Chapter -4
Case Studies in Casting / Foundry Industry

4.1.0 Introduction:
As has been already discussed, various aspects related to TQM and energy conservation have been investigated and analyzed critically in this research project for the following sectors
1) Casting/ Foundry industries, 2) Cement Industries (large scale and medium scale), 3) Thermal Power Plants, 4) Mini cement plants- representative of SSI and 5) Selected Chemical Industries inclusive of refineries.
Amongst these different industrial sectors, casting/foundry sector appears to be of prime importance and all the relevant aspects have been considered in this Chapter.
Field/ plant Visits were arranged to following foundries for these case studies:
1. Shining Engineers & Founders, Shaper,
2. Prashant Castings (P) Ltd, Rajkot,
3. Accutech Metal Pvt. Ltd. Meghdoot Foundry, Rajkot,
4. Sardar Casting Private Limited, Rajkot,
5. Kamani Foundry, Rajkot,
6. Gautam Technocast, Rajkot,
7. Patel Foundry, Rajkot,
8. Rasik Foundry, Rajkot

This chapter under consideration has been divided in three parts as under
1) Optimization of casting process parameters using fuzzy logic
2) Optimization of casting process parameters using Taguchi Method
3) Energy conservation opportunities in foundries.

4.2.0 Optimization of Casting Process Parameters Using Fuzzy Logic:

4.2.1 Introduction:

Designing a part and then identifying the process and material is a thing of past as this approach becomes time consuming and costly. The current trend is Design for production, wherein the requirement of the products, various alternative processes of producing the product, their advantages and limitations are considered at the design stage itself and if required minor modifications are done in design stage itself for ease of manufacturing as well as economy in manufacturing. The same applies to the manufacture of the casting. Selecting the right process will result in substantial saving of time as well as money. Computer assisted process selection using fuzzy logic helps in the same. A novel approach can be to create the database for various process parameters for each process (Giachetti). The requirements of the product are then checked against the process parameters of each and every process and then we can have on our hand the compatibility of various processes for the given component. Weightage can be given to various parameters in terms of their importance and the best process can be identified for a particular component.

4.2.2 Fuzzy Logic Basics:

Fuzzy logic has the capability of recognizing, representing, manipulating, interpreting, and utilizing data and information that are vague and lack certainty. In fuzzy logic methodology (Utku), the part process compatibility value will gradually grow from zero to one, instead of suddenly jumping from zero (incompatible) to one (fully compatible).

As in the figure 4.1 showing capability vs compatibility
Where:
Vmin-abs = the absolute minimum value
Vmin-des = the desire minimum value
Vreq = the requirement value
Vmax-des = the absolute maximum value
Vmax-abs = the desire maximum value

The compatibility P(xi) for a value xi of an attribute i can be calculated by using the following equations:

\[ P(xi) = 1 \] if \( Vmin-des < xi < Vmax-des \) \hspace{1cm} -(1)
\[ P(xi) = (xi - Vmin-abs) / (Vmin-des - Vmin-abs) \] if \( Vmin-abs < xi < Vmin-des \) \hspace{1cm} -(2)
\[ P(xi) = (Vmax-abs - xi) / (Vmax-abs - Vmax-des) \] if \( Vmax-des < xi < Vmax-abs \) \hspace{1cm} -(3)
\[ P(xi) = 0 \] if \( xi < Vmin-abs \) or \( xi > Vmax-abs \) \hspace{1cm} -(4)

For \( P(xi) = 1 \), process is fully compatible, \( P(xi) = 0 \), process is fully incompatible.
Finding the compatibility for different parameters and applying the Weightage to each parameter, we can find the overall compatibility index of each process and decide which one is best suitable for the required component.

### 4.2.3 General Factors to Be Considered For Casting Process:

The various factors to be considered for casting process selection and their interactions are shown in figure 4.2

#### i) Type of Materials:

The type of alloy selected for a particular casting design depends primarily on the required service properties of the final cast product, for example mechanical properties. The alloy to be cast, however, can influence the choice of casting process; for example, metal mould-based casting processes are generally limited to low melting temperature alloys while a ceramic mould has no limitation to alloy melting temperature. Certain casting alloy properties, for example inadequate fluidity on mould filling and lack of resistance to hot tearing during solidification can have an adverse effect on the process choice available. According to materials processes are treated as either compatible or incompatible and any casting process that cannot cast the material is straight away rejected (Ravi).

As example die-casting cannot cast steel alloys or cast-iron successfully and hence gets rejected at start itself.

#### ii) Shapes:

Casting design involves a wide scope of expertise, which aims at the economical design of castings that achieve the desired functional performance. When choosing between different casting processes a compromise will normally have to be reached between technical requirements pertaining to the final cast component and the possibility of casting the shape with the desired quality whilst maintaining the minimum cost. Some of the main critical attributes within casting design include:

- Geometric complexity including casting integrity, wall thickness, internal features, fillets and radii among others.
- Casting accuracy including dimensional tolerances and surface finish.
- Size and weight.

As example, true centrifugal casting can cast only shapes that are cylindrical parts or shapes that are symmetrical about axis of rotations. For other shapes process gets rejected. The shapes considered can be: Planar, Surface of revolution, Prismatic, Constant cross section, thin wall, etc.

#### iii) The Required Quantity:

The quantity to be produced has major effect on the selection of process. The process gets eliminated if production quantity requirement is below the break even quantity.

The break even quantity for some of the processes can be as shown in table 4.1:

<table>
<thead>
<tr>
<th>Process</th>
<th>Breakeven quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell Moulding</td>
<td>100</td>
</tr>
<tr>
<td>Gravity Die Casting</td>
<td>100</td>
</tr>
<tr>
<td>Pressure Die Casting</td>
<td>1000</td>
</tr>
<tr>
<td>Investment Casting</td>
<td>5000</td>
</tr>
</tbody>
</table>

**Table 4.1 Breakeven Quantity for Few Casting Processes**

![Figure 4.1 Capability Vs Compatibility](image-url)}
### 4.2.4 Specification requirements to be considered for casting process:

Specification requirements can be divided into broad four categories covering geometrical parameters, quality parameters, economic parameters and production parameters (Sirilertworakul et al ).

i) Geometrical parameters:

These include Size of the part, Weight of the part, Thickness of Section, Hole Size and Tolerance

#### a) Size of the part:

<table>
<thead>
<tr>
<th>Process</th>
<th>Vmin-abs.(mm)</th>
<th>Vmin-des.(mm)</th>
<th>Vmax-des.(mm)</th>
<th>Vmax-abs.(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>5</td>
<td>10</td>
<td>Unlimited</td>
<td>unlimited</td>
</tr>
<tr>
<td>plaster</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Die</td>
<td>5</td>
<td>10</td>
<td>450</td>
<td>500</td>
</tr>
<tr>
<td>Vacuum</td>
<td>10</td>
<td>20</td>
<td>1500</td>
<td>20000</td>
</tr>
</tbody>
</table>

Table 4.2 Size Limits for Dimension for Few Casting Processes

As seen from table 4.2, while sand casting has unlimited capacity, in die casting dimension is limited to 500mm, beyond that process will be incompatible.

