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A decision support system for the selection of a casting process using analytic hierarchy process

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Keywords casting process selection, decision support system, analytic hierarchy process, priority weights

Abstract. This paper presents an Analytic Hierarchy Process (AHP) based decision support system to select the most suitable casting process for a given product. The hierarchical structure of the proposed method allows the decision maker to compare the different casting processes using the material suitability and flexibility, geometrical complexity, dimensional tolerance and surface finish of the casting, and the cost as the criteria for selection. Judgemental inconsistency of the decision maker in selecting the casting process is taken care by ensuring that the value of consistency ratio is below (0.1). A numerical example is presented to illustrate the effectiveness of the proposed methodology for selecting the suitable casting process.

1. Introduction

Selection of the most suitable casting process is an important part of casting design and manufacture. It is a complex problem that can not be readily solved using conventional statistical techniques alone. Their solution often relies on the use of empirical knowledge or expertise gained over many years. Different casting methods offer different technical and cost advantages, and selection of an appropriate method requires a sound understanding of the interactions between casting design constraints, required product properties, technical limitations of individual casting methods, available casting production tooling, and the overall cost determining factors. A tool that could identify the optimum method of manufacturing castings to meet specified requirements would therefore, be of immense importance to the designer, as well as to the manufacturer of castings.

This study proposes an efficient and simple solution based on well known technique, Analytic Hierarchy Process (AHP), to assess the best kind of casting method for a particular product. AHP was developed by Saaty

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(1980) and uses a hierarchical representation of factors (elements) influencing a decision to make pairwise comparisions among the factors in order to rank the available alternatives. In effect, it attempts to analyse the impacts of the alternatives or elements, at the lowest level, on the overall objective, or the focus of the hierarchy.

In the past two decades, AHP has been applied to numerous decision problems such as transportation problems, corporate planning problems, and problems concerned with marketing strategies, energy policy, project selection, budget allocation, and so on (Wilhelm and Parsaei 1996).

Luong (1998) used AHP for the selection of computer-integrated manufacturing technologies. Lin and Yang (1996) proposed the use of AHP in evaluation of machine selection. Cheung and Tsoi (1997) used AHP to prioritize team building factors for software project development. In this paper, AHP has been used to solve the problem of casting process selection for a given product. In this study the relationship among various selection criteria and casting processes will be specified through suitable weighting. The hierarchical structure of the proposed method allows the decision maker to compare different selection criteria more efficiently. The outcome of the proposed methodology is a best or optimum casting process, considering all the objectives, tangible and intangible criteria, and alternatives in a single inter-rated framework.

The paper is structured as follows: In section 2 a brief description of AHP and steps involved in the process are described. In section 3 the problem of casting process selection is addressed using AHP for a particular product and discussions on the factors affecting the above selection process. Solution procedure is given in section 4. In the final section, the computational results are given followed by the conclusion.

2. Analytic hierarchy process (AHP)

The Analytic Hierarchy Process was developed by Thomas Saaty in early 1970. The strength of the AHP approach lies in its ability to structure a complex, multi-attribute, multiperson and multiperiod problem hierarchically. In addition, it can also handle both qualitative and quantitative attributes. Pairwise comparisions of the elements (usually, alternatives and attributes) can be established using a scale indicating the strength with which one element dominates another with respect to a higher level element. This scaling process can be translated into priority weights (scores) for comparison of alternatives.

The general approach followed in AHP is to decompose the problem and to make pairwise comparisions of all the elements (attributes, alternatives) at a given level with respect to the related elements in the level just above. AHP consists of three stages of problem solving decompositions, comparative judgements and synthesis of priorities. The degree of preference of the decision maker in the choice for each pairwise comparison is quantified on a scale of 1 to 9, and these quantities are placed in a matrix.

The solution process primarily consists of three stages, however an optimal fourth stage can be considered to ensure the consistency in making pairwise comparisons.

These stages are as follows:

(1) Determination of the relative importance of the attributes and subattributes, if any
(2) Determination of the relative weight of each alternative with respect to each subattribute, if applicable
(3) Determination of the overall priority weight (score) of each alternative.

3. Casting process selection

Casting process selection depends upon many factors. The factors identified in his paper include alloy to be casted (material consideration), casting size and weight, geometrical features of the casting, dimensional tolerances and surface finish requirements, and cost per piece. These factors act as attributes in AHP and different casting processes considered serve as alternatives thus constituting the last level of hierarchy.

