JJMIE

Volume 2, Number 1, Mar. 2008
ISSN 1995-6665
Pages 45 - 52

Jordan Journal of Mechanical and Industrial Engineering

Selection of Metal Casting Processes: A Fuzzy Approach

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Abstract

Choosing the right manufacturing process for making a component is an important consideration at the early stages of design. In metal casting process, there are over forty different processes with different capabilities. A designer can benefit from knowing the manufacturing process alternatives available to him. Inaccurate process selection can lead to financial losses and market share erosion. In this paper, an automated advisory casting process selection system is designed. The designed system named (CACPS**)** the objectives of this system to solve the problems of process selection and evaluation **(**PS&E**)** activities. The designed system depends on methodology for selection and evaluation of process that based on a number of user-specified criteria or requirements. The decision model enables the representation of the designer's preferences over the decision factors it is based on weighted property index (W.P.I**)** algorithms to determine the relative importance of each criterion. A compatibility rating between product profile requirements and the alternatives stored in the database for each decision criteria are generation using fuzzy logic **(**F.L**)** methodology. These requirements were matched with the capabilities of each process the compatibility ratings are aggregated into single rating of that alternative's compatibility. A ranked set of compatible alternative processes is out put by the system. This approach has advantages over the existing systems, which are equipped with a decision module or a database.

Keywords: Metal Casting; Process Selection; Fuzzy logic; Design for Manufacturing; and Decision-Making;

1. Introduction

The designer needs a systematic and rousts way of evaluating the available options and identifying which might be the best. Manufacturing process selection is the task of choosing a method for transforming a set of material into a given shape using one or more processes. The best process is normally considered to be the economic, subject to it meeting the technical constraints. [1]. The material and manufacturing process selection problem is a multi-attribute decision-making problem. These decisions are made during the preliminary design stages in an environment characterized by and uncertain requirements, parameters, and relationships. Material and process selection (MPS) decisions occur before design for manufacturing (DFM) can begin [2]. 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 [3].

In this paper a development of an advisory system called Computer Aided Casting Process Selection (CAMS) that aids the designer in decision-making (D.M). The objectives of the designed system are to evaluating and selecting the optimal and alternatives process that satisfied the design specifications. The (CACPS) system indicate to the designer the compatibility degree between the selected processes to all the specified criteria and capabilities then these selected processes are ranked according to its compatibility's.

2. Classification of Manufacturing Processes

For the purpose of selection, a rigorous definition of a process is not required. It is sufficient to consider it manufacturing step that alters the characteristics of one or more materials in some way in order to produce or modify a component or components. By this measure, a large number of processes exist at all levels of complexity and scale. To help compare the various processes for selection purposes it is helpful to find some means of classification them [4]. A process taking a broad view is a method for shaping or finishing or joining a material as shown in Figure 1. The kingdom of processes contains broad families such as casting, deformation, molding, machining, etc. each family contains many classes; casting contains sand –casting, die-casting, and investment casting, for

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instance. These in turn have many members; there are many variants of sand –casting, some specialized to give greater precision, other modified to allow exceptional size, still others adapted to deal with specific materials [5].

Kingdom	Family	Class	Member	Attribute
Processes…....>>	Deformation Molding Powder Casting………..…>> Machining Composite Deposition Fabrication Rapid Prototyping	Investment Full Mould Shell Sand……………>> Die Squeeze Ceramic Mould Permanent Mould	Sand 1 Sand 2 Sand 3……>> Sand 4 Sand 5	Material Size Range Shape Min Section Precision Finish Quality Cost Eco- Impact

Figure 1: A schematic illustrating the taxonomy of the manufacturing processes [5].

3. Fuzzy Logic Methodology

Fuzzy logic (F.L.) is one of the elements of artificial intelligence that is gaining in 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, hence the term fuzzy [6]. 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.

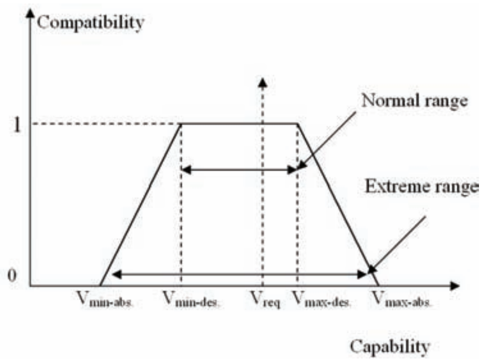

Figure 2: Fuzzy mapping of process capability [7].

