JJMIE
Jordan Journal of Mechanical and Industrial Engineering

Volume 3, Number 3, September 2009
ISSN 1995-6665
Pages 162 - 167

Fuzzy Logic Approach for Metal Casting Selection Process

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Abstract

Selecting the proper material is a vital step in the design process because the appropriateness of the choice has a significant impact on part performance and cost. A poorly selected material adds unnecessary cost and may affect the ease of processing. In this paper an automated advisory material selection system is designed. The designed system is named (CAMS). The objectives of this system are to solve the problems of Materials selection and evaluation (M/P&E) activities. The designed system depends on methodology for selection and evaluation of materials that are based on a number of user-specified attributes or requirements. The decision model enables the representation of the designer's preferences over the decision factors, and it is based on weighted property index (W.P.I) algorithms to determine the relative importance of each requirements.
A compatibility rating between product profile requirements and the alternatives stored in the database for each decision criteria are generated using fuzzy logic (F.L) methodology. These requirements were matched with the capabilities of each (alloy) or material. The compatibility ratings are aggregated into single rating of that alternative's compatibility. A ranked set of compatible alternative alloys is produced t by the system. This approach has advantages over the existing systems that don't have a decision module or are not integrated with a database.

Keywords: Materials Selection; Fuzzy Logic; Weighted Algorithm.

1. Introduction

The selection of the correct materials for a design is a key step in the process because it is a crucial decision that links computer calculations and lines on an engineering drawing with a working design. Materials and the manufacturing processes, which convert the material into useful part, strengthen all of engineering design. [1]. The material and manufacturing process selection problem is a multi-attribute decision-making problem. These decisions are made during preliminary design stages in an environment characterized by uncertain requirements, parameters, and relationships. Material and process selection (MPS) decisions occur before design for manufacturing (DFM) can begin [2, 3]. Studies have indicated that although the cost of product design is only around 5% of the total product cost, decisions made during the design stage affect (70 – 80 %) of the final product cost [4].

In this paper, a development of an advisory system is called Computer Aided Material Selection (CAMS) that aids the designer in decision-making (D.M). The objectives of the designed system are to evaluate and select the optimal and alternative materials (alloy) that satisfy the design specifications. The system (CAMS) indicates to the designer the compatibility degree between the selected materials (alloy) to all the specified properties and characteristics, and then these selected materials are ranked according to their compatibilities.

2. Importance of Materials Selection

The increasingly tough competition on international markets forced many firms to search for new methods of producing high quality products at low cost. Designing for better products must take into consideration the balance between cost, quality, and performance triplex. To achieve such objectives, designers must use quantitative and qualitative techniques. The possible advantages result from manufacturing by using more flexible methods of production and more efficient equipment [5]. The recognition of importance of materials selection in design has increased in recent years. The adoption of concurrent engineering methods has brought materials engineers into the design process at an earlier stage, and the importance given to manufacturing in present day product design has reinforced the fact that materials and manufacturing are closely linked in determining final product performance [1]. Figure (1) shows the structure for material classification, ending with a schematic of a record some of attribute [6].

3. General Criteria in Material Selection Process

Selection of materials on the basis of performance characteristics is the process of matching values of the properties of the materials with the requirements and constraints imposed by the design. Selection on the basis

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of processing characteristics deals with finding the process that will form the material into the required shape with a minimum of defects at the least cost. Selection on the basis of an environmental profile is concerned with the impact of the material throughout its life cycle upon the environment. The chief business consideration that affects materials selection is the cost of the part that is made from the material [1]. Materials are selected on the basis of the following four general criteria [1]:

1. Performance characteristics (properties).
2. Processing characteristics.
3. Environmental profile .
4. Business considerations .

