PRODUCT DESIGN AND PROCESS SELECTION - ECONOMIC ANALYSIS

M.Tech Second Stage Project Report

by

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CHAPTER 1

INTRODUCTION

Product engineer often design components with limited knowledge of the manufacturing processes. The result is that the tooling is unnecessarily expensive or the process is not fully utilized. A small change in the design or a better selection of process can thus significantly reduce overall costs or improve product performance.

Design of casting aimed at optimal utilization of material, energy and other sources while ensuring defect free products is still challenging task owing to large number of inter-dependent geometric, material and process parameters involved. Therefore, casting designer have to interact with casting experts in order to ensure the product designed is castable and the optimum casting method is selected. This two way communication results in long design lead times and lack of it can easily lead t o incorrect design and incorrect process selection This gap prevents optimization of various issues in product life cycle. A computer-based system having ability to decide what is most suitable can resolve this problem.

The process of material and process selection is studied in the domain of casting. Material selection process is to be carried out at preliminary design stage, which aids the design engineer in further design considerations. Material selection problem is multi-criteria decision-making problem, as we have to select an optimal material for an engineering design from among two or more alternative materials on the basis of two or more properties. Material selection at early design stage, is characterized by impreciseness and qualitative nature of material properties and qualitative nature of design information. Analytic hierarchy process (AHP) and fuzzy set theory is used to solve this multi-criteria decision-making problem. Material selection module is described in chapter 3. Similar approach is used for selection of casting processes, which is described in the chapter 4.

CHAPTER 2

ADVANCED LITERATURE SURVEY

Summary of literature survey done in first stage concludes that the design of casting with optimal utilization of material, energy and other resources is still challenging task due to large number of geometric, material and process parameters involved in it. Different approaches had developed to assist the designer for castable design and optimal material and process selection. Several knowledge base and data base support systems had developed for material and process selection. These database or knowledge base supported systems select the materials when the properties are well defined and the criteria are exact. Also these systems list all the suitable materials and processes satisfying the product requirements but doesn't gives the raking or compatibility of suitable material and processes.

Taking into consideration above points, further literature survey is done, which accounts impression in design information and material properties.

Giachetti, R. E.[1] has developed a prototype material and manufacturing process selection system called MAMPS, which integrates a formal multi-attribute decision model with a relational database. The problem of material and process selection is considered as a multi-attribute decision-making problem. The decisions are made during the preliminary stage in an environment characterized by imprecise and uncertain requirement, parameters and relations. Possibility theory is used to generate compatibility rating between product requirements and the alternative for each decision criteria. The vector of compatibility ratings are aggregated into a single rating, depending upon it system outputs the ranked set of compatible material and manufacturing process alternatives.

Thurston, D.L. and Carnahan J. V.[2] has analyzed the problem of preliminary material selection for an automotive bumper beam, using the techniques of fuzzy set analysis and multi-attribute utility analysis. They recommends to use fuzzy analysis in the earliest stages of preliminary design or in situations limited to semantic input from design decision makers. While utility analysis is used in later stages of design, where numerical quantification of attribute level is possible.

Liang G. S. and Wang M. J.[3] had proposed facility site selection algorithm, which is based on the concept of fuzzy set theory and hierarchical structure analysis. Fuzzy suitability indices are obtained by aggregation of decision-makers linguistic assessment about criteria weightings and the suitability of facility sites versus various selection criteria. Then these suitability ratings are ranked to determine best facility site selection.

Warren T. L.[4] had presented a fuzzy multi-criteria decision making method developed to supported material selection decisions in engineering design application. He has discussed the fuzzy characteristic of material selection problem and how fuzzy set theory is used to handle imprecision and qualitative nature of decision criteria.

Analytical hierarchy process (AHP) and fuzzy set theory is revived in brief below.

2.2 Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) is a decision-making method developed by Saaty (1980). The fundamental problem of decision making is how to derive weights for a set of activities according to importance. Importance is usually judged by several criteria that may be shared by some or all of the activities. This weighting of activities with respect to importance is a process of multi-criterion decision making. AHP has been used successfully in many situations where decision making is characterized by a large number of complimentary and conflicting factors[5].

AHP aims at quantifying relative priorities for a given set of alternatives on a ratio scale. It provides a comprehensive structure to combine the intuitive, rational and irrational values during the decision making process. AHP unites perception and purpose into overall synthesis. It is a theory of measurement for dealing with tangible and intangible criterion.

Perhaps the most creative task in making a decision is to choose the factors that are important for that decision. In AHP, the factors once selected, are arranged in a hierarchical structure descending from an overall goal to criteria, sub criteria and alternatives in successive levels.

AHP has found many applications in real life (Zahedi, 1986); for example, technology related problems, political problems, allocation of energy to industries, vendor section etc. The applications process of AHP consists of three stages of problem solving. These are the principle of decomposition, comparative judgements and synthesis priorities[6].

Steps in AHP :

1. Define the problem and determine the objective.
2. Structure the hierarchy from top through the intermediate levels to the lowest level.
3. Construct a set of pairwise comparison matrices for each of these lower levels. An element in the higher level is said to be a *governing* element for those in the lower level, since it contributes to it or affects it. The elements in the lower level are compared to each other based on their effect on the *governing* element above. This yields the square matrix of judgements. The pair wise comparisons are done in terms of which element dominates another. These judgements are then expressed as integers. If element A dominates over element B, then the whole number integer is entered in row A, column B and the reciprocal is entered in row B, column A. If the elements being compared are equal, number 1 is assigned to both positions.
4. There are n*(n-1)/2 judgements required to develop the step of matrices in step 3. (Reciprocals are automatically assigned in each pairwise comparison).
5. The next step consists of computation of a vector of priorities from the given matrix. In mathematical terms, the principle vector is computed, and when normalized becomes the vector of priorities.
6. The process of comparing the elements in each level is continued down the hierarchy, comparing the set of elements in each level with respect to elements in the level above which they affect in real importance. A set of local priorities is generated from pair wise comparison matrices.

7. At this point syntheses of priorities are carried out. Priorities are synthesized from second level down by multiplying local priorities by the priority of their corresponding criterion in the level above. The second level elements are each multiplied by the one weight of the single top level goal. This gives the composite priorities of that element which is then used to weight the local priorities of element in the level below it and so on until the bottom level.
8. We have to check the consistency for every pairwise comparison matrix. The consistency ratio should be about 10% or less to be acceptable. If not, the quality of the judgements should be improved.

