WEB-BASED CASTING PROCESS SELECTION AND PRELIMINARY PROCESS PLANNING

Dissertation

Submitted in the partial fulfillment of the requirements for
the award of the degree of

MASTER OF TECHNOLOGY

By

BORADE NIKET P.
(Roll No. 00310405)

Under the guidance of

PROF. B.RAVI

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY
JANUARY 2002

Dissertation Approval sheet

Dissertation entitled *"Web-based casting process selection and preliminary process planning"* by Borade Niket P. (Roll No. 00310405) is approved for the degree of Master of Technology.

Guide:

Examiners:

---------------------------(Internal)

---------------------------(External)

Chairman:

Date:

TABLE OF CONTENTS

Abstract

Casting technology offers a widest variety of routes to cast a product. An accurate and early decision about the selection of a casting process is important for implementing concurrent engineering approach to reduce lead time and hence cost. This is a complex, multi-criteria decision making problem. Hence a casting process selection and planning system is developed to aid casting product designer. There are different approaches to solve the problem of casting process selection and planning. The various criteria that influence the casting process selection are identified and on the basis of this a material specific database of casting processes is created. The casting process is systematically divided into a number of steps required to take to cast a product. This forms the basis for creating a casting process planning database. The casting process database and casting process planning database are stored by using self-describing XML-compatible Casting Data Markup Language (CDML). The system is implemented by using WebICE (Web-based Integrated Casting Engineering) framework. The database can be easily viewed and updated. User input in terms of casting product requirements is given to the system. Critical criteria that affect the casting process selection namely casting weight, size, minimum wall thickness, minimum core hole diameter and delivery quantity are used to compare the corresponding criteria values from the database to screen the database and enlist feasible processes. The CDML tree can be easily browsed to display the process planning steps. The system is web enabled to make it easily accessible to users at lowest cost.

LIST OF FIGURES

List of Tables

CHAPTER 1

INTRODUCTION

1.1 Metal Casting Process

A casting may be defined as a “metal object obtained by allowing molten metal to solidify in a mold”, the shape of the object being determined by the shape of the mold cavity.

Metal casting is one of the oldest industries in human society. The art of foundry is about 7000 years old. The strength of the foundry industry rests on the fundamental nature of casting as a process for causing metals to take shapes that will serve the needs of man. Practically all metal is initially cast. Certain advantages are inherent to the metal-casting process. These may form the basis for choosing casting as a process to be preferred over other shaping processes in a particular case [Heine, 1995]. Some of the reasons for the wide use of the casting process are listed below.

1. The most intricate of shapes, both internal and external may be cast.
2. Because of their metallurgical nature, some metals can only be cast to shape since they cannot be hot-worked into bars, rods, plates or other shapes from ingot form as a preliminary to other processing.
3. Objects may be cast in a single piece that would otherwise require construction in several pieces and subsequent assembly.
4. Metal casting is highly adaptable to the requirements of mass production.
5. Extremely large, heavy metal objects may be cast when they would be difficult or economically impossible to produce otherwise.
6. Some engineering properties are obtained more favorably in cast metals, like uniform properties from a directional standpoint, strength and lightness in certain light metal alloys that can be produced only as castings and good bearing qualities. In general, a wide range of alloy composition and properties is produced in cast form.

7. A decided economic advantage exists as a result of any one or a combination of the above points.

Castings are used in extremely wide and diverse fields. They range in size from a few grams to more than 100 tons. In function they range from decorators trinkets to critical bridge structure parts. Some of the disadvantages associated with the casting process are high energy consumption for melting the metal, large lead time for new product and unpleasant working conditions.

1.2 Need for Process Selection

There is increasing realization in the manufacturing industry that increasing manufacturing efficiency and reducing costs does not only accrue from investment in automation and advanced machine tools. Selecting the most appropriate manufacturing process in terms of technological feasibility and cost for a component design is one of the most important decision making tasks [Allen, 1990]. To ensure that most appropriate manufacturing process is selected, the product designer must be aware of the manufacturing route by which a component is produced. There are many manufacturing processes available and selection of the most appropriate process depends on a large number of factors. This is a complex problem and requires a considerable manufacturing expertise and there is a lack of systematic techniques to assist the designer in this area. The problem becomes more acute in the casting domain, since it offers a very wide variety of routes to make a product.

Since there are a large number of casting processes available to cast a product, the casting product designer generally has limited knowledge of casting processes and he often has to consult the casting process experts. This leads to the increase in the lead time and hence the cost. The design of a product and its fabrication processes must be simultaneously pursued to reduce the lead time. Some of the most important decisions, those with the greatest effect on overall cost, are made during engineering design. It is indicated that more than 70 % of a products cost is determined during the design stages [Giachetti, 1988]. This realization leads to an interest in concurrent engineering, which involves early consideration of manufacturing in the product development process to reduce lead time, production cost, and quality problems. This is called design for manufacturing (DFM) and is typically conducted with a particular manufacturing process in mind, in which, the decision regarding the selection of materials and manufacturing processes is very critical [Bralla, 1988]. The greatest opportunity in design for manufacture occurs at the initial design stage because at this stage the modifications in the product design are easy and they costs less [Allen, 1990]. This is illustrated in the Figure 1.1.

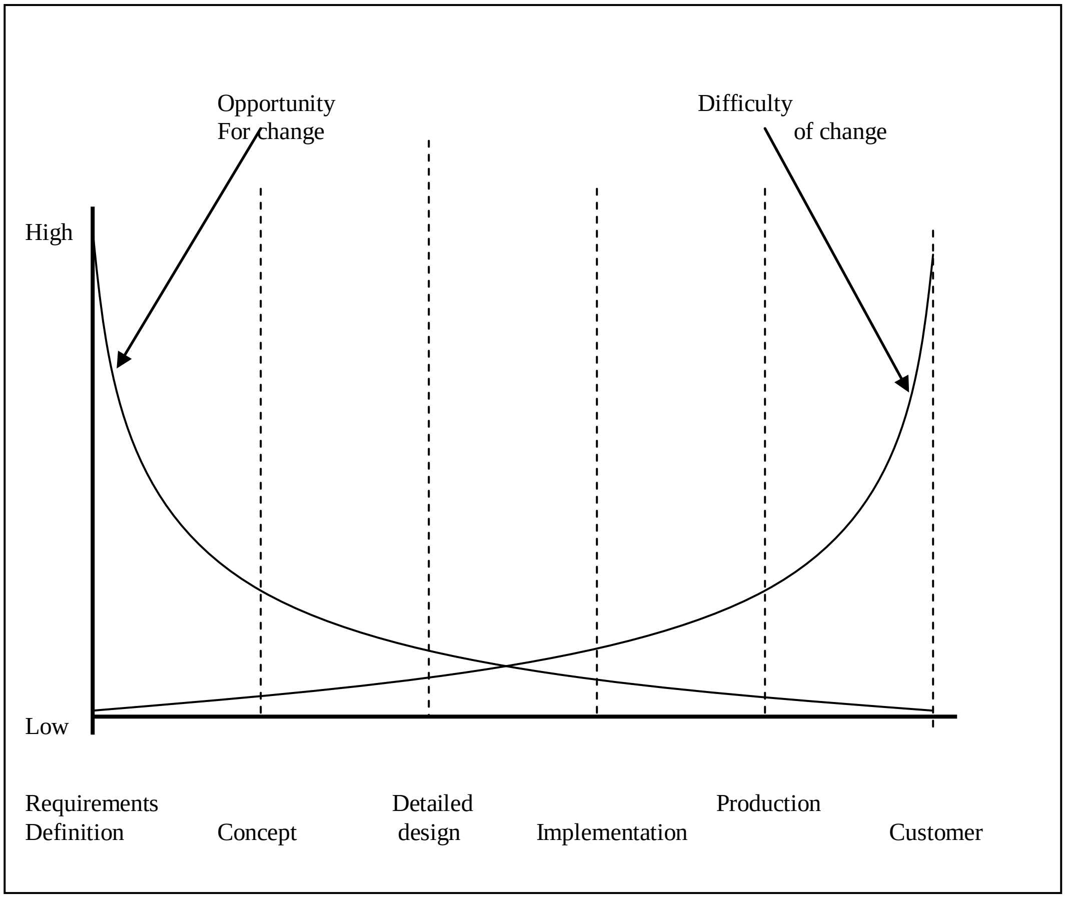


Figure 1.1 Opportunity for change in product design [Allen, 1990]

Design of casting entails the knowledge of various interacting factors that are unique to casting process. Also this knowledge is must to ensure that the product designed is capable and the optimum casting method is selected [Er, 1996]. This is a complex problem to solve, since metal casting technology offers the widest variety of routes to produce a component in a range of shapes, sizes, metals, quantities and quality requirements.

Therefore, selecting the most suitable casting process and evaluating its suitability is a difficult task for a product designer. While most designers are aware of the importance of design for castability, they are often unaware of the variety of casting processes, their characteristics and their influence on castability. Thus problem features such as excess rib thickness, inadequate fillet radius, narrow holes and tight tolerances are quite common in cast components, which result in excess weight, unnecessary tooling cost, additional labor cost and higher percentage of defects. In extreme cases casting process becomes a bottleneck and product design has to be modified to optimize time, material, energy, and labor [Akarte, 1999].

Selection of the most suitable process for the given product design is a critical step in product life cycle. It influences all down stream decisions like tooling, vendor selection, machining operations and hence cost. An early and informed decision about the casting process will not only insure the castability of a given design, but also provide an opportunity to improve its castability through suitable design changes. Since the casting product designers do not have foundry specific knowledge they have to liaise with casting experts in order to ensure that the product designed is castable and optimum casting method is selected. This two way communication results in long lead times and lack of it can lead to incorrect casting design. A computer based system at the discretion of a design engineer can, however, alleviate this problem and enhance the prospect of casting design for manufacture [Er, 1996].

1.3 Emergence of Web

Internet, often referred to as the "*network of networks*", is growing very fast. With the emergence of World Wide Web (WWW), nowadays a lot of applications are web based. WWW is an up-scale multimedia service, and is the fastest growing part of the Internet today. It is a distributed hypermedia-based information service, and is one of the most popular tools for the dissemination or retrieval of multimedia information. As a result of this rapid emergence of WWW, new businesses are emerged and old ones are getting transferred.

Today a large number of organizations are setting up their own Web *home page*, the main entry point that provides useful general information about the organization. No industry can afford to remain behind in this race of adaptation of new technologies of Internet and World Wide Web. The metal casting industry is realizing the importance of Internet and the opportunities offered by it. Internet can be used to give/receive the information about the products and the services and for business to business (B2B) electronics commerce. This can reduce the cost and increase the speed of the communication and transactions.

Since, the selection of a correct casting process for a given product design is a very critical issue and casting designers normally have to consult with casting experts to ensure that the product is castable and most suitable casting process is selected for the given material and quantity. This increases the lead time and hence the cost. Therefore, knowledge based expert systems are developed for casting process selection and they are linked with the designers' computers. However, the high initial cost and annual maintenance cost, need for qualified engineers and the lack of adequate local technical support prevent many small and medium enterprises from taking the immediate advantage of these knowledge based expert systems for casting process selection. If the system is made web enabled the enterprises can access it through Internet and avail the required services from it just by paying some fees. Thus, they will be relived of the high initial & maintenance cost of the system. Hence, client/server architecture over Internet can be effectively used to develop a web-based casting process selection system.

1.4 Problem Definition

The metal casting technology provides wide range if routes to manufacture a product, each with its own individual capabilities to achieve the given product design requirements. Hence it is important to select the most appropriate and economical process to cast a given product. In the present situation there are very few decision support systems available for casting process selection.

A large number of casting processes are available today, which differ greatly in terms of capabilities, advantages and limitations. These characteristics vary with the type of cast metal, leading to a large number of material dependent process-characteristics [Akarte, 2001].

Selecting the most suitable casting process for a given product design is the very important task, since it determines the type of tooling, skill and equipment required and hence the cost. If the material, quality and quantity requirements are given, the casting designer should select the casting process, which will produce the component at the most effective cost, with available resources. To make these decisions, the casting designers have to rely on casting experts. Contacting and consulting them is expensive and time consuming. Hence, there is a great need of developing a casting process selection system and make it easily accessible.

The main goal of the current work is to build an information system for casting process selection and preliminary process planning, and to web-enable the system to make it accessible to the large number of users.

1.4.1 Objective

1. To prepare a material specific database of the casting processes.
2. To identify the criteria influencing the selection of casting process.
3. To develop a methodology for casting process selection and planning.
4. To implement the methodology in a web-enabled system.

1.4.2 Scope and Approach

In the domain of the casting, the area of study is limited to the following processes only:

1. Green sand casting
2. High pressure sand casting
3. Shell molding
4. No-bake process
5. Gravity die casting
6. Low pressure die casting
7. High pressure die casting
8. Wax investment process
9. Foam investment process

The system includes the following nine materials viz. Gray Iron, Ductile Iron, Alloy Iron, Steel, Alloy steel, Aluminum, Copper, Magnesium and Zinc. A literature review is carried out to study the different approaches adaptable by different researchers to solve the problem of casting process selection. It is found from the literature review that there are many criteria, which influence the selection of the most suitable casting process. These criteria are identified and a material specific database of casting processes is prepared by literature review and visiting various foundries.

A systematic method (algorithm) for the casting process selection and planning is developed. User input in terms of the product requirements is given to the system. Certain basic criteria that are very critical for the selection of the casting process are identified and compared with the user input and based on these comparisons the database is screened to get list of suitable processes. Casting process is systematically divided in to a number of steps required to take to cast a product. These steps form the basis for the preliminary process planning for casting.

XML-compatible Casting Data Markup Language (CDML) is used to store and manage the database and the web-based system is implemented in WebICE (Web-based Integrated Casting Engineering) framework.

1.5 Organization of the Report

The **first** chapter discusses the casting processes and need of process selection and based on this the problem is defined. The **second** chapter contains the literature review on the process selection. Different approaches to casting process selection and planning are discussed. The **third** chapter deals with the methodology for casting process selection and process planning. The framework of the project, i.e. CDML and WebICE is discussed briefly in **fourth** chapter. The process library database and casting process planning database are also discussed in this chapter. The **fifth** chapter focuses on the implementation and testing of the material selection system. Finally, the **sixth** chapter concludes with discussing the contribution, limitations and scope for future work of the project.

CHAPTER 2

LITERATURE REVIEW

2.1 Process Selection

The need to provide the design activity with information regarding manufacturing process capabilities and costs has been recognized for many years. There is comparatively little published work in this area. Books on design rarely provide any relevant data and the data available in manufacturing volumes is insufficient. Also the information is inconsistent making the designer's task more difficult [Allen, 1990]. Selection of an appropriate casting method requires a sound understanding of the interactions between casting design constraints, required product properties, technical limitations of individual casting methods, available tooling and overall cost determining factor. Various authors have suggested different approaches for process selection.

2.1.1 Classification of Casting Processes

Metal casting, a 7000-year technology; over the years have evolved a large number of techniques to cast a product. There can be many criteria on the basis of which casting processes can be classified. The mold is the foundry man's forming tool; good casting cannot be made without good molds. Because of the importance of the mold, casting processes and castings are often described by the materials and methods employed in molding. They can be broadly classified into the following three groups: expendable mold type, permanent mold type and special processes.

The expendable mold type process can further be classified as permanent pattern and expendable pattern processes depending upon the type of the pattern being used. Permanent pattern expandable mold processes includes: water and clay bond, resin bond, plaster bond, silicate bond and no bond (vacuum or V- process). Here, water and clay bond process involves, green sand molding, skin dry sand molding, dry sand molding, core sand molding, floor and pit molding, loam molding and high pressure molding. Resin bond process involves, shell molding, hot box molding and cold box molding process. Whereas, silicate bond process involves CO_2 process, ceramic molding process and show process. Expendable pattern process includes investment (wax) casting and full mold (lost foam) casting.

