

(b) Mis-management of information by the system.

He believes that a new approach to system management is called for, possibly through intelligent knowledge-based systems and eventually Artificial Intelligence. He considers the latter to be still in its infancy, an area for research and development, and appreciates that the problems and formulation of solutions is not well understood.

2.9.3 Linking of Packages

With recent trends towards computer integrated manufacture (CIM), the information stored within a material properties databank may have wider application than 'a material selection for design' role. Lockett [26] reviewed the current status of plastics design data. Aspects covered included :

- material property characterisation;
- test method development and simplification;
- standardisation of test methods and data presentation;
- validation of data;
- effects of processing on properties.

He recognises that design information is not composed solely of material data, but also procedures and expertise, and he outlines the necessary components of a computer system taking this into account. This includes a design management package which uses the back-up facilities of other packages for product and materials design procedures, for example lamanal, process and mould design procedures. The latter utilise data from the material properties databank. He suggests that a qualitative information and expertise component may be incorporated via an expert system.

2.9.4 Advances in Computer technology

Tackling the problems of material selection using just database techniques, even relational and object oriented, will only bring limited returns. The combinatorial explosion when trying to evaluate even a limited subset of several hundred materials each of which may have sixty or more properties against dozens of often conflicting criteria places severe demands on conventional computerised approaches. It is clear from the material selection approaches discussed that there are two main requirements for good selection. Knowledge and expertise relating to the product application, relevant properties, and the design and processing of materials *and* access to current, relevant and appropriate materials data. Computers can aid greatly in the storage and presentation of data, but this has to be in a format that is useful to the intended user. Advances in computer hardware and software enable new approaches to tackling some of the problems of material selection. Research in Artificial intelligence has revealed ways of embedding knowledge in computerised systems that enable 'hard' problems to be tackled. One thing that everybody agrees on is *material selection is a hard problem,* for both humans and computers. Many people believe that the application of human knowledge and the storage and processing power of computers are both required for better materials selection.

CHAPTER THREE

COMPUTERISED PLASTIC INFORMATION SYSTEMS

Computerised materials databases and selection systems can help store and process the materials data that is needed to conduct a thorough evaluation of alternative materials. Many commercial systems have been developed to help satisfy this requirement. The majority of these systems have been developed for plastic materials: "*Of all material classes, 'plastics' (..... both polymers and polymer-composites) is the one which has the greatest number of information systems.*" (C. K. Bullough [27]). The reasons for this have been illustrated in the previous two chapters. These systems can be accessed in a number of ways, and are often designed with specific (but differing) objectives in mind. There are various ways of classifying these different systems. Bullough breaks them into two main types, conventional databases (structured as Bibliographic, Full-Text, Factual or Numeric databases) and advanced systems such as Expert systems and Hypertext Interfaces.

3.1 Bibliographic, Full-Text, Factual and Numerical Databases

As its name suggests, bibliographic databases are most commonly used for literature references and abstracts. The information stored in a bibliographic database is exclusively textual and data structure is analogous to a card index file. A search for specific information is performed through the use of search words, which may be truncated, and Boolean operators (viz. "AND", "OR" and "NOT"). Examples of bibliographic databases for materials are METADEX [29] and COMPENDEX. PLUS [36]. Free-text databases are similar to bibliographic databases but the data are less structured or are not abstracted. Typical examples of free-text databases are those that contain newspaper or magazine articles.

Factual and Numerical databases differ from bibliographic databases, in the way that the searches are performed. Instead of sometimes ambiguous search words, searches are based on more specific search criteria. Often, factual and numerical databases allow further analysis on the search results, usually through graphical output or calculations. Factual and numerical databases vary widely in features, while some are sophisticated and hold critically-assessed data, others do not vary from bibliographic databases considerably. One successful example of such a 'simple' database is the Metals Datafile [28], which is closely related to the bibliographic database METADEX [29], and contains materials property data extracted from published sources. A complete list of materials databases identified by C. K. Bullough is shown in figure 3.0 and 3.1.

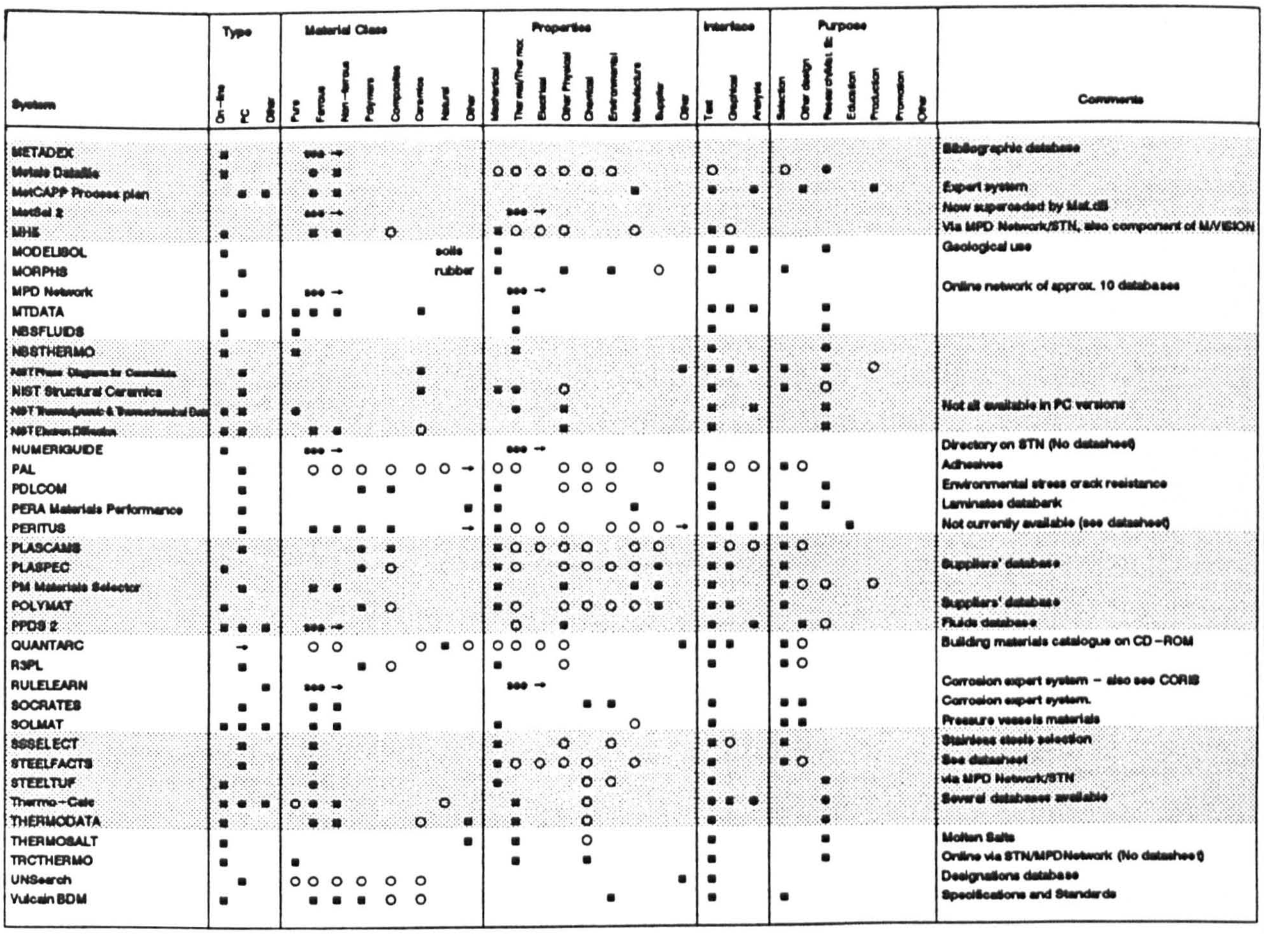
Many factual and numerical materials databases are currently available, the following sections review three widely available numerical databases designed specifically for plastic materials (polymers and polymer composites), they are EPOS, CAMPUS and PLASCAMS. Obviously when reviewing, evaluating or comparing these systems, the criteria used are of crucial significance. The questions addressed by the reviews are:

- What were the objectives in developing the system?
- What does the system do?
- Who is it intended for?
- How successful is the system?
- Good and Bad points?
- The future direction of development?

System	Type			Material Class								Properties									Interface			Purpose							Comments
	On-line	PC	Other	Pure	Ferrous	Non-ferrous	Polymers	Composites	Ceramics	Natural	Other	Mechanical	Thermal/Thermal mec	Electrical	Other Physical	Chemical	Environmental	Manufacture	Supplier	Other	Text	Graphical	Analysis	Selection	Other design	Research/Mat. &	Education	Production	Promotion	Other	
AAASD	■					■						■	○	○	○			○			○			■	○	○					Online via MPD Network and STN
ACDB		■							■				■■■ →																		Few details known, internal use or limited availability.
ACHILLES		■			■	■						○				○	■			○	○				○	■					Expert system
ACTIS		■			■	■				■	■	■			■	■				■	■			■		■					Tribological data
Active Library on Corrosion		→			■	■						○		○	○	■	■			○	■	■		■		■					Hypertext system. Requires CD-ROM.
ADEP	■			■					■				■	○		○					○	○	■			■					
ALFRAC	■					■						■				○					○				○	■					Online via MPD Network and STN
Aluminium-Bronze Alloys		■				■						■	■		○	○		○			■			■					■		
ALUSELECT		■				■						■	■	■		○		○			■			■	○	○			■		
Ann. national des mat'x composites		■						■										○	■		■								■	■	Suppliers databank
BEILSTEIN	■			■							■	○	■	■	○	■				■	■			■						■	Organic chemistry. (via MPD Network and STN)
Brit. Stand. Service on CD-ROM		→		○	○	○	○	○		○	○	○	○	○	○	○		○	○	■	○	■		■■■ →						■	CD-ROM: Semi bibliographic
CAMPUS		■					■	■				■	○		○	○	○	○	■		■	■		■					■		Some 20 suppliers' databases available
CAPS		■					■	■				■	○		○	○	○	○	■		■	■		■					■		
CAPS - WeDaBaS		■			■	■						○	○		○	○		■			■	■		○	■	○		■			Metal processing database
CenBASE		■					■	■				■	○	○	○	○	○	○	■		■			■	○						
CETIM - materiaux	■				■	■	■	○				■		○	■			■			■			■	○						Related to the PC systems below
CETIM - adhesifs		■			○	○	○	?	?	?	■	■	○	○		○		■	■	→	■			■							Adhesives, suppliers database, available 1992.
CETIM - anestra		■						■					■■■ →								■	○	■	○	■						Composites design and analysis databank
CETIM - telemac		■					■	■				■	■	■	○	○			■		■			■	○						
CETIM - siclop		■			■							■	■	■	○						■		○	■	○						Structural steels database
CHEMRES II		■					■	■								■	■				■			■	○						Companion to PLASCAMS
CIS	■				■■■ →											■	■				■									■	Chemistry, toxicology, environmental, safety (issues)
CMS		■		■	○	○	○	○	○	○		■	■	■	○		○		○			■	■	■	○	○	■				
COMAR	■			■	○	○			○	○						■			○		■					○				■	Reference materials
COMETA	■				■	○			■		→	■	○	○	○	○	■	?	?		■		○	○	■	○					Also component data
COMMIT			■		■	■		○	○			■	○	○	○		○	■	○		■		?	■	■	■		■			Rolls-Royce internal database
Compendex plus	■				■■■ →								■■■ →																		Bibliographic database
Copper and Copper Alloys		■				■						■		○		○	○	○			■			■					■		
Copper - Nickel Alloys		■				■						■		○		○	○	○			■			■					■		
CopperSelect		■				■						■		○		○	○	○			■			■					■		Data only – no search software.
CORIS			■		■	■						■				○	■				■	?	?		○	■					Modular corrosion information system
COR.SOR databases		■			■	■										■	■				■	■		■	○	○					
CUTDATA diskette version		■			■	■												■			■				○			■			
Database of Aeromaterials		■			■	■		■				■	○	○	○	○	○				■			■	?						
DIAmond		■			■■■ →								■■■ →								■										Bibliographic, on diamond and similar materials
DIPPR	■	■		■									■		○		○				■		○			■					Online and PC versions available
DOMIS	■				■■■ →																										Directory database
EASEL		■			○	○	○	○	○	○	→	○	○		○	○	○		○		■			■							Adhesives (see PAL)
EDTA - CRPG	■				■■■ →								■■■ →																		Soils database
EI Chem Disc		→			■■■ →								■■■ →																		Bibliographic database: requires CD ROM
EI EEDisc		→			■■■ →								■■■ →																		Bibliographic database: requires CD ROM
EI Energy/ Environme		→			■■■ →								■■■ →																		Bibliographic database: requires CD ROM
EI Page One		→			■■■ →								■■■ →																		Bibliographic database: requires CD ROM
ELBASE		■			■■■ →								■■■ →								■							○			Bibliographic database on metal finishing
EMPD																															
ENSTAL	■				■	■						○					○				■	■	?			■					Not available in the UK
EPOS-90		■					■	■				■	■	■	○	○		○	○		■			■	○			○			
EUROSCAN	■				■■■ →								■■■ →																		Metal materials research database (no datasheet)
ESR System		■			■	○						■			○	○	○				■	■				○		○			
FADAPS	■				■						→	○					○	○			■	■	■		○	■		○			Weldment properties
GMELIN	■			■											○	■					■	○	○			■					Inorganic chemistry
Guide de Choix Engine Plast	■						■					■		○	■	■			■		■			■							On-line via Minitel
HIGHTEMP		■			■	■	■					■	○		○	○	○				■	○		■		○					
HODOC	■			■											■					■	■					■					Organic chemistry
HIMOB	○				■	○						■				○					■	■	■		○	■					
Hydrogen	■				■	■										■	■				■					■					Hydrogen materials interaction
IMMAMAT		■			■	■						■			■				■		■			■							
INFOMAT	■				■■■ →								■■■ →																		Directory of materials databases via Swiss Videotex
INFOS		?			■	■						○						■			■							■			Cutting values
INTERGLAD		→									■	■	■	■	○	○	○		○		○	○		○		○					Glass database on CD-ROM
IPS	■						■	■				■		○	○	○	○		■		■	?	?	■							
IRD			■		■	■						■	○		○	○	○				■	?	?		■						Internal use only, at present
JARDAS	■				■■■ →																										Bibliographic database
M/VISION			■		■	■	■	■	■			■	■	○	○	○	○	○	■	■	■	■	■	■	■	■					7 databases available for UNIX workstations
Magnesium Alloys Database		■				■						■	■		○	○		○			■			■					■		
MARTUF	■				■	■						■				○	■				■			○		■					Toughness of marine alloys.
Mat.DB		■			■	■	■	■	■			■	■			○			○					■		■	○				Modular, approx. 13 databases incl. some free
MATEDS		■				■						■			■			■			■			■			■				Educational system
MATUS	○				■	■	○					■		○	○		○	○	■		○			■				○			

KEY
- ■ Major feature of system
- ○ Minor feature of system
- ? Possible feature of system
- → See notes at right

Figure 3.0 : Summary of Databases (Source [27])



	Type			Material Class								Properties									Interface			Purpose							
System	On-line	PC	Other	Pure	Ferrous	Non-ferrous	Polymers	Composites	Ceramics	Natural	Other	Mechanical	Thermal/Thermo.	Electrical	Other Physical	Chemical	Environmental	Manufacture	Supplier	Other	Text	Graphical	Analysis	Selection	Other design	Research/Mat. dev	Education	Production	Promotion	Other	Comments
METADEX	■				see	→																									Bibliographic database
Metals Datafile	■				■	■						○	○	○	○	○	○				○			○		■					
MetCAPP Process plan		■	■		■	■												■			■		■		■			■			Expert system
MetSel 2					see	→							see	→																	Now superseded by Mat.DB
MHS	■				■	■		○				■	○	○	○			○			■	○									Via MPD Network/STN, also component of M/VISION
MODELISOL	■									soils		■									■	■	■			■					Geological use
MORPHS		■								rubber		■			■		■		○		■			■							
MPD Network	■				see	→							see	→																	Online network of approx. 10 databases
MTDATA		■	■	■	■	■			■				■								■	■	■			■					
NBSFLUIDS	■			■									■								■					■					
NBSTHERMO	■			■									■								■					■					
NIST Phase Diagrams for Ceramists		■							■											■	■	■	■	■		■		○			
NIST Structural Ceramics		■							■			■	■		○						■			■		○					
NIST Thermodynamic & Thermochemical Data	■	■		■									■		■						■		■			■					Not all available in PC versions
NIST Electron Diffraction	■	■			■	■			○						■						■					■					
NUMERIGUIDE	■				see	→							see	→																	Directory on STN (No datasheet)
PAL		■			○	○	○	○	○	○	→	○	○		○	○	○		○		■	○	○	■	○						Adhesives
PDLCOM		■					■	■				■			○	○	○				■					■					Environmental stress crack resistance
PERA Materials Performance		■									■	■						■			■			■		■					Laminates databank
PERITUS		■			■	■	■	■			→	■	○	○	○		○	○	○	→	■	■	■	■			■				Not currently available (see datasheet)
PLASCAMS		■					■	■				■	○	○	○	○		○	○		■	○	○	■	○						
PLASPEC	■						■	○				■	○		○	○	○	○	■		■	■		■							Suppliers' database
PM Materials Selector		■			■	■						■			■			■	■		■			■	○	○		○			
POLYMAT	■						■	○				■	○		○	○	○	○	■		■	■		■							Suppliers' database
PPDS 2	■	■	■		see	→							○		■						■		■		■	○					Fluids database
QUANTARC		→			○	○			○	■	○	○	○	○	○					■	■	■		■	○						Building materials catalogue on CD-ROM
R3PL		■					■	○				■			○						■			■	○						
RULELEARN			■		see	→							see	→																	Corrosion expert system – also see CORIS
SOCRATES		■			■	■										■	■				■			■	■						Corrosion expert system.
SOLMAT	■	■	■		■	■						■						○			■			■	■						Pressure vessels materials
SSSELECT		■			■							■			○		○				■	○		■							Stainless steels selection
STEELFACTS		■			■							■	○	○	○	○		○			■			■	○						See datasheet
STEELTUF	■				■							■				○	○				■					■					via MPD Network/STN
Thermo-Calc	■	■	■	○	■	■				○			■			○					■	■	■			■					Several databases available
THERMODATA	■				■	■			○		■		■			○					■					■					
THERMOSALT	■										■		■			○					■					■					Molten Salts
TRCTHERMO	■			■									■			■					■					■					Online via STN/MPDNetwork (No datasheet)
UNSearch		■		○	○	○	○	○	○											■	■										Designations database
Vulcain BDM	■				■	■	■	○	○								■				■			■							Specifications and Standards

KEY
- ■ Major feature of system
- ○ Minor feature of system
- ? Possible feature of system
- → See notes at right

Figure 3.1 : Summary of Databases (Source [27])

It may not always be possible to establish complete answers for all these questions for all the databases, but these are desirable objectives.

3.2 EPOS (Engineering Plastics On Screen)

EPOS [14] is a rival plastic materials database system to CAMPUS [13], it was developed by Polydata for ICI and LNP Engineering Plastics, and was first launched in 1985. The aim of EPOS is to help engineers evaluate the complimentary product ranges of polymers and compounds provided by ICI and LNP. In presentations they cited the following points to justify EPOS development :

- *The number of polymers and compounds is growing rapidly.*
- *There are an increasing number of applications for quality plastics.*
- *The specifiers influence is strong*
- *Product information flow is becoming more complex.*
- *Manpower is finite and workload infinite*

The ever-increasing flow of information from the large number of polymer suppliers creates a problem for specifiers and processors, who need to compare properties of materials, and their prices, simply and quickly. EPOS is intended to help overcome such difficulties by providing rapid information retrieval; the type of information that can be expected from material suppliers specification sheets.

EPOS is supplied free to potential customers and runs on the same PC set-up as Campus, and in many ways, is very similar to Campus.

3.2.1 Discussion of the system

The facilities offered by EPOS can be explored by using its data retrieval and material selection strategies. This has been undertaken and the overall strategy employed in the system has been deduced and is shown in fig 3.2 and fig 3.3.

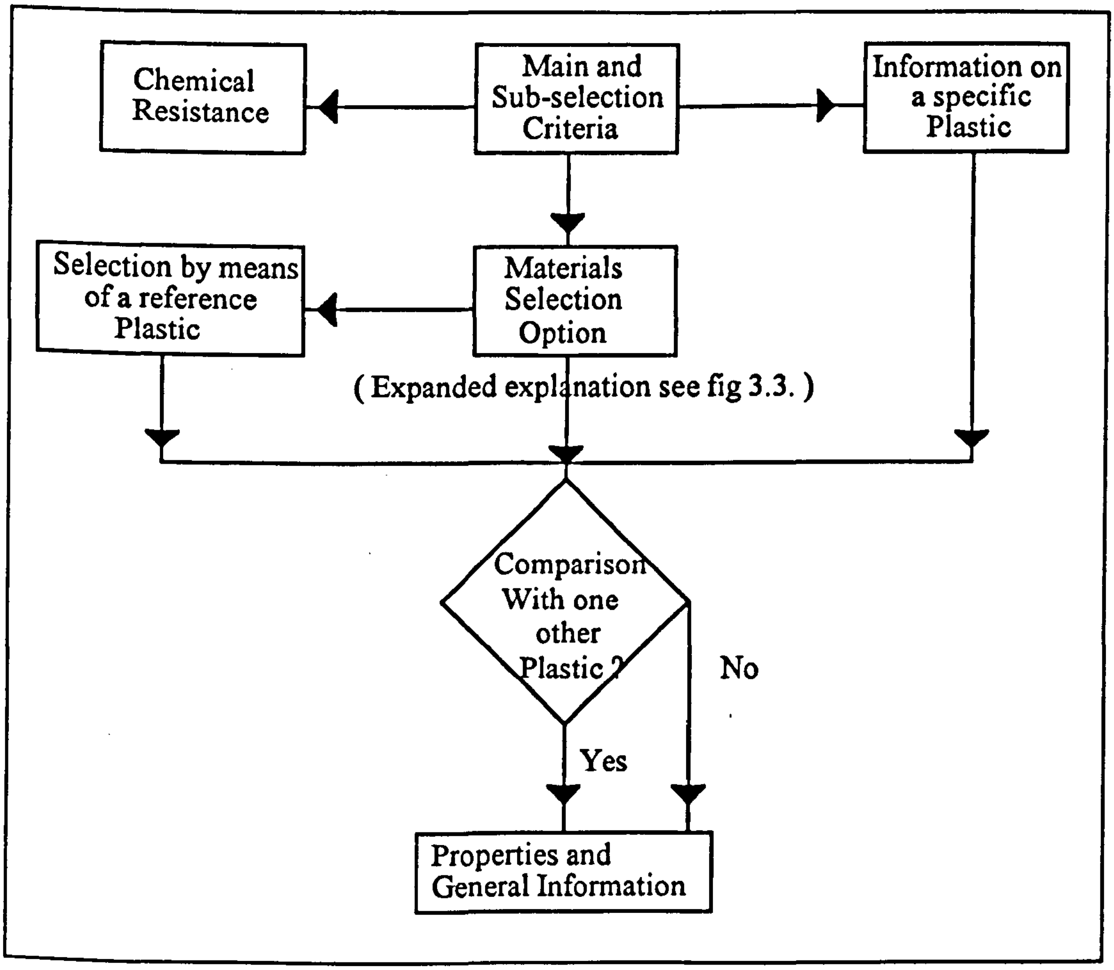


Figure 3.2 : EPOS Selection strategy

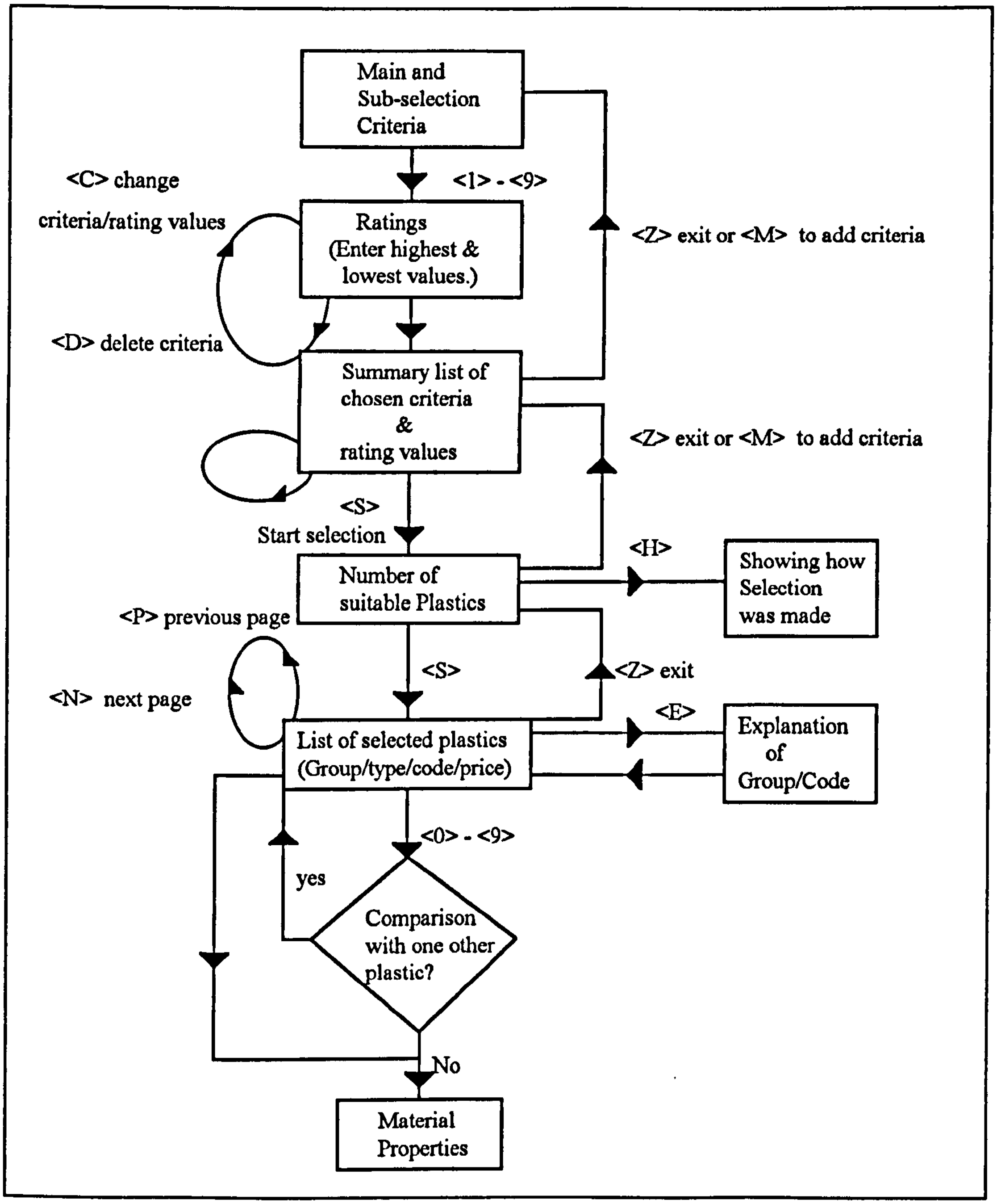
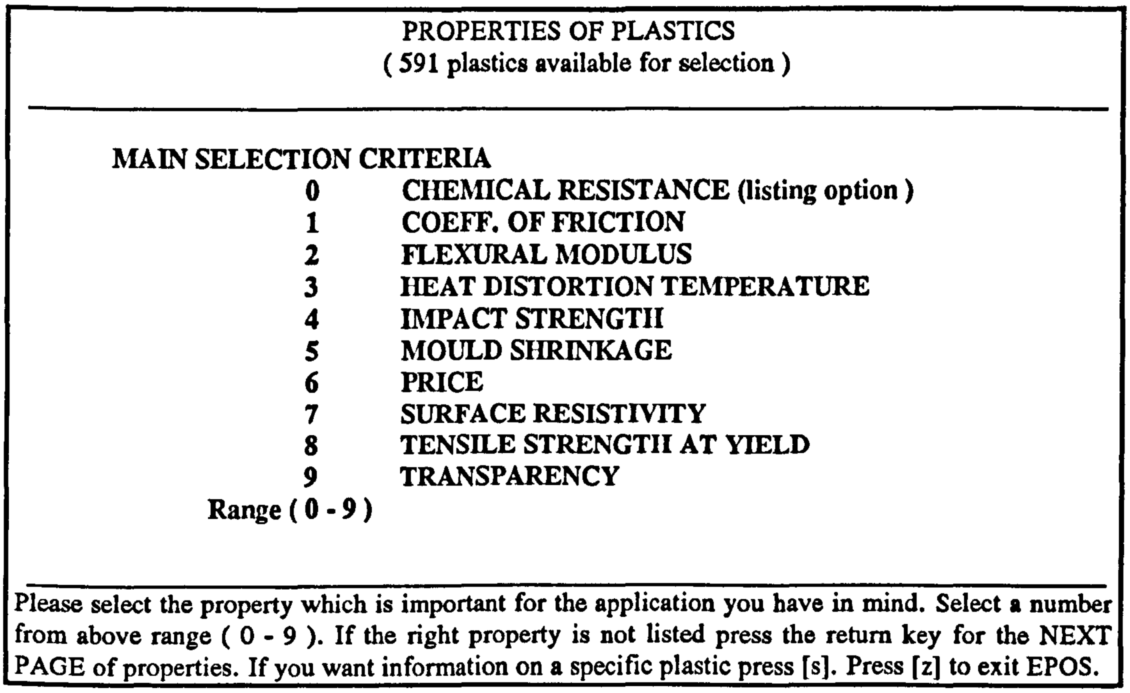


Figure 3.3 : Material Selection option procedure

Each sub strategy is now considered in the order in which it appears in program operation. First are the main and sub-selection criteria.

3.2.1.1 Main and sub-selection criteria

Properties are divided into main and secondary selection criteria. for example, chemical resistance, flexural modulus and transparency are main selection criteria, and density, dielectric constant and hardness are sub-selection criteria. The listings in figure 3.4 and 3.5 show only the searchable properties although others are included later, thus EPOS has predetermined the users requirements and limited choice.



```
                         PROPERTIES OF PLASTICS
                   ( 591 plastics available for selection )
-----------------------------------------------------------------------------

      MAIN SELECTION CRITERIA
                      0       CHEMICAL RESISTANCE (listing option )
                      1       COEFF. OF FRICTION
                      2       FLEXURAL MODULUS
                      3       HEAT DISTORTION TEMPERATURE
                      4       IMPACT STRENGTII
                      5       MOULD SHRINKAGE
                      6       PRICE
                      7       SURFACE RESISTIVITY
                      8       TENSILE STRENGTII AT YIELD
                      9       TRANSPARENCY
             Range ( 0 - 9 )

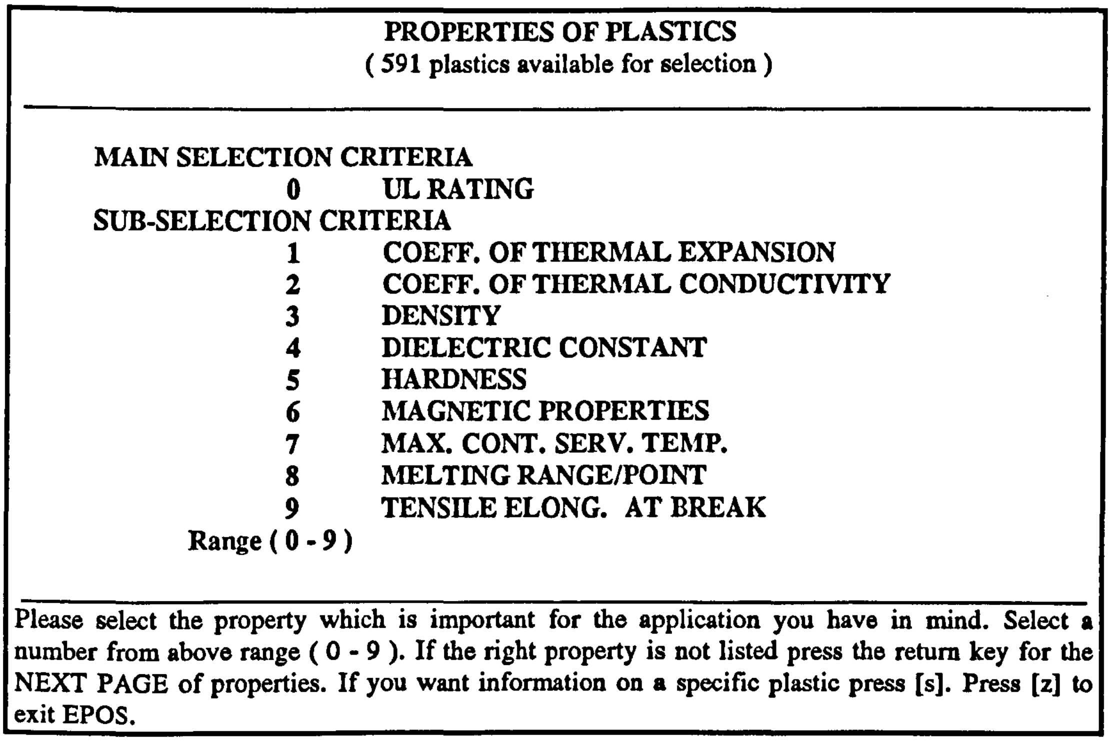
-----------------------------------------------------------------------------
Please select the property which is important for the application you have in mind. Select a number
from above range ( 0 - 9 ). If the right property is not listed press the return key for the NEXT
PAGE of properties. If you want information on a specific plastic press [s]. Press [z] to exit EPOS.
```

Figure 3.4 : EPOS Main Selection Criteria

The division into Main and sub-selection criteria (figure 3.5) is seemingly of no consequence to the way in which data is subsequently treated, apart from chemical resistance which provides a listing option. Whichever properties are considered for material selection (main or sub-selection criteria) the program route is the same. A separate option is 'specific material properties' that can be retrieved from the materials databank, but it is likely that only experienced users can benefit from this.

3.2.1.2 The Materials Selection Option

Once a particular property has been selected, Epos next presents a table of rating values versus a numerical or descriptive range. For example, the table for flexural modulus has a numerical range and the table for transparency has a descriptive range. One advantage of using rating values for properties which must be described, such as transparency, is that they allow such properties to be assessed. However, this means that only experts would be truly conversant with the input of such subjective information.



```
                         PROPERTIES OF PLASTICS
                   ( 591 plastics available for selection )
-----------------------------------------------------------------------
     MAIN SELECTION CRITERIA
                     0      UL RATING
     SUB-SELECTION CRITERIA
                     1      COEFF. OF THERMAL EXPANSION
                     2      COEFF. OF THERMAL CONDUCTIVITY
                     3      DENSITY
                     4      DIELECTRIC CONSTANT
                     5      HARDNESS
                     6      MAGNETIC PROPERTIES
                     7      MAX. CONT. SERV. TEMP.
                     8      MELTING RANGE/POINT
                     9      TENSILE ELONG.  AT BREAK
            Range ( 0 - 9 )
-----------------------------------------------------------------------
Please select the property which is important for the application you have in mind. Select a
number from above range ( 0 - 9 ). If the right property is not listed press the return key for the
NEXT PAGE of properties. If you want information on a specific plastic press [s]. Press [z] to
exit EPOS.
```

Figure 3.5 : EPOS Sub - Selection Criteria

Next, Epos endeavours to select materials by using a direct comparison approach for ordering the data.

3.2.1.3 The Direct Comparison Approach for Ordering Data

Evidence of this approach is obtained by asking Epos to justify a materials selection. The system responds by printing a list of all the materials that it knows, along with their rating values for each selected property. The system requires a direct 'match' between user ranked values and ranked material values in the databank before it will suggest that a material is suitable. The problem with this approach is that the system views each property as equally important to a materials selection problem. In a typical materials selection problem some properties, such as the flexural modulus, will be essential, while others, such as resistance to detergent, can be regarded as 'optional extras' which are of lesser importance. The Epos direct comparison approach allows materials to be chosen on the basis of properties essential to an application, but it does not provide any facility for ranking other materials according to the suitability of their 'optional extras'.

The materials in EPOS have not been assigned a complete set of ranked values, for each searchable property. Epos does not choose a material if information is missing, a consequence of the direct comparison approach. However, this does not mean that such a material is necessarily unsuitable for the application. This means that many potentially suitable materials may be overlooked by the system. It may be better to present these materials which have selection criteria data missing to the user, so that missing information can be acquired from other sources.

As a consequence of the direct comparison approach and lack of information, Epos often fails to find any suitable materials. Selection using more than just a few properties may even terminate the Epos program.

The facility for showing how a materials selection was made is limited to tracing through the system's selection path. This facility produces a mass of data with no explanation and is of limited use.

3.2.1.4 Presentation of Selected Material Data

Table 3.0 illustrate the typical properties available for each material within the Epos system. The choice of units and testing methods appears to be rather unique and does not correspond very well with data available from other sources, such as Plascams or trade catalogues. In addition to the facility for displaying materials properties graphs for particular plastics, EPOS provides "Processing Data" graphs that shows the moulding temperature for some of the plastics stored in the database.

3.2.1.5 Material Selection Example

An understanding of Epos operation can be gained by examining its behaviour on a typical problem. The problem chosen was the selection of a plastic gear for a clock mechanism. A typical outline specification is given.

Specification : Gear for clock mechanism

The critical requirements are injection mouldability, reasonably low shrinkage and good dimensional stability. The material must also be cheap and have a low tendency to warpage. Wear resistance is not particularly important as only very light loads are envisaged. No lubrication is required so there are no chemical resistance considerations.

Selection : Gear for clock mechanism

The first selection screens on Epos are shown in figure 3.4 It can be seen that there is no selection criteria pertaining to injection mouldability. The 'low shrinkage' is obviously related to 'mould shrinkage' and good dimensional stability is assumed to be related to 'coeff. of thermal expansion'. Selection weightings of 0 to 1 (mould shrinkage) and 0 to 2 (thermal expansion) were chosen. It can be appreciated that the weighting choice can be rather arbitrary.

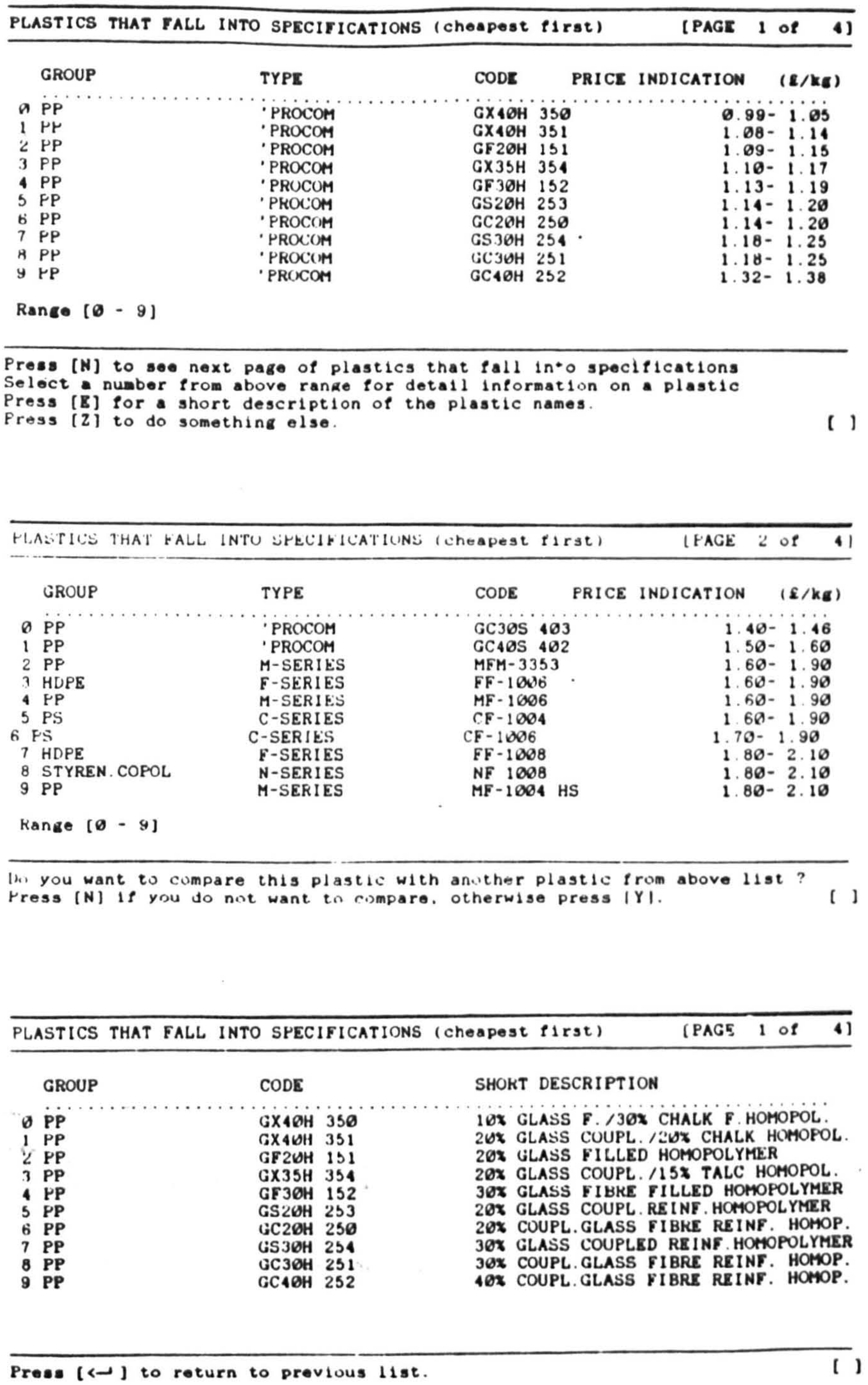
MECHANICAL PROPERTIES	THERMAL PROPERTIES	ELECTRICAL PROPERTIES	OPTICAL PROPERTIES	GENERAL PROPERTIES
Coeff. of friction	Heat distortion temp.	Surface resistivity	Transparency	Moulding shrinkage
Flexural modulus	UL rating	Dielectric constant	Colour	Price
Impact strength	Coeff. of thermal expansion	Volume resistivity	Refractive index	Density
Tensile strength at yield	Coeff. of thermal conductivity	Dielectric strength		Magnetic properties
Tensile elong at break	Max. cont. serv. temp.	Dielectric factor		Water absorption
Wear factor K	Melting range/point	Arc resistence		Share strength
Flexural strength	Vicat softening point	Power factor		
Compressive strength	Processing temp.	Electrical tracking index		
Torsion modulus	Limiting oxygen index	High amp arc ignition		
Hardness	Specific heat Burning rate Glass transition temp. Smoke emission			

Table 3.0 Epos properties

Operation of Epos with these criteria reveals that 212 'suitable' materials exist in the database. This is obviously too large a number to be useful for further detailed investigation.

We could now consider the secondary criteria 'cheapness' and 'warpage'. There is a price main selection criterion but none of the other criteria seem to relate to warpage directly. If price is added to the list of selection criteria with a rating of 0 to 2, then the list of suitable materials is reduced to 32. The 20 cheapest materials with expanded descriptions of the first ten are shown in figure 3.6

At this stage, without an in-depth plastics expertise, we could reduce the ratings range to the most strict criteria. Re-running the system reveals that then no suitable plastics are in the database. If we increase the price criteria to 0 to 1, this gives us 6 potentially suitable plastics. These 6 materials are shown in figure 3.7 along with a mechanical properties comparison between PP (Epos optimum selection) and PS (Plascams favoured material) in figure 3.8. Epos provides no further information after this and directs the system user to liaise with the manufacturer. The selection behaviour of Epos is further examined in the discussion in section 3.5.



```
PLASTICS THAT FALL INTO SPECIFICATIONS (cheapest first)      [PAGE  1 of   4]

 GROUP             TYPE            CODE      PRICE INDICATION    (£/kg)
 .......................................................................
0 PP               'PROCOM         GX40H 350               0.99- 1.05
1 PP               'PROCOM         GX40H 351               1.08- 1.14
2 PP               'PROCOM         GF20H 151               1.09- 1.15
3 PP               'PROCOM         GX35H 354               1.10- 1.17
4 PP               'PROCOM         GF30H 152               1.13- 1.19
5 PP               'PROCOM         GS20H 253               1.14- 1.20
6 PP               'PROCOM         GC20H 250               1.14- 1.20
7 PP               'PROCOM         GS30H 254               1.18- 1.25
8 PP               'PROCOM         GC30H 251               1.18- 1.25
9 PP               'PROCOM         GC40H 252               1.32- 1.38

Range [0 - 9]

Press [N] to see next page of plastics that fall in*o specifications
Select a number from above range for detail information on a plastic
Press [E] for a short description of the plastic names.
Press [Z] to do something else.                                      [ ]
```

```
PLASTICS THAT FALL INTO SPECIFICATIONS (cheapest first)      [PAGE  2 of   4]

 GROUP             TYPE            CODE      PRICE INDICATION    (£/kg)
 .......................................................................
0 PP               'PROCOM         GC30S 403               1.40- 1.46
1 PP               'PROCOM         GC40S 402               1.50- 1.60
2 PP               M-SERIES        MFM-3353                1.60- 1.90
3 HDPE             F-SERIES        FF-1006                 1.60- 1.90
4 PP               M-SERIES        MF-1006                 1.60- 1.90
5 PS               C-SERIES        CF-1004                 1.60- 1.90
6 PS               C-SERIES        CF-1006                 1.70- 1.90
7 HDPE             F-SERIES        FF-1008                 1.80- 2.10
8 STYREN.COPOL     N-SERIES        NF 1008                 1.80- 2.10
9 PP               M-SERIES        MF-1004 HS              1.80- 2.10

Range [0 - 9]

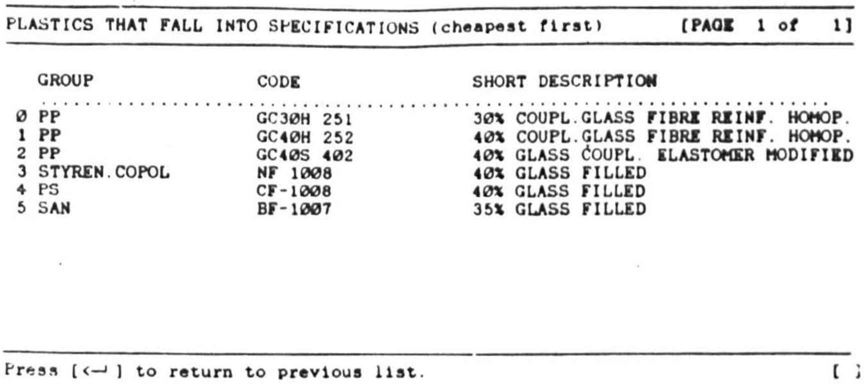
Do you want to compare this plastic with another plastic from above list ?
Press [N] if you do not want to compare, otherwise press [Y].        [ ]
```

```
PLASTICS THAT FALL INTO SPECIFICATIONS (cheapest first)      [PAGE  1 of   4]

 GROUP             CODE            SHORT DESCRIPTION
 .......................................................................
0 PP               GX40H 350       10% GLASS F./30% CHALK F.HOMOPOL.
1 PP               GX40H 351       20% GLASS COUPL./20% CHALK HOMOPOL.
2 PP               GF20H 151       20% GLASS FILLED HOMOPOLYMER
3 PP               GX35H 354       20% GLASS COUPL./15% TALC HOMOPOL.
4 PP               GF30H 152       30% GLASS FIBRE FILLED HOMOPOLYMER
5 PP               GS20H 253       20% GLASS COUPL.REINF.HOMOPOLYMER
6 PP               GC20H 250       20% COUPL.GLASS FIBRE REINF. HOMOP.
7 PP               GS30H 254       30% GLASS COUPLED REINF.HOMOPOLYMER
8 PP               GC30H 251       30% COUPL.GLASS FIBRE REINF. HOMOP.
9 PP               GC40H 252       40% COUPL.GLASS FIBRE REINF. HOMOP.

Press [<-┘] to return to previous list.                              [ ]
```

Figure 3.6 : EPOS suitable materials

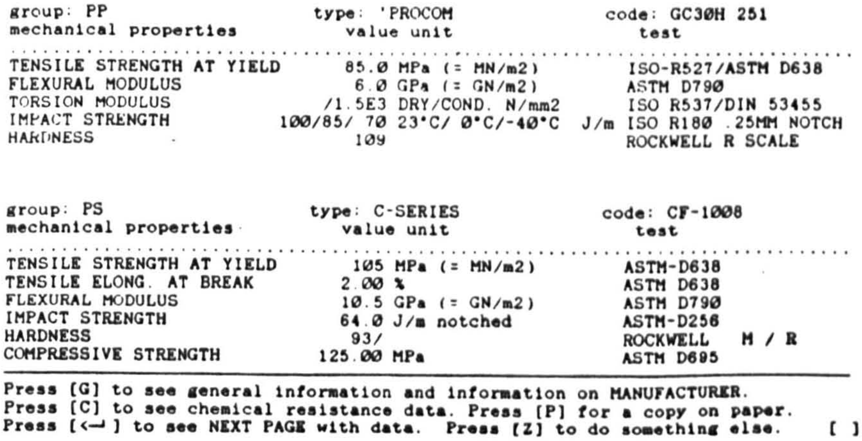


```
PLASTICS THAT FALL INTO SPECIFICATIONS (cheapest first)         [PAGE  1 of   1]

    GROUP                CODE                  SHORT DESCRIPTION
    .............................................................................
  0 PP                   GC30H 251             30% COUPL.GLASS FIBRE REINF. HOMOP.
  1 PP                   GC40H 252             40% COUPL.GLASS FIBRE REINF. HOMOP.
  2 PP                   GC40S 402             40% GLASS COUPL. ELASTOMER MODIFIED
  3 STYREN.COPOL         NF 1008               40% GLASS FILLED
  4 PS                   CF-1008               40% GLASS FILLED
  5 SAN                  BF-1007               35% GLASS FILLED

Press [<—┘] to return to previous list.                                      [ ]
```

Figure 3.7 : EPOS reduced list of suitable materials



```
group: PP                       type: 'PROCOM                code: GC30H 251
mechanical properties             value unit                   test
..................................................................................
TENSILE STRENGTH AT YIELD          85.0 MPa (= MN/m2)           ISO-R527/ASTM D638
FLEXURAL MODULUS                    6.0 GPa (= GN/m2)           ASTM D790
TORSION MODULUS                 /1.5E3 DRY/COND. N/mm2          ISO R537/DIN 53455
IMPACT STRENGTH             100/85/ 70 23°C/ 0°C/-40°C  J/m ISO R180 .25MM NOTCH
HARDNESS                            109                         ROCKWELL R SCALE


group: PS                       type: C-SERIES               code: CF-1008
mechanical properties             value unit                   test
..................................................................................
TENSILE STRENGTH AT YIELD          105 MPa (= MN/m2)            ASTM-D638
TENSILE ELONG. AT BREAK           2.00 %                        ASTM D638
FLEXURAL MODULUS                  10.5 GPa (= GN/m2)            ASTM D790
IMPACT STRENGTH                   64.0 J/m notched              ASTM-D256
HARDNESS                           93/                          ROCKWELL    M / R
COMPRESSIVE STRENGTH            125.00 MPa                      ASTM D695
Press [G] to see general information and information on MANUFACTURER.
Press [C] to see chemical resistance data. Press [P] for a copy on paper.
Press [<—┘] to see NEXT PAGE with data.  Press [Z] to do something else.    [ ]
```

Figure 3.8 : Comparison of the mechanical properties of PP and PS

3.3 CAMPUS

(Computer Aided Material Pre-selection by Uniform Standards)

CAMPUS was developed by a consortium of four German chemicals manufacturers, BASF, Bayer, Hoechst and Hüls. The software was intended to overcome " *the two serious disadvantages of existing solutions* " [30]

* *Some of the existing commercial databases have major deficiencies in relation to updating, accuracy and completeness of the data stored there. Data management appears to be far more difficult in practice than is generally assumed.*

* *The existing databases of the plastics manufacturers have the disadvantage that each only contains information on the products of one manufacturer. Comparison with the products of other manufacturers is made difficult by having to use different operating procedures and by the fact that the selections of characteristic data and test standards vary.*

The software was developed by Polydata Gmbh on behalf of these companies. The first version of CAMPUS was released in 1989; it is now in its second version. CAMPUS is distributed free by the chemicals manufacturers concerned, and serves to publicise the companies and their materials.

The CAMPUS data supplied is from the chemicals companies involved, and is distributed as separate databases on diskettes. CAMPUS appears to have been successful among plastics experts. The success of CAMPUS has created a demand for other plastic materials manufacturers to join the original collection of companies. There are now over twenty companies that provide data for CAMPUS (see table 3.1). CAMPUS runs on a basic PC set-up under MS-DOS, or equivalents operating systems.