Where:

$V_{min\text{-}abs}$	= the absolute minimum value
$V_{min\text{-}des}$	= the desire minimum value
V_{req}	= the requirement value
$V_{max\text{-}des}$	= the absolute maximum value
$V_{max\text{-}abs}$	= the desire maximum value

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

The compatibility $P(x_i)$ for a value x_i of an attribute i can be calculated by using the following equations [7]:

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

$$P(x_i) = (x_I - V_{min\text{-}abs}) / (V_{min\text{-}des} - V_{min\text{-}abs}) \quad \text{if } V_{min\text{-}abs} < x_i < V_{min\text{-}des} \qquad (2)$$

$$P(x_i) = (V_{max\text{-}abs} - x_i) / (V_{max\text{-}abs} - V_{max\text{-}des}) \quad \text{if } V_{max\text{-}des} < x_i < V_{max\text{-}abs} \qquad (3)$$

$$P(x_i) = 0 \quad \text{if } x_i < V_{min\text{-}abs}, \text{ or } x_i > V_{max\text{-}abs} \qquad (4)$$

Fuzzy technologies and devices can be applied successfully in areas such as robotics and motion control, evaluation of design alternatives, decision making, and the design of intelligent systems, in materials selection involving multi-criteria, image processing and machine vision [6].

4. Casting Process Selection

Casting process selection influences other major decisions such as the type of tooling, process parameters, and extent of machining, heat treatment, and quality control procedures. These in turn affect the economic quantity, tooling, labor costs, and lead time forecasting. Casting process combination is characterized by different range of geometric features that can be produced (minimum section thickness, minimum core size, etc), achievable quality (surface finish, porosity…etc) and production parameters (sample lead-time, economic lot size…etc).

To select a feasible casting process, the part requirements or attributes with the corresponding capabilities of the process must be considered. For example if an aluminum alloy sand cast part has a minimum wall thickness of 3.75mm, in comparison to the process capability range of 3.5 to 4.5 mm, then the part and process are compatible with respect to minimum wall thickness criterion. Similarly, other requirements can be checked and other process that satisfies all the requirements of the part is considered as a feasible process.

The above approach is simple and easy to apply in order to select a set of feasible processes. However, the approach does not capture the real situation of process capabilities, and secondly, it is difficult to compare two different feasible processes with respect to a given part in a quantitative manner. For example, it is difficult to accept that a wall thickness of 3.49mm would imply complete incompatibility where as 3.51 mm would imply complete compatibility. To overcome this difficulty and reflect real-life situations more realistically, fuzzy logic (F.L) is applied. In this approach an introduction of two, more limits: minimum desirable and maximum desirable values of process characteristics. Thus if take minimum desirable value of minimum wall thickness 4 mm then a value of 3.75 indicates 50% compatibility with respect to the wall thickness criterion.

For example, if surface finish capability of sand casting process is taken as (6, 12, 25 and 50 µm) indicating $V_{min-abs}$, $V_{min-des}$, $V_{max-des}$ and $V_{max-abs}$ respectively, the part process compatibility for surface finish criterion will be zero (i.e.-applying equation 8). Taking into account that the requirement falls outside even the absolute range

If an alternative process such as investment casting with four limits as (0.8, 1.6, 3.2, and 6.4 µm), then the part process compatibility will be 0.75 (applying equation 6) implying that it would be possible to achieve the requirement, but the process control has to be tighter. The other way to achieve part-process compatibility would be to modify the surface finish requirement of the part to more than six µm so that it falls within the range of the limits of sand casting. The overall compatibility of a part and process can be computed by taking a weighted average of the part-process compatibility with respect to different criteria.

Four limits for each criterion is considered because in practice the process characteristics also depend on the equipment, manpower, skill, quality management practices and other company decisions. This can be captured in a band of values for each process capability characteristics.

5. Assignment of Compatibility to Selected Casting Process

Usually at the beginning of the conceptual design, designers are given functional requirements and relevant business requirements such as time to market, likely production volume, and total production quantity. During the conceptual design stage designers identify critical design requirements such as size, material requirements, gross shape, form features, tolerances, surface finish requirements…etc. at this stage there exist sufficient information to start preliminary process planning (e.g. material and process selection). A selection of optimal and alternative casting process with compatible alloy that can meet these critical requirements with the minimum cost is considered.