2.3 Fuzzy-set Theory:

Much of the decision making in the real world takes place in an environment in which the goals, the constraints and the consequences of possible action are not known precisely according to Bellman and Zadeh.

Decision making method using fuzzy-set theory has gradually gained acceptance because of their capabilities in handling the impreciseness that is common in system specifications States and alternative ratings. Also linguistic variables can be represented and manipulate using fuzzy-set theory. Fuzzy set theory was developed exactly based on the premise that the key elements in human thinking are not numbers, but linguistic terms or labels of fuzzy sets[7].

The fuzzy set theory was introduced by Zadeh(1965), to deal with the problem in which the absence of sharply defined criteria is involved. It has been considered as a modeling language to approximate situation in which fuzzy phenomena and criteria exist.

Fuzzy set theory sates that, in a universe of discourse X, a fuzzy subset A of X is defined by a membership function f_A (x), which maps each elements x in X to a real number in the unit internal [0,1]. The function value f_A (x), represents the grade of membership of x in A. the larger the f_A (x) is, the stronger the grade of membership for x in A.

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Fuzzy number:

A fuzzy number A is a special fuzzy sub set of real number R. Its membership function f_A (x) is a continuous mapping from R to a closed interval [0,1], which has the following characteristics

f_A (x) = 0 for all x in (-∞,α] U [δ,∞);

f_A (x) is strictly decreasing in [α,β];

f_A (x) = 1 for all x in [β,τ];

f_A (x) is strictly increasing in [τ,δ].

The membership function f_A (x) of the fuzzy number A can be expressed as,

$$
\begin{aligned}
f_A(x) &= f_A^L(x), && \alpha \le x \le \beta \\
&= 1, && \beta \le x \le \tau \\
&= f_A^R(x), && \tau \le x \le \delta \\
&= 0 && \text{otherwise}
\end{aligned}
$$

Where $f_A^L : [\alpha, \beta] \rightarrow [0,1]$ and $f_A^R : [\tau, \delta] \rightarrow [0,1]$.

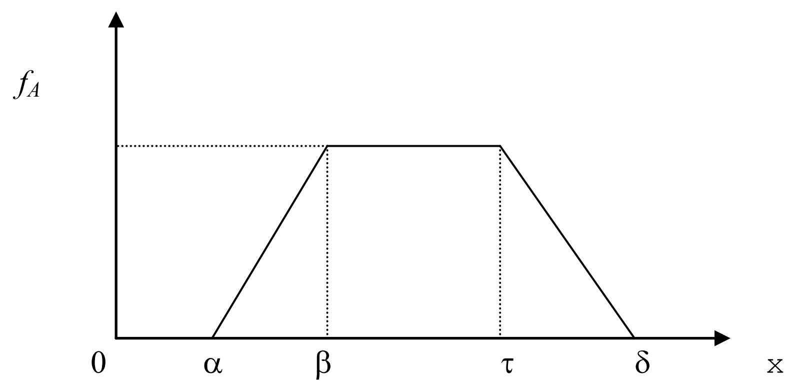


Fig. 2.1 Fuzzy Membership Function of Fuzzy Number**.**

CHAPTER 3

MATERIAL SELECTION MODULE

3.1 Introduction

At an early stage in design and before proceeding to the detailed determination of shape, the casting process, the alloy and a general outline of the proposed manufacturing method need to be established. i.e. material selection and production methods have to be considered before the final design of the product is frozen.

Material selection problem is multi-criteria decision-making problem. As we have to select an optimal material for an engineering design from among two or more alternative materials on the basis of two or more properties. The material selection decisions are difficult due to several reasons[1].

1. Selection is made during preliminary engineering design at which we have fair idea of product. The preliminary design environment is characterized by imprecise and uncertain requirements, parameters and relations. Many design requirements are described in qualitative terms and imprecise data.
2. Material properties are also of varying degrees of importance for different design requirements. Also for same design requirements different material properties are of unequal importance. More-ever, many of the requirements can be classified as soft requirements or designer preferences which are also flexible.
3. The values of material properties are often qualitatively described or imprecisely measured using ranges. The desired values and importance weight of a material property are usually described in a linguistic fashion e.g. It is "important" that corrosion resistance property of selected material must be "good". Thus the material properties which are difficult to quantify makes the problem of selection more trouble some.
4. There are large numbers of material alternatives to evaluate and new materials are continuously being developed. It is impossible for designer to have knowledge of all the possible candidate materials.

Material selection at early design stage is characterized by

1. Impreciseness and qualitative nature of material properties.
2. Qualitative nature of design information.

Due to dynamic nature of these characteristics, material selection problem can be modeled as multi-criteria decision-making problem, which can be solved by using fuzzy-set theory.

Decision making method using fuzzy-set theory has gradually gained acceptance because of their capabilities in handling the impreciseness that is common in system specifications States and alternative ratings. Also linguistic variables can be represented and manipulate using fuzzy-set theory.

In material selection module we will use only two kinds of fuzzy numbers trapezoidal and triangular fuzzy number. A fuzzy number A in R is a trapezoidal fuzzy number if it's membership function $f_A : R \rightarrow [0,1]$ is

$$
\begin{aligned}
f_A(x) &= (x - a) / (b - a) && a \leq x \leq b \\
&= 1 && b \leq x \leq c \\
&= (x - d) / (c - d) && c \leq x \leq d \\
&= 0 && \text{otherwise}
\end{aligned}
$$

With $a \leq b \leq c \leq d$. The trapezoidal fuzzy number, as given above is represented as (a, b, c, d).

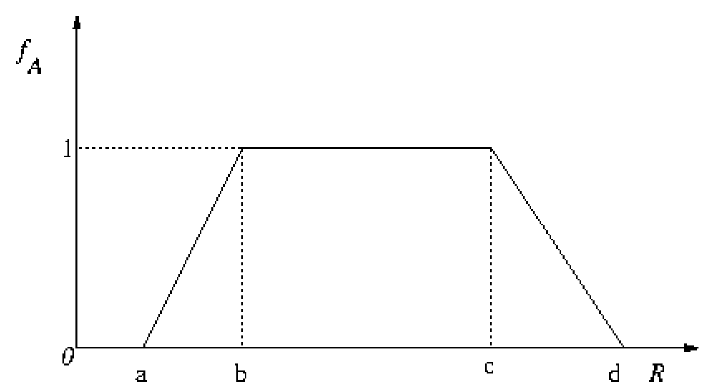


Fig. 3.1. Membership Function of trapezoidal Fuzzy number A = (a, b, c, d).