#### b) Weight of the part:

<table>
<thead>
<tr>
<th>Process</th>
<th>Vmin-abs.(kg)</th>
<th>Vmin-des.(kg)</th>
<th>Vmax-des.(kg)</th>
<th>Vmax-abs.(kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell</td>
<td>0.03</td>
<td>0.05</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Plaster</td>
<td>Very small</td>
<td>Small</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Squeeze</td>
<td>Very small</td>
<td>small</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Investment</td>
<td>0.001</td>
<td>0.005</td>
<td>90</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4.3 Part Weight Limits for Few Casting Processes

With advancement in technology, there is improvement in the weight of part that can be casted compared to previous as is seen from table 4.3.
c) **Thickness of Section:** The capabilities to manufacture thin sections vary from foundry to foundry, even with a given casting process. To calculate the compatibility for each process by using fuzzy logic technique four limits are required for applying fuzzy logic. The values can be as in table 4.4 for die casting process.

<table>
<thead>
<tr>
<th>Vmin-abs.(mm)</th>
<th>Vmin-des.(mm)</th>
<th>Vmax-des.(mm)</th>
<th>Vmax-abs.(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1</td>
<td>8</td>
<td>12</td>
</tr>
</tbody>
</table>

**Table 4.4 Limits for Section Thickness for Die Casting**

d) **Hole Size of the part:**
Casting processes have different capabilities in making the hole size. For example, in the sand casting the hole size depends on the core size, while other processes like centrifugal casting don’t use cores. To calculate the compatibility for each process by using fuzzy logic technique four limits are required for applying fuzzy logic.

e) **Tolerance of the part:**
Generally, tolerances depend on the geometry of the part. However, foundries generally state the tolerances that can be obtained by using its processes and provide guidelines to the designer to work towards these tolerances. These tolerances are called as *as cast* tolerances because they are obtained without any additional processes such as machining. Tighter linear tolerance than available in the chosen casting process can be obtained by secondary processes such as machining.

ii) **Quality parameters:**
These include Surface Finish, Mechanical Properties and Porosity

a) **Surface finish:**

<table>
<thead>
<tr>
<th>Process</th>
<th>Vmin-abs.(μm)</th>
<th>Vmin-des.(μm)</th>
<th>Vmax-des.(μm)</th>
<th>Vmax-abs.(μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand casting</td>
<td>6</td>
<td>12</td>
<td>25</td>
<td>50</td>
</tr>
<tr>
<td>Shell casting</td>
<td>1</td>
<td>3</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Plaster casting</td>
<td>0.75</td>
<td>1.3</td>
<td>2.5</td>
<td>4</td>
</tr>
<tr>
<td>Investment casting</td>
<td>0.8</td>
<td>1.6</td>
<td>3.2</td>
<td>6.4</td>
</tr>
</tbody>
</table>

**Table 4.5 Limits for Surface Finish Criterion.**

To produce finish of 1.5 μm, from the table 4.5, it can be seen that sand casting is incompatible. Using the fuzzy logic equations, it will be plaster casting that is most compatible.

b) **Mechanical Properties:**

<table>
<thead>
<tr>
<th>Process</th>
<th>Mechanical Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand casting</td>
<td>Good</td>
</tr>
<tr>
<td>Shell casting</td>
<td>Good</td>
</tr>
<tr>
<td>Plaster casting</td>
<td>Poor</td>
</tr>
<tr>
<td>Pressure Die casting</td>
<td>Very good</td>
</tr>
</tbody>
</table>

**Table 4.6 Casting Methods with Mechanical Properties.**

The type of casting process selected is affected to the quality of mechanical properties of the part such as plaster casting has poor mechanical properties but squeeze casting has excellent mechanical properties. This is shown in table 4.6.

c) **Porosity:**

<table>
<thead>
<tr>
<th>Process</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand casting</td>
<td>Bad</td>
</tr>
<tr>
<td>Investment casting</td>
<td>Good</td>
</tr>
<tr>
<td>Squeeze casting</td>
<td>Best</td>
</tr>
<tr>
<td>Centrifugal casting</td>
<td>Very Good</td>
</tr>
</tbody>
</table>

**Table 4.7 Porosity for Few Casting Processes.**

As seen in table 4.7, porosity can be a problem in sand casting compared to other methods

iii) **Economic parameters:**
These include Tooling cost, Relative Cost per unit in small quantity and Labor cost as shown in table 4.8. The tooling cost is cost of pattern and core box for sand casting and metal mould for die-casting as well as investment casting (for wax patterns).

<table>
<thead>
<tr>
<th>Process</th>
<th>Tooling</th>
<th>Relative Cost per unit in small quantity</th>
<th>Labor cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand casting</td>
<td>Low</td>
<td>Very Low</td>
<td>Low-Medium</td>
</tr>
<tr>
<td>Lost foam Casting</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Pressure die Casting</td>
<td>Highest</td>
<td>Highest</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Table 4.8 Economic Parameters for Few Casting Processes.**
iv) Production parameters:
These include, Production Rate, Flexibility and Lead time

a) Production rate:

<table>
<thead>
<tr>
<th>Process</th>
<th>Production rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand casting</td>
<td>(50-150)</td>
</tr>
<tr>
<td>Plaster casting</td>
<td>(1-50)</td>
</tr>
<tr>
<td>Die casting</td>
<td>(&gt; 1000)</td>
</tr>
</tbody>
</table>

Table 4.9 Production Rate for Few Casting Processes

The production rate as shown in table 4.9 will depend on size and shape of casting but in general die casting will have large production rate.

b) Flexibility and lead time:

<table>
<thead>
<tr>
<th>Process</th>
<th>Flexibility</th>
<th>Lead time(weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand casting</td>
<td>Excellent</td>
<td>1-2</td>
</tr>
<tr>
<td>Shell casting</td>
<td>Fair</td>
<td>1-2</td>
</tr>
<tr>
<td>Die casting</td>
<td>Poor</td>
<td>3-4</td>
</tr>
</tbody>
</table>