Although the software is accompanied by a short instruction booklet, CAMPUS provides minimal on-screen instructions or explanations and is not particularly intuitive to use. However, once the operating procedures are known, it is relatively simple to use. Searches through CAMPUS databases are initiated by selecting the "families" (i.e. trade classes) of plastics to apply the search to, then one or more desired selection criteria can be selected from a total of over sixty materials characteristics (figure 3.9). The materials characteristics used by CAMPUS are based on the table of basic plastics properties drawn up by the standards committee for plastics in DIN (FKN-UA 102.1). Desired properties are marked, or maximum and minimum are assigned to them (Fig 3.9)

COMPANY NAME	ADDRESS
Akzo Plastics BV	Arnhem, Netherlands
Bakelite GmbH	Iserlohn
BASF AG	Ludwigshafen
Bayer AG	Leverkusen
Bergmann GmbH & Co	Gaggenau
Ciba-Geigy Marienberg GmbH	Bensheim
Degussa AG	Hanau
Deutsche Solvay-Werke GmbH	Rheinberg
Dow Vertriebsgesellschaft mbH	Dusseldorf
DSM-Kunststoffen B.V	Geleen, Netherlands
Du Pont De Nemours (Deutschland) GmbH	Bad Homburg v.d.H
Ems-Chemie AG	Zurich, Switzerland
Enimont Deutschland AG	Eschborn, TS
Exxon Chemicals	Machelen, Belgium
General Electric Plastics	Bergen op Zoom, Netherlands
Himont Deutschland GmbH	Eschborn, TS
Hoechst AG	Frankfurt
Huls AG	Mari
Monsanto Europe S.A.	Louvain-La-Neuve, Belgium
Neste Oy chemicals	Kolloo, Finland
Petrochemie Danuba GmbH	Linz, Austria
Rohm GmbH	Darmstadt

Table 3.1 : Alphabetical list of CAMPUS Plastics Data Bank Licensees

The appropriate materials are selected by CAMPUS through a Direct Property Matching technique, this matches the user's inputs of the required properties and corresponding values for material properties stored in the database. The selected materials are then displayed and their properties can also be viewed (Fig 3.10. and 3.11). For some grades, graphs of certain functions are available for the user to examine (Fig 3.12).

As the name suggests, the material property test standards utilised in CAMPUS are claimed to be consistent. However, there is a lack of independent evaluation of the data [27], and data for each material are often incomplete. It seems reasonable to conclude that the popularity of CAMPUS is mainly due to the claimed consistency of data and test standards across a number of manufacturers, the fact that it is supplied free of charge, and that it runs on low specification PC's. It is mainly aimed at the problem of providing accurate, consistent and up-to-date data to experts. The search facilities are limited to direct property matching and as is discussed later this is only of limited value in real life. The software is of limited value to the non-plastics expert. In a questionnaire sent to BAYER AG they confirm the evaluation impressions given above by stating " *The main purpose of CAMPUS is the idea of comparable and informative data. The program itself is not the main subject.* "

3.4 PLASCAMS

(PLAStics : Computer Aided Materials Selector)

The information in Plascams has been obtained from a variety of sources including published data (research reports etc.) and the experience of a team of plastics engineers, technologists and designers from Rapra

Technology Limited and Lucas. Rapra is an independent organisation promoting the use of plastic materials for 'technology's sake'.

Figure 9: Max-Min selection

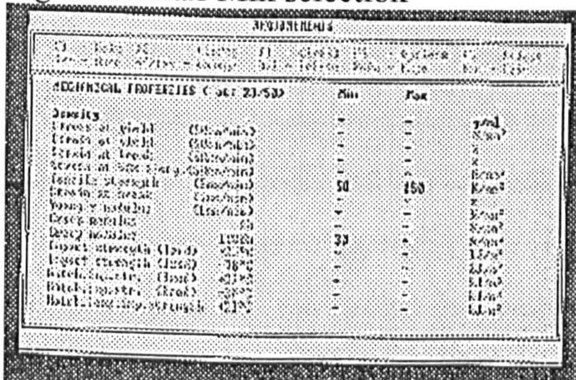
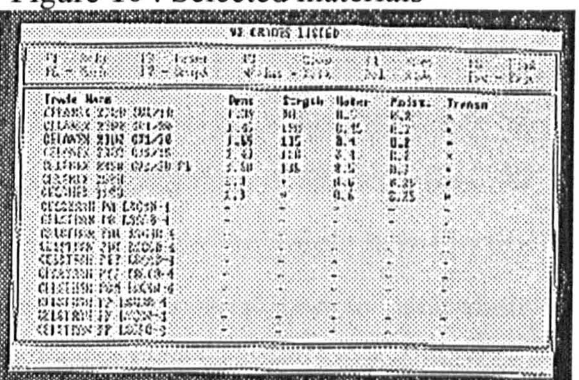


Figure 10 : Selected materials



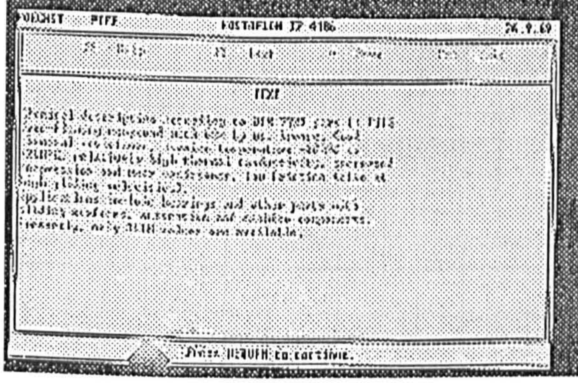


Figure 3.11 : Material text

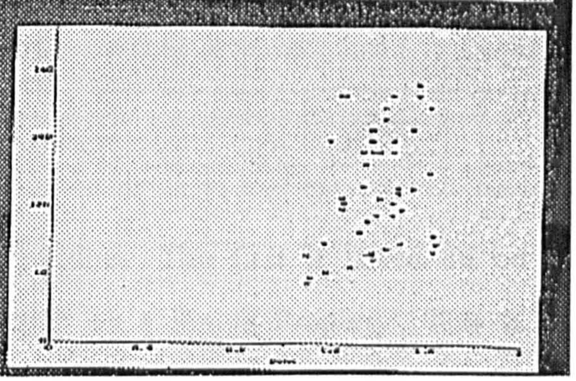


Figure 3.12 : Data Plot

This enables them to give (they claim) an unbiased criticism of plastic materials, whereas suppliers data sheets tend to emphasise the strengths of materials. Due to the service nature of Rapra, data is gathered from many sources against a wide background of experience.

Plascams, currently contains 351 different materials, both thermoplastic and thermosetting. Some 72 properties and processing ranges are contained in the data files on each material. The purpose of Plascams is to provide designers with a tool to help select the most suitable plastic material for a particular application. It is claimed that designers inexperienced with plastics will rapidly gain more knowledge through using Plascams. In addition it is possible to use it as an electronic data retrieval system, as a file of trade names and a trade directory are stored within the system. It is possible to examine the materials data files wherever required and to compare the properties of several different materials.

Plascams has been devised to aid designers and materials specifiers in the selection of a plastic material. The normal output from Plascams is a short list of potentially suitable candidate materials. Typical uses and some typical materials data are included in Plascams to aid confirmation of the selection. At this point it is usual to approach one of the raw material suppliers listed in the commercial index for further information on the material and to seek their advice on the selection of a suitable grade. Plascams contains two modules - Materials Selection and Materials Data.

3.4.1 Materials Selection module

The module contains two search routines. The first is based on an elimination procedure and is termed 'Search on a Single Property'. This is designed to identify materials that satisfy certain essential criteria. For example which materials are capable of operating continuously at 120°C, are fatigue resistant and paintable? In this case three successive elimination searches would be conducted to identify those materials that had all the required qualities.

The second search routine termed 'Search on Combined Weightings' can be viewed as an optimisation procedure. For example, after having generated a short-list of those materials with the essential properties Plascams can rank or order the short-list against other desirable properties, perhaps cheapness or surface finish. This is achieved by the operator entering weighting values to bias the search to meet his requirements. For example surface finish may be more important than cheapness. The data stored in the Plascams system which is accessed in the search routines is in two forms.

Each of the materials contained in Plascams has been assigned a ranked value judgement in the range 0 to 9 for each of the searchable qualities. These judgements have been made by a panel of independent experts in plastics technology and are based on the representation of the quality in that material. For example polypropylene has excellent resistance to fatigue and so has been assigned a value judgement of 9. Polystyrene has poor resistance to fatigue and has a value of 1. If a quality is not represented at all in a material then it is assigned a value judgement of zero. For example, phenolic has a rating of 0 for transparency and PTFE has a rating of 0 for blow mouldability. Where possible the value judgements have been assigned on a decile basis so that approximately 10 per cent of the total number of materials have value judgements of 9 etc., so it is possible to identify, say, the top 30 per cent of materials for a particular quality. For certain qualities in addition to assigning a value judgement, a specific property value has been filed. This is the case for properties such as maximum continuous operating temperature or dielectric constant.

3.4.2 Materials Data module

The module contains texts, data sheets and a list of commercial suppliers. The texts indicate particular strengths and weaknesses of a material together with typical applications. The data sheets cover short term mechanical, electrical and thermal properties plus some processing data and material cost. Commercial suppliers are listed with their trade names, addresses and telex details. A trade name search facility is included. The current system covers 351 materials grouped generically into 84 groups, and includes the major modifications to the basic material such as fibre reinforcement and lubricants. An example for polyamide 6/6 is given in Table 3.6.

Polyamide 6/6 (UV stabilised)
Polyamide 6/6 (fire retardent)
Polyamide 6/6 (high impact)
Polyamide 6/6 (40% mineral filled)
Polyamide 6/6 (33% glass fibre reinforced)
Polyamide 6/6 (40% glass bead filled)
Polyamide 6/6 (glass fibre and bead filled)
Polyamide 6/6 (30% carbon fibre reinforced)
Polyamide 6/6 (molyb. disulphide lubricated)
Polyamide 6/6 (20% PTFE lubricated)
Polyamide 6/6 (super tough)
Polyamide 6/6 (super tough; fire retardant)
Polyamide 6/6 (super tough; 33% glass fibre reinforced)

Table 3.2 : Generic sub grouping for polyamide 6/6

General and electrical properties

• Maximum operating temperature
• Heat distortion temp. @ 1.8 MPa (261 psi)
• Heat distortion temp. @ 0.45 MPa (66 psi)
• Expansion coefficient
• Dielectric strength
• Dissipation factor (50 Hz)
Dissipation factor (1 MHz)
• Dielectric constant
Arc resistance
Tracking resistance

Flame spread
• Oxygen index
• Flammability
Ease of flow
• Shrinkage
Warpage
Surface finish
Transparency
• Volume resistivity
• Specific gravity

Mechanical properties

• Tensile strength
• Toughness @ 20°C (70°F)
Toughness @ -40°C (-40°F)
Brittle temperature
• Flexural modulus
Fatigue index
Surface hardness

Wear
Friction
Dimensional stability
• Elongation at break
• Strain at yield
• Water absorption

Chemical and radiation resistance

Hydrolytic stability
Detergent (20°C/70°F)
Dilute acid (20°C/70°F)
Concentrated acid (20°C/70°F)
Dilute oxidising acid (20°C/70°F)
Concentrated oxidising acid (20°C/70°F)
Aliphatic hydrocarbons (20°C/70°F)
Aromatic hydrocarbons (20°C/70°F)

Halogenated hydrocarbons (20°C/70°F)
Alcohols (20°C/70°F)
Phenol (20°C/70°F)
Ketones (20°C/70°F)
Esters (20°C/70°F)
UV radiation (weathering)
Gamma radiation

Cost factors

Material cost
Volume/unit cost

Flexural modulus/unit cost
Tensile/unit cost

Production methods

Injection moulding
Compression moulding
Transfer moulding
Blow moulding
Rotational moulding
Vacuum forming
Extrusion

Pultrusion
RIM
Structural foam moulding
Casting
Resin injection
Cold press moulding
Contact moulding

Post processing

Bonding
Welding (med. freq.)
Welding (ultrasonic)

Plating
Machining
Painting

Figure 3.13 : Searchable Qualities

A material selection is made on the basis of selecting a quality that is required in the material such as resistance to dilute acid and specifying the level of performance required. Each of the materials has been assigned a value judgement in the range 0 to 9 as described previously.

The searchable qualities included in the system are grouped into six selection sub-menus, the contents of which are shown in figure 3.13 .

3.4.3 Discussion Of The System

Plascams is menu driven so that a novice can easily use the system without extensive consultation of the manual. It allows search on all the properties in any order, so the user can choose the primary and secondary importance criteria. Usually essential properties are covered by single criteria searches and desirable qualities by search on combined weighting. The principle can be seen in operation in section 3.4.4 where a typical search procedure is described..

Plascams retains the previous search criteria list when additional criteria are added and the system re-run. This means that if the additional criteria are not helpful to the selection elimination process, the previous criteria can be easily recovered.

Plascams uses a value judgement system, this means that subjectively qualitative properties such as transparency can be described and compared. Plascams value judgements for the properties of a particular material are agreed by a panel of experts who attempt to place that value in relation to the values of the whole population. Thus the 0 to 9 value judgements for materials and their properties attempts to place each within 10 per cent of the whole population. Hence, if we select a value judgement range 0 to 1 for a particular property we are limiting selection to 20 per cent of the spread of that property across all materials. This approach could run into difficulties when adding new materials to the database.

The end user is not allowed to add materials and information himself. This has the advantage of preventing incorrect information from entering the system. The information already present in Plascams has been studied by a panel of experts and is more likely to be correct than that supplied by an individual. However there is also the disadvantage that as experience in plastics is gained by individuals it cannot be immediately entered into the system, and therefore cannot benefit other end users. This experience may be relevant, in the main, to a particular company involved in the manufacture of a particular type of component or part. They will require some alternative method of documenting their own experience.

The data presented by Plascams is consistent in format and structure. This eases the task of comparison when choosing between different materials on a shortlist. The data presented by Plascams is not design data as such, but is typical of the property data for a particular modification or grade. The quality of data on the system is such that the final choice between the short listed materials still requires a high degree of plastics experience and knowledge. In fact, Rapra recommend that the user at this stage approach the suppliers recommended by Plascams for final decision making.

Critical evaluation of Plascams choice of material for a particular application is difficult to carry out. For instance, which expert is going to argue his view across the whole range of materials present in the Plascams database, when he knows that the data has been agreed by a panel of experts? Is it even reasonable to assume that there are people who are sufficiently 'expert' across the whole range of materials?

The other alternative method of system evaluation would be to choose current applications where the preferred material is known and to see if

Plascams concurs with the choice. There are again problems with this approach because the real reason for use of that material may not be adequately covered by Plascams. For instance the engineer responsible may have been familiar with a particular material or the company may have had particular under-utilised facilities.

3.4.4 Materials Selection Problem

To enable a comparison with Epos the same thermoplastic gear wheel for a clock mechanism specification has been chosen. The search begins with the series search routine 'Search on a Single Property'. Three successive elimination searches are made for injection mouldability, shrinkage and dimensional stability. The top 50 per cent of materials with respect to mouldability and then shrinkage are selected and then the top 30 per cent in terms of dimensional stability. This yields a short list of 36 materials.

Single pass search on injection moulding

Conducted on new (thermoplastics only) materials list of 336 materials
Minimum value : 5
Maximum value : 9

174 materials identified.

Single pass search on shrinkage

Conducted on current (thermoplastics only) short-list of 174 materials
Minimum value : 5
Maximum value : 9

80 materials identified.

Single pass search on dimensional stability

Conducted on current (thermoplastics only) short-list of 80 materials
Minimum value : 7
Maximum value : 9

36 materials identified.

At this stage, materials that satisfy the essential criteria have been identified and these have been presented in a computer file with no discrimination between them. This list of candidate materials is now optimised against certain desirable features. These are, good ease of flow, low tendency to warp, reasonable wear resistance and low cost. Weighting factors are applied according to the relative importance of these qualities.

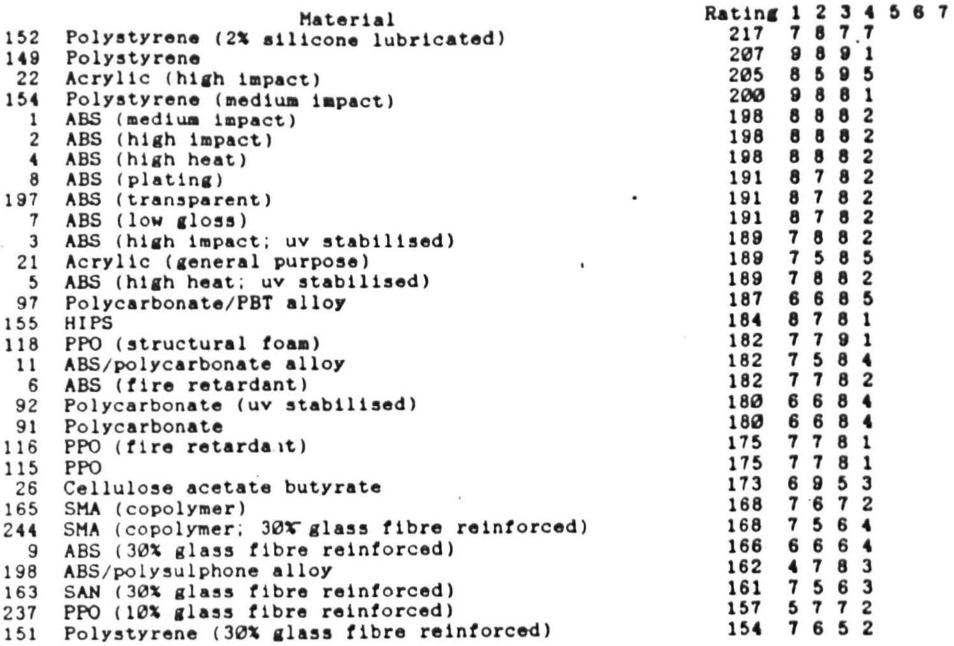
Combined weighting search on current (thermoplastics only) short-list of 36 materials

Qualities and weightings :

1	Volume/unit cost	(9)
2	Ease of flow	(7)
3	Warpage	(7)
4	Wear	(7)

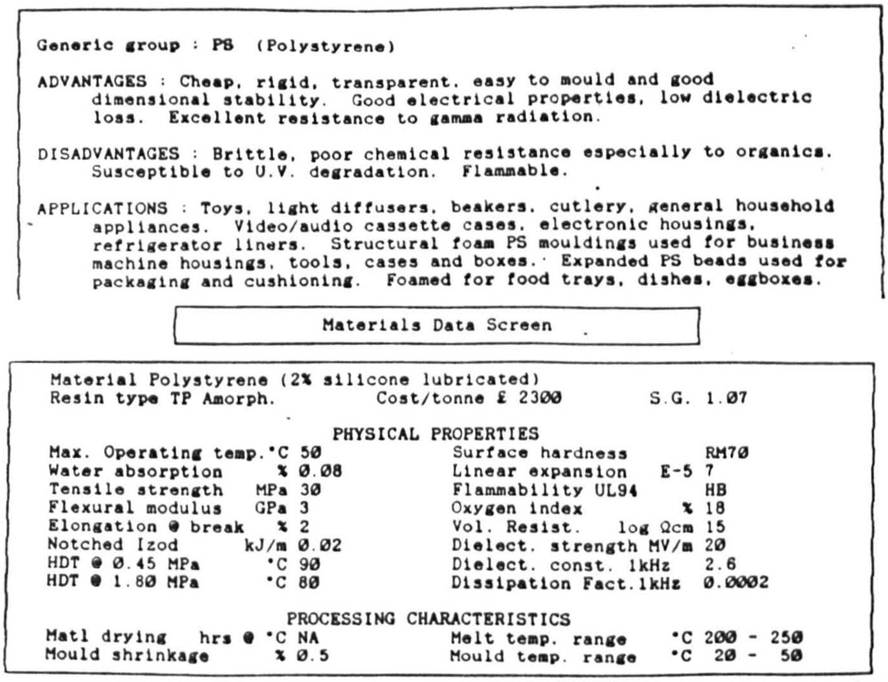
30 materials selected for current short-list.

This short-list, shown in figure 3.14, shows the relative strengths and weaknesses of the materials against the input optimisation specification. The rating factor permits broad comparison between the various materials and is the sum of the products of the weighting factor and value judgements. Examination of the value judgements shows the balance of qualities exhibited by each material. Examination of the texts and data sheets, figure 3.15, for the top generic material confirms that the selection is reasonable. Suppliers suitable for providing this material can be obtained from the materials data module.



```
                       Material                                  Rating 1 2 3 4 5 6 7
152  Polystyrene (2% silicone lubricated)                          217  7 8 7 7
149  Polystyrene                                                   207  9 8 9 1
 22  Acrylic (high impact)                                         205  8 5 9 5
154  Polystyrene (medium impact)                                   200  9 8 8 1
  1  ABS (medium impact)                                           198  8 8 8 2
  2  ABS (high impact)                                             198  8 8 8 2
  4  ABS (high heat)                                               198  8 8 8 2
  8  ABS (plating)                                                 191  8 7 8 2
197  ABS (transparent)                                             191  8 7 8 2
  7  ABS (low gloss)                                               191  8 7 8 2
  3  ABS (high impact; uv stabilised)                              189  7 8 8 2
 21  Acrylic (general purpose)                                     189  7 5 8 5
  5  ABS (high heat; uv stabilised)                                189  7 8 8 2
 97  Polycarbonate/PBT alloy                                       187  6 6 8 5
155  HIPS                                                          184  8 7 8 1
118  PPO (structural foam)                                         182  7 7 9 1
 11  ABS/polycarbonate alloy                                       182  7 5 8 4
  6  ABS (fire retardant)                                          182  7 7 8 2
 92  Polycarbonate (uv stabilised)                                 180  6 6 8 4
 91  Polycarbonate                                                 180  6 6 8 4
116  PPO (fire retardant)                                          175  7 7 8 1
115  PPO                                                           175  7 7 8 1
 26  Cellulose acetate butyrate                                    173  6 9 5 3
165  SMA (copolymer)                                               168  7 6 7 2
244  SMA (copolymer; 30% glass fibre reinforced)                   168  7 5 6 4
  9  ABS (30% glass fibre reinforced)                              166  6 6 6 4
198  ABS/polysulphone alloy                                        162  4 7 8 3
163  SAN (30% glass fibre reinforced)                              161  7 5 6 3
237  PPO (10% glass fibre reinforced)                              157  5 7 7 2
151  Polystyrene (30% glass fibre reinforced)                      154  7 6 5 2
```

Figure 3.14 : Plascams final shortlist



```
Generic group : PS  (Polystyrene)

ADVANTAGES : Cheap, rigid, transparent, easy to mould and good
     dimensional stability.  Good electrical properties, low dielectric
     loss.  Excellent resistance to gamma radiation.

DISADVANTAGES : Brittle, poor chemical resistance especially to organics.
     Susceptible to U.V. degradation.  Flammable.

APPLICATIONS : Toys, light diffusers, beakers, cutlery, general household
     appliances.  Video/audio cassette cases, electronic housings,
     refrigerator liners.  Structural foam PS mouldings used for business
     machine housings, tools, cases and boxes.  Expanded PS beads used for
     packaging and cushioning.  Foamed for food trays, dishes, eggboxes.
```

```
                         Materials Data Screen
```

```
Material Polystyrene (2% silicone lubricated)
Resin type TP Amorph.          Cost/tonne £ 2300          S.G. 1.07

                        PHYSICAL PROPERTIES
Max. Operating temp.°C 50            Surface hardness         RM70
Water absorption     % 0.08          Linear expansion    E-5  7
Tensile strength   MPa 30            Flammability UL94        HB
Flexural modulus   GPa 3             Oxygen index           % 18
Elongation @ break   % 2             Vol. Resist.   log Ωcm   15
Notched Izod      kJ/m 0.02          Dielect. strength MV/m   20
HDT @ 0.45 MPa      °C 90            Dielect. const. 1kHz     2.6
HDT @ 1.80 MPa      °C 80            Dissipation Fact.1kHz    0.0002

                     PROCESSING CHARACTERISTICS
Matl drying   hrs @ °C NA            Melt temp. range      °C 200 - 250
Mould shrinkage      % 0.5           Mould temp. range     °C  20 -  50
```

Figure 3.15 : Plascams text and data sheets for PS

3.5 Comparison Of The Material Selection Packages

When making comparisons between Epos, Campus and Plascams, it is important to remember that they have fundamentally different origins. Epos and Campus are available free to suitable applicants and are basically a marketing exercise for the companies who collaborated in their production.. Thus Epos only contains data on the product ranges of ICI and LNP. This limitation is to an extent overcome because ICI provide a very wide range of materials and the two companies have (they claim) complimentary product ranges. The structure of Campus data is more rigidly defined and a growing number of companies are contributing data to the system (currently twenty, see table 3.1). Each company provides a diskette of its own data, structured to defined standard, that can be accessed by the system. Direct comparison by the system of the products of the different companies is difficult because only one company database can be loaded at a time. There is little or no central co-ordination and people have expressed fears about the overall quality of the data. Nevertheless the claimed consistency and quality has attracted a large (and growing) user base. Plascams has been developed as a package for commercial sale by an independent research and advisory association (RAPRA) and as such escapes some of the criticism of bias directed at Epos and Campus. It also means though that users expect a much higher level of performance from Plascams.

One of the major limitations with Epos is that having selected a few appropriate materials, selection between those materials is almost impossible from the materials data provided by Epos. The user can ask Epos to compare materials but there is no consistency of units and test standards between the comparison data presented. Plascams and Campus are much superior in this respect because all comparison data is uniform. That is, the same properties are tested to the same standards. Unfortunately not all Campus contributors have completed re-testing, and missing data occasionally occurs.

The materials in the Epos data module only represent some thirty two generic groups of plastics whereas Plascams covers approximately sixty four generic groups. Hence the choice of a suitable plastic for an unusual application is more probable with Plascams. Campus with its growing list of data suppliers possibly provides the widest choice of them all, though of the Campus databases the author has seen (BASF, BAYER) the choice is of particular grades. With Plascams generic groups are identified and it is recommended that particular grades are discussed with supplier salespeople. This also leads us to make the point that as many new materials are constantly being developed all systems need regular updates to their materials database to stay competitive. It seems to be a surprising omission that the systems do not allow the user to add his/her own materials to the database and hence keep it up to date, or customise the system to their own particular requirements. The reason for this maybe the desire by the suppliers to prevent corrupt or incorrect data being entered on the system, and in particular with Plascams, the value judgements are assessed by a panel of experts and any independent additions may not conform to those values. Plascams does offer a customisation option which lets the user store data about their own particular applications at extra cost.

Overall the Plascams system is more systematic, more extensive and easier to use. For instance with Plascams the user can make alterations to the selection criteria, observe the effects, and if unsatisfactory go back to the previous criteria. With Epos and Campus the selection procedure has to be partially repeated and the original criteria remembered.

The systems use completely different material assessment methods. Plascams relies on value judgements provided by its panel of experts who compare a material against the whole range of appropriate materials. Hence the value judgements represent a percentile population, thus for instance it is possible to identify, say, the top 30% of materials for a particular quality. This also means that the ratings are relatively difficult to modify as additional materials are introduced. Campus and Epos rank materials by relating to the specific property values and not relative relationships. This makes it potentially difficult to cater for materials where the properties can be altered by fillers or other additives and hence it would be difficult to incorporate such materials adequately in a property value ranking. Both Campus and Epos (to a lesser extent) tackle this problem by providing graphing facilities for plotting material characteristics. Interpretation can then be used to select an appropriate level of filler, for instance.

All the systems allow search on a single property but Plascams also allows search on combined weightings. Single property search is required for essential material properties but combined weighting is required to give adequate consideration to desirable properties. It is essential when completing a material specification to correctly identify essential and desirable properties for the subsequent materials search. Plascams features a greater list of search properties than Epos, for instance consideration of production and post processing methods is often essential but Epos and Campus does not cater for them.

All the systems run on the same type of computer hardware and operating system. The IBM PC/XT/AT 80286 upwards or compatibles running under MSDOS used for the systems under consideration are probably the de-facto standard for industry. With a hard disk they have ample memory and processing capability for material selection type applications.

In summary it can be said that Campus, Epos and Plascams represent a tremendous advance over the traditional data catalogue and suppliers specification sheets. However they are not the same, Clive Maier of British Plastics and Rubber [31] thinks *Plascams is a selection system, a materials textbook and a supplier directory rolled into one, and is complementary to Campus* (and Epos) *rather than in opposition. Indeed, it would make a lot of sense to use Campus as a grade specifier after running Plascams as a material type selector.* They do not however eliminate the need to discuss the potential application with the applications engineers of a suitable supplier identified by the systems, because they still require a knowledge of material properties and their relationship to product design and manufacturing processing. Ideally such knowledge should be embedded within the selection system. One of the most promising ways of overcoming such drawbacks is to make use of some of the recent advances in artificial intelligence research, namely the development of practical knowledge-based systems.

3.6 Knowledge-based Systems and Hypertext/Hypermedia systems

Though many systems, including those discussed above claim to be "intelligent" or "expert" they are technically not. It can be seen that conventional systems, although easily manageable by the experienced user, are not always totally suitable to the varied requirements that a company may have for its materials databases. In particular the importance of knowledge rather than data or even information, in the selection process must not be underestimated. Expert systems are one of the practical products of the research into artificial intelligence and are an attempt to represent "Knowledge" rather than "Information" and are usually composed of a set of rules, rather than data. The rules may be generated from the knowledge held by human experts, or from a database of examples or case studies. Expert systems have been shown to be a useful tool in aiding the understanding of complex or sparse datasets (e.g. remote satellite sensing). In the field of materials, there are a number of expert systems concerned with corrosion. There are many more systems concerned with selection and an interesting system is PAL (Permabond Adhesive Locator)[32]. A module in this adhesives selection database, called P-Stress provides 'knowledge' about the design of joints which can be used to guide the selection process. However, Bullough [27] says " *P-Stress is not a design tool - but is intended to give an insight into the design of joints.* "

A hypertext interface is one in which links are embedded between related data, facts or information. The user can navigate his way through the data and information via these links. The information gathering or learning process is greatly simplified and eased by the "pointers". An example of a hypertext materials information system is the "Active Library on Corrosion" produced by Elsevier/NACE [33].

A "Hypermedia" interface allows the user to view associated images (still and motion) and to hear sounds in addition to the text and graphics of Hypertext.

3.7 Knowledge-based Systems

The term expert system (ES) is often used inter-changeably with knowledge-based system (KBS) though in fact an ES is a subset of KBS. It is obvious from the examination of the existing commercial material selection systems that expertise or knowledge is still very important in using these systems correctly to obtain good, reliable answers. Plascams does contain knowledge embedded in its materials ratings, however it does not utilise Expert system techniques in its structure or operation. There is very little evidence of the commercial availability of full Expert systems that allow or guide users through an intelligent materials selection procedure. These systems need to contain knowledge, for example, about how to convert a product specification into an appropriate material specification, or on selecting appropriate manufacturing processes etc. The author has supervised a number of MSc projects relating to building expert systems for plastic material selection and these are examined in the next section. An introduction to Knowledge-based systems is provided first.

CHAPTER FOUR

KNOWLEDGE-BASED SYSTEMS

Knowledge and experience are powerful tools when tackling complex problems. An overview of knowledge-based systems to provide an understanding of the approach and some background to its evolution follows. This is provided because it is anticipated that the majority of readers will be design or materials oriented. Three demonstration systems for plastic material selection using knowledge-based techniques are described. These systems were developed by students under the authors supervision, and were designed to explore particular aspects of the problem of plastic materials selection.

4.1 The Origins of Knowledge-based Systems

Knowledge-based Systems (KBS), often called Expert Systems in the past, are a practical outcome of research in the field of Artificial Intelligence (AI). Artificial Intelligence was defined by Barr and Feigenbaum [35] as "*... the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behaviour - understanding language, learning, reasoning, solving problems, and so on.*" However, since AI spans many disciplines (including mathematics, computer science, and psychology), there are many varying definitions of AI.

Although the idea of intelligent machines has existed for centuries and fraudulent attempt have been made to create such machines such as Wolfgang von Kempelen's chess playing automation in the 18th century, it was not until the arrival of the computer that real achievements to make machines appear intelligent were a reality. The first major success in creating artificial intelligent behaviour in a computer was the General Problem Solver (GPS) program written by Newell, Shaw and Simon in 1957, which could solve puzzles and classic AI problems such as the Tower of Hanoi. The GPS solved these problems through the use of a number of mathematical techniques, but it was found that the GPS was only successful at solving problems in a limited number of areas. It was believed that more problems could be solved if more mathematical techniques were added to the program. However, this was not proved true. *Domain-independent* problem solving programs like GPS were too ambitious for the current state of knowledge about how the brain operates and the available hardware and software inadequate. Some success was obtained by reducing the overall scope of the problem by limiting the domain of interest.

The first *domain-dependant* problem solving program, DENDRAL (DENDRitic ALgorithm), which identified the structure of unknown organic compounds from their mass spectra, used not only algorithms but also heuristics (or rules of thumb) like human experts. DENDRAL was very successful at its task and led to a change in AI research to concentrate on domain-dependent rather than domain-independent problem solving programs. Some years later Professor Feigenbaum christened this change of direction the 'paradigm shift in AI', the paradigm shift from power-based techniques to knowledge-based ones. [37]

A knowledge-based system (or expert system) was described by the British Computer Society as *"... the embodiment within a computer of a knowledge-based component, from an expert skill, in such a form that the system can offer intelligent advice or take an intelligent decision about a processing function. A desirable additional characteristic, which many would consider fundamental, is the capability of the system, on demand, to justify its own line of reasoning in a manner directly intelligible to the inquirer. The* *style adopted to attain these characteristics is rule-based programming."* (N. Bryant [38].

4.2 Characteristics of Knowledge-based Systems

A knowledge-based system has a set of characteristics that distinguishes it from traditional computer applications [38]:-

4.2.1 Single purpose in a specific area of knowledge

A knowledge-based system relates to one particular area of expertise or knowledge rather than a set of data. Knowledge-based systems are domain-dependent. Each knowledge-based system has a single purpose, e.g. perform materials selection.

4.2.2 Contains rules

The knowledge in a knowledge-based system will usually be in the form of rules. Human knowledge is often considered to be a collection of heuristics or rules. There are other ways of encoding human knowledge in computer systems, but rules have proved to be the most popular.

4.2.3 Knowledge and inference are separate

The knowledge and inference mechanism are separate entities, unlike conventional programs. The inference mechanism (inference engine) may be applied to different knowledge-bases. For example the process of doing medical diagnosis is very similar to diagnosis of faults on a motor car, it is the data that varies.

4.2.4 Knowledge is extensible

The knowledge in a knowledge-based system can be extended if required. Hence, knowledge may be added gradually without a complete rewrite of the knowledge-base. Related knowledge bases may also be combined to construct a large system.

4.2.5 Capable of handling uncertainty

As with human reasoning, a knowledge-based system should cope with incomplete or uncertain information.

4.2.6 Provides advice

As the aim of knowledge-based systems is to emulate human expertise, they are constructed to provides advice rather than absolute answers.

Since a knowledge-based system is designed to provide advice, often to non-experts, it should provide a help facility to explain its reasoning.

While a traditional program can be seen to consist of algorithms and data, a knowledge-based system can be seen to consist of knowledge and inference. The differences are summarised in table 4.0.

Conventional Programs	**Knowledge-based Programs**
Representation and use of data	Representation and use of knowledge
Integration of knowledge and control	Separation of knowledge and control
Algorithmic processing	Inferential Processing
Manipulation of large databases	Manipulation of knowledge-bases
Run-time explanation impossible	Run-time explanation is a characteristic

Table 4.0 : Conventional vs. Knowledge-based Programs

(Source : C.L. Dym [44])

4.3 Advantages and Limitations of using Knowledge-based Systems

According to N. Bryant [38], the advantages of using knowledge-based systems over humans include:

(1) Once captured, the knowledge is permanent and will not fade with age, it can be retained within an organisation even when the expert is lost.

(2) It is easy to transfer the knowledge to any number of users provided they have a computer.

4.2.4 Knowledge is extendible

(3) The knowledge-base system would be consistent in application and the possibility of human error is reduced.

(4) Knowledge-based systems can reduce the dependence on human experts, who are in high demand and are expensive. Hence, encapsulating their knowledge in a knowledge-based system enables it be used at any time, and is affordable, due to the relatively low cost of the hardware and software required.

The advantages of knowledge-based systems noted by Bryant [38] are confirmed by A. Goodall [39], who states that knowledge-based systems can:-

(1) Increase profitability through increased output and productivity.

(2) Increase reliability because they do not become tired or bored, and do not overlook possible solutions.

(3) Handle large volumes of data and respond more rapidly.

(4) Perform previously un-programmable tasks.

The following examples of real knowledge-based system applications provide an illustration of Goodall's remarks.

(1) The *XCON* knowledge-based system, developed by DEC to configure their VAX computers enabled the company to increase the throughput of VAX orders fourfold. The XCON system takes a customer's order for a VAX machine, which specify some of the components required. XCON first checks that the list is reasonable and then selects the rest of the components. It then designs the spatial layout of the components and the cable layout in the computer's cabinets. XCON reduced the error rate on orders from 35% to around 2%.

(2) An example of saving money on equipment is the use of DENDRAL. DENDRAL uses its knowledge of chemical structure to enumerate all possible molecules that fit a given mass-spectrum. A human expert will not normally perform this time consuming task, instead he uses details shown in high-resolution spectra to eliminate possible structures. DENDRAL does not require these details and can use information provided by cheaper, lower-resolution mass spectrometers.

(3) An example where conventional programming failed and knowledge-based systems succeeded is the XCON knowledge-base system. DEC had tried to write a conventional program to configure its computers before XCON was written, but had failed. ICL's equivalent system, Dragon, which configured their 2900 series computers took around six man-months to develop. It was estimated that with conventional methods, it would have taken greater than four man-years to write. Also, it would have been more difficult to update its knowledge.

However, knowledge-based systems also have their limitations. Some of these limitations are as follows:-

(1) Knowledge-based systems are limited by the experts they represent, and by the representation techniques available.

(2) Knowledge acquisition is recognised as the main obstacle in developing knowledge-based systems. It is difficult to extract expertise from human experts, it is often difficult for experts to explain their reasoning, they often provide examples rather than formalised rules. Also, different experts may have different approaches to solving problems. As well as the difficulties in interpreting the experts' knowledge, there is often difficulty in obtaining an expert's time, since they are a rare resource. The expert may also be reluctant to "give away his expertise and be replaced by a computer".

(3) It may not be sufficient to extract knowledge from a single source and several experts may be required. This makes the knowledge acquisition process more difficult, not only are the problems in (2) magnified but also the task of combining the knowledge is difficult.

(4) Knowledge stored in a knowledge-base may become out of date, in time. The knowledge base requires management.

4.4 Applications of Knowledge-based Systems

The applications of knowledge-based systems are diverse, ranging from Law to the Military. Due to the suitability of knowledge-based systems for diagnostic work, there are many knowledge-based systems written for the medical field. One of the earliest and most famous is MYCIN, which contains knowledge about bacterial infections and the relevant treatments, ICI's Wheat COUNSELLOR diagnoses plant infections and suggests treatments with fungicides [41].

Knowledge-based systems have been used for planning and scheduling. TWA's GATES system helps controllers at JFK Airport in assigning gates to arriving and departing flights. PLANPOWER, a system for financial planning, provides plans for investment, insurance, and asset acquisition or disposal [41]. The use of knowledge-based systems written by legal advisors to interpret legislation is an increasing area of application for KBS's [41]. Many Employment Law advisors have been developed to advice employees on their rights. Knowledge-based systems have been applied as teaching aids. Examples include MECHO, a system that trains students to solve physics problems, and ExperTAX, which helps junior auditors in learning about tax planning [41].

4.5 Knowledge-based System Structure

Although different knowledge-based systems have different designs and specific structures, all knowledge-based systems can be considered to consists of four fundamental components shown in Figure : 4.0: (1) Knowledge base, (2) knowledge acquisition, (3) inference engine; and (4) user interface.

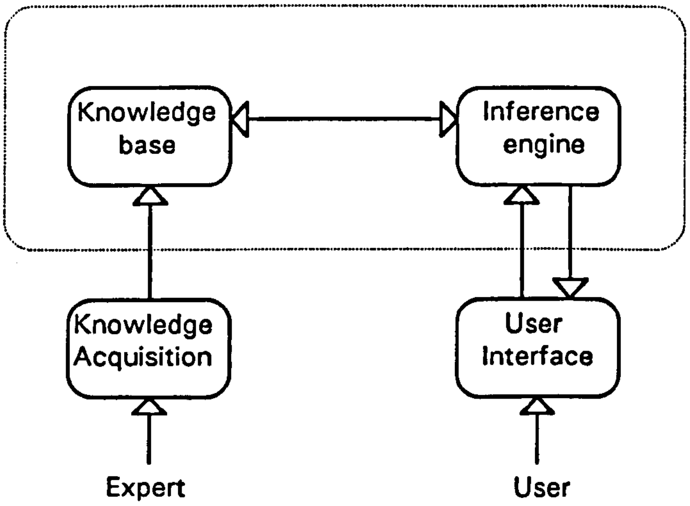


Figure 4.0 : Knowledge-based system structure

4.5.1 Knowledge base

The knowledge base is the information store for expert knowledge and heuristic rules. It is not a passive collection of records in a database. The information in the knowledge base can be stored in one of several knowledge-representation forms. The task of constructing the knowledge base is often performed by the *knowledge engineer*. The knowledge engineer must decide on the most appropriate knowledge representation scheme for the knowledge domain concerned. The dominant forms of knowledge representation are: Production rules, semantic nets, frames and logic.

4.5.1.1 Production rules

Production rules have been in use in formal grammar and in the design of programming languages before they was introduced to psychological modelling and to knowledge-based systems (Buchanan and Feigenbaum, 1978 [41]). In knowledge-base usage, production rules are sometimes called "condition-action rules", since they are in the form of "IF..(condition)..THEN..(action)" statements. Knowledge-base systems that use production rules are often called "production systems" or "rule-based systems" and are popular due to their simple structure, and their resemblance to natural human reasoning [42].

4.5.1.2 Semantic nets

As its name suggests, semantic nets were originally used in interpreting natural language expressions. Semantic nets consists of nodes representing objects or concepts, which are linked by arcs that represent the relationship between the nodes.

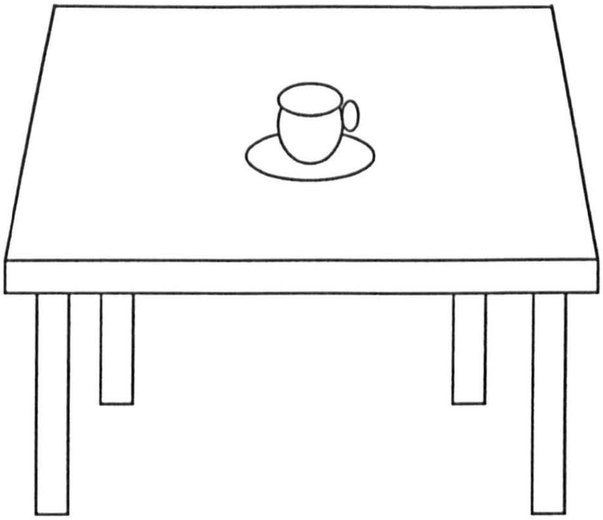


Figure 4.1 : Structured description

Fig. 4.2 is a semantic net that describes the situation in Fig. 4.1. Semantic nets were popular in the seventies, but experience suggests that the net tends to become unmanageable as the number of links grow because inheritance is not included in the representation, i.e. the properties of all the objects must by defined explicitly [41].

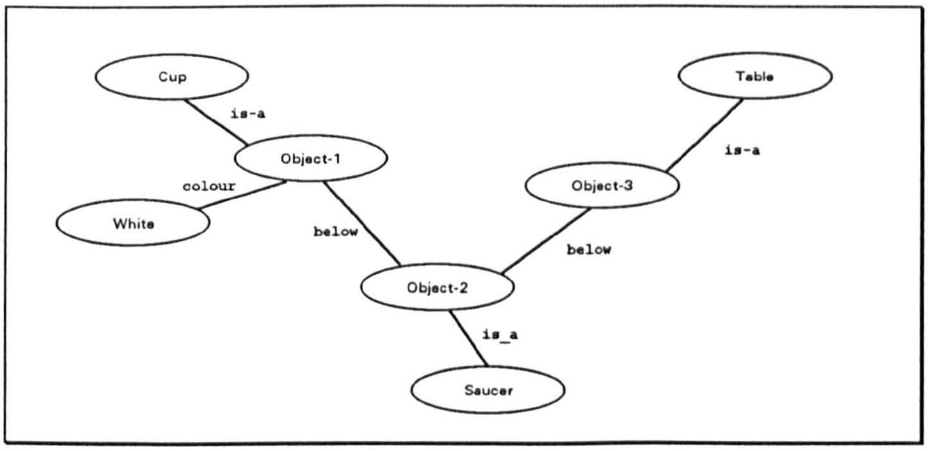


Figure 4.2 : Schema for Fig. 4.1

4.5.1.3 Frames

The frames representation of knowledge uses a hierarchical structure to describe objects or events, this allows the property of inheritance. Each frame inherits the characteristics of all related frames at the higher levels. Each frame consists of two elements: slots and fillers (fig. 4.3).

Slot 1	Filler 1
Slot 2	Filler 2
Slot 3	Filler 3
....	....
Slot n	Filler n

Figure 4.3: Frame structure

Each slot is a set of attributes that describes the object or event, and the corresponding filler can be value, pointers to objects or events, or even rules (fig. 4.4).

Object-1	
IS-A:	Cup
ABOVE:	Object-2
COLOUR:	White
Object-2	
IS-A:	Saucer
ABOVE:	Object-3
Object-1	
IS-A:	Table

Figure 4.4: Frame representation

4.5.1.4 Logic

Propositional logic is a method of applying inference rules that transform expressions containing statements (propositions) linked by one or more connectives into new expressions. Hence given two related facts, a third fact may be deduced, e.g. if the propositions "A carnivore eats meat" and "A dog is carnivore" are true then we can deduce with logic that "A dog eats meat".

4.5.2 Knowledge Acquisition

Knowledge acquisition was defined by Buchanan et el.[41] as *"the transfer and transformation of potential problem-solving expertise from some knowledge source to a program"*. This process is often performed by a knowledge engineer. The steps involved in knowledge acquisition are [37]:

(1) The elicitation of information from several sources (experts, books, documents, etc.),
(2) organisation of the information,
(3) encoding of the relevant information into the knowledge base;
(4) verification and adjustment of the knowledge base.

Knowledge acquisition is the most crucial and as explained in section 4.3, the most difficult part of developing a knowledge-based system.

4.5.3 Inference Engine

The inference engine provides the reasoning mechanism for the knowledge-based system. According to P.S. Sell [37], the functions of the inference engine are: *"to determine what data it needs to solve the problem at hand, to get this data via the support software, to lodge it in the database, to* *employ the contents of the knowledge base to draw inferences, and to record these as well in the database. It exercises these functions repeatedly, until it can do, or need do, no more."* The inference engine operates on the rules provided by the knowledge base to prove or disprove facts. The inferencing (or reasoning) with these rule can be performed by processing the rules in different sequences. The two most important inferencing methods are forward and backward chaining.

4.5.3.1 Forward chaining

Forward chaining is used to reason from facts forwards to form conclusions. Forward chaining is a "data-driven" process. For example, provided with a set of conditions, A and B, and rules 1 and 2, a conclusion E may be reached, given that:-

Rule 1 = If A and B then C
Rule 2 = If C then E

4.5.3.2 Backward chaining

Backward chaining involves the identification of a hypothesis (or goal) and then the attempt to prove or disprove this hypothesis through the verification of the existence of the prerequisite states. Backward chaining is a "goal-driven" process. It starts with a goal to be proved as true or false. The inference engine then searches for a rule with the specified goal as the conclusion. The conditions for this conclusion are verified for to satisfy the conclusion. If the rule fails, another rule with the same conclusion will be searched and checked in the same way. This process continues until the rule is satisfied or all possible rules with the requisite conclusion are verified. For example, provided with a set of conditions A and B, and rules 1 and 2, a conclusion E may be reached, given that:-

Rule 1 = E, if C
Rule 2 = C, if A and B

For problems where there are a few known possible outcomes, backward chaining will be a more efficient inferencing method than forward chaining. However, forward chaining is more appropriate if the number of possible outcomes are large or unknown. According to N. Bryant [38], most knowledge-based systems are for diagnostic or advisory applications and tend to use backward chaining. This is because the possible outcomes are known. However, many systems combine both forward and backwards chaining in inferencing.

Forward and backward chaining are not the only methods of inferencing. For dealing with uncertainty, Bayesian statistics, fuzzy set theory, and Dempster-Shafer theory of evidence [44] are more appropriate approaches. However, it is recognised that there is no single superior inferencing method that exists for all applications.

4.5.4 User Interface

The user interface is the link between the knowledge-based system user and the knowledge base. At the user interface, information is exchanged between the user and the computer system: Through the user interface, the relevant questions are asked by the system, the answers to these questions are given by the user, the solutions and explanations are provided by the system. The design of the user interface is an important consideration in the development of a knowledge-based system. The user interface design will influence the usage and effectiveness of the system.

The wording of questions is a main concern in producing the user interface. It is desirable to use a natural language interface, because it creates a user-friendly environment. However, natural language is often ambiguous and care in the phrasing questions must be heeded. According to P.S. Sell [37], in knowledge-based systems *"there is far more opportunity than in other systems to introduce ambiguities in the questions put to the user and a greater risk for the user to misunderstand what is asked of him, to answer the wrong question, or to answer the right one but incorrectly."*

In developing a user interface, the ergonomic aspects of the interface should be considered. An attractive ergonomic design not only encourages the use of the knowledge-based system but also reduces the health problems caused by prolonged use of computer software. In January 1993, the Health and Safety Commission's European Directive came into force, which provided regulations regarding the use of computer in the work-place, this included the design of screens to reduce eye strain for prolonged periods of work.

4.6 Knowledge-based Systems for Plastic Materials Selection

The skilled performance of a task is a function of the knowledge and experience applied to the task. Whenever tackling a new or difficult task, it is desirable to have an expert close at hand to give guidance and advice. Knowledge-based systems enable knowledge to be close at hand via a computer system. As discussed in chapter two, plastic materials selection is often a difficult task that requires consideration of many conflicting factors and an extensive knowledge and understanding of plastic materials. The selection process usually relies on experts applying heuristic rules of thumb based upon their experience and knowledge.

It is the ability of knowledge-based systems to apply heuristics and to work with incomplete data that makes knowledge-based systems more suitable for problem solving that requires expertise, than conventional programs. Many of the benefits of using knowledge-based systems described in section 4.3 explain why they are profitable tools for tackling plastic materials selection. The question that may be asked then is "why are there no KBS based materials selectors available in the market?" Three main reasons may be suggested, firstly the tools, techniques and understanding for delivering such systems have only recently become available. For example, within this project compare the operation of the first generation of materials selectors built using tools such as MicroExpert and ESP Advisor with the second generation using Leonardo and Crystal (described in section 4.8). Secondly, it is suggested by experts that KBS systems are most suited to problems that utilise narrow, well defined domains of knowledge. Materials selection requires quite a broad understanding of customer requirements, design techniques, economics, future trends, manufacturing processes and materials properties as well as the interactions between these factors. It is very difficult to predict in advance all the considerations a particular user may have. In fact it could be argued that no <u>one</u> human expert is capable of being skilled in all these areas. Thirdly, actually understanding how an expert goes about the process of material selection is extremely difficult. Experts are often unable to articulate fully the process by which they solve complex problems. Often their idiosyncratic approach can only be selectively applied to particular types of problem, whereas for computer-based systems a more general and systematic approach is required.

4.7 Knowledge-based System Development Tools

Knowledge-based systems have been developed using a range of software development tools. These tools may be divided in three groups: Computer languages, Toolkits or Environments; and Shells.

4.7.1 Computer languages

Knowledge-based systems have been written in AI programming languages, such as PROLOG or LISP, and conventional high level languages, such as FORTRAN, PASCAL, and C. (M. Jackson [27]).

AI languages are more appropriate for developing knowledge-based systems, over conventional programming languages. AI languages were designed for symbolic processing, i.e. for programming logical problems that requires knowledge, whereas conventional programming languages are more suited to algorithmic processing and repetitive tasks. However, when conventional languages have been used to develop knowledge-based systems they were, because AI languages require more memory (E. Turban [45]) and were slower in execution, unless run on expensive dedicated hardware eg. "LISP machines".

4.7.2 Toolkits or Environments

Toolkits provide the programmer facilities to develop powerful and complex systems. Initially these toolkits were only available for large or dedicated AI computers. Toolkits tends to be much more expensive than conventional programming languages and expert system shells. The advantage of toolkits is that they include a variety of knowledge representation and inferencing techniques. However, to use toolkits effectively, often requires the programmer to be proficient in symbolic programming and knowledge engineering.

4.7.3 Shells

Expert system shells are software that provide the basic framework to build knowledge-based systems (expert systems) applications. An expert system shell will consist of some form of knowledge representation scheme and an inference engine. In addition, expert systems shells often provide facilities for producing user interfaces.

There are several advantages in using expert system shells. Firstly, the knowledge-based system developer can concentrate on knowledge acquisition and also develop applications relatively quickly since the framework for the system is already provided. Expert system shells are also often easier to learn than the other development tools. Unlike toolkits, many expert systems shells are available for standard PCs, hence there is no need for expensive or dedicated hardware.