5.1. Problem Statement

The technique is dependent on the selection consist of two phases or steps these are Screening phase and Ranking phase. They can be summarized as the following:

5.1.1. Screening Phase

This phase consists of the following criterion.

5.1.1.1. Type of Materials:

Materials are treated as go-no-go decision and any casting process that cannot cast the material is eliminated. As example die-casting cannot cast steel alloys or cast-iron successfully. In the designed (CACPS) system, aluminum and steel alloys are considered in database materials, with about 95 alloys with different conditions and chemical composition.

5.1.1.2. Shapes:

Shapes also are treated as go-no-go decision and any casting process cannot cast the required shape is eliminated. As example, centrifugal casting can cast only shapes that are cylindrical parts or shapes that are symmetrical about axis of rotations. In the designed (CACPS) system there are total of seven shapes are considered dependent:

1. Planar
2. Surface of revolution
3. Prismatic
4. Constant cross section
5. Thin wall
6. Free from drape
7. Free from general

5.1.1.3. The Required Quantity:

The quantity required affects process selection to a considerable extent. The cost of a process has break-even point over the economic production quantities. The die design and fabrication costs take a significant percentage of the production cost of the part. This percentage differs from process to process. For example the die design and fabrication cost for die-casting differ from the cost of mold in sand casting because the die is used to produce thousands of parts, but a preparation of one mold for each part produce in sand casting. Therefore, the number of the required parts must be economical to cover the costs of design and fabrication of the mold [8]. These are differing from process to process as illustrated in Table 1.

Table 1: Storing economical region for some Casting Processes.

Process	Lower quantity	Upper quantity
Shell	100	No upper limit
Gravity die	100	No upper limit
Pressure die	1000	No upper limit
Lost foam	5000	20000

Therefore, any number of required parts does not fall in the economical region of the process will be eliminated. For example, the economical region for die-casting is above 1000 units and the economical region for sand casting is above 1. If the user wants to produce 500 castings then the sand casting will be economical and the die-casting will be uneconomical method.

5.1.2. Screening and Ranking Phase

This phase contains the specification requirements, which consist of four main groups of criterion, some of these criterions working as screening phase and others working as ranking phase these are shown in Table 2.

Table 2: : Specification requirements

Geometric Attributes	**Economic Considerations**
Size	Tooling cost
Weight	Cost per unit
Section Thickness	Relative cost in quantity
Hole Size	Relative cost in small No.
Tolerance	Labor cost
Quality Requirements	**Production Requirements**
Surface Finish	Production Volume
Mechanical Properties	Production Rate
Complexity	Flexibility
Porosity	Lead time

5.1.2.1. Geometric Attributes

Size:Size of the casting part is the maximum dimensions in length in millimeter units. The size of the candidate designs limits the selection of the casting process. For example size capability of die casting is limited to 500 mm (i.e. size larger than 500 mm cannot be casted by using die casting method) but the capability to sand casting to cast part unlimited in size. Therefore, any size does not fall within the capability of the process will be eliminated. To clear the compatibility of the different processes to cast the required size, four limits are specified as it is shown in Table 3. below which specifies some of casting method with different limits in size.

Table 3: Size limits for some casting processes [9].

Process	$V_{min\text{-}abs.}$ (mm)	$V_{min\text{-}des.}$ (mm)	$V_{max\text{-}des.}$ (mm)	$V_{max\text{-}abs.}$ (mm)
Sand	5	10	Unlimited	unlimited
plaster	5	10	10	50
Die	5	10	450	500
Vacuum	10	20	1500	20000

Part Weight:Each casting process has a range of casting weights that it can produce under normal conditions. While handling part weights, it may be incorrect to simply. Consider the upper and lower bound of each process regarding the maximum and minimum weight that can be casted. With the increasing pace of technology improvements, larger parts are being casted with processes earlier kwon for casting only parts with a small or medium weight. However, it is still true that every casting process is most advantageous over a certain weight range. Outside this range, the process will be infeasible. The designed consider this by defining the typical and extreme limits for each casting process as show in Table 4.