A triangular fuzzy number is special case of trapezoidal fuzzy number, where c = b. Its membership function $f_A : R \rightarrow [0,1]$ is

$$f_A(x) = (x - a) / (b - a) \qquad a \le x \le b$$

$$= (x - d) / (b - d) \qquad b \le x \le d$$

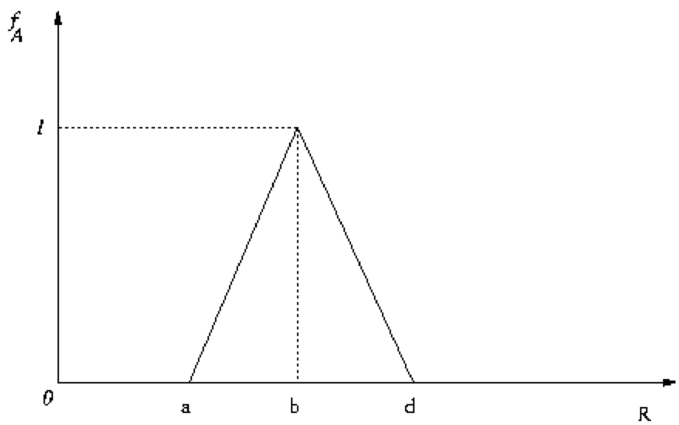


Fig. 3.2. Membership Function of Triangular Fuzzy number A = (a, b, b, d).

3.2 Material Properties:

Every material has different physical, mechanical and chemical properties. These properties are generally classified in to following two categories based on the way these are measured.

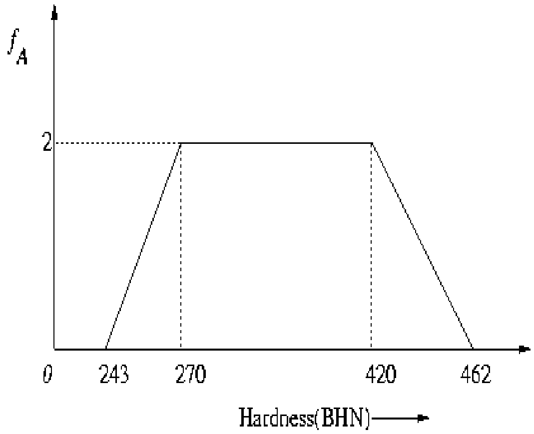
1. Quantitative Properties :

These properties can be expressed numerically, generally material properties are not fixed but range between two values e.g. hardness of Grey iron (grade 220)varies between 165-245.

Membership values:

Quantitative properties of materials are represented by trapezoidal function. Because value of quantitative property can be apporimxtely equal to a number or between two numbers. These are represented as (a, b, c, d)

Eg. For a material having hardness range between 270 & 420 is represented as (243,270,420,462) shown in fig.3.3. and Property of material with a value equal to 300 is represented as (270,300,300,330) shown in fig3.3.



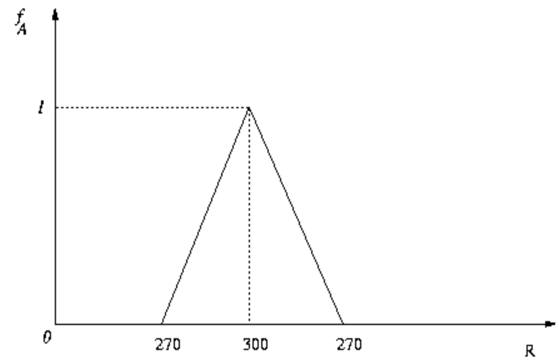


Fig. 3.3 Fuzzy Representation of Material Properties.

2. Qualitative Properties

Some material properties can not be easily expressed numerically. Instead, these properties are qualitatively described by fuzzy terms such as "good", "fair", etc. E.g. machinability, corrosion resistance.

Membership values:

A qualitatively property is a linguistic variable whose values are words" or sentences in natural or artificial language. For example "corrosion resistance" is a linguistic variable, its values are very good, good, etc. A normalized range between 0 and 1 is partitioned in to five overlapping linguistic sets. The sets are very poor, poor, fair, good and very good {VP,P,F,G,VG}the membership function of these linguistic values are shown in fig. 3.4.

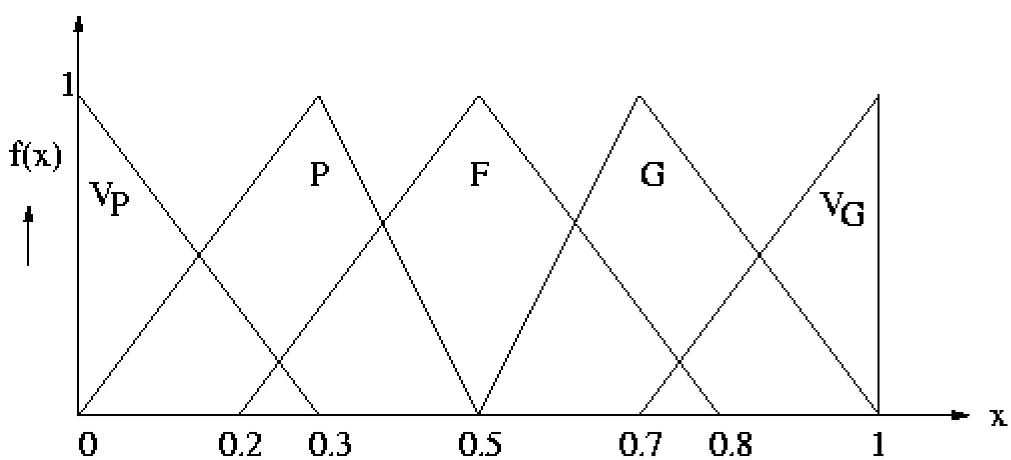


Fig. 3.4 Membership Function for the Linguistic values

Very Poor	(0, 0, 0, 0.3)	$f(x) = 1\text{-}10x/3$	$0 \le x \le 0.3$
Poor	(0, 0.3, 0.3, 0.5)	$f(x) = 10x/3$	$0 \le x \le 0.3$
		$= 5/2 - 5x$	$0.3 \le x \le 0.5$
Fair	(0.2, 0.5, 0.5, 0.8)	$f(x) = 10x/3 - 2/3$	$0.2 \le x \le 0.5$
		$f(x) = 8/3 - 10x/3$	$0.5 \le x \le 0.8$
Good	(0.5, 0.7, 0.7, 1)	$f(x) = 5x - 5/2$	$0.5 \le x \le 0.7$
		$f(x) = 10/3 - 2/3$	$0.2 \le x \le 0.5$
Very Good	(0.7, 1, 1, 1)	$f(x) = 10x/3 - 2/3$	$0.7 \le x \le 1$

3.3 Flow chart:

Following figure shows the schematic diagram of material selection module.