Permanent mold process involves pressure die casting, gravity die casting, centrifugal process and vacuum process. Pressure die casting may be hot chamber or cold chamber process. Gravity die casting involves permanent core, expendable core and slush casting process. Whereas, centrifugal casting can be further classified as, true centrifugal, centrifugal and semi-centrifugal casting process.

Apart from the above-mentioned processes, there are some special processes like squeeze casting, continuous casting and chilled casting. This classification of casting processes is schematically represented in Figure 2.1.

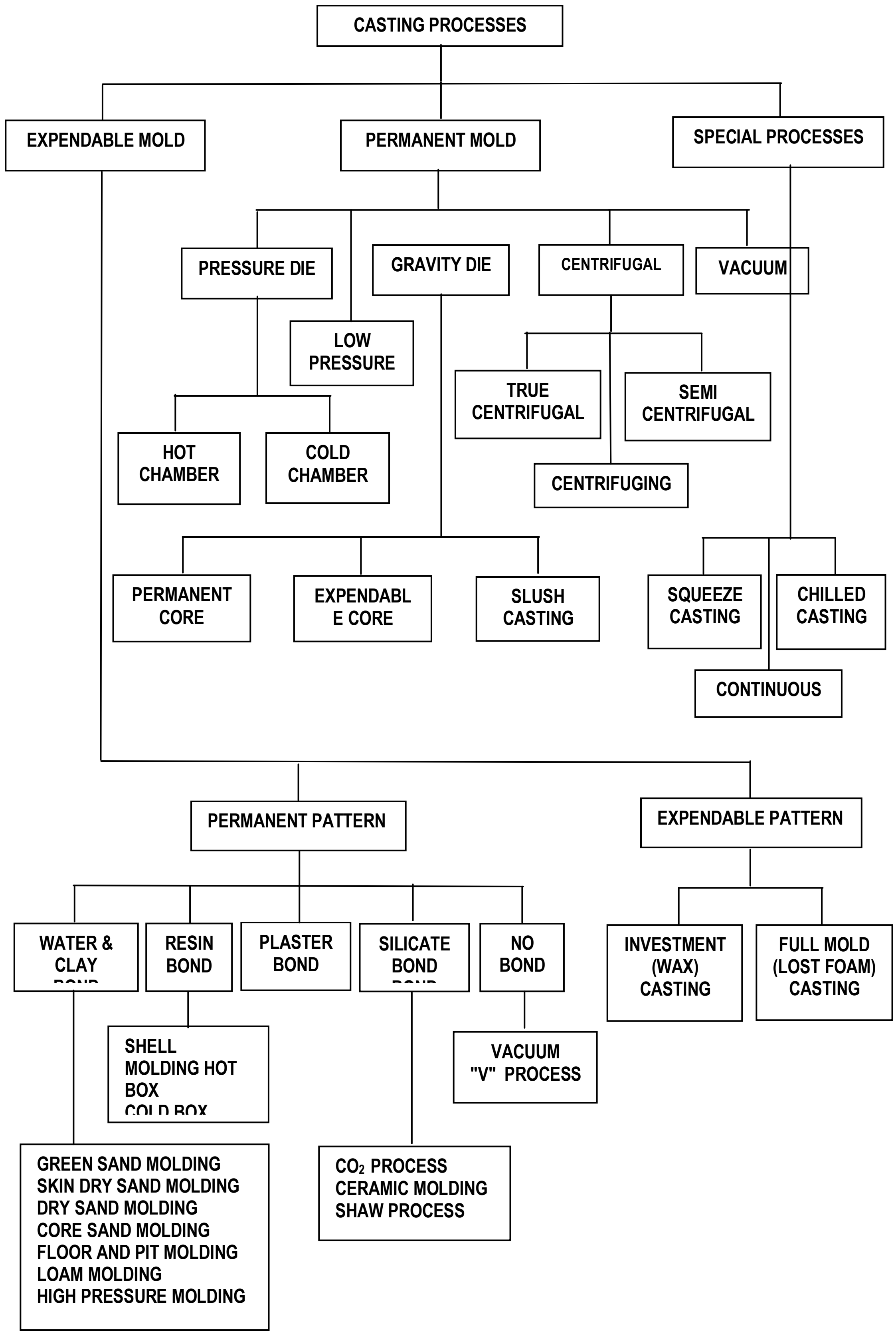


Figure 2.1 Classification of casting processes [Akarte, 1999].

2.1.2 Process Capabilities

The casting process offers the widest range of design and process parameters in terms of material, weight, shape complexity, batch size and quality of a product [Ravi, 1995]. This includes the parameters like part weight, size, production rate, minimum section thickness, minimum core hole diameter, surface finish, dimensional tolerances, machining allowance, porosity voids, material utilization, flexibility, lead time etc. Each casting process has its own capabilities, advantages and limitations in terms of design, quality, production and cost characteristics [Giachetti, 1988]. For example, minimum wall thickness achievable by Green Sand Casting of Aluminum is different than the minimum wall thickness achievable by High Pressure Die Casting of Aluminum. Even for the same process minimum possible wall thickness is different for different materials. This dependence of the process characteristics on the type of cast metal and often even on the class of application leads to a large number of sets of process characteristics. The process characteristics also depend on the equipment, manpower skills, quality management practices, and other company-dependent factors. All the process characteristics are not quantitative. Many characteristics are indicated as a band of values (minimum, maximum, and most common values). Some are described qualitatively (for example, surface detail capability of investment casting process is HIGH) [Akarte, 1999].

There is a large overlap in the capabilities of processes and process chains and there is unlikely to be one ‘best’ process. As a result, it is important to define the basis on which a short list of suitable process will be made. The basis for short-listing suitable processes can be technical performance, economic performance or a combination of both [Lavott, 1998].

The Table 2.1 compares the casting processes on the basis of the different parameters that are grouped in to three categories viz. Part, Cost and Production.

Table 2.1: General Characteristics Of Casting Processes [Schey, 1997]

	Green Sand	Resin-bond Sand	Plaster	Lost Foam	Investment	Permanent Mold	Die
Part							
Material (casting)	All	All	Zn - Cu	Al - C.I.	All	Zn - C.I.	Zn - Cu
Porosity & voids (a)	C-E	D - E	D - E	C - E	E	B - C	A - C
Shape	All	All	All	All	All	Most	Most
Size, Kg	0.01-300,000	0.01 - 100	0.01 - 1000	0.01 - 100	0.01 - 100	0.1 - 100	<0.01 to 50
Min. section, mm	3 - 6	2 - 4	1	2 - 4	1	2 - 4	0.5 - 1
Min. core dia., mm	4 - 6	3 - 6	10	4 - 6	0.5 - 1	4 - 6	3 (Zn 0.8)
Surface details (a)	C	B	A	C	A	B - C	A - B
Cost							
Equipment (a)	C - E	C	C - E	B - C	C - E	B	A
Die (or Pattern) (a)	C - E	B - C	C - E	B - C	B - C	B	A
Labor (a)	A - C	C	A - B	C	A - B	C	E
Finishing (a)	A - C	B - D	C - D	C - D	C - D	B - D	C - E
Production							
Operator skill (a)	A - C	C	A – B	C	A – B	C	C – D
Lead time	Days	Weeks	Days	Weeks-Months	Hours – Weeks	Weeks	Weeks – Months
Rate, (pieces/hr mold)	1 – 20	5 – 50	1 – 10	1 – 20	1 – 1000	5 – 50	20 – 200
Min. quantity		~ 100	~ 10	~ 500	~ 10 – 1000	~ 1000	~ 100,000

Note: (a) Comparative ratings, with A indicating the highest value of the variable, E the lowest (e.g., investment casting gives very low porosity, produces excellent surface details, involves moderate to low equipment cost, medium to high pattern cost, medium to low finishing cost, and higher operator skill. It can be used for low or high production rates and requires a minimum quantity of 10 to 1000 to justify the cost of the pattern molds).

2.1.3 Different Approaches to Process Selection

Accurate decision about the selection of a casting process at the design stage is very critical issue. It influences the product cost to a great extent because the process selection determines the type of tooling, equipments, labor skill and lead time required. The correct decision about the process selection at the design stage ensures the castability of the product. It also provides an opportunity to make some modifications in the product design to improve its capability. This helps in adopting a concurrent engineering approach in casting domain to reduce lead time and cost.

Various authors have explored different approaches to the problem of process selection. The knowledge based system suggested by *Er, Sweeney,* and *Kondic* is based on production rules knowledge representation technique [Er, 1996]. The system suggested in their study confined to those casting processes for which knowledge and data could be easily obtained. Sets of IF-THEN rules were determined by them in order to aid process selection. A part of the rule for considering cored feature is written as follows:

> IF (no cores are required OR (casting has internal features that require use of cores AND core type required is appropriate AND minimum core size is appropriate))…
>
> THEN X casting process is suitable.

Each casting process has its own capabilities. One critical feature obtainable by a specific casting process may not be feasible by another process [Dieter, 1991]. Furthermore, there is a large overlap in the capabilities of different process chains and there is unlikely to be one 'best' process [Lavott, 1998]. This complicates the problem of process selection and implementation of above IF-THEN statements becomes difficult and complex.

Ishii, Lee, and *Miller's* methodology involved identification of decision variables or the major factors that affect process selection at the early stages of design. Their research focused on single parts that are to be net-shape manufactured. The major factors that influence the selection process are: Mechanical properties, Part shape, Part size, Tolerances and surface finish, Materials, Time to market, Production quantity and Production rate. They believed that an iterative nature of the decision process exists in selecting a manufacturing process [Ishii, 1990]. Representation of processes was done in the following three ways.

1. Case-based compatibility knowledge-used at preliminary stages.
2. Cost interval analysis – for each process more details needed.
3. Life cycle cost estimate – when complete details are available.

Jyh-Cheng Yu, Sherveen Lotfi, Kos Ishii proposed the methodology of Design Compatibility Analysis (DCA) in which design parameters are measured against process capabilities to arrive at an overall index [Yu, 1993]. Ranking of each process is based on its feasibility with the basic geometry, material and production requirements. DCA compiles the compatibility information in an object-oriented representation called C data. The computer program for process selection used the C-data to access the suitability of candidate process to a given set of inputs: geometry classification, materials and production specifications. They classified the factors influencing process selection into the following three categories.

1. Material factor: which includes Mechanical properties, Physical properties and Alloy specifications
2. Geometry factors: which includes Part shape, Part envelop size, Part weight, Dimensional tolerance, Surface finish and Secondary operations
3. Production factors: which includes Lead time, Production volume and Production rate.

Darwish and *El-Tamimi* developed a simple expert system using the Rule Master shell for coding the process characteristics. They have identified different attributes and organized them in four groups viz. design, production, manufacturing and trade off attributes. It involves the user input regarding product requirements and comparison is done to list feasible processes [Darwish, 1996]. They used the following criteria to shortlist the alternatives: material, weight, minimum thickness, surface roughness, dimensional accuracy and production rate and production volume. The selection procedure involves identifying the relevant possible alternatives and ranking them according to their performance.

Perzyk and *Meftah* developed a module called manufacturing process selection system [MPSS], which consists of two parts: evaluation system for manufacturing processes [ESMP] and evaluation system for alternative designs [ESAD]. The ESMP uses the data on process capabilities, design for manufacturability rules and materials processing. The results are expressed in the form of process indices calculated as fuzzy numbers. The system works in the MS Windows environment and the databases are written in the form of MS Excel spreadsheets. They proposed coefficients to the rules in the range 0-1, where 0 means that a rule does not apply at all [Perzyk, 1998]. *Giachetti* recognized the need for both decision support and database support for process selection [Giachetti, 1988]. A formal multi-attribute decision model with a relational database is integrated. His decision model enables the representation of the designer's preferences over the decision factors. A compatibility ranking between the product profile requirements and the alternatives stored in the database for each decision criteria is generated using probability theory. He used possibility theory to classify product-process compatibility in terms of strictly compatible, strictly incompatible and partially compatible, giving fuzzy values. However, he used linguistic terms (very important, etc) to assign weights to the criteria, which may lead to incorrect weights given the number of criteria involved.

A.M.K.Esawi and *M.F.Ashby* uses systematic procedure based on comparing the attributes required by the design with those that lie within the capacity of a large number of processes [Esawi, 1998]. This gives subset of feasible processes, which are then ranked by economic criteria. *P.P.Dargie, K.Parmeshwar* and *W.R.D.Wil*son developed a system, which is based on the idea that certain characteristics of a part restrict the choice of manufacturing process and materials for it to a relatively small number of alternatives [Dargie, 1982]. The most important characteristics are expressed by means of twelve-digit number classification code, in which different positions relate to different characteristics. The program eliminates the unsuitable processes and ranks the reminder. Whereas *A.J.Allen* and *K.G.Swift* suggests a technique to explore the range of processes that can be used for a component design and estimates the manufacturing cost in each case [Allen, 1990]. The technique enables the exploration of material-process combinations for technological feasibility and cost. *Sirilertworakul, Webster*, and *Dean*, after the alloy material selection went on to select an appropriate casting process. The knowledge base consisted of various casting processes. The casting dimensions menu contained casting weight, minimum section thickness, maximum section thickness, minimum hole diameter, tolerances and number off [Sirilertworakul, 1993]. In addition to this menu the knowledge base consisted of advantages and disadvantages of each process.

Cost is one of the most important factors influencing process selection. Information about economics of process selection that includes the cost factors primarily is discussed [Bralla, 1998]. Design engineers, manufacturing engineers, and industrial engineers in analyzing alternative methods for producing a part or a product or for performing an individual operation or an entire process are faced with cost variables that relate to materials, direct labor, indirect labor, special tooling, perishable tools and supplies, utilities, and invested capital. The interrelationship of these variables can be considerable, and therefore a comparison of alternatives must be detailed and complete to assess their full impact on total unit costs. *Lavott* and *Shercliff* proposed a comprehensive methodology for process selection based on initial screening, primary assessment, performance assessment and economic evaluation [Lavott, 1998]. While the first two steps are based on attribute matches and incompatibility checks, the next two depend on process and activity-based cost models to select the best process. They extended their approach by using fuzzy logic to represent process characteristics and demonstrated it for process selection for Aluminum parts. *M.M. Akarte* and *B. Ravi* addressed some of the limitations of the earlier work done in casting process selection and attempted to link it with a CAD system to provide an integrated environment to a design engineer so that he can not only evaluate product-process compatibility but also use it for design improvements [Akarte, 1999]. They have used fuzzy logic to model the process characteristics and introduced the technique of AHP for complex and multi-attribute problems – to objectively assign the relative weights to process evaluation criteria.

From the above discussion it is clear that most of the systems are knowledge based expert systems. The database of process is created and then screening is done to get the list of technologically feasible processes. Different approaches are used to evaluate and rank these processes. Cost being one of the most important criteria for evaluation. There are many other criteria, which affect the selection of a casting process. Different authors has identified various criteria and grouped them differently. The importance of the different criteria is also different according to different authors. The Table 2.2 compares the different criteria considered by different researchers and the system developed in this work.