The factors affecting the casting process selection are as follows:

(1) Material suitability and flexibility: The casting process selected should be able to produce the given product with the specified material or with different materials. This is important when any change in material or its composition is to be made in order to improve or incorporate new properties in the casting.
(2) Geometrical complexity: It has significant effect on the casting process selection. This factor cannot be expressed in terms of a single parameter. It includes various parameters such as type and size of cores, minimum casting thickness etc.
(3) Dimensional accuracy and surface finish of the casting: The casting process selected should be able to meet the dimensional tolerances and surface finish requirements of the casting. Therefore, it is an important criteria for the comparison of various casting processes.

(4) Cost (per piece): Cost is a major factor which influences the casting process selection. A casting process involving higher cost is liable to be rejected on economic ground. The total production quantity also influences the overall cost.

3.1. *Proposed steps of casting process selection using AHP*

(i) Define the overall objective.
(ii) Define the structured hierarchy consisting of attributes (criteria for selection of casting processes for a given product) and alternatives (casting processes to be considered).
(iii) Determination of the priority weights of the attributes using pairwise comparison matrix and its consistency ratio.
(iv) Determination of priority weights of alternatives with respect to attributes (comparison of various casting processes with respect to the individual criteria for selection) and consistency ratio for each pairwise comparison matrix.
(v) Enumeration of overall priority weights for all the alternatives (casting processes) and consistency ratio for entire hierarchy.

The casting process having the highest priority weight is selected. Various steps of the casting process selection are described in figure 1.

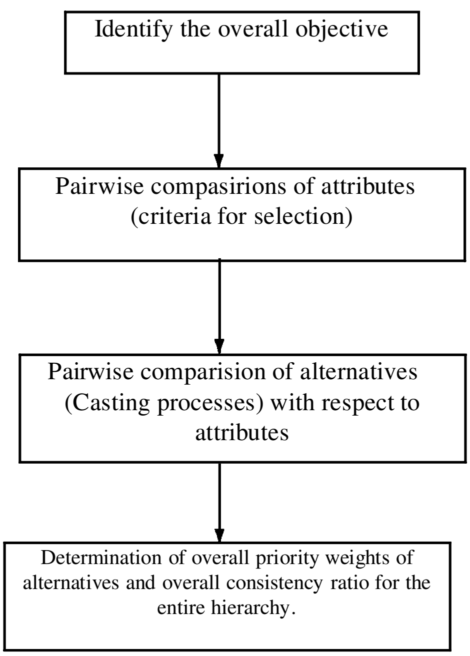

Figure 1. Process of casting process selection using AHP.

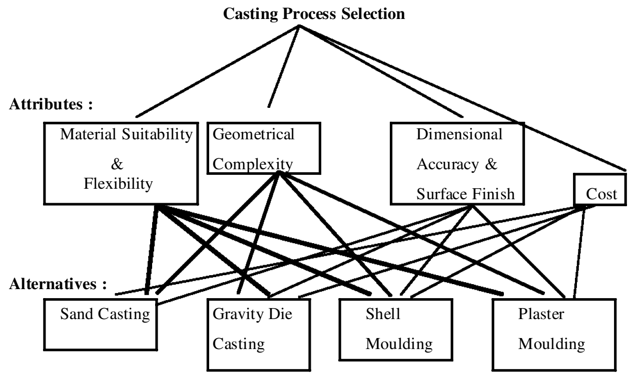

Figure 2. Decision hierarchy of casting process selection.

3.2. *A case study*

In this paper the problem of casting process selection is solved using AHP for a given product—Cam Carrier. This product is taken from the article by Er *et al.* (1996). The specifications of the product are as follows:

Alloy	aluminium
Casting weight	3.5 kg
Core requirement	yes
Minimum core diameter	30 mm
Minimum casting thickness	4 mm
Casting size	800 mm
Dimensional tolerance requirement	± 2.0 mm on the length
Surface finish	$< 6\ \mu$m

Four casting processes namely sand casting (SC), gravity-die casting (Gr Die), shell moulding (SM), and plaster moulding (PM) are considered for manufacturing the cam carrier and the most suitable process is to be selected using AHP. The decision hierarchy for the casting process selection is shown in figure 2.

4. Solution procedure

Step 1. The overall objective is to select the suitable casting process which can produce the given product cam carrier economically and efficiently and also meet the criteria pertaining to the product.

Step 2. The criteria for selection of the casting processes are:

(a) Material flexibility and suitability (*MF*)
(b) Geometrical complexity (*GC*)
(c) Dimensional accuracy and surface finish of the casting (*CA*)
(d) Cost (*C*)

Table 1. Values of random index (RI) for corresponding matrix order (n).