Section Thickness:When evaluating the feasibility of casting processes to manufacture a given section thickness, the following uncertainties are encountered [11]: The capabilities to manufacture thin sections vary from foundry to foundry, even with a given casting process. For example, some sand foundries may be able to manufacture thinner sections than others may.

The ability to make a thin wall section also depends on the metal to be casted and the foundry capabilities. As example investment, castings can cast thin walls ranges from 0.22 mm. to 0.98 mm. These two are internally defined as lower thin section and upper thin section. To calculate the compatibility for each process we specify four limits to section thickness criterion in Table 5.

Table 4: Part weight limits for some casting process [10].

Process	$V_{min\text{-}abs.}$ (kg)	$V_{min\text{-}des}$ (kg)	$V_{max\text{-}des}$ (kg)	$V_{max\text{-}abs.}$ (kg)
1- Shell	0.03	0.05	50	100
2-Plaster	Very small	Small	30	50
3-Squeeze	Very small	small	10	15
4-Investment	0.001	0.005	90	100

Table 5: Limits for section thickness criterion [11].

Process	$V_{min\text{-}abs.}$ (mm)	$V_{min\text{-}des}$ (mm)	$V_{max\text{-}des}$ (mm)	$V_{max\text{-}abs}$ (mm)
Die casting	0.5	1	8	12

***Hole Size*:**Hole size is the minimum or maximum diameter for hole that can be made in the casted part. Casting processes are different capabilities in making the hole size from process to process. For example in the sand casting the hole size depend on the core size, while other process don't uses core. This has differences in hole size such as lost foam casting. To calculate the compatibility for each process by using fuzzy logic technique four limits are required for applying (F.L).

***Tolerance*:** Tolerance is defined as the acceptable variation to the ideal or nominal dimension. These are described by the system of geometric dimensioning and tolerance (GD&T) and are based on the ASME standard 1994. Tighter tolerances than normal will lead to increased cost and lead-time. Generally, tolerances depend on the geometry of the part. However, foundries generally state the tolerances that can be obtained by using its processes and provide guidelines to the designer to work towards these tolerances. These tolerances are called *as cast* tolerances because they are obtained without any additional processes such as machining or using additional equipment. Table 6. specify four limits for tolerances to calculate process compatibility.

Table 6: Limits for dimensional tolerance criterion [9].

Process	$V_{min\text{-}abs.}$ (mm)	$V_{min\text{-}des}$ (mm)	$V_{max\text{-}des}$ (mm)	$V_{max\text{-}abs}$ (mm)
Sand casting	0.55	0.65	6	6.5

Casting tolerances greatly depend on both the metal and the process. (CAPP-CT) uses a database of casting tolerance to suggest an appropriate casting process. Tighter linear tolerance than available in the chosen casting process can be obtained by secondary processes such as machining. For example in investment casting there are several ways to obtain a tolerance tighter than what can be commonly obtained. Some of the methods displayed on the investment casting foundry are:

1. Part redesign including addition of tie bars, ribs, and gussets to certain shapes.
2. Tuning of wax injection tooling after the first sample to meet the nominal dimensions.
3. Straightening after casting.
4. Gauging and hand fitting.
5. Machining.
6. Other secondary operations.

5.1.2.2. Quality Requirements

Surface Finish:The surface finish of a part determines its appearance affects the assembly of the part with other parts and may determine its resistance to corrosion. The surface roughness of a part must be specified and controlled because of its influence on fatigue failure, friction, wear, and assembly with other parts. In metal casting processes, each casting process has the ability to produce surface finish different to other process and this depending on the molding material used. The (CACPS) system considers only as cast surface finishes. It does not favor processes that need secondary processes that can be used to give a better surface finish. For example investment casting typically provide as cast surface finish that vary from 0.8 µm to 6.4µm. Process overlap with regard to finish that can be obtained from them. Suppose the designer wishes to obtain an as cast finish of 1.5 µm. neglecting other considerations such as weight, tolerance etc. and considering surface finish, the designer is faced with several processes which can give the desired finish such as pressure die casting, investment casting, plaster casting, shell casting, and ceramic casting. To determine the degree of compatibility for each process, four limits are considered as illustrated in Table 7. below:

Table 7: Limits for surface finish criterion [12].