Table 2.2: Various Criteria affecting process selection

S. No.	Criterion \ Reference no.	Sirilertworakul, 1993	Giachetti, 1988	Lavott, 1998	Er, 1996	Darwish, 1996	Yu, 1993	Akarte, 1999	Esawi, 1998	Perzyk, 1998	This work
1	Casting weight min (mm)	Y				Y	Y	Y			Y
2	Casting weight max (mm)					Y	Y	Y			Y
3	Size min (mm)			Y		Y	Y	Y	Y		Y
4	Size max (mm)			Y		Y	Y	Y	Y		Y
5	Economic quantity min								Y	Y	Y
6	Economic quantity max										Y
7	Production rate min (no/yr)										Y
8	Production rate max (no/yr)										Y
9	Wall thickness min (mm)	Y			Y	Y		Y	Y		Y
10	Wall thickness max (mm)	Y	Y		Y	Y			Y		Y
11	Wall thickness typical (mm)								Y		Y
12	Core hole dia min (mm)	Y			Y			Y	Y		Y
13	Core hole dia max (mm)				Y						Y
14	Core hole dia typical (mm)				Y			Y	Y		Y
15	Tolerance min (mm)		Y	Y	Y		Y	Y	Y	Y	Y
16	Tolerance max (mm)		Y	Y	Y		Y	Y	Y	Y	Y
17	Tolerance typical (mm)	Y									Y
18	Surface finish min (um)			Y	Y	Y	Y	Y	Y	Y	Y
19	Surface finish max (um)		Y	Y	Y	Y	Y	Y	Y	Y	Y
20	Surface finish max (um)					Y	Y	Y	Y	Y	Y
21	Machining allowance min (mm)										Y
22	Machining allowance max (mm)										Y
23	Machining allowance typical										Y
24	Porosity voids					Y	Y				Y
25	Material utilization							Y	Y		Y
26	Total casting unit per yr			Y			Y	Y	Y		Y

Continue on the next page….

S. No.	Reference no. / Criterion	Sirilertworakul, 1993	Giachetti, 1988	Lavott, 1998	Er, 1996	Darwish, 1996	Yu, 1993	Akarte, 1999	Esawi, 1998	Perzyk, 1998	This Work
27	Production capacity (tons/yr)					Y	Y	Y	Y		Y
28	Order size min (no/yr)			Y	Y	Y			Y		Y
29	Order size max (no/yr)										Y
30	Lead time (week)		Y	Y			Y	Y	Y		Y
31	Shape number		Y				Y		Y		
32	Shape Complexity		Y					Y	Y		Y
33	Draft angle (deg)							Y	Y		Y
34	Tooling cost							Y	Y		Y
35	Environmental impact									Y	Y
36	Machining typical										Y
37	Volume min (cubic mm)										
38	Volume max (cubic mm)										
39	Aspect ratio									Y	Y
40	Direct labor cost							Y			
41	Equipment cost							Y			
42	Finishing cost							Y			
43	Adjacent section ratio								Y		
44	Min. corner radius (mm)								Y		
45	Capital cost								Y		
46	Precision								Y		
47	Delivery quantity min										Y
48	Delivery quantity max										Y
49	Delivery frequency min										Y
50	Delivery frequency max										Y

(Note: In the table, Y means the criterion is considered.)

2.2 Process Planning

Process planning can be defined as the systematic determination of the detailed methods (process and parameters) by which work pieces or parts can be manufactured economically and competitively from initial stage (raw material form) to finished stage (desired form), subject to constraints of part specifications and available resources [Alting, 1994].

Following is the basic information essential for process planning:

1. Design and Quality requirement data,
2. Production type data,
3. Raw material data,
4. Resources and capability data.

Since process planning activity acts as an effective bridge between design and manufacturing, it dictates cost, quality and production rate in a manufacturing organization. It thus decides the competitiveness of the company.

In general, approaches to process planning can be classified into two main categories viz. Manual or traditional process planning and Computer-aided process planning (CAPP).

2.2.1 Traditional Process Planning

The traditional manual approach to process planning involves examining an engineering part drawing and developing manufacturing process plans and instructions based upon the individual knowledge of process and machine/equipment capabilities, tooling, materials, related costs and shop practices [Alting, 1994].

The manual approach thus draws heavily upon the expertise of the process planner. The main limitations of the traditional approach to process planning are as under.

1. The manufacturing logic is individualistic.
2. The task is labor intensive, time consuming and monotonous.
3. Results are often inconsistent and non-unique.

4. Process information may not be updated regularly.
5. It requires the presence of an extremely skilled process planer.

The advantages of this approach are flexible and law investment costs. The limitations of this technique surface when the number of process plans and revisions to these plans increase.

2.2.2 Computer Aided Process Planning (CAPP)

CAPP is the application of computers to assist the human process planner in the process planning function. In its lowest form it will assist in report generation, storage and retrieval of plans. In its most advanced state it will provide the automated interface between CAD and CAM and in the process achieve complete integration within the manufacturing system. The following benefits accrue as a result of application of CAPP [Chang, 1985].

1. The skill required of the planner is reduced.
2. More consistent and accurate plans are obtained.
3. It reduces process planning time.
4. It reduces both process planning and manufacturing costs.

2.2.3 **Approaches to Process Planning:**

There are two approaches to process planning, described here.

Variant process planning system: This is generally based on the concept of Group Technology (GT). Group Technology can be defined as the identification of similar product within the population at large for the purpose of design and manufacturing efficiencies through the consistent application of best practice technology to the characteristic attributes of the family [Noten, 1990]. The variant approach to process planning is a computer-assisted extension of the manual approach i.e. creating and routing by recalling, identifying and retrieving an existing plans for a similar part and editing it. The computer assists by providing an efficient system for data management, retrieval, editing and high speed printing of process plans [Steudel, 1984].

Generative process planning: As the name implies, this approach to CAPP attempts to convert design specifications into process plans using decision rules and technology data [Alting, 1994]. A process plan is generated from scratch considering various constraints in design and manufacturing. The successful implementation of this approach requires the development of the following factors [Chang, 1985].

1. The logic of process planning must be very clearly identified and captured in the software in an algorithmic way.
2. The part to be produced must be represented and defined in a computer compatible format.
3. The captured logic and part description data should be incorporated into a unified manufacturing database. It should be possible to tune the logic to account for shop floor variations and decisions of the process planning departments.

2.3 Casting Process Planning

The CAPP in the casting domain is an area in manufacturing system, which has been given a very little attention. A very little work has been done in the area of casting process planning as compared to the similar work done in the area of the processes like machining. Very little literature is available for process planning in casting domain. The growing complexities of running a foundry and increasing competition have forced foundries to look for an alternative to the traditional approach for planning and estimation to improve the productivity. The ability to make an accurate estimate of casting weight, production time and cost is vital to the success of any manufacturing enterprise furthermore an accurate and rapid estimation of these things are essential for deciding realistic selling price and job delivery date.

There are some packages, which are commercially available for cost and weight estimation but they lack in flexibility to handle the large number of material and process options and different methods for sand preparation, core making and molding [Ajmal, 1985].

The system developed by *Ajmal and Dale* is organized in modular format. There are different modules to estimate volume and weight, density and cost per unit weight, labor time, labor and material cost. The limitation of the system is that casting weight is the base for estimating labor time and cost. However, casting weight is estimated by considering the casting as a number of separate basic shapes like rectangle, triangle and cylinder. This is very difficult to apply to complex shaped castings and also the accuracy is not good.

2.4 Summary

Various authors have suggested different approaches for process selection. Sets of IF-THEN rules were determined to develop a casting process selection system. Each casting process has its own capabilities and also there is a large overlap in the capabilities of different processes. This makes the implementation of simple IF-THEN statements difficult and complex. Therefore, methodologies have been developed which involves identification of decision variables or the major factors that affect process selection at the early stages of design. Cost is one of the most important criteria affecting the process selection. The major factors that influence the selection process have been identified. It is found that many systems use the Database of different processes. Then a program is developed that combines preliminary screening of processes from the database. Then various techniques like Design Compatibility Analysis (DCA) are used to rank each process based on its feasibility with the basic geometry, material and production requirements. On the other hand, some simple expert systems obtain the user input regarding product requirements and compare it to list feasible processes from the database of the processes. The database of process characteristics is stored and the final result is shown as a fuzzy rating of each process in comparison to an 'ideal' process fully compatible with product requirements. It is observed that very little work has been done in the area of casting process planning. Some systems have been developed for cost and weight estimation but they lack in flexibility to handle the large number of material and process options and different methods for sand preparation, core making and molding. Hence, knowledge based casting process selection and planning system is developed in this work, which is described in the following chapter.

CHAPTER 3

CASTING PROCESS SELECTION AND PLANNING

As discussed in the previous chapter, casting technology offers a wide range of routes to cast a product. Different casting processes have different capabilities to achieve the various design, production and quality parameters. In this work the various criteria, which affect the casting process selection, are identified and based on this a casting process database is created and stored. The system needs user input in terms of the product requirements.

3.1 Process Selection Methodology

The casting process selection methodology involves screening the casting process database to get a set of feasible alternative for the given product requirements. User gives the casting product requirements in terms of design, production and quality parameters as an input to the system through the user interface screen. These parameters includes weight, casting size, metal, preferred casting process, minimum wall thickness, minimum core hole size, dimensional tolerance, surface finish, order size, delivery quantity, delivery frequency, production rate, latitude and longitude. The screening process involves comparing these casting product design requirement values with the respective value of an alternative to discard those, which do not satisfy the requirements. The following criteria are used to screen the feasible processes from the various alternatives available.

1. Casting weight.
2. Maximum size.
3. Minimum core hole diameter.
4. Minimum section thickness.
5. Delivery quantity.
6. Foundry production capacity.

This screening process results into a set of alternatives that are feasible for the given casting product requirements. The product design can further be modified to test the castability of the product for the selected processes. For example, if the minimum wall thickness value given was is 3 mm and A, B and C processes are screened by the system. Now if the minimum value of the wall thickness is reduced to 2.6 mm and after the screening if it is found that process B is now not listed. This means the casability of the product by the process B is not very good and close process control is required to achieve the desired results. The Figure 3.1 shows the simplified flow chat for the process selection.

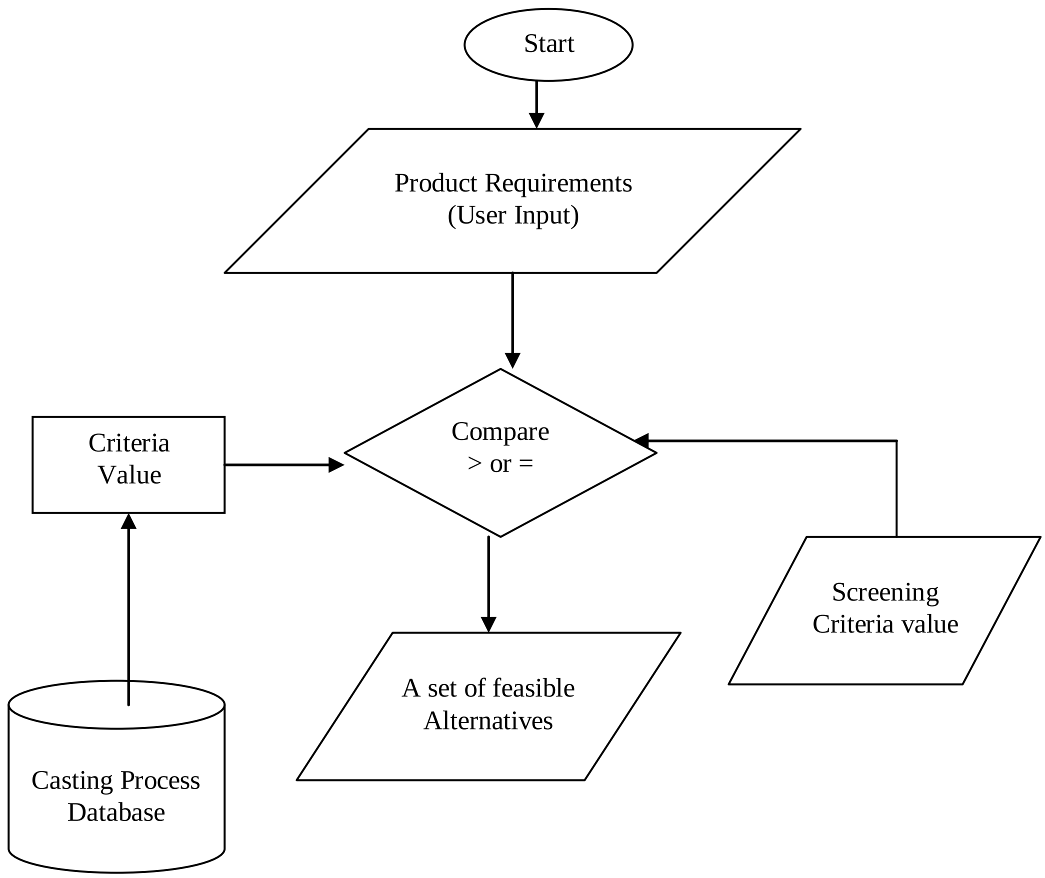


Figure 3.1: Simplified process selection flow chart

3.2 Process Planning Methodology

After doing the literature survey on casting process planning and visiting various foundries to study the process planning techniques being actually practiced by the industry, an activity-based approach is adopted for developing a generalized system for preliminary casting process planning. In this approach the foundry operations are systematically divided into a number of steps required to cast a product. This is achieved in three levels viz. *activity, task* and *steps.* This approach is applied to the sand casting process because still it is a main casting process. According to a study 72.97% of the castings made in India are from sand casting process [Akarte, 2001]. Also the other processes considered in this work are extensions of sand casting process viz. high pressure sand casting, no bake, shell etc.

In this method, the casting process is first divided in to three different *activitie*s viz.

1. Pre-casting Activity.
2. Casting Activity.
3. Post-casting Activity.

Each activity can further be divided into different *tasks*. For example, **Pre-casting** *activity* consists of the following *tasks*:

1. Core sand preparation.
2. Core making.
3. Core dressing.
4. Molding sand preparation.
5. Mold making.

Each *task* consists of different *steps* required to take to accomplish the *task.* These steps depend upon the *method* employed to accomplish the *task*. This is because there may be different *methods* to accomplish a task. For example, core sand preparation task can be achieved by different *methods* like, oil sand method, hot box method, cold box method etc. The *steps* involved in these different *methods* will be different. To take care of this a database for process planning is prepared which contains the information about the various *steps*, which should be taken to accomplish different *tasks* through different *methods.* For example, HOT BOX *method* of core sand preparation consists of following *steps*.

1. Receive the raw material.
2. Inspect the silica sand.
3. Inspect the hot box resin and catalyst.

4. Charge and mix the raw material into the mixer.
5. Inspect the sand mix.

Whereas OIL SAND method consists of the following *steps*:

1. Inspection of raw material.
2. Charge and mix raw material (Sand 400 Kg, Bentonite 1.5 to 3 kg, Dextrine 6 to 8 Kg, Water 3 to 5 Lit, Oil 5 to 6 Lit.)
3. Mixing (Bentonite and Dextonite- 1.5 to 2 Mins, Water- 1.5 to 2, Oil 3 to 4 Mins.)
4. Inspection of the sand mix.

Here, additional information about the step is given in the brackets, which is useful as a guideline to perform the specific step. In the similar way Casting *activity* can be divided in to Melting, Holding and Pouring whereas Post-casting activity consists Shakeout, Cleaning and Fettling. Each of these tasks is further divided into different *steps* according to the *method* employed for its accomplishment. This information is systematically stored in the library and can be easily browsed by clicking the corresponding node of the CDML tree.

The methodology is explained in Figure 3.2.