In a survey of knowledge-based system developers in the UK (J.S. Edwards [46]), it was found that over half the operational systems were developed using shells. The figures for the usage of different development tools in the UK (1990) were:

Conventional languages	11%
Toolkits	11%
AI language	23%
Expert system shells	56%

An expert system shell was used in the development of a knowledge-based system for plastic materials selection in this project. The development of the system is described in Chapter six.

4.8 Knowledge-based Materials Selection Systems

The author's interest in Knowledge-based systems and materials selection was originally initiated in 1987, by the problem of trying to decide which KBS technique was suited to what types of problems. To resolve this, after having seen the "intelligent" materials selection packages such as EPOS and PLASCAMS, a program of building a simple Knowledge based Material Selection System, using a number of commercially available Shells was initiated. The idea of using shells was that it would let us get down towards tackling the problem, time would not be wasted developing interfaces, implementing inference schemes, debugging aids etc. As a result three systems were initially built, using the Micro-Expert, KES and ESP Advisor shells. The selection approach was based upon that elucidated by Dr. Gordon Smith, Program Manager of the Plastics and Composites group at the Rover Advanced Technology centre at the University of Warwick. The resultant systems where fairly simple, Table 4.1 illustrates the questioning structure devised. A number of problems existed with the systems, such as the difficulty in putting sufficient materials data in the knowledge base without excessive clutter, and the lack of flexibility in operation. The prototype systems implemented on the three different shells have had various degrees of success despite attempting to use basically similar structure. This was because of the variations in inference procedure, uncertainty handling and style of user interface offered by the three systems. Overall though, the improvement in plastic material selection capability, especially for non plastics experts were clear. Fuller details of the systems developed are provided by Smith [49]. The work of Smith et al, indicated that this was a promising approach, but three main limitations where identified. Firstly the problem of materials data, this needs to be stored separately from the knowledge base for flexibility and ease of update. Also it is impractical to expect to be able to maintain a custom

Material selection Criteria	***Question and Response***
Application	What is the application area of the plastic material ? 1. Building 2. Industrial 3. Agricultural 4. Transport 5. Medicine 6. Packaging 7. Sports goods 8. Man-made fibres
Functionality	Is the material going to be used as part of a load-bearing structure ? 1. Yes 2. No
Appearance	Is appearance of the plastic component important ? 1. It is important. 2. It is not important
Stiffness	How would you describe the stiffness of the material ? 1. Stiff 2. Flexible 3. Not sure
Strength	How would you describe the strength of the material ? 1. Strong 2. Moderate 3. Not applicable
Impact resistance	Does the final product need to withstand impact ? 1. Yes 2. Not sure
Operating temperature	What is the maximum temperature that the product has to operate, without deformation ?
Insulating property	Does the material have to be an insulator of the electrical current ? 1. Yes 2. Not applicable
Environmental resistance	Is the product going to be used in open environments ? 1. Yes 2. Not sure
Chemical resistance	Of the following chemicals. choose the ones your product has to withstand corrosion : 1. Water 2. Strong acid 3. Strong alkali 4. Organic solvents 5. Chlorinated organic solvents

Table 4.1 : KES : Attributes and corresponding questions.

materials property database without considerable resources. Secondly the Shells utilised proved inadequate in the range of facilities and options provided This may have been due to the fact that ESP Advisor and MicroExpert where both first generation shells, and KES was more of a Programming language, than a fully featured shell. Thirdly , it proved very difficult to 'extract' from Dr. Smith and his colleague Dr. Kells how exactly they went about the process of choosing a suitable plastic. Knowledge elicitation did actually prove very difficult!

As a result of the work done, the author initiated three further projects. The chief objectives of which were:

(1) For the KBS to access the materials data provided by one of the commercial database oriented packages to relieve the worries about quality and maintenance of data.
(2) Use the latest generation expert system shells to help in building a user friendly, flexible system.
(3) Evaluate the use of a structured documented expert methodology versus the approach of Dr. Smith.
(4) Assess how much expert advice could actually be provided within a system

The systems developed are described. It should be noted that each of the systems did not tackle all of objectives identified above, just a subset.

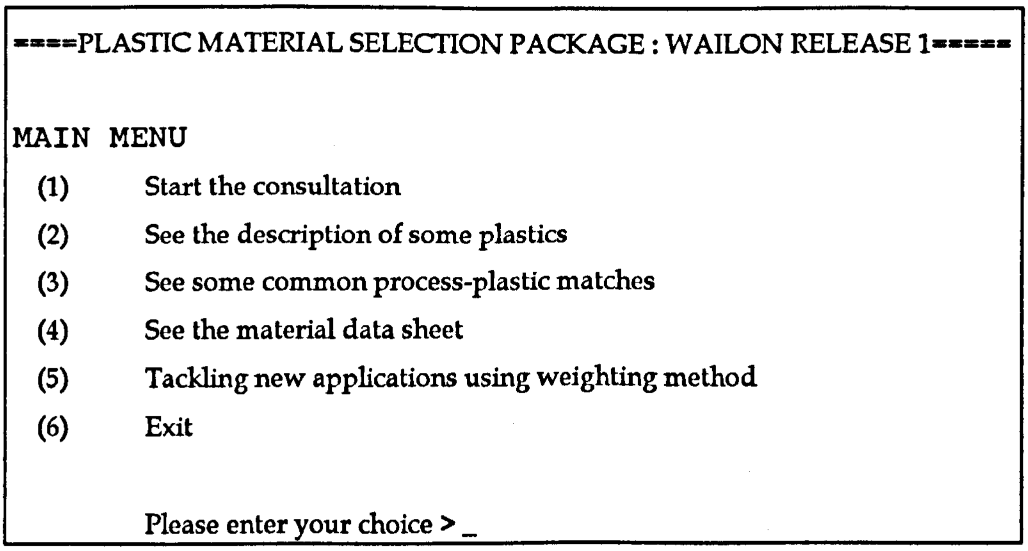
The three systems are identified as WAILON [50], PLASMA [51], and PMSES [52], and were built by taught course MSc students at the University of Warwick, under the guidance and supervision of the author.

4.9 WAILON

WAILON was built by Wai Leung KWONG, [50] who was an MSc student in Manufacturing Systems Engineering at the University of Warwick, using Leonardo version 3 which is an expert system shell provided by Creative Logic Limited. The particular aspects explored by Wailon were :

(1) The use of Frame based knowledge representation structure.
(2) Establishment of a separate database containing materials data and information.
(3) Application of Dr. Smith's heuristics.
(4) The use of a positive and negative combined weighting method to emphasise between desirable and undesirable properties.

The system employs a top-down modular approach where building blocks on the same hierarchical level are independent of each other. The main menu of the system is shown in figure 4.5, it is divided into five major sub-systems, Consultation, Material description, Process-material match, Material data sheet, and Tackling new applications using weighting method. Users can select any option.



```
====PLASTIC MATERIAL SELECTION PACKAGE : WAILON RELEASE 1=====

MAIN MENU
  (1)      Start the consultation
  (2)      See the description of some plastics
  (3)      See some common process-plastic matches
  (4)      See the material data sheet
  (5)      Tackling new applications using weighting method
  (6)      Exit

           Please enter your choice > _
```

Figure 4.5 : Main Menu of WAILON Release 1

4.9.1 Consultation

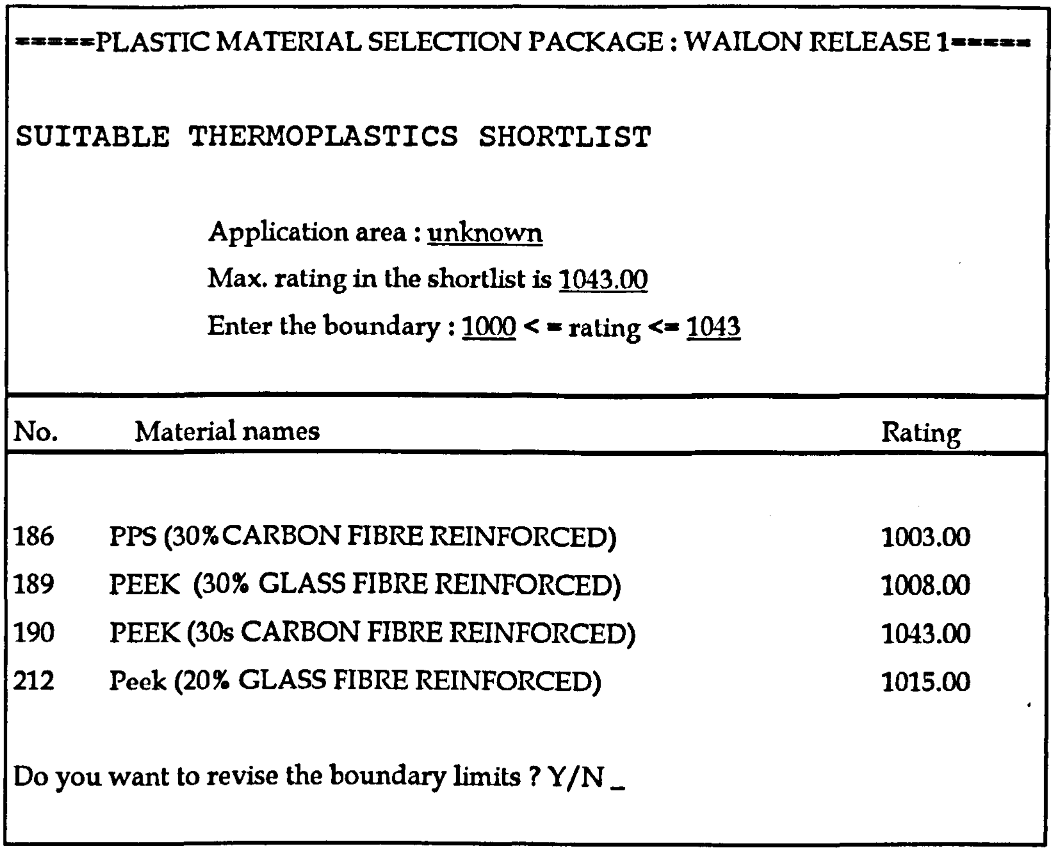
At the beginning of this option, the application area of the component is requested. There are seven application areas, Structural, Thermal, Electrical, Chemical, Decoration, Optical, and Packaging. Wailon also provides an option 'Unknown' for application areas that cannot be easily classified into the above. The system contains some past records of application-material matches. If the component falls into any one of these areas, the system screens the records and directly prompts with the recorded materials for such applications. If the user answers "unknown", a series of pre-defined questions about the service, processing and cost requirements of the component, is asked. The concept of defining application area first allows the system to define priorities for the materials, for example if the application area is structural, then strength is of ultimate importance for the part. The primary function of the part is assumed to be load bearing.

After the questioning stage, the system will go through a two-stage process in material selection. Firstly it performs screening by the application area selected secondly, it evaluates the screened materials using the combined weighting method.

Finally a list of candidate materials with their ratings is generated. The higher the rating, the more appropriate the material for those specific requirements. The user can input boundary limits on ratings to obtain the required portion of the suggestion listing. An example is shown in figure 4.6.

4.9.2 Material Description

This sub-system provides a general descriptions of the materials stored in the database. There are three classes of materials: thermoplastics, thermosets, and composites. Most common generic groups in each class are included. The user can select the class and then the generic group about which he wants to get a description. The information provided includes descriptions on general properties, advantages and disadvantages, possible processing methods, and some application examples.



```
=====PLASTIC MATERIAL SELECTION PACKAGE : WAILON RELEASE 1=====

SUITABLE THERMOPLASTICS SHORTLIST

            Application area : unknown
            Max. rating in the shortlist is 1043.00
            Enter the boundary : 1000 < = rating <= 1043

No.      Material names                                    Rating

186   PPS (30% CARBON FIBRE REINFORCED)                    1003.00
189   PEEK  (30% GLASS FIBRE REINFORCED)                   1008.00
190   PEEK (30s CARBON FIBRE REINFORCED)                   1043.00
212   Peek (20% GLASS FIBRE REINFORCED)                    1015.00

Do you want to revise the boundary limits ? Y/N _
```

Figure 4.6 : Boundary Limits on Ratings in WAILON Release 1

4.9.3 Process-Material Match

This sub-system provides a description of selected processes and suggests materials which are commonly processed by that particular processes.

4.9.4 Material Data Sheet

This sub-system provides access to the material data sheets for thermoplastics and thermosets available in the system. The data sheets contain data about the general and electrical properties, mechanical properties, chemical and radiation resistance, production methods and post-processing of the materials selected.

4.9.5 Tackling New Application with Combined Weighting option

This sub-system allows the user to select particular material properties that he wants to consider in selecting appropriate materials for his component. It employs Positive and Negative Combined Weighting Method to evaluate the materials in the database. The user can assign either positive or negative weighting on the selected properties (positive weighting for desirable and negative weighting for undesirable properties). For instance if the user prefers high impact strength and injection moulding to transfer moulding, he can put positive weighting on impact strength and injection moulding but put a negative weighting on transfer moulding. According to the input weighting, all the materials will be evaluated and a shortlist of candidate materials, with their ratings, will be generated.

Apart from the five options developed in the main program, three programs have been devised for maintaining the material database of this expert system by the user themselves. They are MAIN1.PKB, MAIN2.PKB and MAIN3.PKB which are used for database navigation, database editing and database appending respectively.

4.10 PLASMA

PLASMA (PLAStic MAterial Advisor) was built by Victor LI [51], who was a MSc student in Manufacturing Systems Engineering at the University of Warwick in 1989-90, using the Crystal 3.0 expert system shell. The system can be run on a floppy disk or installed on a hard disk in a normal IBM PC environment with 640k basic memory. Plasma was intended to evaluate the following aspects :

1. The linking of an expert system to a separate commercial materials database (Plascams).
2. The provision of in-depth design guidance in a design consultation module concerning the two key areas of :

   Design for Manufacture, and

   Design for stiffness.
3. The use of a generic group intermediate data structure for the polymer data. This is useful because with specific grades, data can change often as the materials are improved or reformulated. However the properties of generic groups are much more constant
4. The use of Production rules based structure for encoding the expertise.

The program structure of PLASMA is shown in Figure 4.7, the system consists of three main modules: Plastic Material Selection, Design Consultation, and Plastic Materials Database Maintenance.

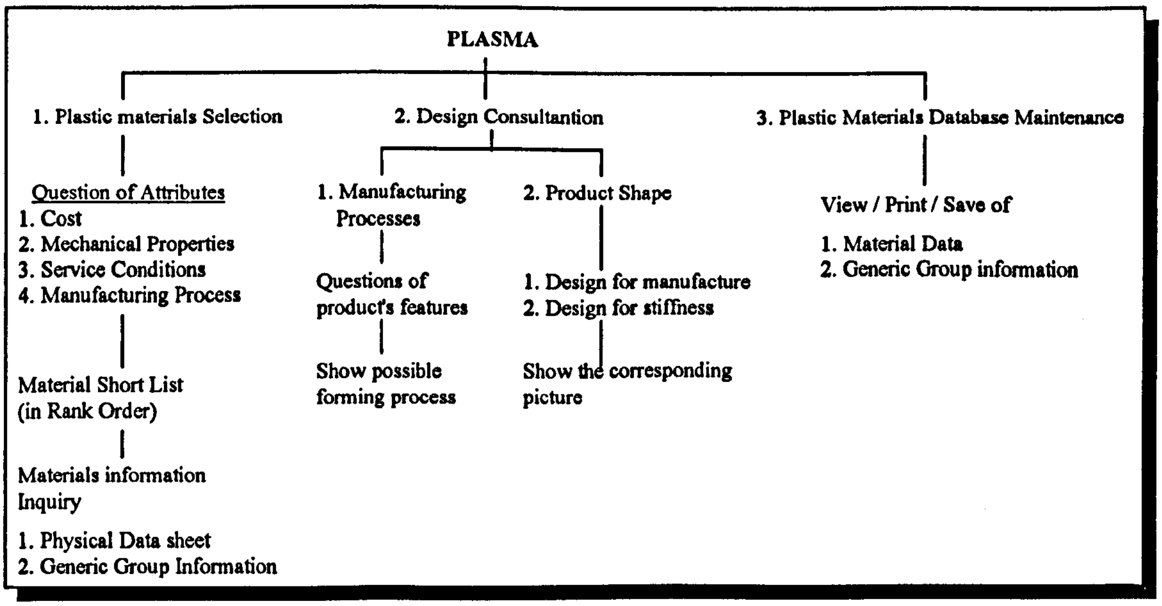


Figure 4.7 Program Structure of PLASMA

4.10.1 Materials Selection

This module can suggest a shortlist of candidate plastic materials for the specific requirements of the product. The selection approach employed in this module is a combination of "Direct Property Match (DPM)" and "Weighted Property Index (WPI)" approaches. WPI is similar to the "Combined Weighting Search (CWS)" discussed before. The difference between the two approach is that the "property ratings" in CWS is replaced by "scaled property values " in WPI.

Evaluation of material by WPI:

$$WPI_i = \sum_{j=1}^{N} (W_j * S_j) \qquad \text{Equation 6}$$

where WPI_i = Weighted Property Index for material i

W_j = Weighting factor for property j

N = Number of material characteristics specified

S_j = Scaled property
= Value of property/Max. value in list
(if higher value is better)

or = Min. value in list/value of property
(if lower value is better)

In asking pre-defined questions about the desired attributes on Cost, Mechanical Properties, Service Conditions, and Manufacturing Process of the product, the user selects the weighting factors (from 1 to 9) for these attributes to represent the degree of importance for the specific application. Based on these weighting, the system will screen the database for all qualified plastics. In the screening process, those plastics which have scale property values higher than the weighting input by the users, will qualify. All the materials with scale property values lower than the corresponding weighting will be eliminated at this stage. If the system fails to find any plastic fulfilling all the criteria according to the input weighting, the user is allowed to amend the weighting. The system can then start the screening process again. The overall process is illustrated in figure 4.8.

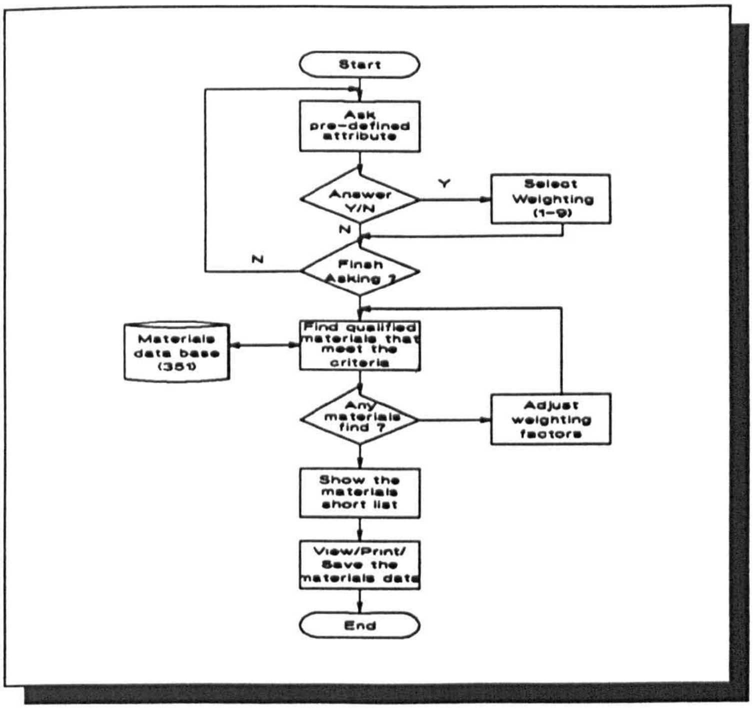


Figure 4.8: PLASMA Overall Selection Procedure.

The overall balanced performance of each qualified material for the specific requirements is then judged. WPI of each qualified plastic is determined and a material shortlist is generated. A larger value of WPI may indicate the material is of higher suitability for the specific application. A fundament problem with this approach in practise was that very often no materials qualified after the first screening i.e. no material in the database was equal-to or better on performance than the requirement ratings. Subsequent selections had to be carried out with relaxed criteria.

4.10.2 Design Consultation

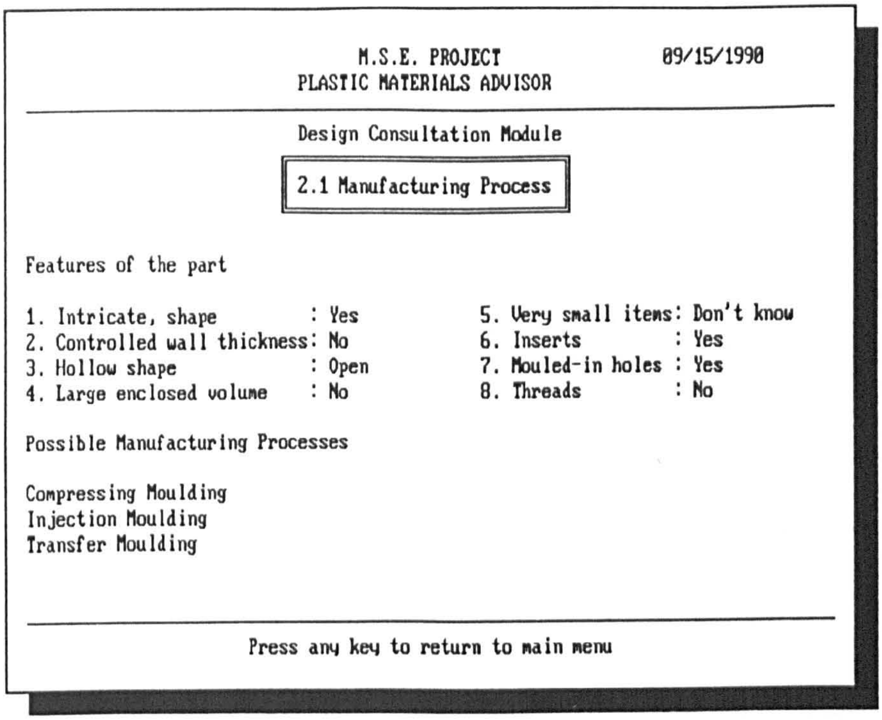
This module aims to deliver to system users expert guidance concerning 'Plastic Forming Methods' and 'Shape & Dimensions'. Due to the time constraint, the later was not completely developed.

Plastic Forming Method:

This sub-module suggests possible manufacturing processes for a component by asking pre-defined questions about the shape and dimensions of the component, its wall thickness and presence or absence of constant cross section, inserts, threads and moulded-in holes, etc.. Table 4.2 illustrates the decision criteria utilised within the system and Figure 4.9 illustrates a possible resulting advice screen.

Forming Process	Shape Limitation	Intricate, Complicated, Shapes	Controlled Wall Thickness	Open, Hollow Shapes	Enclosed Hollow Shapes	Large Enclosed Volume	Very Small Items	Inserts	Moulded-in Holes	Threads
Compression moulding	Mouldable	Yes	Yes	Yes			Yes	Yes	Yes	Yes
Transfer moulding	Mouldable	Yes	Yes	Yes			Yes	Yes	Yes	Yes
Injection moulding	Mouldable	Yes	Yes	Yes				Yes	Yes	Yes
Extrusion	Constant X-Section	Yes	Yes					Yes		
Rotational moulding	Hollow			Yes	Yes	Yes		Yes	Yes	Yes
Blow moulding	Hollow Thin Wall			Yes	Yes	Yes				Yes
Casting	Mouldable	Yes	Yes					Yes	Yes	
Foam moulding	Mouldable	Yes	Yes	Yes					Yes	
Cold-press moulding	Mouldable	Yes	Yes	Yes						
Pultrusion	Constant X-Section	Yes	Yes							

Table 4.2 : Decision criteria utilised in Plasma



```
                          M.S.E. PROJECT                    09/15/1990
                       PLASTIC MATERIALS ADVISOR
----------------------------------------------------------------------
                       Design Consultation Module

                       2.1 Manufacturing Process

Features of the part

1. Intricate, shape          : Yes        5. Very small items: Don't know
2. Controlled wall thickness: No          6. Inserts          : Yes
3. Hollow shape              : Open       7. Mouled-in holes  : Yes
4. Large enclosed volume     : No         8. Threads          : No

Possible Manufacturing Processes

Compressing Moulding
Injection Moulding
Transfer Moulding

----------------------------------------------------------------------
                   Press any key to return to main menu
```

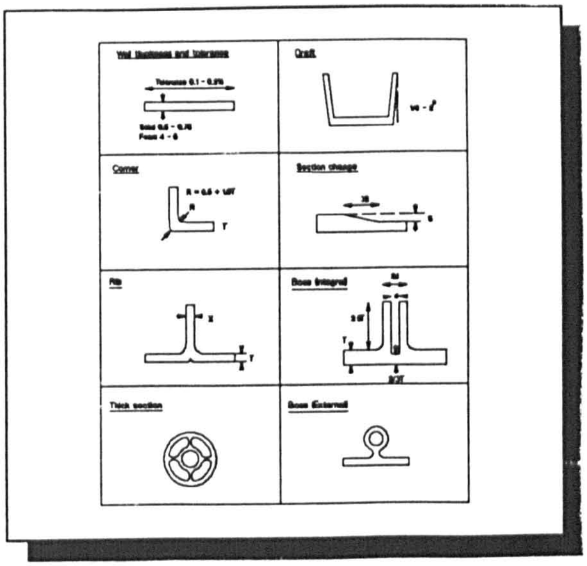
Figure 4.9 : Advice screen in Plasma

Shape and Dimensions:

Knowledge of the requirements for shape and dimensions, because of the interaction of the manufacturing process with material properties, is usually gained by experience. This sub-module acts as a library providing pictures about possible shapes and dimensions of a plastic product under different situations. The influential factors, based on the experience of West [53], are shown in Table 4.3. New pictures can also be added in the library to enhance and update the knowledge of the system. This picture-library consists of two part. The first part is called "Design for Manufacture" and consists of pictures concerning the shape and dimensional requirements of a product for manufacturing, an example is shown in figure 4.10. The second part is Design for Stiffness which provides pictures of methods for improving the stiffness of a component. Some possible shapes for improving stiffness are provided, such as shown in figure 4.11. Unfortunately, this element has not been fully implemented.

Design Detailing	Avoidance of Part Distortion	Joining	Efficient Use of Materials
• Wall thickness and tolerance • Draft • Corner • Section change • Rib • Boss (Integral, External) • Thick Section • Threaded inserts • Screws - self tapping • Snap-fit (internal, external) • Welding spin • Ultrasonic • Staking • Adhesive joints (lap, tongue & groove, double lap butt)	• Edge stiffening • Shrinkage compensation • Symmetrical section • Slots	• External threads • Internal threads • Threaded boss	• Designing for Uni-directional stiffening • Designing for multi-directional stiffening • Section stiffness (equal areas)

Table 4.3 : Influential design factors (from West [53])



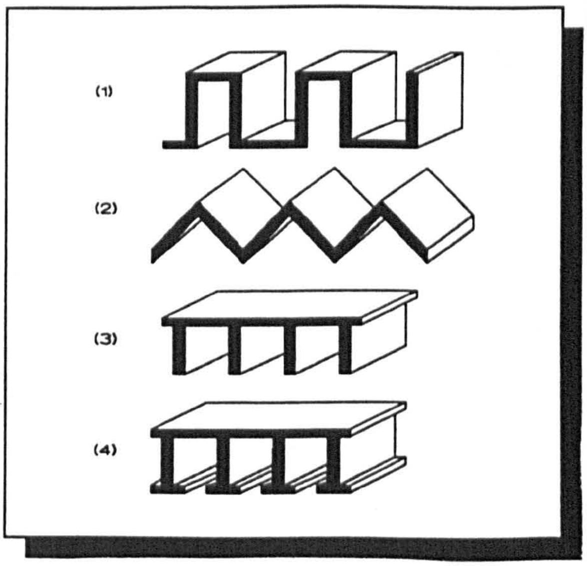


Figure 4.10 : Design for Manufacture Figure 4.11 : Design for stiffness

4.10.3 Plastic Material Database Maintenance Module

Since the database is the source of material information, the quality of the data in the database will directly affect the quality or accuracy of the material selection of the system. After a period of time, the information stored in the database may become out of date, perhaps because of a growth in experience or in technology. The system allows users to update or modify the materials data. Data modification may be necessary when the owners unique experience or knowledge suggests a different interpretation.

This module allows the user to view, update, delete or append the data in the database which consists of materials' physical data, generic group information, and scaled property values. In addition, the database can be expanded by adding newly developed plastic materials so that they can also be evaluated by the system when selecting materials for specific application.

Large parts of Plasma were incomplete, though the concept of practical design guidance was good, it really needs to be implemented within CAD design package to provide on-line interactive advice. The format adopted by Plasma is no more useful that looking at diagrams in a book or pamphlet. The material selection process utilised seldom provided an initial shortlist. Considerable modification and adjustment of the requirement ratings was required. Basically the process is one of direct matching, done simultaneously for all the selection criteria, rather than sequentially as offered by EPOS and CAMPUS.

4.11 PMSES (Plastic Materials Selection Expert System)

This was built by Kwok Yiu Sang (Sammy) [52], who was a MSc student in Manufacturing Systems Engineering at the University of Warwick in 1989-90, using the Crystal 3.0 expert system shell. It can be run on an IBM PC or compatible with 640K Bytes of RAM memory, with Crystal 3 installed on a hard disk or off a high density floppy disk drive. The particular aspects of the materials selection process tested by this prototype where :

1. The use of a systematic process of selection, very loosely based upon that prescribed by Kusy [7]
2. The linking of an expert system to a separate commercial materials database (Plascams). The ability to easily update data and to customise data.
3. The provision of a direct property matching (using weightings).
4. The provision of access to materials application information as well as data.
5. To shortcut the selection process by providing " What has been used before" information.

PMSES consists of five knowledge bases and four database files. Each Knowledge base links with the appropriate database file to perform particular functions. There are seven modules contained in the system (figure 4.12), the first four provide different data searches, two display information and the last is used for database maintenance.

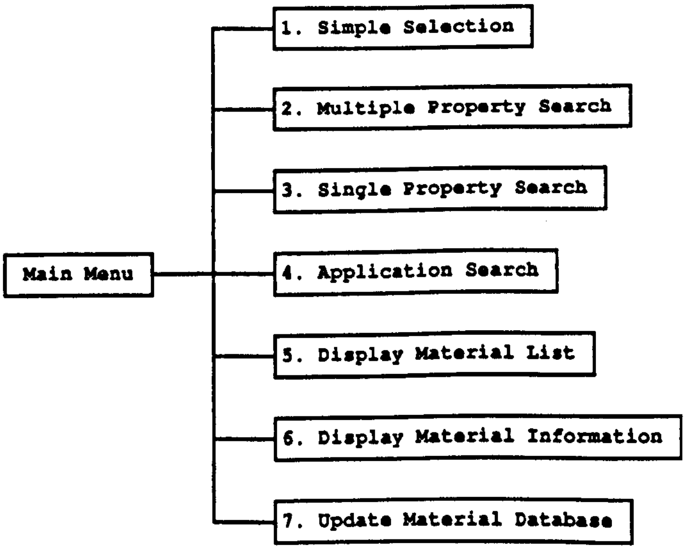


Figure 4.12 Structure of PMSES

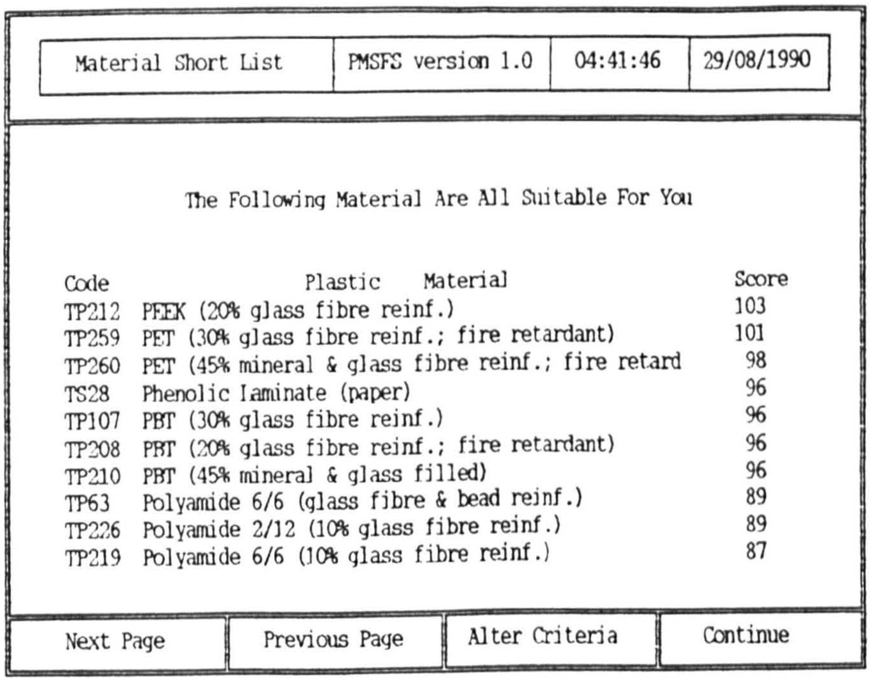
4.11.1 Simple Selection Module

Similar to the "Consultation" module in Wailon and "Materials Selection" module in Plasma, this module can suggest appropriate materials for specific applications by asking a set of pre-defined questions about, common material properties and production volume. It is designed to simulate a question-and-answer dialogue between a human expert and the user. The process is very loosely based upon the systematic methodology proposed by Kusy [7]. The questions asked relate to:

(1) Outdoor Use
(2) Maximum Operation Temperature
(3) Tensile strength
(4) Impact Strength
(5) Dimensional Stability
(6) Wear Resistance
(7) Stiffness
(8) Surface Hardness
(9) Fatigue
(10) Appearance
(11) Electricity
(12) Chemical Resistance
(13) Cost Considerations.

In question 13, users may choose one of nine pre-set cost limits (£/Kg) or input a specific value. Then a further question ascertains the production quantity which is used to establish the weighting for cost in materials selection.

The systems converts the user inputs into minimum acceptable property values and then conducts a direct comparison search with the database of materials. The pmaster datafile is utilised. For example, if the user chooses "Good" for stiffness requirement, this is interpreted a rank value of four, and the database is searched for materials ranked five or better on stiffness. The system only selects materials which meet all the criteria, and hence, in practise often no suitable materials are located on initial searches and criteria have to be relaxed for subsequent attempts. After all the materials selected have been assigned a score, the system arranges them in descending order. A search output is shown in figure 4.13.



```
                 The Following Material Are All Suitable For You

Code                  Plastic    Material                                Score
TP212  PEEK (20% glass fibre reinf.)                                      103
TP259  PET (30% glass fibre reinf.; fire retardant)                       101
TP260  PET (45% mineral & glass fibre reinf.; fire retard                  98
TS28   Phenolic Iaminate (paper)                                           96
TP107  PBT (30% glass fibre reinf.)                                        96
TP208  PBT (20% glass fibre reinf.; fire retardant)                        96
TP210  PBT (45% mineral & glass filled)                                    96
TP63   Polyamide 6/6 (glass fibre & bead reinf.)                           89
TP226  Polyamide 2/12 (10% glass fibre reinf.)                             89
TP219  Polyamide 6/6 (10% glass fibre reinf.)                              87
```

Figure 4.13 : A "Simple selection" output screen

4.11.2 Multiple Property Search Module

This module allows the user to choose the specific properties he wants to consider in selecting materials for his component. Users are requested to input in minimum and maximum ranked values acceptable for each property chosen, the system then searches the full list of materials. If additions are made to the properties searched for, only the previous shortlist is examined, any changes to the min or max acceptable values causes the full list from the pmaster datafile to be re-examined. At search completion a ranked list is generated. The list is ranked by a material score. The formula for calculating the score is:

Score =

$$\frac{\left[\sum (WeightingFactor)x(RankedPropertyValue) - (MaterialCost)x(CostFactor)\right]}{BasicScore}$$

The weighting factor for each property is calculated from the maximum and minimum ranked values selected by the user.

$$WeightingFactor = \frac{(MaximumRanking + MinimumRanking)}{2}$$

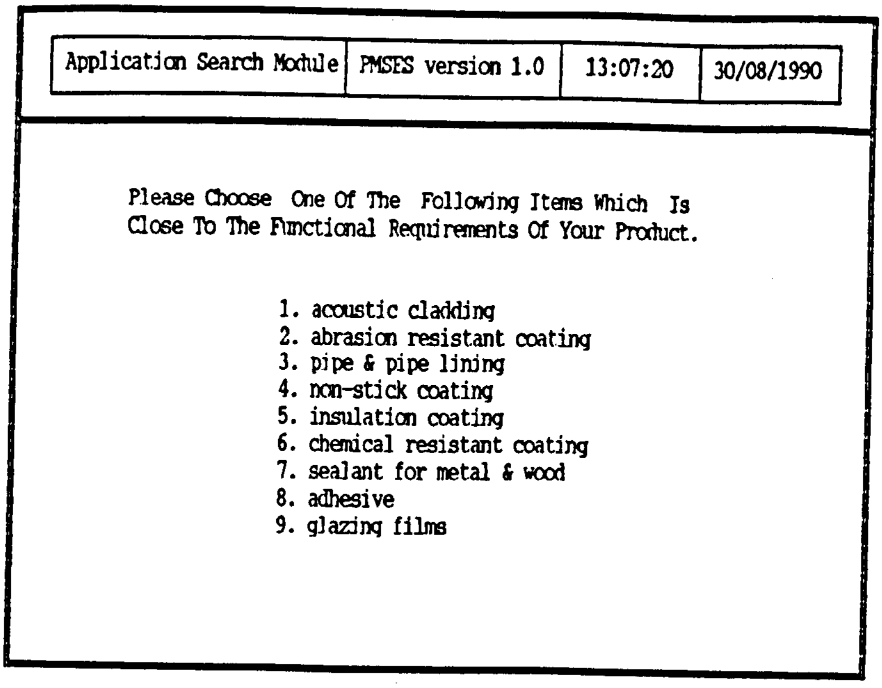
and the $BasicScore = \sum (WeightingFactor)^2$

4.11.3 Single Property Search Module

In operation this is identical to the multiple property search module, but it allows search on only a single property. No score is calculated. The materials are displayed according to a ranking based upon material property ranking derived from Plascams. The pmaster datafile is used.

4.11.4 Application Search Module

This module allows materials to be searched for based upon previous use in that application. Nine categories of application are defined at the top level, for example machinery manufacture or coating materials. At the next sub-level components in that category are displayed (see figure 4.14) and the user is requested to select one. All the materials suitable for use in that component are then displayed, ranked according to the cost/kg.



```
Application Search Module | PMSES version 1.0 | 13:07:20 | 30/08/1990

Please Choose One Of The Following Items Which Is
Close To The Functional Requirements Of Your Product.

            1. acoustic cladding
            2. abrasion resistant coating
            3. pipe & pipe lining
            4. non-stick coating
            5. insulation coating
            6. chemical resistant coating
            7. sealant for metal & wood
            8. adhesive
            9. glazing films
```

Figure 4.14 : Items under "Coating Materials" category

4.11.5 Display Materials List

This module displays all the materials that are contained in the database, with a code number based upon the position in the overall file pmaster.

4.11.6 Display Materials Information

This module allows the display of data and application information for the materials in the pmaster datafile. Access is made via the code number described above (section 4.11.5).

4.11.7 Update Material Database Module

This module allows the user to update the database files, Pmaster, Pdata and Ptext which contain the materials list, data and text information used by the system.

4.12 Discussion

Broadly speaking, all of these three expert systems for plastic material selection can not only suggest appropriate plastic materials for specific applications, but also provide some useful information on materials, processes, design and cost to help the user. They appear superior to numerical database systems because they are usable by a wider range of clients. The main benefit is that the questions these systems ask can be answered by all designers. They do not require expertise in, and an understanding of plastic materials properties. However, each of them has its own approach to different aspects of the problems. The operation and features of these systems are compared under a number of pertinent headings.

4.12.1 Selection Methodology

Selecting candidate materials for the user's specific requirements is the most important function of these expert system. Each system has its own methodology in selection. In Wailon, candidate materials are screened out by application area and then evaluated through Combined Weighting Search. This is the approach Dr. G.F. Smith was able to elucidate when asked how he goes about selecting a plastic material. However there is considerable overlap in potential requirements between these areas and some appropriate materials which are designated to other areas may be overlooked. Wailon does feature the potential ability to short-circuit the full selection search by naming possible appropriate materials from a '*this is what has been used for that type of application*' list maintained in the system, and triggered by a particular sequence of answers. Evaluation of the system indicated that correct selection of application area is critical to appropriate material selection. If the application area for a computer housing was deemed to be *electrical*, then the materials resulting from the selection were not very appropriate in practise. However, if application area, *decoration*, is chosen, the selection quality is much better. The two stage search procedure utilised is potentially restrictive when applied in a computerised system because preferred characteristics are embedded within the core system (within application area). There could be many reasons which require deviation from the assumptions made by the system, but it is not possible for the user to control or modify them. For example enhancements in the properties of a particular material may cause that material to become applicable, and maybe even preferred because of cost for example, but the system user cannot modify the system to reflect this, though the updated material is in the system database. The use of a positive and negative combined weighting method for the second stage of the search procedure provides the ability to be critically more distinctive between desirable and undesirable criteria compared with standard combined weighting. In practise though apart from providing a wider range of scores, it did not appear to provide any benefits in actual quality of selection.

The material selection methodology employed by PLASMA is loosely based on that proposed by Kusy [7]. This is a systematic approach compared to that adopted by Wailon. Plasma uses a single stage search system. A series of questions relating to Cost, Mechanical properties and Service conditions, and Manufacturing process is asked. These generate an internal list of required property values which are then compared with the materials in the database, using direct comparison. A shortlist of qualified materials is generated, this is then ranked using a weighted property approach. In Plasma, the materials which fail to satisfy <u>all</u> the user requirements are eliminated. It is very possible that no qualified material can be found and the system may overlook potentially appropriate materials. In practise several selection runs may be required, each time with reduced performance requirements on the search criteria, to generate a suitable shortlist.

A systematic approach to plastic selection loosely based on the methodology of Kusy is also employed by PMSES, as is a single stage search procedure. Single stage searches can be very inefficient when trying to select from a large number of plastics on many criteria, They also have a high possiblity of finding no suitable materials on initial runs.

All these systems also provide a direct matching search as provided by the three commercial database oriented systems (EPOS, CAMPUS and PLASCAMS). The search efficiency of two stage search systems (Wailon) is greater, because stage one provides a reduced list for the more detailed search of stage two. This is significant if the system contains a large number of materials in the database or a large number of properties are searched against. Wailon could be improved if the stage one search criteria were more constant and less subject to change and interpretation. For example, if the first stage search was by manufacturing process, different processes are always likely to prefer particular materials, despite changes in material performance. Whereas application area may radically change if a materials performance on a particular parameter changes.

4.12.2 System Features

All three systems provide the ability to:

(a) Conduct an 'intelligent' search for suitable plastics.
(b) Conduct a 'direct property matching' search.
(c) View information regarding materials properties and applications.
(d) Add, delete or update materials information in the database by the user.
(e) Convert Plascams data disks into systems data.

Plasma also provides information regarding manufacturing processes. PMSES and Wailon provide support to take into account 'what has been used before' in this application. Plasma attempts to provide a degree of design guidance on other than material selection. In practise Wailon was much superior in its intelligent search procedure because it required fewer iterations to generate a shortlist.

4.12.3 System Knowledge

Since these are knowledge based system, it is reasonable to ask "where's the knowledge?" since to many users they appear to be database systems. All these systems combine the use of a database to store information that may frequently change (materials and their property data), and a knowledge representation structure to store information that changes rarely (about the process of selection). Two specific examples of expert knowledge stored in the systems are, firstly, the conversion from product behavioural requirements identified by the system questions to material property requirements, and secondly, the materials ratings stored in the database.

4.12.4 System Development

The ease of development and the resulting appearance of the systems is really determined by the choice of KBS techniques utilised and features provided by the development environment. Of the two KBS shells utilised, Crystal proved the easier to learn and was judged by users to provide the 'nicer' interface. Looking at the features claimed by the shells, Leonardo (as used in Wailon) offers more (e.g. Frames and Rules) but for the problem of materials selection they did not appear to provide any advantage in speed and ease of development or in the resulting performance and appearance of the system.

4.13 Prototype Conclusions

After reviewing both available database systems and expert systems for material selection, it was found that expert systems have the ability to overcome some of the limitations which appear in the database systems discussed in chapter three. Though not proven in these applications, expert systems should be able to consider the interactions between component shape, manufacturing processes and material properties, as well as costs, in material selection. They can apply heuristic rules of thumb developed by human experts and so simulate the performance of the human reasoning process (human-like manner) in the selection process. In addition they allow the users to input component requirements rather than material properties. Those users which have limited knowledge of material properties can benefits from using these packages. It is also valid to ask "can even an expert be totally familiar with thousands of materials and hundreds of properties?"

The information provided and the properties being considered in these systems vary. Each has its own advantages and disadvantages. It is very difficult to decide on a overall best system among them. However it is clear none of them can be regarded as an optimum system in terms of overall features and abilities.

CHAPTER FIVE

SYSTEM REQUIREMENTS

According to C.K. Bullough [27] the fact that materials information systems are not widespread in industry may be due to lack of awareness, market inertia or the fact that they are *not* the most useful form of materials information supply. This chapter examines the requirements of an ideal materials selection system. An 'ideal' system for general use is probably impossible, so maybe a 'more ideal' system should be the objective. The requirements developed are based upon the comments of experts, the issues discussed in previous chapters and the authors knowledge of procedures at Rover Group Plc.

The desirable features of a materials selection database will obviously depend on the requirements and characteristics of users. For example, one criticism of the current commercial systems is that a considerable degree of expertise is required to utilise them effectively. Those expecting publicly available computerised systems to supply all of their materials information needs, from conceptual design to the production stage will be disappointed. Materials supply companies possess considerable skill in tailoring the properties of their materials to the needs of customers. In depth consultation on the final material choice with suppliers will always be advised by materials selection experts whether selection is by data book or databank. It has also been noted in the literature that sometimes engineers wish for facilities that are unavailable or a level of detail that is presently impossible to provide [34]. Desirable features for a commercial plastic material selector are:

5.1 The system should be IBM PC (or compatible) based

Rationale:

These are the most commonly available computers in engineering and manufacturing companies and their operation is readily understood by many employees. Distribution of the materials selection system based on PC standards will ensure the widest possible user base. C.K Bullough defines suitable PC configurations in his report, however they are too atypical. A suitable system should be able to available on PC's with :

Intel 80286 processors and upwards.
1MByte of RAM
!.44MB 3.5" or 1.2MB 5.25" Floppy drive
5MB Free Hard disk space.
Keyboard and Monitor

5.2 The system should use knowledge based techniques.

Rationale:

The widest possible user base is possible if the system is suitable for a range of different roles and types of users. It thus should be able to support the needs of both experienced (expert) and naive users. KBS techniques provide the best method for achieving this flexibility, because of their ability to embed expertise and cope with uncertain or missing information.

5.3 The system must be easy to use

Rationale:

The information held in a materials databank is seldom unavailable in some other form, their main advantage is that they ease the review of readily available data. The ease of searching a materials databank compared with say, a materials catalogue enables much greater productivity. Moreover, they can allow comparisons and presentation of data in ways that are impossible in book form, such as the customised graphs available in Campus, and the balloon diagrams of the Cambridge Materials Selector. The system must be easy to access or install, menu based and intuitive to use.

5.4 The system must be capable of being networked.

Rationale:

Control over the quality of data can be centrally maintained and access to the latest data ensured. The affect will be similar to maintaining a central drawing office and issue control system.

5.5 The system should be capable of customisation by the company and individuals.

Rationale:

Materials information is a company resource. Yet few companies acknowledge the vast effort and cost invested in their knowledge of materials in design, analysis and manufacture. Thus materials information stores can act as maintained stores of valuable company information. Such systems can also aid company review procedures, and aid the interaction of functions within the company. Three important areas of customisation identified are:

(a) Database customisation. It should be possible to add to or delete materials information in the database. It should also be possible to add new materials properties and to modify existing property values. This should be allowed for approved users.

(b) New selection criteria that can be incorporated into the main selection routines should be allowed. For example, if paintability is important, it should be possible to produce shortlists based on paintability.

(c) An applications database, where a person (or company) can store information relating what material was used for what application and why.

5.6 The system should be capable of linking with other systems.

Rationale:

Materials information is not used in isolation, and future systems should be designed so that they can interface with a wide variety of other software. Typically spreadsheets, databases, CAD packages and analysis packages such as mouldflow.

5.7 A variety of selection techniques should be provided.

Rationale:

Many systems still use selection techniques based upon target properties. Materials not having the target properties are rejected. An alternative approach is one in which a weighted function is applied, so that the materials having the best values of the most important materials properties have the maximum value of the function. This results in a list or ranking of materials, and has the advantage that no materials are 'rejected'., as tends to be the case with the target properties approach.

5.8 The system should allow facilities for easily retrieving materials texts, data sheets and process-material matches.

Rationale:

An important aspect of the system is that they should contain suppliers' and manufacturers' information. Fortunately most existing systems do supply such information. An important initiative in this respect is the Campus series of databases (described in section three) that originate from the manufacturers themselves.

5.9 The expertise within the system should be separated from the materials data.

Rationale:

The expertise (selection know-how), usually stored in a knowledge base, changes relatively infrequently. However the data of individual plastics, usually stored in a database, may change often. For ease of development and maintenance, it is advisable to separate the two 'bases' and to manage them separately.

Some of the requirements on the database can be identified in detail now.

A database intended for widespread use must have the following requirements :

(a) *Access to the database must be simple*

Access to national or international networks usually requires modems, passwords and long command procedures. Access must be made easy, via single easily remembered names, otherwise users with little or no computer experience feel greatly inhibited.

(b) *The database must be easy to operate*

A menu operated system with an on-line help is required if the system is to be used by a variety of users. In addition the following requirements must be taken into account:

- Short familiarisation time and little learning effort for beginners.
- Short set up time for occasional users.
- Maximum efficiency for regular users.
- Increased work satisfaction for all user groups.

(c) *The data inventory must be easy to update.*

The advantage of central databases is that they contain a binding set of data, the latest version of which is always accessible to all users.

In decentralised databases updating must be ensured, for example by mailing new floppy disks at regular intervals or as required. It is possible that decentralised databases can be updated by data over the telephone system using modems.

(d) *Overall costs must be low.*

In addition some desirable characteristics of the data stored within the database can be defined.

(e) *The data must be informative.*

A great number of test procedures are laid down in National and International standards, meaning that the simple selection of the relevant method for a specific application could lead to difficulties. However, the characteristic data determined on specimens only becomes usable for dimensional mouldings if supplementary information is available on their applicability to other geometry's, stress situations and environmental factors. Mechanical data, in particular, are not pure material values, but moulding data, because they may also be dependent on the geometry of the specimens, the process parameters used for production, the test parameters and any pre treatment.

(f) *The data must be comparable*

The test data available is often gathered under different test conditions, for example the standards on impact strength testing alone, DIN 53453, ISO 179 and ISO 180, list 33 different versions. The data available in materials databanks is often to different versions and not directly comparable.

5.10 The selection process should consider property interaction.

Rationale:

A complete materials selection system needs to consider not just materials properties but the interaction between them and component geometry and the manufacturing process utilised. For example, some materials may satisfy the service performance, but not the processing requirement, or maybe not with that particular component geometry.

5.11 The system should help identify suitable manufacturing processes for the component.

Rationale:

Selection of a suitable process is a critical factor in the overall performance and economics of a particular design.

5.12 It is desirable to have graphical representation of the component geometry within the system.

Rationale:

To be able to help the system and user in the consideration of the interactions between shape, process and materials properties, graphical representation is desirable.

5.13 The system should help identify the likely material property requirements.

Rationale:

With existing commercial systems the user is required to input material property numerical values (Epos, Campus and Plascams) or value ratings (Plascams) to be able to use the selection process. No guidance as to what are reasonable values for your application is provided. The author believes that this is a major obstacle in the use of the existing systems.

5.14 The system should enable consideration of 'green' issues.

Rationale:

Increasingly 'Green' issues can considerably affect material choice. The system should allow the user to take these into account in the selection process, if desired.

5.15 The system should be able to cope with uncertain or incomplete information.

Rationale:

The user is often unaware of particular information or data, the system should not overlook any materials as a result of this. In addition particular materials data in the materials database is often missing. Campus and Epos have many segments of missing data because supplier data is not yet available.

5.16 The system should allow a full evaluation of "cost considerations"

Rationale:

Materials cost is always a consideration, in fact some people regard it as the major consideration. Most material selection systems however only consider material cost !, and ignore all the other costs associated with the product such as tooling and manufacturing cost. The ideal system should allow final product piece part cost to be estimated.

5.17 The system should allow easy 'what-if' analysis.

Rationale:

Quite often the sensitivity of particular design decisions needs to be explored. The system should allow the user to achieve this easily.

5.18 Explanation Facility should be provided.

Rationale:

Users need to be able to examine why a particular material or process has been recommended. The system should also provide an on-line help facility to aid the user in answering questions.

5.19 The system should be modular in structure.

Rationale:

To aid construction and subsequent maintenance and enhancement the system should be modular in structure. A KBS systems capability can 'grow', similar to the way an expert increases his expertise if the system structure is designed to allow this. The author is not implying 'self-learning' by the system with this statement, merely that the development of a 'better' system is an evolutionary process.

If these features can be implemented into a system for material selection, a system to satisfy Rovers requirements will have been established. It is likely, however, that such a system will also satisfy the requirements of the majority of users interested in applying plastics. Though the proposed system discussed and implemented is biased towards the selection of plastics the approach should be readily transferable to all types of materials.