Matrix Order (n)	1	2	3	4	5	6	7	8
Random index (RI)	0	0	0.58	0.9	1.12	1.24	1.32	1.41
Matrix order (n)	9	10	11	12	13	14	15	—
Random index (RI)	1.45	1.49	1.51	1.48	1.56	1.57	1.59	—

These factors have already been discussed in section 3.

The priority weights for various attributes (criteria for selection) are obtained using pairwise comparison matrix. Here, equal weightage is given to all the criteria however this may depend upon customer's specification and requirements. The consistency index (CI) is evaluated and value of random index (RI) is obtained from table 1, thereafter consistency ratio $CR = CI/RI$ is determined and is found to be less than 0.1. So, the comparison is consistent. Detailed analysis and calculations associated with this step are given in table 2.

Step 3. The priority weights for various alternatives (casting processes considered) with respect to each of the attributes (criteria) are determined. Thus, various casting processes viz. sand casting, gravity die casting, shell moulding and plaster moulding are compared with each other considering the individual criteria for selection. Therefore, priority weights for various casting processes are obtained first with respect to material flexibility and suitability thereafter with respect to geometrical complexity and so on. In this way, four pairwise comparison matrices are achieved. The consistency ratios for each of the comparison matrices are determined and are found to be less than 0.1, so all the comparison matrices are consistent. Tables 3, 4, 5, 6 and 7 cover the detailed calculations related to this step.

Step 4. The last step involves the computation of overall priority weights for various alternatives. The casting process having the highest priority weight is then selected. Overall consistency ratio for entire hierarchy is determined and it is found that the overall consistency ratio (CR) is 0.0102 which is much less than 0.1. So the entire hierarchy is consistent. Enumeration of overall priority weights of each alternative is shown in table 8. Calculation related to determination of the overall consistency ratio is given as follows:

Table 2. Pair wise comparision of attributes. $CI = 0$, $RI = 0.9$, $CR = 0$.

	MF	*GC*	*CA*	*C*	Priority weights
MF	1	1	1	1	0.2500
GC	1	1	1	1	0.2500
CA	1	1	1	1	0.2500
C	1	1	1	1	0.2500

Table 3. Pairwise comparision of casting processes with respect to material suitability and flexibility. $CI = 0.0146$, $RI = 0.9$, $CR = 0.0163$.

	SC	Gr Die	SM	PM	Priority weights
SC	1	1/3	1/5	1/3	0.0789
Gr Die	3	1	1/3	1	0.2069
SM	5	3	1	3	0.5194
PM	3	1	1/3	1	0.2009

Table 4. Pairwise comparision of casting processes with respect to geometrical complexity. $CI = 0.0114$, $RI = 0.9$, $CR = 0.0126$.

	SC	Gr Die	SM	PM	Priority weights
SC	1	1/5	1/2	2	0.1263
Gr Die	5	1	3	6	0.5473
SM	2	1/3	1	3	0.2221
PM	1/2	1/6	1/3	1	0.0773

Table 5. Pairwise comparision of casting processes with respect to dimensional accuracy and surface finish of casting (CA), $CI = 0.0145$, $RI = 0.9$, $CR = 0.0161$.

	SC	Gr Die	SM	PM	Priority weights
SC	1	3	3	5	0.5193
Gr Die	1/3	1	1	3	0.2009
SM	1/3	1	1	3	0.2009
PM	1/5	1/3	1/3	1	0.0789

Table 6. Pairwise comparision of casting processes with respect to cost (per piece) (C). $CI = 0.0326$, $RI = 0.9$, $CR = 0.0362$.

	SC	Gr Die	SM	PM	Priority weights
SC	1	3	3	1/3	0.2225
Gr Die	1/3	1	1/2	1/6	0.0772
SM	1/3	2	1	1/4	0.1247
PM	3	6	4	1	0.5462

Table 7. Summary of all the pairwise comparison and resulting priority weights for alternatives with respect to each attribute.