Process	$V_{min\text{-}abs.}$ (µm)	$V_{min\text{-}des}$ (µm)	$V_{max\text{-}des}$ (µm)	$V_{max\text{-}abs}$ (µm)
Sand casting	6	12	25	50
shell casting	1	3	6	8
plaster casting	0.75	1.3	2.5	4
Investment casting	0.8	1.6	3.2	6.4

The calculations of compatibility for each process in Table 10. to surface finish criterion by using fuzzy logic approach as in the following:

1. Sand casting process compatibility P (1.5) to produce finish (1.5 µm) is 0 by applying eq. [$P(x_i) = 0$ if $x_i < V_{min\text{-}abs}$] (i.e. this process incapable to produce this finish) . This case be can represent in figure 3.
2. Shell casting process compatibility P (1.5) to produce finish 1.5 µm is 25 % , which can be represented in figure (7). $P(x_i) = (x_I – V_{min\text{-}abs}) / (V_{min\text{-}des} - V_{min\text{-}abs})$ if $V_{min\text{-}abs} < x_i < V_{min\text{-}des}$.
   $P(1.5) = (1.5 –1) / (3- 1) = 0.5 /2 = 0.25$
3. Plaster casting process compatibility P (1.5) to produce finish 1.5 µm is 100 % (fully compatible). Figure 5. show this case.
   $P(x_i) = 1$ if $V_{min\text{-}des} < x_i < V_{max\text{-}des}$ …(5)
   $P(1.5) = 1$ because $1.3 < 1.5 < 2.5$

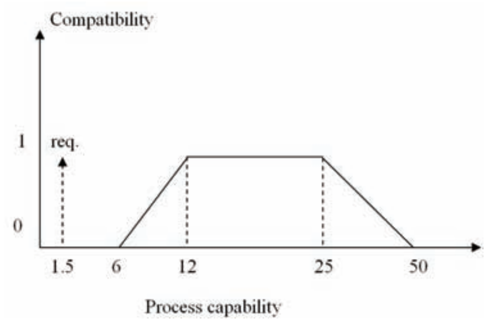

Figure 3: Sand casting surface finish capability

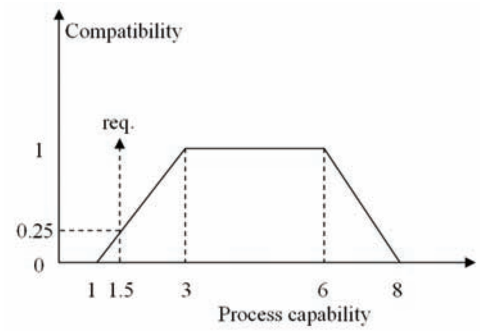

Figure 4: Shell casting surface finish capability

4. Investment casting process compatibility P (1.5) to produce finish (1.5 µm) is 87.5 % as shown in figure (6).
   $P(x_i) = (x_I – V_{min\text{-}abs}) / (V_{min\text{-}des} - V_{min\text{-}abs})$
   if $V_{min\text{-}abs} < x_i < V_{min\text{-}des}$ (-6)
   $P(1.5) = (1.5 – 0.8) / (1.6 – 0.8) = 0.7 / 0.8 = 0.875$

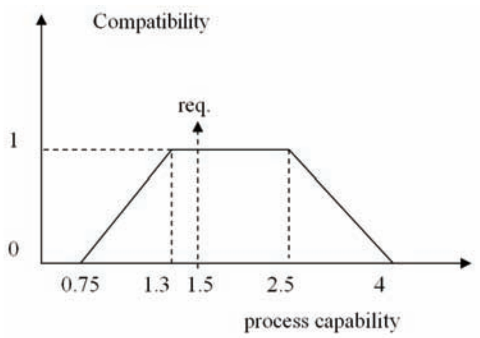

Figure 5: Plaster casting surface finish capability

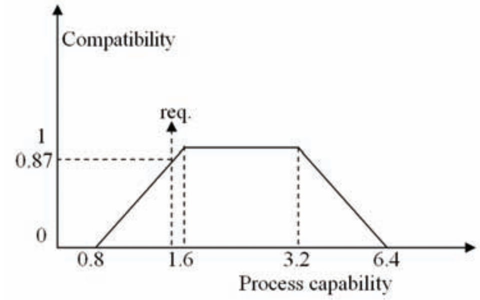

Figure 6: Investment casting surface finishes capability

Then it can be concluded from the previous calculations the process that preferred to produce surface finish (1.5 µm) is the plaster casting which is considered as the optimal process for this criterion.