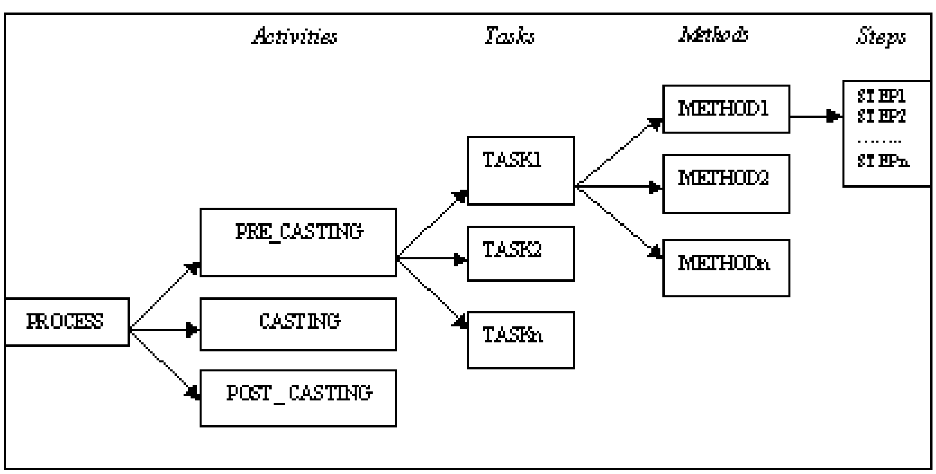


Figure 3.2: Process planning methodology

3.3 Database development

The database collection was one of the most important tasks of the work. A material specific database is required because the sand casting of gray iron is different from the sand casting of aluminum. Lot of literature is available on casting processes and their description but the exact values for the different process capabilities are not readily available at one source. The values for different criteria like minimum possible core hole size, surface finish, minimum wall thickness, draft angle etc for each feasible process-material combination are collected. This data is not readily available. Some times the data is available for a particular criterion of a specific process but how it varies from material to material within the same process is not mentioned. The data are collected from different books, handbooks, websites and papers. Some times different sources give different values for a specific criterion. An average value is taken in such case. Some data is also collected from the industry sources by visiting different foundries. Mostly any foundry deals only with a few specific processes and furthermore the data is not well documented. But foundry visits have been very useful, especially to create the process planning database.

The information collected about the casting processes and planning is well organized in a web compatible database. This database design and implementation is elaborated in detail in the following chapter.

CHAPTER 4

DATABASE DESIGN

The current work is based on a self-describing XML-compatible Casting Data Markup Language (CDML) and the WebICE (Web-based Integrated Casting Engineering) framework [Akarte, 2001]. These are briefly described here, in the context of the current work on casting process selection and preliminary process planning.

4.1 Casting Data Markup Language (CDML)

Rapid access to the right information is very important in the process of design, development and manufacture of a cast component for improved decision-making and for reducing the lead-time. This can be achieved through a systematic approach to modeling, managing and sharing the relevant information by a team of engineers responsible for the development of cast component. The use of Internet technology, especially web, makes this type of information transfer very useful for geographically disparate team members. The XML provides an effective way for modeling the information for the web applications.

This work uses, the XML based language developed specially for castings, which is named Casting Data Markup Language (CDML), which permits definition of domain specific tags. The data contained in the CDML is self-describing. The following sections describe different types of information captured by the CDML, its systematic classification and modeling for the web application.

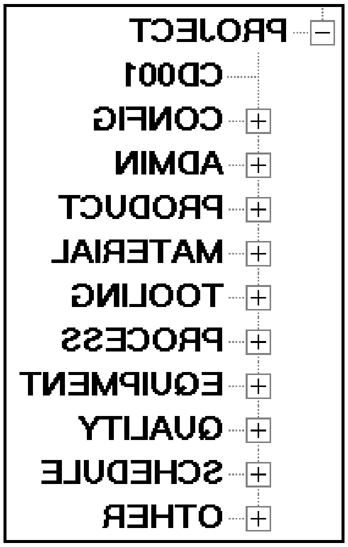
CDML structure

The CDML is a template for storing casting life cycle data (also referred as the casting *project data*). The approach to classify the casting project information in a hierarchical tree structure, which when used with other tools can be very helpful in web based information systems. This structure so developed is a good candidate for web base databases. Easy location and fast retrieval of the required information over the Internet is the basic requirement of Information modeling for the web applications. Hierarchical tree structure of CDML enables easy location of the required information and the small file size facilitates better access speed.

The CDML consists of two parts, CDML tree and data blocks. The *CDML tree* represents the hierarchical relationship between different types of life cycle information involved in a casting project, whereas the *data blocks* are used for storing the actual project data. An important feature of the CDML is that it includes systematic hierarchical classification of information for easy locating and viewing. The CDML tree is used for gross level and data blocks for detailed level information. This hierarchical classification is supported with a well-defined numbering scheme, which provides flexibility to incorporate additional information in the tree as well the data blocks. Each type of information has been specified by the unique name and number that allow linking of tree with data blocks. . Most of the data blocks are 1 KB to 2 KB in size, which ensures fast retrieval of information. Data block allows sharing of information and Separation of the tree (node) structure from the data blocks enables restructuring of the tree without modifying any associated programs using the data.

Each node of the CDML tree corresponds to one type of information. For example, information about the foundry will come under the node 'FOUNDRY' whereas the information about the process will come under the node 'PROCESS'. In the similar way, total 245 nodes have been defined for the initial version of CDML [Akarte, 2001].

The CDML tree has been structured in the form of parent-child-grandchild for easy location of the information. Each node in the tree has a specific name and a number. For example, the top node is called PROJECT and it is numbered 001. Similarly the block for foundry has been numbered 140. The unique numbering and naming approach enables us to link the nodes with the block numbers. This type of structure is so flexible that we can easily incorporate additional nodes in the tree. The hierarchical node structure has been converted into the standard XML (version '1.0') format by using node name as starting and ending tags. The tags are just like an HTML format. The unique number of the node has been used as the default child node in XML tree format representing the data block file name for the particular node. Figure 3.1 shows the CDML tree and its format (partial).




```
<?xml version="1.0"?>
<PROJECT>
        <CD001/>
        <ADMIN>
        <CD002/>
                <ORDER>
                <OEM>
                <TOOLMAKER>
                <FOUNDRY>
                                <CD140/>
                                <ADDRESS>
                                <CAPABILITY>
                                <FACILITY>
                                < OTHER>
                                < ECO_FRIENDLY>
                </FOUNDRY>
                <LEADTIME>
                <COASTING>
        </ADMIN>
        <PRODUCT>
        <MATERIAL>
        <TOOLING>
        <PROCESS>
        <EQUIPMENT>
```

Figure 4.1 CDML tree with its format

Each data block comprises several pairs of field names (with unit, if any) and their values representing the detailed content of a particular node. For linking node and data block, the node number has been used as a basis to obtain the file name for the corresponding data block. For example, the file name of FOUNDRY data block is given by CD140.XML, which is obtained from the FOUNDRY node number 140.

Web Integrated Casting Engineering

WebICE (Web-based integrated casting engineering) environment is used for creating, viewing, modifying and updating casting project data (stored in CDML) over the Internet. WebICE framework also supports application interface (by linking application program for decision making) as XML based data storage (CDML data block) enables easy extraction of the required casting life cycle data. The webICE structure consists of two parts viz. client side and server side. Client side has been used to provide the graphical user interface while databases and functions (programs) has been stored at server side. An important feature of the architecture is its high speed. System is designed for satisfactory performance even at the low bandwidth. An innovative context sensitive user interface minimizes the need for training and technical support and simplicity is ensured by keeping system independent of the program implementation and can be used through a simple web browser. Programs developed based on CDML can be linked with webICE for improved decision-making. Library Interface facilitates display, browsing and copy of library options into the project, which reduces the need for manual input [Akarte, 2001].

Client-Server Approach

Client-server computing is the logical extension of modular programming approach, where the program modules developed for the better interaction and maintenance can be placed and executed either completely at the server side or at the client side or distributed between them. The calling module is the client and it requires the service, whereas the called module is the server and it provides the service.

This work uses the two-tier client-server structure of webICE in which distributed environment has been chosen to minimize the client-server interaction. HTML, JavaScript and XML-DOM functions are used to build the user interface whereas PHP3 (platform independent scripting language) has been used as a scripting language on server side.

The client side consists of display of CDML tree, data blocks, functions, user inputs and the results of the computations. The server side has four main components: casting project databases, library database, user projects and functions (application and supporting programs).

4.2 Process Library Database

The casting process information has been stored under the node named FOUNDRY. The FOUNDRY information has been classified into five child nodes: ADDRESS, CAPABILITY, FACILITY, OTHER and ECO_FRIENDLY. Communication information has been classified into ADDRESS while overall foundry profile for the type of metal handled, type of casting process employed, casting weight, wall thickness, tolerance, surface finish, lead time etc has been classified into CAPABILITY. FACILITY data block stores foundry facilities such as sand preparation, molding, core making, melting, pouring, heat treatment, testing and machining. Additional capability details like software (solid modeling, simulation, NC process planning and CMM), tooling development (in-house or outsourcing), quality certification (ISO 14000, ISO 9000, QS 9000, self certification) and awards at national and international level has been stored into OTHER data block. The data block ECO_FRIENDLY contains information about the environment friendliness of the process and it contains the fields like chemicals used, operator safety and harmful byproducts.

The casting process database is a material specific database, because the Sand Casting of Gray Iron is different from the sand casting of Aluminum. Therefore, Sand Casting of Gray Iron is one option; Sand Casting of Aluminum is second option and so on. Thus, the each 'o*ption*' is considered as one '*foundry*'. Two types of foundries are identified viz. *ideal foundry* and *real foundry*. Ideal foundry is a virtual foundry producing cast components under best (ideal) foundry conditions. Hence its process capabilities for a given option are better than that of the real foundries for each individual criterion.

Representation of Libraries

The casting process information fall into the block 140 in the main library file of CDML. The four level of hierarchy can be easily represented in XML. Each level starts with an opening tag and closes with a closing tag. The opening of the tags will be in the ascending order of levels ie level 1, 2, 3 etc. while the closing of the tags is in the descending order. The last level will be the one that closes first and continues in the descending order of levels. The portion of the CDML library structure where FOUNDRY block falls is shown in Figure 4.2.

```
<CD140_LIB-001>
        <PROCESS NAME="GREEN_SAND">

                <MATERIAL NAME="GRAY_IRON">
                        <CD140_LIB-110> Ideal_foundry      </CD140_LIB-110>
                        <CD140_LIB-111> Realfoundry1       </CD140_LIB-111>
                        ……………………………………………………………
                </MATERIAL>
                <MATERIAL NAME="DUCTILE_IRON">
                        <CD140_LIB-120> Ideal_foundry      </CD140_LIB-120>
                        <CD140_LIB-121> Realfoundry1       </CD140_LIB-121>
                        ……………………………………………………………
                </MATERIAL>
                        ……………………………………………………………
        </PROCESS>
        <PROCESS NAME="HIGH_PRESSURE_SAND">

                <MATERIAL NAME="GRAY_IRON">
                    <CD140_LIB-110> Ideal_foundry      </CD140_LIB-110>
                        <CD140_LIB-111> Realfoundry1       </CD140_LIB-111>
                        ……………………………………………………………
                </MATERIAL>
                <MATERIAL NAME="DUCTILE_IRON">
                        <CD140_LIB-120> Ideal_foundry      </CD140_LIB-120>
                        <CD140_LIB-121> Realfoundry1       </CD140_LIB-121>
                        ……………………………………………………………
                </MATERIAL>
                        ……………………………………………………………
        </PROCESS>
                        ……………………………………………………………
</CD140>
```

Figure 4.2: FOUNDRY block of the library structure

4.2.2 Fields And Values

CDML tree has about 3000 nodes and since each node is associated with a data block there are 3000 data blocks. These data blocks are stored in XML format. Each data block comprises several pairs of field names and their values. The use of XML for data storage also allows easy representation of units (Example, mm), if any required for the specific casting information. Following example shows three field names: Minimum wall thickness, order size and shape complexity. The value of minimum wall thickness is ‘1.58’, the value of order size is ‘1250’ and the value of shape complexity is ‘HIGH’. The minimum wall thickness has a unit ‘mm’ while order size has ‘quantity/year’ whereas shape complexity has no unit.

```
<WALL_THICK_MIN UNIT="mm">        1.58    </WALL_THICK_MIN>
```

<ORDER_SIZE UNIT="Quantity/Year"> 1250 </ORDER_SIZE>

<SHAPE_COMPLEXITY> HIGH </SHAPE_COMPLEXITY>

For linking node and data block, the node number has been used as a basis to obtain the file name for the corresponding data block. For example, the file name of ADMIN data block is given by CD100.XML, which is obtained from the ADMIN node number 100.

First eight fields names of each data block are constant. These are root node – CDML, VERSION, NAME, FILE, DATE, TIME, MODEL and IMAGE. The importance of these field names is given below.

The root node – CDML is an essential part of XML and it represents the parent for all information classified into a particular data block. The field name VERSION represents the current version of a particular data block. This can be useful to check the incompatibility of a program for a particular version of a data block. NAME field indicates the name of the data block, which represents three levels in the CDML tree hierarchy: child, its parent and grandparent, giving clear view of information classification. FILE gives the file name of the data block that can be used either to read from or to modify the content of the file. The field name DATE and TIME stores the date and time of data block creation or last update.

The CAPABILITY data block fall under the FOUNDRY data block, which in turn is under ADMIN block. The exploded view of the foundry data block is shown in the following figure. The foundry data block consists of the five child data blocks at its lower level in the CDML hierarchy. They are ADDRESS, CAPABILITY, FACILITY, OTHER and ECO_FRIENDLY.

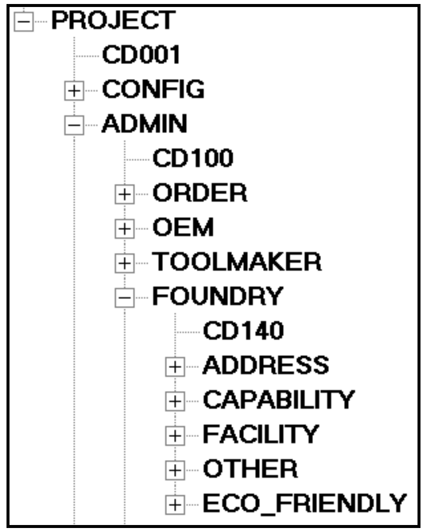


Fig 4.3 Exploded View of FOUNDRY Block

Each of these child data blocks contains the following information in it.

ADDRESS data block

The address data block contains the following information:

1) Contact Person	2) Designation
3) Phone	4) Fax
5) Email	6) Building
7) Company Name	8) Address
9) Street	10) Area
11) City	12) State
13) Country	14) Zip
15) Phone	16) Fax
17) Website	18) Longitude
19) Latitude	

CAPABILITY data block

This contains the information about the following foundry capabilities:

1) Main Product	2) Process
3) Metal Type	4) Weight
5) Size	6) Economic Quantity

7) Production Rate
8) Wall Thickness
9) Core Hole Diameter
10) Tolerance
11) Surface Finish
12) Machining allowance
13) Draft Angle
14) Machining type
15) Shape Complexity
16) Porosity Voids
17) Material Utilization
18) Flexibility
19) Total Casting Units per year
20) Production Capacity (Tons Per Year)
21) Order Size (No Per Year)
22) Delivery Quantity
23) Delivery Frequency
24) Lead time

FACILITY data block

This data block contains the information about the facilities in the foundry like:

1) Molding Process
2) Melting Unit
3) Pouring Method
4) Sand Preparation Method
5) Molding Equipment
6) Core Making Method
7) Machining
8) Heat Treatment
9) Testing Facilities

OTHER data block

1) Tooling Development
2) Software available
3) Quality Certifications
4) Awards
5) Reference Customers

ECO_FRIENDLY data block

This data block contains the information about eco-friendliness of the process like:

1) Chemicals Used
2) Operator Safety
3) Harmful Byproducts
4) Energy Required

4.2.3 Indexing Mechanism of the Process Database

The NAME of the data block corresponding to FOUNDRY node (no.140) is PROJECT.ADMIN.FOUNDRY and its FILE name is CD140_LIB-xyz.XML. Where 'xyz' is a three-digit number, in which the first digit (i.e. x) indicates the Casting Process, the second digit (i.e. y) indicates the material and the third digit (i.e. z) indicates whether the foundry is '*Ideal foundry'* or not. If the third digit is 0, it is an ideal foundry; else it is a real foundry. This is depicted in the following figure. The first digit represents the process and the second digit represents the material.