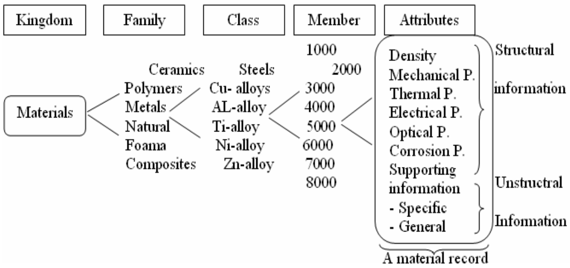

Figure 1. A hierarchical structure for material classification [6].

There are literally hundreds of different properties of materials. The most important to consider when selecting a material for a given product are those that are essential to the function of the product. Generally, most designers put equal importance on the factors of properties, availability, and economics, which list these factors along with some pertinent sub factors [7]. One of the critical factors affecting material selection practice is the function and performance requirement. Functional and performance requirements for materials include [7]:

a- **Structural Requirements:**
Such as strength, stiffness, and their degree of retention in adverse service environments.

b- **Non structural Requirements:**
Such as corrosion resistance, electrical or thermal performance, plus color and texture.

c- **C-Design & Production Criteria:**
Such as part size, shape, and production rate desired. All determine which process and technologies are best suited to the application.

Some attributes which knowledge based materials selector needs to process are suggested. A selector, which can reason with a large number of diverse materials, needs [8]:

1. The ability to deal with simple and complex data structures .
2. Powerful structures for data acquisition and updating. by modifications.
3. To manage spares data.
4. To compare incomplete descriptions.
5. To reason with appropriate classifications.
6. To model confidence .
7. To maintain consistency.
8. To be easily extensible.

4. Methodology of the Weighted Approach

In material / process selection, there are many factors that are affected in selection material or alloy to be manufactured. These factors are different in degree of importance for each application or a specific situation. The differences between factors (properties) depend on the design requirement for each part. Then each property has a degree of importance differ from another property. Each input property is assigned a weight between (0 and 1), with (0) being unimportant and (1) being very important. Since different properties are expressed in different units, the best procedure is to normalize these differences by using a scaling factor. Scaling is a simple technique to bring all the different properties within on numerical range. Since different properties have widely different numerical values, each property must be so scaled that the largest value does not exceed 100 [1].

$$\beta = (NVP / LV)\ 100 \quad (1)$$

β = Scaled property
NVP = Numerical value of property
LV = Largest value under consideration

For properties such that it is more desirable to have low value e.g. density, corrosion loss, cost, and electrical resistance, the scale factor is formulated as follows [1]:

$$N = n\,(n-1) / 2 \quad (2)$$

5. Fuzzy Logic Approach

Fuzzy logic (F.L.) is one of the elements of artificial intelligence that is gaining popularity and applications in control systems and pattern recognition. It is based on the observation that people make decisions based on imprecise and numerical information. Fuzzy models or sets are mathematical means of representing vagueness and imprecise information, Accoedingly the term used is fuzzy [9]. These models have the capability of recognizing, representing, manipulating, interpreting, and utilizing data and information that are vague and lack certainty. The concept of fuzzy can be illustrated in figure (2).

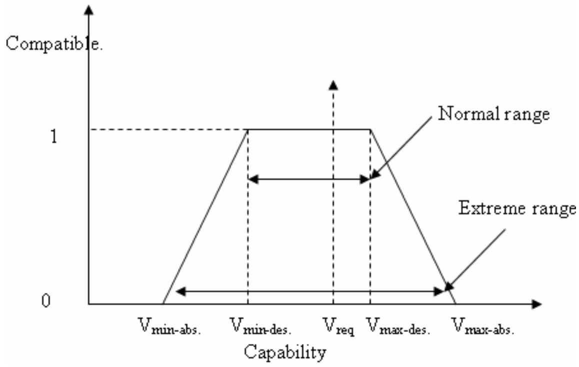

Figure 2. Fuzzy mapping of process capability [9].

Where:
$V_{min-abs}$ = the absolute minimum value.
$V_{min-des}$ = the desire minimum value .
V_{req} = the requirement value.
$V_{max-des}$ = the absolute maximum value.
$V_{max-abs}$ = the desire maximum value.