5.20 System Development

Expert Systems like all other software projects need to planned and developed according to a fairly rigid strategy or methodology to ensure consistent and correct results. The two methodologies that the author encountered in his literature survey will be briefly mentioned. The methodologies are the KADS Methodology and the Methodology by Scott , Clayton and Gibson [66] .

The KADS Methodology is a guiding framework for the development of an ES. In this sense it is normative rather than prescriptive , it provides a guidance on what should be produced rather than how. However , KADS takes a particular view of the development process which provides the basis for a more prescriptive approach while at the same time maintaining flexibility. The KADS Methodology is a software system that is inclusive of supporting training materials , project management guidelines , quality management guidelines (ISO 9000 Standard).

The key features of the KADS approach are : [67]

- A total quality management approach to the development process.
- A results - oriented , risk - driven approach.
- A normative framework for system development.
- The identification of a formalised model of expertise.
- Training material of ISO 9000 standard.
- Guidance to appropriate methods and techniques.
- Guidance on product breakdown and work breakdown structures.

The other methodology as presented by Scott , Clayton and Gibson [66] . is shown in figure 5.0, and the steps are described below.

Identification

This entails identifying a problem that could be solved with the aid of an ES and becoming sufficiently familiar with the current operations or problem to see how an expert could be helpful. This leads to a problem for any developer of an ES , and that is becoming sufficiently familiar or a "Mini Expert" in that particular task domain. This problem has led to systems being developed by the " Domain Expert " and so eliminating the system developer who has a limited amount of knowledge in that particular task domain. This approach has a drawback of not having a second or third person to objectively evaluate the system during development.

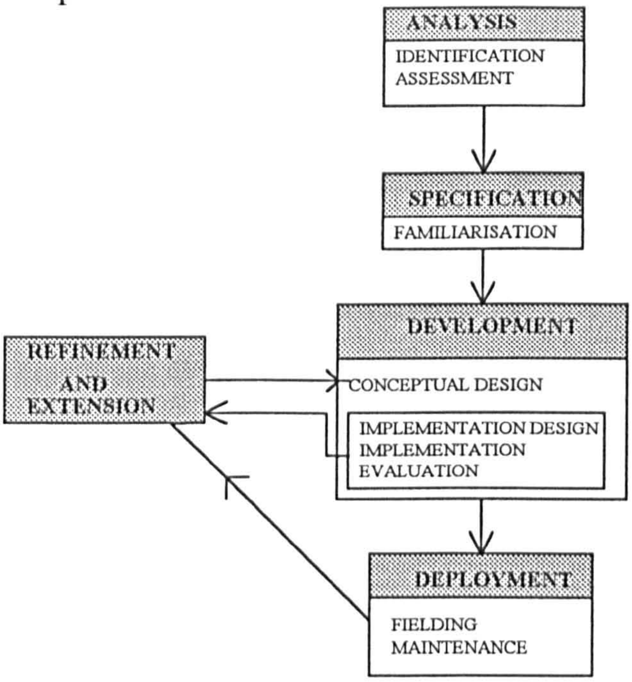


Figure 5.0 : Incremental Prototyping Design Methodology for ES's
Source : A Practical Guide to Knowledge Acquisition
Scott ,Clayton , Gibson Pg. 14

Assessment

Once a problem domain has been selected a feasibility study must be carried out to assess the viability of the system. This assessment should consider three aspects of feasibility :

- Technical
- Economic
- Practical

Familiarisation

In this step a clear definition of the systems ability must be assessed. The developer must also gain a general view of how the expert or experts carry out their tasks so this logic can be transferred to the system.

Conceptual Design

A coherent understanding of the process by which the expert operates must be grasped at this stage of the development process. The different types of input data and how they effect the experts decisions , hypotheses and actions in the domain must be obtained. Once this has been achieved a conceptual model must be formalised. The conceptual model specifies the :

- Sequence of steps the expert system will take in order to accomplish the task.
- The inference it will perform.
- The information it will use.

Implementation Design

The ES developer will develop and implement the design by selecting the appropriate representation for the knowledge that has been and has to be gathered. The conceptual tool specified what the system must do and now the implementation design will specify how the task will be accomplished with the chosen ES tool. In this section the implementation design for the expert system must merge the requirements of the conceptual design with the constraints of the operating environment.

Implementation

A working ES will be created by developing a knowledge base according to the implementation design. At the advanced stages of this task the ES will be introduced into its operating environment. In the development of the ES for plastic material selection , the system was shown to potential users and experts in the domain field to obtain feedback on the appropriateness of the system and its operation.

Evaluation

The systems will have to be rigorously evaluated as the output of the ES cannot always be guaranteed as it could be dealing with unknown data. This forces the ES to make inferences according to the data in the knowledge base to generate a solution. These inferences and their logic must be checked to ensure the system operates as intended. In the early stages the evaluation could be simple functionality tests by the system developer , where after the evaluation needs to be detailed and preferably carried out by the Domain Expert. Any errors found will be corrected by the system developer. The system will then be sent back to the expert for re-evaluation. This is known as Incremental Prototyping and is the preferred way of developing ES's. [67]

Another method of evaluation that was used when developing the current system was to introduce potential users to the system and then let these users evaluate the system according to a questionnaire that was set up by the system developer. The system developer then reacted to the comments obtained from the users to improve the existing system.

When both the expert and system developer are satisfied with the system the experts would use the system in parallel with their normal work to undertake further and more detailed evaluation.

Fielding

This incorporates the integration of the system with other systems as well as user training.

Maintenance

One of an ES's requirements is that it must be easily upgraded to cater for new expertise or developments in the problem domain. This requires regular maintenance of the system to install the "new" knowledge and expertise. The system that was developed was split into logical stages which were then interconnected via a menu backbone. This modularity aided the maintenance and upgrading of knowledge and also improved the usability of the system.

The methodology as proposed by Scott , Clayton and Gibson [8] was utilised when developing the current system and can be seen to be that of incremental prototyping. Here prototypes are developed and gradually by means of evaluation and correction are built up to the required system. It must be remembered that methodologies are guides and that the steps mentioned are not always applicable to a particular application therefore they must be used in the context of the application. The reason for not choosing the KADS Methodology was its emphasises on detailed planning throughout the project. The problems of following a detailed planning strategy are :

- The scope of ES projects are difficult to ascertain early on in the project.
- ES's contain uncertainty and the exact output of the system cannot always be predicted.
- It may limit the natural human dynamics of the system.
- It is time consuming.

The methodology used does not neglect planning in the initial stages , as this is important for the success of the system , but in the latter stages uses a form of incremental Prototyping which relies on getting a prototype built and then evaluating and continuously improving it.

CHAPTER SIX

SYSTEM DEVELOPMENT

The knowledge-based system developed to achieve more ideal plastic materials selection is named PLASSEL (PLAStic materials SELector). Its development is described in this chapter. The system development needs to be focused towards providing an 'ideal' system based upon the requirements identified in chapter five, bearing in mind though that an ideal system for all users is probably an impossibility. Some lessons learned from evaluation of the prototype systems were: Interaction between component shape, manufacturing process and material properties must be taken into consideration.: A two stage search procedure is desirable for efficiency reasons and the stage one criteria should be reasonably stable. That is, unlikely to change due to improvements in material properties: A true combined weighting search is required, otherwise iteration of input parameters is often required to generate an initial shortlist.

The definition of an ideal system still requires further enhancement, for example how useful would be a bibliographic database approach as opposed to a numeric approach. The system development should also be used to test the validity and appropriateness of a number of different approaches. Some issues which need clarification before development can commence are:

6.1 System Functionality

Through interviews with various experts, a number of things that the system must be capable of doing have been identified.. These are :

- Simulating a selection consultancy with an expert.
- Let the user create a specific search routine.
- Provide materials information, both textual and numerical.

- Provide information about the available manufacturing processes.
- Illustrate typical property-material matches that have been previously utilised.
- Allow the user to establish typical property value requirements for their application from previous examples.
- Simulate the manufacturing process selection methodology.
- Allow selection to take into consideration environmental factors, energy saving factors and post processing requirements.
- Conduct a piece part cost analysis.
- Allow the user to add custom selection criteria e.g. smell
- Allow the user to store his heuristic experience.
- Provide facilities to modify the database if required.

This range of attributes is certainly beyond the capability of any of the systems currently available or discussed in the literature. Figure 6.0 shows the modules implemented in Plassel.

6.2 Environment Selection

We have established that the system should be IBM PC (or compatible) based. A number of programming languages are available for implementation, conventional languages like 'C' or Pascal, Object oriented languages such as C++ or Smalltalk or AI oriented languages such as Prolog or Lisp. The problem with adopting one of these is that it would take a very long time to build a comprehensive system, all the basic structures of a KBS would have to be implemented manually. This approach, though providing the most flexibility, would probably take the longest to implement. Use of an AI environment like Kappa, Knowledge craft or Inference Art would provide a ready built development environment, however, high cost and difficulty in running the

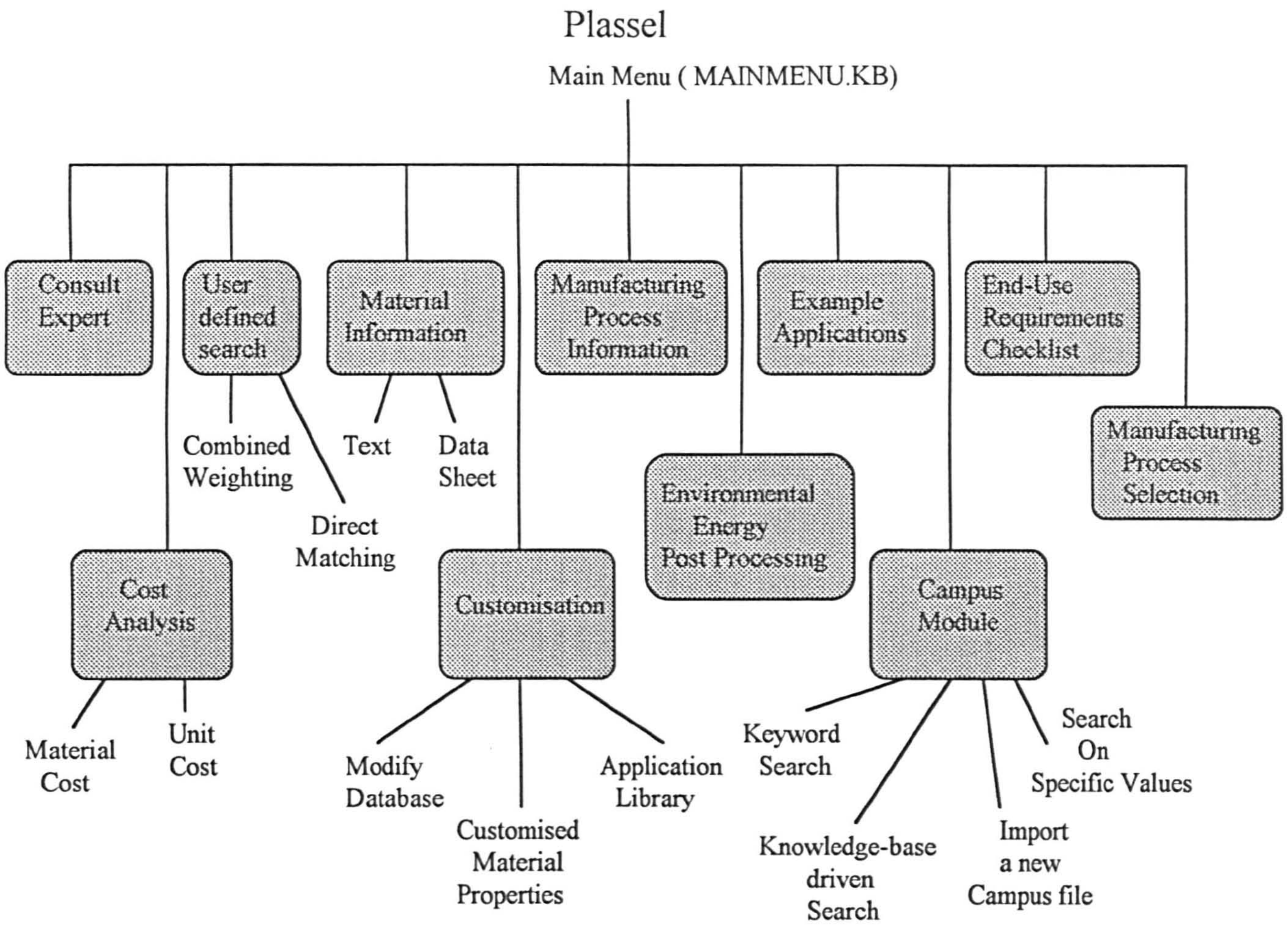


Figure 6.0 : Plassel Module Structure

systems on basic IBM PC's rules them out. A KBS shell would be the most suitable development tool. Most are suitable for our chosen hardware, inexpensive to purchase, and reasonably capable. As is illustrated in 4.7.3, they are the most common tool for developing commercial KBS systems.

Many hundreds of KBS shells are available. The Crystal shell was chosen because:

(1) It proved successful for selection problems in earlier appraisals.

(2) It is widely available, and is the most popular shell utilised in the UK.

(3) The author was familiar with the shell.

6.2.1 The Crystal 3 Expert System Shell

PLASSEL was developed under the *Crystal 3* Expert System Shell from Intelligent Environments. *"Crystal is a PC-based product, requiring 360K RAM for development and 220K RAM at runtime. It runs under DOS, versions 2 or higher. A network version is also available"* (H. Drenth et al. [48]).

As discussed in section 4.7 there are several advantages of using expert system shells over other development tools in developing knowledge-based systems. The Crystal 3 shell has many features that makes it a suitable development tool for this project, they are outlined below:

(i) Crystal 3 allows the developer the ability to manipulate dBase III, ASCII, and Lotus 1-2-3 files, through the provisions of software interfaces. This feature permits the developer to build a system that can interface with other applications and to utilise data provided in these formats.

(ii) Programming using the Crystal 3 is relatively easy to learn, since the shell provides menus of all the functions to select from and the syntax of each rule is automatically checked before another is entered. Crystal 3 provides development interface through a rule base editor and several other functions, including macros and a screen editor. The documentation supplied with the shell is also comprehensive and simple to use. In an evaluation of four PC-based expert system shells that included Crystal by H. Drenth et al. [48], it was found that *"Crystal's biggest advantage is its ease of learning and use."*

(iii) The knowledge representation scheme used in Crystal is production rules. This is suitable for the selection of plastic materials, where the decisions can be considered in terms of (If...Then) rules.

(iv) Crystal 3 provides a simple method for the developer to produce Explanation or Help Screens in their knowledge-based applications. The shell also allows the user to view the inferencing at any stage during the runtime. These facilities allows the user to debug the selection processes used in the system. This is often a major problem with KBS because the complex interactions that can arise between rules and between rules and data.

(v) The Crystal 3 shell allows applications to be developed in a modular way. Information can be exchange between modules through the use of Import and Export functions. Each module can be loaded into memory separately, hence very large applications can be divided into smaller sections that demand less computer memory and are easier to maintain.

6.3 Data Quality

There is an old computing adage that says " Garbage in, garbage out !". The quality of materials data and information utilised by the system will obviously have a crucial bearing on the quality of advice provided by the system. It is clearly impractical for a computer system developer to be responsible for ensuring data consistency, accuracy, relevance etc., and for updating a materials database. Data ownership and responsibility should reside with the people who have the capability to discharge such responsibility. In the case of materials data, there are three possible bodies who can effectively handle such a task, material suppliers, trade organisations, and independent materials consultancies. The commercial plastics material selection systems examined in section three contained an example of each of these approaches. EPOS contained ICI and LNP data, CAMPUS contained data from a consortium of companies to uniform standards, and PLASCAMS contained data from an independent consultancy organisation (RAPRA). All of these data sources are available structured in ASCII like format, but are not directly compatible. The Campus series of databases provides access to the widest range of data of consistent quality, with an increasing number of suppliers contributing. PLASCAMS data features a number of advantages, it is provided independently of supplier (less need to be "economical with the truth") and it actually contains more intrinsic *knowledge* because of the ratings assigned by a panel of experts to the performance of each material on each property, also it deals in generic materials rather than particular formulations and hence covers the complete spread of materials properties available. Clive Maier of "British Plastics and Rubber" magazine considers Plascams and Campus to be complimentary "*Indeed, it would make a lot of sense to use Campus as a grade specifier, after running Plascams as a materials type selector*" [31]. To ensure the best data quality and avoid problems with maintenance and support of data, it makes sense to build a system that can access data from a variety of proven sources. It has been identified in section 5.9, that materials data needs to be separated from the selection knowledge for maximum flexibility. How then should the data be stored? Within a database file structure or in a simple sequential file structure? This really depends on the type of data accesses that will be required. It would be desirable to allow access to both Plascams and Campus data sources within the prototype. Plascams data was structured in a dBase standard format and Campus in ASCII format to evaluate ease of access and implementation within a selection system. If numerical oriented search is the primary characteristic then a database approach should be preferred. As discussed in section 3.5, Campus data is more grade specific and closer to a final material decision than Plascams data which is organised more generically.. A text search facility on Campus data would allow a more direct application search to be performed, for example if we wanted a plastic for wrapping chocolate, we could conduct a text matching search for chocolate in the Campus applications data. This would identify plastics which have previously had an association with chocolate.

The ability to easily import data onto the system is also important, as well as regular updates of data provided by suppliers, it is also necessary to allow authorised users to add custom data to the database. This could be in the form of additional data properties, amended data values, or new, or specialised materials.

6.4 The Plascams Data Module

Plascams data is available in ASCII type format (though not compatible with Crystal ASCII format). Conversion of this into a 'record' based structure is relatively easy to perform. Crystal provides a built-in interface to dBase3+ format files. Plascams data can be converted by using dBase3+ or a special conversion program. The first step requires the creation of an empty database file with the specified structure, suitable for Crystal and the plastic material selection methodology utilised. The two database structures identified as necessary are shown in appendix A. The contents of the ASCII code file can then be appended to the database file. For example if the ASCII code file is named plascams.dat, then typing "append from plascams.dat delimited" in the dBase3+ environment should create a suitable application file. However the sequence of data in the ASCII code file should match to each field of the database file because they are sequential in nature. This approach requires the overhead of dBase3+ being available. This can sometimes be a problem and a direct conversion file was written and is shown in appendix C. **Note, that use of Plascams data requires a license from RAPRA [12].**

An interface to the database files created, DATA_MAT.DBF (the material properties and its values), RANK_DAT.DBF (the material property rankings) is required for system users. This is to allow additional materials to be added (or existing ones to be deleted), and material properties to be modified to reflect the experience of users.

6.5 The Campus Data Module

As discussed in System Requirements (5.1), Plassel should be able to accumulate and utilise extensive materials data from a variety of sources. One of the main disadvantages of the systems reviewed was that they were only able to utilise data from a single source. The data used in all of the knowledge-based systems were taken from the PLASCAMS materials database, which contain data for 351 individual plastic grades.

Although PLASSEL provides a facility to append individual records to its database (DATA_MAT.DBF) manual inputting of a large number of records would be a laborious task, and their inclusion would slow the materials search procedure considerably.

It is suggested that PLASSEL should be able to import and use data from external plastic materials databases. However, one of the problems in computerised materials databases its that there are no specified standards for their design, making the transfer of data from one database management system to another problematic, although attempts have been made in the USA to develop such standards (section 6.5.1.2). Therefore, it is suggested that PLASSEL should be able to import and utilise plastic materials data from

CAMPUS materials databases as well as PLASCAMS. The reasons that CAMPUS was chosen were:

1. The success of CAMPUS has caused many plastic materials manufacturer to join the CAMPUS project. This means that a large number of plastic materials databases are available in the CAMPUS format.
2. CAMPUS is one of the most popular computerised plastic materials database systems among users. Its popularity is reflected in the literature on computerised materials databases [27][54].
3. The CAMPUS format databases are easily available from the plastics manufacturers involved, including BASF and Du Pont, and can be obtained free or at nominal cost.

Program modules were developed for PLASSEL, to import CAMPUS ASCII format data and to used this imported data for plastic materials selection.

6.5.1 Conversion of CAMPUS ASCII data

Two forms of CAMPUS databases are available from the manufacturers involved in the CAMPUS project. They are an ASCII format, and a compressed, binary format. As the binary code was extremely difficult to decipher for the author, only the ASCII format can be used for importing to PLASSEL.

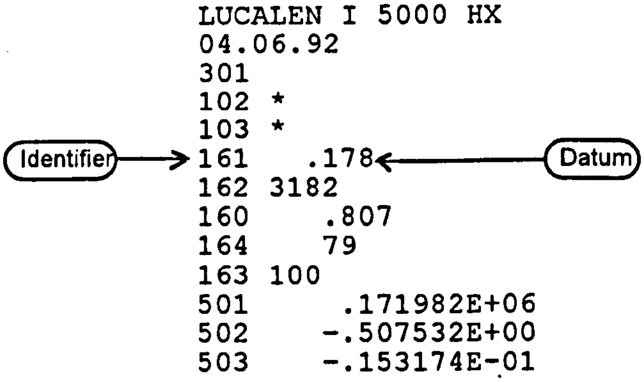
There are currently no specified standards for materials database design. Hence many computerised materials database systems use proprietary structures for storing materials data. This is true for the CAMPUS group of databases. Whereas a common structure for ASCII format database files that is accepted by many software packages, consists of a fixed number of fields, separated by delimiters (often commas), with a new line for each record, the ASCII database structure used for CAMPUS is more complicated.

6.5.1.1 Structure of CAMPUS ASCII data

Each CAMPUS database consists of three ASCII files, with the file extensions, ASC, PRP, and TXT. The information and data for the materials are stored in the ASC and TXT files. The ASC file contains the materials property data for each material in the database, while the TXT file contains general information for the materials.

The ASC file consists of sequential lines of text for each field in a record. The length of each record is not fixed, some records are longer than others, their size varies depending on the available data for the material concerned. An extract from an ASC file showing part of a record is given in Fig. 6.1.

Figure 6.1 : CAMPUS.ASC file extract.



```
LUCALEN I 5000 HX
04.06.92
301
102 *
103 *
161    .178
162 3182
160    .807
164    79
163 100
501      .171982E+06
502     -.507532E+00
503     -.153174E-01
```

Each record in the ASC file begins with the name of the plastic material, followed by the date the data was last updated. The lines that follow are the materials property data, each consisting of an identifier and, if applicable, the datum. The meaning of the identifier is found in the PRP file (Appendix C.2).

For example, the identifier 102 means that the datum in that line is the stress at yield (50mm/min) of the material in MPa.

6.5.1.2 A structured ASCII format for the databases.

The CAMPUS ASCII data files could be converted into dBase III files, since Plascams data has been converted this way and uses the Crystal dBase III interface, and it was thought that the same knowledge base could be applied to the converted CAMPUS data. An alternative was to convert the ASCII file into a more conventional ASCII database arrangement, which can be handled by the Crystal ASCII interface more reliably and quickly than the existing CAMPUS structure. The conversion of the CAMPUS ASCII files into a dBase format is inappropriate. The reasons are as follows:

(i) The data so far used in PLASSEL was obtained from the PLASCAMS plastic materials database. This database contains a significantly different set of materials properties compared to the CAMPUS database, hence the existing knowledge base in PLASSEL was unsuitable for the CAMPUS data. Therefore it was necessary to write a new knowledge base to use CAMPUS data.

(ii) The conversion of the ASCII files to a dBase format would require the ASCII file to be converted to a more conventional ASCII format database structure (i.e. into fields separated by delimiters), before it can be imported into a suitable program that can write dBase III format (DBF) files. Hence, an additional stage, and an additional program, would be required for the conversion of the CAMPUS database files to a dBase III format, as compared to the conversion to a structured ASCII format.

As previously mentioned, there is no single accepted standard for the design of materials databases (C.K. Bullough [27]), hence the exchange of materials data between different database management systems is difficult (M.K. Hossain et al. [54]). However, standards for materials property records in materials databases are being developed, e.g. the ASTM E49 committees and the ISO STEP project (F. Cverna et al. [55]). A standard was developed by ASM International for importing and exporting materials properties data, which used only ASCII characters [56]. ASCII was chosen for the standard because it *"has compatibility with virtually all operating systems and transmission protocols"* [56]. Since if PLASSEL was written using only the Crystal dBase III interface, it could not read or write ASCII files. It was considered that for the knowledge-based system to integrate with other software applications, there was a need to use the Crystal ASCII interface, which can handle these files, since ASCII files are more universally accepted and used than dBase III files.

6.5.1.3 File Conversion

The Crystal ASCII interface reads ASCII files in three main ways:

(1) As consecutive strings in the form of text or numbers (or dates),
(2) as fields separated by commas (the delimiter used by the interface); and
(3) as rows of text surrounded by quotation marks, with a maximum length of fifty characters.

In reading strings or fields, the commands ASreadtxt$, ASreadnum, or ASreaddate are used in the ASCII interface. Therefore the character string to be read from an ASCII file must be either a word, a number, or a date depending on which command is used, e.g. if ASreadnum is used to read a string of letters an error would be generated and the string must be re-read using another read command until it is successfully read.

From examining the CAMPUS ASC and TXT files, which contain materials properties data and materials information respectively, one can deduce three problems for the Crystal ASCII interface to read these files in their original forms. Firstly, some of the plastic materials names contain commas and spaces, e.g. "ULTRAMID A3K, DRY". Crystal will therefore read each string (separated by the spaces) individually, since plastic material names may contain a varying number of strings, the Crystal program used to read the database would have to use a complex and slow procedure to recognise where the end of a material name ends and the next datum begins. Also Crystal would recognise the commas as delimiters and will separate the name of a plastic even further, rendering the apparently simple process of reading the name complicated. To avoid this problem the names must be surrounded by quotation marks. This will allow Crystal to recognise that the character strings should be read as a whole.

The second problem, is that the length of each record in CAMPUS.ASC files are not fixed, as fields in each record are missing. This means that reading each field would most likely require the use of the both commands, ASreadnum and ASreadtxt$, before it is read, this will slow down the search process and the effect is considerable for large data files.

The final problem is that the materials information in CAMPUS.TXT files consists of lines seventy characters in length. Crystal is only capable of reading strings with a maximum of fifty characters, therefore the ASC files must be converted to consist of lines each consisting of 50 characters. These lines must also be 'quoted', since the lines contain spacing and commas.

6.5.1.4 Reasons for writing the conversion programs in Turbo Pascal

It is clear that the conversions cannot be performed by Crystal itself, and another programming language must be used. Turbo Pascal was chosen for a number of reasons. Firstly, Turbo Pascal can read and write ASCII files in a simple manner that is also fast, and can be programmed to arrange the data in CAMPUS ASC files into a structured ASCII database format. Turbo Pascal programs can be compiled into executable forms, this means that the user of PLASSEL would not be required to purchase additional software. In addition, any alterations may be made easily by future programmers who may want to develop PLASSEL further, since Pascal is simple to learn.

6.5.1.5 The CAM2PLAS and CAMPINFO conversion programs

Two programs were written to convert CAMPUS ASC and TXT file formats to ASCII file structures that can be used by Crystal as described in section 6.5.1.3. The listings for these programs are shown in Appendix C.3. The CAM2PLAS program constructs a structured ASCII data file from a CAMPUS ASC file. It also writes a Crystal Export File (CAM2PLAS.EX) that PLASSEL uses identify the source and destination of files for ranking the materials properties in the converted file. The converted files are written with the file extension "ADF" (ASCII Data File).

The CAMPINFO program converts CAMPUS TXT files to files formats that is suitable for Crystal to read. The text in the CAMPUS TXT file, which are seventy characters long, are divided into sets of thirty-five character lines of text by the program. Control characters are used to indicate the start and end of each set of information, and each line is quoted for use with the ASSTYLE (1) mode in the Crystal ASCII interface. The converted text are written with the file extension INF (INformation File) .

6.6 System Interfaces

Two interface issues can be identified :

- The ability to install, access and manage the system.
- The ease of use of the system. This can be broken down into user friendliness for occasional users and for frequent users.

It must be stressed that, however advanced a piece of software is, the lack of a good user interface means that few people will be able, or willing to use it. However, as H. Thimbleby [64] states "*User interfaces are often not as good as they could be: very often they are an afterthought and in themselves may be difficult to understand, causing the user to make unnecessary mistakes.*".

All of the screens for PLASSEL are simplified, using a reduced set of colours to provide clarity in displaying information, and a standard design (a plain with a title bar) to provide functionality and consistency. There is also an ergonomic consideration in selecting the main text and background colours used, as the selection of appropriate colour schemes can reduce eye-strain. "*A lot of research has gone into the best colours for users. NASA found that white on blue was the best combination for the dashboard in shuttles ..., while other studies found that orange on black was more restful for the eyes. One of the most widespread combinations, particularly in accounts' departments, is green on black, which has to be one of the worse. It is up to the user which combination they prefer*" (C. Eade [57]). After experimenting with several colour schemes, the author found that white on blue was the best combination for providing clarity which also appeared user-friendly (compared to white on black, or orange or black, which although provided clarity, appeared austere).

Design inputs by the user are generally made by sliding a cursor along a bar, since they reflect intuitive values and judgements by the designer, this was felt to be the best method of input. Some minor, but useful, additional features were included to improve the user interface. One of these, is the inclusion of a "progress bar" on the display during selection or long processing procedures. Its presence does not only assure the user that the system is still running, but also gives an indication of the time required by the process.

The ability for the user to "escape" quickly to the main menu of PLASSEL at any time by pressing the ESC key is very important and was included. This was possible through the use of the DOS batch file written to integrate the modules in PLASSEL.

Of the areas pursued, the considerations for an effective user interface and for the ability of the system to employ an extensive source of materials data were considered to be fundamental for the success of a plastic materials selection system. This is illustrated in a 1990 DTI survey that investigated how computerised sources of information and data could improve the industrial exploitation of modern materials, it was found that the use of computerised materials databases in manufacturing companies was small in comparison with other source [54]. The study provided some reasons for the resistance to using the computerised systems: *"Engineers are unlikely to use a database if they have to follow a lengthy operator's manual or learn detailed keyboard commands... To some extent the problem of infrequent use would be relieved if there were more commonalty in the 'look and feel' of materials databases or if the data they contain were transferable between database management systems."*.

6.7 Selection Procedures

The need for a number of selection approaches has been identified, such as textual search, direct numerical matching, single property search and multiple property search.. The implementation of these is discussed:

6.7.1 Consult Expert Material Selection.

Both systematic and non-systematic methods of material selection employ a similar fundamental selection strategy. A few candidate materials are identified according to some important attributes, these materials are then compared to arrive at an ordered final shortlist

The process adopted is based upon this approach and is shown in figure 6.2. The procedure followed is generally in accordance with that recommended by Ashby [1] *" It is important to start with a full menu of materials in mind ; failure to do so may mean a missed opportunity. The immensely wide choice is narrowed, first, by applying primary constraints dictated by the design, and then by seeking a subset of materials which maximise the performance of the component. "*

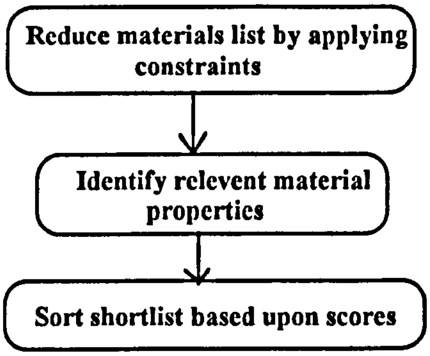


Figure 6.2 : The three stages in the material selection process.

The "Consult Expert" module is regarded as the "heart" of the system and is responsible for recommending a shortlist of candidate plastic materials for the required component. The module is intended to emulate the essence of a consultation with an expert. The module consists of four knowledge based programs:

Manufacturing Process selection (PROCESS.KB)
Materials Property assessment (PROPERTY.KB)

Customised Material Properties (CM1-2.KB)

Environmental, Energy and Post Processing (EEP.KB)

The knowledge bases can be run independently to perform selection by that criteria, but in consult expert they represent the whole selection process. The overall procedure for selection is shown in figure 6.3. The implementation of these is discussed separately.

6.7.2 Manufacturing Process Selection

The manufacturing method is of the greatest significance in determining the successful application of a given material to a design [58]. It is of no profit to select a material which offers ideal properties for the application but cannot be made or produced economically into the required shape. Manufacturing process selection is used to constrain the material property search, so that a shortlist of materials is generated for further detailed evaluation. This represents the first box in figure 6.2. The process for selection of manufacturing process by shape, size, quantity etc. is shown in figure 6.4 It can be divided into four stages, and is a repetition of the overall process shown in figure 6.2. The best way to illustrate how "Manufacturing Process Selection" works is by a demonstration showing all the screens and the user's responses to the questions at all stages. For example, what are the appropriate manufacturing processes for a simple square plastic basket with size 30cm^3.

6.7.2.1 STAGE A

Dialogue with user to identify manufacturing process requirements.

In this stage, the user is requested to answer a set of pre-defined questions about some attributes which are generally considered in selecting manufacturing processes for a component. The user interface is menu driven. This module considers six factors, shape, production rate, size, surface finish, dimensional tolerance and total production volume in the selection process. On-line help is provided to the user to explain both selection mechanism and the terminology used in the system. If the user does not know, or is not sure of the answer to a question, he may choose " I am not sure" as a menu response. In some cases "real examples are cited to enable the user to answer.

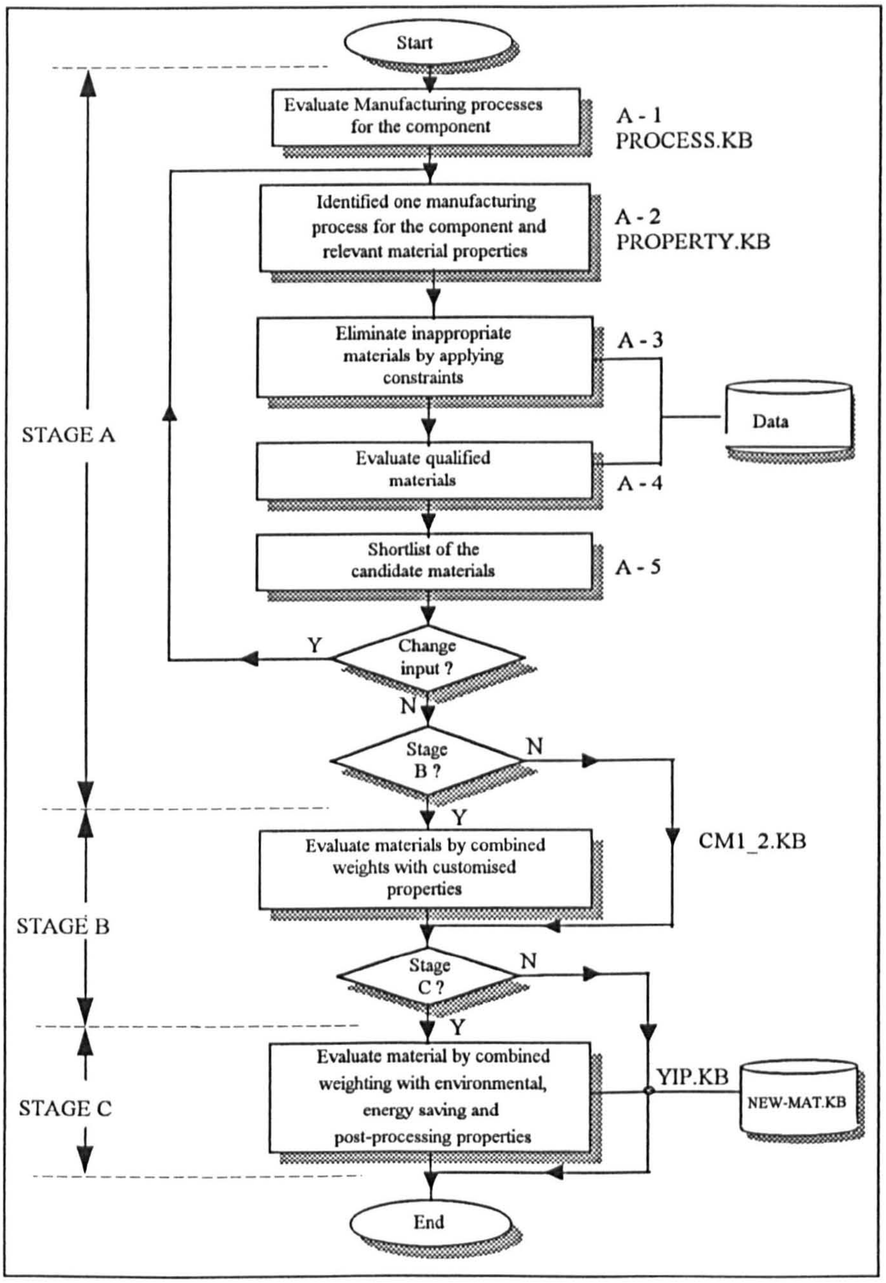


Figure 6.3 : Material Selection Process

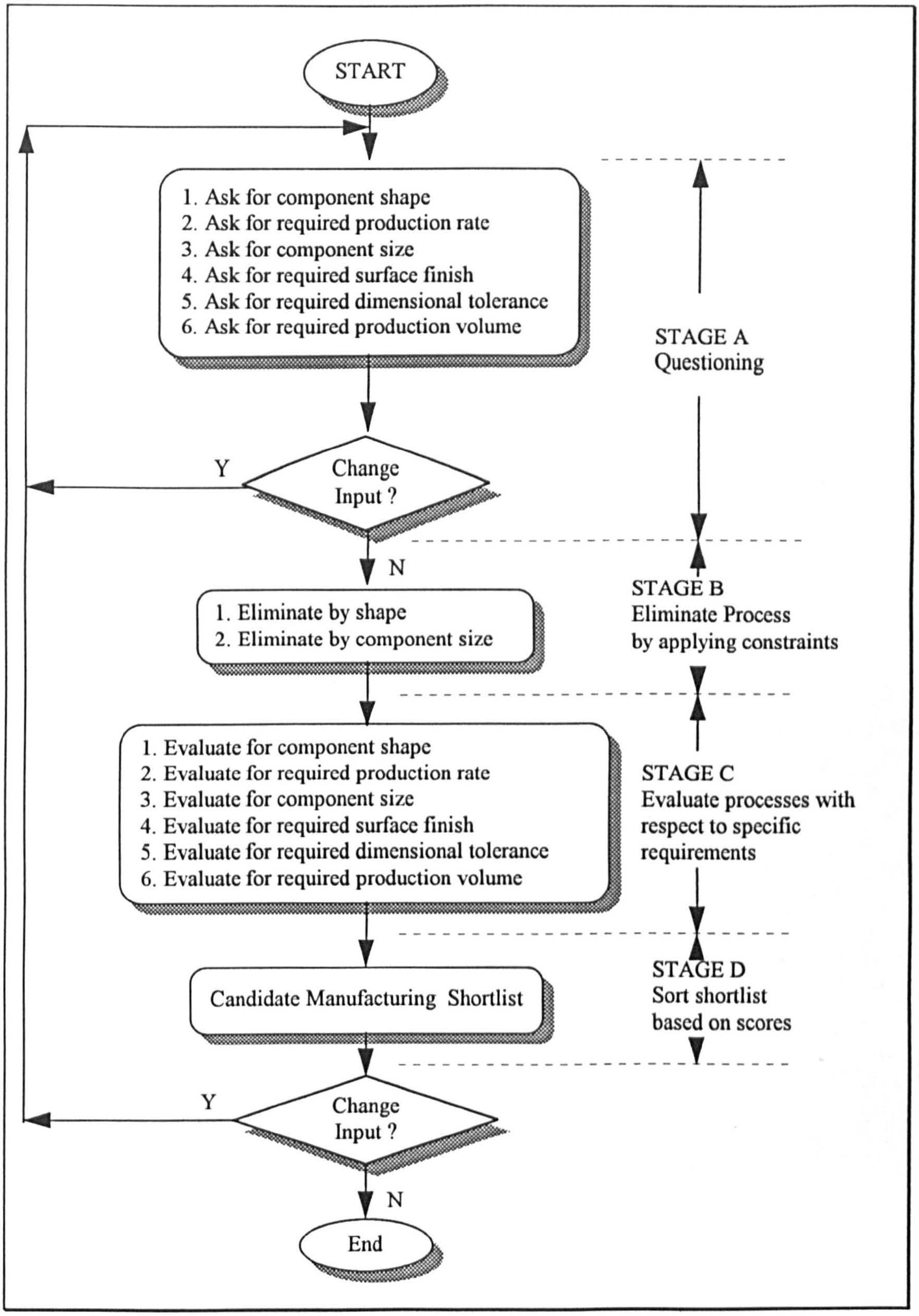
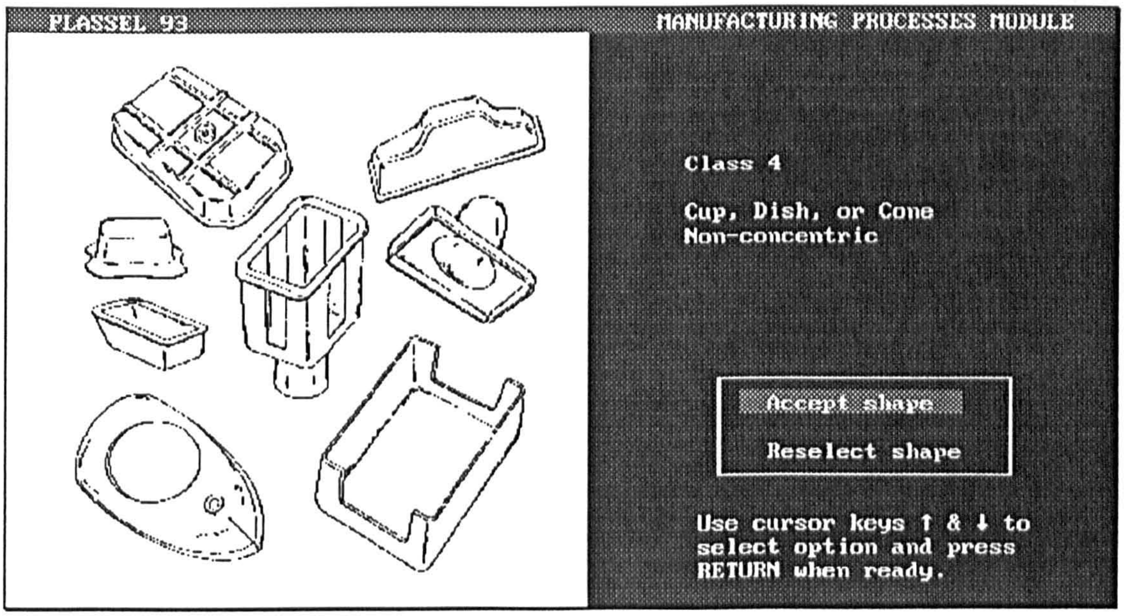


Figure 6.4 : Manufacturing Process selection

STAGE A1: Ask for component shape ?

Shape of the component is the one of the most important factors in selecting its manufacturing processes. Particular processes can only produce specific shapes. Different processes may also prefer particular shapes for optimum performance. According to Paul F. Kusy [7], component shapes can be divided into nine classes. In order to help the user to classify the component shape appropriately, the graphical representation (screen 1) of each class is supported on the screen.



Class 4

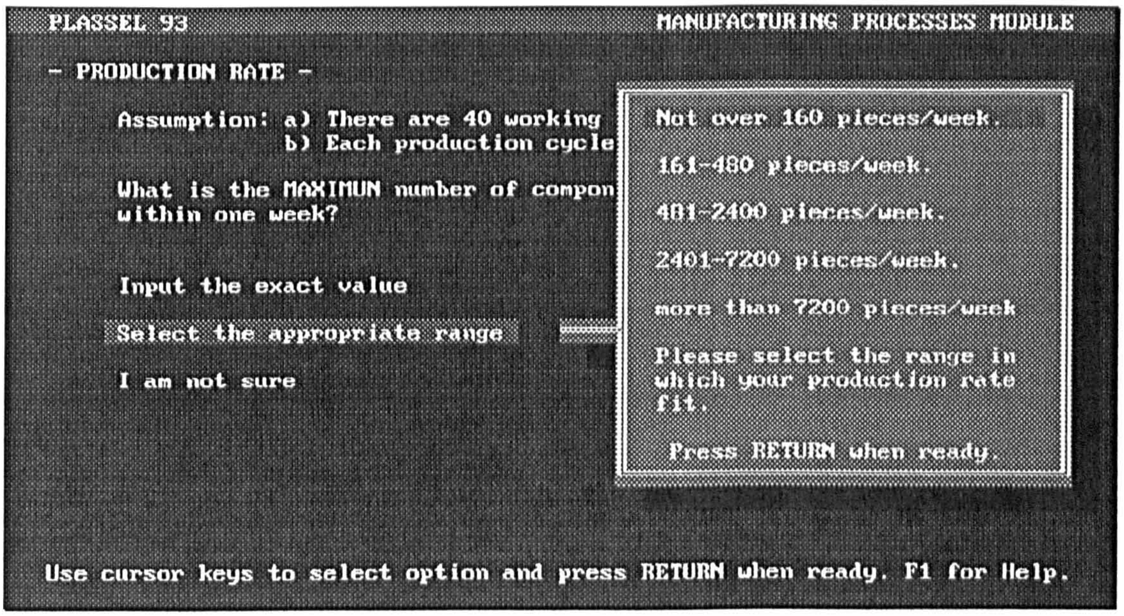
Cup, Dish, or Cone
Non-concentric

Use cursor keys ↑ & ↓ to select option and press RETURN when ready.

Screen 1: Graphical representation of Class 4.

STAGE A2 - Ascertain required production rate

According to Lyndon Edwards and Mark Endean [10], production rates can be generally divided into five ranges (Screen 2). The user can choose any one of them or enter the maximum number of pieces he expects to produce in one week directly. He can also choose a "I am not sure" option, the effect of which is to eliminate this consideration from process selection.



```
PLASSEL 93                                    MANUFACTURING PROCESSES MODULE

- PRODUCTION RATE -

    Assumption: a) There are 40 working   Not over 160 pieces/week.
                b) Each production cycle
                                          161-480 pieces/week.
    What is the MAXIMUN number of compon
    within one week?                      481-2400 pieces/week.

                                          2401-7200 pieces/week.
    Input the exact value
                                          more than 7200 pieces/week
    Select the appropriate range
                                          Please select the range in
    I am not sure                         which your production rate
                                          fit.

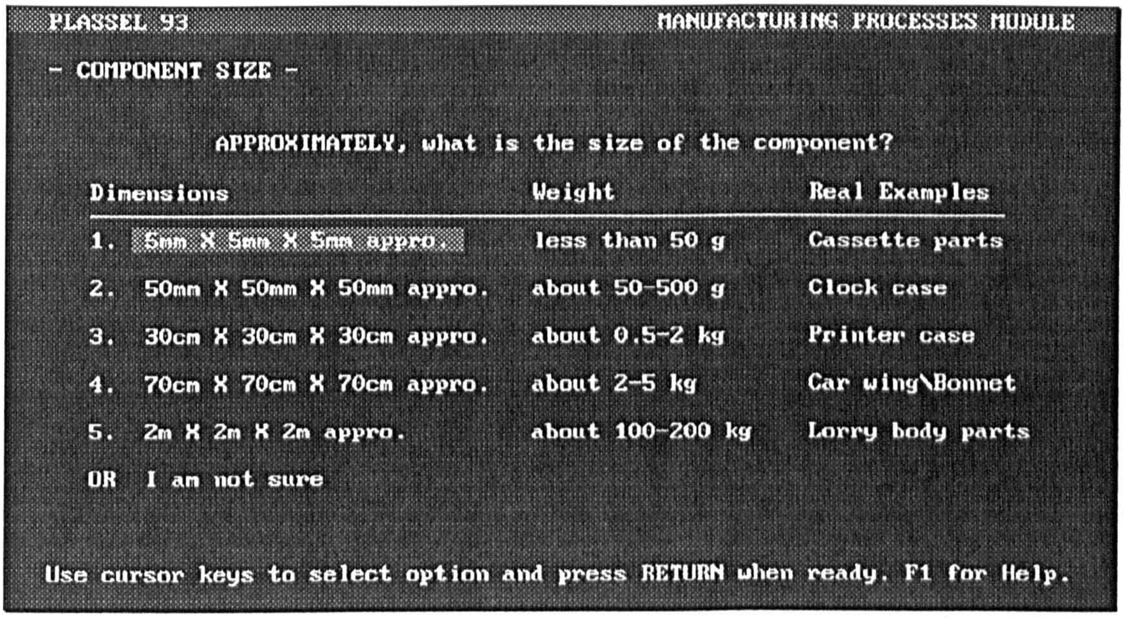
                                           Press RETURN when ready.


Use cursor keys to select option and press RETURN when ready. F1 for Help.
```

Screen 2 : Production Rate Options

STAGE A3 - Elicit component size

Component size is a important factor in selecting manufacturing processes for the component. According to Mr D. Wimpenny (ROVER ATC), size can normally be divided into five classes (screen 3). Some examples are given for each class to help the user choose appropriately.



PLASSEL 93 MANUFACTURING PROCESSES MODULE

- COMPONENT SIZE -

APPROXIMATELY, what is the size of the component?

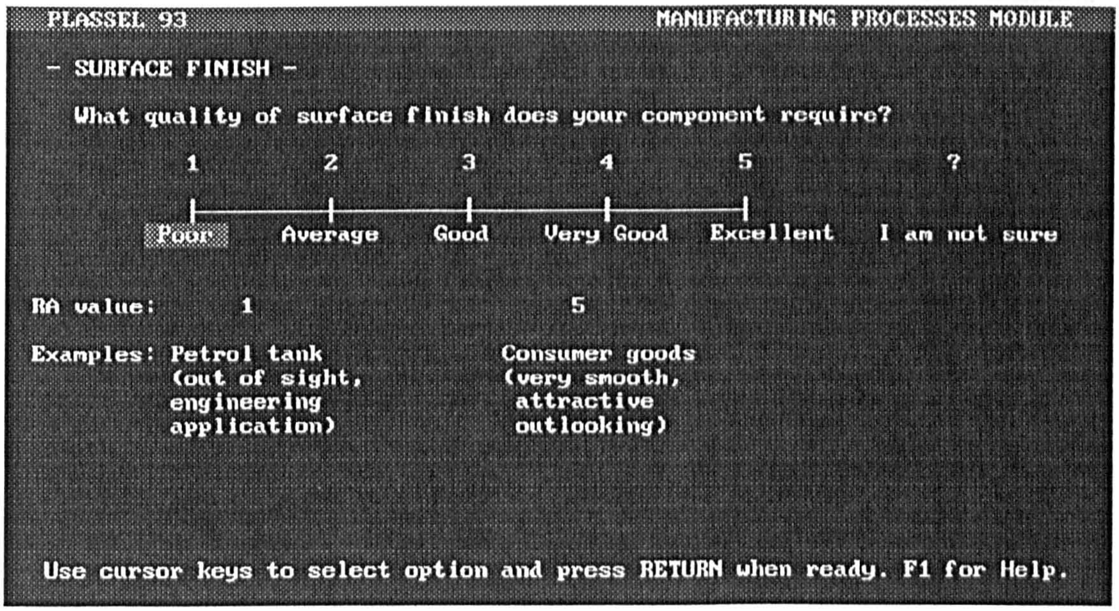
Dimensions	Weight	Real Examples
1. 5mm X 5mm X 5mm appro.	less than 50 g	Cassette parts
2. 50mm X 50mm X 50mm appro.	about 50-500 g	Clock case
3. 30cm X 30cm X 30cm appro.	about 0.5-2 kg	Printer case
4. 70cm X 70cm X 70cm appro.	about 2-5 kg	Car wing\Bonnet
5. 2m X 2m X 2m appro.	about 100-200 kg	Lorry body parts
OR I am not sure		

Use cursor keys to select option and press RETURN when ready. F1 for Help.