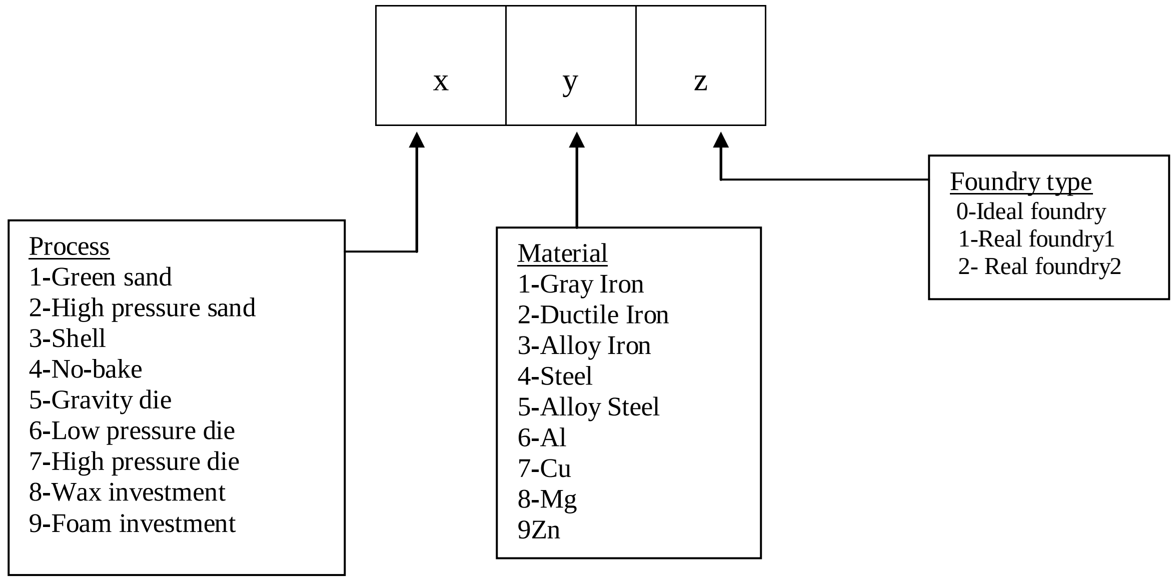


Figure 4.4: XML File Designation

4.2.4 Library Files

The XML format of the library block is similar to that of the data block to which it belongs except with an additional field called 'target file'. It enables uniquely identifying the type of library block (with or without child) and simplifies the coding. In case of a block without child, the target file field uses the value of a single targeted data block.

<TARGET_FILE> CD140.XML </ TARGET_FILE >

While for the data block with children the target file field uses the range of blocks

<TARGET_FILE> CD141.XML_TO_CD145.XML </ TARGET_FILE>

The options information for each data block is stored in a separate file (XML format). It represents the option *meta data* information – data about the options available for a particular data block. The meta data information enables fast tracing and retrieval of option using XML-DOM functions. Here the particular tag TARGET_FILE targets to five different XML files.

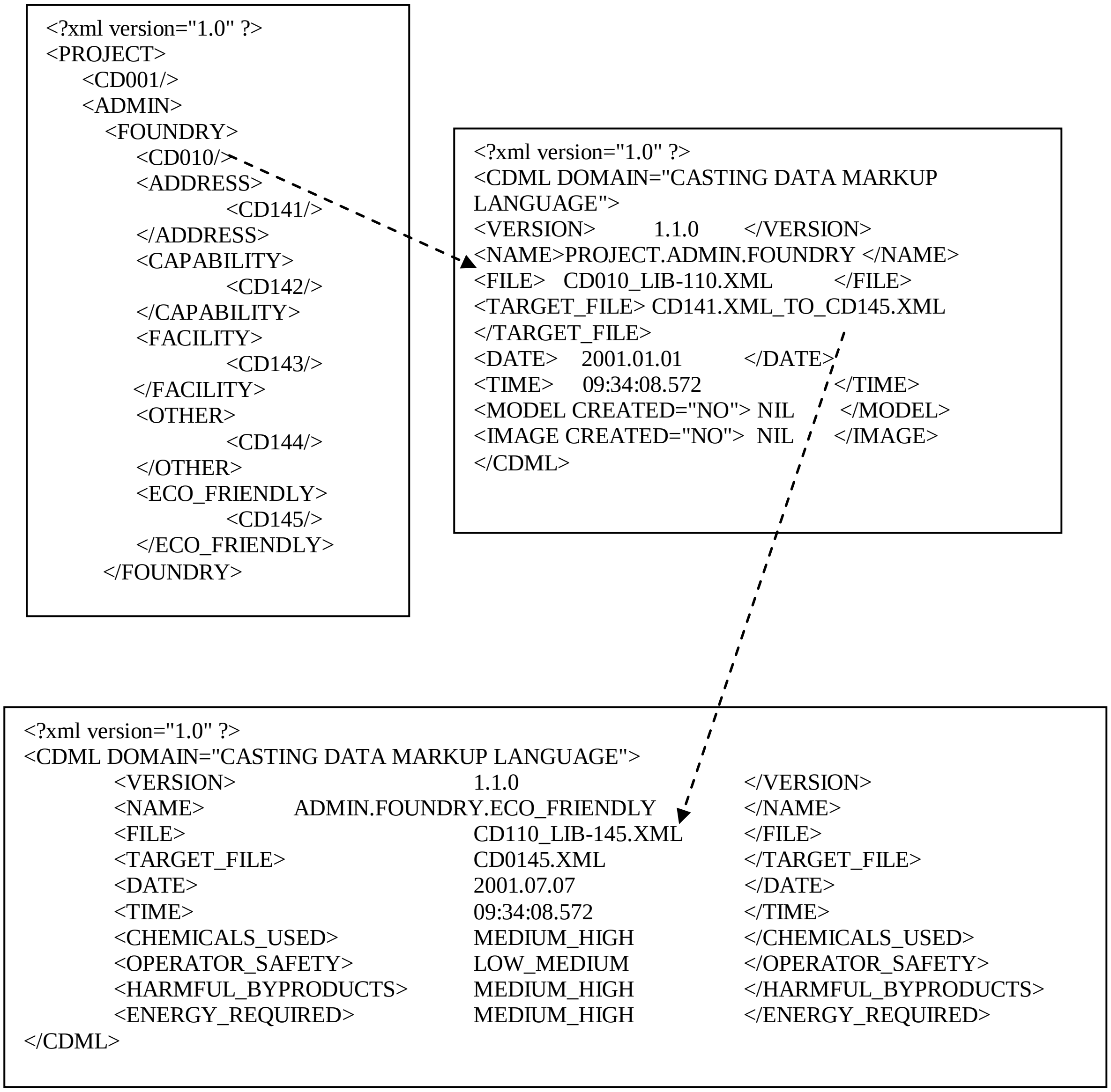


Figure 4.5: FOUNDRY data block with child node

The structures of the data blocks for FOUNDRY node are shown in figures given below.

```
<?xml version="1.0" ?>
<CDML DOMAIN="CASTING DATA MARKUP LANGUAGE">
        <VERSION>                  1.1.0                        </VERSION>
        <NAME>                     PROJECT.ADMIN.FOUNDRY        </NAME>
        <FILE>                     CD140_LIB-110.XML            </FILE>
        <TARGET_FILE>              CD141.XML_TO_CD145.XML       </TARGET_FILE>
        <DATE>                     2001.07.07                   </DATE>
        <TIME>                     09:34:08.572                 </TIME>
        <MODEL CREATED="NO">       NIL                          </MODEL>
        <IMAGE CREATED="NO">       NIL                          </IMAGE>
</CDML>
```

Figure 4.6: Data block ADMIN.FOUNDRY

```
<?xml version="1.0" ?>
<CDML DOMAIN="CASTING DATA MARKUP LANGUAGE">
        <VERSION>                  1.1.0                 </VERSION>
        <NAME>             ADMIN.FOUNDRY.ADDRESS         </NAME>
        <FILE>                     CD110_LIB-141.XML     </FILE>
        <TARGET_FILE>              CD141.XML             </TARGET_FILE>
        <DATE>                     2001.07.07            </DATE>
        <TIME>                     09:34:08.572          </TIME>
        <MODEL CREATED="NO">       NIL                   </MODEL>
        <IMAGE CREATED="NO">       NIL                   </IMAGE>
        <CONTACT_PERSON>           NIL                   </CONTACT_PERSON>
        <DESIGNATION>              NIL                   </DESIGNATION>
        <PHONE>                    NIL                   </PHONE>
        <FAX>                      NIL                   </FAX>
        <EMAIL>                    NIL                   </EMAIL>
        <BUILDING>                 NIL                   </BUILDING>
        <COMPANY_NAME>             NIL                   </COMPANY_NAME>
        <ADDRESS>                  NIL                   </ADDRESS>
        <STREET>                   NIL                   </STREET>
        <AREA>                     NIL                   </AREA>
        <CITY>                     NIL                   </CITY>
        <STATE>                    NIL                   </STATE>
        <COUNTRY>                  NIL                   </COUNTRY>
        <ZIP>                      NIL                   </ZIP>
        <PHONE>                    NIL                   </PHONE>
        <FAX>                      NIL                   </FAX>
        <WEBSITE>                  NIL                   </WEBSITE>
        <LONGITUDE>                NIL                   </LONGITUDE>
        <LATITUDE>                 NIL                   </LATITUDE>
</CDML>
```

Figure 4.7: Sample Data block ADMIN.FOUNDRY.ADDRESS

```xml
<?xml version="1.0" ?>
<CDML DOMAIN="CASTING DATA MARKUP LANGUAGE">
    <VERSION>        1.1.0        </VERSION>
    <NAME>        ADMIN.FOUNDRY.CAPABILITY        </NAME>
    <FILE>        CD110_LIB-142.XML        </FILE>
    <TARGET_FILE>        CD142.XML        </TARGET_FILE>
    <DATE>        2001.07.07        </DATE>
    <TIME>        09:34:08.572        </TIME>
    <MODEL CREATED="NO">        NIL        </MODEL>
    <IMAGE CREATED="NO">        NIL        </IMAGE>
    <MAIN_PRODUCT-1>        NIL        </MAIN_PRODUCT-1>
    <MAIN_PRODUCT-2>        NIL        </MAIN_PRODUCT-2>
    <PROCESS>        GREEN_SAND        </PROCESS>
    <METAL_TYPE>        GRAY_IRON        </METAL_TYPE>
    <WEIGHT_MIN UNIT="kg">        0.02        </WEIGHT_MIN>
    <WEIGHT_MAX UNIT="kg">        400000        </WEIGHT_MAX>
    <SIZE_MIN UNIT="mm">        3        </SIZE_MIN>
    <SIZE_MAX UNIT="mm">        10000        </SIZE_MAX>
    <ECONOMIC_QUANTITY_MIN UNIT="No">        1        </ECONOMIC_QUANTITY_MIN>
    <ECONOMIC_QUANTITY_MAX UNIT="No">    1000000        </ECONOMIC_QUANTITY_MAX>
    <PRODUCTION_RATE_MIN UNIT="Qty">        1        </PRODUCTION_RATE_MIN>
    <PRODUCTION_RATE_MAX UNIT="Qty">        60        </PRODUCTION_RATE_MAX>
    <WALL_THICK_MIN UNIT="mm">        3.175        </WALL_THICK_MIN>
    <WALL_THICK_TYPICAL UNIT="mm">        6.35        </WALL_THICK_TYPICAL>
    <WALL_THICK_MAX UNIT="mm">        1000        </WALL_THICK_MAX>
    <CORE_HOLE_DIA_MIN UNIT="mm">        4.76        </CORE_HOLE_DIA_MIN>
    <CORE_HOLE_DIA_TYPICAL UNIT="mm">  6.35        </CORE_HOLE_DIA_TYPICAL>
    <CORE_HOLE_DIA_MAX UNIT="mm">        19        </CORE_HOLE_DIA_MAX>
    <TOLERANCE_MIN UNIT="mm">        0.5        </TOLERANCE_MIN>
    <TOLERANCE_MAX UNIT="mm">        2        </TOLERANCE_MAX>
    <TOLERANCE_TYPICAL UNIT="mm">        0        </TOLERANCE_TYPICAL>
    <SURFACE_FINISH_MIN UNIT="um">        3.2        </SURFACE_FINISH_MIN>
    <SURFACE_FINISH_TYPICAL UNIT="um">    15        </SURFACE_FINISH_TYPICAL>
    <SURFACE_FINISH_MAX UNIT="um">        50        </SURFACE_FINISH_MAX>
    <MACHINE_ALLOWANCE_MIN UNIT="mm">    2.3    </MACHINE_ALLOWANCE_MIN>
    <MACHINE_ALLOWANCE_MAX UNIT="mm">    16    </MACHINE_ALLOWANCE_MAX>
    <MACHINE_ALLOWANCE_TYPICAL UNIT="mm"> 5  </MACHINE_ALLOWANCE_TYPICAL>
    <DRAFT_ANGLE_MIN UNIT="degree">        1        </DRAFT_ANGLE_MIN>
    <MACHINING_TYPICAL>        ROUGH        </MACHINING_TYPICAL>
    <SHAPE_COMPLEXITY>        MEDIUM        </SHAPE_COMPLEXITY>
    <POROSITY_VOIDS>        HIGH        </POROSITY_VOIDS>
    <MATERIAL_UTILIZATION>        MEDIUM        </MATERIAL_UTILIZATION>
    <FLEXIBILITY>        VERY_HIGH        </FLEXIBILITY>
    <TOTAL_CASTINGS UNIT="per_year">        0        </TOTAL_CASTINGS>
    <PROD_CAPACITY UNIT="tons_per_year">    4500000        </PROD_CAPACITY>
    <ORDER_SIZE_MIN UNIT="no_per_year">        34        </ORDER_SIZE_MIN>
    <ORDER_SIZE_MAX UNIT="no_per_year">        456        </ORDER_SIZE_MAX>
    <DELIVERY_QUANTITY_MIN>        600        </DELIVERY_QUANTITY_MIN>
    <DELIVERY_QUANTITY_MAX>        2000        </DELIVERY_QUANTITY_MAX>
    <DELIVERY_FREQUENCY_MIN>        1        </DELIVERY_FREQUENCY_MIN>
    <DELIVERY_FREQUENCY_MAX>        30        </DELIVERY_FREQUENCY_MAX>
    <LEADTIME>        DAYS        </LEADTIME>
</CDML>
```


Figure 4.8: Sample Data block ADMIN.FOUNDRY.CAPABILITY

4.3 Process Planning Database

The process planning information has been stored under the node named PROCESS. Its node number is 500. The PROCESS information has been classified into eight different child nodes. The casting process planning information is stored under the child nodes PRE_CASTING, CASTING and POST_CASTING numbered 530, 540 and 550 respectively. The PRE_CASTING data block further stores the information about the pre-casting *tasks* in CORE_SAND_PREP (531), CORE_MAKING (532), CORE_DRESSING (533), MOLDING_SAND_PREP (534) and MOLD_MAKING (535). Here the number in the bracket is the corresponding node number. The Figure 3.13 shows the expanded view of PROCESS node.