In fuzzy logic approach, the part process compatibility value will gradually grow from 0 to 1, instead of suddenly jumping from 0 (incompatible) to 1 (fully compatible). For analysis, the process of compatibility and the range of capability are needed in the previous values to be mapped on a normalized scale as in the previous figure. If the value of part requirement falls within $V_{min-des}$ and $V_{min-abs}$ then the compatibility is considered to be fully compatible. If the part requirement value is between $V_{min-abs}$ and $V_{min-des}$, or between $V_{max-des}$ and $V_{max-abs}$, then the compatibility is considered to be less than 1 but more than 0. If the part requirement value is less than $V_{min-abs}$ or more than $V_{max-abs}$, then the compatibility is considered to be zero.

The compatibility $P(x_i)$ for a value x_i of an attribute i can be calculated by using the following equations [9]:

$$P(x_i) = 1 \text{ if } V_{min-des} < x_i < V_{max-des} \quad (5)$$

$$P(x_i) = (x_I – V_{min-abs}) / (V_{min-des} - V_{min-abs}) \text{ if } V_{min-abs} < x_i < V_{min-des} \quad (6)$$

$$P(x_i) = (V_{max-abs} – x_i) / (V_{max-abs} - V_{max-des}) \text{ if } V_{max-des} < x_i < V_{max-abs} \quad (7)$$

$$P(x_i) = 0 \text{ if } x_i < V_{min-abs} \text{ , or } x_i > V_{max-abs} \quad (8)$$

Fuzzy technologies and devices can be applied successfully in areas such as robotics, motion control, evaluation of design alternatives, decision making, design of intelligent systems, materials selection involving multi-criteria, image processing, and machine vision [10].

6. Methodology of Materials Selection

The methodology used in this paper for selection material is one of the artificial intelligence techniques, and it is suitable when there is fuzziness in the in requirements. The material selection module assesses the degree of compatibility between a material alternative and the product profile requirements. Material compatibility is performed via selection queries on the database for each product specifications. The queries are based on the application of fuzzy logic approach to determine the degree of compatiblity for each material. This approach differs from existing approaches in determining the values of compatibilities for both optimal and alternatives selection alloys, and this doesn’t exist in the other approaches. Then this method is more accurate than other methods.

In this paper, we selected aluminum and steel alloys as a database in material selection database dependent on references [11], [12], and [13]. There are about seventy alloys of aluminum and steel with different chemical composition. Then each alloy gave properties different to other alloy. To select the optimal alloy from alternative alloys, the user or designer can inter the range of values for mechanical properties with degree of accuracy required or named fuzzy limit. Then by using fuzzy logic approach (FLA) as mentioned in previous section, any alloy that has values out of the range of absolutely limits will be eliminated.

7. Computer Aided Material Selection (CAMS)

To select the optimum alloy or alternative alloys, the system will display the main window, which contains the sub-windows are:

1. General Applications Environment,
2. Properties Required,
3. Properties priorities,
4. Material Selection,
5. Evaluation , and
6. Final Results.

The firs and second windows contained questions about the required properties and specifications. The third window asked the user about the preference degree of each selected property. The fourth window gave the selected alloys with degrees of compatibility’s to ensure the specified properties. The fifth window gave the evaluations for each selected alloy with compatibility to each property. The final window gave the final results with draw diagrams to show the total compatibility with properties to select optimal and alternative alloys; we will clear the application of the system form case study.

8. Case Study

To evaluate the working of the (CAMS) system, we select bearing cover (B.C) part that is used in many applications like in ceiling fan. Then the problem is to select the type of alloy that are satisfied (B.C) part with specifications and quality. The required specifications can be illustrated in table (1) as follow:

Table 1. the required material properties for producing (B.C) part.