Screen 3 : Elicit component size

STAGE A4 - Elicit required surface finish

In this stage the user is requested to indicate the importance of the surface finish required for the component. According to the expert, Mr D. Wimpenny, surface finish can be generally divided into five grades (screen 4). The user can choose any one of them to indicate the weighting of importance of surface finish for the component. Some examples are given to help the user to choose appropriately.



```
 PLASSEL 93                                  MANUFACTURING PROCESSES MODULE

 - SURFACE FINISH -

  What quality of surface finish does your component require?

          1         2         3         4         5            ?

          |---------|---------|---------|---------|
        Poor     Average     Good    Very Good  Excellent   I am not sure

RA value:        1                      5

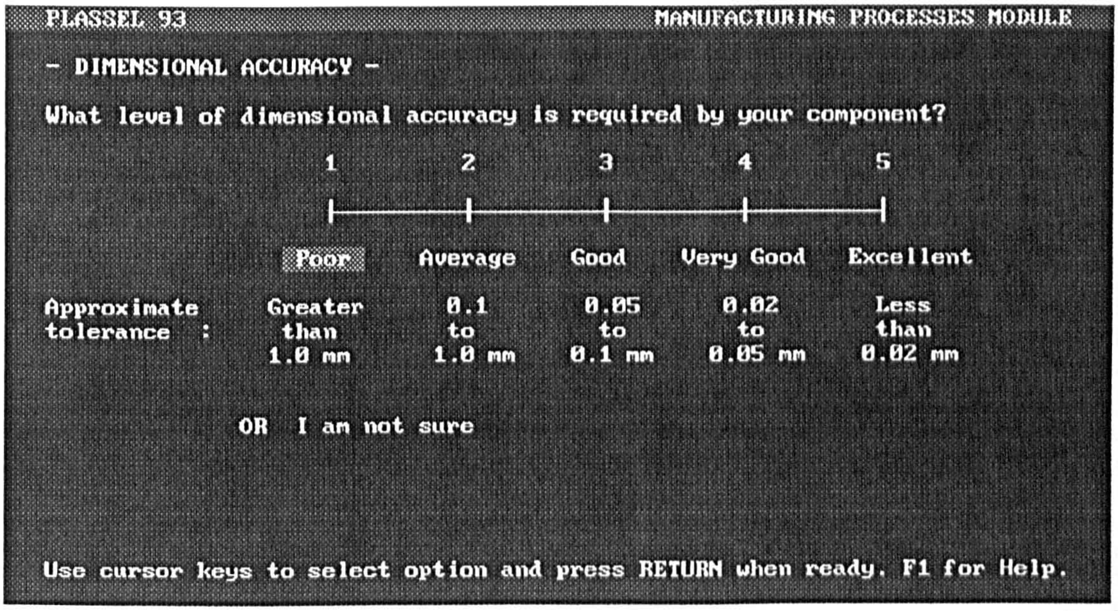
Examples: Petrol tank             Consumer goods
          (out of sight,          (very smooth,
          engineering              attractive
          application)             outlooking)


 Use cursor keys to select option and press RETURN when ready. F1 for Help.
```

Screen 4 : Elicit required surface finish

STAGE A5 - Elicit required dimensional tolerance

At this stage the user is requested to indicate the importance of dimensional tolerance required for the component. According to the expert, Mr D. Wimpenny, tolerance can be generally divided into five ranges (screen 5). The user can choose any one of them to indicate the importance of tolerance to the component.



```
PLASSEL 93                                    MANUFACTURING PROCESSES MODULE

- DIMENSIONAL ACCURACY -

What level of dimensional accuracy is required by your component?

                       1        2        3        4        5
                       |--------|--------|--------|--------|
                     Poor    Average    Good   Very Good  Excellent

Approximate         Greater     0.1      0.05     0.02      Less
tolerance  :         than       to       to       to        than
                    1.0 mm    1.0 mm   0.1 mm   0.05 mm   0.02 mm

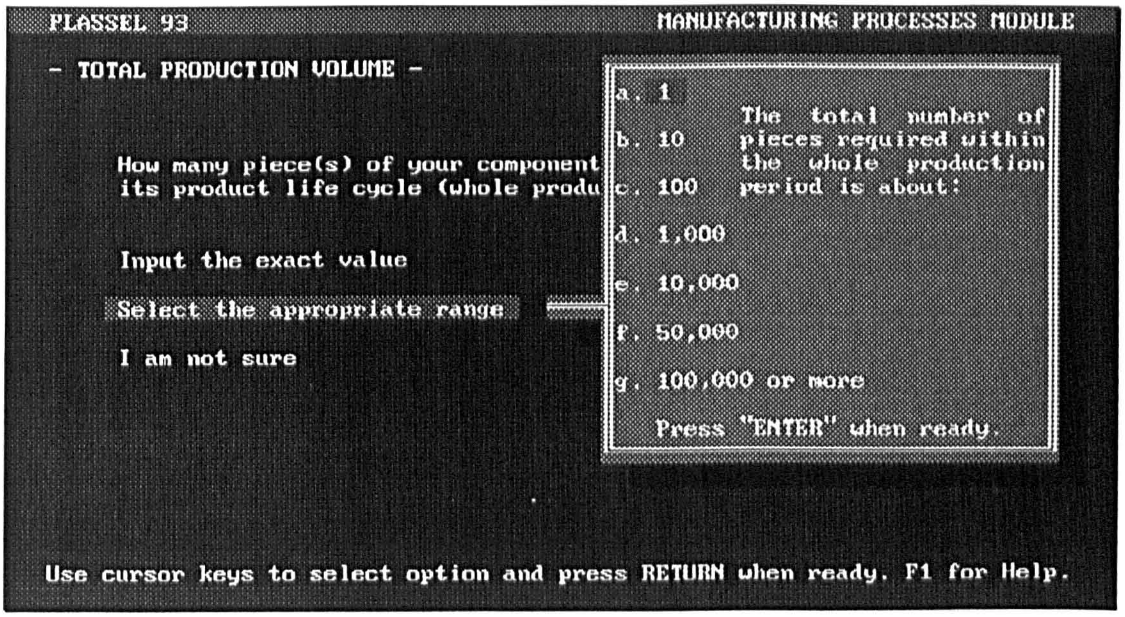
                 OR  I am not sure

Use cursor keys to select option and press RETURN when ready. F1 for Help.
```

Screen 5 : Elicit required dimensional tolerance

STAGE A6 - Elicit the required production volume.

Total production volume is a very important factor in selecting manufacturing processes for a component. It will directly affect the manufacturing cost/unit of the component. The tooling cost and necessary labour cost vary for different processes. For example, the tooling cost for injection moulding is higher than that of casting but labour cost for casting is higher than that of injection moulding. If only ten components are required, casting will be relatively preferred because the tooling cost of injection moulding is very high which cannot be overcome by such low production volume. According to Paul F. Kusy [7], production volume can be generally divided into seven ranges. The user is requested to select any one of them (screen 6) or directly input the exact number of pieces he experts to produce.



PLASSEL 93
MANUFACTURING PROCESSES MODULE

- TOTAL PRODUCTION VOLUME -

How many piece(s) of your component
its product life cycle (whole produ

Input the exact value
Select the appropriate range
I am not sure

The total number of pieces required within the whole production period is about:

a. 1
b. 10
c. 100
d. 1,000
e. 10,000
f. 50,000
g. 100,000 or more

Press "ENTER" when ready.

Use cursor keys to select option and press RETURN when ready. F1 for Help.

Screen 6 : Elicit the required production volume

6.7.2.2 STAGE B

Eliminate inappropriate processes by applying constraints.

Particular manufacturing processes can only produce specific shapes and sizes. Those processes which cannot produce the desired shapes and sizes are eliminated, leaving a list of qualified processes.

STAGE B1 - Eliminate by Shape.

Particular manufacturing processes can only produce specific shape. In this stage those processes which cannot produce the desired shape of the component will be eliminated leaving a list of qualified processes. The value judgements on the manufacturing processes (the heuristic rules of thumb) on this attribute were given by expert, Dr G. Smith (ROVER ATC).

For instance:

If class 4 is selected for the plastic basket, all the manufacturing processes with a value judgement of 0 on this shape will be eliminated, such as rotational moulding, blow moulding, extrusion, sheet forming and pultrusion.

STAGE B2 - Eliminate processes by component size

Particular manufacturing processes can only produce specific sizes. Those qualified processes (after the previous stage) which cannot produce the desired component size will be eliminated leaving a list of qualified processes for subsequent evaluation. The value judgements of the manufacturing processes or the heuristic rules of thumbs on this attribute were given by expert, Mr D. Wimpenny (ROVER ATC).

For instance:

If the size of the basket is 30cm^3, all the manufacturing processes with a value judgement of 0 on this size will be eliminated. Fortunately, all the qualified manufacturing processes can produce this size of component. No further process is eliminated at this stage.

6.7.2.3 STAGE C

Evaluate qualified process with respect to specific requirements.

The evaluation method employed in this stage is Weighted Property Index (WPI) discussed in section 3.3.5. WPI is the best tool for choosing between the competing property requirements in a general engineering situation [3]. It is used for evaluating the overall combined performance of manufacturing processes for criteria such as shape, size, production rate, production volume, surface finish and dimensional tolerance. It can also consider the trade-off of performance and economic factor by considering cost as one of the properties, usually with a high weighting factor.

Evaluation of manufacturing processes by WPI.

$$WPI_j = W_j * R_j \qquad \text{Equation 8}$$

where WPI_j = Weighted Property Index for manufacturing process i

W_j = Weighting factor for selection criteria j input by the user

R_j = Value judgement (rating) on selection criteria j

Overall Process Performance Index:

$$PPI_i = \sum_{j=1}^{N} (W_j * R_j) \qquad \text{(Equation 9)}$$

where PPI_i = Overall Performance Index for manufacturing process i

N = Number of selection criteria specified

To utilise WPI we need to have ratings for each process against each criteria. It is difficult to obtain these from a single source. The ones adopted where provided by Dr G. F. Smith (Rover ATC), Mr David Wimpenny (Rover ATC) and Paul F. Kusy [7]. Heuristic rules of thumb should be applied in the evaluation process in order to make the result more reliable and similar to those of a human expert. According to Dr G. Smith (ROVER ATC), the six factors encountered have different ratings of importance in actually selecting a manufacturing processes. The ratings are comparatively ranged from 1 to 5. Rating 5 being most critical and 1 being least critical to process selection. The following table shows the rating for each factor in the total score as advised by Dr G. F. Smith.

Factor	Rating of importance
1. Component shape	3
2. Production rate	4
3. Component size	1
4. Dimensional tolerance	2
5. Surface finish	4
6. Total production volume	5

Total (highest) score for overall performance : 190

Table 6.0 : Rating of importance of selection factors

Stage C-1- Evaluate processes by component shape (Score represents: 30/190)

At this stage, the qualified processes are evaluated (or scored) according to their ability to produce the desired shape of the component. The value judgements (rating) of the manufacturing processes were given by the expert, Mr D. Wimpenny (ROVER ATC).

For instance:

The rating of Compression Moulding for producing a class 4 shape is 5. It is very capable and will a high WPI contribution (the highest score) of 30 (5*(30/5)) on this attribute. The rating of Contact moulding on this attribute is just 3. It is relatively less capable and only scores 18 (3*(30/5)).

Stage C-2 - Evaluate process by production rate (Score represented: 40/190)

At this stage, the manufacturing processes are evaluated with respect to the importance of the production rate required for the component. The value judgements (ratings) of the performance of various manufacturing processes on this attribute, ranged from 1 to 5 are adapted from Lyndon Edward and Mark Endean [10].

For instance:

If the weighting for the importance of production rate entered by the user is 3 (2000 pieces/week is within the 3rd range) and the rating of Compression Moulding on this attribute is 2, Compression Moulding will obtain a score of 9.6 (3*2*(40/25)).

Stage C-3 - Evaluate processes by component size (Score represented 10/190)

Different manufacturing processes prefer particular sizes for optimum performance. Consequently the manufacturing processes can be scored according to their capability in producing the desired size of the component. The value judgements (ratings) of the manufacturing processes on this attribute ranged from 1 to 5 were given by the expert, Mr D. Wimpenny.

For instance:

If the size of the component is 30cm^3, the rating of 4 for Compression Moulding on this attribute indicates that Compression Moulding is relatively preferred for producing this component. It will obtain a score of 8 (4*(10/5)), on this attribute.

Stage C-4 - Evaluate processes by surface finish (Score represented: 40/190)

At this stage the manufacturing processes are evaluated with respect to the quality of the surface finish required for the component. The value judgements (ratings) of the performance of various manufacturing processes on this attribute are ranged form 1 to 5. The processes which can generate better surface finish will have relatively higher ratings. The ratings are provided by the expert, Mr D. Wimpenny, with respect to their relative performance on this attribute.

For instance:

If the weighting of importance of surface finish entered by the user is 4 (very good) and the rating of Compression Moulding on this attribute is 3, Compression Moulding will obtain a score of 19.2 (4*3*(40/25)).

Stage C-5 - Evaluate processes by dimensional tolerance (Score represents: 20/190)

At this stage, the manufacturing processes are evaluated with respect to the importance of the tolerance required for the component. The value judgements (ratings) of the performance of various manufacturing processes on this attribute range from 1 to 5. The ratings are provided by the expert, Mr D. Wimpenny.

For instance:

If the weighting of importance of tolerance entered by the user is 3 (good) and the rating of Compression Moulding on this attribute is 4, Compression Moulding will obtain a score of 9.6 (3*4*(20/25)) on this attribute.

Stage C-6 - Evaluate processes by production volume (Score represented: 50/190)

Production volume is the most critical factor in selecting manufacturing processes for a component. It directly affects the relative processing costs for the component. At this stage, the manufacturing processes are evaluated with respect to their capability to produce the desired number of components by considering their relative processing costs (per unit).

The relative processing costs (per unit) of the 16 manufacturing process covered by the system vary with the number of pieces required. The value judgements (ratings) of the manufacturing processes on their ability to produce the desired number of component are ranged from 1 to 9 relatively and are provided by Paul F. Kusy [7]. The processes with rating 1 are least preferred because of their relatively high processing cost for the desired production volume.

For instance:

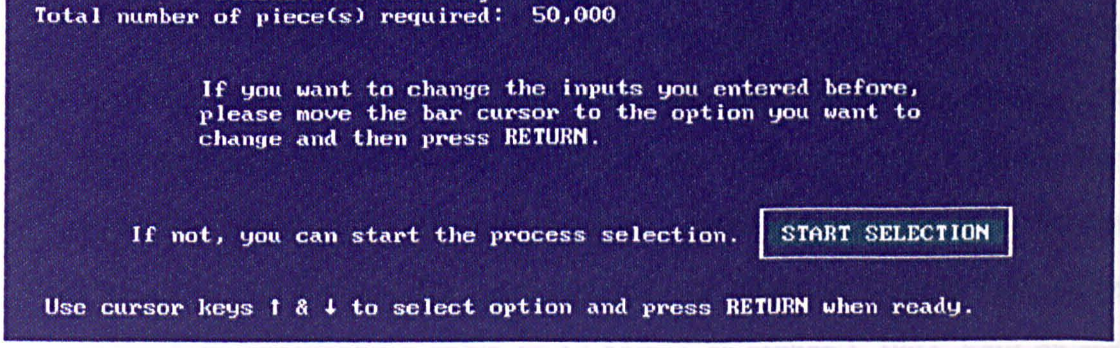
If 50,000 pieces are required, Compression Moulding has a value judgement of 9 because its processing cost (per unit) for this production volume are relatively the lowest. The score obtained by Compression Moulding on this attribute will be the highest, 50 (9*(50/9)).

6.7.2.4 STAGE D

Sort shortlist based on scores

At this stage, a shortlist of manufacturing processes ranked in descending order of their total scores on the overall combined performance is generated. The relative flexibility and the relative processing cost (per unit) of each manufacturing process are also provided. Flexibility here means the ease with which a process can be adapted to produce different products or product variants. The higher the rating, the more flexible will be the process relatively. The ratings of the processes on flexibility are provided by Dr G. Smith. Consequently the user can consider the trade-offs between "combined performance", "cost" and "flexibility" of the processes and select the most suitable one for himself.

To improve user friendliness, before the shortlist is sorted and displayed, a screen showing all the selections made, is shown and the user requested to confirm the inputs, before further processing (screen 7). The module also provides a "What if" function for the user. He is allowed to change one or more inputs and then test the changes of the results. This can encourage the user to consider the relationship



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 PLASSEL 93                                    MANUFACTURING PROCESSES MODULE

                         SUMMARY OF YOUR INPUTS

    Component shape:  4. Cup, Disk or Cone - Non-Concentric
          Maximum production rate:  481-2400 pieces/week.
                   Component size:  30cm X 30cm X 30cm appro.
                   Surface finish:  Very Good
              Dimensional accuracy:  Good
 Total number of piece(s) required:  50,000

              If you want to change the inputs you entered before,
              please move the bar cursor to the option you want to
              change and then press RETURN.

          If not, you can start the process selection.  START SELECTION

 Use cursor keys ↑ & ↓ to select option and press RETURN when ready.
```

Screen 7 : Summary input manufacturing process screen between the inputs and the results to achieve an optimum solution. For example, if the component shape is changed from Class 4 to Class 9 and the size is changed to 70cm^3, the result on the shortlist will change.

6.8 Consult Expert - Materials Property Assessment

The knowledge-base Property.KB is automatically loaded by the system. Very often a full choice of processes may not be available to the component designer, for example the investment required for a new process may not be justified, or the company has familiarity with and a desire to use a particular process. CONSULT EXPERT allows the user to select his preferred process from the recommended list for further processing.

At this stage the preferred process decision is used to eliminate materials that cannot be processed by the chosen process. This can drastically reduce the number of materials that it is necessary to evaluate. This is very important because often many thousands of materials need to be assessed, each having hundreds of possible assessable properties. Two important aspects of the subsequent material evaluation are

(1) Plascams material data is used for the initial selection. This has two key advantages, firstly Plascams contains data on generic groups of materials so that all categories can be assessed, and secondly, the materials data contains ranked values. This means that we can ask the user to indicate preferences rather than having to specify particular acceptable values. For example, when indicating the required tensile strength, it is easier to indicate a requirement for good strength by selecting 8 on a 1-10 scale rather than specifying a value of 32 MPa (or higher). Plus, how do we know that it is a value of 32 MPa or higher that we need ?

(2) A Combined Weighting evaluation method is utilised. A good material selection process should allow for a overall balanced assessment of suitable materials. It should allow the user to judge whether a slightly lower value on a property is compensated for by excellent performance on others. The normal selection process of sequential property search (as used in Campus and Epos) does not allow this evaluation to be performed very easily. Often, using this approach, the search ends in no suitable materials being identified, and further searches have to be performed using more relaxed criteria. Within the Combined weighting search, the following formula for evaluating materials is applied (based on A.A. Hopgood [56]).

Total score for material i,

$$= \sum_{j=1}^{N} [\text{ Performance value}(i,j) * \text{Weight}(j)] \qquad \text{(Equation 10)}$$

where

performance value (i,j) is the performance value judgement of material i for property j;

weighting (i) is the weighting value entered by the user for property j to indicate the importance of this property to his component; and N is the number of the material characteristics specified.

If the user has answered "Not Sure" to some questions in stage 2, zero will be assigned to the weight(j) for the corresponding properties. This means that score being calculated will remain unaltered.

A "Bayesian updating" style inferencing method is used by the system to deal with uncertainty. Provided with an initial probability of some hypothesis, Bayesian updating can be used to modify that probability with new evidence. In the case of selecting materials, the probability being updated represents the suitability of the material for the specific application. It is interpreted as a score for each material because it is determined independently of one another and expressed as odds. In "Consult Expert" of PLASSEL, the value judgements are treated as probabilities of events in updating the score for each material. The amount by which the score is updated is determined from the 'desired' ratings entered by the user for each property concerned.

6.9 Consult Expert - Material Properties.

Plascams data contains information on 48 materials properties, split into general & electrical properties, mechanical properties and chemical & radiation resistance properties. Designers seldom think directly about specific material properties, instead they need to translate product operational requirements into material property values. this is a task which requires materials expertise and knowledge. According to the experts (Dr G. F. Smith, Mr D. Wimpenny), the key attributes we need to know about are:

Stiffness
Strength
Impact Strength
Operating temperature
Weight
Appearance
Resistance to UV radiation

Chemical resistance (Water)
Chemical resistance (Aliphatic hydrocarbons)
Chemical resistance (Aromatic hydrocarbons)
Chemical resistance (Halogens).

"Consult Expert" requests desired ratings for these which then can be, either, directly matched against material properties stored in the database or against a combination of properties. For example, strength could be defined as a combination of the properties, 'Toughness @ 20C', 'Tensile strength' and 'Heat distortion temperature @ 1.8MPa'. To aid usability, desired ratings are entered via a sliding pointer on a bar marked one to ten.

A shortlist in which the top thirty candidate materials are ranked in descending order based on their scores for overall combined performance, is generated. At this stage, Plassel allows the user to change one or more inputs in this stage and then repeat selection to test for changes in the recommendations. The user can also print the suggested material shortlists.

6.10 Consult Expert - Customised Properties.

Very often when selecting materials, some special non standard property may be of extreme importance, for example when searching for a plastic for vehicle wheel trims in-mould paintability may be essential. The ability to add specific search criteria can allow companies to customise the materials selection system to their own unique requirements. Another example may be that the material may be required to be efficiently machined by a particular machine, or , be bonded using a particular type of glue. None of the existing systems uncovered in the literature search allows this facility fully.

At this stage 'Consult Expert' asks if a customised search is required, if yes!, it loads up the CM1_2.KB knowledgebase and conducts a combined weighting search on customised properties previously specified. The search can be conducted on the shortlist from the previous ' Consult Expert' module or on the full material data file. The procedure for entering customised property search criteria and data is described in section 6.18. This module then generates a further shortlist, and requests if environmental, energy saving, and post processing considerations want to be taken into account. If so, the next module is loaded.

6.11 Consult Expert - Environment, Energy and Post Processing.

Increasingly not only manufacturing methods, materials properties, and component design can affect materials selection, but environmental, energy utilisation, and post processing factors are increasingly important. At present there is very little quality data available to aid in considering these factors fully in selection, however, because of legislative and consumer pressure, more is becoming available. Often a particular company will have to (at great cost) generate its own data. A material selection system needs to allow this data to be stored as it becomes available, and to allow selection against it. This section currently only contains typical data obtained from the Rover Advanced Technology Centre. This module can be utilised as part of 'Consult Expert' or run independently and is more fully described in section 6.20.

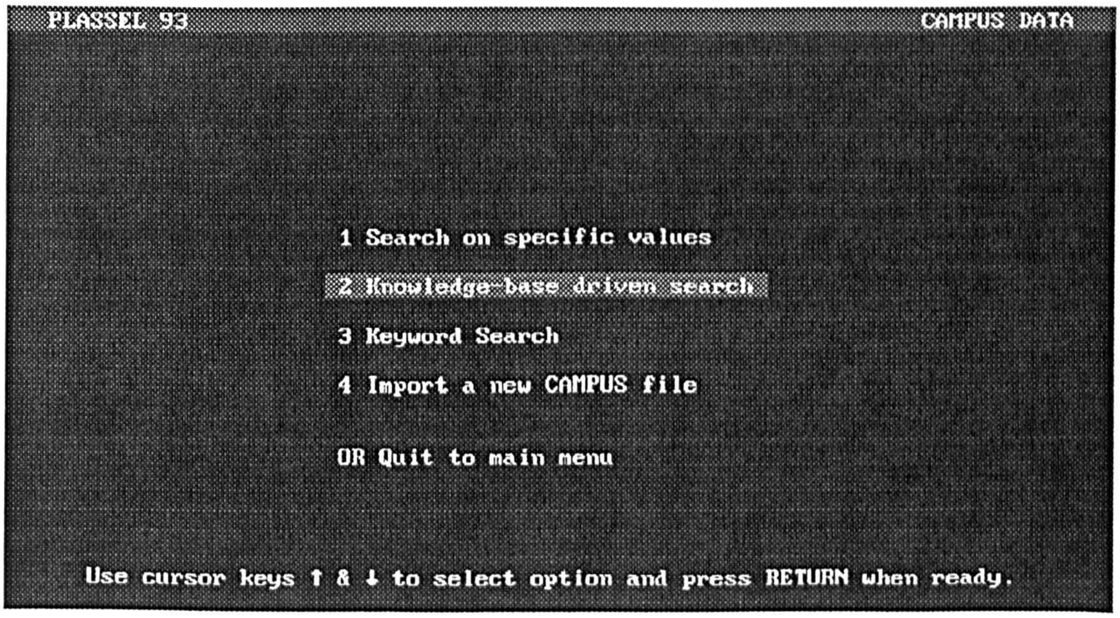
This represents the end of the ' Consult Expert' module. We have a shortlist of suitable materials that can be further investigated, in four ways :

1. We can obtain further information, from Plassel by querying textual and property data on file.
2. Further what-if scenario's can be conducted using either 'Consult Expert' or the individual selection modules.
3. We can consult a suppliers salesperson.

4. We can search and consult Campus data in Plassel, to identify specific grades and formulations that may be available from the different Campus suppliers. Details of the Plassel Campus data search routines are provided in the next section (6.12).

6.12 CAMPUS Data Search Routines

A key attribute of an 'ideal' materials selection system is the need to provide access to a wide variety of data sources. Campus data has a number of advantages and disadvantages for the purposes of material selection. Among the key advantages are its uniform standards, wide range of contributors, and level of detail. It is of little benefit though, to just duplicate the selection methodology developed for Plascams data in this research. The Campus search routines need to explore other approaches. A key area is to: examine the benefits of ASCII structured data versus database structure. Screen 8 shows the Campus data modules developed. A major disadvantage is that the Campus materials data does not contain ranking information. For a combined weighting search, ranked properties are desirable.



Screen 8 : Campus Module Menu Options

6.12.1 Ranking of the materials properties

The rankings applied in PLASSEL were provided by the PLASCAMS database that was used. However, CAMPUS databases do not supply rankings of materials properties. Therefore a PLASSEL module (CAMPURNK.KB) was written to rank certain materials properties for all the materials stored in PLASSEL ADF files. The ranked files have the file extension ARF (ASCII Rank File). The ranking is performed by finding the maximum and minimum values for each property, then the range for that property is split into ten equal divisions. The rank of a material for that particular property is then allocated according to which division that property for the material lies in. A rank value from 1 to 10 (low ranking to high ranking) is then assigned according to whether a high value or a low value is preferred for that property. A zero is assigned if the datum for that property is not available.

6.12.2 Search on Specific Values Module

It was considered that PLASSEL should provide an optional method to perform a more restrictive search for materials, than the weighted property method, based upon actual materials properties values. This option would help the user to make the final material selection decision, if the user has one or more required materials properties values. This option is provided by the Search on Specific Values module (CAMPUS_1.KB).

The selection in this module is performed by the elimination of materials in the selected ADF file that do not have the user-defined properties. The user assigns the desired properties with maximum and minimum limits. The selected material(s) must have all the required properties falling within the range specified.

6.12.3 Knowledge-base Driven Search Module

The Knowledge-base Driven Search module (CAMPUS_2.KB) uses the .ARF (ranked properties) files to perform a "Bayesian updating" process to select suitable materials Bayesian updating is the continuous process of modifying an initial probability of a hypothesis according to updated evidence available. In the case of the plastic material selection system, the probability being modified is the likelihood that a given material is suitable for a defined application. Since the probability of each material considered in the selection is actually determined independently of each other, it is interpreted as a score rather than a ratio.

The amount by which the score is updated for an individual material is calculated from the weightings supplied by the user for each property considered and the "performance value judgements" (A. Hopgood [38]) of the material for these properties. The performance values judgements used in the Campus Knowledge-base Driven Search module are the rank values stored in the relevant ARF files. The differences between the Consult Expert module and the Knowledge base Driven Search in PLASSEL are in the way the database files are manipulated (because the ARF files are in ASCII format, whereas the RANK_MAT.DBF file used in Consult Expert is a dBase III file) and the properties used in the selection, since the set of data used in CAMPUS differs from PLASCAMS. The material properties chosen for ranking and use in the Knowledge base Driven Search were based upon the selection criteria for choosing appropriate materials using the CAMPUS data set suggested by Mr D. Wimpenny (Rover ATC).

During the selection process, the top thirty high scoring materials are selected and sorted according to their scores using the SORT2 function in Crystal. On completing the search, the final thirty materials are displayed to the user in the sorted order.

Following the knowledge base driven selection, one of the options provided to the user is to view information on the materials in the short list. This information is stored in the relevant PLASSEL INF file and is retrieved by the CAMPUS_3.KB module. As explained in section 6.5.1.5, the information for each material is stored as blocks of text consisting of thirty-five characters. The CAMPUS_3.KB module searches for these blocks in the relevant INF file and reconstructs the information as given by the CAMPUS TXT from which it was derived.

6.12.4 Keyword Search Module

The Keyword Search Module (CAMPUS_4.KB) allows the user to search through the PLASSEL.INF files. The aim is to allow the user to find information on the material(s) found in the direct properties search, and for searching materials using keywords or truncated text that may appear in the selected INF file, for example, the user may enter the text "INJECT" to search for all its occurrences in the INF file in order to find materials that can be injection moulded.

A simplified description of the CAMPUS_4.KB module is that it reads the thirty-five character text blocks for each material in the specified INF file, then searches for the required string using the FIND($,$) function in Crystal.

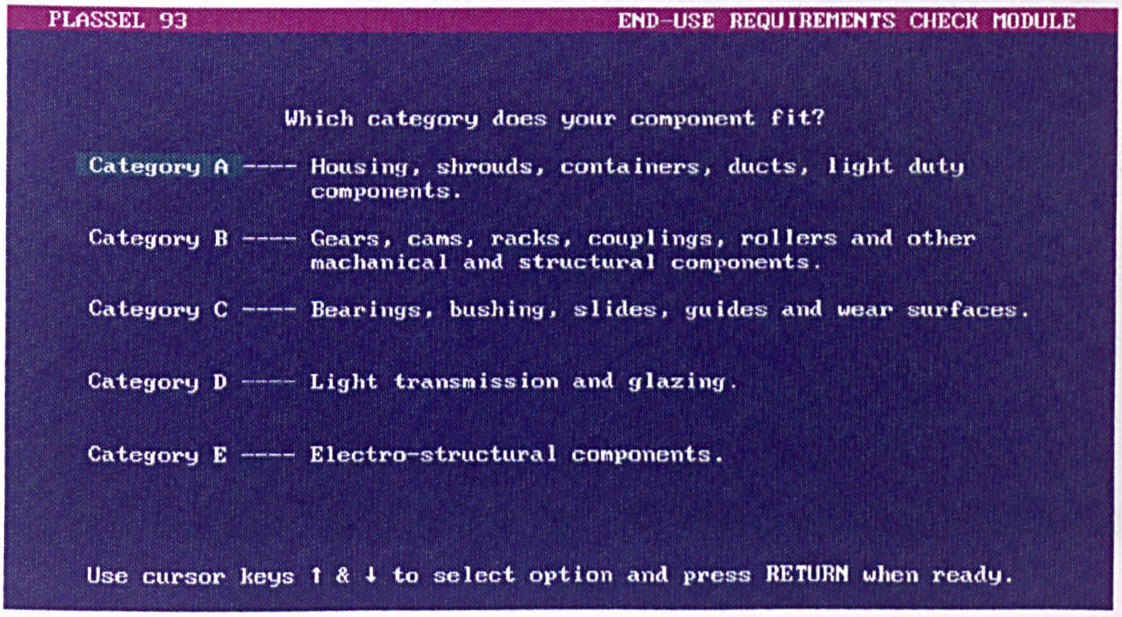
This facility provides a number of interesting possibilities for modifying the normal search procedure. The Campus data provides textual descriptions of the features and typical applications of the materials supported. We can conduct key word searches to identify relevant materials directly e.g. say we want a plastic suitable for storing chocolate, we could directly conduct a key word search for chocolate, and obtain a list of suitable materials.

6.13 End-Use Requirements Checklist Module.

An extremely difficult aspect of materials selection is the estimation of the property data values required for a particular application. This is one of the key advantages of non-systematic or heuristic search because the expert has a understanding of reasonable values of properties for a particular application. When questioning Dr Smith about material selection his first query was always "Whats the application area?", the response to which allowed him to apply appropriate weightings to the property values. This is also a major limitation with using current material property databases, for without knowledge of what are reasonable values, how can we program the search?. This is one of the reasons that current systems are difficult for non-experts to use. The objective of this module is not only to help designers, if necessary, to check the functional requirements of the component, but also help them to identify the material property requirements fully before running "Consult Expert". The knowledge base dealing with this module is ENDUSE.KB.

According to Paul F. Kusy [7], components are divided into five main categories (Screen 9) which are based on like type applications. Particular categories typically use similar types of plastic materials. Initially the user identifies the broad application area, for example, if the user wants to know about the end use requirements of gears or mechanical and structural components, category B is selected. The user can then select any property for the component category B to look at. The properties are divided into seven main categories (Screen 10).

An example of the end use requirements of component category B on mechanical properties is shown on Screen 9. All the information supplied in this module is according to an End Use Requirement Check List adapted from Paul F. Kusy [7]



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PLASSEL 93                                    END-USE REQUIREMENTS CHECK MODULE

                     Which category does your component fit?

   Category A ---- Housing, shrouds, containers, ducts, light duty
                   components.

   Category B ---- Gears, cams, racks, couplings, rollers and other
                   machanical and structural components.

   Category C ---- Bearings, bushing, slides, guides and wear surfaces.

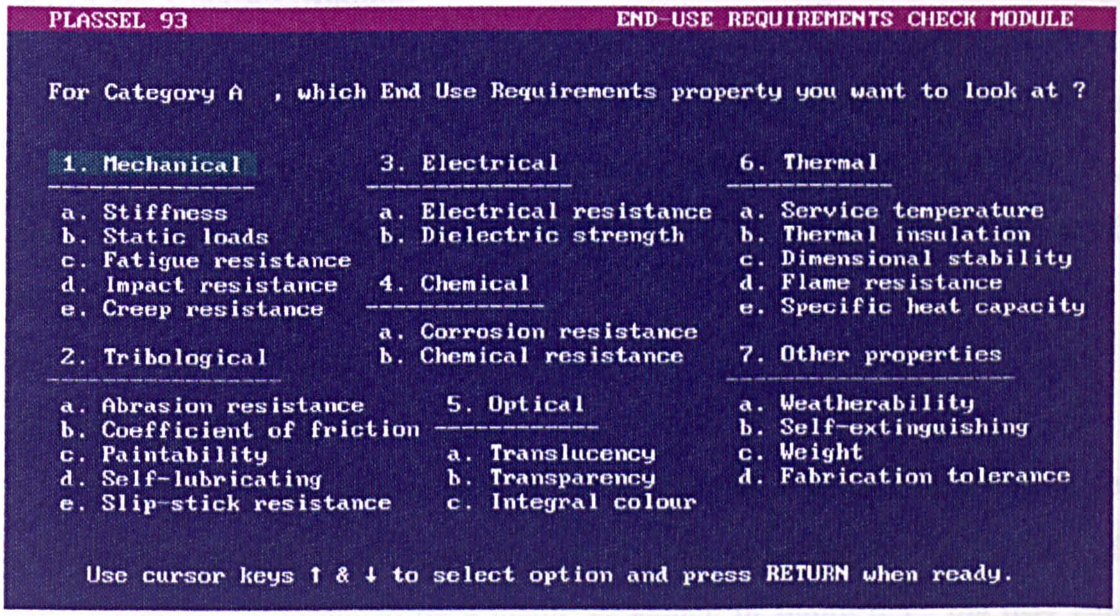

   Category D ---- Light transmission and glazing.


   Category E ---- Electro-structural components.



   Use cursor keys ↑ & ↓ to select option and press RETURN when ready.
```

Screen 9 : Ask for component category



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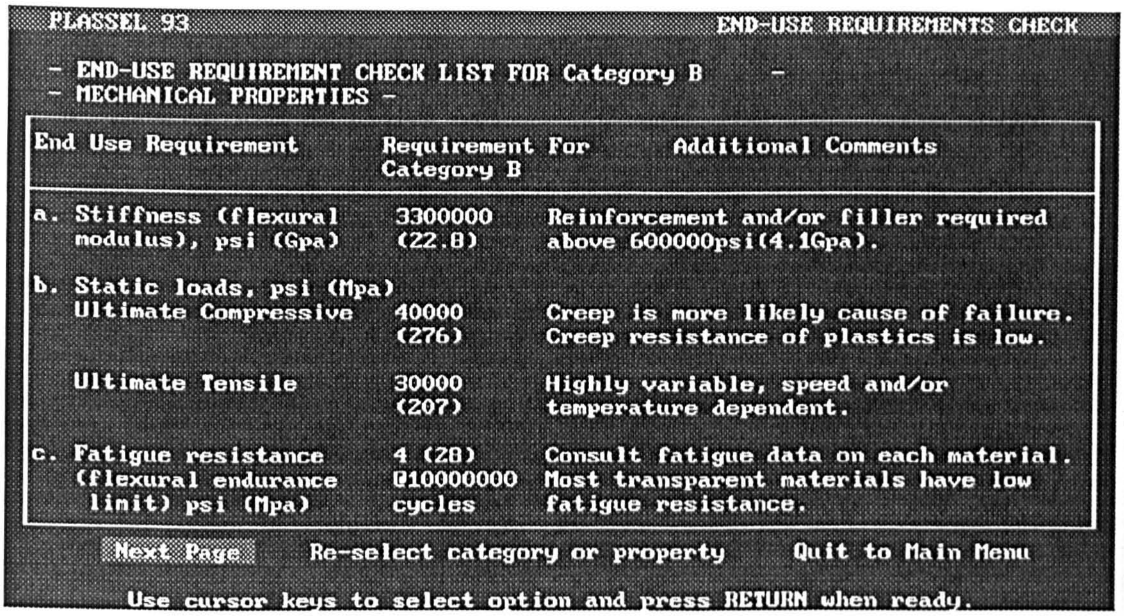
PLASSEL 93                                    END-USE REQUIREMENTS CHECK MODULE

For Category A  , which End Use Requirements property you want to look at ?

 1. Mechanical          3. Electrical              6. Thermal
 --------------         --------------             ------------
 a. Stiffness           a. Electrical resistance   a. Service temperature
 b. Static loads        b. Dielectric strength     b. Thermal insulation
 c. Fatigue resistance                             c. Dimensional stability
 d. Impact resistance   4. Chemical                d. Flame resistance
 e. Creep resistance    -------------              e. Specific heat capacity
                        a. Corrosion resistance
 2. Tribological        b. Chemical resistance     7. Other properties
 ----------------                                  -------------------
 a. Abrasion resistance     5. Optical             a. Weatherability
 b. Coefficient of friction -----------            b. Self-extinguishing
 c. Paintability            a. Translucency        c. Weight
 d. Self-lubricating        b. Transparency        d. Fabrication tolerance
 e. Slip-stick resistance   c. Integral colour

   Use cursor keys ↑ & ↓ to select option and press RETURN when ready.
```

Screen 10 : Ask for property category



```
PLASSEL 93                                            END-USE REQUIREMENTS CHECK

 - END-USE REQUIREMENT CHECK LIST FOR Category B       -
 - MECHANICAL PROPERTIES -

End Use Requirement        Requirement For      Additional Comments
                           Category B

a. Stiffness (flexural      3300000     Reinforcement and/or filler required
   modulus), psi (Gpa)      (22.8)      above 600000psi(4.1Gpa).

b. Static loads, psi (Mpa)
   Ultimate Compressive     40000       Creep is more likely cause of failure.
                            (276)       Creep resistance of plastics is low.

   Ultimate Tensile         30000       Highly variable, speed and/or
                            (207)       temperature dependent.

c. Fatigue resistance       4 (28)      Consult fatigue data on each material.
   (flexural endurance      @10000000   Most transparent materials have low
    limit) psi (Mpa)        cycles      fatigue resistance.

     Next Page      Re-select category or property      Quit to Main Menu

       Use cursor keys to select option and press RETURN when ready.
```

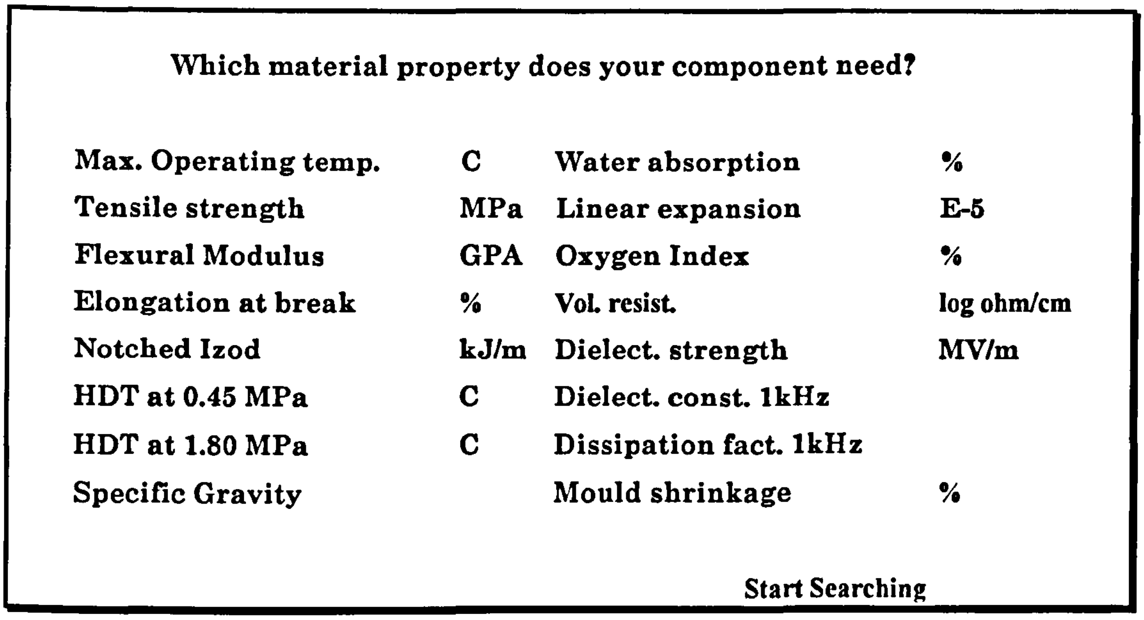
Screen 11: The recorded mechanical requirements for category B

6.14 User Chooses Module

This module allows the user to specify the search process more directly. In many ways it is very similar to the functions available in CAMPUS, EPOS etc., and hence is not described in full detail. The user can specify two types of search:

Specific Value Search

The user can conduct a direct value matching search, or a series of these searches to "extract" components that meet exact specifications. A number of key properties are provided on a menu, as shown in figure 6.5, the user can pick which he wants to select by, and to what property values.



Which material property does your component need?

Max. Operating temp.	C	Water absorption	%
Tensile strength	MPa	Linear expansion	E-5
Flexural Modulus	GPA	Oxygen Index	%
Elongation at break	%	Vol. resist.	log ohm/cm
Notched Izod	kJ/m	Dielect. strength	MV/m
HDT at 0.45 MPa	C	Dielect. const. 1kHz	
HDT at 1.80 MPa	C	Dissipation fact. 1kHz	
Specific Gravity		Mould shrinkage	%

Figure 6.5 : Menu for " Search on Specific Values "

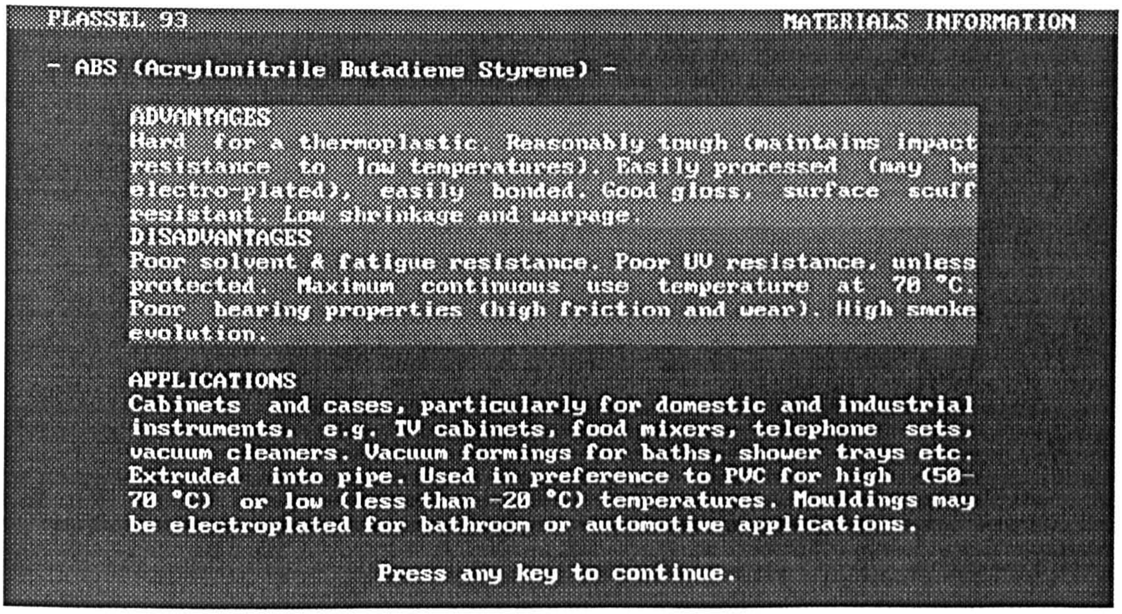
The system conducts a direct matching search, any material that meets or exceeds the users numerical specification is selected from the database file DATA_MAT.DBF.

Combined Weighting Search

This search module is exactly the same as the first two stages of "Consult Expert", but separated into manufacturing processes and material property requirements. Any questions not selected are treated as " Not Sure" answers and allocated a weighting of zero.

6.15 Materials Information Modules

Materials information from the Plascams and Campus derived data is available for viewing by the user. This is useful for gathering extra information about materials on a shortlist. Two types of information are available, advantages, disadvantages and applications (Screen 12) which is stored in INFRO.KB knowledgebase and property data information in DATA_MAT.DBF datafile.


PLASSEL 93 MATERIALS INFORMATION

- ABS (Acrylonitrile Butadiene Styrene) -

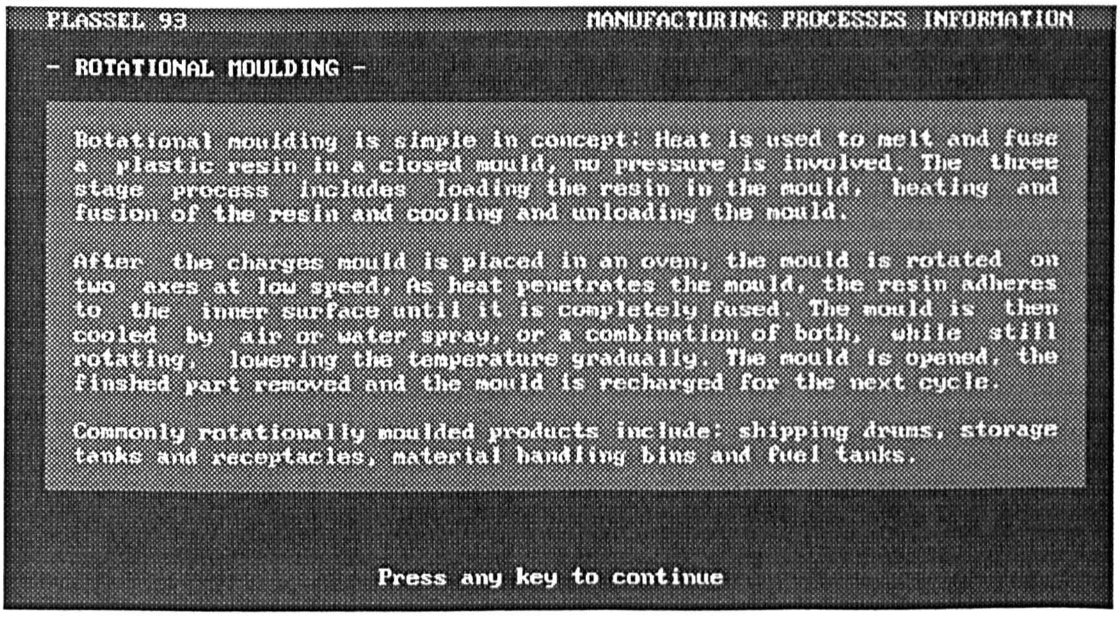
ADVANTAGES
Hard for a thermoplastic. Reasonably tough (maintains impact resistance to low temperatures). Easily processed (may be electro-plated), easily bonded. Good gloss, surface scuff resistant. Low shrinkage and warpage.
DISADVANTAGES
Poor solvent & fatigue resistance. Poor UV resistance, unless protected. Maximum continuous use temperature at 70 °C. Poor bearing properties (high friction and wear). High smoke evolution.

APPLICATIONS
Cabinets and cases, particularly for domestic and industrial instruments, e.g. TV cabinets, food mixers, telephone sets, vacuum cleaners. Vacuum formings for baths, shower trays etc. Extruded into pipe. Used in preference to PVC for high (50-70 °C) or low (less than -20 °C) temperatures. Mouldings may be electroplated for bathroom or automotive applications.

Screen 12 : Materials information

6.16 Manufacturing Process Information Module

Introductory information about a range of polymer processing processes is provided. An example for Rotational moulding is shown in shown in Screen 13.


PLASSEL 93 MANUFACTURING PROCESSES INFORMATION

- ROTATIONAL MOULDING -

Rotational moulding is simple in concept: Heat is used to melt and fuse a plastic resin in a closed mould, no pressure is involved. The three stage process includes loading the resin in the mould, heating and fusion of the resin and cooling and unloading the mould.

After the charges mould is placed in an oven, the mould is rotated on two axes at low speed, As heat penetrates the mould, the resin adheres to the inner surface until it is completely fused. The mould is then cooled by air or water spray, or a combination of both, while still rotating, lowering the temperature gradually. The mould is opened, the finshed part removed and the mould is recharged for the next cycle.

Commonly rotationally moulded products include: shipping drums, storage tanks and receptacles, material handling bins and fuel tanks.

Screen 13 : Rotational Moulding information

6.17 Example Applications Module

This provides a few screens of information indicating what types of plastics are utilised for a range of different applications. This was suggested by Dr G. F. Smith who's personal selection methodology is very applications oriented. His first question always being what is the application area (see chapter 4.9.1). The main function performed is that of education and confirmation.

6.18 Customised Material Properties Module

The design of a materials selection system requires the full anticipation of the needs and requirements of customers and users. This is a futile task, because the full range of requirements are impossible to predict, for example a particular user may want to select by material smell, another by a ' nice feel '. Each user is actually trying to select a material from a unique standpoint based on requirements and capability. Often data on the particular criteria of interest is unavailable, and companies derive their own data, of particular relevance to them. An example of this is for environmental data, Rover may be interested in how much exposure in the paint oven in their process will alter the value of a particular material property. The only currently feasible way to allow this is by allowing users to customise the selection process and the materials database. To incorporate their own knowledge and experience into the selection process.

The objective of this module is to help users to consider specific properties, information on which is not readily available from materials suppliers, in selecting materials for their products. This module allows designers to increase the capability of the system by adding the new material properties, specifically required to be considered for their products (customised properties).

This module consists of three parts (I, II, III).

Part I : Create Customised Material Properties
Part II : Select Materials by Customised Material Properties
Part III : Modify the Material Databases for Customised Properties

CM1_1.KB, CM1_2.KB, CM1_3.KB are the three knowledge bases dealing with particular parts of this module. CM1_1.KB also acts as the control knowledge base for this module providing a Main Menu, enabling the user to load the other two modules. For example, if the user wants the system to consider a new property, say Paintability, in selecting materials for his products, information about the property and the numerical values or the value judgements (ratings) of the materials on that property must be stored in the system. The required information is input via two stages.

6.18.1 PART 1 - Create Customised Material Properties.

6.18.1.1 Stage One

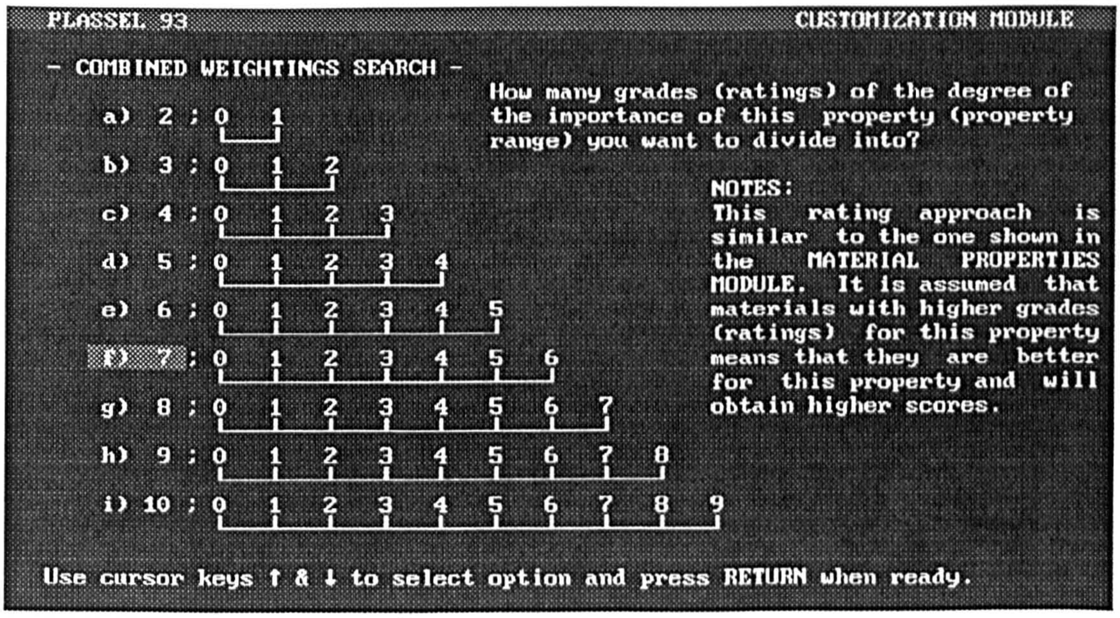
The user must enter the property of interest and the search approach.

Like "User Chooses" this module allows the user to choose "Combined Weighting Searching (CWS)" or "Direct Property Matching (DPM)" as the approach to adopt in selecting materials by their customised properties. These two selection approaches have been described in section 2.2.3. The user can prepare one or both of them for his future searches.

(A) - Prepare for "Combined Weighting Searching":

A1- *Ask for number of weighting factors (grades)*

In "Consult Expert" or the Combined Weighting Search of "User Chooses", the number of weighting factors is ten (1-10). The value judgements of the materials on these properties is divided into ten grades (0-9). However, for some properties that range of property values may be too narrow or to broad. In addition some properties may not be readily expressed in numerical values, some kind of subjective rating is often required [3], e.g., weldability may be adequately described by bad, poor, average, fair and good, five weighting factors. The user should be allowed to decide the number of weighting factors (grades) for the new property. For example, if a user decided that materials being considered in the system can be divided into 7 (0-6) grades with respect to their performance on paintability. The number of weighting factors is 7 (screen 14). The largest value denotes the property of greatest importance.



PLASSEL 93 CUSTOMIZATION MODULE

- COMBINED WEIGHTINGS SEARCH -

a) 2 : 0 1
b) 3 : 0 1 2
c) 4 : 0 1 2 3
d) 5 : 0 1 2 3 4
e) 6 : 0 1 2 3 4 5
f) 7 : 0 1 2 3 4 5 6
g) 8 : 0 1 2 3 4 5 6 7
h) 9 : 0 1 2 3 4 5 6 7 8
i) 10 : 0 1 2 3 4 5 6 7 8 9

How many grades (ratings) of the degree of the importance of this property (property range) you want to divide into?

NOTES:
This rating approach is similar to the one shown in the MATERIAL PROPERTIES MODULE. It is assumed that materials with higher grades (ratings) for this property means that they are better for this property and will obtain higher scores.

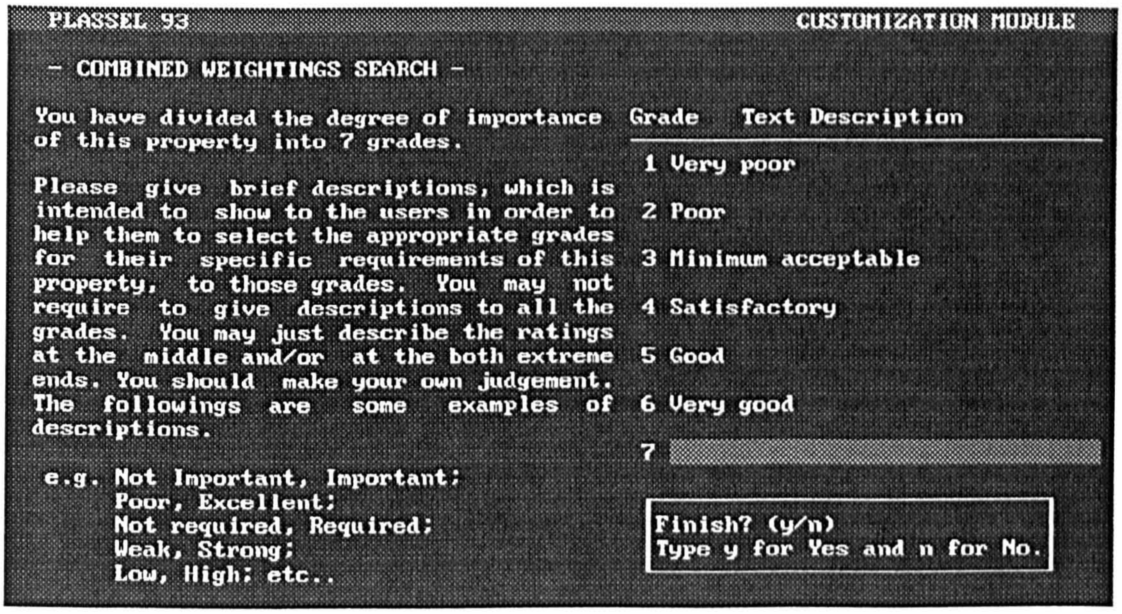
Use cursor keys ↑ & ↓ to select option and press RETURN when ready.

Screen 14 : Ask for number of weighting factors?

A2 - *Ask for descriptions for the weighting factors*

(i) Text descriptions

The user can assign descriptive statements (or examples) to describe the weighting factors. They can give "end-users" a 'feel' for the likely performance of the materials with selected weighting values for the property. This is most useful for properties that are not readily expressed in numerical values, such as weldability. An example is shown on screen 15.



PLASSEL 93 CUSTOMIZATION MODULE

- COMBINED WEIGHTINGS SEARCH -

You have divided the degree of importance of this property into 7 grades.

Please give brief descriptions, which is intended to show to the users in order to help them to select the appropriate grades for their specific requirements of this property, to those grades. You may not require to give descriptions to all the grades. You may just describe the ratings at the middle and/or at the both extreme ends. You should make your own judgement. The followings are some examples of descriptions.

e.g. Not Important, Important;
Poor, Excellent;
Not required, Required;
Weak, Strong;
Low, High; etc..

Grade	Text Description
1	Very poor
2	Poor
3	Minimum acceptable
4	Satisfactory
5	Good
6	Very good
7	

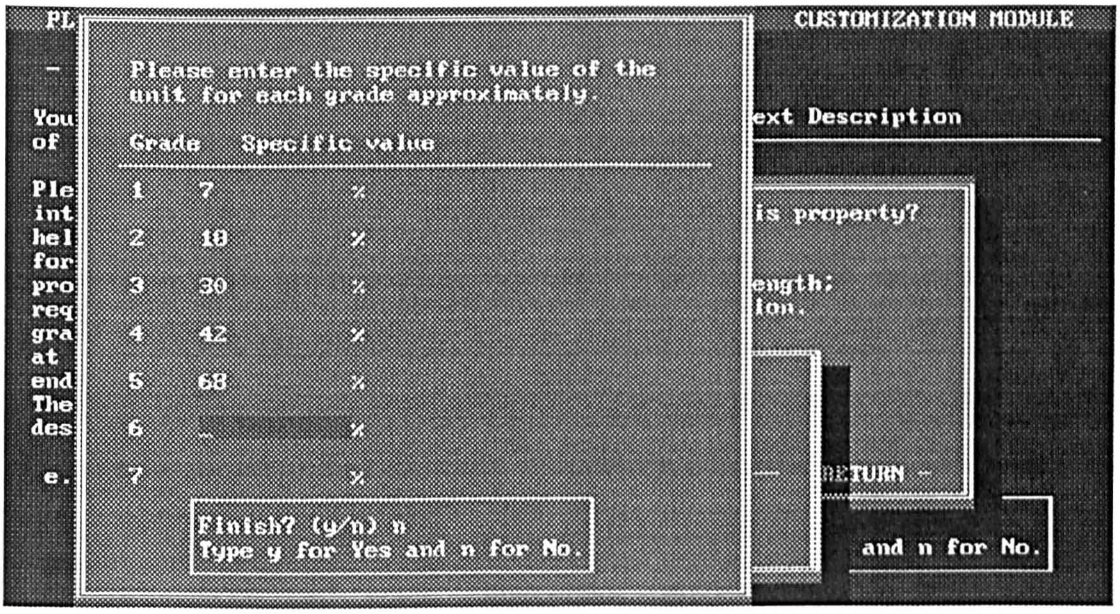
Finish? (y/n)
Type y for Yes and n for No.

Screen 15 : Text descriptions for the weighting factors

(ii) **Numerical descriptions**

The user can also describe the weighting factors by the numerical values of the property (screen 16). For example, the unit for paintability is "%". A particular percentage range can then be allocated to a particular text description. This can take into account non-linear translations, e.g. "Poor" can be between 7% to 18% and good between 30% and 42%.

At the end of preparation for "Combined Weighting Searching", a summary of the inputs is given. The user can change the inputs if it is necessary.