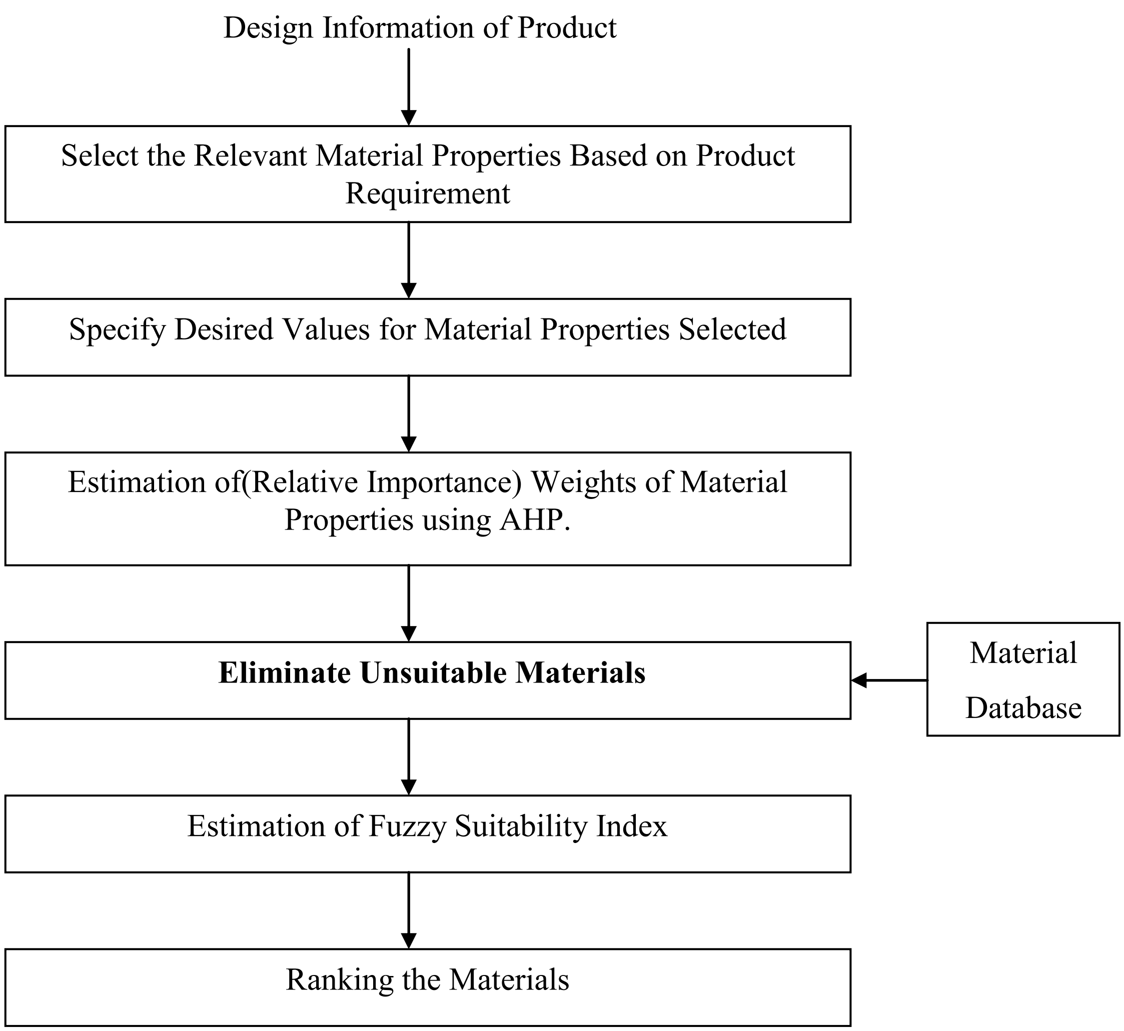


Fig. 3.5 Flow Chart of Material Selection Module

Select the relevant material properties depending upon the functional requirements of the product given by design information. Selected material properties form the basis of selection of the material. Specify the desired values for selected material properties. Values for desired quantitative properties are entered using comparator as shown in fig. 3.6.

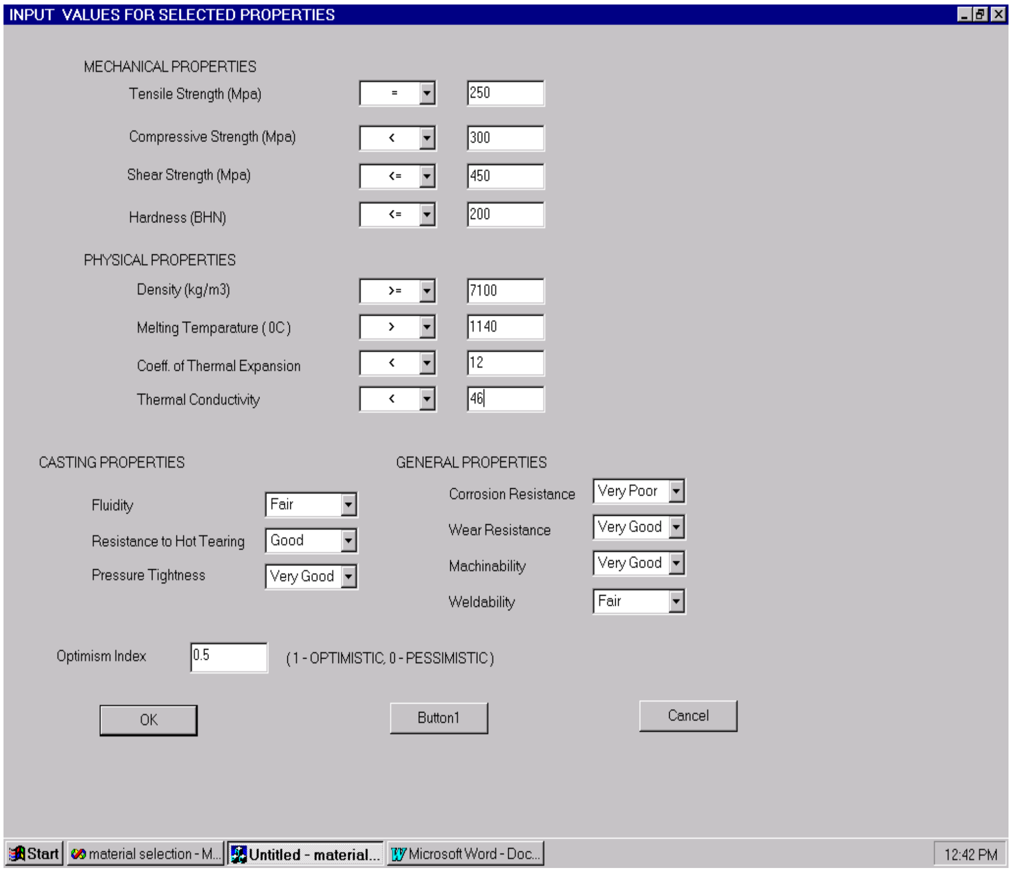


Fig 3.6 Material Property Value Input Form.