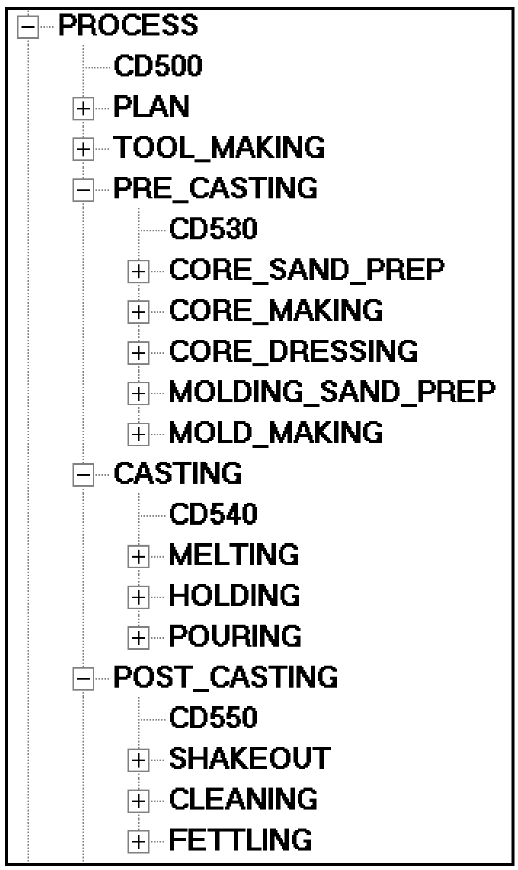


Figure 4.9: Expanded view of PROCESS node

There are different *methods* to accomplish each of these *tasks*. Each of these nodes is connected to different XML files, which contains the detailed stepwise information about the different *methods*.

4.3.1 Representation of Libraries

The process planning information fall into the block 531 to 545 in the main library file of CDML. The portion of the CDML library structure where FOUNDRY block falls, is shown in Figure 3.13.

```
<?xml version="1.0" ?>
<CDML_LIBRARY>
        ……………………………………………………………………………..
        <CD531_LIB-001> CORE_SAND_PREP: HOT_BOX </CD531_LIB-001>
        <CD531_LIB-002> CORE_SAND_PREP: OIL_SAND </CD531_LIB-002>
        ………………………………………………………………………………
        <CD532_LIB-001> CORE_MAKING: HOT_BOX </CD532_LIB-001>
        <CD532_LIB-002> CORE_MAKING: OIL_SAND </CD532_LIB-002>
        ………………………………………………………………………………
        ………………………………………………………………………………
</CDML_LIBRARY>
```

Fig 4.10: Library structure for Process Planning (partial)

The information about the steps of core sand preparation is stored in the XML data file. The NAME of the data block corresponding to node CORE_SAND_PREP (node no.531) is PROJECT.PROCESS.PRE_CASTING.CORE_SAND_PREP and its FILE name is CD531_LIB-001.XML. Where CD531 corresponds to the node number 531 of the CDML tree i.e. CORE_SAND_PREP. To identify that the particular file is a library file a LIB will be followed by CD531. ‘001’ denotes that the file contains information about the first *method* (here, HOT BOX) for core sand preparation. The subsequent methods can be shown by digits 002, 003 etc. Information about the other nodes under PRE_CASTING, CASTING AND POST_CASTING nodes is stored in the same way in XML files.

4.3.2 Fields and values

Apart from the eight common fields names viz. CDML, VERSION, NAME, FILE, DATE, TIME, MODEL and IMAGE, the XML file contains the following tags:

<METHOD> HOT_BOX </METHOD>

<STEP_NUM> 5 </STEP_NUM>

<STEP1> Inspect the raw material </STEP1>

<STEP2> Mixing of the sand </STEP2>

The tag METHOD stores the type of method employed for a particular task and it may contain the values like HOT_BOX, OIL_SAND etc. The tags STEP1, STEP2 etc contains the brief information about the steps in the casting process. The tag STEP_NUM represents the total number of steps in a particular XML file. One sample data block is shown in the Figure 4.11.

```
<?xml version="1.0" ?>
<CDML DOMAIN="CASTING DATA MARKUP LANGUAGE">
        <VERSION>               1.1.0                                   </VERSION>
        <NAME>          PROCESS.PRE_CASTING.MOLD_MAKING                 </NAME>
        <FILE>                  CD535_LIB-001.XML                       </FILE>
        <TARGET_FILE> CD535.XML                                 </TARGET_FILE>
        <DATE>                          2001.10.07                      </DATE>
        <TIME>                          09:34:08.572                    </TIME>
        <MODEL CREATED="NO">            NIL                             </MODEL>
        <IMAGE CREATED="NO">            NIL                             </IMAGE>
        <METHOD>                        HOT_BOX                         </METHOD>
        <STEP_NUM>                      12                              </STEP_NUM>
        <STEP1>                 Inspect the pattern                     </STEP1>
        <STEP2>                 Make cope mold                          </STEP2>
        <STEP3>                 Inspect and clean cope mold             </STEP3>
        <STEP4>                 Open vents                              </STEP4>
        <STEP5>                 Make drag mold                          </STEP5>
        <STEP6>                 Inspect drag mold                       </STEP6>
        <STEP7>                 Paint drag mold                         </STEP7>
        <STEP8>                 Lower the core assembly in the drag mold </STEP8>
        <STEP9>                 Inspect the core assembly in mold       </STEP9>
        <STEP10>                Apply lambi, gum, MS strip for sealing  </STEP10>
        <STEP11>                Close the cope mold on the drag mold    </STEP11>
        <STEP12>                Clamp cope and drag mold together       </STEP12>
</CDML>
```

Figure 4.11: PROCESS.PRE_CASTING.MOLD_MAKING Data block

CHAPTER 5

IMPLEMENTATION AND TESTING

Function Flow Chart

The system includes the following three functionalities:

1. Browsing the casting process database library,
2. Screening the process library as per the product requirements,
3. Browsing the casting process database.

A simplified flow chart for the process selection and planning system is shown below:

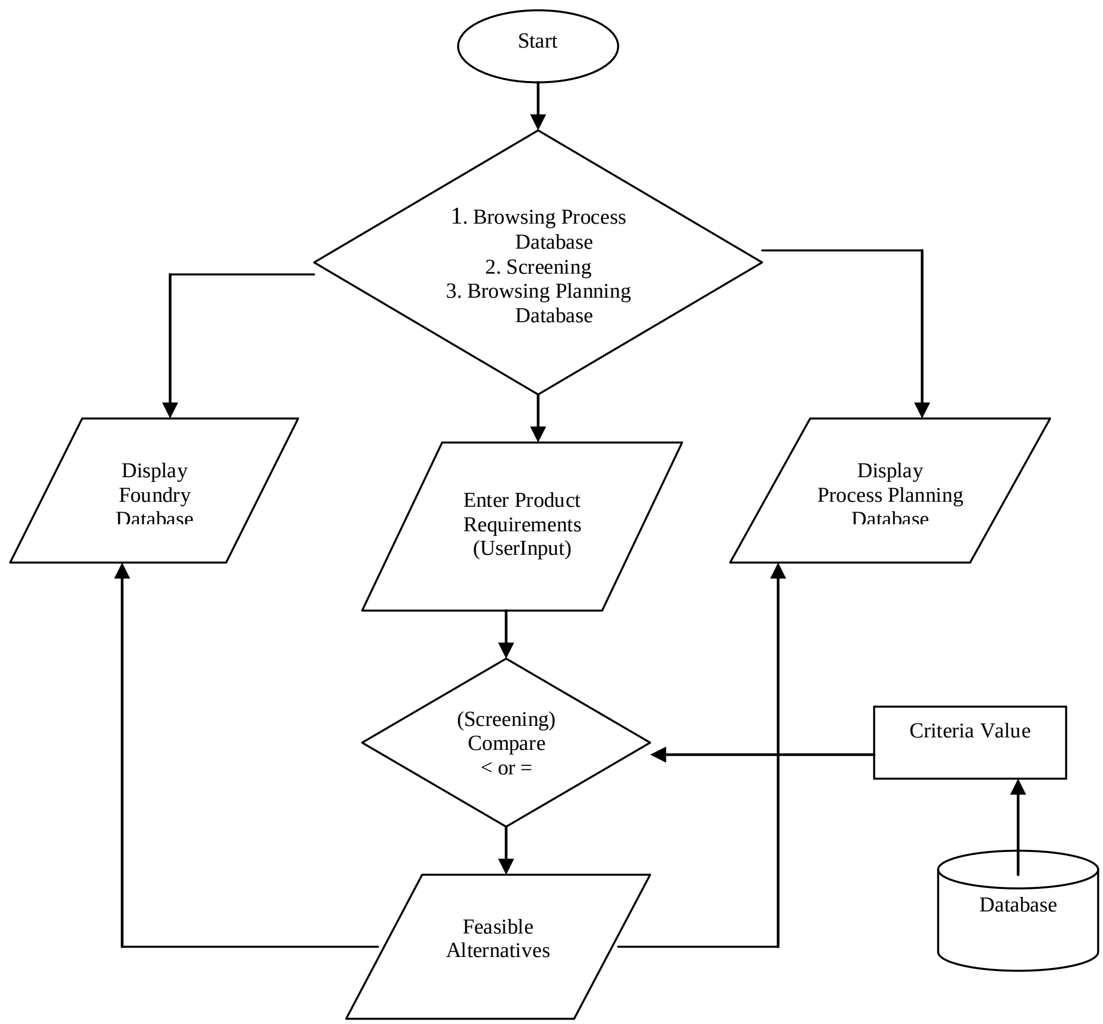


Figure 5.1: Simplified function flow chart of the system

5.1.1 Browsing through the process Database

When the PROJECT data block is expanded and FOUNDRY node of the CDML tree is selected a button named ‘library’ will appear in the seventh window of the user interface screen. The function of this button is to display the process options in the display window along with function ‘view options’. Which further displays the different material options for the selected process and finally the foundry options (GREEN_SAND: GRAY_IRON is one foundry option) along with functions ‘view option’ and ‘copy option’. These functions allow user to browse and display the contents of the selected option or copy it into the project. Thus browsing of the process database is very simple and self-explanatory.

5.1.2 Browsing through the Process Planning Database

To view the casting process planning database PROCESS node of the CDML tree is expanded to select PRE_CASTING, CASTING and POST_CASTING nodes. Expanding these nodes shows the lower level nodes (e.g. CORE_SAND_PREP, CORE_MAKING etc), which corresponds to the respective *task*. Selecting this node (e.g. CORE_MAKING) enables ‘library’ function that displays the various *methods* available for the selected node along with functions ‘view option’ and ‘copy option’. Which displays the *steps* for the selected *method* and copy it.

5.1.3 Screening Function

When user clicks on the node PRODUCT, and then node REQUIREMENT. He can fill the product requirements information in the text boxes that are automatically appeared in the second window. Then he can save the changes by clicking the ‘update’ button. Then after clicking the ‘screen’ button the these product requirements are compared with identified criteria and alternatives (*options*) which match with the product requirements are displayed in the fifth window.

5.2 Implementation Tools

Since this particular type of application follows client server architecture, it is mainly database oriented and has a database created at the server side. The tools needed for this application are:

1. Tools used for developing user interface in web.
2. Tool for creating web compatible database at the server side

3. Scripting language for the client side and server side

5.2.1 Tool for User Interface

HTML (HyperText Markup Language) is the tool used for developing user interfaces at the client side. HTML is an application of SGML (Standard Generalized Markup Language). The Internet protocol, which is used to communicate between Web clients and servers, is HTTP (HyperText Transfer Protocol). It is a simple language used to define and describe the layout of a web pages it also supports multimedia and document links.

5.2.2 Client and Server side Scripting languages

Whenever the user submits a form the request goes to the server. This client-server transaction consumes time. So there should be minimum number of such transactions and simple operations like validating forms should be preformed at the client side only to improve the speed. For this kind of client side scripting JavaScripts are used. JavaScripts facilitates the developer with properties related to document windows, frames forms, loaded documents and links. This is an interpreter-based language and source code files are directly executed at run time. Since JavaScript is an object based language, it supports instances, methods and properties.

The server side scripting language used in this project is PHP3.0. It is an open source. Server side scripting language communicates with the database at the server side and gets the desired results according to the functions. PHP is a server-side, cross-platform, HTML embedded scripting language. PHP is a tool that lets you create dynamic web pages. PHP-enabled web pages are treated just like regular HTML pages and you can create and edit them the same way you normally create regular HTML pages. PHP3.0's strongest feature is its database interfacing capability. Connecting a database to Internet has become easy because of PHP.

5.2.3 Tool for Database

XML (Extensible Markup Language, version 1.0) is used to for storing the casting database. It is based on the same principles of markup languages that make HTML work.

HTML is designed to display only static text. It is the most widely used extension of HTML that has been created to handle more complex tasks that HTML cannot perform. XML is itself a markup language, using the same general tag notation of HTML. But the basic difference is that, it allows us to define our own tags, which make it much more flexible than HTML. By utilizing thus property, databases for web can easily be created.

5.3 User Interface

To facilitate the easy interaction between the remote server and the client (web browser) a separate program have been developed called webICE GUI. When the user initializes the casting project the program is automatically downloaded into the client-browser. It has been developed to provide graphical user interface in the client-browser and linking mechanism between CDML tree, data block, functions, application programs and library options. The size of the program is 25 KB only and it uses XML-DOM functions for accessing the CDML tree and data blocks, HTML for better visual representation and JavaScript for dynamic content.

For better visual representation the screen display at client side is divided into seven windows [Figure 5.2] and the output of various tasks performed by the webICE GUI are ported into different windows. The use of seven windows on the client-browser is shown below.

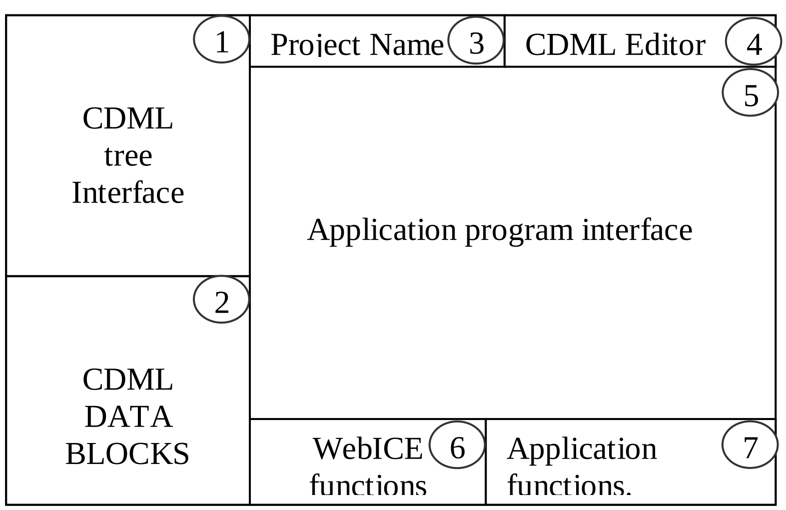


Figure 5.2: User interface layout [Akarte, 2001]

The first window is used to display the CDML tree, which expand or collapse with mouse click. The second window is used to display the detailed information classified under a particular data block. It allows the user to browse and modify the required casting process data. The third window displays the name of the casting project. Fourth window shows the webICE GUI version. The fifth window displays the application program and its interface; the computational results are also displayed in the same window. Functions (delete, link and update) are ported in to the sixth window. The seventh window shows data block functions specific to a particular application, for example, Library and Calculate weights. Any application or library option attached to a specific data block will have a link through this window. The selection (by mouse click) of a particular function in this window will automatically initiate the respective program in window five.