Table 4.10 Flexibility of Design Change for Few Casting Processes

Flexibility is the capability of process to change the design of the casting part. As seen in table 10 sand casting has highest flexibility, while die casting has poor flexibility.  
Lead-time is the time required to preparation and setup tooling and equipment that needed for casting process before production. As seen in table 4.10 sand casting has least lead time, while die casting has large lead time

v) Selecting the right casting process:
Based on the various parameters discussed above, one can create a data base for various process and various raw materials.  
Alternately Process compatibility is performed via selection queries on the database for each product specifications. The queries are based on the application of fuzzy logic approach to determine the degree of compatible for each process. By using fuzzy logic approach based on mechanical parameters any alloy raw material that have values out of the range of absolutely limits will be eliminated. Then search for process that satisfies design requirements will enter to the next step of determining the optimal casting process and this process can be determined according to the degree of compatibility between product specifications and the capability of process.  
The knowledge base construction involved the conversion of the knowledge acquired into If-Then rules followed by coding these rules using the development tool. The resulting system is a ‘goal oriented’ system, that is, all the rules in the knowledge base are evaluated until all the possible outcomes are analysed. This is shown in Figure 4.3.  
The reasoning mechanism to determine if a given ‘X’ casting process is suitable can be summarised by the following master rule:
IF casting alloy is suitable  
AND geometric features are appropriate  
AND casting accuracy is within the process capability  
AND production quantity is economical  
AND casting process is the least costly  
THEN ‘X’ casting process is suitable  

Similarly each parameter in this master rule, in turn, consists of its own set of rules. For example, the reasoning mechanism for evaluating the suitability of casting geometric features for process X is based on the following set of rules:
IF casting has internal holes (or no holes)  
AND shape of hole is appropriate  
AND minimum hole size is achievable  
AND minimum section thickness is achievable  
AND maximum section thickness is possible  
AND casting weight is appropriate  
AND maximum length is appropriate  
AND number of parting planes required is appropriate  
THEN ‘X’ casting process is suitable for the specified geometric features
The above process can be explained in terms as mathematical model as below:

After calculating the compatibility value of each characteristic of all feasible processes for the given product design, an overall compatibility index for each process is computed as follows:

\[ PC_i = \sum_j \sum_k SC_j \sum_k W_{jki} \]

where, \( PC_i \) = Process capability score of ith candidate process.
\( SC_j \) = Total number of criteria belonging to jth group criteria.
\( C_j \) = Importance (weight) of jth group criteria.
\( C_{jk} \) = Importance of kth criteria belonging to jth group.
\( W_{jki} \) = Compatibility of ith process for kth criteria of jth group.

The casting process with the largest value of compatibility index is suggested as the most suitable one for manufacturing the given product.

Figure 4.3. The Decision Route and Various Levels of Casting Process Selector
4.2.5 Conclusions:

Improper process selection can lead to increase in complexity of production, increase in production time as well as increased cost of production. What is required is Design for production. Design for production takes in to account the various manufacturing processes available for manufacturing the component using the best design and best process for ease of manufacture at economical price without affecting the function of the component. In case of casting also, there are large numbers of processes to select from. Choosing the right manufacturing process for making a component is required at early stages of design. The casting processes have different characteristics. Similarly the component to be produced also has its own characteristics that are user defined.

A novel approach can be to create the database for various process parameters for each process. The requirements of the product are then checked against the process parameters of each and every process and then we can have on our hand the compatibility of various processes for the given component. Weightage can be given to various parameters in terms of their importance and the best process can be identified for a particular component.

The database can be fed in to a computer program and what we get is computer assisted process selection using fuzzy logic, which will save the time, improve the quality and reduce the cost of the casting.

Fuzzy logic has the capability of recognizing, representing, manipulating, interpreting, and utilizing data and information that are vague and lack certainty. In fuzzy logic methodology, the part process compatibility value will gradually grow from zero to one, instead of suddenly jumping from zero (incompatible) to one (fully compatible).

The relevant details have been appropriately outlined in special reference to overall compatibility index.

Initially general factors to be considered for casting process like type of material, shapes, required quantity, etc have been discussed followed by appropriate discussion for specification requirement to be considered in selection of the casting process.

Thus some of the main critical attributes within casting design include:

- Geometric complexity including casting integrity, wall thickness, internal features, fillets and radii among others.
- Casting accuracy including dimensional tolerances and surface finish.
- Size and weight.

Based on the various parameters mentioned above, one can create a data base for various process and various raw materials. Process compatibility is performed via selection queries on the database for each product specifications. The queries are based on the application of fuzzy logic approach to determine the degree of compatible for each process. By using fuzzy logic approach based on mechanical parameters any alloy raw material that have values out of the range of absolutely limits will be eliminated. Then search for process that satisfies design requirements will enter to the next step of determining the optimal casting process and this process can be determined according to the degree of compatibility between product specifications and the capability of process.

The knowledge base construction involved the conversion of the knowledge acquired into If-Then rules followed by coding these rules using the development tool. The resulting system is a 'goal oriented' system, that is, all the rules in the knowledge base are evaluated until all the possible outcomes are analyzed. A suitable flow chart indicating the decision route and various levels of casting process selector can be used to prepare the fuzzy logic application for casting process selection. Various tables have been described in this case study for various parameters to be considered in selection of the casting process. It can be concluded as under:

Manual process of selecting the casting methods has some drawbacks. For example, it is difficult to accept that a wall thickness of 3.49mm would imply complete incompatibility where as 3.51 mm would imply complete compatibility. Four limits for each criterion are considered because in practice the process characteristics also depend on the equipment, manpower, skill, quality management practices and other company decisions. This can be captured in a band of values for each process capability characteristics. These models have the capability of recognizing, representing, manipulating, interpreting, and utilizing data and information that are vague and lack certainty. The limitation of this approach is, when there is no result that can meet the initial requirement, the system does not suggest to the user how can change the input value to have results. Nevertheless the fuzzy logic technique is more suitable in selection methodology for casting process because the capability of each process different from one foundry to another.

Thus it can be summarised that in this work, a systematic approach for casting process selection and design improvement has been proposed. This is based on evaluating and maximizing the compatibility between product requirements and process capabilities. The database is independent of the program and can be easily customized to any particular foundry. Fuzzy logic has been used to capture the imprecise nature of process characteristics, and Analytical Hierarchy Process has been employed to objectively assign weights to evaluation criteria. The approach can be implemented in a computer program and successfully used for selection of process and materials for industrial parts.
4.3.0 Optimization of Sand Casting Process Parameter Using Taguchi Method:

4.3.1 Introduction:
Taguchi has introduced several statistical tools and concepts of quality improvement that depend heavily on the statistical theory of experimental design (Antony et al¹). Some applications of Taguchi’s method in the foundry industry have shown that the variation in casting quality caused by uncontrollable process variables can be minimized.

The objective of this research is on optimizing the process parameters of sand casting process including optimum levels and the case study is done in a job foundry.