Complexity: The complexity of a part refers to its shape, size, and number of feature that it contains. For geometrically simple parts such as bolt or straight shafts, the most economical method of manufacturing is relatively apparent. As the shape of part become more complex, selection of suitable process becomes important. Casting processes are more suitable to the intricate and nonsymmetrical shapes. In addition, the capabilities of each process are different to other process such as sand casting used to produce small and large intricate shapes, while die-casting is used to produce small and simple shapes.

Mechanical Properties: Mechanical properties such as strength and hardness have the biggest influence on part size and shape but they also have bearings on the process choose. The type of casting process selected is affected to the quality of mechanical properties of the part such as plaster casting has poor mechanical properties but squeeze casting has excellent mechanical properties. Then if the mechanical properties are important criterion then a suitable casting process is chosen. Table 8. shows some of casting process with mechanical properties that is produced from it.

Table 8: Casting methods with mechanical properties [12].

Casting process	Mechanical property
1- Sand	Good
2- Shell	Good
3- Plaster	Poor
4- Pressure die	Very good
5- Squeeze	Excellent

Porosity: Defects may be internal to the part or concentrated mainly at the surface. Porosity is one of the internal defect in the casting part, the degree of porosity differ from casting process to another. Table (9) below illustrates some of casting processes and their degree of porosity.

Table 9: Casting process and porosity [13].

Casting process	Porosity (Quality)
1- Sand	Bad
2- Investment	Medium
3- Squeeze	Best
4- Centrifugal	Good to best

5.1.2.3. Economic Consideration

Tooling includes pattern and core box for sand casting, and metal mould for die-casting as well as investment casting (for wax patterns). Their cost is driven by the material and manufacturing (mainly machining) of the tooling. The material is decided depending on the tool life required, which is in turn influenced by the order quantity. The tool manufacturing cost is driven by its geometric complexity. Then the tooling costs of casting processes are different from process to process. Table 10. illustrated some of processes with their cost considerations such as tooling cost, cost per unit, relative cost in quantity, relative cost in small number, and labor cost are different from process to process.

Table 10: Cost considerations for casting method [14, 15].

Casting process	Tooling Cost	Cost per	Cost in Unit	Cost in small Quantity	Labor Cost No.
Sand casting	Low	Low	Low	Very Low	Low-Medium
Lost foam Casting	High	Medium	Low	High	High
pressure die Casting	High-Highest	Highest	Very Low	Highest	Low

5.1.2.4. Production Considerations

Production Rate: Each casting process has its own possible production rate or an economical range of production rates although individual rates will differ depending on process capability. For example die casting can produce parts at a rate of thousands per hour while the cycle time for sand casting is typically take long time to produce limited parts than die casting. Table 11. illustrates some of casting process with their production rates.

Table 11: Production rates for some casting process [12].

Casting process	Production rate (unit / hour)
Sand casting	(50-150)
Plaster casting	(1-50)
Die casting	(> 1000)

Lead Time: Lead-time is the time required to preparation and setup tooling and equipment that needed for casting process before production. Each casting process required tools and equipment's differ to other process and these depending on the method used. Therefore, the lead-time is different from process to process such as lead-time for preparation and setup die-casting is longer than lead-time required to sand casting. Then lead-time also affects in selection of a process in Table 12. show some casting processes with the required lead-time.

Table 12: Casting process lead-time [13].

Casting process	Lead-time (week)
Sand casting	(1-4)
Die casting	(12 – 16)
Investment casting	(8-12)

Process Flexibility: Process flexibility is the capability of process to change the design of the casting part. Some of casting processes have a high flexibility to cast different parts such as reusable mold while other processes have limited flexibility to cast different parts such as permanent mold. Therefore, process flexibility affected in selection of casting process. Table (13) illustrates the degree of flexibility of some casting processes.

Table 13: Degree of flexibility for some casting processes [12].