The following figure shows the screen shot of the user interface:

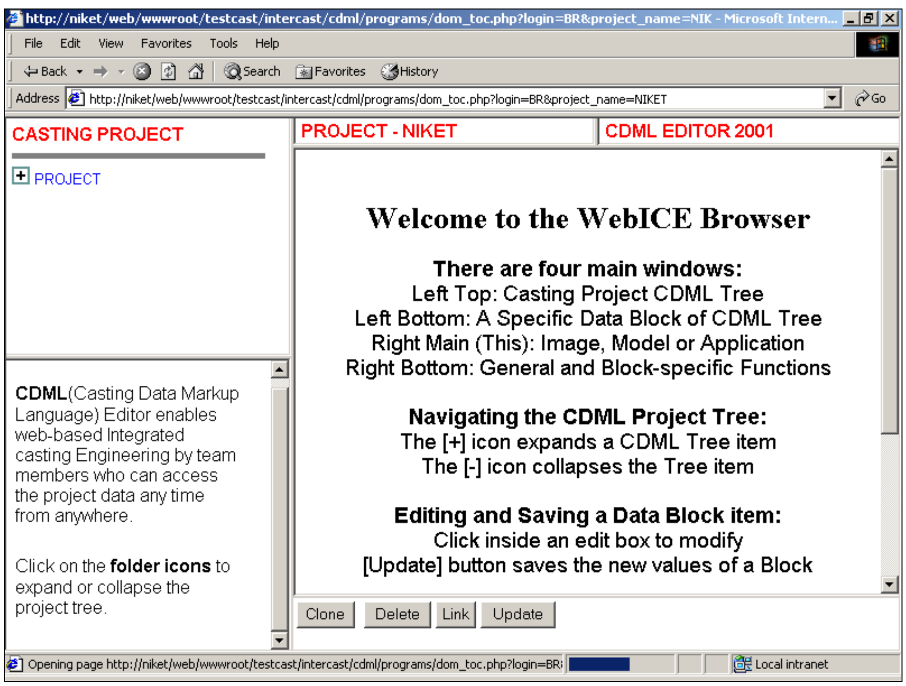


Figure 5.3: User Interface Screen

5.3.1 CDML Tree and Data Blocks

As mentioned in the earlier there is a one to one correspondence between the CDML tree and the corresponding data block and both are stored in XML format. Initially, when the user initiates the project (either a new or existing) the webICE GUI program loads the

CDML tree from server and creates the virtual tree in the browser, which is then displayed into the readable format using the HTML tags.

On selection a particular node from the CDML tree, the client request goes to the server for the corresponding data block file. Server locates the file and sends it back to the client, which is then accessed by XML-DOM function of webICE GUI program and converted into readable and modifiable format using HTML and then displayed in window two.

5.3.2 Function Interface

The linking of application program with the system is through a function name. A simple new approach to the user interface has been developed for linking and displaying the functions in a client browser as an alternative to the conventional pull down menus and icons. The approach uses the notion of context sensitive functions. That is, each function is linked to a particular CDML tree node and is visible only when the user clicks that node.

This approach minimizes the number of functions that are displayed at a particular instance in window seven of CDML editor. In particular, while browsing, at any instant only those function name(s) are displayed which are linked to the data block that is currently being viewed. The function names will disappear from the window seven whenever other data block is loaded and functions, if any, related to the new data block will be shown in window seven. In this situation, the user need not have to remember the function name as they appear automatically while browsing the required information, relieving the function search effort of the user.

5.4 Sample Session

After giving correct login name and password to open an existing project, user can select the project name form the list to open it.

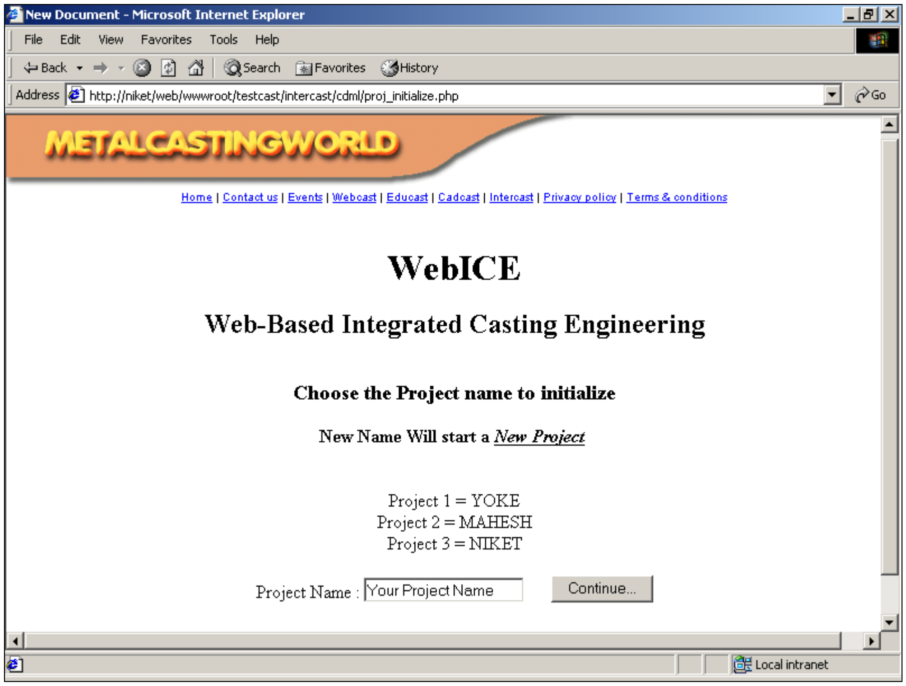


Figure 5.4: Selection of an existing project

After opening a project and expanding the project node and clicking on foundry, listing of processes can be viewed by clicking the library button.

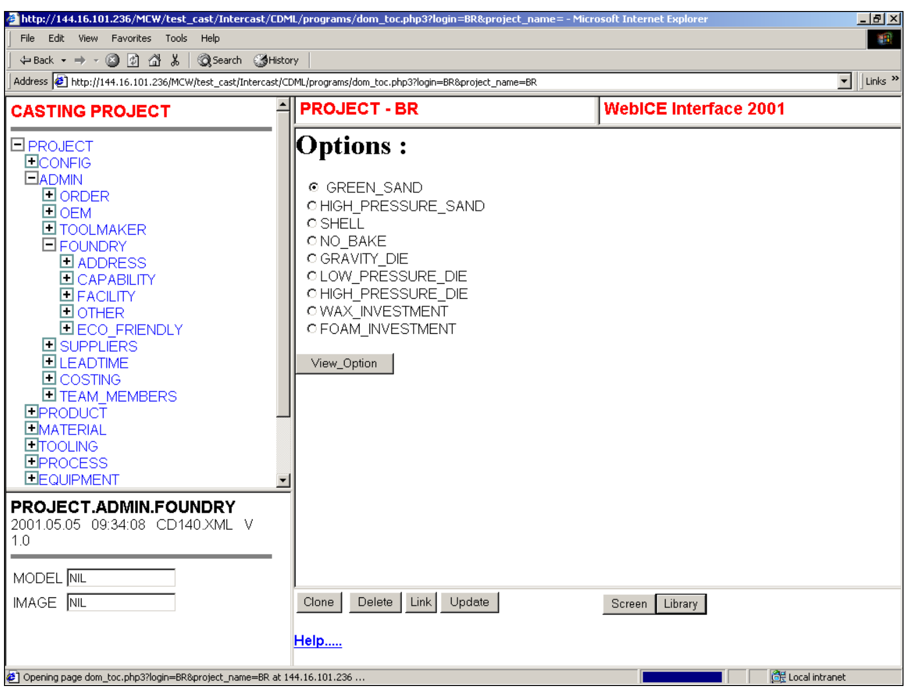


Figure 5.5: Listing of processes from database

After selecting a process the listing of materials for the selected process is shown.

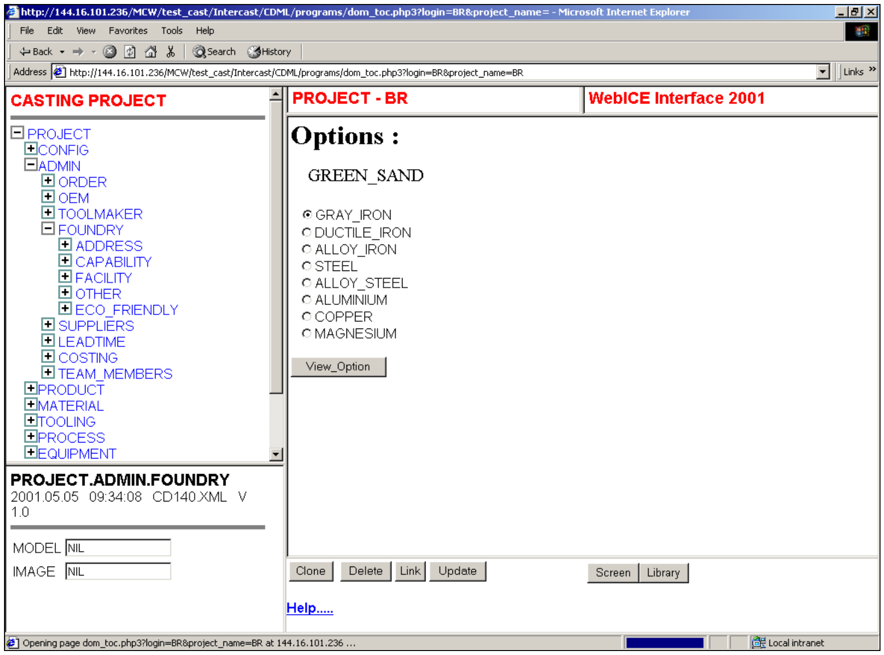


Figure 5.6: Listing of materials for the selected process

Foundry database listing can be displayed. It shows the complete library listing.

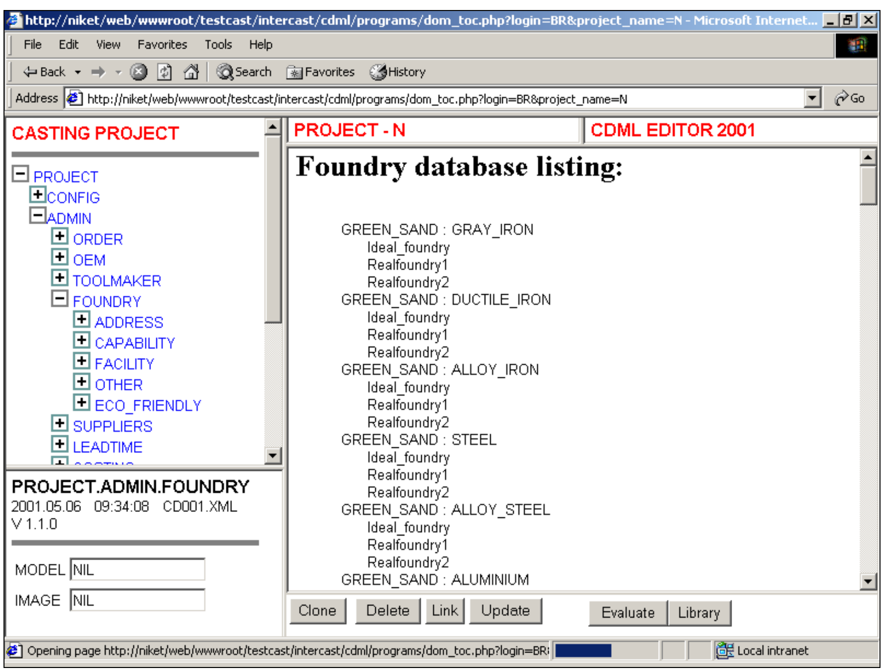


Figure 5.7: Foundry database listing

The foundry options for the selected process and the material is shown

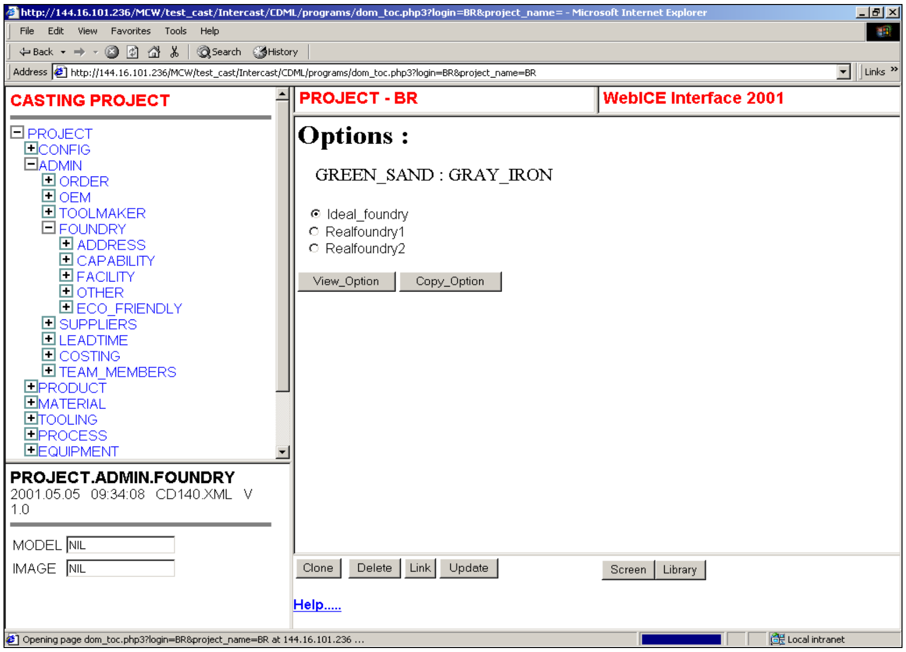


Figure 5.8: Foundry options

After selecting the foundry options links to address, capability, facility, other and eco-friendly data block information are shown.

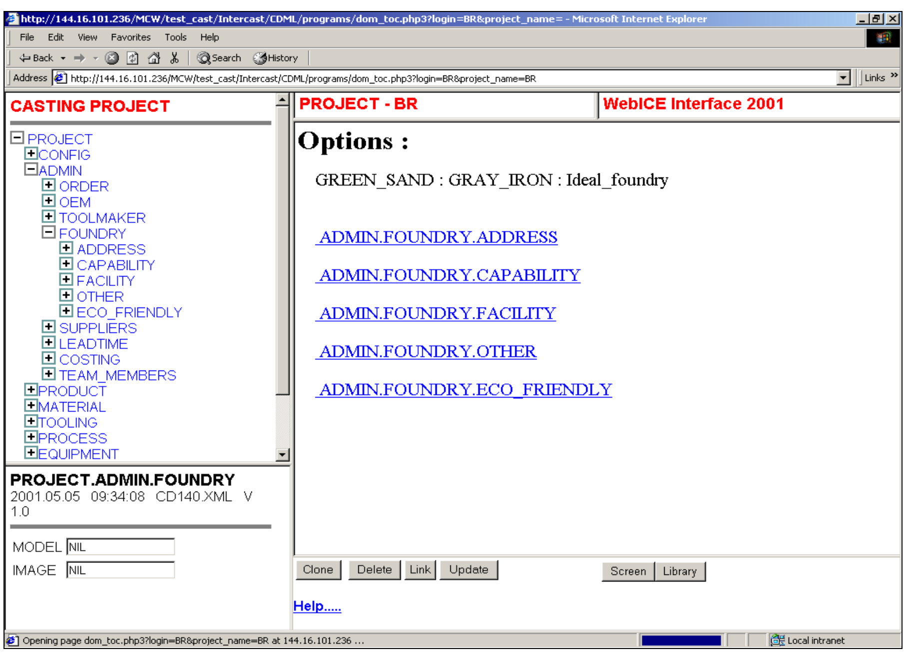


Figure 5.9: Datablock

After clicking any of the above links, the details of that data block are displayed.