4.3.2 Methodology:
The Taguchi method can be applied by using eight experimental steps (Ghani et al¹⁴) that can be grouped into three major categories as follows:
a) Planning the experiment: (1) Identify the main function of casting process. (2) Identify the quality characteristic to be observed and the objective function to be optimized. (3) Identify the control factors and their alternate levels. (4) Identify noise factors and the testing conditions of the process. (5) Design the matrix experiment and define the data analysis procedure.
b) Performing the experiment: (6) conduct the matrix experiment.
c) Analyzing and verifying the experimental results: (7) Analyzing the data, determining the Optimum levels for the control factors, and predicting performance under these levels: (8) Conducting the verification (also called confirmation) experiment and planning future actions.

The basic steps for achieving the above target (Byrne and Taguchi³) are summarized below:
1. To select the most significant parameters that causes variations in the quality characteristics.
2. Casting defects have been selected as the most representative quality characteristics in the green sand casting process, as it is related to many internal defects (sand blow holes, pinholes, scabs, metal penetration, mold shift, mold crack, sand drop.). The target of the green sand casting process is to achieve “lower casting defects” while minimizing the effect of uncontrollable parameters.
3. Make the green sand casting process under the experimental conditions dictated by the chosen orthogonal array and parameter levels. Based on the experimental conditions, collect the data.
4. An analysis of variance (ANOVA) table (Hafeez et al⁶) is generated to determine the statistical significance of the parameters
5. Beside the optimum settings of the control parameters and predict the results of each of the parameters at their new optimum levels.
6. Verify the optimum settings result in the predicted reduction in the casting defects.

i) Process Parameters:
Sand casting is used to manufacture complex shapes of various sizes depending upon the customer requirements. The basic requirements casting are pattern making, preparing a mold, pouring a molten metal, cooling of mold, shakeout, fettling. The main causes of rejection in castings are due to improper pattern, improper gating system, improper control of sand parameters, improper molten metal composition. The process parameters of the sand casting can be listed as follows:

- Sand particle size
- Moisture percentage in sand
- Green compression strength
- Mould hardness
- Permeability
- Pouring temperature of molten metal
- Pouring time of molten metal in mold
- Pressure test

For each process parameter two/three levels are selected which define the experimental region. The levels selected are based on the standards acceptable and foundry men experience in this organization for engine castings and fittings. Significant interactions within control parameters are also considered. The parameters, along with their ranges are given in Table 4.11.
<table>
<thead>
<tr>
<th>Factor designation</th>
<th>Control factors</th>
<th>Range</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Moisture (%)</td>
<td>3.5 – 4</td>
<td>3.5</td>
<td>4</td>
<td>----</td>
</tr>
<tr>
<td>B</td>
<td>Sand particle size (AFS)</td>
<td>50 – 55</td>
<td>50</td>
<td>53</td>
<td>55</td>
</tr>
<tr>
<td>C</td>
<td>Green Strength (g/cm²)</td>
<td>900 – 1200</td>
<td>900</td>
<td>1100</td>
<td>1200</td>
</tr>
<tr>
<td>D</td>
<td>Mould hardness (nu)</td>
<td>50 – 80</td>
<td>50</td>
<td>70</td>
<td>80</td>
</tr>
<tr>
<td>E</td>
<td>Permeability (nu)</td>
<td>150 – 220</td>
<td>150</td>
<td>185</td>
<td>220</td>
</tr>
<tr>
<td>F</td>
<td>Pouring temperature (deg c)</td>
<td>1300 – 1420</td>
<td>1300</td>
<td>1390</td>
<td>1420</td>
</tr>
<tr>
<td>G</td>
<td>Pouring time (sec)</td>
<td>20 – 28</td>
<td>20</td>
<td>24</td>
<td>28</td>
</tr>
<tr>
<td>H</td>
<td>Pressure test (MPa)</td>
<td>1.5 – 2.5</td>
<td>1.5</td>
<td>2</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Table 4.11: Control Factors of Process Parameters and Their Levels

ii) Quality Characteristics:
Casting defects was selected as a quality characteristic to be measured. The most common defects occurring in the foundry were monitored and recorded (Robinson et al.). The smaller the better number of casting defect implies better process performance. Here the objective function to be maximized is:

\[
S/N \text{ ratio } (\eta') = -10 \log \left( \frac{\text{mean square surface defects}}{\text{error variance}} \right)
\]

Maximizing \(\eta'\) leads to minimization of quality loss due to defects. Where \(S/N\) ratio is used for measuring sensitivity to noise factors, \(n\) is the number of experiments orthogonal array, and \(y_i\) the \(i^{th}\) value measured.

iii) Selection of Orthogonal Array:
Selection of an orthogonal array depends upon the number of control factors and interaction of interest. It also depends upon number of levels for the control factors of interest. Therefore with one control factor moisture percentage of two levels and other control factors sand particle size, green compression strength (GCS), mould hardness number, permeability number, pouring temperature of molten metal, pouring time of molten metal in mould and pressure test for casting leakage with three levels are considered, L18 orthogonal array is selected with 18 experimental runs and eight columns. Taguchi has provided in the assignment of factors and interaction to arrays. The tools are: (1) the linear graph and (2) triangular tables. Linear graphs indicate various columns to which factors may be assigned and the columns subsequently evaluate the interactions of those factors. The assigned L18 orthogonal array is shown in Table 4.12 and the experimental orthogonal array having their levels are assigned to columns are shown in Table 4.13.

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<td>3</td>
</tr>
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</table>
Table 4.12 Orthogonal Array L18 (Control Factors Assigned)

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>A Moisture content (%)</th>
<th>B Sand particle Size (AFS)</th>
<th>C Green Strength (g/cm²)</th>
<th>D Mould hardness (nu)</th>
<th>E Permeability (nu)</th>
<th>F Pouring temperature (deg c)</th>
<th>G Pouring time (sec)</th>
<th>H Pressure test (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.5</td>
<td>50</td>
<td>900</td>
<td>50</td>
<td>150</td>
<td>1300</td>
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<td>70</td>
<td>185</td>
<td>1390</td>
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<td>2</td>
</tr>
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<td>3</td>
<td>3.5</td>
<td>50</td>
<td>1200</td>
<td>80</td>
<td>220</td>
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</tr>
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<td>14</td>
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<td>220</td>
<td>1300</td>
<td>24</td>
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<td>1200</td>
<td>70</td>
<td>150</td>
<td>1390</td>
<td>28</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 4.13 Experimental Orthogonal Array

4.3.3 Experiment Results and S/N Ratios:

The experiments were conducted thrice for the same set of parameters using a single-repetition randomization technique. The casting defects that occur in each trial conditions were found and recorded. The average of the casting defects was determined for each trial condition as shown in Table 4.14. The casting defects are the “lower the better” type of quality characteristics. Lower the better S/N ratios were computed for each of the 18 trials and the values are given in Table 4.14. Lower is better: S/N = \(-10 \log \left[ \frac{\sum y^2}{n} \right] \)