Mechanical properties		Physical Properties	
Tensile strength range	(220 to 280) Mpa	Specific Gravity	medium
Yield stress range	(140 to 180) Mpa	Density	minimum
Elongation range	(1 to 3) %		
Brinell Hardness	(60 to 100) HB	Other Properties:	
		Castability	Very Good
		Weldability	Very Good
		Corrosion resistance	Good

The system will display the special window for material selection as shown in figure (3), this window contains six sub-windows.

To determine the required properties for (B.C) part which are the range of values of mechanical properties with fuzzy limit for each property is interned. For physical properties, specific gravity, with medium and minimum density, is selected. For other properties, capability degree from the command bottom shoulde be very good, and good for corrosion resistance is also selected as shown in figure (4).

The selected properties are not equal in degree of preference. Then to determine the degree of importance for each property, a click on command property priorities is made. In this case, the system will display sets of small windows containing only two properties that will ask the user about which property is preferred over other properties. The user must click on the property that is considered most importance than other properties. This is illustrated in figure (5).

After determining weights for each property, the system will display all the alloys that satisfied all the specified properties. The working of the system in this stage takes two steps: first step screening all the alloys that screened in application environment phase (i.e any alloy

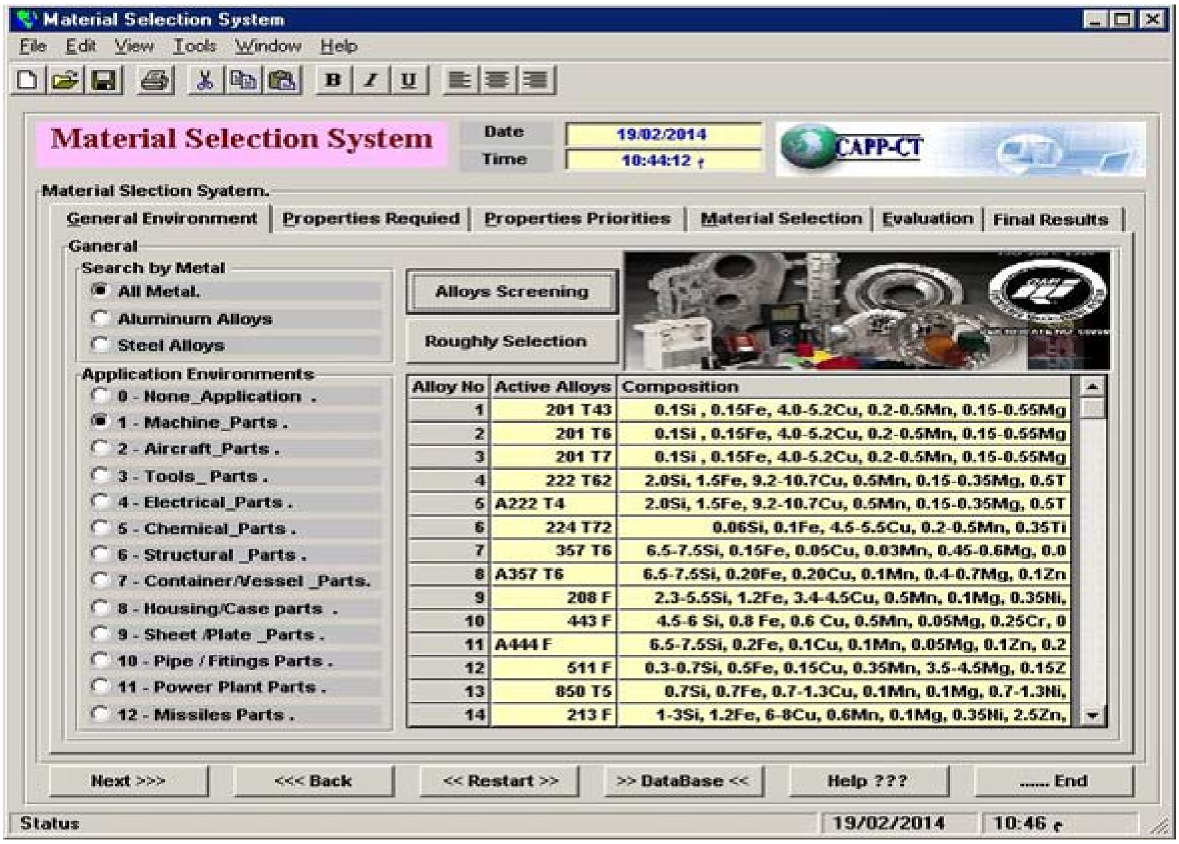

Figure 3 .Application environment window.