```
Please enter the specific value of the
unit for each grade approximately.

Grade   Specific value
1    7          %
2    18         %
3    30         %
4    42         %
5    68         %
6               %
7               %

Finish? (y/n) n
Type y for Yes and n for No.
```

Screen 16 : Numerical assignments against subjective judgements.

After completing preparation for "Combined Weighting Searching", the user can continue, if desired, to prepare for "Direct Property Matching" searches also.

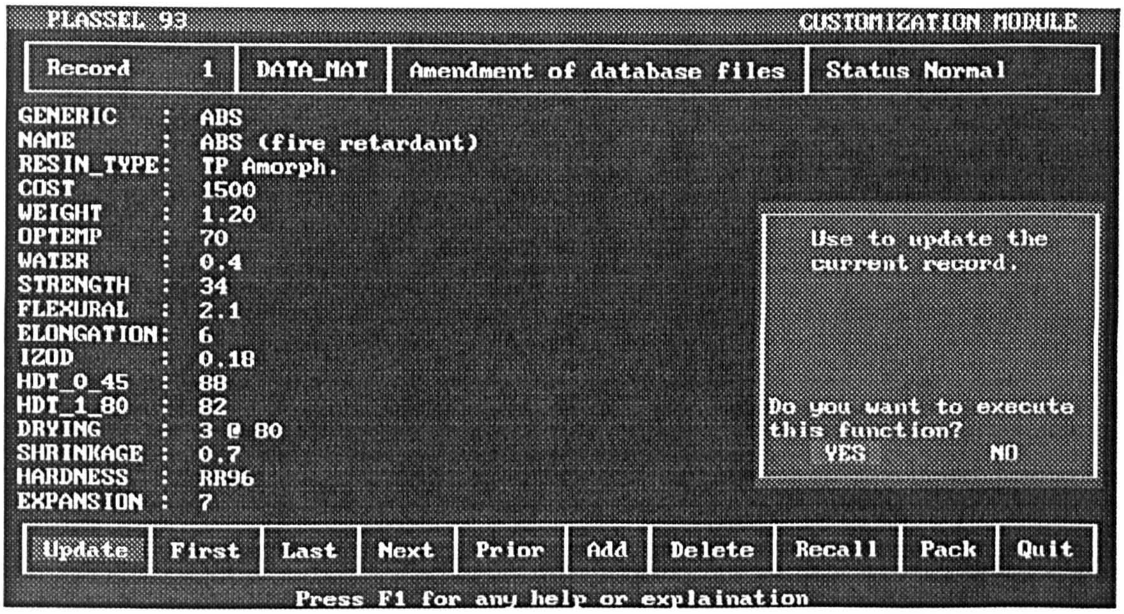
(B) - Prepare for "Direct Property Matching" (DPM) Search:

The preparation for "DPM" is much simpler than that for "CWS". If the property units have been defined in the preparation for "CWS", the user is requested to state whether high or low values are to be preferred. If the property is more desirable for low values. all the materials with the property values higher than the value required by the "end-user" will be eliminated and vice-versa.

6.18.1.2 Stage Two

Input numerical values or the value judgements for the material property.

The data for selection on the new property values is entered onto the material property database using the built-in system interface. The user is requested to enter the numerical values (for "DPM") or the value judgements (for "CWS") for the materials. A new database file is created for each new custom property, the user is required to give a *unique* name to the database file for the new property. For example, a database file, PAINTABI.DBF, may be created for "Paintability". The user can then input the property data, both numerical values and value judgements (grades), of the materials on paintability into the database file through the interface provided (screen 17). (If the property data is not yet available, the user can select "Quit" to leave the database file. When the data is available, he can update this database file by using the "Update/Append Database Files" function of this module.)



```
PLASSEL 93                                          CUSTOMIZATION MODULE
 Record         1 | DATA_MAT | Amendment of database files | Status Normal
GENERIC    :  ABS
NAME       :  ABS (fire retardant)
RESIN_TYPE:  TP Amorph.
COST       :  1500
WEIGHT     :  1.20
OPTEMP     :  70                              Use to update the
WATER      :  0.4                             current record.
STRENGTH   :  34
FLEXURAL   :  2.1
ELONGATION:  6
IZOD       :  0.18
HDT_0_45   :  88
HDT_1_80   :  82                             Do you want to execute
DRYING     :  3 @ 80                         this function?
SHRINKAGE  :  0.7                               YES          NO
HARDNESS   :  RR96
EXPANSION  :  7
                  Press F1 for any help or explaination
```

Screen 17 : Input of customisation data onto custom datafile.

At the end of Part I "Create Customised Material Properties", all the information input before must be saved in an export file. The user must ensure that the export file name is unique. For example the export file name for "Paintability" in this case is PAINTABI.EX.

6.18.2 PART II - Select Materials By Customised Material Properties

The knowledge base for this module is CM1_2.KB. The user can select materials by the customised properties which have been created in Part One (6.14.1). Like the "User Chooses" module, it allows the user to choose the selection approach (CWS or DPM) they want to use in selecting materials for their component. The approach selected must have been prepared in Part I - stage 1. In the example on "paintability", both approaches were prepared.

Combined Weighting Search:

In CWS, the overall combined performance of each material with respect to the selected properties is judged and is determined by the sum of products of the weightings input by the user and the performance values of the material on corresponding properties.

The user can create a selection of customised properties in the system. Then the user can select one or more properties which he wants to consider in selecting materials for the component. The materials are evaluated sequentially, one property after another. For instance, if the user is interested in "Paintability" and "Fatigue resistance". He is requested to indicate the importance or grade of paintability required for the component. The materials are then evaluated with respect to the importance/grade of paintability required by the component. A shortlist of top 30 candidate materials ranked in descending order of scores is generated.

After the evaluation of materials on paintability, the user is asked whether he wants to consider other properties with combined weighting to paintability. If he does, he can choose another property such as "fatigue resistance" and indicate its importance/grades required by the component. A shortlist of candidate materials sorted with combined performance score is then generated.

Direct Property Matching:

In DPM, the user is required to enter the minimum requirement of the property for the component. All the material which cannot fulfil the requirement will be eliminated leaving a shortlist of candidate materials. The user can then enter the minimum requirements of the other properties. A shortlist of candidate materials, which can fulfil the requirements of both properties, is then generated.

6.18.3 PART III - Modified Material Databases for Customised Properties

The knowledge base, CM1_3.KB, is loaded for this part. For reasons of maintainability and customisation, the user is allowed to update or append the material databases for the customised properties through this facility.

6.18.3.1 Modify Databases

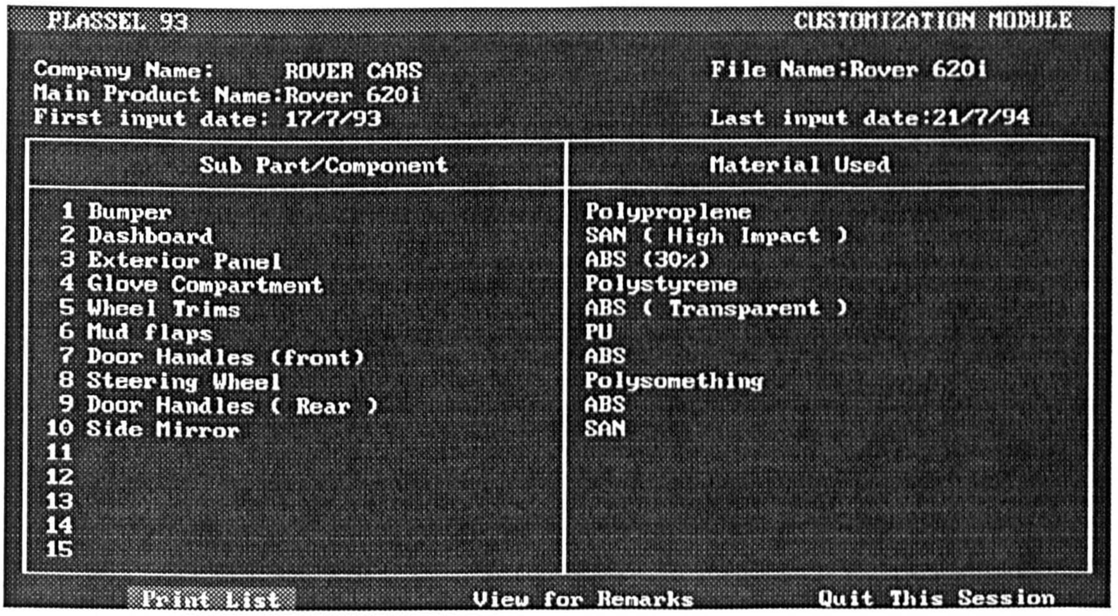
An interface to the database files used in Plassel was built in Crystal to allow the user to modify the databases as required without requiring a database package.. There are four major DBase3+ files in the system that hold Plassel data, there are also a number of Campus ASCII files that may have been converted. Part one of the customisation module also creates a number of files which can be modified using the interface. A screen of the database interface is shown in screen 16

6.18.4 Application Library

Previous experience is an important aspect of product design and of materials selection. Current design systems however do not store, or retain crucial information about WHY particular decisions were taken. A CAD file for example stores the final geometrical and material information in great detail, but the process of how and why that shape emerged is lost. The same is true for material selection systems. A key requirement for Rover was that the system should be able store what plastic was selected for what component and why. It impossible to pre-define fully all the information that the user may require in the future. This section needs to be able to be modified and maintained by the user(s). The module consists of two elements, file viewing and file editing.

(a) File Viewing

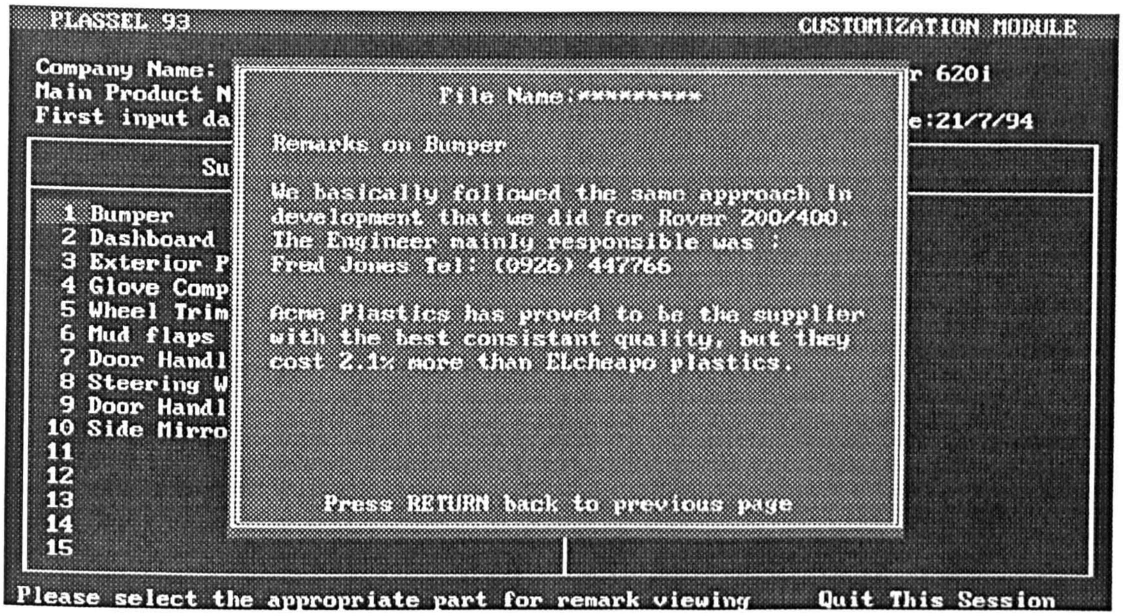
This section enable the user to retrieve any record files within the library which may be of reference in performing a material selection for a particular component. Three levels of hierarchy are built into the system, to reflect the typical component hierarchy. At the top level individual files are created and managed by the system, to represent major products e.g. Rover 216GTI16V. The system displays 'product' files that have been created, and the user can select one for further definition. At the next level, the system can display components/sub components of the products and their material usage. At the third level, remarks relating to usage of a particular material on a particular component can be viewed. Examples of the last two are shown (Screen 18, 19).



Company Name: ROVER CARS
Main Product Name:Rover 620i
First input date: 17/7/93
File Name:Rover 620i
Last input date:21/7/94

Sub Part/Component	Material Used
1 Bumper	Polyproplene
2 Dashboard	SAN (High Impact)
3 Exterior Panel	ABS (30%)
4 Glove Compartment	Polystyrene
5 Wheel Trims	ABS (Transparent)
6 Mud flaps	PU
7 Door Handles (front)	ABS
8 Steering Wheel	Polysomething
9 Door Handles (Rear)	ABS
10 Side Mirror	SAN
11	
12	
13	
14	
15	

Screen 18 : Component level Information



```
File Name:*********

Remarks on Bumper

We basically followed the same approach in
development that we did for Rover 200/400.
The Engineer mainly responsible was :
Fred Jones Tel: (0926) 447766

Acme Plastics has proved to be the supplier
with the best consistant quality, but they
cost 2.1% more than ELcheapo plastics.

Press RETURN back to previous page
```

```
Please select the appropriate part for remark viewing
```

Screen 19 : Component details

b) File Editing

This facility allows 'users' to create and edit 'product' files. The system automatically saves any changes made. The Application Library module can be used flexibly in a number of ways, to store free text information relating to material choice. The three level hierarchy was devised according to the requirements of Rover, but is generally flexible and widely applicable.

6.19 Cost Analysis Module

According to experts (Crane & Charles [2]), cost is one of the most important criteria in selection. The final material decision is usually based on a balance of cost and performance. "Cost" in existing material selection systems relates purely to the material cost. The true cost of a particular material decision is obviously dependent on a number of factors, a key one being the economics of the manufacturing processes associated with that particular material. the following are elements that contribute to the production cost of a product.

(a) Material Cost (plus scrap costs)

(b) Machine Costs - depreciation and operating costs.

(c) Mould Cost - design and manufacture cost.

(d) Labour Costs - direct.

(e) Overhead Costs

6.19.1 Module Structure

The module is split into two elements, the 'materials cost analysis' and the 'production and process analysis'. The first part 'looks-up' material cost in the database files and displays it on the current shortlist. The second, conducts a piece-part cost analysis to produce a balanced comparison of costs between selected materials, so that a wiser decision can be made.

(1) Material Cost Analysis.

The user can select any materials from the current shortlist, or any material in the main database file via their generic groups. The user selects the generic group and the system displays material cost for all the materials in the database within that generic group. Material cost analysis can be saved, reviewed and printed for design documentation. All cost analysis are stored under file extensions "*.MC1" or "*.MC2" or ".MC3" representing the three pages of the materials shortlist.

(2) Production Cost and Process Analysis

The analysis is based upon the comments of Dr G. F. Smith and Mr D. Winpenny. This section calculates the production cost by ascertaining:

Production volume	Labour hour (hour/week)
Manufacturing Process	Mould Cost (£)

Basic material cost (£/kg)
Labour cost (£ per hour)
Product weight (g)
Cycle time (minutes)
Overhead cost (£/week)

These are obtained by questioning the user. A summary input screen is presented. When the user is satisfied with the input data a calculation is performed. The data for the module is maintained in a database file MP_COST.DBF. The calculation is based upon the following equation:

Production cost (PC) = Basic material cost (BMC) +
Machinery cost (MC) +
Labour cost (LC) +
Mould cost (MOC) +
Overhead cost (OC)

Where:

BMC = (material cost (£/kg)/1000) * product weight (g)
MC = machinery cost / ten year depreciation term (£/second)
LC = labour cost/ hour x cycle time x 1/60
MOC = mould cost / production volume
OC = (overhead cost per week / labour hour per week) x cycle time

The machinery cost is obtained from the database file MO_COST.DBF. The information relating to material wastage, relative tooling and labour costs is obtained from P. E. Kusy [7].

6.20 Environmental, Energy And Post-Processing Module

Environmental considerations can be significant in the selection of materials for components and will be increasingly more so. In the selection of plastics three major environmental issues that can bear an influence on the selection process are:

Environmental :
Use of recycled plastics and the disposal of products at the end of their life. This has forced vehicle manufacturers, for instance, to consider setting up dismantling centres.

Energy Saving :
Energy consumption in manufacturing, in service and in recycling may have an important influence on material selection.

Post Processing :
Plastic manufacturing processes generally offer the advantage of producing near 'net shape', however often some kind of post processing is still essential.

An ideal plastic materials selection system needs to offer the ability to screen materials by these characteristics. In Plassel the knowledge base EEP.KB provides the facility to select from the full materials list or shortlists according to these criteria. The structure of EEP.KB is shown in figure 6.6 and a sample screen in Screen 20. The actual data required for selection is not readily available yet from the major materials suppliers. All the data related to the module is stored in a database file NEW_RANK.DBF, which can be edited and enhanced as data becomes available.

6.21 Discussion

In the space available only an overview of the considerations, problems and approaches applied in tackling the problem of building a full system for plastic material selection can be provided. This chapter can never be totally complete, but an exploration of the actual software produced can provide a fuller appreciation. The extent to which the software generated satisfies the objectives set is examined in the next chapter

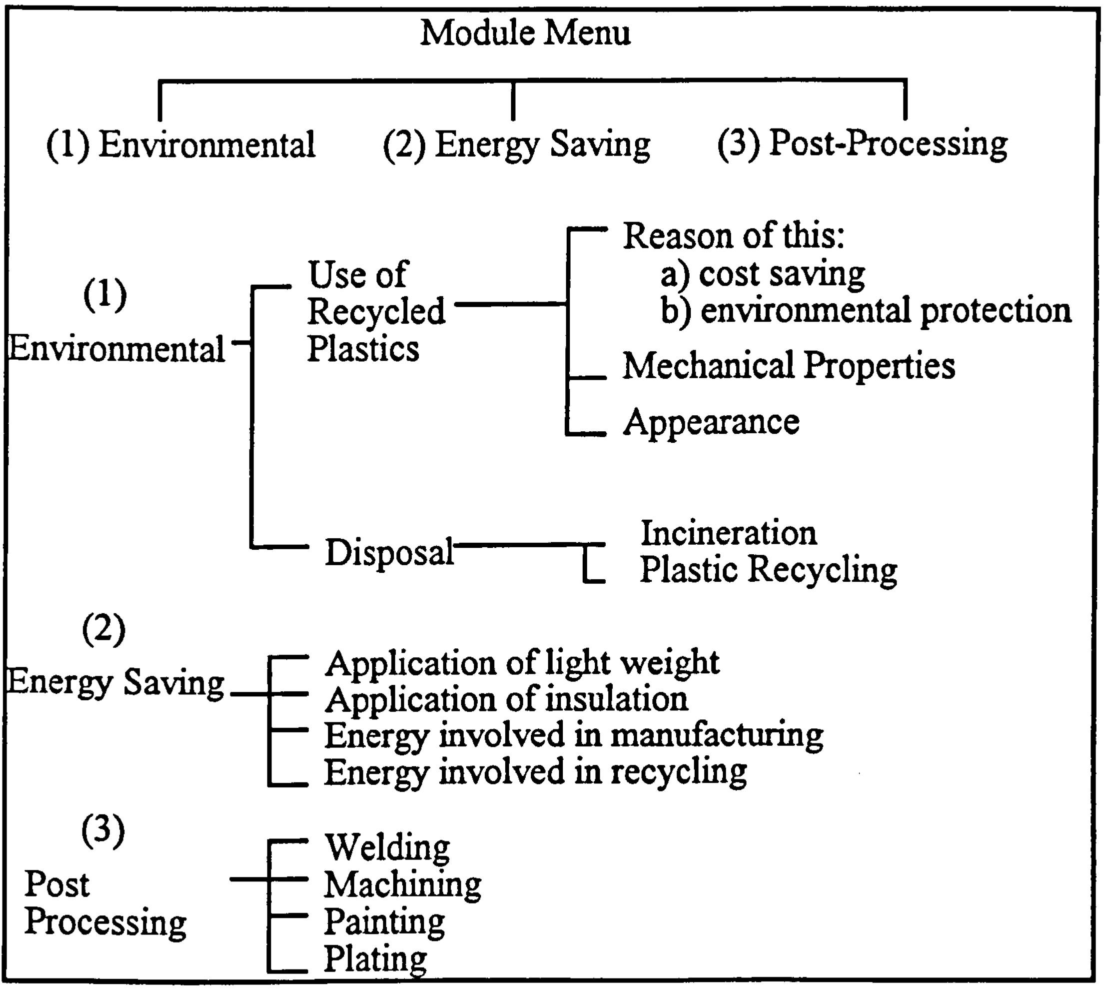
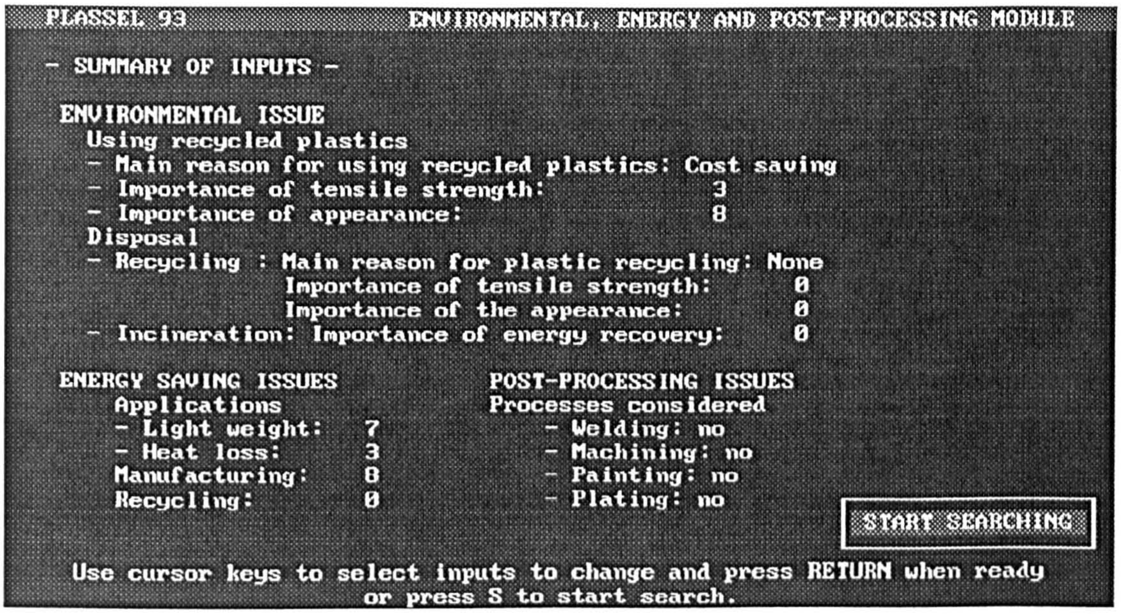


Figure 6.6 : Structure of EEP.KB



```
PLASSEL 93                  ENVIRONMENTAL, ENERGY AND POST-PROCESSING MODULE

- SUMMARY OF INPUTS -

 ENVIRONMENTAL ISSUE
   Using recycled plastics
   - Main reason for using recycled plastics: Cost saving
   - Importance of tensile strength:               3
   - Importance of appearance:                     8
   Disposal
   - Recycling : Main reason for plastic recycling: None
                 Importance of tensile strength:       0
                 Importance of the appearance:         0
   - Incineration: Importance of energy recovery:      0

 ENERGY SAVING ISSUES           POST-PROCESSING ISSUES
     Applications               Processes considered
     - Light weight:    7           - Welding: no
     - Heat loss:       3           - Machining: no
     Manufacturing:     8           - Painting: no
     Recycling:         0           - Plating: no
                                                           START SEARCHING