For example, the S/N ratio for trial number 1 is:

\[ \eta = -10 \log \left[ \frac{\sum (y^2)}{3} \right] \]

\[ S/N = -10 \log \left[ \frac{5.25^2 + 5.7^2 + 4.21^2}{3} \right] = -10 \log \left[ \frac{(27.5625 + 32.49 + 17.7241)}{3} \right] = -10 \log \left[ \frac{77.7766}{3} \right] = -10 \log [25.925] = -14.138 \]

i) Main Effects of Factors and Analysis of Variance:

The average effect of factors is shown in Table 4.15. After the experiments are conducted, the ANOVA is used to analyze the results of the experiments. The significant factors and/or their interactions are identified (Arvidsson, M. and I. Gremyr), for various trial conditions and the parameters which significantly influence the casting defects. However, some more information is required to conclude with an optimum setting of parameters. In applying ANOVA technique, certain assumptions must be checked through analysis of residuals before interpreting and concluding the results. It is highly recommended to examine these residuals for normality, independence, and constant variance, when using ANOVA. In this study, F ratio test is employed to check constancy of residual variance. If the F ratio test statistic is equal to or less than its corresponding critical value, the residuals have constant variance. The F-ratio value can be found using the ratio of mean square of a factor to variance of error. It can seen from the F-ratio value result that the significant factors are the control factors in the order of C (green compression strength), A (moisture), F (pouring temperature) and E (permeability). The other control factors are pooled due to less significance and percent contribution. The
expected amount of sum of squares (SS) for each factor is computed by using variance. The percent contribution (P) for each factor is calculated by using expected amount of sum of squares (SS) in Table 4.16. The ANOVA table after pooling until the DOF of the error term is approximately half the total DOF of the experiment is shown in Table 4.16.

\[ \text{Table 4.14 Casting Defects Values and Signal-To-Noise Ratio against Experimental Trial Numbers} \]

*Average casting defects = 6.108 Standard deviation= 1.548*

<table>
<thead>
<tr>
<th>Trial no.</th>
<th>Percentage defects in experiment</th>
<th>Average</th>
<th>S/N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.25 5.7 4.21 15.16</td>
<td>5.053</td>
<td>-14.138</td>
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<tr>
<td>2</td>
<td>4.48 5.58 5.56 15.62</td>
<td>5.206</td>
<td>-14.374</td>
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<tr>
<td>3</td>
<td>6.47 7.13 5.12 18.72</td>
<td>6.24</td>
<td>-15.982</td>
</tr>
<tr>
<td>4</td>
<td>3.93 4.16 5.04 13.13</td>
<td>4.376</td>
<td>-12.875</td>
</tr>
<tr>
<td>5</td>
<td>6.24 6.68 4.68 17.6</td>
<td>5.866</td>
<td>-15.46</td>
</tr>
<tr>
<td>6</td>
<td>7.29 7.17 6.79 21.25</td>
<td>7.083</td>
<td>-17.009</td>
</tr>
<tr>
<td>7</td>
<td>2.64 3.05 3.87 9.56</td>
<td>3.186</td>
<td>-10.178</td>
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<td>8</td>
<td>3.75 5.54 5.13 14.42</td>
<td>4.806</td>
<td>-13.746</td>
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<tr>
<td>9</td>
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<tr>
<td>10</td>
<td>6.34 4.83 7.24 18.41</td>
<td>6.136</td>
<td>-15.872</td>
</tr>
<tr>
<td>11</td>
<td>5.67 7.1 7.53 20.3</td>
<td>6.766</td>
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</tr>
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<td>6.67 5.2 6.33 18.2</td>
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<td>7.17 6.87 5.54 19.58</td>
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<td>7.29 7.64 7.64 22.57</td>
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\[ \text{Table 4.15 Main Effects} \]

<table>
<thead>
<tr>
<th>Factors</th>
<th>DOF</th>
<th>Sums of Squares</th>
<th>Variance</th>
<th>F-Ratio</th>
<th>Pure Sum</th>
<th>Percent</th>
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<tbody>
<tr>
<td>Moisture %</td>
<td>1</td>
<td>17.537</td>
<td>17.537</td>
<td>33.563</td>
<td>17.015</td>
<td>22.226</td>
</tr>
<tr>
<td>Sand particle size</td>
<td>(2)</td>
<td>(5.403)</td>
<td>POOLED</td>
<td>(CL = 84.14%)</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>green compression strength</td>
<td>2</td>
<td>32.422</td>
<td>16.211</td>
<td>31.024</td>
<td>31.377</td>
<td>40.987</td>
</tr>
<tr>
<td>Mould hardness nu</td>
<td>(2)</td>
<td>(.541)</td>
<td>POOLED</td>
<td>(CL = <em>NC</em>)</td>
<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>
ii) Expected Cost Savings at Optimum Conditions:
The performance of the expected optimum conditions is estimated considering the factors and interactions. The significant contributions made by factors A1, C1, E2 and F3 have a total contribution of 3.924 decibels. As the current grand average of performance is -15.544 decibels, the expected result at the optimum condition is computed at -11.619 decibels. Therefore the improvement expected in reduction of defects is 37.66 per cent. Estimating the performance of all factors at an arbitrary condition the expected result at optimum condition of S/N ratio is -9.689. In order to calculate the expected cost savings, Taguchi’s loss function has been used using equation.

\[
L = \left(1 \times 10^{\frac{(S/N)_1 \times (S/N)_2}{10}}\right) \times 100\% \text{ of } L_1
\]

Here \((S/N)_1 = -15.444\) and \((S/N)_2 = -9.689\)

<table>
<thead>
<tr>
<th>Column &amp; Factor</th>
<th>Level description</th>
<th>Level</th>
<th>Contribution</th>
</tr>
</thead>
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<tr>
<td>1. Moisture</td>
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<td>0.987</td>
</tr>
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</tr>
<tr>
<td>4. Mould hardness</td>
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<td>5. Permeability</td>
<td>185</td>
<td>2</td>
<td>0.508</td>
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<td>6. Pouring temp.</td>
<td>1420</td>
<td>3</td>
<td>0.856</td>
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<td>7. Pouring time</td>
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<td>2</td>
<td>0.493</td>
</tr>
<tr>
<td>8. Pressure test</td>
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<td>3</td>
<td>0.436</td>
</tr>
<tr>
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<td></td>
<td>5.855</td>
</tr>
<tr>
<td>Current grand average of performance</td>
<td></td>
<td></td>
<td>-15.444</td>
</tr>
<tr>
<td>Expected result at optimum condition S/N ratio</td>
<td></td>
<td></td>
<td>-9.689</td>
</tr>
</tbody>
</table>

iii) Variation Reduction Data and Savings:
The objective of the study is to reduce the variation and getting closer to the target. After implementation of Taguchi method in the foundry a reduction of 37.66 % was observed. This was due to the improved signal to noise ratio from -15.544 to -9.689. The improved standard deviation was 0.788 from the current standard deviation 1.547. The optimum condition and performance factors are shown in Table 4.18, moisture percentage 3.5, GCS 900 g/cm², permeability number 185 and pouring temperature 1420 Celsius. The total contribution of all the factors is 3.924.