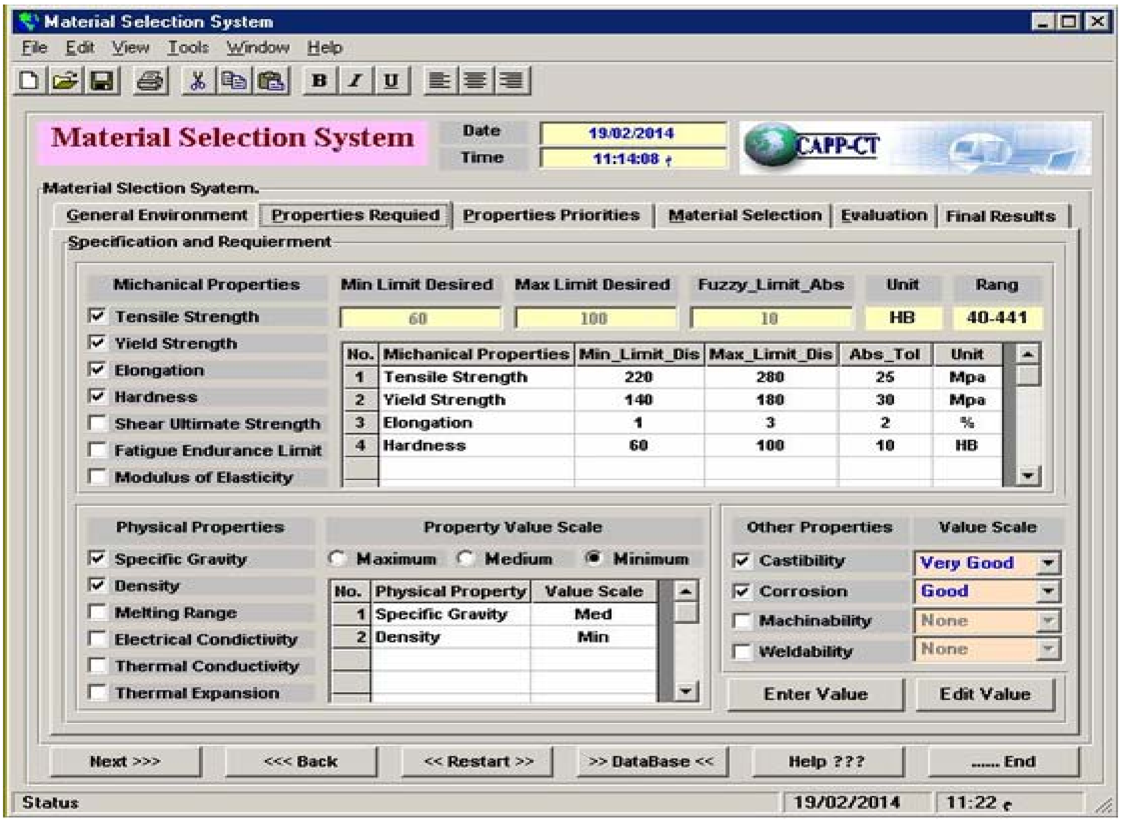

Figure 4. Materials properties window for (CAMS) system .