  Use cursor keys to select inputs to change and press RETURN when ready
                          or press S to start search.
```

Screen 20 : Environmental, Energy and Post Processing Summary

CHAPTER SEVEN

SYSTEM EVALUATION

7.1 Design Quality

Any product that is designed or produced needs to have sufficient quality to satisfy its customers, or users needs. In software development, quality factors are developed in order to evaluate whether the final software has quality. These factors are often defined by the users, example factors may be usability, portability or flexibility and are converted by the software engineer into software quality criteria. Software quality factors are defined as the requirement which specify the degree to which software possesses the attributes that enhance quality [59]. The number of quality factors could be endless depending on the type of application. For this discussion factors developed by the Rome Air Development Centre (RADC) are considered. There are no internationally accepted standards for software quality, though the Institution of Electrical and Electronic Engineers (IEEE) is in the process of drafting such a standard based upon the RADC guidelines.

RADC suggest thirteen quality factors that all software should posses. Figure 7.0 lists these factors. These factors can be subject to varying interpretations.

7.1.1 Efficiency

This is a measure of how well the system uses its resources. Efficiency can be measured in terms of the time taken to process a query or to prepare a report. A major benefit of the two stage search procedure adopted was its improved efficiency. In terms of input, a system can be said to be efficient if the users feel that it is easy to enter new data or modify existing data. Query processing time within Plassel is really dependent on the size of the materials database. A maximum search time of one minute (with the current databases) was adopted as an initial target, based on comments by Rover materials staff. In evaluations the overall query time did not prove to be a problem, but an indication of how much of the search had been conducted and of how much longer to go was requested. This was implemented by a search progress bar, and '% search completed' display. Input of new data has been catered for by the provision of conversion programs that process source data into Plassel compatible formats. This process takes considerably longer, approximately one hour for Plascams data, and one and a half hours for Campus data. Fortunately this should only be required a few times a year. Data modification is an easy process through the built-in interface to the data files. This provides on-line guidance to inexperienced users.

Software Quality Factors
1. Efficiency
2. Integrity
3. Reliability
4. Survivability
5. Usability
6. Correctness
7. Maintainability
8. Verifiability
9. Expandability
10. Flexibility
11. Interoperability
12. Portability
13. Reusability

Figure 7.0 : Software Quality Factors (Source - Keller)

7.1.2 Integrity

This is usually defined with respect to security threats to the system. At this stage Plassel does not feature security measures such as system and database access passwords, though these could be implemented. Integrity could also be interpreted by users as 'entireness' and 'wholeness' as defined by Chambers Compact English Dictionary. Much effort has gone into Plassel to develop a complete integrated system. Both Generic and specific databases are provided within the system, the 'End-Use requirements module helps identify likely property requirements, manufacturing considerations are integral, customisation is catered for, and piece part costing is provided. These are all accessed via a main menu, and have a common "look and feel".

7.1.3 Reliability

According to Gilb [60] reliability is a measure of whether the systems performs as intended, consistently. The use of expert system techniques provides some additional robustness to the system, as does factors such as the use of weighted property indices (WPI) for evaluation. An important reliability issue for knowledge-based systems is graceful degradation, rather than sudden system collapse. The availability of 'don't know' responses within the WPI approach helps achieve this.

7.1.4 Survivability

This is a measure of how the system performs under adverse conditions. In an office environment adverse environmental conditions for IBM PC compatible computers are unlikely. For material selection an adverse condition could be interpreted as when little knowledge or information available about the true operating conditions and the necessary materials properties. Plassel provides " Don't Know" response options on all key stages. Using this option obviously impairs the accuracy of selection, but functionality is maintained, and a best estimate is provided.

7.1.5 Usability

Usually taken to be a measure of the ease of use of the system. Gilb [60] says *"usability is a measure of how well people are going to be able to, and motivated to use the system"*. The element of motivation makes an important difference. A system can be easy to use, but if people do not have a motivation for using it (i.e. it is of some use to them!) then usability has not been achieved. Tests of the usability of Plassel in comparison with Campus and a Microsoft Access based material selector (MSIS) were conducted by Mr Steven King, senior research fellow at the Rover Advanced Technology centre. The results are discussed in section 7.2.

7.1.6 Correctness

This is a measure of how well the system conforms to the system requirements identified. It is not a measure of 'correctness' of output. The prototype system has attempted to implement the full set of features identified in chapter five. The extent of fulfilment has to be assessed.

7.1.7 Maintainability

Good systems must be easy to maintain, that is to repair in the event of non-functionality. Plassel provides a modular structure of knowledge bases and database files to ease maintainability. The implementation of Plassel in Crystal is also important in enhancing maintainability. Program structure is very rigidly fixed by Crystal and the code is very 'readable', being of a

IF...AND...OR structure. The Crystal interface also provides debugging tools.

7.1.8 Verifiability

The system performance must be easily verified and quantified. For KBS applications, a more meaningful interpretation may be the ability to trace or check the systems conclusions or recommendations. In Plassel this can be achieved by the Rule Trace facility provided by Crystal for debugging purposes.

7.1.9 Expandability

A measure of the system capacity to be upgraded. Gilb [60] uses the word extendibility for this factor. New capabilities can be added relatively easily to Plassel because of its modular structure and implementation in Crystal.

7.1.10 Flexibility

Is a measure of how easily the system can be changed or modified. Gilb [60] uses the word "improvability" to describe this measure. For Plassel some of the features already discussed such as modularity and rule-based operation, cater for this.

7.1.11 Interoperability

This is a measure of how well the system interfaces with other systems or programs. Performance on this criteria is mainly governed by the choice of Crystal as the system implementation tool. It provides built-in interfaces to standard spreadsheet and databases packages. Interface modules have been written to convert ASCII files into standard Crystal format. It is possible to write custom interfaces, using Crystal, to most external software.

7.1.12 Portability

Is a measure of the systems ability to be used across different platforms. Crystal is DOS based system, though an OS/2 version has recently been released. It is capable of being networked.

7.1.13 Reusability

Measures the ease of reuse of code into other applications. This is an important consideration for Plassel because the approach developed should be suitable for a wide range of material selection tasks, and also for selection of other items e.g. people, equipment etc. Some of the basic software procedures developed within Plassel are very amenable to reuse for other applications. The structure of combined weighting, or direct matching search on data in a file external to the knowledge base is one that could be applied to a whole variety of "selection" problems. The author has supervised an MSc project using this methodology for recruitment [61]. Other elements that have proved to be reusable are the "Application database " (see section 6.14.3).

The software quality factors discussed above need to be satisfied by the quality criteria described for Plassel. Quality criteria need to have measurements attached to them describing the level of achievement. These then become quality tests. For example :

Quality Factor	Usability.
Quality Criteria	Time required for new users to learn software.
Quality Measurement	New users should take on average 25 minutes to get accustomed to the software.

To conduct this test new users are timed on how long they take to feel comfortable with the software.

7.2 Usability Study

There are many sources of materials data and many computerised materials selection systems. Despite this *"materials information systems are not widespread in Industry"* [27]. The early systems were mainly on-line systems connected to remote computers. These proved to be difficult to set-up and use, take up has increased with PC based systems, but is still far from the norm. The evaluations conducted in chapter three and four indicated that current systems still deter; particularly, occasional and novice users. Hence Usability can be seen as a key criterion of a successful selection system. A usability study was conducted comparing Plassel with Campus and a Microsoft Access (MSIS) based system. Campus was chosen for comparison because it is the most popular of current systems. The 'Access' (MSIS) based system was developed by an MSc project student [62] , to assess the ease of building a system, a simplified Plassel, using a database approach, and the Microsoft Access development tool, hence, it features 'windows' based concepts of usability. This is important because many people associate good usability with Microsoft Windows.

7.2.1 Questionnaire

The usability study was conducted using a test script and questionnaire. Users are asked to use the system functions specified in the test script before answering the questionnaire. A script and questionnaire are shown in appendix B. The questions were derived from a Quality Assurance Forum report [63]. The ranking system used follows that suggested in the report. Users are given an option of responses, these are shown in table 7.1.

Value	Meaning
+3	Very Satisfied
+1	Satisfied
0	Neither satisfied Nor Dissatisfied
-1	Dissatisfied
-3	Very Dissatisfied

Table 7.1 : Response Matrices

The QA forum report suggested the following method for evaluating the questionnaire responses.

Development Satisfaction

100 times the sum of the development question response scores

divided by 3 times the total number of development question responses.

The results will range between -100 (complete dissatisfaction) and +100 (complete satisfaction).

7.2.2 Usability Tests

A usability study was conducted with six new users. The six evaluators were :

1. Mr Steven King, Lecturer at the School of Management, Leeds University, formerly Senior Research fellow in Information technology at the Rover Advanced Technology Centre, University of Warwick. Mr King is an Information systems development expert.
2. Mr Stuart Muscutt, Sales Support consultant, Simtel Ltd, has expertise in manufacturing systems.
3. Mr Wayne Oosthuizen, Lecturer in Electronics design at Port Elizabeth Technikon, South Africa and has developed an expert system for the design

of manufacturing systems.

4. Dr Dan Kells, Group Leader-Advanced Materials, Sowerby Research Centre, Bristol.
5. Mr Foong Chow Chan, formerly MSc (1994) student in Warwick Manufacturing Group. A complete novice to materials selection.
6. Mr Soon Loong Lor, formerly MSc (1993) student in Warwick Manufacturing Group and an expert Crystal developer.

The results discussed are those based upon Mr S. King, which were typical of the group.. The study had two aspects, the time taken to complete the test scripts and the subsequent questionnaire responses. Time estimates were (table 7.2):

Campus	20 minutes
Plassel	30 minutes
MSIS	20 minutes

Table 7.2 : Time Estimates

These times were derived from those taken by the author. These act as a pass or go filter criterion. The questionnaire scores are processed as described above (section 7.2.1). Generally if systems have a processed score of +67 or higher, they can be regarded as being usable and the user is satisfied with the system. This target figure is derived from an average of +2 being awarded to each question. This is midway between satisfied (+1) and very satisfied (+3). The actual time taken by Mr King are shown in Table 7.3.

	Average	Mr King
Campus	17 minutes	20 minutes
Plassel	22 minutes	28 minutes
MSIS	16 minutes	12 minutes

Table 7.3 : Actual Times Taken

All of the systems pass the basic acceptability test. The times taken include time for questions and distractions, this can include testing the help facilities. The other measure of usability, derived from the questionnaire, gives a better estimate of the users liking of the system. The mode raw scores for each system are shown in table 7.4. For Campus five out of seven questions were answered, most receiving a good response, similarly with Plassel. The MSIS system received six responses. The processed scores are shown in table 7.5.

System	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Total
Campus	+1	+3	+3	+1	NA	NA	+3	+11
Plassel	+3	+3	+3	+3	NA	NA	+1	+13
MSIS	+1	+3	+1	+1	+3	NA	+1	+10

Table 7.4 : Mode Raw Scores for each System

System	Raw Score	Calculation	Processed score
Campus	+11	100 x 11 / 3 x 5	+ 73.3
Plassel	+13	100 x 13 / 3 x 5	+ 86.7
MSIS	+10	100 x 10 / 3 x 6	+ 55.5

Table 7.5 : Processed score

For the two usability measures the system rankings are : Plassel, Campus and MSIS. Both Campus and Plassel passed the devised usability tests, scoring over +67. Plassel generally received the highest possible marks in applicable categories. The failure of MSIS indicates that the system needs further development, but also, possibly, that a 'Windows' interface is not a guarantee of good usability. The users made the following observations :

CAMPUS

The system appeared to provide fewer selection factors. The help system was not clear enough. The entry of selection criteria was confusing with little indication of where in the process the current location was, and how much further to go. There was no summary of input criteria before data search commenced.

PLASSEL

Plassel provided many more functions than Campus and was more likeable. The system does not allow the user to scroll suggested material lists. The materials lists produced cannot be printed or saved to a file. A summary of inputs and selections is not provided before database search begins. The user was unable to delete any records in the database.

Note : As a result of the comments, modifications to Plassel were made. The ability to scroll and save or print suggested materials lists was implemented. A data summary screen is provided after main questioning stages for confirmation before database search.

MSIS

The system only provides a direct matching approach, similar to Campus. After using Plassel the user wanted a combined weighting approach as well. There is no help system.

Another important aspect of usability which is often overlooked is that of software installation and start-up. Plassel can be provided in compressed format on a single 3 1/2 inch floppy disk. A batch file on disk self extracts the software and loads it onto a designated hard disk. The system can then be run by typing "Plassel".

7.3 Knowledge Evaluation

The quality of the suggestions made by a material selection system is of the greatest important but is not really addressed by the quality factors above. Performance in this respect may be addressed in four ways :

1. Expert examination.
2. Test by example.
3. Correctness by construction
4. Real life usage

The latter is obviously the most thorough, but impractical in this case because of time requirements. It may be many years before it can be judged whether a recommended material was most appropriate or not. The "correctness by construction" approach is one that is used in the electronics industry extensively. The philosophy is that if we utilise proven sub-components to build a system according to proven rules, then by implication, the final system is proven. In the case of Plassel, all the data and knowledge utilised comes from reputable sources, the selection methodologies (combined weighting and direct property matching) are proven techniques, hence, then the system should produce reliable (similar to the source experts) results.

In this section the performance of the developed system in suggesting materials is evaluated in a simulated environments. Since no real data is currently available for "Customised Material Properties" and "Environmental, Energy Saving and Post-Processing" only stage A of "Consult Expert" including the "Manufacturing Processes Selection" is tested. The evaluation is split in two parts, firstly manufacturing process is selected using the full set of considerations as described in chapter six and then material selection is then based on that chosen process (Plassel 93). In the second part, (Plassel 90) manufacturing processes are recommended based upon component shape and desired quantity only, and all are taken into consideration when choosing appropriate materials. This procedure tests the worth of Dr Smiths suggestions on process selection criteria and their relative importance.

Warwick Manufacturing Group at the University of Warwick provide a full week module "Polymer Materials, Processes and Products" conducted by Mr P J Rowberry (Module Tutor), Several exercises on material selection are conducted within the module for a few sample products. The results of "Washing machine outer stationary drum" and "Windsurfer board" are compared with those suggested by the Plassel system.. A conventional analysis for these products is shown in appendix D. In addition "Computer housing", is also used in this section to test Plassel.

The responses for all questions asked for the components are summarised in the Table 7.6.

Criteria	Washing machine stationary outer drum	Windsurfer board	Computer housing
Component shape	4	7	4
Importance of production rate	4	2	4
Component size	4	2	4
Importance of surface finish	2	5	5
Importance of tolerance	3	3	3
Number to be produced	7	5	7
Importance of stiffness	7	6	7
Importance of strength	9	7	7
Importance of impact strength	5	8	9
Importance of operating temperature	6	4	1
Importance of weight	5	2	5
Importance of appearance	1	10	10
Importance of resistance to UV radiation	1	10	7
Importance of water resistance	10	10	3
Resistance to aliphatic hydrocarbons	1	1	5
Resistance to aromatic hydrocarbons	1	1	1
Resistance to halogens	-	1	1

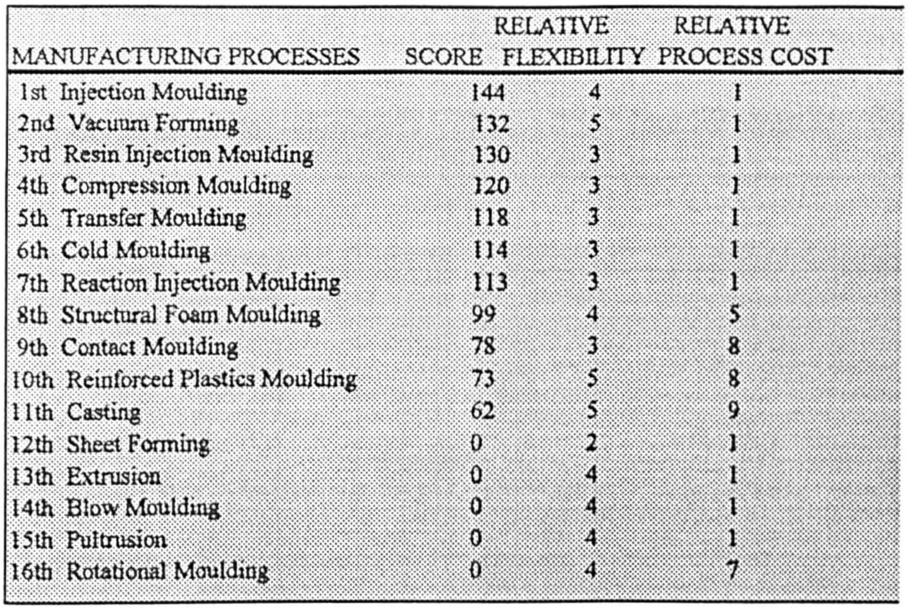
Table 7.6 Responses to the questions asked for the component.

7.4 Washing Machine Outer Stationary Drum

The requirements for a washing machine outer drum as analysed are explained in appendix D.

7.4.1 Manufacturing Processes for Washing Machine Outer Drum

Using the requirements identified in appendix D, Plassel suggests the following processes (Table 7.7).



MANUFACTURING PROCESSES	SCORE	RELATIVE FLEXIBILITY	RELATIVE PROCESS COST
1st Injection Moulding	144	4	1
2nd Vacuum Forming	132	5	1
3rd Resin Injection Moulding	130	3	1
4th Compression Moulding	120	3	1
5th Transfer Moulding	118	3	1
6th Cold Moulding	114	3	1
7th Reaction Injection Moulding	113	3	1
8th Structural Foam Moulding	99	4	5
9th Contact Moulding	78	3	8
10th Reinforced Plastics Moulding	73	5	8
11th Casting	62	5	9
12th Sheet Forming	0	2	1
13th Extrusion	0	4	1
14th Blow Moulding	0	4	1
15th Pultrusion	0	4	1
16th Rotational Moulding	0	4	7

Table 7.7 : Washing machine drum Process shortlist-1

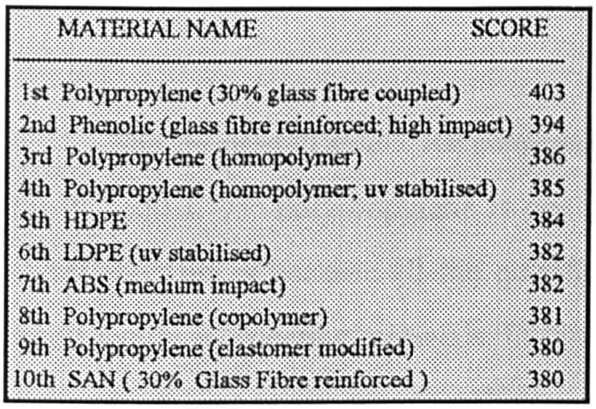
The suggested manufacturing process in the class exercise is structural foam injection moulding which is in eighth position on the process shortlist (Table 7.7). The reason is that the system does not consider the material property requirements at the selection stage for the manufacturing process. Consequently injection moulding has the highest score this is probably due to a very high preference for injection moulding for mass production and its better general overall performance.

7.4.2 Materials for washing machine outer drum

If injection moulding is selected as the manufacturing process for this product, the material with the highest score (Table 7.8) is polypropylene (30%

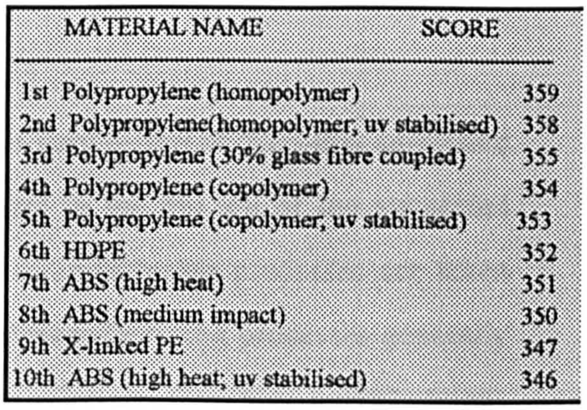
glass fibre coupled) which is also suggested in the exercise in appendix D. However if structural foam injection moulding is selected instead of injection moulding, it is found that the first five materials are polypropylene, but polypropylene (30% glass fibre coupled) is in third place on the shortlist (Table 7.9) with four points less than the top score.

Table 7.8 Material shortlist (standard)



MATERIAL NAME	SCORE
1st Polypropylene (30% glass fibre coupled)	403
2nd Phenolic (glass fibre reinforced; high impact)	394
3rd Polypropylene (homopolymer)	386
4th Polypropylene (homopolymer; uv stabilised)	385
5th HDPE	384
6th LDPE (uv stabilised)	382
7th ABS (medium impact)	382
8th Polypropylene (copolymer)	381
9th Polypropylene (elastomer modified)	380
10th SAN (30% Glass Fibre reinforced)	380

Table 7.9 Material shortlist (foam)

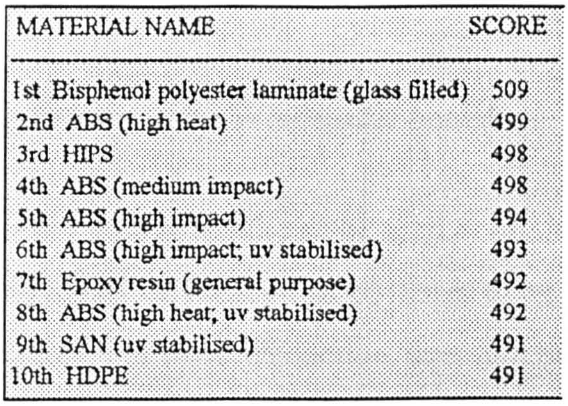


MATERIAL NAME	SCORE
1st Polypropylene (homopolymer)	359
2nd Polypropylene(homopolymer; uv stabilised)	358
3rd Polypropylene (30% glass fibre coupled)	355
4th Polypropylene (copolymer)	354
5th Polypropylene (copolymer; uv stabilised)	353
6th HDPE	352
7th ABS (high heat)	351
8th ABS (medium impact)	350
9th X-linked PE	347
10th ABS (high heat; uv stabilised)	346

7.4.3 Comparison with Plassel 90

Selection of the manufacturing process has considerable influence on material selection. In Plassel 90 material processes were recommended based purely on production volume and shape criteria. The subsequent material selection is then conducted assuming that the recommended process has been selected. Plassel considers a wider range of process selection criteria, and the recommended process does not have to be adopted for subsequent analysis. The Plassel 90 material shortlist for washing machine outer drum is shown below.

Table 7.10 : Material shortlist (Plassel 90)



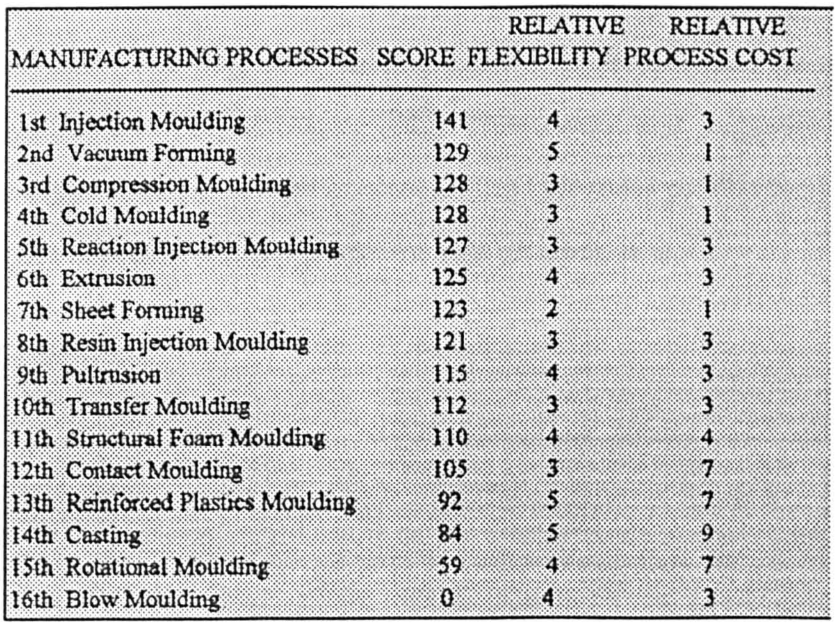
MATERIAL NAME	SCORE
1st Bisphenol polyester laminate (glass filled)	509
2nd ABS (high heat)	499
3rd HIPS	498
4th ABS (medium impact)	498
5th ABS (high impact)	494
6th ABS (high impact; uv stabilised)	493
7th Epoxy resin (general purpose)	492
8th ABS (high heat; uv stabilised)	492
9th SAN (uv stabilised)	491
10th HDPE	491

The shortlist (Table 7.10) suggested is very different from that suggested by PLASSEL 93. Polypropylene is not found in the top ten of the suggested shortlist . This is because all the qualified manufacturing processes are taken into account in selecting materials. Different manufacturing processes generally prefer particular materials for optimum operation, in this case polypropylene has a high preference for (structural foam) injection moulding but low for the other processes. So if all the qualified manufacturing processes are taken into account in selecting materials, materials which have very high preference for a highly rated manufacturing processes, may obtain scores higher than polypropylene.

7.5 Windsurfer Board

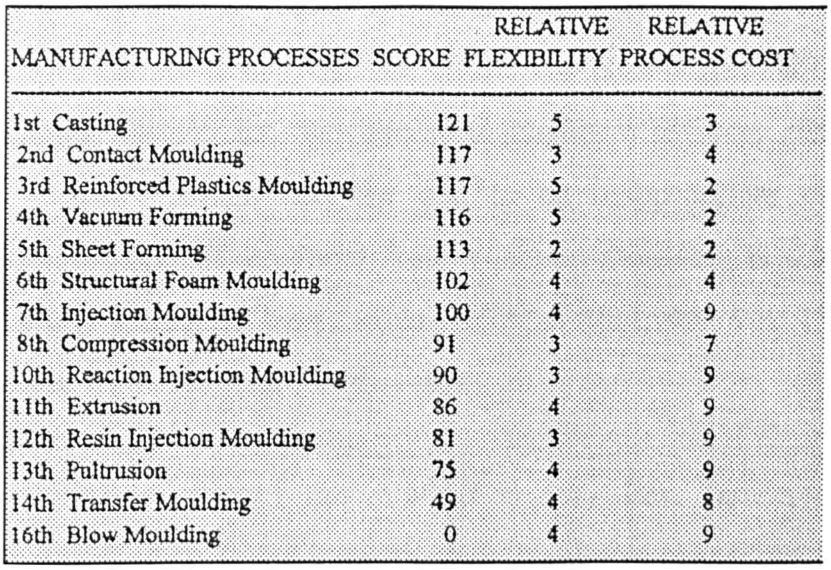
7.5.1 Manufacturing Processes for Windsurfer board

There are several methods which can be used to produce a windsurfer board. Choice depends highly on the number of pieces to be produced and the acceptable processing cost. For mass production, injection moulding is highly preferred compared to other processes (Table 7.11). However if the production volume is restricted, for example to 100, it is found that injection moulding is at 7th position. Processes such as casting and reinforced plastics moulding, with low tooling costs are more highly recommended by the system (Table 7.12).



MANUFACTURING PROCESSES	SCORE	RELATIVE FLEXIBILITY	RELATIVE PROCESS COST
1st Injection Moulding	141	4	3
2nd Vacuum Forming	129	5	1
3rd Compression Moulding	128	3	1
4th Cold Moulding	128	3	1
5th Reaction Injection Moulding	127	3	3
6th Extrusion	125	4	3
7th Sheet Forming	123	2	1
8th Resin Injection Moulding	121	3	3
9th Pultrusion	115	4	3
10th Transfer Moulding	112	3	3
11th Structural Foam Moulding	110	4	4
12th Contact Moulding	105	3	7
13th Reinforced Plastics Moulding	92	5	7
14th Casting	84	5	9
15th Rotational Moulding	59	4	7
16th Blow Moulding	0	4	3

Table 7.11: Windsurfer Board Process shortlist (High Volume)

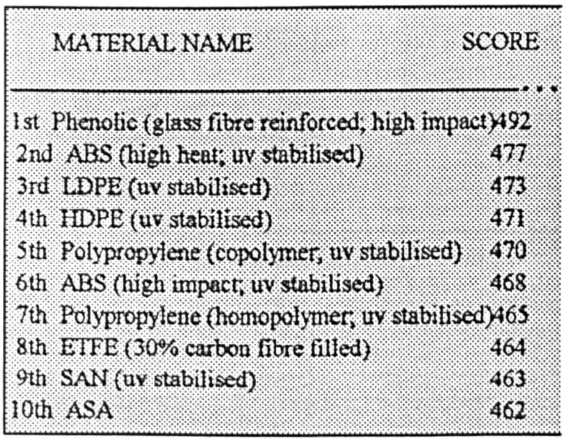


MANUFACTURING PROCESSES	SCORE	RELATIVE FLEXIBILITY	RELATIVE PROCESS COST
1st Casting	121	5	3
2nd Contact Moulding	117	3	4
3rd Reinforced Plastics Moulding	117	5	2
4th Vacuum Forming	116	5	2
5th Sheet Forming	113	2	2
6th Structural Foam Moulding	102	4	4
7th Injection Moulding	100	4	9
8th Compression Moulding	91	3	7
10th Reaction Injection Moulding	90	3	9
11th Extrusion	86	4	9
12th Resin Injection Moulding	81	3	9
13th Pultrusion	75	4	9
14th Transfer Moulding	49	4	8
16th Blow Moulding	0	4	9

Table 7.12 : Windsurfer board process shortlist (Low volume)

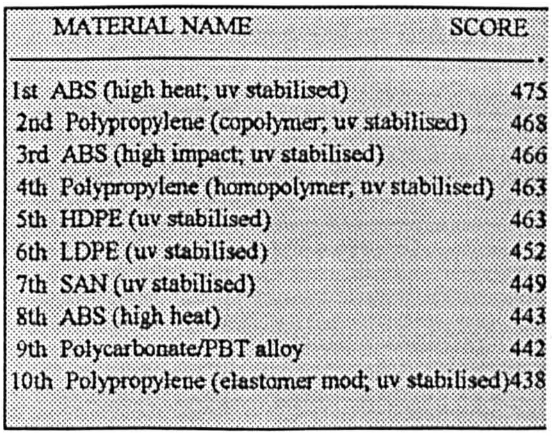
7.5.2 Materials for windsurfer board

According to the guide books for polymers from Hoechst [64] and Bayer [65], (polymer manufacturing companies), windsurfer boards can be made of Polypropylene (PP) and Polycarbonate (PC). These were also suggested by the class exercise (appendix D). If injection moulding (for mass production) is selected as the manufacturing process for this product, it is



MATERIAL NAME	SCORE
1st Phenolic (glass fibre reinforced; high impact)	492
2nd ABS (high heat; uv stabilised)	477
3rd LDPE (uv stabilised)	473
4th HDPE (uv stabilised)	471
5th Polypropylene (copolymer; uv stabilised)	470
6th ABS (high impact; uv stabilised)	468
7th Polypropylene (homopolymer; uv stabilised)	465
8th ETFE (30% carbon fibre filled)	464
9th SAN (uv stabilised)	463
10th ASA	462

Table 7.13: Injection shortlist (3)



MATERIAL NAME	SCORE
1st ABS (high heat; uv stabilised)	475
2nd Polypropylene (copolymer; uv stabilised)	468
3rd ABS (high impact; uv stabilised)	466
4th Polypropylene (homopolymer; uv stabilised)	463
5th HDPE (uv stabilised)	463
6th LDPE (uv stabilised)	452
7th SAN (uv stabilised)	449
8th ABS (high heat)	443
9th Polycarbonate/PBT alloy	442
10th Polypropylene (elastomer mod; uv stabilised)	438

Table 7.14: Foam Shortlist (4)

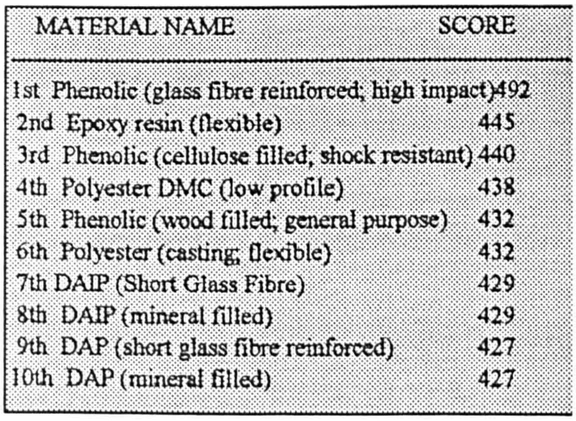
found that both materials are on the shortlist (Table 7.13: Material shortlist (3)) but with lower positions (5th, 7th, 15th). The reason probably is that the system does not consider the importance of toughness or creep resistance for the board. Another reason may be due to an inappropriate selection of manufacturing process. If structural foam injection moulding is selected, it is found that both PP and PC have higher positions (2nd, 4th, 9th, 13th) on the shortlist (Table 7.14 : material shortlist (4))

If the production volume of this product is very low, reinforced plastics moulding is preferred (3rd) and it has the lowest relative processing cost. Since different manufacturing processes prefer particular materials for optimum operation, the materials suggested by the system will also change.

On Table 7.15 material shortlist (93-5), it is found that some more expensive materials are suggested instead of PP and PC. This is because the material cost is relatively not as an important a factor in low volume production and materials with better performance have been selected.

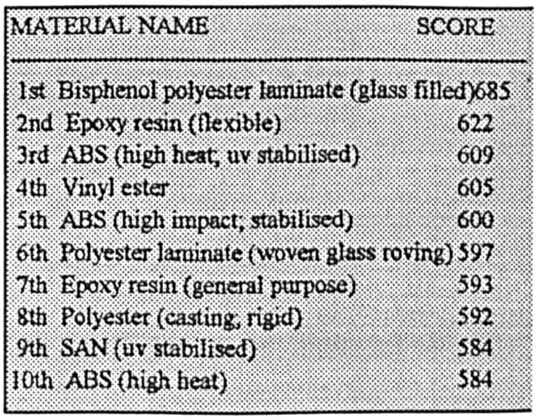
7.5.3 Comparison with Plassel 90

The shortlist (Table 7.16) suggested by Plassel 90 for this product differs



MATERIAL NAME	SCORE
1st Phenolic (glass fibre reinforced; high impact)	492
2nd Epoxy resin (flexible)	445
3rd Phenolic (cellulose filled; shock resistant)	440
4th Polyester DMC (low profile)	438
5th Phenolic (wood filled; general purpose)	432
6th Polyester (casting; flexible)	432
7th DAIP (Short Glass Fibre)	429
8th DAIP (mineral filled)	429
9th DAP (short glass fibre reinforced)	427
10th DAP (mineral filled)	427

Table 7.15 : Low Volume (93-5)



MATERIAL NAME	SCORE
1st Bisphenol polyester laminate (glass filled)	685
2nd Epoxy resin (flexible)	622
3rd ABS (high heat; uv stabilised)	609
4th Vinyl ester	605
5th ABS (high impact; stabilised)	600
6th Polyester laminate (woven glass roving)	597
7th Epoxy resin (general purpose)	593
8th Polyester (casting; rigid)	592
9th SAN (uv stabilised)	584
10th ABS (high heat)	584

Table 7.16 :Plassel Shortlist (90-2)

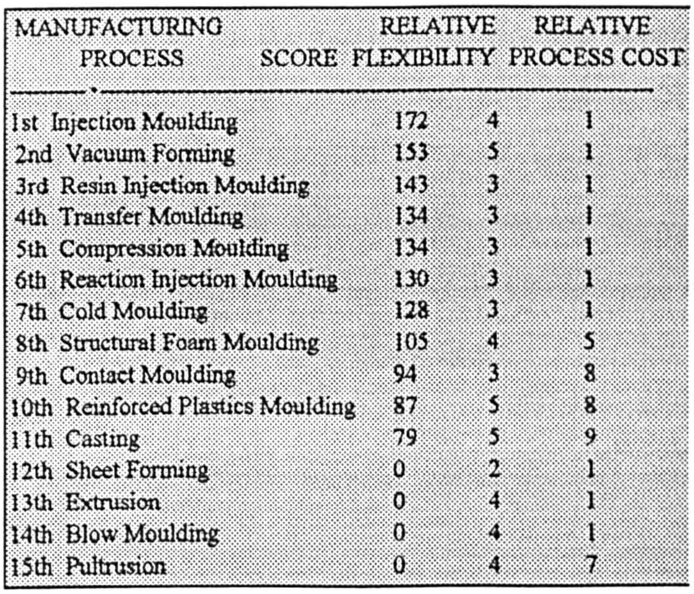
greatly from that suggested by PLASSEL 93. No PP or PC can be found on the shortlist. The reason is that materials with a higher preference for all qualified processes will obtain higher scores than PP and PC which may greatly prefer (structural foam) injection moulding.

7.6 Computer Housing

7.6.1 Manufacturing Processes for computer housing

If mass production is required, injection moulding is highly preferred as the manufacturing process for computer housings. (Table 7.17).

Table 7.17: Computer Housing Process shortlist 4

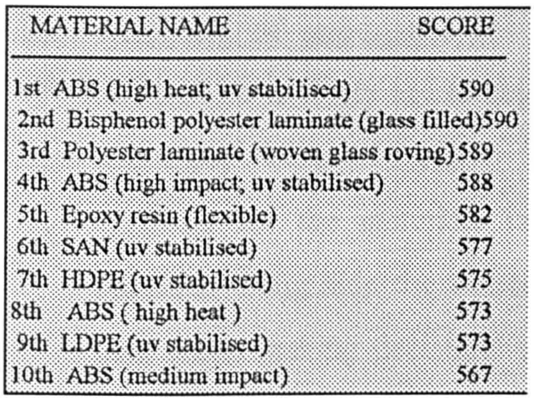


MANUFACTURING PROCESS	SCORE	RELATIVE FLEXIBILITY	RELATIVE PROCESS COST
1st Injection Moulding	172	4	1
2nd Vacuum Forming	153	5	1
3rd Resin Injection Moulding	143	3	1
4th Transfer Moulding	134	3	1
5th Compression Moulding	134	3	1
6th Reaction Injection Moulding	130	3	1
7th Cold Moulding	128	3	1
8th Structural Foam Moulding	105	4	5
9th Contact Moulding	94	3	8
10th Reinforced Plastics Moulding	87	5	8
11th Casting	79	5	9
12th Sheet Forming	0	2	1
13th Extrusion	0	4	1
14th Blow Moulding	0	4	1
15th Pultrusion	0	4	7

7.6.2 Materials for computer housings

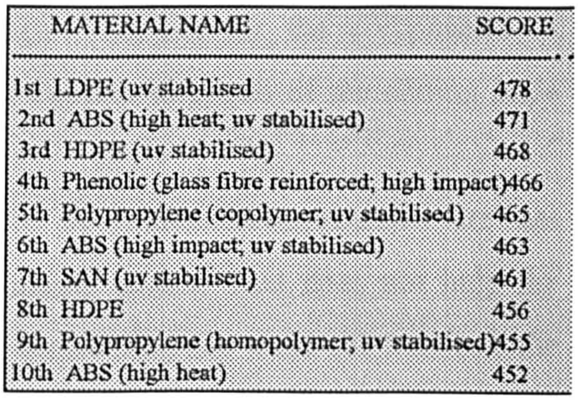
ABS can be found in the 2nd and 6th positions of the material shortlist (93-6), table 7.18. Similarly in Plassel 90 (shortlist 90-3, table 7.19), modified polyphenylene oxide (PPO) and Polycarbonate (PC) do not have prominent positions on the shortlist of materials. Both shortlists are similar and the materials suggested only have small changes in position.

Table 7.18: Material shortlist 93-6



MATERIAL NAME	SCORE
1st ABS (high heat; uv stabilised)	590
2nd Bisphenol polyester laminate (glass filled)	590
3rd Polyester laminate (woven glass roving)	589
4th ABS (high impact; uv stabilised)	588
5th Epoxy resin (flexible)	582
6th SAN (uv stabilised)	577
7th HDPE (uv stabilised)	575
8th ABS (high heat)	573
9th LDPE (uv stabilised)	573
10th ABS (medium impact)	567

Table 7.19: Plassel shortlist 90-3



MATERIAL NAME	SCORE
1st LDPE (uv stabilised	478
2nd ABS (high heat; uv stabilised)	471
3rd HDPE (uv stabilised)	468
4th Phenolic (glass fibre reinforced; high impact)	466
5th Polypropylene (copolymer; uv stabilised)	465
6th ABS (high impact; uv stabilised)	463
7th SAN (uv stabilised)	461
8th HDPE	456
9th Polypropylene (homopolymer; uv stabilised)	455
10th ABS (high heat)	452

7.7 Expert Comments

The system has been shown to the experts Dr Gordon Smith, Mr David Wimpenny of the Rover Advanced Technology Centre and to Dr Dan Kells, Manager of Advanced Materials at the BAe Sowerby research centre. Also demonstrations have been made to mixed audiences of Rover Advanced Technology Staff and to MSc students. The overall verdict was satisfactory. However some deficiencies identified are listed below:-

a) The user may suffer from waiting when loading other modules knowledge bases.

b) Although graphical representations of typical examples of the component shape are provided, the user may still have difficulty in classifying the component shape.

c) In "Customisation Properties Module", the materials can only be evaluated one property at a time. This is very time consuming if several properties are considered.

d) The on-line Help/Explain facility is not fully implemented in all modules as in "Consult Expert" to explain the terminology (e.g. aliphatic and aromatic hydrocarbon) used.

e) It is quite difficult for the user to make his judgement in selecting the weighting of importance (between 1 to 10) for the component. In addition he is likely not to select the two extremes of the sliding scale due to psychological factors.

f) Costs for the materials in the recommendation shortlist are not provided along side the corresponding scores. This does not help the user when making decisions by considering the trade-off between the performance and the costs of materials.

g) The information provided by "End Use Requirements Checklist" is not specific enough.

According to the material selection experts, the knowledge-based driven searches in PLASSEL short-listed plastic materials that were generally suitable for the applications specified. However there were anomalies, some selected materials were not suited to the specified requirements. It was considered that this was caused by the lack of restrictions in the selection of the suitable materials, for example, paintability of the plastics are not considered unless the customisation module has been used to create a search for it. It is not possible to automatically include some of these additional considerations, because there is no relevant data available in the PLASCAM and CAMPUS set of databases. Nevertheless, additional properties may be directly added to the knowledge base driven search by the simple modification of the CAMPURNK.KB and CAMPUS_2.KB knowledge bases. The author did not include all the materials properties provided by CAMPUS for use in the knowledge base driven search because: Firstly, the ranking of the materials would require considerably more time, secondly, the searches would be slower since more fields in the rank file must be read, finally, many of the properties not included were those for which data were often missing in the original CAMPUS databases and were not considered essential properties.

It was noted that, as the cost of materials is an important selection criteria, this should also be included into the CAMPUS DATA module for evaluating materials as it is in PLASCAMS module. However, this is not possible since the CAMPUS databases do not include cost information on the materials.

One of the problems encountered in using the knowledge base driven search was that it was difficult for some user to decide which weighting to select, as the choices available do not provide any meaningful definition of what each rank represents. It was considered that some definitions for each rank should be provided. Other problems with the assigning of weightings may be envisaged, e.g. different individuals may obtain slightly different results with the knowledge base driven search for the same application in mind, depending on how the individuals assign the weighting for each property. Also users may tend, either to assign all the properties with high ratings (believing it will select the best overall material), or not assign extreme ratings at all due to the undesired consequences imagined.

All of the reviewers of PLASSEL approved of the user interface. They liked the consistent layout of the screens and the menu driven options. In particular, the non-experts in materials selection found the inclusion of diagrams in the Manufacturing Processes Selection helped their selection of the appropriate shape. The ability to "escape" to the main menu during any operation in the system was also considered as a very useful feature.

However, it was indicated that some screens did not provide sufficient instructions or help was not given. Some screens were not as intuitive to use as most screens in the system. The inclusion of the signalling bleeps at the end of the searches confused some users, who may have thought that they were signalling an error.

It was commented that the CAMPUS DATA module in PLASSEL was not fully integrated with the PLASCAMS modules. These were deliberately kept separate because they store different types of data and provide different functions. The CAMPUS data does not necessarily cover all types of plastics, but provides detailed data and information about particular grades, and hence it is more suitable for the latter stages of material identification.. Plascams data is more generic and better suited to initial searches.

A main problem with Crystal found by the author is that it is slow at file handling. This makes the searches through the databases much slower than it would be desired. The problem is most pronounced when Crystal has to reread a string (or field, or line) from a file because the inappropriate function was used, e.g. using ASreadnum function to read a string of letters. This is problem for the ranking of the CAMPUS databases, since many fields are missing for the material properties, hence numerical data are missing that are either replaced by a symbol (e.g. an asterix) or are not included in the file. Therefore repeated rereading of a CAMPUS file is often required by the CAMPURNK.KB knowledge base to rank the data. If the CAMPUS file being ranked is large, then the ranking process is often over an hour long. For this reason, it is suggested that the conversion and ranking should be performed when the computer is not for other use (e.g. overnight). Although, the conversion process for a single CAMPUS database can be performed without the presence of the user, it would be useful if batches of files can be converted sequentially, allowing the option to convert these files overnight more efficient.

The general comments were very favourable, the main virtues being ease of use and the breadth of functions provided. It is very difficult to elicit comment on other than very general terms about the actual material recommendations. The recommendations were welcomed as acceptable and no serious criticism made.

7.8 Discussion

In "Manufacturing Processes Selection", generally it is found that the recommendations offered are similar to the class case studies. Since component shapes and production volume are the most important factors in manufacturing process selection, an acceptable suggestion will result if these two factors are input accurately. However it is also found that some manufacturing processes, which are expected by the expert for specific products, may be at a relatively low position on the shortlists. A reason may be that the system does not consider the property requirements of the component. The material properties may be affected by the manufacturing processes. For example in the case of "Washing Machine Drum", the material properties can be increased by using structural foam injection moulding instead of injection moulding.

In "Consult Expert", the material recommendations are not identical to those discussed in the exercises in appendix D. This may be due to the inaccurate input weightings, knowledge missing in the system or inappropriate suggestions given in the exercises performed by the system developer and/or inappropriate selection of manufacturing process for the components. In the case of "washing machine outer drum", it was found that the "desired" material, polypropylene (glass-filled), will obtain the highest score if the input weightings are accurate and manufacturing process are selected appropriately. The use of another manufacturing process will result in a large change in the recommendations. Although the system does not request specific values for the desired material properties, it can be quite difficult for the user to judge the selection weightings of importance (between 1 to 10) for the component appropriately. For instance, if the user wants to select a material for a windsurfer board, he may not know which weighting, 8,9, or 10 is most appropriate to indicate for the importance of resistance to UV radiation. The results from the system may be different if he enters 8 instead of 10.

The materials suggested on the shortlist at the end of a consultation are generally suitable, the final optimisation requires the user to assess the spread of scores for the materials, and select an appropriate subset. As with the commercial selectors available, final decisions should be made in consultation with technical experts from material suppliers. This is the only feasible approach because:

1. Material properties can be varied slightly by the supplier.
2. Prices can change and this is always a important consideration.
3. It is impossible for a computerised system to fully take into account all the broad range of factors that may influence a material decision.
4. Legal considerations concerning product liability make it unacceptable to rely only on a KBS system.

Three critical success factors (CSFs) could have been identified in advance for a material selection system. They are :

- **Usability -** The system must be easy to use for both experienced and inexperienced designers
- **Correctness -** The system recommendations must be appropriate.
- **Data -** The system must be able to access a variety of reliable sources of materials data

The evaluation conducted and the structure of the system indicate that these have been satisfied by Plassel.

CHAPTER EIGHT

DISCUSSION

There are a number of key problems in the process of materials selection.

8.1 Interaction in Selection Parameters

The central problem of materials selection in mechanical design is the interaction between function, material, process and shape [1]. This is illustrated in figure 8.1 below.

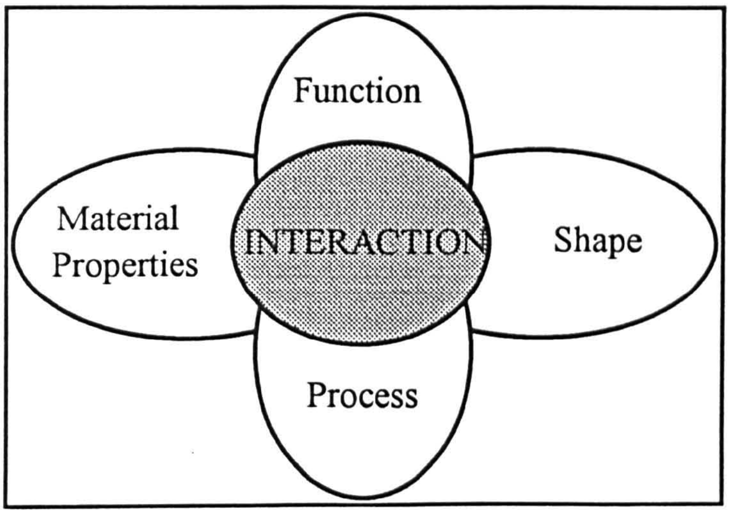


Figure 8.0 : Key Interactions

This interaction causes a magnification of the problem, selection on any one criteria is relatively easy, this however is all that the majority of existing materials selectors do. To tackle the problem we have to break the link, at some stage and proceed from there. That is what Plassel does, using Shape and key functional requirements the Process is determined, this then, with further functional requirements, is used to define the required material properties and hence, material. At this stage it would be desirable to reason backwards, looking for further optimisation, and to repeat the cycle. Plassel does not do this automatically, but confirmation of material choice can be obtained from the material texts provided in the databases or from the plastic materials applications module. Of the other plastic material selectors uncovered, only Peritus was intended to work in a similar manner. Peritus has recently been withdrawn from sale probably because recent evaluations concluded *"other systems can now better perform the same functions"* [27]. A number of systems e.g. Campus allow the user to graphically display material performance. A leading champion of this approach is Professor Ashby [1], and his innovative methods for selecting materials are incorporated in one of the latest selectors to become available, the Cambridge Material Selector (CMS). This has two main features, the use of material selection charts as described in Section 2.2 and illustrated in figure 2.2. and a method for checking the validity of internal data. The latter establishes whether the values for a particular property of a material are likely to be valid based upon the other data values and basic physical relationships. The CMS approach though very appealing conceptually suffers from a number of limitations. The selection approach is sequential and two dimensional. A sequential approach forces the user to go through a process of deciding the priority of his criteria, and then searching a (reducing) search list for each criteria. This approach was adopted in one of the trial systems built , PLASMA by Victor Li (section 4.10), unfortunately, usually the first search terminated with no suitable materials and subsequent searches with certain criteria relaxed were required. The other problem is that the user is only selecting by optimising two properties at any one time. The overall approach is useful for obtaining a subset of suitable materials at the conceptual stage of design but does not easily allow for a judgement between them. The materials data available to the system is very limited. Customised databases are sold in support of the system, these can never contain the necessary detail and the very latest information, unless directly supported by independent agencies like Rapra or the material suppliers.

8.1.1 Interaction Between Materials And Manufacturing Processes.

Manufacturing method is of the greatest significance in determining the successful application of a given material to a design. A material selection system should encourage the user to consider the interaction between materials and manufacturing processes.

Material selection in Plassel is based on one manufacturing process which is selected by the user for his product. The other manufacturing processes are not taken into account in scoring materials as in Plassel 90. Different manufacturing processes prefer particular materials for optimum operation, this encourages the user to consider the interaction between manufacturing processes and materials directly. The user can select other processes to test for changes in the recommendations. This ensures that the suggested materials have optimum performance with the selected process. If all manufacturing processes are considered during material property evaluation, anomalous results can occur, because of very strong preferences by some materials for particular processes. In Chapter Seven, it was found that the materials suggested by Plassel are consistent with real examples if the manufacturing process is selected appropriately.

8.1.2 Manufacturing Processes Selection

In selecting manufacturing processes for components, the system considers six factors, component shape, component size, production rate, surface finish, dimensional tolerance and production volume. However since the material properties required for the component can be affected by its manufacturing process, properties requirements of the component should also be taken into account in selecting manufacturing processes. For example contact moulding may be preferred to casting if a higher toughness is required. This means that the material property requirements should be considered not only in the material selection, but also in the manufacturing processes selection. Due to the time constraints on this project, This was not evaluated in the system. Further research is required: what properties are mainly affected by manufacturing processes? how they are affected by different processes? etc..

The value judgements (ratings) of the manufacturing processes on the six factors are not stored in a database separated from the knowledge base, like material data. This means that the user is not allowed to change these ratings. This is because the objective of the module is to compare the manufacturing processes relatively with respect to the specific requirements of the six factors. They are assumed to be compared with the same standard (technology level). The ratings are relative values and are judged by experts based on their experience. No accurate specific value , like material data, is involved. Consequently, in order to ensure that the manufacturing processes are compared to the same standard, all the ratings are stored in the knowledge base and are not allowed to be changed by users. In addition it is found that the selection time is much faster than that of material selection process where data is stored in a separated database.

8.2 Conversion of functional requirements.

A major difficulty for designers inexperienced with materials and their properties is to convert a products desired performance level to the material property value to achieve that. For example a car bumper needs to be "tough but soft", resistant to damage in low impact situations but yielding and absorbent to high impact levels. What material properties are involved in specifying this requirement? and secondly, what values of those properties are required. This is an area that seems to be totally ignored by the existing commercial plastic material selectors. Plassel tackles this by asking general questions relating to desired performance requirements, it then automatically converts these to target property values. This conversion knowledge utilised is based upon the suggestions of Dr. Smith, Dr Kells and Mr Wimpenny. The actual conversions can be defined as ratios, for example, Toughness (for bumper rating =7) = Tensile strength rating/Flexural modulus rating >= 6.5 . A search on this criteria would lead to a shortlist of materials. Another possible conversion could be, toughness = 60% {Toughness@20^{0}C} + 40% {Toughness@ -40^{0}C}. This is an extremely flexible approach, and in essence eliminates the need to study Ashby's material selection charts or to plot ratio curves as Campus allows. In Plassel these conversion ratios have been fixed, but in practise it could be arranged that the user is able to specify and alter them. This would allow users to further customise Plassel to their own unique environment.

Nevertheless, it is still desirable for users to be able to establish what are typical property values for that kind of application. This can help supply values for direct searches and for estimating weightings for 'combined' searches. The 'End-Use Requirements Checklist' module helps achieve this by providing typical property values ranges and considerations for a range of applications identified by Kusy [7].

8.3 Data Management

Any materials selection system intended for designers that cannot access independently available commercial data is ultimately doomed to failure. The success of Campus is based around this whole concept of independent data tested to uniform standards. However a full selection system need to provide a range of types of data. Three type can be identified:

- (1) Conceptual Data : approximate, easy access data for the widest possible range of materials.
- (2) Embodiment Data : Class Specific handbooks and databases.
- (3) Detail data : Manufacturers data sheets, in-house tests etc.

Conceptual data is usually utilised to choose between the broad material classes, and is beyond the scope of Plassel at this stage, which is intended for plastic material selection. It does however need to supply the other two classes. It does so, by providing access and selection on Plascams data (Embodiment) and Campus data (Detail). Please note that use of Plascams data requires a licence [12]. Plassel provides two basic data management schemes, standard Dbase3+ structured (Plascams) and Text structured (Campus). This was done to establish if their were any major advantages or dis-advantages with either approach since Crystal can handle either. Search speed for Dbase3+ data was found to be quicker, but this was the only advantage identified. Most databases of materials data tend to be available in ASCII like format and conversion difficulties centre around the compatibility between Crystal ASCII and the data ASCII. Conversion to Dbase 3+ format was found to be easier. The conversion and ranking of CAMPUS data was considered as one of the main problems encountered in the project.

The programs written for converting and ranking the CAMPUS data required the longest time to develop, since the need to consider the data quality was essential and mistakes should not be made in manipulating the data. Therefore these programs were extensively tested and rewritten many times over. The task of converting and ranking the data in these files was made more difficult since the functions provided by Crystal for manipulating ASCII files were limited.

The knowledge acquisition stage in developing knowledge based systems is often considered as the most difficult phase (section 4.3). Although, the Knowledge-base Driven Search module in the Campus module of Plassel is based upon the principles of the Plascams data based Consult Expert module, there are differences in the type of materials property data available for the two knowledge based modules used to select relevant materials. Therefore knowledge acquisition was still required for the construction of a knowledge base for selecting suitable materials from CAMPUS data files. The main problem encountered in knowledge acquisition was that the materials selection experts are often unavailable, and a considerable amount of time in this project was taken in pursuing the experts.

8.4 Customisation

A very broad and ill defined range of influences can affect material selection. This contradicts one of the basic guidelines for developing knowledge based systems, that the problem domain be narrow and well defined. This is a key reason why broad knowledge based materials selectors have not really been successful. Practical examples have tended to focus towards more specific areas such as corrosion advice, or adhesives selection. Plassel tackles this problem by allowing the user to customise the search process. Some of the existing commercial systems allow users to modify the database of materials. New materials can be added or existing data modified to reflect changed circumstances, Plassel also allows this. They cannot however allow new selection criteria to be added and combined into the search procedure as Plassel does. Within Plassel users can define their own selection criteria and incorporate them into the materials in the database and into the search process. Hence the user can, if they want, select by factors such as smell, paint-ability, glue-ability, biodegradable half-life, etc., whatever is important to the user.

Environmental issues are becoming increasingly important in material selection. Plassel contains built-in searches for major environmental factors. However materials data is not readily available on these factors from public sources, and often has to be deduced or derived from in-house testing. Plascams allows such data to be entered and managed within the system. Many major corporation such as Rolls Royce go to great expense to create their own materials databases to achieve similar results.

In-house data can be fairly readily stored in a number of ways. What is more difficult is to store specialised knowledge and experience. A CAD file for example may contain information relating to dimensions, materials and processes, what it does not contain however is information relating to why those dimensions where chosen, why that particular material is preferred, what parameters the process was selected by. It is crucial to store this knowledge and to make it available from one project to the next or from one designer to another. This was a key requirement for Rover. Plassel provides a library structure within the system which the user can use to store this type of information. This key element is missing in the current systems evaluated, and helps to make Plassel a more complete materials selection system.

8.5 Application of Multimedia

When presenting information " a picture is worth a thousand words!" and animation, sound and live video possibly even more. A materials information and selection system could benefit from the application of multimedia techniques. Within Plasma [13] design advice for plastics was presented using captured pictures, and a picture library of suitable techniques (to improve stiffness for example) was utilised. This could be enhanced by using multimedia techniques. However, the addition of multimedia techniques into the existing knowledge base system is not practical to implement. The main reason is that it would be ineffective to continuously switch between the Crystal application to a multimedia program, because Crystal does not provide support for Multimedia hardware and the Crystal shell reserves much of the available memory for itself, therefore external programs are difficult to run under shell. Also most existing Multimedia applications for the PC are developed for the Microsoft Windows environment (In fact, the Multimedia PC (MPC2) standard, is based upon Windows 3.1) and range of software for developing Multimedia applications under DOS are limited.

A picture library of snapshots such as in Plasma may be implemented in Plassel and be of benefit, though a key problem would be making sure that they were shown in the correct context, especially with novice designer users.

8.6 Reliability of the System and Product Liability Considerations

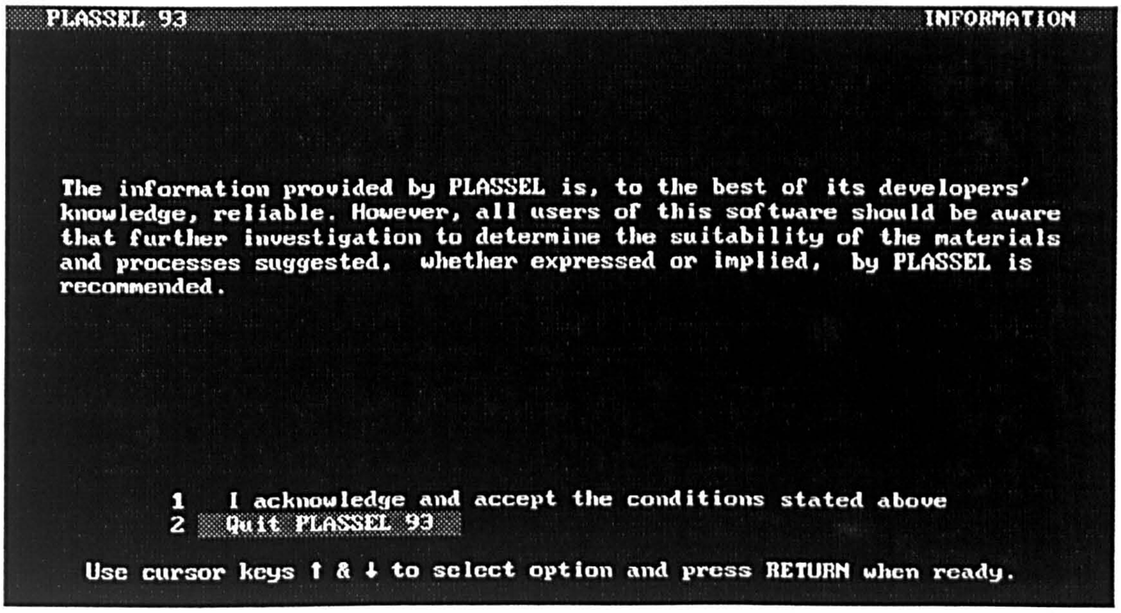
As the main aim of Plassel is to provide advice on the selection of plastic materials for product and component designs, the results provided by the system must be as reliable as the available data and the limitations of knowledge-based systems permits.

The selection of an inappropriate material by the system for a component or product design may result in substantial costs due to (1) unsuitable processing capabilities of the material, (2) low performance of the product, and (3) high failure rates of the product. The latter consequence may be the most critical and harmful if not rectified. Component failure may result in considerable damage or loss. At worse, it may cause injury or death.

In the English Legal system, consequential losses induced by a defective product are considered in Product Liability law. However, much of English Law is based upon judicial precedence (Common Law), compounded with the fact that many of the concepts applied to Product Liability cases are difficult to translate, in terms of modern information technology, the liability of "defective" computer software is unclear. According to C. Reed [47], the problem of product liability in information technology *"... lie not so much in the technology as in the application of existing principles to facts that are entirely novel and have few conceptual similarities with the kind of facts the judiciary are accustomed to encounter."*

There are three main areas of Law, under which Product Liability may be considered: (1) liability under Contracts, (2) liability under Negligence; and (3) the Consumer Protection Act 1987. Since Plassel, at present, is not considered to be sold as a product or a service, or as bespoke software, then the rôles of contractual liability and the Consumer Protection Act are of limited consideration here.

The rôle of negligence is perhaps the most important area to consider in developing a knowledge-based system. There are two areas where negligence may relate to a plastic materials selection system that should be avoided and protected against. Firstly, negligence in the design of the knowledge-based system itself: It must be proved that every reasonable care was taken in developing the software in order to "invalidate" negligent design. The comments relating to "correctness by construction" in section 7.3 are particularly relevant. Secondly, a user relying solely on the system's output may also be considered negligent (C. Reed [47]): The users of the system may be considered negligent if he or she relies on the output of the system alone, when it is not sufficient to justify this reliance. As a consequence all of the computerised plastic materials database systems reviewed in section three provide warnings to users not to rely on their software in isolation, for the selection of appropriate plastic materials. The use of contractual agreements to confirm the users' awareness of this fact, in the initial screens of these databases, provide the software originators some protection from product liability litigation. As with these systems, Plassel must include consideration of product liability and contains an initial 'acceptance' screen. On starting Plassel, a title screen is displayed, then a screen providing the contractual terms and an exclusion clause is displayed. The contractual agreement is accepted or rejected by the user through the selection of the appropriate option (screen 20). The default action is exit from PLASSEL, a positive acceptance has to be made to proceed



PLASSEL 93 INFORMATION

The information provided by PLASSEL is, to the best of its developers' knowledge, reliable. However, all users of this software should be aware that further investigation to determine the suitability of the materials and processes suggested, whether expressed or implied, by PLASSEL is recommended.

1 I acknowledge and accept the conditions stated above
2 Quit PLASSEL 93

Use cursor keys ↑ & ↓ to select option and press RETURN when ready.

Screen 21 : Acceptance of legal responsibility

8.7 Applicability to other materials

An aim of the project was to assess how well the techniques utilised and the structure developed was applicable to other types of materials. Plastics have particular characteristics identified in section one that may cause Plassel to be unsuitable for other materials such as metals or ceramics. Two key factors which could affect this consideration are :

1. The selection of suitable process and use of this to restrict the data search.

The importance of process on material properties for all materials seems to be as great if not greater than for plastics. The structure of suitable process selection and the use of that as a search constraint, appears to be well suited to selecting materials other than plastics.

2. The availability of suitable databases of materials data.

   C. K. Bullough identified a number of databases (figures 3.0 and 3.1) some of which may be suitable. Ashby [1] however sums up the problem " *One day there may be a universal materials data bank. It is a long way off. If you want data today, you have to know your way around the sources, and the quirks and eccentricities of the ways in which they work.*" The quality of materials data does vary considerably between the different groups. However, apart from a few specific groups such as 'fine' ceramics, data is generally more readily available and often of higher quality, especially metals, than for plastics [1].

In conclusion the approach developed in Plassel appears to be also suitable for selection of a wide range of materials other than plastics. However of the three stages of selection (section 8.3) the approach adopted in Plassel is least suited to "conceptual selection", that is, between the main material categories. This is because the breadth of the knowledge domain and the vagueness of its borders is the greatest for conceptual selection.

8.8 Accurate Weighting

The accuracy of the weightings input by the user to indicate the importance of the properties required by the component is very critical to the accuracy of the recommendations. Although the use of a weighting (1-10) scheme eliminates the need for specific numerical data for material properties, it is quite difficult to make judgements. It may take the user time to become familiar with the weightings. Consequently, in order to help him to identify the weightings accurately, some typical examples or specific values of the weightings should be provided. This has been done in the "Manufacturing Processes Selection" module, but not yet in "Consult Expert" and "Environmental, Energy Saving and Post-Processing". However the system should still have enough robustness to deal with this possible human error, so that correct or acceptable results are provided even if the user inputs a few inaccurate weightings. Another possible approach may be the adoption of Monte Carlo type variability analysis to the rating selected. A number of system runs could be completed automatically, and the optimised material selection presented. This would also be useful for identifying the key parameters, so a greater care could be taken in their definition.

8.9 Separated Databases

Separated databases are employed in the system to store a massive amount of material data. This enhances the maintainability of the system, and also provides a customisation facility. The user can change the original databases for ones containing the materials and property data of their own interest. For example, the material database files developed by members of the CAMPUS consortium can be exchanged. However the user must ensure that the format of his own databases must be compatible to the original. If not the system suggestions will be biased. Separated database are sometimes disliked by users though because they prefer to (sometimes) be able to search all sources of data in one selection run.

8.9 Data Quality

The quality of the data is very critical to the quality of the suggestions, and hence the success of the system. The system allows the user to update or append separate material databases easily through the interface facility built.

New plastics on the market can be added into the database and the plastics in which the user is no longer interested can be deleted. However there is a potential risk to the data quality because the user may corrupt the material data. As a result the system may give inappropriate material recommendations for the specific requirements or provide wrong material information. Consequently in order to assure the data quality, the material databases should only be modified by authorised personnel.

8.10 Component Shape Analysis

The classification of component shapes employed in Plassel is as suggested by Paul F.Kusy [7]. Graphical representations of typical examples of the classes are supported to help the user to identify his component shape. However the classification may not be specific or precise enough, the user may still find it difficult to match his component shape to the shapes given in the classification. It is actually very difficult to design a precise classification for the component shapes in such a system. Lyndon Edwards and Mark Endean [10] stated that the definition of shape is a current research area in the field of Computer Aided Design (CAD) and can become extremely complex. Integrating the system with a Computer Aided Design (CAD) system would be a possible solution. CAD systems based on KBS techniques [65] and parametric systems such as Pro-Engineer can incorporate material shape/property considerations directly. However these have not yet been used to select from a broad range of materials but purely from a limited pre-defined set.

8.11 Integrate Computer Aided Design (Cad) And Computer Aided Manufacturing System (Cam)

CAD systems are commonly used to help the designers to create, modify and analyse product designs. With CAD/CAM, it should be possible to integrate and automate virtually every aspect of the design and production operations of the firm, thereby increasing the efficiency and the productivity of these operation [r36].

A CAD system may manage the design variables correctly to decide which shape category the component belongs to, so the human error mentioned in section 8.9 can be eliminated. The design data of the component such as geometry, size, surface finish and dimensional tolerance are stored in a database. If an expert system can integrate with the CAD system through the database successfully, such design data can be directly used by the expert system for manufacturing processes selection.

Conversely, having recommended appropriate materials, the specific property data of the selected materials can be fed back to the CAD system for engineering analysis if the system is equipped with appropriate analysis packages. For example, a finite element analysis can utilise the material property data to simulate and determine the performance of the component with the selected material and designed geometry under thermal or loading stresses. As a result, the designer can know directly whether the performance of the combination of the material selected and the component design satisfy the specific requirements. It means that the integration of the expert system and CAD system can allow the user to consider the interaction between component geometry and materials directly to find the optimal solution.

CAD and CAM can come together through common or linked databases. Therefore if the expert system is linked with CAD/CAM, the material property data (melting point, viscosity, density, shear rate, etc.) of the selected material and the design data (size, geometry, tolerance, etc.) can be used in CAM such as "Mould Design" or "Mould Flow Analysis".

8.12 Customised End Use Requirements Checklist

The objective of the "End Use Requirements Checklist" in the system is to help the user to identify the material properties of his component. However the component classification suggested by Paul F. Kusy is not specific enough, a component may be at the crossover between specific categories. The information provided is the maximum or the minimum value of those materials most often used for the applications in each category. The information may not be directly applicable to the user. In addition since the information is stored in a knowledge base, the user is not allowed to modify it.. Consequently it is advisable to modify this module to make it like the "Application Library". The user can then save the property requirements for their specific components in the system. He can also modify or up-date it if necessary.

8.13 Cost

In the "Product Cost and Process Analysis" module, the user is requested to enter a value of mould cost to aid in determining the cost for the product. However at the beginning of the product design stage, it is quite difficult for the user to enter this value. This is because many factors such as mould material, size of the mould, manufacturing process, mould cavities, complexity of the product geometry, tolerance and surface finish are required to be considered in determining the mould cost. The system should help the user to estimate the mould cost. Much knowledge about mould design is required to achieve this, and was not attempted in this project.

Similarly although overheads are taken into account for product cost, it is quite difficult for the user to provide exact values. Those costs which cannot be allocated to specific jobs are overheads which are obviously different from one company to another. In most situation, all overhead items are aggregated and the resulting total divided among all products by means of an agreed rate, Overhead Recovery Rate. This rate may be a fixed percentage of the labour cost, say 250% for example. Consequently it is more appropriate for the system to ask for overhead recovery rate instead of exact value of the overheads.

For the purposes of material selection the exact value of mould cost and overhead cost may not be of direct importance. The process of obtaining the best process/material match is a comparative one, so ratios can be utilised.

Although the system can provide cost information for each material through the 'material cost analysis', it would be more appropriate if the material cost can be shown alongside the overall performance score of each material in the recommendation shortlists. This allows the user to make the trade-off between performance and cost of suggested materials directly.

A purchasing department is always interested in the lowest possible costs of the materials, especially for mass production. The system should provide material cost information for the materials from various suppliers including their quantity discount schemes. It can help the purchasing department to choose an appropriate material supplier or calculate the Economic Order Quantity (EOQ) of the material. However the prices of plastic materials change constantly, it is quite difficult to maintain the databases. Consequently it is advisable for the system to provide the information on the suppliers such as telephone number and addresses together with the cost information. This information is available in the system through the Plascams data.

8.14 Learning Systems

It is desirable for a material selection system to modify its performance by itself like human experts. It must be able to modify some part of the knowledge base to store the knowledge it is gaining and apply that knowledge if it is necessary. Thus a learning system is required.. This is however still very much an area of research.

Most system can only utilise the knowledge already stored in the knowledge base to suggest materials for specific requirements. They cannot develop or modify their internal knowledge representation on the basis of experience or feedback on material recommendations to improve their performance, like human experts.

Plassel attempts to achieve some improvement in selection performance by allowing users to modify data and store their experience. This could be further improved by making use of the database-knowledgebase link provided in Plassel. Currently some of the ratings and weightings are stored in the knowledgebase, these could be moved to a database and made accessible to the average user. Through a process similar to that implemented in the "select on customised properties" module, users could tune the system to reflect their own circumstances or changing circumstances and their acquired experience.

8.15 Execution Time

Since material data is stored in separate databases, the system makes use of the Crystal3 data interface functions to access data in selecting materials. This takes quite a long time (about two minutes) to complete the selection process. Furthermore the execution time will be considerably increased if the size of the database is expanded by adding more new materials (records). Memory limitations in basic computers can also cause the system to run slowly as can running the system under Microsoft "Windows".

8.16 Knowledge Acquisition

Knowledge acquisition is always recognised as a major bottleneck in developing an expert system. This is no exception in this project. Most practical expertise is usually not in textbooks, most textbook knowledge is too idealised for real situations. In this project, most of the knowledge is extracted from human experts, however it is far from easy. There is no knowledge elicitation method particularly recommended. "Interviews" and "questionnaire" are the methods through which the knowledge was elicited during this project. However it is quite difficult to document the interviews. Consequently tape recording the interviews was used by the developer.

8.17 System Evaluation

Four methods were identified in section 7.3 for evaluation of the suggestions made by Plassel. A wider view may be taken, and a broader systems evaluation conducted. Again four methods can be deduced, they are:

Apply it in real situations

Plassel could be used in parallel during a real design exercise to gauge system effectiveness. Some aspects such as the cost module have been tested in this manner. As part of their examination of the system, this approach has been replicated by the domain experts in using Plassel to re-examine their recent decisions. Potentially this is the most comprehensive way, but to fully test each aspect like this would take an exceedingly long time.

Compare it with other available systems

Except for the usability analysis conducted directly against Campus, this comparison has not been fully done. However the initial investigation of the features and capability of existing systems did reveal their strengths and weaknesses, and these formed a major consideration when identifying requirements for Plassel. This comparison also happens, in an informal manner, when the experts examined Plassel.

Compare the system to theoretical and academic ideals

Some evaluation of the system was conducted against the Rome Air Development Centre (RADC) guidelines for software quality. This type of evaluation can be extremely difficult to conduct, because the guidelines or 'ideals' often require considerable interpretation as can be observed in section seven. Independent test centres are sometimes available, but Plassel was not tested in this way.

User evaluation of the system

Hayes-Roth [66] state that by employing user evaluation, the system developer can find out what capabilities are useful, what others are required and/or desired and which can be ignored. It is said that this is the easiest and least expensive way for obtaining measurement data on the system [67]. The evaluation conducted on Plassel by potential users (experts and novices) provided very useful feedback on screen layout and system features and operation.

CHAPTER NINE
CONCLUSIONS AND RECOMMENDATIONS

The selection of appropriate materials for a design can be critical to its success. The process of selection is extremely difficult, requiring consideration of many interacting factors and access to large amounts of data. Many computerised systems are available to help in this process. Effective use of these systems however still requires much expertise and experience.

Full expert systems for material selection are not generally available. The development of such systems is hampered by the need for them to contain broad knowledge with ill defined boundaries. In selecting materials a range of considerations which are impossible to fully define in advance may influence selection in any particular case. Success has only been achieved in specialised highly focused applications [1]. With current technology, a feasible approach towards tackling this problem is to allow the system to be easily customised by the user. As the users knowledge and experience expands, the materials selection system can incorporate more and more of the unique considerations of that user in addition to the general pre-programmed procedures.

Plassel achieves some of these aims through its ability to allow customised searches, access a broad range of data, rank materials and modify selection data easily. These new elements to a material selection package add considerably to Plassel being a 'fuller' system for material selection. Customisability could be further improved by allowing users to modify some of the weighting criteria that are currently embedded within the knowledgebase..

To further develop Plassel towards being a fuller system, a number of aspects need to be investigated:

1. Linking of the package to design tools such as spreadsheets and simulators such as "mouldflow".
2. Provide access to data from CAD packages, this could be done via an IGES, DXF or STEP interface.
3. Store expert weightings and ratings in external files and allow authorised users to modify them to tune the system.
4. Examine alternative implementation packages to Crystal which are Microsoft Windows compatible and not memory restricted.
5. Allow some consideration of materials properties within the Process selection stage.
6. Investigate techniques for 'normalising' subjective inputs, or for taking into account subjective input variation. A Monte Carlo style variability analysis may be an aid.

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Campus information is available from members of the Campus consortium. Two of the most prominent are:

CAMPUS - BAYER
Bayer UK Limited
Plastics Business Group
Strawberry Hill
Newbery
Berks

CAMPUS - DU PONT
Du Pont (UK) Ltd8***
Marylands Avenue
Hemel Hampstead
Herts

[14] EPOS -90
ICI, Advanced Materials, PO Box 6, Shire Park, Bessemer Road, Welwyn Garden City, Herts, UK.

[15] Achilles Expert System on Corrosion and Protection
Dr N. Smart, AEA Technology, Building 393, Harwell Laboratory, Harwell, Oxon.

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Institute of Materials, 1 Carlton House Terrace, London.
Tel : 071 8394071

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APPENDIX A

Database Structure of DATA_MAT.DBF
No. of material records: 336

Field	Field Name	Description	Width	Type
1	GENERIC	1 = thermoplastic, 2 = thermoset	30	Character
2	NAME	Material name	50	Character
3	RESIN_TYPE	Resin type	15	Character
4	COST	Cost/tonne	10	Character
5	WEIGHT	Specific gravity	10	Character
6	OPTEMP	Max. operating temp.	10	Character
7	WATER	Water absorption	10	Character
8	STRENGTH	Tensile strength	10	Character
9	FLEXURAL	Flexural strength	10	Character
10	ELONGATION	Elongation at break	10	Character
11	IZOD	Notched Izod	10	Character
12	HDT_0_45	HDT at 0.45 MPa	10	Character
13	HDT_1_80	HDT at 1.80 MPa	10	Character
14	DRYING	Matl. drying	10	Character
15	SHRINKAGE	Mould shrinkage	10	Character
16	HARDNESS	Surface hardness	10	Character
17	EXPANSION	Linear expansion	10	Character
18	FLAMMABLE	Flammability	10	Character
19	OXYGEN	Oxygen index	10	Character
20	RESISTANCE	Vol. resist.	10	Character
21	DIELECT_ST	Dielect. strength	10	Character
22	DIELECT_CO	Dielect. const.	10	Character
23	DISSIP_FAC	Dissipation factor	10	Character
24	MELT_TEMP	Melt temp. range	10	Character
25	MOULD_TEMP	Mould temp. range	10	Character
		Total:	316	

APPENDIX A

Database Structure of RANK_MAT.DBF
No. of material records: 336

Field	Field Name	Description	Width	Type
1	TYPE	1 = thermoplastic, 2 = thermoset	1	Character
2	MATERIAL	Material name	55	Character
3	MAX_OPTEMP	Maximum operating temp.	1	Numeric
4	HDT_1_80	Heat distortion temp.	1	Numeric
5	FLAME	Flame spread	1	Numeric
6	SURF_FINIS	Surface finish	1	Numeric
7	VOL_COST	Volume/unit cost	1	Numeric
8	SG	Specific gravity	1	Numeric
9	TENSILE	Tensile strength	1	Numeric
10	TOUGH_20	Toughness (20C)	1	Numeric
11	TOUGH_40	Toughness (-40C)	1	Numeric
12	FLEXURAL	Flexural modulus	1	Numeric
13	FATIGUE	Fatigue index	1	Numeric
14	WEAR	Wear	1	Numeric
15	FRICTION	Friction	1	Numeric
16	WATER	Water absorption	1	Numeric
17	HYDRO_STAB	Hydrolytic stability	1	Numeric
18	DETERGENT	Detergent	1	Numeric
19	ALIPHATIC	Aliphatic hydrocarbons	1	Numeric
20	AROMATIC	Aromatic hydrocarbons	1	Numeric
21	HALOGEN	Halogenated hydrocarbons	1	Numeric
22	ALCOHOL	Alcohols	1	Numeric
23	UV	UV radiation (weathering)	1	Numeric
24	INJECTION	Injection moulding	1	Numeric
25	COMPRESS	Compression moulding	1	Numeric
26	TRANSFER	Transfer moulding	1	Numeric
27	BLOW	Blow moulding	1	Numeric
28	ROTATIONAL	Rotational moulding	1	Numeric
29	VACUUM	Vacuum forming	1	Numeric
30	EXTRUSION	Extrusion	1	Numeric
31	PULTRUSION	Pultrusion	1	Numeric
32	RIM	R.I.M.	1	Numeric
33	FOAM	Structural foam moulding	1	Numeric
34	CASTING	Casting	1	Numeric
35	RESIN	Resin injection	1	Numeric
36	COLD_PRESS	Cold press moulding	1	Numeric
37	CONTACT	Contact moulding	1	Numeric
		Total:	92	

APPENDIX B

Please tick which system is being evaluated.

CAMPUS ☑ PLASSEL ☐ Material Selection Information Systems ☐

1. How satisfied are you that the functions of the system (i.e. what is does) help you to do your job?

-3 -1 0 [✓ +1] +3

Comments: 1) Possible that certain requirements not covered by CAMPUS?
2) No fuzzy matching ∴ might rule-out suitable Materials?

2. How satisfied are you that the system gives the correct results?

-3 -1 0 +1 [✓ +3]

Comments:

3. How satisfied are you that the system is easy to understand and simple to use?

-3 -1 0 +1 [✓ +3]

Comments:

4. How satisfied are you with the consistency in design of screen layouts and meaningful screen messages?

-3 -1 0 [✓ +1] +3

Comments: Needs more informative, context-sensitive help for novice users.

5. How satisfied are you with the consistency of report layouts?

-3 -1 0 +1 +3

Comments: N/A

6. What important changes or improvements would you like made to the reporting part of the system?

-3 -1 0 +1 +3

Comments: N/A

7. How do you rate your overall satisfaction with the system?

-3 -1 0 +1 [✓ +3]

Comments:

8. Other related comments :

See Q1.

Helpful to provide indication of how far the user has progressed in the selection sequence.

Thank you for taking the time to fill in this questionnaire. This is highly appreciated.

Name: Steve King

Signature:

Position

Date: 17/8/93

Please tick which system is being evaluated.

CAMPUS ☐ PLASSEL ☑ Material Selection Information Systems ☐

1. How satisfied are you that the functions of the system (i.e. what is does) help you to do your job?

-3 -1 0 +1 [✓ +3]

Comments: Far more functions than CAMPUS!

2. How satisfied are you that the system gives the correct results?

-3 -1 0 +1 [✓ +3]

Comments:

3. How satisfied are you that the system is easy to understand and simple to use?

-3 -1 0 +1 [✓ +3]

Comments: Various usability comments.

(1) Can't scroll backwards/forwards when a list of materials is produced

(2) Can't print list, or save to file have to rerun + note manually!

(3) Not Mouse-driven, eg. have to pgDn all attributes before quitting database maintenance screen.

(4) No feedback on ~~list~~ attributes values entered so far in "Consult Expert' and "User Chooses' screens.

(5) Can't delete database records.

4. How satisfied are you with the consistency in design of screen layouts and meaningful screen messages?

-3 -1 0 +1 [✓ +3]

Comments:

5. How satisfied are you with the consistency of report layouts?

-3 -1 0 +1 +3

Comments: N/A

6. What important changes or improvements would you like made to the reporting part of the system?

-3 -1 0 +1 +3

Comments: N/A

7. How do you rate your overall satisfaction with the system?

-3 -1 0 [✓ +1] +3

Comments: Very good idea, marred by some fundamental failings in implementation — all to do with the database aspects!

eg. saving to file / printing / record maintenance.

8. Other related comments :

Thank you for taking the time to fill in this questionnaire. This is highly appreciated.

Name: Steve King
Signature:
Position:
Date: 19/8/93

Please tick which system is being evaluated.

CAMPUS ☐ PLASSEL ☐ Material Selection Information Systems ☑

1. How satisfied are you that the functions of the system (i.e. what is does) help you to do your job?

-3 -1 0 [✓ +1] +3

Comments: Similar functionality to CAMPUS, lacks PLASSEL's 'English-language' front-end and fuzzy matching capabilities

2. How satisfied are you that the system gives the correct results?

-3 -1 0 +1 [✓ +3]

Comments:

3. How satisfied are you that the system is easy to understand and simple to use?

-3 -1 0 [✓ +1] +3

Comments: Help system required.

4. How satisfied are you with the consistency in design of screen layouts and meaningful screen messages?

-3 -1 0 [✓ +1] +3

Comments:____

5. How satisfied are you with the consistency of report layouts?

-3 -1 0 [✓ +1] +3

Comments:____

6. What important changes or improvements would you like made to the reporting part of the system?

-3 -1 0 +1 +3

Comments: N/A

7. How do you rate your overall satisfaction with the system?

-3 -1 0 [✓ +1] +3

Comments:____

8. Other related comments :

Aim of the paper was to emulate/improve upon PLANTEL using conventional database technology. The database aspects of PLANTEL have been achieved ([illegible] queries, by various tables and ([illegible] / [illegible] (lookup records)) but the claimed 'expert' part of PLANTEL has not been sufficiently addressed ∴ the Access system represents a marginal improvement on CAMPUS and is not as ~~[illegible]~~ comprehensive as PLANTEL.

Thank you for taking the time to fill in this questionnaire. This is highly appreciated.

Name: Steve King

Signature:

Position:

Date: 12/8/93

APPENDIX C

dBASE 3 Program —— CONVERT.PRG