The comparators used are ≤, ≥, ≈, <, >. The meaning and membership function of each comparator is given in below fig. 3.7.

Desired values are converted in to fuzzy numbers based on which comparator is used and specified value of fuzziness. E.g. Tensile Strength ≤ 200 Mpa (10% Fuzziness). Thus the desired value of tensile strength is represented as (180,200,200,200).

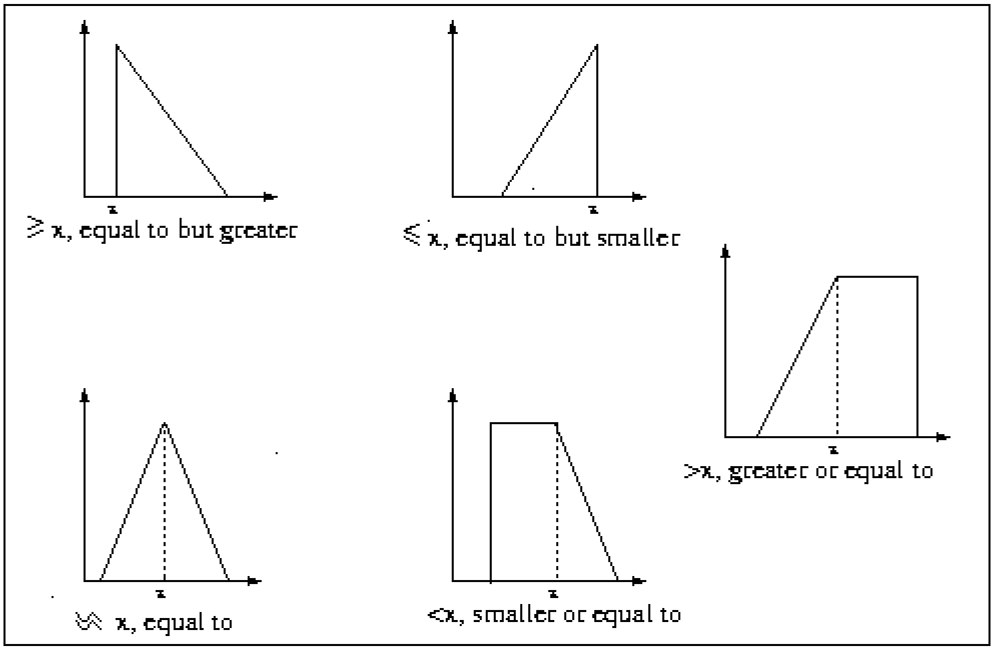


Fig. 3.7 Forms of Membership function for Comparators

Values for desired qualitative properties be specified in terms of words and transferred in to fuzzy number depending upon the membership function of linguistic variables. For example, the fuzzy values for corrosion resistance having material requirement as “good” are given by (0.5, 0.7, 0 .7, 1) as shown in fig. 3.4.

3.4 Estimation of weights of material properties using Analytic Hierarchy Process (AHP).

The weights of material properties are estimated by Saaty’s analytic hierarchy process (AHP) as discussed in chapter 2. For material selection module hierarchy is shown in Fig. 3.8.

AHP is applied at level 1, to get the weights for overall material properties in level 2. For this, the overall material properties are compared with each other’s, which yields a square matrix of judgement. The pair wise caparison procedure asks the question: how much more important is the material property on the left side of the matrix when it is compared with the material property on the top of the matrix. These judgements are then expressed as integers by using the scale of relative importance.

The scale that was used to represent judgement entries ranges from 1 to 9 as follows.

1: equally important

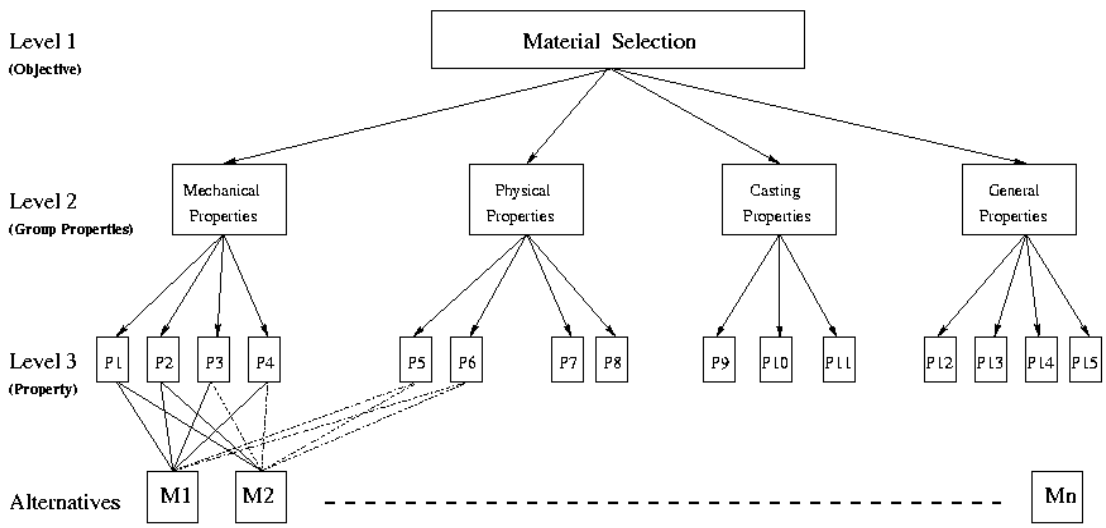
3: weakly more important

5: strongly more important

7: demonstrably more important

9: absolutely more important

2,4,6 and 8 are intermediate values for comparison



. Fig 3.8 Hierarchy of Material Selection Module.