<table>
<thead>
<tr>
<th>Factors</th>
<th>Level description</th>
<th>Level</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Moisture %</td>
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<td>1</td>
<td>0.987</td>
</tr>
<tr>
<td>2 GCS g/cm²</td>
<td>900</td>
<td>1</td>
<td>1.574</td>
</tr>
<tr>
<td>3 Permeability</td>
<td>185</td>
<td>2</td>
<td>0.508</td>
</tr>
<tr>
<td>4 Pouring temp.</td>
<td>1420</td>
<td>3</td>
<td>0.856</td>
</tr>
<tr>
<td>Total contribution from all factors</td>
<td></td>
<td></td>
<td>3.924</td>
</tr>
<tr>
<td>Current grand average of performance</td>
<td></td>
<td></td>
<td>-15.544</td>
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<tr>
<td>Expected result at optimum condition</td>
<td></td>
<td></td>
<td>-11.619</td>
</tr>
<tr>
<td>Improvement expected</td>
<td></td>
<td></td>
<td>37.66%</td>
</tr>
</tbody>
</table>

Table 4.18 Optimum Condition and Performance
4.3.4 Conclusions:
Sand casting is used to manufacture complex shapes of various sizes depending upon the customer requirements. The basic requirements casting are pattern making, preparing a mold, pouring a molten metal, cooling of mold, shakeout, fettling. The main causes of rejection in castings are due to improper pattern, improper gating system, improper control of sand parameters, improper molten metal composition. The process parameters of the sand casting can be listed as follows:
- Sand particle size
- Moisture percentage in sand
- Green compression strength
- Mould hardness
- Permeability
- Pouring temperature of molten metal
- Pouring time of molten metal in mold
- Pressure test

The objective of this study is on optimizing the process parameters of sand casting process including optimum levels and the case study is done in a job foundry. The Taguchi method can be applied by using eight experimental steps that can be grouped into three major categories as follows:
- Planning the experiment:
  (1) Identify the main function of casting process. (2) Identify the quality characteristic to be observed and the objective function to be optimized. (3) Identify the control factors and their alternate levels. (4) Identify noise factors and the testing conditions of the process. (5) Design the matrix experiment and define the data analysis procedure.
- Performing the experiment:
  (6) Conduct the matrix experiment.
- Analyzing and verifying the experimental results:
  (7) Analyzing the data, determining the Optimum levels for the control factors, and predicting performance under these levels: • (8) Conducting the verification (also called confirmation) experiment and planning future actions.

For achieving the above mentioned target, the following methodology of six steps needs to be followed:
1. To select the most significant parameters that causes variations in the quality characteristics.
2. Casting defects have been selected as the most representative quality characteristics in the green sand casting process, as it is related to many internal defects (sand blow holes, pinholes, scabs, metal penetration, mold shift, mold crack, sand drop.). The target of the green sand casting process is to achieve “lower casting defects” while minimizing the effect of uncontrollable parameters.
3. Make the green sand casting process under the experimental conditions dictated by the chosen orthogonal array and parameter levels. Based on the experimental conditions, collect the data.
4. An analysis of variance (ANOVA) table is generated to determine the statistical significance of the parameters
5. Beside the optimum settings of the control parameters and predict the results of each of the parameters at their new optimum levels.
6. Verify the optimum settings result in the predicted reduction in the casting defects.

The relevant detailing with respect to selection of experimental orthogonal array has been done and experiments were conducted with the objective of optimizing sand casting process parameters.
All the experimental results have been tabulated and considering the factors and the interactions, the performance of the expected optimum is also estimated.
The main objective of the study was to reduce the variation and getting close to the target.
After implementation of Taguchi method in the foundry a reduction of 37.66 % in variation was observed. This was due to the improved signal to noise ratio from -15.544 to -9.689. The improved standard deviation was 0.788 from the current standard deviation 1.547. The optimum condition and performance factors are shown in Table 4.18, moisture percentage 3.5, GCS 900 g/cm^2, permeability number 185 and pouring temperature 1420º Celsius. The total contribution of all the factors is 3.924.

The summary of optimum conditions and concluding remarks are as under:
The optimum conditions for the factors computed are:
- Moisture (%) – Level 1 – Minimum 3.5
- Green compression strength (g/cm^2) – Level 1 – Minimum 900
- Permeability – Level 2 – Minimum 185
- Pouring temperature (deg. Celsius) – Level 3 – Maximum 1420
The improvement expected in minimizing the variation is 37.66 percent which means reduction of casting defects from present 6.16 percent to 3.84 percent of the total castings produced in the foundry. This also reflects that by using Taguchi method the factor levels when optimized will result in reduction of casting defects and increase the yield percentage of the accepted castings without any additional investments. A usage of quality tools like Pareto chart is useful for finding the major defects in the daily operations of foundry. Quality of castings can be improved by aesthetic look, dimensional accuracy, better understanding of noise factors and the interaction between variables, quality cost system based on individual product, scrap reduction, reworking of castings and process control.

4.4.0 Energy Conservation in Foundry:
The Rajkot engineering cluster has about 500 foundries ranging in size from micro to large scale. Most of the foundries in Rajkot produce grey iron castings for the manufacturers of automobiles, pump sets and machine tools; a number of foundries also produce high-value (precision) castings. A number of Rajkot foundries export their products to countries in Europe, the Middle East and Southeast Asia. The majority of Rajkot foundries use conventional coke-based cupola furnaces or induction furnaces to melt metal. In general, the melting process consumes the maximum amount of energy in a foundry. Hence, foundries can cut costs by reducing energy (fuel) consumption during the melting process. This can be done by replacing the conventional cupola with the energy efficient divided blast cupola (DBC), or by reducing heat losses in the induction furnace.