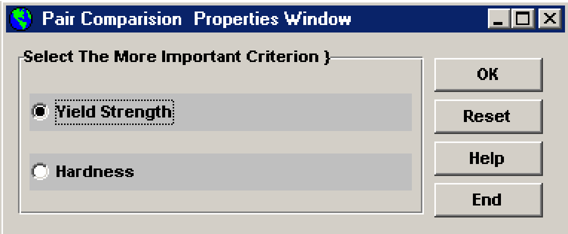

Figure 5. Pair comparison properties window.

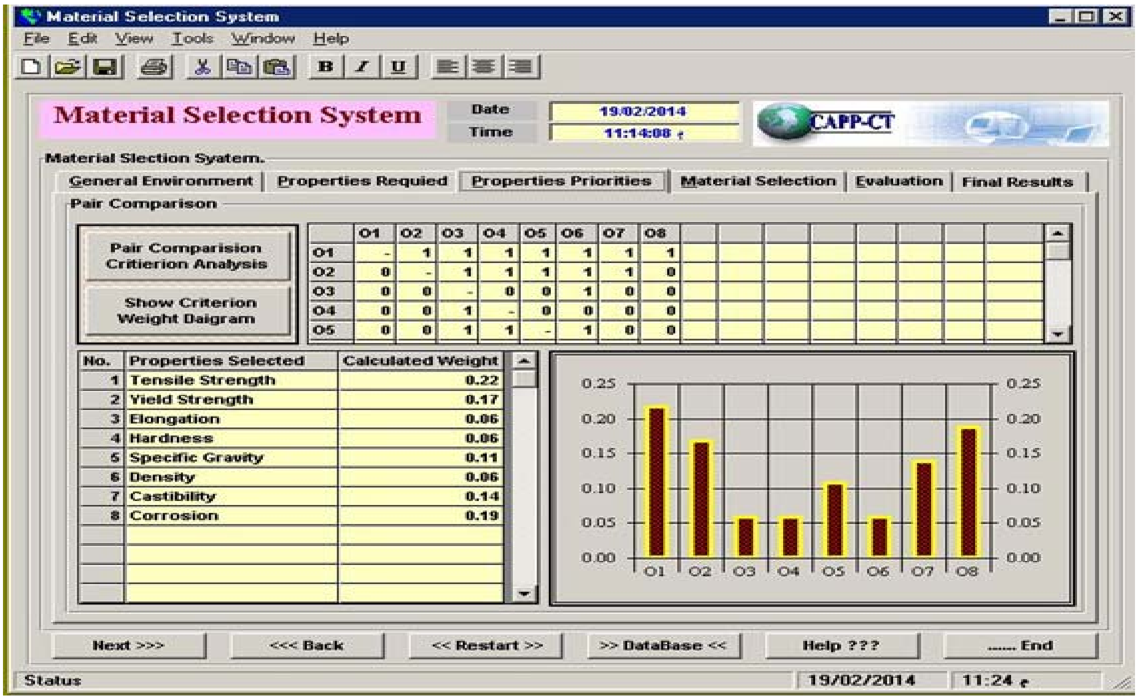

Figure 6. Weights drawing window .