Where,

P1 – tensile strength.

P2 – Compressive strength

P3 - Shear Strength

P4 – Hardness

P5 - Density

P6 – Melting Temp.

P7 – Thermal Conductivity

P8 – Coeff. Of Thermal Expansion

P9 - Fluidity

P10 – Pressure Tightness

P11- Resistance to Hot Tearing

P12 – Corrosion Resistance

P13 – Wear Resistance

P14 – Machinability

P15 - Weldability

The next step is the computation of a vector of weights from the pair wise comparison matrix. Multiply the n elements in each row of matrix and take the n^{th} root (n is size of matrix) i.e. geometric mean (GM) of each row is calculated. Resulting numbers are normalized which result in weight of each property. Matrix for overall (group) properties is shown in fig.3.9.

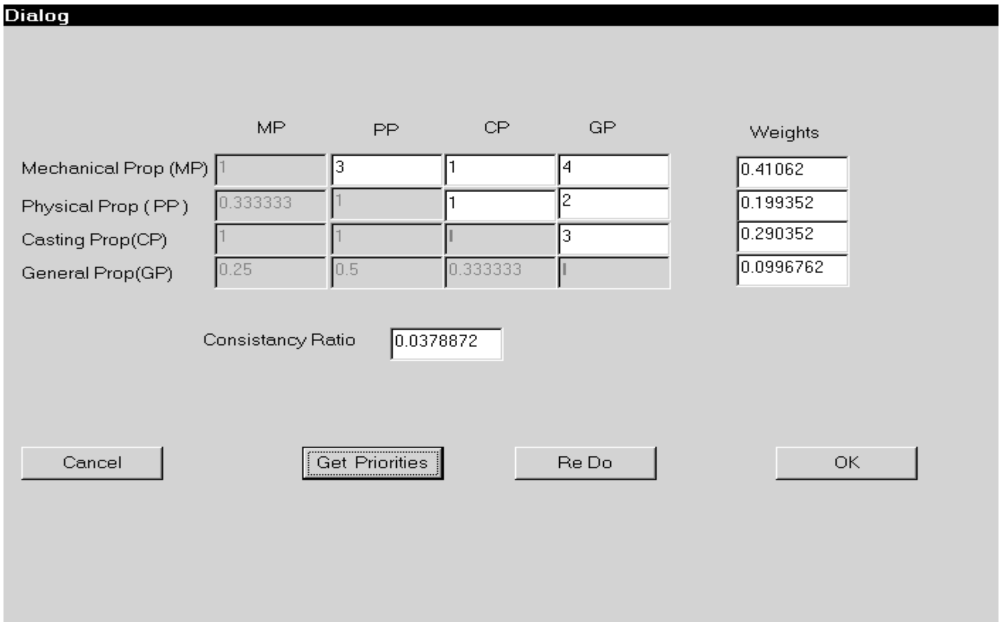


Fig. 3.9 Comparison matrix for group properties.

After computing the weights for each element in level 2, we have to check the consistency for the pairwise comparison matrix by calculating consistency ratio. The consistency ratio should be 10 % or less to be acceptable. If not, the quality of the judgments should be improved. The procedure for calculating consistency ratio (CR) of the comparison matrix, is as given below (Saaty, 1980).

Let the pairwise comparison matrix be denoted by M1 and the weight vector by M2. Calculate M3 and M4 such that M3 = M1*M2 and M4 = M3 / M2. Then,

Maximum eigen value (λ_{max}) = Average of M4 elements.

Consistency Index (CI) = (λ_{max} - n)/ n-1   n = size of matrix

Consistency ratio (CR) = CI/ R   R = random matrix

In above case values are: λ_{max} = 4.09 , CI = 0.03, CR = 0.037

The same procedure of AHP is applied to all the elements in the 2^{nd} level of the model, to obtain weights of material properties in level 3. Then the total weight of material property in level 3 is equal to product of weight of property and weight of its respective overall property in level 2. Similarly total weights of all material properties in level 3 are calculated.

Then this weights is represented as trapezoidal fuzzy number denoted by $w=(w_a, w_b, w_c , w_d)$ e.g. If total weight of material property 'tensile strength is 0.23, then with fuzziness 5% it is represented as (0.20, 0.23, 0.23, 0.25)

3.5 Elimination of unsuitable materials

A material is considered not suitable for an application if the value of any one of its properties does not meet the requirements. The decision is made based on the comparison of the property value with desired value. Let $D_j=(da_j, db_j, dc_j, dd_j)$ be the desired value and $P_{ij} = (pa_{ij}, pb_{ij}, pc_{ij}, pd_{ij})$ be the property value of property j for material i. material I is concluded to be unsuitable if $pd_{ij} \leq da_j$ whenever a large value of property j is desired, or $pa_{ij} \geq dd_j$ whenever a small value of property j is desired. Based on the above evaluation, unsuitable material are identified and eliminated from further consideration in material selection process [4].

3.6 Estimation of fuzzy suitability index:

Fuzzy suitability index indicates the suitability of a material for an engineering design application. The index accounts for the ambiguities involved in evaluation of the appropriateness of alternate materials and importance of material properties.

The rating S_{ij} is assigned to material i for a property j using the extended algebraic equations. S_{ij} indicates the compatibility between the adjusted material property AP_{ij} and desired property D_j. The extended algebraic operations Ĕ, ⊕, ⊗, Ĕ on trapezoidal fuzzy numbers are derived as given Appendix 1. Given P_{ij} and D_j, following equations are used to calculate S_{ij} if a large value of D_j is desired.

$S_{ij} = (AP_{ij}\ \breve{E}\ D_j)\breve{E}\ D_j$

Where,

$AP_{ij} = nd_j \oplus (pa_{ij}, pb_{ij}, pc_{ij}, pd_{ij})$

$nd_j = |\min(pa_{ij})\text{-}dd_j|$

Following equations are used to calculate S_{ij} if a small value of D_j is desired.

$S_{ij} = (D_j\ \breve{E} AP_{ij})\breve{E}\ D_j$

$AP_{ij} = (pa_{ij}, pb_{ij}, pc_{ij}, pd_{ij})\ \breve{E}\ nd_j$

$nd_j = |da_j - \max(pd_{ij})|$

The calculation of S_{ij} follows the extended algebraic operations represented above. S_{ij} is a trapezoidal fuzzy number represented as (sa_{ij}, $sa_{ij,}$ $sa_{ij,}$ sa_{ij}). The final suitability index for material S_i is obtained as:

$S_I = 1/n \otimes [(S_{i1} \otimes w_1) \oplus (S_{i2} \otimes w_2) \oplus \ldots\ldots \oplus (S_{in} \otimes w_n)]$

Where n is the total numbers of relevant material properties selected and w_i is total weight of selected material property.