4.4.1 Energy Savings in Cupolas:
Cupola, which is the most commonly used melting furnace in the Indian foundries, is also the most energy intensive operation. It accounts for up to 50% of a foundry’s total energy consumption and is a prime candidate to focus attention on, for improving energy use efficiency in a foundry.

i) Measures for Energy Savings in Cupolas:
For efficient cupola operation, the following operating practices under various operations, starting from preparation of the cupola to tapping of molten metal are recommended.

a) Bottom Sand:
The base of the cupola plays an important role in proper cupola functioning and in the flow of hot metal from the cupola.
Note the following points while making up the base of the cupola
- Ensure that the bottom sand is free from iron, etc., and that it has the proper moisture and clay content.
- It should be dense, with a correctly rammed bottom, heeled up around the wall and sloping towards the tap hole.

b) Preparation of Coke Bed:
The most important part in the successful operation of a cupola is the preparation of the coke bed. The initial height of the bed above the tuyeres and the degree to which it is burned before the charging commences are vital factors governing, to a large extent, the metal temperature and melting rates obtained during the early part of the melt.
- Clean the vent holes on the damper plates
- Select and weigh the bed coke carefully every day
- Place kindling wood or torches properly to ensure even lighting
- Measure the bed height with a calibrated rod/gauge. If needed, add green coke to bring the height to the required level
- Record all coke bed data

c) Charging:
The operating efficiency of a cupola depends, to a large extent, on the charging of raw material. The following practices should be adopted in order to ensure proper operation of the melting furnace.
- The acid insoluble content in flux stone should not exceed 5% of its total weight.
- The diagonal dimension of a single piece of metal should be less than 1/3rd the hearth diameter to ensure that the cupola operates efficiently.
- The weight of a single piece of metal should be limited to 1% of the hourly melting rate.
- The quality of purchased scrap should meet the specifications of the product to be manufactured.
- The charging sequence of the metal must be maintained.
- Once charging starts, it has to be continued till, (i) the cupola shaft is filled up with the charging material, (ii) the cupola is lit up, and (iii) the blower and tuyeres are switched on.
- Use light scrap for filling up to achieve initial tap temperatures.
- Ensure that the cupola is full before turning on the blast.
d) Melting:
- Establish the proper initial blast rate and maintain it right through to tap-out.
- Dry and thoroughly pre-heat all runners and ladles daily.
- Use only dry inoculants. If the alloy is wet, proper inoculation will not take place; pinholes or other defects may occur.
- Black top gas suggests that the blower motor is blocked or greasy scraps have been used in the charge.
- If the stack discharge appears reddish, the reasons could be:
  - Oxidizing conditions on account of low bed or high blast
  - Excessive amount of rust in charge material
- Scaffolding or hanging of charge
- Strong flame and high temperature at the charge door indicate a high bed and excessive coke splits between charges, or low stack height in the cupola.
- A blue-pink flame moving up and down the walls and clinging to projections indicates good melting conditions.
- During melting, burn-back occurs above the tuyeres in the melting zone.
- The following factors contribute to burn-back:
  - Low temperature of the melting zone
  - High blast rate
  - Incorrect tuyere dimensions
  - Uneven charge distribution

e) Tapping and Slagging:
Slag is removed from the hot metal with the help of a slag overflow notch. Normal slag is colored grey to grey-green. The color and other properties of slag appearance can point to problems in the cupola’s performance. Check for the following:
- Thick, viscous slag indicates insufficient flux or low temperatures.
- Dark to black slag indicates a low bed (slag sometimes foamy) and oxidizing conditions.
- Light green to cream color slag indicates excess flux.

ii) Use of Advanced Technology:

a) Oxygen Enrichment:
Another advanced technology used in cupola operation is oxygen enrichment of the cupola. The enrichment quantity usually required is around 2-4% of the air blast. The following advantages are achieved over the conventional cupola operation.
  - Carbon pick-up is higher
  - Molten metal temperatures are higher by about 30°C

b) Divided Blast Cupola (DBC) and Its Benefits:
- The divided blast cupola (DBC) is an energy efficient coke-based melting furnace. The DBC typically saves 20–30% of the coke consumed by a conventional cupola, thereby reducing fuel expenses and increasing profits. It also produces molten metal at temperatures 50°–100° C higher than in the conventional cupola; this enables production of better quality castings and also reduces the volume of ‘rejects’, further adding to productivity and profitability. Although the capital cost of a DBC is higher than that of a conventional cupola, it offers an attractive payback on investment (often, within a year) due to savings in coke. Studies indicate that electrical melting by using an induction furnace costs nearly twice as much as coke based melting using the DBC. Hence, the DBC can provide a cost-effective technological option for the electrical induction furnace as well; particularly in a scenario when power is becoming increasingly costly. The 21-inch DBC performance at Steelcon Metal Cast has been monitored following its installation, and the results clearly show its benefits in terms of better melting rate and lower coke consumption:
  - Melting rate: 2.25 to 2.7 tonnes per hour, Coke to metal ratio: 1:13 (indicating that coke consumption has been reduced by nearly 35% compared to conventional cupola)
  - The new DBC cost around Rs 6.65 lakhs, compared to Rs 4 lakhs for the conventional cupola at that time. Due to its higher energy efficiency, the DBC saves around Rs 850 per tonne of liquid metal produced.

4.4.2 Energy Savings in Induction Furnaces:
Induction melting furnaces are inherently more efficient than cupolas. They are also easier to use because there are fewer steps in their operation and maintenance compared to cupolas. Further, most of the operating parameters in an induction furnace are electrically controlled and specifications are pre set as per the manufacturer’s guidelines. Hence, the only factor that needs to be controlled in order to save energy during
induction melting is cycle time. Adopting the following practices will optimize the cycle time and allow efficient operation of the induction furnace.

- Plan the charge mix and material beforehand.
- Weigh and keep the charge and alloying elements ready before charging.
- Keep the size of the charge materials about 1/3rd of the crucible’s diameter.
- First charge the steel and carburizers.
- Always keep the crucible full of charge and keep poking in order to achieve maximum compaction.
- Always operate the furnace at full power.
- Use proper frequency in the induction furnace for various alloys, to ensure a faster mixing of additives and to reduce the cycle time.
- Cover the crucible with an asbestos blanket after charging.
- Do not superheat the metal beyond the required temperature.
- Avoid holding of molten metal.
- Avoid delay in the de-slagging operation.
- Keep the charge free from dirt and rust.
- Foundry return should be, preferably, shot blasted.

4.4.3 Energy Savings in the Mould and Core-Making Process and Heat Treatment:
Making moulds and cores is another important operation in any foundry. Mould and core making and heat treatment together account for 25–27% of the total energy consumed in a foundry. Given below is a list of operating practices that must be followed to improve the efficiency of these processes.

- Remove any metal pieces from the sand using sand processing equipment so that no undesirable object appears in the mould. Malfunction of even a single mould can lead to the loss of material and energy.
- Ensure that components of the mould/core such as sand additives meet rated specifications. Any deviation from the rated composition may lead to frequent failure of moulds/cores. This could mean rejection of the entire lot of castings.
- The water content in the mould plays an important role in binding of material. Too much water gives way to casting defects, while too little water may result in insufficient binding and the collapse of the mould at critical points.
- For heat treatment furnaces with larger capacities and voluminous heating chambers, always install more burners with smaller firing capacities in place of a few burners with larger firing capacity.
- Clean burner nozzles once in a month.
- Do proper planning to avoid furnace cold starts.
- Don’t leave air supply open while fuel supply is closed.
- Use temperature indicators and automatic controllers in place of human judgement. This will reduce the chances of overheating of the material and the resulting energy/material loss.
- Do not obstruct the flow of hot gases, the flame path and the exhaust port. Ensure this by placing/arranging the material correctly and through optimal loading of the furnace.