	Attributes	Alternatives	Priority weights
(1)	Material suitability and flexibility (*MF*)	Sand casting	0.0789
		Gr die casting	0.2009
		Shell moulding	0.5194
		Plaster moulding	0.2009
(2)	Geometrical complexity and flexibility (*GC*)	Sand casting	0.1263
		Gr die casting	0.5743
		Shell moulding	0.2221
		Plaster moulding	0.0773
(3)	Dimensional accuracy and surface finish of the coating (*CA*)	Sand casting	0.5193
		Gr die casting	0.2009
		Shell moulding	0.2009
		Plaster moulding	0.0789
(4)	Cost (per piece) (*C*)	Sand casting	0.2225
		Gr die casting	0.0772
		Shell moulding	0.1247
		Plaster moulding	0.5462

The values are taken from table 2.

$$CI = 1 \times (0) + [0.25 \;\; 0.25 \;\; 0.25 \;\; 0.25]$$

$$\times \begin{array}{c} \begin{bmatrix} 0.0146 \\ 0.0114 \\ 0.0145 \\ 0.0326 \end{bmatrix} \end{array} \begin{array}{l} \longrightarrow \text{From table 3} \\ \longrightarrow \text{From table 4} \\ \longrightarrow \text{From table 5} \\ \longrightarrow \text{From table 6} \end{array}$$

$$= 0.0183$$

$$RI = 1 \times (0.9) + [0.25 \;\; 0.25 \;\; 0.25 \;\; 0.25]$$

$$\times \begin{array}{c} \begin{bmatrix} 0.9 \\ 0.9 \\ 0.9 \\ 0.9 \end{bmatrix} \end{array} \begin{array}{l} \longrightarrow \text{From table 3} \\ \longrightarrow \text{From table 4} \\ \longrightarrow \text{From table 5} \\ \longrightarrow \text{From table 6} \end{array}$$

$$= 1.8$$

$$CR = CI/RI = 0.0183/1.8 = 0.0102$$

$$\text{Since}, CR < 0.1, \text{ the entire hierarchy is consistent}$$

In the present case shell moulding has highest priority and hence selected. However the priority weight of gravity die casting is quite close to that of shell moulding and can also be selected. Thus, the casting processes selected are: (a) shell moulding, (b) gravity die casting.

Table 8. Enumeration of overall priority weights of each alternatives.

	AF	*GC*	*CA*	*C*	Priority weights
Attribute weights	0.25	0.25	0.25	0.25	
Alternatives					
SC	0.0789	0.1263	0.5193	0.2225	**0.2368**
Gr Die	0.2009	0.5743	0.2009	0.0772	**0.2633**
SM	0.5194	0.2221	0.2009	0.1247	**0.2668**
PM	0.2009	0.0773	0.0789	0.5462	**0.2258**

5. Conclusion

In the metal processing industry, casting is the most popular means for achieving a desired shape (net shape) in a single step. The casting process selection needs experienced technicians and it is an iterative task between casting designers and foundry experts. There is a lot of wastage of resources and time during the design-manufacturing cycle when a part is being engineered. Initial estimates of manufacturability are valuable to the designer as it avoids costly redesign efforts. There are several casting processes which can be used to manufacture a product. It is therefore desirable to select a casting process which should satisfy the following criteria:

(1) Material suitability and flexibility
(2) Geometrical complexity
(3) Dimensional accuracy and surface finish requirements
(4) Cost.

In this paper, the analytic hierarchy process is used for casting process selection for a given product cam carrier. This method provides a comprehensive framework for solving the problem of casting process selection. It enables the engineer to cope with the intuitive, the rational, and irrational factors, all at the same time. This method can be regarded as a factor weighting approach providing a formal weighting mechanism to achieve a higher level of consistency.

The proposed selection methodology was found suitable not only for the product Cam carrier but also for other products. The preference numbers in the pairwise comparison of attributes and alternatives are given keeping in mind the product specifications. ASM (1992) and ASM (1967) and Conserva *et al.* (1992) have been consulted for this purpose. In actual application, the future user can devise more hierarchies and consider the problem in greater details. The advantages of using AHP, in the casting process selection are listed below:

(i) The casting process selection by AHP takes into consideration both the quantitative and qualitative factors.

(ii) AHP can display complicated selection factor in simple concepts of hierarchy, which can be accepted easily by a decision maker.

(iii) AHP goes through a dynamic group discussion and denotes the priority of a decision with certain numerical values. It does not involve statistics or probability theory, thus giving the user a better sense of reality.

(iv) AHP involves group discussion and dynamic adjustment to finally achieve the consensus. The evaluation is conducted by the participating experts who decide jointly on the parameters for pairwise comparison. It is thus more of a qualitative analysis.

(v) Non-quantified elements, after group evaluation and a mathematical process can be quantified by numerical values to indicate a decision's priority. A decision maker can reach the choice of casting process in a very short time without resorting to precise data.

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