3.7 Material ranking

Method of ranking fuzzy numbers with integral value is selected for ranking the suitability of materials. This method was proposed by Liou and Wang [4]. If A is a fuzzy number with membership function $f_A(x)$ as expressed in defination, then the total integral value with index of optimism λ is defined as :

$$I_T^{\lambda} = \lambda I_R(A) + (1-\lambda) I_L(A)$$

Where $I_R(A)$ and $I_L(A)$ are the right and left intergral values of A, respectively, and λ = [0, 1]. $I_L(A)$ and $I_R(A)$ are defined as :

$$I_L(A) = \int_0^1 g_A^L(y)dy$$

$$I_R(A) = \int_0^1 g_A^R(y)dy$$

Where, $g_A^L(y)$ and $g_A^R(y)$ are the inverse function of $f_A^L(x)$ and $f_A^R(x)$ respectvely. The index of optimism (λ) represents the degee of optimisim of a decision maker. The larger λ indicates a higher degee of optimism.

The inverse functons of f_A^L and f_A^R for trapezoidal fuzzy numbers are $g_A^L(y)$ = α+ (β - α)y and $g_A^R(y)$= δ + (τ - δ)y, respectively. Thus

$$I_L(A) = \int_0^1 g_A^L(y)dy = \int_0^1 [\alpha + (\beta - \alpha)y]dy = \frac{\alpha + \beta}{2}$$

$$I_L(A) = \int_0^1 g_A^R(y)dy = \int_0^1 [\delta + (\tau - \delta)y]dy = \frac{\tau + \delta}{2}$$

Given a λ (the design engineer is asked to decide it), the total integral value of the trapezoidal fuzzy number A can be directly obtained as :

$$I_T^\lambda(A) = \frac{1}{2}[\lambda(\tau + \delta) + (1 - \lambda)(\alpha + \beta)]$$

The ranking of material 1 is said to be higher than material 2 if $\mathrm{I}_\mathrm{T}^\lambda(\mathrm{S}_1) > \mathrm{I}_\mathrm{T}^\lambda(\mathrm{S}_2)$.

CHAPTER 4

PROCESS SELECTION MODULE

4.1 Introduction

Selecting the most suitable process for the given product requirements is a very crucial step in casting manufacturing environment. Early consideration of manufacturing process at design stage guarantees the manufactruablility of casting. While, early comparison and selection of most suitable process allows the designer to tailor the design attributes according to process capabilities giving an advantages like higher quality and lower weights. Therefore, to achieve the most efficient and economical manufacturing, the designer must be aware of an alternative processes and their capabilities. Selecting most suitable process alternative requires an understanding of large number of process characteristics. These process characteristics differ widely in terms of their capabilities, advantages and limitations. These characteristics also vary with the type of cast metal, leading to large number of process-material dependent characteristics. The detailed knowledge of process characteristics and their capabilities is very much essential in evaluating the process against the given design specifications. For this knowledge, the designer may often needs to consult either a foundry expert or a reference handbook. In addition, a decision making for the suitability of a process requires comparison of every characteristic in each process with design attributes, which is very time consuming and tedious.

Following methodology of process selection is adapted from Akarte Milind, Research Scholar in the Dept. of Mechanical Engg., IIT Bombay.

4.2 Process Selection Methodology:

The schematic representation of casting process selection methodology is shown in figure 4.1. The objective of this work is to,

1) Capture the designer's decision of assigning relative importance between evaluation criteria.
2) Develop and integrate databases of casting process capabilities to support the decision-making.

3) Evaluate process capabilities based on quantitative imprecise and qualitative data. This approach uses fuzzy logic, linear weighing model and AHP tool to evaluate the compatibility and suitability of process for the given design.

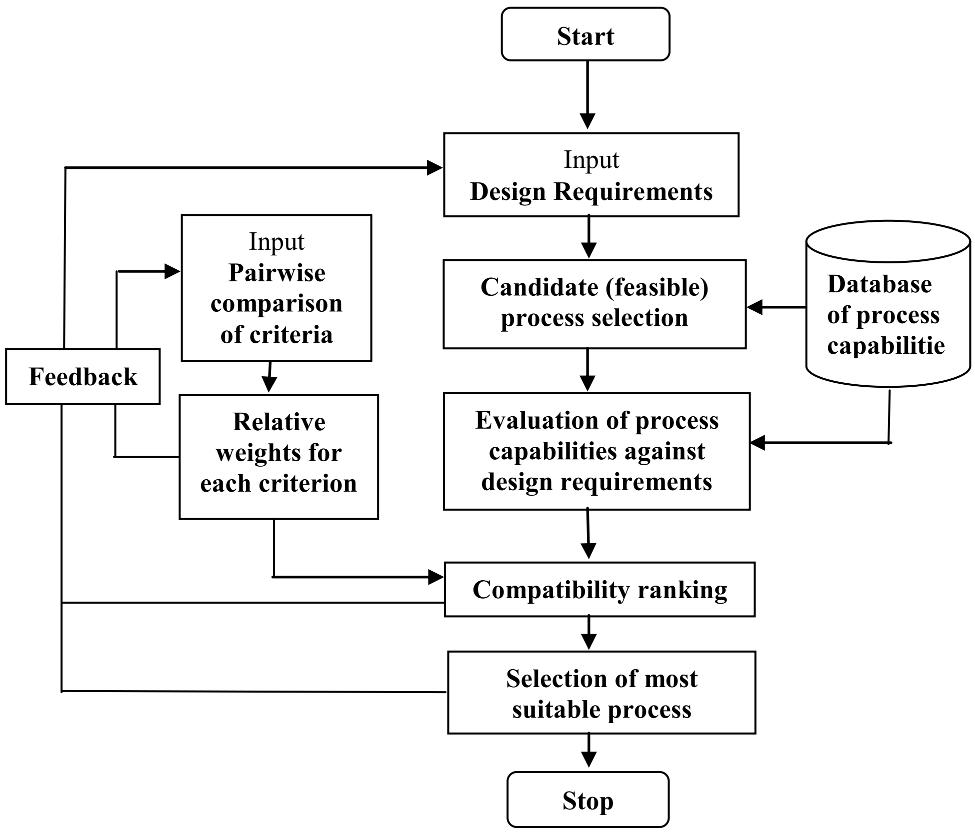


Fig. 4.1 Flow Chart of Process Selection Module.