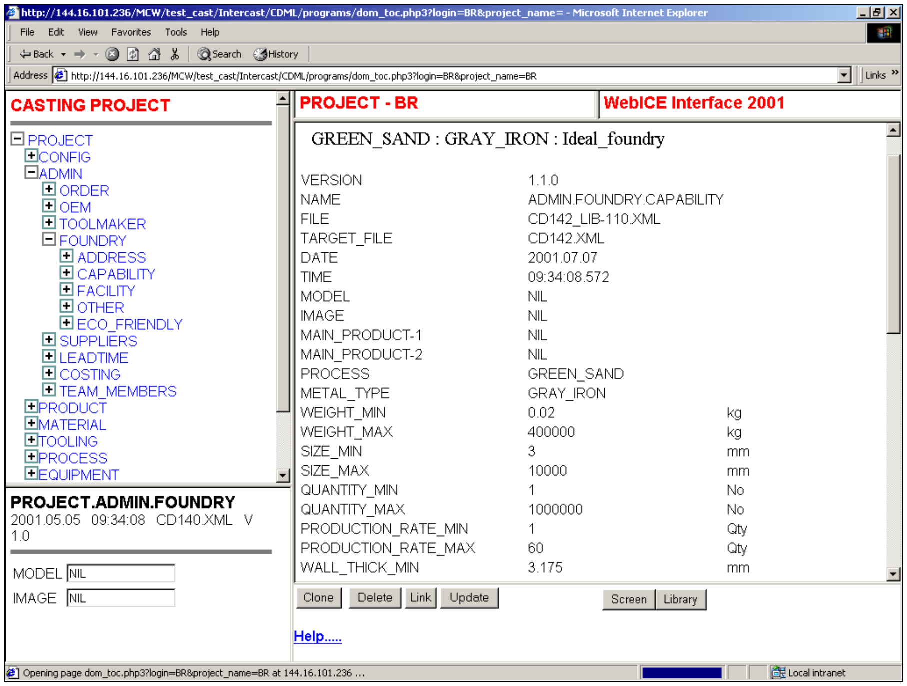


Figure 5.10: Foundry CABILITY details

User gives the product requirements in the data block window by clicking product-requirements node and save it by clicking update button.

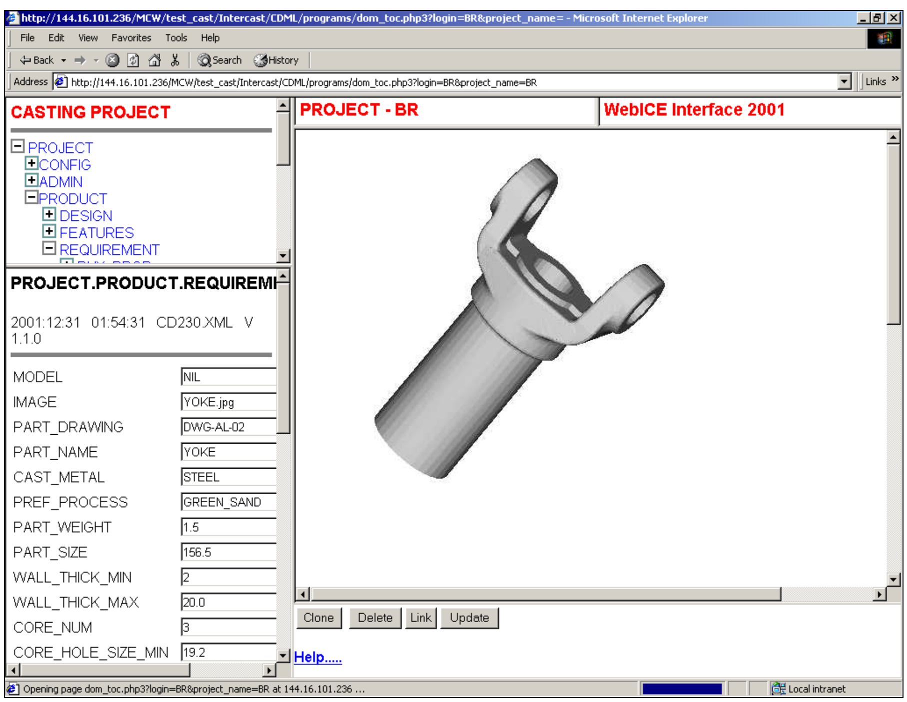


Figure 5.11: Product requirements

After giving the product requirements the database is screened to see the feasible processes. Which are evaluated to select the best process.

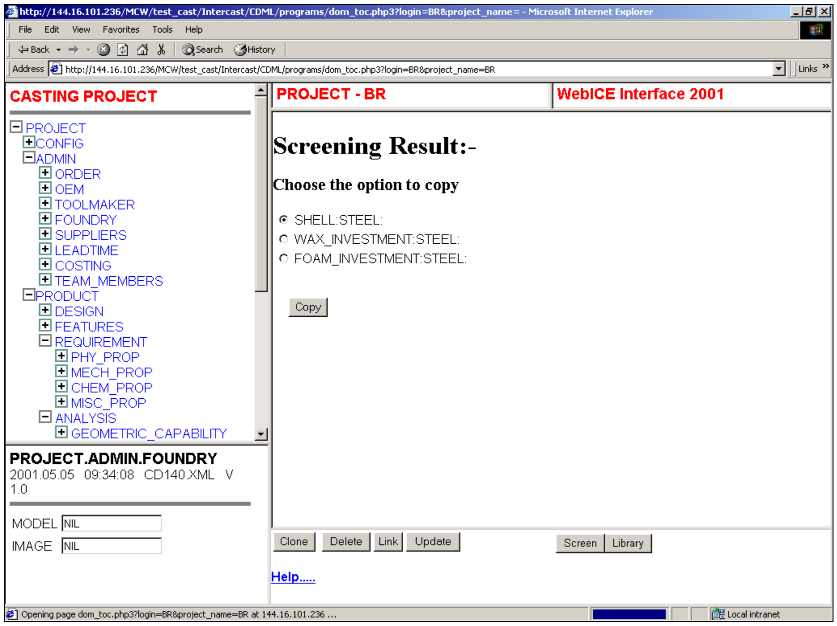


Figure 5.12: Screening Results

The casting process planning database can be viewed by clicking the corresponding nodes from the CDML tree. By clicking a particular node different *method* options for that node are displayed.

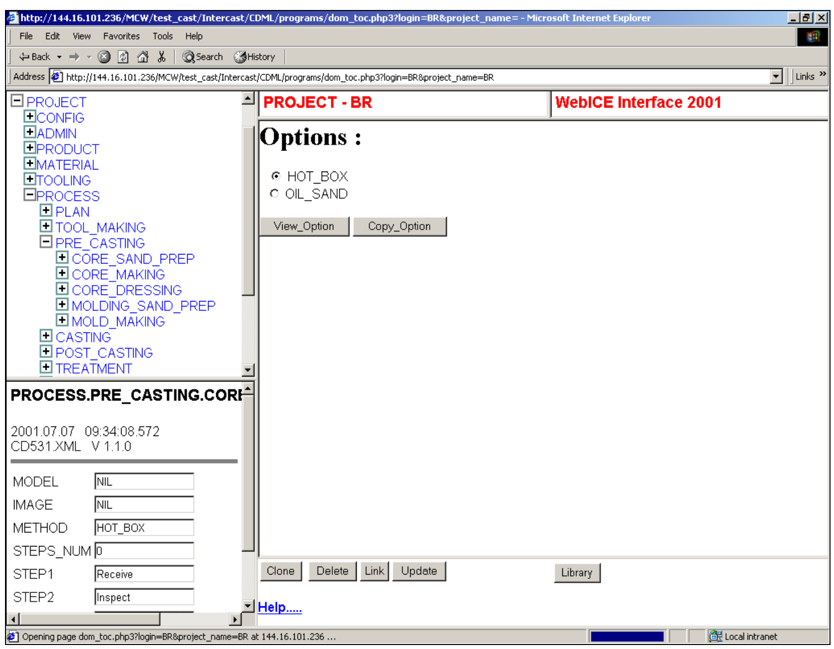


Figure 5.13: Methods for core sand preparation

After selecting a specific method and clicking 'view options', the detailed steps in that particular node are displayed.

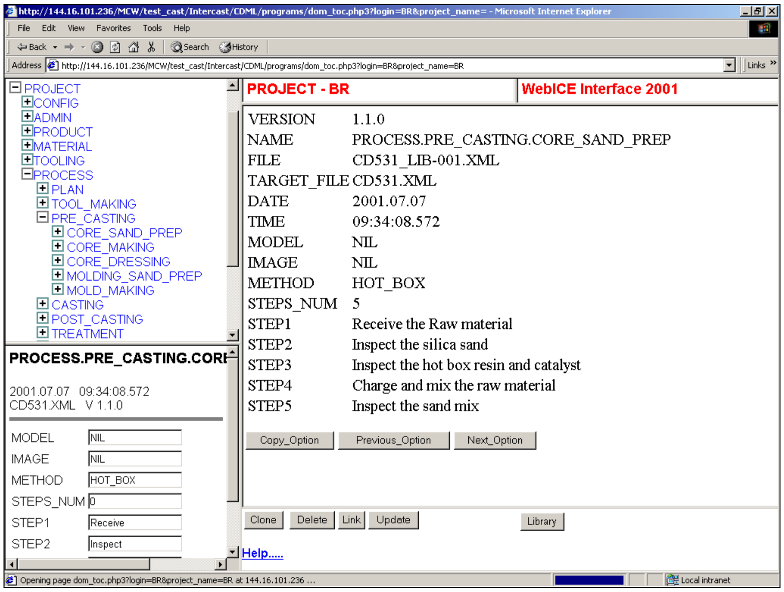


Figure 5.14 Hot Box core sand preparation steps

Thus the system is very simple to use and no special training is required to use it. This is achieved by the new innovative user interface. The required functions appears in the seventh window when the corresponding node is selected from the CDML tree.

CHAPTER 6
CONCLUSIONS

6.1 Contributions

Important criteria, which influence the casting process selection, have been identified. Casting information has been collected as per the identified criteria to prepare casting processes and planning database. Material specific database has been created for the following casting processes:

1. Green sand casting
2. High pressure sand casting
3. Shell molding
4. No-bake process
5. Gravity die casting
6. Low pressure die casting
7. High pressure die casting
8. Wax investment process
9. Foam investment process

The following materials are considered in this work: Gray Iron, Ductile Iron, Alloy Iron, Steel, Alloy steel, Aluminum, Copper, Magnesium and Zinc.

The information about the process and process planning is prepared using XML and stored in CDML. The tool used for this is XML, which is the widely used tool for web compatible databases. The system is designed, developed and implemented by using WebICE framework.

The tools used for this system and design of the database files is so done, so as to make maximum utilization of the web. The functional requirements of the system are decided, thinking from the users point of view.

The functional requirements implemented in this system are: Browsing the casting process database, screening the database, browsing the process planning database.

6.2 Limitations and Future Work

The scope of this process selection system is limited to only nine casting processes, for which the database has been created. The database is required to be updated continuously to accommodate newest improvements in the process control and hence process capabilities. The process planning database also needs to be updated. The preliminary process planning system enlists the casting steps only and does not calculate the actual time required for casting a product.

Since it is a web-based system, the user should have access to Internet to use this system. This selection system can be used only through an MS Internet explorer or Netscape navigator. Thought from the system design point of view care has been taken to make it work at high speed; the speed of this system is dependent on the network speed.

Evaluation methodology can be implemented to evaluate the screened processes. The preliminary process planning can be developed to get a more detailed process plan by going one level below the *steps*. The tools used in this system have to be upgraded when new versions of the same are released. The system can be modified to an expert system, by building an appropriate database by consulting with various experts in foundries.

REFERENCES

1. Ajmal A. and Dale B.G., "*A microcomputer-Aided Interactive process planning and Estimation system for use in Jobbing foundry*," Advances in manufacturing technology, University of Nottinggham, Kogan Page Ltd, pp 491-501, (1985).
2. Akarte M.M., "*A Framework for Web-based Integrated Casting Engineering and its application to product-process-producer compatibility evaluation*," Ph.D.Thesis, IIT Bombay, (2001).
3. Akarte M.M., B.Ravi and R.C.Creese, "*Casting process selection using AHP and Fuzzy Logic*," Int. Seminar on Mfg. Tech. Beyond 2000, Bangalore, (November, 1999).
4. Alting L. and Zhang H.C., "*Computerised Manufacturing Process Planning*," Chapman and Hall, (1994).
5. Allen A.J., B.Eng and K.G.Swift, "*Manufacturing Process Selection and Costing*," Proc. Instn. Mech. Engrs., Vol. 204, pp 143, (1990).
6. Bralla J.G., "*Handbook for product design for manufacturing*," McGraw-Hill, New York, pp 1-9, (1988).
7. Chang T.C. and Wysk R.A, "*An Introduction to automated process planning system*," Prentice-Hall Inc, (1985).
8. Darwish S.M., A.M.El-Tamimi, "*The selection of the casting process using an expert system*," Computers in Industry, Vol.30, pp.77-86, (1996).
9. Dieter G.E., "*Engineering Design: A material and processing approach*," McGraw-Hill, New York, (1991).
10. Er A., Sweeney E.T. and Kondic, "*A knowledge based system for casting process selection*," AFS Casting Congress, Philadelphia, pp. 20-23, (April, 1996).
11. Esawi A.M.K., and M.F.Ashby, "*Computer-based selection of manufacturing processes: methods, software and case studies*," Proc Instn Mech Engrs, Vol.212, Part B, (1998).

12. GiachettiR.E., "*A decision support system for material and manufacturing process selection*," J. of Intelligent manufacturing, Vol.9(3), pp.265-276, (1988).

13. Heine R.W., and Rosenthal, P.C., "*Principles of metal casting*," McGraw-Hill, New York, (1995).

14. Ishii K., Lee, C.H., and Miller R.A., "*Methods for process selection in Design*," ASME, Vol.27, pp.105-112, (1990).

15. Lovatt A.M. and H.R.Shercliff, "*Manufacturing process selection in engineering design. Part 1: the role of process selection*," Materials and Design, Vol.19, pp.205-215, (1998).

16. Nolen J., "*Computer automated process planning for manufacturing*," Markel dekker Inc, (1990).

17. Perzyk M., O.K.Meftah, "*Selection of manufacturing process in mechanical design*," J. of Materials Processing Technology, Vol.76, pp.198-202, (1998).

18. Ravi B. and M.M.Akarte, "*Internet – Millennium Mantra for Metalcasters*," Indian Foundry Congress, New Delhi, (2001).

19. Ravi B. and Akarte MM, "*Casting Information Management*," Transactions of the AFS, 104, pp. 217-223, (1996).

20. Ravi B., and M.N.Srinivasan, "Features-based castability evaluation," Int. J. of Production Research, Vol.33, No.12, pp 3367-3380, (1995).

21. Schey J.A, "*Manufacturing processes and their selection*," ASM Handbook, Vol. 20, pp 687, (1997)

22. Sirilertworakul N., P.D.Webster and T.A.Dean, "*A knowledge base for alloy and process selection for casting*," Int.J.Machine Tools Manufacturing, Vol.33, No.3, pp.401-415 (1993).

23. Steudel H.J, "*Computer-aided process planning: Past, present and future*," Int. J. of production research, 22(2), pp.253-266, (1984).

24. Yu Jyh-Cheng, Sherveen Lotfi, Kos Ishii, "*Process selection for the design of aluminum components*," Advances in Engg. Software, Vol.18, pp.177-186, (1993).

Acknowledgement

It gives me great pleasure in expressing sincere and deep gratitude towards my project guide **Prof. B. Ravi** for his valuable guidance and support in the completion of this work.

I wish to convey my sincere thanks to **Mr. S. V. Khare** (General Manager), **Mr. S. P. Sohoni** (Production Manager) and staff of Foundry PU, Mahindra and Mahindra Ltd. and **Mr. Banerjee** and staff of The Indian Smelting and Refining Co. Ltd. Also, I take this opportunity to express my gratitude towards all the people from various other foundries that allowed me to visit their facilities and gave useful information.

I also thank **Mr. M. M. Akarte, R.G. Chougule** and all my friends who directly or indirectly helped me during the course of this work.

I.I.T. BOMBAY **Niket P. Borade**

Jan. 2002 Roll No. 00310405