Casting Process	Degree of Flexibility
Sand casting	Excellent
Shell casting	Fair
Lost Foam	Good
Die casting	Poor

6. Methodology of Process Selection

The process selection module assesses the degree of compatibility between a process alternative and the product requirements. process 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 compatible for each process. In this paper we selected twelve casting process as a database in material selection database. 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 mention in previous section any alloy that have values out of the range of absolutely limits will be eliminated. The (CACPS) has been designed by using visual basic language version (6) which links with Microsoft Access system in building database for casting process capabilities. The system interacts with user or designer to specify the specifications of required criteria. Then the selected process that satisfies design requirements will inter to the next step of determining the optimal casting process and this process can be determined according to the degree of compatibility between product specifications and the capability of process

This approach is differing from the existing approaches in determining the values of compatibilities for both optimal and alternatives selection processes, and this does not existing in the other approaches. Then this method is more accrued from the other methods. The limitation of this approach is, when there is no result that can meet the initial requirement, the system does not suggest to the user how can change the input value to have results.

7. Case Study: Selection Process for Elevator Control Quadrant

The elevator control quadrant component is a part of control system for the wing-elevator of a commercial aircraft. It is to be made of a light alloy (aluminum) [14]. The required specifications as in the following:

1. Metal Type: Aluminum
2. Weight: 5kg
3. Section Thickness: 5 mm
4. Surface finish: 10 μ m
5. Tolerance: 0.5 mm

To select the optimum process for manufacturing the elevator control quadrant part that satisfied the above requirements the inputted criterion to the (CACPS) system as in figure 7.

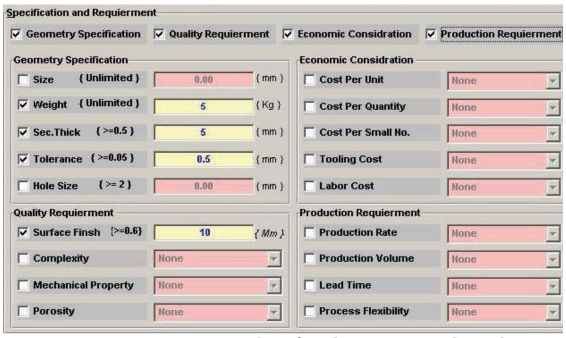

Figure 7: Input criterion window for elevator control quadrant

The results that are obtained from applying (CACPS) system can be illustrated in Figure 8.

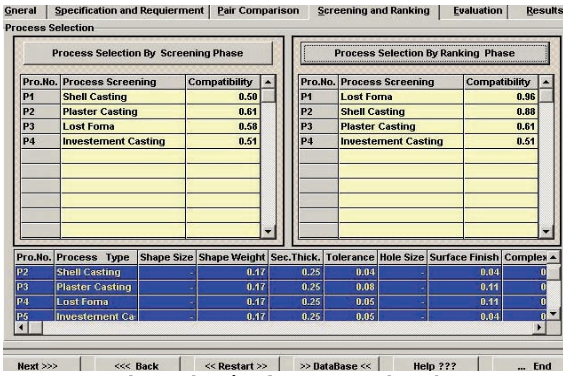

Figure 8: Results window for elevator control quadrant

From the above window, the system selected four processes. All the selected processes (Lost foam, shell, plaster, and investment casting with degree of computability's 96%, 88%, 61%, and 51% respectively) are satisfied the requirements specifications and these results compatible with the selected processes in reference [14].

8. Conclusions

In this paper fuzzy logic (F.L) technique used successfully for decision making in conceptual design phase, to select casting process. The (F.L) technique is more suitable in selection methodology for casting process because the capability of each process different from foundry to another. Also in practice, the process characteristics also depend on the equipment, labor skills, quality management practices and other company-dependent factors. This can be captured in a band of values for each process capability characteristic. then (F.L) used to calculate the degree of compatibility between requirements and process capability. 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 criterion. The system capable of drawing in diagrams for compatibility degree for both selected process and with each criterion its clear the real representation of capability for each process to the satisfied requirements. Hence the designer can benefits from these diagrams in decision making for selecting the most preferred to him. The alternatives selected processes enable the designer to make some of modifications in the design stage until reach to satisfaction the requirements of design.

If the product specification required high accuracy or surfaces finish more than the capabilities of some casting process and the part must be produced by (sand casting as example) secondary operations (such as machining) must be made on casting part to ensure these specification. The system can be extending to involve other materials and other manufacturing processes.

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