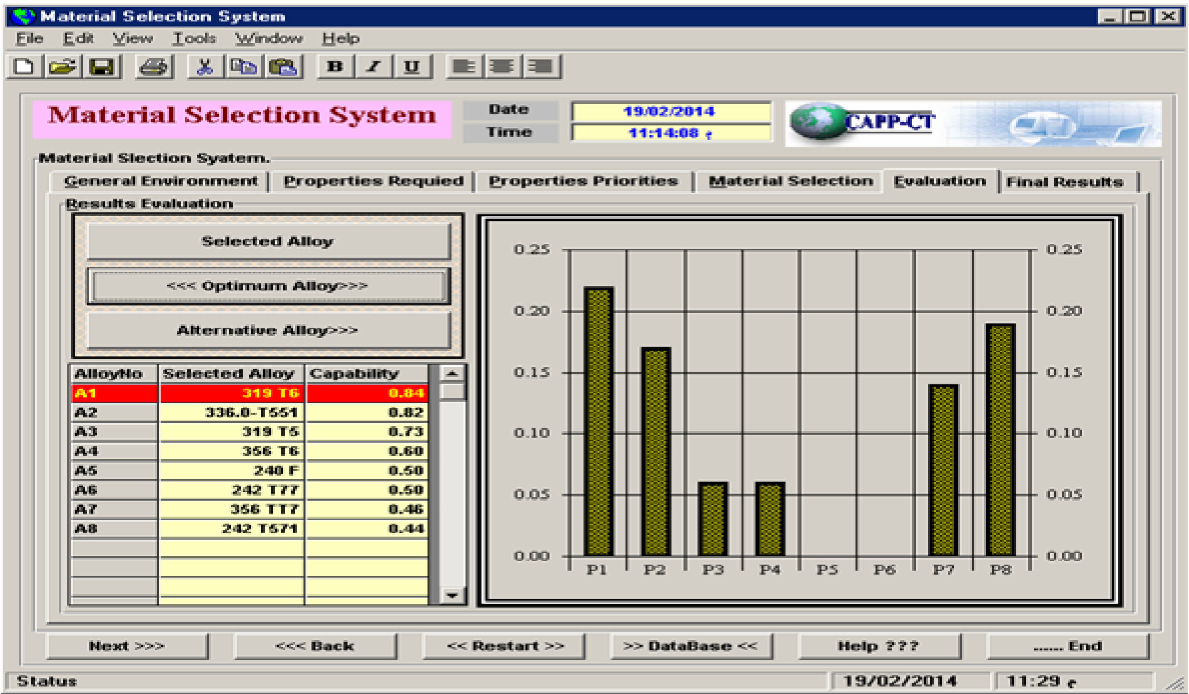

Figure 7. Evaluation alloys window.

does not satisfy the specified mechanical properties will be eliminated) and give each satisfied alloy value of compatibility with respect to mechanical properties. The second step is ranking the satisfied alloys according to the degree of compatibility with all other properties (i.e, .physical, and other properties). The weights for each property with its diagrams can be illustrated in figure (6).Then the system will display the optimum alloy with all alternative alloys, and draw in a diagram of each alloy with degree of compatibility to each specified property as shown in figure (7).

From the above window, the designer or the decision maker (D.M) can select the optimal alloy which has the maximum compatibility degree with the specifications required. If the optimal alloy doesn't available or costly, the (D.M) can select the other alternatives available alloys take into the consideration the degree of compatibility with the property required. Also the (D.M) can benefit from the diagrams that are drawn for each property with respect to the alloy compatibility.

The final step is where the (CAMS) system will display the selected optimum or alternatives alloy with chemical composition, and will display all the properties for the selected alloy, and will draw the diagram for value of the total compatibility with respect to all specified properties.

9. Conclusions

The methodology that is used in this paper for selection material selection is one of the artificial intelligence techniques, and it is suitable when there is fuzziness in the in requirements. The designed system serves not only to select the optimum or alternative material, but also to serve to evaluate the degree of compatibility with specifications requirements. The (CAMS) system gives the real representation in a diagram for each selected material for showing the degree of compatibility with respect to properties or characteristics are required.

After applying the (CAMS) system on the part (B.C), the optimum alloy that is selected is (Aluminum 319) with degree of compatibility for the specified properties is 84 %. Also there are other alternative alloys that are ranked according to the degree of compatibility. If the optimum alloy does not exist in the company, the alternative alloy is (Aluminum 336) with degree of compatibility 82 %. The degrees of compatibility that are obtained from the system are varying from part to part and depending on the user preference to the required properties or requirements. The diagrams of compatibilities that are drawn between each alloy or to each property are clear real representation of capability for each alloy to the satisfied requirements. Hence, the designer can benefit from these diagrams in decision making for selecting the most preferred to him. The alternatives selected alloys / processes enable the designer to make some of modifications in the design stage until reaching satisfaction of the requirements of design.

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