4.2.1 Selection Criteria:

Various criteria are to be considered in evaluating the overall compatibility of casting process with regard to the design specifications. Criteria are classified in to three categories, critical, objective and subjective. Critical criteria are those which must be fulfilled by the respective characteristics of the process. Objective criteria are those that can be precisely quantified. Examples are minimum core hole diameter and production rate. Subjective criteria are those criteria characterized by linguistic variables. Examples are tooling cost, lead-time. Table 1 shows the complete list of all criteria and their classification for evaluation purpose. Critical criteria (also objective type) are used to find out the suitability of processes, i.e. to obtain candidate processes, while objective and subjective criteria evaluates the compatibility of candidate processes against the given design.

Criteria Name		Classification		
Group	Sub-criteria	Critical	Objective	Subjective
Design	Material	√		
	Weight	√		
	Size	√		
	Quantity	√		
	Minimum core size	√	√	
	Minimum Section thickness	√	√	
	Shape complexity		√	
Quality	Tolerance along parting line		√	
	Tolerance across parting line		√	
	Surface roughness		√	
	Surface detail			√
Production	Production rate		√	
	Lead time			√
	Material utilization			√
	Porosity and voids			√
Cost	Tooling cost			√
	Direct labour cost			√
	Equipment cost			√
	Finishing cost			√

Table 1. Criteria for Process Selection

4.2.2 Hierarchical structuring of criteria:

The hierarchical structuring of these criteria is carried out in three levels. The top level consists of overall objective for process selection. Four important groups of criteria are identified at level 2. These are design, quality, production and cost. The detailed criteria (total 15) are at level 3, under the appropriate group. The schematic representation of various levels in AHP model is shown in figure 4.2. The relative weights are calculated using AHP as discussed in chapter 2.

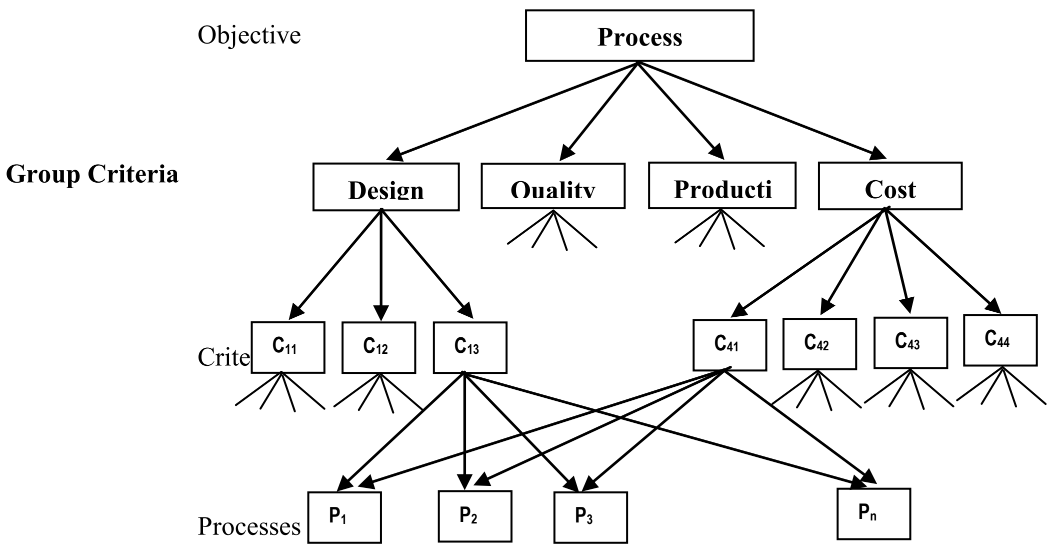


Fig. 4.2. Hierarchy of Process Selection Module.

4.2.3 Compatibility evaluation and ranking:

Feasible processes selection and their compatibility ranking for the given design is a multi-criteria decision-making problem. A systematic approach for casting process selection problem by using the concept of fuzzy logic and linear weighing model to evaluate candidate process is used as discussed in chapter 3.

4.2.2 Evaluating process characteristics:

Initially critical criteria scrutinizes the processes for their suitability to design and then, objective and subjective criteria are used to evaluate the candidate process characteristics according to the compatibility of their capabilities with design. A linear weighing model and a fuzzy logic are used for evaluating process characteristics against the subjective and objective criteria respectively. Process characteristics, to be evaluating against subjective criteria, are generally expressed in terms of linguistic variables (example, low tooling cost, very high finishing cost lead-time is days to weeks). Quantification of these qualitative rating is mapped to a number between [0,1]. In this application, variables (low, low to medium, medium,

medium to high, high, high to very high and very high) refers to the rating (0, 0.167, 0.333, 0.5, 0.667, 0.83, 1.0).

Process characteristics, to be evaluated against the objective criteria, are not precisely defined for the decision-maker, in casting domain. For example, selection thickness process capability of die casting varies from 0.762 mm to 2.032 mm for aluminum cast metal [Barlla, 1988].

4.2.5 Ranking candidate process:

Ranking of candidate processes is calculated by multiplying (a) compatibility performance (normalized values) of process characteristic against each criteria (b) with the relative importance of criteria (weights at level 2) and its sub-criteria (weights associated at level 3) Mathematically, the ranking score for all candidate processes can be given by,

$$RPi = \sum_{J=1}^{4} \sum_{K=1}^{SCj} C_j C_{jk} W_{jki}$$

Where,

RP_I = process capability score of i^{th} candidate process.

C_j = Importance (weight) of j^{th} group criteria at level 2

C_{jk} = Importance of k^{th} criteria at level 3, belonging to j^{th} group criteria at level 2.

W_{jki} = Compatibility of i^{th} candidate process for k^{th} criteria of j^{th} group criteria.

CHAPTER 5

CONCLUSION

5.1 Summary of Work Done

Work done in the second stage include:

- Advanced literature review on material selection and processes selection.
- Evaluation of the factors affecting material selection.
- Evaluation of the factors influencing process selection.
- Detailed design of material selection and process selection modules.
- Preliminary implementation of material and process selection module.

5.2 Plan for next stage

The next stage of project will be carried out at Fiat Research Center, Italy from Sept. to Dec. 1999.

Proposed work for the next stage includes:

- Development of material and process selection module.
- Collection and storage of practical data based on
    - Material properties
    - Process parameters
- Detailed study of cost factors.
- Developing the systematic method for cost estimation.

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