```
set echo off
set talk off
close all
close database
clear all
clear
comp = '        '
@10,10 say 'Which Company? [BASF, BAYER_E, GUARANTY, HOECHST]' get comp
read
select 2
cmd = 'use ' + comp
&cmd
go bottom
xtitle = title
delete
pack
append blank

select 1
use temp
if xtitle <> ' '
   locate for temp = xtitle
   if .not. found()
      go top
   endif
else
   go top
endif

do while .not. eof()
   select 1
   if temp = ' '
      skip
      select 2
      append blank
      @1,1 say 'BLANK OK! '
      loop
   endif
   if isalpha(temp)
      @1,2 say a->temp
      select 2
```

```
      replace b->title with a->temp
      select 1
      skip
      @1,1 say 'TITLE OK! '
      loop
   endif
   if substr(temp,2,1) = '.' .or. substr(temp,3,1) = '.'
      @1,2 say a->temp
      select 2
      *if b->date <> ' '
      *   append blank
      *endif
      replace b->date with a->temp
      select 1
      skip
      @1,1 say 'DATE OK!  '
      loop
   endif
   if left(temp,1) = '3'
      @1,2 say a->temp
      select 2
      replace b->families with a->temp
      select 1
      skip
      @1,1 say 'FAMILY OK!'
      loop
   endif
   i = 4
   do while i <= 93
      select 2
      if left(a->temp, 3) = substr(field(i),2)
         cmd = 'replace b->' + field(i) + ' with substr(a->temp,5)'
         &cmd
         select 1
         skip
         @1,1 say str(i) + '<-->' + a->temp
         exit
      endif
      i = i + 1
   enddo
   select 1
enddo
```

C1 - Extract from a Campus.txt File

```
ˉGARANTIE

           The  data  on  this diskette  are based on
our  current
           knowledge  and experience.  This  does not
relieve  the
           purchaser  of our products  from incoming
inspection and
           does not guarantee the suitibility of our
products for a
           specific application.

-
POLYSTYROL 144 C
  PS
  VERY  EASY FLOWING GRADE, OFTEN USED AS AN ADMIXING
COMPONENT FOR
EASY
_ FLOWING IMPACT RESISTANT POLYSTYRENE.
-
POLYSTYROL 143 E
  PS
  POLYSTYRENE,  EASY  FLOWING  GENERAL  PURPOSE  GRADE
HAVING
MODERATE
_ STRENGTH PROPERTIES.
-
POLYSTYROL 148 H
  PS
  HIGH HEAT CRYSTAL POLYSTYRENE WITH, IN COMPARISON TO
POLYSTYROL 158  K
  AND 168 N, BETTER FLOW. BECAUSE OF ITS RAPID SETTING,
POLYSTYROL 148 H
  CAN,  ESPECIALLY  WITH  THICK  WALLED  PARTS, SHORTEN
THE COOLING TIME
  PRIOR TO EJECTION AND THEREFORE REDUCE THE OVERALL
CYCLE TIME.
-
POLYSTYROL 158 K
  PS
  POLYSTYRENE, GENERAL PURPOSE GRADE THAT IS RESISTANT TO
DISTORTION
AT
  ELEVATED TEMPERATURES AND WHICH SOLIDIFIES RAPIDLY.
USED ALSO IN
MANU-
_ FACTURE OF EXPANDED SHEET.
-
POLYSTYROL 165 H
  PS
  POLYSTYRENE,  HIGH-MOLECULAR WEIGHT GRADE, OFTEN USED
AS ADMIXING
COM-
_ PONENT FOR HIGH IMPACT RESISTANCE EXTRUSION TYPES.
-
```

C.2: Extract from a CAMPUS.PRP file

```
1 MECHANICAL PROPERTIES (at 23øC/50% R.H.)
001* Density                                 g/ml
Dens
002* Stress at yield     (50mm/min)          MPa
StssYi
003* Strain at yield     (50mm/min)          %
StraYi
004* Strain at break     (50mm/min)          %
StrB50
058* Stress at 50% elong.(50mm/min)          MPa
Stss50
005* Tensile strength     (5mm/min)          MPa
Strgth
006* Strain at break      (5mm/min)          %
StrB5
007* Young's modulus      (1mm/min)          MPa
YMod
008* Creep modulus               1h          MPa      Ec1
009* Creep modulus            1000h          MPa
Ec1000
010* Impact strength (Izod)   +23øC          kJ/mý
Imp+23
011* Impact strength (Izod)   -30øC          kJ/mý
Imp-30
012* Notch.imp.str.  (Izod)   +23øC          kJ/mý
NImp23
013* Notch.imp.str.  (Izod)   -30øC          kJ/mý
NIm-30
014* Notch.tens.imp.strength  +23øC          kJ/mý
TenImp

1 THERMAL PROPERTIES
015* Heat defl.temp. HDT/A at 1.8  MPa       øC
HDT1.8
016* Heat defl.temp. HDT/B at 0.45 MPa       øC
HDT.45
017* Heat defl.temp. HDT/C at 5.0  MPa       øC
HDT5.0
018* Vicat A/50                  (10N)       øC
VicatA
019* Vicat B/50                  (50N)       øC
VicatB
020* Therm.exp.coef. long.     23-80øC       E-4/K
Expa L
021* Therm.exp.coef. tran.     23-80øC       E-4/K
Expa T

1 ELECTRICAL PROPERTIES (at 23øC/50% R.H.)
022* Relative permittivity  50Hz             -
Perm50
023* Relative permittivity  1MHz             -
Perm1M
024* Dissipation factor     50Hz             E-4
Diss50
025* Dissipation factor     1MHz             E-4
```

C2-CAMPUS.PRP

```
DissiM
026* Dielectric strength                     kV/mm
DieStr
027* Comp.tracking index    CTI              steps    CTI
028  CTI 100 drops value                     steps
CTIH
029* Comp.tracking index    CTI M            steps
CTI-M
030  CTI M 100 drops value                   steps
CTI-MH
031* Spec. volume resistivity                Ohm*cm
SpVoRe
032* Spec. surface resistivity               Ohm
SpSuRe
033* Electrolytic corrosion                  steps
ElCorr

1 PROCESSING PROPERTIES
036* Melt volume rate MVR (1st value)        ml/10min
MVR1
037       at test temperature                øC
Temp1
038       at test load                       kg
Load1
039* Melt volume rate MVR (2nd value)        ml/10min
MVR2
040       at test temperature                øC
Temp2
041       at test load                       kg
Load2

1 OTHER PROPERTIES
050* Viscosity coeff.                        ml/g
ViscC
051* Characteristic density 23øC             g/ml
ChDens
052  Isotaxie index                          -
Isotax

1 BEHAVIOR TOWARDS EXTERNAL INFLUENCES
044* Flammability UL94 (1.6 mm)              steps    UL-
1.6
045       at thickness                       mm
Thick1
046  Flammability UL94 (2nd value)           steps    UL-
*.*
047       at thickness                       mm
Thick2
066* Flammability UL94 - 5V                  steps    UL-
5V
067       at thickness                       mm
Thick3
048  Water absorption (23øC-sat.) 1L         %
Water
049* Moisture absorption (23øC/50% R.H.)1L   %
Moist.
```

```
1 OPTICAL PROPERTIES
034* Refractive index                              -
RefInd
035* Deg. of light transmission                    %
Transm

1 SPECIMEN PRODUCTION (TEST accd. to DIN)
059  Specimen and properties accd. to DIN          -        DIN
053  Melt temperature                              øC
MeltTe
054  Mould temperature                             øC
MouldT
055  Flow front velocity                           mm/s
Veloc.
056  Press temperature                             øC
PressT
057  Press cooling rate                            K/min
CoolRa

1 DATA FOR RHEOLOGICAL CALCULATIONS
060  Density of melt                               g/ml
DeMelt
061  Thermal conductivity of melt                  W/(m K)
ThCoMe
062  Specific heat capacity of melt                J/(kg K)
SpHCMe
065  Eff. thermal diffusivity                      mý/s
ThDiff
063  No-Flow Temperature                           øC
NoFlow
064  Freeze Temperature                            øC
Freeze

5 FUNCTION CONST. FOR RHEOL. CALCULATIONS
001  Power approximation constant  A
Pow-A
002  Power approximation constant  B
Pow-B
003  Power approximation constant  C
Pow-C
004  Carreau-WLF approximation constant K1
Car-K1
005  Carreau-WLF approximation constant K2
Car-K2
006  Carreau-WLF approximation constant K3
Car-K3
007  Carreau-WLF approximation constant K4
Car-K4
008  Carreau-WLF approximation constant K5
Car-K5
```

C.2- CAMPUS PRP file

```
2 PROCESSING & DELIVERY FORM
001* Injection moulding
003* Film extrusion
031* Round profile extrusion
002* Other extrusion
004* Coating
005* Blow moulding
006* Calandering
007* Transfer moulding
008* Casting
009* Thermoforming
040
010  Pellets
011  Gravel
012  Powder

2 ADDITIVES
013* Blowing agent
014* Lubricants
015* Antiblocking agent
016* Release agent
017* Metal deactivator
018* Flame retarding agent
019* Plasticizer
020* With fillers
021* Without fillers

2 SPECIAL CHARACTERISTICS
022* Transparent
023* Increased electrical conductivity
024* Anti-static
025* Flame retardant
026* Platable
027* High impact/high impact modified
028* Stabilized/stable to light
029* Stabilized/stable to weather
030* Stabilized/stable to heat
```

Appendix C - 3

```
{
   CAM2PLAS.PAS
   Turbo Pascal program for the conversion of ASCII-type
CAMPUS data files
   to structured text database files for use in PLASSEL
93. The program
   also writes a Crystal 3.50 export file, this is used
by the CAMPURANK
   module of PLASSEL 93.
   Date: 1/8/93
Version 3.2h
}
program CAMPUS2PLASSEL;
uses crt,dos;
type
  CampusRec = record
     Name: string[30];
      Dens: string[20];
      StssYi: string[20];
      StraYi: string[20];
      StrB50: string[20];
      Stss50: string[20];
      Strgth: string[20];
      StrB5: string[20];
      YMod: string[20];
      Ec1: string[20];
      Ec1000: string[20];
      Imp_23: string[20];
      Imp_30: string[20];
      NImp23: string[20];
      NIm_30: string[20];
      TenImp: string[20];

      HDT1_8: string[20];
      HDT_45: string[20];
      HDT5_0: string[20];
      VicatA: string[20];
      VicatB: string[20];
      Expa_L: string[20];
      Expa_T: string[20];

      Perm50: string[20];
      Perm1M: string[20];
      Diss50: string[20];
      Diss1M: string[20];
      DieStr: string[20];
      CTI: string[20];
      CTIH: string[20];
      CTI_M: string[20];
      CTI_MH: string[20];
      SpVoRe: string[20];
      SpsuRe: string[20];
      ElCorr: string[20];
```

```
        MVR1: string[20];
        Temp1: string[20];
        Load1: string[20];
        MVR2: string[20];
        Temp2: string[20];
        Load2: string[20];

        ViscC: string[20];
        ChDens: string[20];
        Isotax: string[20];

        UL_1_6: string[20];
        Thick1: string[20];
        UL_X_X: string[20];
        Thick2: string[20];
        UL_5V: string[20];
        Thick3: string[20];
        Water: string[20];
        Moist: string[20];

        RefInd: string[20];
        Transm: string[20];

        DIN: string[20];
        MeltTe: string[20];
        MouldT: string[20];
        Veloc: string[20];
        PressT: string[20];
        CoolRa: string[20];

        DeMelt: string[20];
        ThcoMe: string[20];
        SpHCMe: string[20];
        ThDiff: string[20];
        Noflow: string[20];
        Freeze: string[20];

        Pow_A: string[20];
        Pow_B: string[20];
        Pow_C: string[20];
        Car_K1: string[20];
        Car_K2: string[20];
        Car_K3: string[20];
        Car_K4: string[20];
        Car_K5: string[20];
    end; {CampusRec}

var CampusDat: CampusRec;
     Field_count: array [1..500] of integer;
     Old, New, Export: text;
    dat, CAMPUSfile, STARTdir, CAMPUSnewfile: string;
     materials, counter, i, j, ref, bar, percent:
integer;
     CAMPUSpath: PathStr;
     CAMPUSdir: DirStr;
    CAMPUSnam: NameStr;
    CAMPUSext: ExtStr;
```

```
procedure MATERIALS_COUNT;
begin
   field_count[materials]:=counter+1;
   materials:=materials+1;
end;

procedure FIELDS_COUNT;
begin
   if (ord(dat[3])=46) then
   counter:=0;
   counter:=counter+1;
end;

procedure WRITE_FIELD (Field: string);
begin
   while Pos(' ',Field)<>0 do Delete (Field,Pos('
',Field),1);
   write (New,Field,',');
end;

procedure WRITE_LAST_FIELD (Field: string);
begin
   while Pos(' ',Field)<>0 do Delete (Field,Pos('
',Field),1);
   write (New,Field);
end;

procedure RESET_RECORD;
begin
   with CampusDat do
      begin
         Dens:='*';
         StssYi:='*';
         StraYi:='*';
         StrB50:='*';
         Stss50:='*';
         Strgth:='*';
         StrB5:='*';
         YMod:='*';
         Ec1:='*';
         Ec1000:='*';
         Imp_23:='*';
         Imp_30:='*';
         NImp23:='*';
         NIm_30:='*';
         TenImp:='*';

         HDT1_8:='*';
         HDT_45:='*';
         HDT5_0:='*';
         VicatA:='*';
         VicatB:='*';
         Expa_L:='*';
         Expa_T:='*';

         Perm50:='*';
         Perm1M:='*';
         Diss50:='*';
```

```
        Diss1M:='*';
        DieStr:='*';
        CTI:='*';
        CTIH:='*';
        CTI_M:='*';
        CTI_MH:='*';
        SpVoRe:='*';
        SpSuRe:='*';
        ElCorr:='*';

        MVR1:='*';
        Temp1:='*';
        Load1:='*';
        MVR2:='*';
        Temp2:='*';
        Load2:='*';

        ViscC:='*';
        ChDens:='*';
        Isotax:='*';

        UL_1_6:='*';
        Thick1:='*';
        UL_X_X:='*';
        Thick2:='*';
        UL_5V:='*';
        Thick3:='*';
        Water:='*';
        Moist:='*';

        RefInd:='*';
        Transm:='*';

        DIN:='*';
        MeltTe:='*';
        MouldT:='*';
        Veloc:='*';
        PressT:='*';
        CoolRa:='*';

        DeMelt:='*';
        ThCoMe:='*';
        SpHCMe:='*';
        ThDiff:='*';
        NoFlow:='*';
        Freeze:='*';

        Pow_A:='*';
        Pow_B:='*';
        Pow_C:='*';
        Car_K1:='*';
        Car_K2:='*';
        Car_K3:='*';
        Car_K4:='*';
        Car_K5:='*';
    end;
end;
```

```
procedure WRITE_NEW_FILE;
begin
   with CampusDat do
      begin
         write (New,'"',Name,'",');
         WRITE_FIELD (Dens);
         WRITE_FIELD (StssYi);
         WRITE_FIELD (StraYi);
         WRITE_FIELD (StrB50);
         WRITE_FIELD (Stss50);
         WRITE_FIELD (Strgth);
         WRITE_FIELD (StrB5);
         WRITE_FIELD (YMod);
         WRITE_FIELD (Ec1);
         WRITE_FIELD (Ec1000);
         WRITE_FIELD (Imp_23);
         WRITE_FIELD (Imp_30);
         WRITE_FIELD (NImp23);
        WRITE_FIELD (NIm_30);
        WRITE_FIELD (TenImp);
        WRITE_FIELD (HDT1_8);
         WRITE_FIELD (HDT_45);
         WRITE_FIELD (HDT5_0);
         WRITE_FIELD (VicatA);
         WRITE_FIELD (VicatB);
         WRITE_FIELD (Expa_L);
         WRITE_FIELD (Expa_T);
        WRITE_FIELD (Perm50);
         WRITE_FIELD (Perm1M);
         WRITE_FIELD (Diss50);
         WRITE_FIELD (Diss1M);
         WRITE_FIELD (DieStr);
         WRITE_FIELD (CTI);
         WRITE_FIELD (CTIH);
         WRITE_FIELD (CTI_M);
         WRITE_FIELD (CTI_MH);
         WRITE_FIELD (SpVoRe);
         WRITE_FIELD (SpSuRe);
         WRITE_FIELD (ElCorr);
         WRITE_FIELD (MVR1);
         WRITE_FIELD (Temp1);
         WRITE_FIELD (Load1);
         WRITE_FIELD (MVR2);
         WRITE_FIELD (Temp2);
         WRITE_FIELD (Load2);
        WRITE_FIELD (ViscC);
         WRITE_FIELD (ChDens);
         WRITE_FIELD (Isotax);
        WRITE_FIELD (UL_1_6);
         WRITE_FIELD (Thick1);
         WRITE_FIELD (UL_X_X);
         WRITE_FIELD (Thick2);
         WRITE_FIELD (UL_5V);
         WRITE_FIELD (Thick3);
         WRITE_FIELD (Water);
         WRITE_FIELD (Moist);
        WRITE_FIELD (RefInd);
         WRITE_FIELD (Transm);
```

```
          WRITE_FIELD (DIN);
           WRITE_FIELD (MeltTe);
           WRITE_FIELD (MouldT);
           WRITE_FIELD (Veloc);
           WRITE_FIELD (PressT);
           WRITE_FIELD (CoolRa);
          WRITE_FIELD (DeMelt);
           WRITE_FIELD (ThCoMe);
           WRITE_FIELD (SpHCMe);
           WRITE_FIELD (ThDiff);
           WRITE_FIELD (NoFlow);
           WRITE_FIELD (Freeze);
          WRITE_FIELD (Pow_A);
           WRITE_FIELD (Pow_B);
           WRITE_FIELD (Pow_C);
           WRITE_FIELD (Car_K1);
           WRITE_FIELD (Car_K2);
           WRITE_FIELD (Car_K3);
           WRITE_FIELD (Car_K4);
           WRITE_LAST_FIELD (Car_K5);
           writeln (New);
      end;
  end;

  procedure INDEX;
  begin
        read (Old,ref);
        case ref of
           101: begin
                   read (Old,dat);
                   CampusDat.Dens:=dat;
                end;
           102: begin
                   read (Old,dat);
                   CampusDat.StssYi:=dat;
                end;
           103: begin
                   read (Old,dat);
                   CampusDat.StraYi:=dat;
                end;
           104: begin
                   read (Old,dat);
                   CampusDat.StrB50:=dat;
                end;
           158: begin
                   read (Old,dat);
                   CampusDat.Stss50:=dat;
                end;
           105: begin
                   read (Old,dat);
                   CampusDat.Strgth:=dat;
                end;
           106: begin
                   read (Old,dat);
                   CampusDat.StrB5:=dat;
                end;
           107: begin
                   read (Old,dat);
```

```
          CampusDat.YMod:=dat;
        end;
    108: begin
          read (Old,dat);
          CampusDat.Ec1:=dat;
        end;
    109: begin
          read (Old,dat);
          CampusDat.Ec1000:=dat;
        end;
    110: begin
          read (Old,dat);
          CampusDat.Imp_23:=dat;
        end;
    111: begin
          read (Old,dat);
          CampusDat.Imp_30:=dat;
        end;
    112: begin
          read (Old,dat);
          CampusDat.NImp23:=dat;
        end;
    113: begin
          read (Old,dat);
          CampusDat.Nim_30:=dat;
        end;
    114: begin
          read (Old,dat);
          CampusDat.TenImp:=dat;
        end;
    115: begin
          read (Old,dat);
          CampusDat.HDT1_8:=dat;
        end;
    116: begin
          read (Old,dat);
          CampusDat.HDT_45:=dat;
        end;
    117: begin
          read (Old,dat);
          CampusDat.HDT5_0:=dat;
        end;
    118: begin
          read (Old,dat);
          CampusDat.VicatA:=dat;
        end;
    119: begin
          read (Old,dat);
          CampusDat.VicatB:=dat;
        end;
    120: begin
          read (Old,dat);
          CampusDat.Expa_L:=dat;
        end;
    121: begin
          read (Old,dat);
          CampusDat.Expa_T:=dat;
        end;
```

```
122: begin
        read (Old,dat);
        CampusDat.Perm50:=dat;
     end;
123: begin
        read (Old,dat);
        CampusDat.Perm1M:=dat;
     end;
124: begin
        read (Old,dat);
        CampusDat.Diss50:=dat;
     end;
125: begin
        read (Old,dat);
        CampusDat.Diss1M:=dat;▓
     end;
126: begin
        read (Old,dat);
        CampusDat.DieStr:=dat;
     end;
127: begin
        read (Old,dat);
        CampusDat.CTI:=dat;
     end;
128: begin
        read (Old,dat);
        CampusDat.CTIH:=dat;
     end;
129: begin
        read (Old,dat);
        CampusDat.CTI_M:=dat;
     end;
130: begin
        read (Old,dat);
        CampusDat.CTI_MH:=dat;
     end;
131: begin
        read (Old,dat);
        CampusDat.SpVoRe:=dat;
     end;
132: begin
        read (Old,dat);
        CampusDat.SpSuRe:=dat;
     end;
133: begin
        read (Old,dat);
        CampusDat.ElCorr:=dat;
     end;
136: begin
        read (Old,dat);
        CampusDat.MVR1:=dat;
     end;
137: begin
        read (Old,dat);
        CampusDat.Temp1:=dat;
     end;
138: begin
        read (Old,dat);
```

```
          CampusDat.Load1:=dat;
       end;
139:   begin
          read (Old,dat);
          CampusDat.MVR2:=dat;
       end;
140:   begin
          read (Old,dat);
          CampusDat.Temp2:=dat;
       end;
141:   begin
          read (Old,dat);
          CampusDat.Load2:=dat;
       end;
150:   begin
          read (Old,dat);
          CampusDat.ViscC:=dat;
       end;
151:   begin
          read (Old,dat);
          CampusDat.ChDens:=dat;
       end;
152:   begin
          read (Old,dat);
          CampusDat.Isotax:=dat;
       end;
144:   begin
          read (Old,dat);
          CampusDat.UL_1_6:=dat;
       end;
145:   begin
          read (Old,dat);
          CampusDat.Thick1:=dat;
       end;
146:   begin
          read (Old,dat);
          CampusDat.UL_X_X:=dat;
       end;

147:   begin
          read (Old,dat);
          CampusDat.Thick2:=dat;
       end;
166:   begin
          read (Old,dat);
          CampusDat.UL_5V:=dat;
       end;
167:   begin
          read (Old,dat);
          CampusDat.Thick3:=dat;
       end;
148:   begin
          read (Old,dat);
          CampusDat.Water:=dat;
       end;
149:   begin
          read (Old,dat);
          CampusDat.Moist:=dat;
```

```
         end;
134:    begin
            read (Old,dat);
            CampusDat.RefInd:=dat;
         end;
135:    begin
            read (Old,dat);
            CampusDat.Transm:=dat;
         end;
159:    begin
            read (Old,dat);
            CampusDat.DIN:=dat;
         end;
153:    begin
            read (Old,dat);
            CampusDat.MeltTe:=dat;
         end;
154:    begin
            read (Old,dat);
            CampusDat.MouldT:=dat;
         end;
155:    begin
            read (Old,dat);
            CampusDat.Veloc:=dat;
         end;
156:    begin
            read (Old,dat);
            CampusDat.PressT:=dat;
         end;
157:    begin
            read (Old,dat);
            CampusDat.CoolRa:=dat;
         end;
160:    begin
            read (Old,dat);
            CampusDat.DeMelt:=dat;
         end;
161:    begin
            read (Old,dat);
            CampusDat.ThCoMe:=dat;
         end;
162:    begin
            read (Old,dat);
            CampusDat.SpHCMe:=dat;
         end;
165:    begin
            read (Old,dat);
            CampusDat.ThDiff:=dat;
         end;
163:    begin
            read (Old,dat);
            CampusDat.NoFlow:=dat;
         end;
164:    begin
            read (Old,dat);
            CampusDat.Freeze:=dat;
         end;
501:    begin
```

```
                read (Old,dat);
                CampusDat.Pow_A:=dat;
             end;
         502: begin
                read (Old,dat);
                CampusDat.Pow_B:=dat;
             end;
         503: begin
                read (Old,dat);
                CampusDat.Pow_C:=dat;
             end;
         504: begin
                read (Old,dat);
                CampusDat.Car_K1:=dat;
             end;
         505: begin
                read (Old,dat);
                CampusDat.Car_K2:=dat;
             end;
         506: begin
                read (Old,dat);
                CampusDat.Car_K3:=dat;
             end;
         507: begin
                read (Old,dat);
                CampusDat.Car_K4:=dat;
             end;
         508: begin
                read (Old,dat);
                CampusDat.Car_K5:=dat;
             end;
         else read (Old,dat);
      end;
end;

procedure PREPARE_FILE;
begin
   assign (Old,CAMPUSfile);
   reset (Old);
   ChDir(STARTdir);
   assign (New,CAMPUSnewfile+'.adf');
   rewrite (New);
   write (New,materials+1,',');
   for i:=1 to 72 do
       write (New,'*,');
   writeln (New,'*');
   readln (Old,dat);
   while dat[length(dat)]=' ' do
   delete (dat,length(dat),1);
   CampusDat.Name:=dat;
   readln (Old);
   readln (Old);
   for j:=1 to (field_count[1]-3) do
      begin
         INDEX;
      end;
   for i:=2 to materials-1 do
       begin
```

```
           percent:=(round(i/materials*100));
           bar:=percent div 10;
           case percent of
                10,20,30,40,50,60,70,80,90,100: begin
                textcolor(magenta);
                GotoXY(bar+(percent div 10)+10,22);
                write(chr(219));
                GotoXY(bar+(percent div 10)+11,22);
                write(chr(219));
                textcolor(white);
                end;
           end;
           GotoXY(35,22);write(percent,'%');
           WRITE_NEW_FILE;
         RESET_RECORD;
         readln (Old);
         readln (Old);
         readln (Old,dat);
         while dat[length(dat)]=' ' do
         delete (dat,length(dat),1);
         CampusDat.name:=dat;
         readln (Old);
            for j:=1 to (field_count[i]-2) do
               begin
                      INDEX;
               end;
      end;
      WRITE_NEW_FILE;
      RESET_RECORD;
      readln (Old);
      readln (Old);
      readln (Old,dat);
      while dat[length(dat)]=' ' do
      delete (dat,length(dat),1);
      CampusDat.name:=dat;
      readln (Old);
      for i:=1 to (field_count[materials]-2) do
         begin
            INDEX;
         end;
      WRITE_NEW_FILE;
    close(Old);
    close(New);
end;

begin { MAIN PROCEDURE }
   TextBackground(blue);
   Textcolor(white);
   Clrscr;
   GotoXY(0,0); TextBackground(magenta); write('
PLASSEL                 ');
   writeln ('
CAMPUS DATA   ');
   TextBackground(blue);
   GetDir(0,STARTdir);
   GotoXY(5,10); write ('Enter the full path of your
original CAMPUS file');
   GotoXY(5,12); write ('( e.g. A:\PLASTICS\DATA.ASC )');
```

```
   GotoXY(5,11); readln (CAMPUSpath);
   GotoXY(5,15);
   write ('Enter the name for the new file (without the
file extension)');
   GotoXY(5,16); write ('(maximum of 8 characters, e.g.
DATAFILE)');
   GotoXY(5,17); readln (CAMPUSnewfile);
   FSplit (CAMPUSpath,CAMPUSdir,CAMPUSnam,CAMPUSext);
   Delete (CAMPUSdir,length(CAMPUSdir),1);
   CAMPUSfile:=CAMPUSnam+CAMPUSext;
   assign (Export, 'CAM2PLAS.EX');
   rewrite (Export);
   writeln (Export,
   '*  campudat.kb                          Sun Jan 31
00:00:00 1993');
   writeln (Export,'EXPORT RULES');
   writeln (Export);
   writeln (Export,'EXPORT VARIABLES');
   writeln (Export,'   file$ = "',CAMPUSnewfile,'"');
   writeln (Export,'   cfile$ = "',CAMPUSnam,'"');
   writeln (Export,'   cdir$ = "',CAMPUSdir,'"');
   writeln (Export,'   sdir$ = "',STARTdir,'"');
   writeln (Export);
   writeln (Export,'EXPORT ARRAYS');
   close (Export);
   ChDir (CAMPUSdir);
   assign (Old, CAMPUSfile);
   reset (Old);
   materials:=0;
   counter:=0;
   for i:=1 to 500 do
      begin
         field_count[i]:=0;
      end;
   RESET_RECORD;
      GotoXY(50,22);
      writeln ('Reading CAMPUS file ...');
      while not seekeof (Old) do
     begin
        read (Old,dat);
        if (ord(dat[1])<91) and (ord(dat[1])>65)
        then MATERIALS_COUNT
        else FIELDS_COUNT
     end;
     field_count[materials]:=counter+1;
      close (Old);
      GotoXY(50,22);
      writeln ('Writing ',CAMPUSnewfile,'.adf',' ...
');
      GotoXY(12,22); textbackground(cyan);write('
');
      textbackground(blue);
      GotoXY(50,10);
      PREPARE_FILE;
     ClrScr
end.
```

C.3: CAM2PLAS.PAS

```
Program InfoFile;
var ExFile, TextFile, NewFile :text;
    LineOne, LineTwo, TotalLine, Charac, TxtFile,
    OldFile, OldDir, StartDir :string;

Procedure FIND_FIRST_MATERIAL;
begin
   assign (ExFile,'cam2plas.ex');
   reset (ExFile);
   readln (ExFile);
   readln (ExFile);
   readln (ExFile);
   readln (ExFile);
   readln (ExFile,TxtFile);
   delete (TxtFile,1,12);
   delete (TxtFile,length(TxtFile),1);
   readln (ExFile,OldFile);
   delete (OldFile,1,13);
   delete (OldFile,length(OldFile),5);
   readln (ExFile,OldDir);
   delete (OldDir,1,12);
   delete (OldDir,length(OldDir),1);
   readln (ExFile,StartDir);
   delete (StartDir,1,12);
   delete (StartDir,length(StartDir),1);
   ChDir (OldDir);
   assign (TextFile,OldFile+'.txt');
   reset (TextFile);
   ChDir (StartDir);
   assign (NewFile,TxtFile+'.inf');
   rewrite (NewFile);
   while LineOne<>'~' do
   begin
      readln (TextFile,LineOne);
   end;
   readln (TextFile,LineOne);
   readln (TextFile,LineTwo);
   while LineTwo[1]=' ' do
   delete (LineTwo,1,1);
   writeln (NewFile,'~');
   writeln (NewFile,'"',LineOne,'"');
   writeln (NewFile,'"',LineTwo,'"');
end; { FIND_FIRST_MATERIAL }

Procedure READ_MATERIAL_INFO;
begin
   while not seekeof (TextFile) do
   begin
      readln (TextFile,LineOne);
      if LineOne<>'~' then
      begin
         if length(LineOne)>35 then
         begin
            LineTwo:=copy(LineOne,36,70);
```

```
            delete(LineOne,36,70);
            writeln (NewFile,'"',LineOne,'"');
            writeln (NewFile,'"',LineTwo,'"');
            LineTwo:='';
         end else
         writeln (NewFile,'"',LineOne,'"');
      end else
      begin
         writeln (NewFile,'¯');
         readln (TextFile,LineOne);
         readln (TextFile,LineTwo);
         while LineTwo[1]=' ' do
         delete (LineTwo,1,1);
         writeln (NewFile,'"',LineOne,'"');
         writeln (NewFile,'"',LineTwo,'"');
      end;
   end;
end; { READ_MATERIAL_INFO }
begin { Main }
   FIND_FIRST_MATERIAL;
   READ_MATERIAL_INFO;
   close (TextFile);
   close (NewFile);
end.
```

C4- Plassel Control File

```
@echo off
echo.
echo PLASSEL 93 (c) 1993 University of Warwick
echo.
echo.

rem *************************************
rem *                                   *
rem *   PLASSEL 93 control batch file   *
rem *   version 2.4       15/8/93       *
rem *   written           by D. J. Bal  *
rem *                                   *
rem *************************************

rem Initialise - signals the start of PLASSEL 93
md begin___.dir

rem Tests for the existance of Control Directories
:start
if exist c:\plassel\begin___.dir\nul goto begin
if exist c:\plassel\campus__.dir\nul goto campus
if exist c:\plassel\rankcamp.dir\nul goto rankcamp
if exist c:\plassel\end_____.dir\nul goto end

rem Run mainmenu.kb
:mainmenu
dbcr/r mainmenu
goto start
```

```
rem Run Title Screen (plastart.kb)
:begin
rd begin___.dir
dbcr/r plastart
goto start

rem Run campus_1.kb
:campus
rd campus__.dir
echo PLASSEL 93 - loading CAMPUS DATA MODULE
ascr/r campus_1
goto start

rem Run CAMPUS to PLASSEL ASCII conversion programs
:rankcamp
echo PLASSEL 93 - loading CAM2PLAS Conversion Program:
STAGE 1
rd rankcamp.dir
cam2plas
echo PLASSEL 93 - please wait ...
campinfo
echo PLASSEL 93 - loading CAM2PLAS Conversion Program:
STAGE 2
ascr/r campurnk
goto start

rem Terminate PLASSEL 93
:end
rd end_____.dir
echo.
echo PLASSEL 93 unloaded
echo.
```

APPENDIX D

Washing machine Outer Stationary Drum

Function:

The drum of a washing machine consists of a inner movable drum and a outer stationary drum. The inner one will oscillate during the washing process, and will rotate very rapidly during the drying process in order to separate out the water from the clothes. The outer one will always keep stationary. It has two main functions. 1) To contain the water. 2) To locate and support the movement of the inner drum. We are going to focus on the outer stationary drum.

Characteristics and Material Requirements:

One of the main functions of the outer drum is to contain water and washing powder. This contains many different chemicals such as soap, sodium perborate, phosphates, sodium carbonate, sodium sulphate and brightening agents, etc. Therefore, the material used for the outer drum must be capable of low water absorption and high chemical resistance in order to prevent any changes in material properties due to water absorption and chemicals reaction. The volume of the drum is quite large, usually about 30-40 litres. If the washing machine can wash a maximum of 10 Kg clothes, the loading of the drum may be about 50 Kg including clothes, inner movable drum and water. In addition, due to the rotational movement of the contents (water and clothes) the during washing process and the rapid rotation (about 1000 rpm) of the inner drum during the drying process, the forces (centripedal) acting on the drum are large. Therefore, the drum must have good dimensional stability and tensile strength to bear load in all directions, good stiffness to maintain its shape, good rigidity and creep resistance to prevent from deformation and good stress cracking resistance. Moreover, most washing machines include hot wash cycles, usually about 60-95°C. Consequently, the maximum working temperature must be high enough, greater than 100°C will be best. Also, due to the need to support to the inner movable drum, the outer drum has to be able to absorb the vibration generated by the rotational movement of the inner drum. Finally, for the high frequency cycling, the material must have good fatigue resistance. The ability of the material to withstand fatigue loading should be good.

Materials Selection:

After analysing the above characteristics, the material suggested for a washing outer stationary drum is Glass-filled Polypropylene in Structural Foam form. Compared with other polymers, polypropylene(PP), even without glass-filled re-inforcing, has good enough temperature resistance (100°C safe working temperature), excellent fatigue resistance, excellent chemical resistance, low specific gravity (light weight) and very low water absorption (24hr Water Absorption = 0.03%). Other polymers can fulfil part of the above criterion, but not all. For examples, PP is similar to high density polyethylene (HDPE) with excellent chemical resistance and low cost, but its mechanical properties are more suitable for moulded parts than is polyethylene. PP is stiffer, harder, more stress-crack resistant and often of higher strength than many grades of polyethylene. The safe working temperature of polyethylene (PE) is not high enough (75C). Although polybutylene (PB) is very similar to PP in its chemical properties, it is soluble in aromatic and chlorinated solvents at relatively low temperatures. The safe working temperature of ABS is only 80C, so it is also not a suitable material. Although, the heat resistance and the strength of the majority of thermoset plastics is good enough (may be better than PP, a thermoplastic), the cost is relatively high and the chemical resistance may be relatively low. In addition, PP can be re-melted and re-used unlike thermosets. Overall the physical and chemical properties of PP are very suitable for an outer drum. However, the mechanical properties, such as, strength, stiffness, toughness and the rigidity of PP may not be sufficient to withstand typical loading. Consequently, Glass Fibre is used as a filler to reinforce the strength and dimensional stability of polypropylene (PP). It also enhances the stiffness and the temperature resistance of PP. The reinforcement of such properties are achieved by coupling reactions taking place between organofunctional silanes on the glass fibres and reactive groups introduced into the polypropylene molecules. Randomly distributed fibres (30%), in which the fibres are as long as the granules are used in order to reinforce the strength in all directions. Glass-filled polypropylene has about three times the tensile strength and four times the rigidity at room temperature, and four times the strength and eight times the rigidity at 100 C than the corresponding unfilled one. (unfilled: 25-35 MPa , filled: 75 MPa of tensile strength). The ability of PP to withstand fatigue loading is also very good. This means that the tensile strength, the stress cracking resistance, the rigidity and toughness and fatigue resistance of glass-filled polypropylene are strong enough to fulfil the requirement of the mechanical properties of a outer drum.

Structural foam is used in this case because it consists of a sandwich structure with a low density cellular core and a relatively dense skin. This cellular structure has several advantages. Foamed structures are more rigid than a solid moulding with a given weight. It increases the stiffness but minimises weight. In addition, the shrinkage is uniform and almost fully free from orientation effects. As a conclusion, obviously, taking into account all the physical, chemical and mechanical properties and costing, Glass-filled polypropylene in Structural Foam form is the most suitable material for the outer stationary drum of a washing machine.

Processes Selection:

The manufacturing process suggested for this product is Structural Foam Injection Moulding. The market demand is very large. This means that the production volume is likely to be large (mass production is required). Injection moulding is a very suitable for mass production of a single component. Its initial costs and mould costs are very high, but per unit costs for large numbers are very economical. It is especially suitable for thermoplastics, runners and sprues can be reground and reused.

Structural foam injection moulding is very similar to the conventional injection moulding. In fact, foamed articles can be produced well using a normal screw-type injection moulding machines. The foam structure is achieved by the dispersion of inert gas through the molten resin (polypropylene and glass fibres), during the moulding operation. The gas may be generated either by pre-blending the resin with a chemical blowing agent which releases gas when heated or by direct injection of inert gases, nitrogen or fluorocarbon. The former method is preferred to the later because it is more convenient. The polypropylene resin and dispersed blowing agent are pre-mixed. This mixture is then rapidly injected into the mould cavity, where the released gas expands explosively and the resin is forced into all parts of the mould. A denser integral skin is formed when the material is firstly cooled by the mould surface, but the core is of a foam form.

In structural foam injection moulding, the injection pressures are lower than that in conventional injection moulding. So, less clamping force per unit area of the moulding is required. this reduces the mould costs because cheaper mould materials with lower strength may be used.

However, due to the involvement of glass fibres in injection, the abrasive wear is high, therefore, a special screw and barrel with better wear resistance are usually required. In addition, the plasticising unit of the injection moulding machine must not apply too large shear force which will make the chopped glass fibres too short. This affects the strength of the product.

Windsurfer Board

Functions:

A windsurfer board must float well, not absorb water and be resistant to the chemicals likely to be found in the sea. It must have sufficient rigidity and strength to withstand the pounding the sea will provide.

Characteristics and Material Requirements:

For floating on the water, the density of a windsurfer board must be less than that of sea water. In addition, the mechanical properties must be good enough to withstand any loading or force acting on it from its working environment. This means that the stiffness, impact strength, tensile strength, toughness, dimensional stability, rigidity and creep resistance of a windsurfer board must be satisfactory. In addition, the hardness and wear (abrasion) resistance of the material must be good because windsurfer boards may slide impact rough surfaces, for example sand on the beaches during transportation. Of course, as aquatic sport equipment, it must has excellent resistance to outdoor exposure, UV light degradation and changes of climate (temperature, humidity, etc.) may make the windsurfer broad crack. The weathering resistance of the board must be good. Also it must have low water absorption which can affect its physical and mechanical properties. Usually sea water increases the rate of corrosion of materials. Consequently, the board material should have good chemical resistance.

Materials Selection:

The material suggested to make a windsurfer board is foamed Polycarbonate. The density of many polymers is higher than water. There are some materials with a density just slightly lower than 1, but this is insufficient because the board must float with a persons weight on it. In addition, their mechanical strength and rigidity maybe insufficient to withstand the weight or forces acting on the board. Consequently, foamed structure is required. It not only greatly reduces the density of the board, but also increase its strength and rigidity. It provides better stiffness/weight ratio and strength/weight ratio than a solid mouldings.

Polypropylene, ABS, Polystyrene, PU, modified PPO and polycarbonate are popular materials used for foam moulding. Although PU is easily foamed and can have a very low density of about 0.45-0.5 g/cm. The tensile strength is only just 0.4 N/mm2 which is not enough. Exposure to sun light will reduce the impact strength of foamed ABS which has lower strength than foamed polycarbonate. Similarly, the strength of modified PPO is also lower than that of polycarbonate. Foamed PS is low cost and its chemical resistance is good. However, it also is not strong enough, has poor impact strength and yellows with long exposure to UV light.

As a result, Polycarbonate is selected because it has low water absorption, very high impact strength, high resistance to creep under load, high stiffness, high abrasion resistance and very good dimensional stability. Although, the weathering and chemical resistance of polycarbonate are not excellent, just moderate, anti-degradants (eg. UV-light absorber to improve the resistance of cast foam) can be added to improve it. In fact, UV degradation will not happen beyond a depth of 0.075-0.125cm because of the good light absorption of polycarbonate. In addition, much better properties can be obtained if polycarbonate is processed by structural foam moulding. The flexural strength to weight ratio can be twice that of most metal but the density is just 0.6 -0.8 g/cm3. The flexural modulus can be up to 8 x 10 ^{5} psi. The tensile strength is 37.7 N/mm2 and the izod impact is 0.74 J/cm2. The chemical resistance of polycarbonate in foam structure is also improved because of the low moulded-in stresses. Although polycarbonate is quite expensive, cost is not a significant factor in this kind of application. For more demanding applications where much higher strength and rigidity is required, the foamed polycarbonate can be reinforced by glass fibres.

Processes Selection:

The manufacturing process suggested for production of windsurfer boards is Structural Foam Injection Moulding. This process has been described before. Basically, there are two methods of introducing gases to the material to achieve the foam effect. One is pre-blending the resin with blowing agents and the other is direct injection of inert gases. However, in order to have a denser, non-porous good surface with a cellular core in one moulding step, the former method is preferred. This means that a volatile blowing agent, such as chlorotrifluoromethane or methylene dichloride, is pre-blended in the polycarbonate resin. Critical factors in this process are close control over the mould temperature and metering of the materials. The mould walls must be cool enough to condense the blowing agent in the resin near the wall and it must be exothermic enough for the blowing agent to vaporise in the core. The porosity near the mould wall can also be reduced by the internal vapour pressure in the core acting on the skin. In addition, polycarbonate will degrade in a moist environment, consequently, polycarbonate must be kept scrupulously dry. In fact, polycarbonate granules are supplied in tins which are sealed in a vacuum environment at a high temperature. The tins must be heated in an oven at about 110°C for several hours before they are opened. A heating hopper is preferred in order to reduce the moisture.

There are several advantages to structural foam injection moulding. Compared with conventional injection pressures, the injection pressure of the foam injection moulding is lower. Therefore, the clamping force per unit area of the moulding is less and this means that inexpensive, lower strength materials can be used for making the moulding. The capital costs of the machines are also lower. In addition, the sink marks are reduced due to the internal pressure of the released gas which forces the plastic against the mould wall.