4.4.4 Energy Savings in the Machine Shop:
For efficient operation, carry out routine and simple maintenance of machine tools. This will help avoid expensive breakdown maintenance, which also leads to loss of production and other associated losses. Such routine maintenance takes only a few minutes to complete and should be conducted before the shift begins. The following checks should be carried out in the routine maintenance of machine tools:

- Clean chips from the chip pan.
- Check hydraulic oil level in the main hydraulic tank and top up if required.
- Check the coolant levels in the coolant sump and top up, if required. □ Perform alignment check between spindle, carriage assembly and other components to ensure accuracy of cut.
- Undertake periodic calibration of gauges and instruments.

4.4.5 Energy Savings in the Compressed Air System:
Air compressors are used in the machine shop for pneumatic equipment and machine tools. Air compression consumes a lot of energy. From Figure 2 it is clear that only 10 – 30% of input energy to the compressor reaches the point of end-use and the balance 90 – 70% of the input energy is wasted in the form of friction and heat loss. Energy savings of up to 30% can be realized in a compressed air system by regular simple maintenance measures. Some practices that will optimize air compression are listed below.
The location of air compressors and the quality of air drawn by the compressors will have a significant influence on the amount of energy consumed. The following points should be taken into consideration while deciding the location of compressors or combined compressed air systems.

- Locate the compressor away from heat sources such as kilns, dryers and other items of equipment that radiate heat.
- The compressor should be located such that it draws cool ambient air from outside because the temperature of the air inside the compressor room is high. While extending the air intake from the outside of the building, minimize excess pressure drop in the suction line by selecting a duct of large diameter with the smallest number of bends. The compressor should be placed where there is no particulate matter. Do not place the compressor near spray coating booths, sawing machines, the buffing section, etc.
- Any moisture in the inlet air to the compressor will affect its performance adversely. The compressor should be placed away from equipment which may add moisture to the atmosphere, for example, rinsing lines, cooling towers, dryer exhaust, etc. If the compressed air is moist the components of the compressed air system will corrode. Also, the specific power consumption will increase.
- Air grid, because it wastes the energy that is consumed in building up the excess. Choose the pressure setting in the compressed air system very carefully. Judge/assess the requirement of different compressed air users before connecting them to common compressed air grid. This is the most important criterion for optimizing the efficiency of the compressed air system.
- Segregate users of compressed air on the basis of the pressure they require for proper operation. Set up two or more compressed air grids if needed, with each having the air pressure set according to the requirement of equipment in that particular grid. A single compressed air network will always have delivery pressure set equal to the requirement of the equipment which demands the highest pressure. This is not desirable.
- Some items of equipment in the grid require air at low pressures. Do not use valves to reduce the pressure in the compressed pressure. Compressed air pressure must be set at the point of generation.
- Optimization of compressor loading and unloading pressure, and segregation of high and low pressure loads in the compressed air grid can lead to significant energy savings without any major investment requirement.
- Minimize the pressure drop in the line between the point of generation and the point of use. Excess pressure drop can result from the following:
  - Inadequate pipe size
  - Choked filter elements
  - Improperly sized couplings and hoses
- Put the right kind of compressor to use. This is especially important in a compressed air network consisting of several compressors of the same or different size, capacity, operational efficiency, etc. Clean the air intake filters regularly so that clean air can enter the compressor and permit a low pressure drop across the filters.
- It has been observed that Free Air Discharge (FAD) by compressors increases by as much as 12.5% in some cases by simply cleaning the air intake filters.
- Maintain the proper level of tension in the belt in compressors connected by belt drives. Improper belt tension, loose or vibrating belts can cause an increase in power consumption of the prime mover by as much as 6%.
- The following points should be noted while deciding the operating pattern of compressors:
  - If all compressors are similar, adjust the pressure setting of the compressors so that only one compressor handles the load variation; the others should operate with full load, to the extent possible.
  - If compressors are of different sizes, the pressure switch should be set such that only the smallest compressor is allowed to modulate (vary in flow rate) according to the demand of compressed air. Avoid air leaks and associated energy losses.
- Conduct leakage tests regularly (once a month) to remove air leaks in the compressed air system.

4.4.6 Energy Savings in the Electrical Distribution System:

The electrical system is an integral part of all foundry units. An efficient electrical distribution system together with demand management can reduce the electricity bill significantly. Adopt the following practices in order to maintain an efficient electrical distribution system.

- Stagger the non-critical load according to the electricity tariff to reduce the energy bill.
• Maintain a high power factor, which will lead to reduced demand, better voltage, high system efficiency as well as rebates from the electricity supply company. The power factor can be improved by installing capacitors in the electrical system.

• Any shortfall in power factor from the desired value can be made up by the use of capacitor banks. Transformers are normally designed to operate at maximum efficiency between loadings of 32% and 35% of their full capacity. If the load on the transformer increases beyond 80% of the designed capacity, it is better to buy a new or bigger transformer to prevent a sharp rise in transformer losses.

• Control the maximum demand by tripping non-critical loads through a demand controller. This will avoid the penalty levied when usage is greater than the sanctioned load.

• Balance the system voltage to reduce the distribution losses in the system. For every 1% increase in voltage imbalance, the efficiency of the motors decreases by 1%.

4.4.7 Energy Savings in Electrical Utilities – Motors and DG Sets:

Electrical motors are the principal source of motive power in any foundry unit. Machine tools, auxiliary equipment and other utilities come equipped with one or more electric motors. A machine tool can have several electric motors other than the main spindle motor. These are used for allied operations. Motors are generally efficient, but their efficiency and performance depends on the motor load. Since there are many motors in a foundry unit, it is very important to maintain them and adopt proper operating practices. These practices will save a significant amount of energy. A list of such practices and measures is presented below.

• Always use motors sized according to the requirement of the load. It is good practice to operate motors between 75 -100% of their full load rating because motors run most efficiently near their designed power rating.

• Oversized motors result in energy losses owing to a decrease in efficiency and power factor. Oversized motors can be identified by measuring the actual power drawn and comparing it with the rated power of the motor. Oversized motors should, therefore, be replaced with motors of appropriate rating.

• When replacing motors, always buy energy efficient motors instead of conventional motors. The cost of energy consumed by a conventional motor during its life is far greater than the incremental cost of the energy efficient motor.

• A properly balanced voltage supply is essential for a motor to reach its rated performance. An unbalanced three-phase voltage affects a motor’s current, speed, torque, and temperature rise. Equal loads on all three phases of electric service help in assuring a voltage balance while minimizing voltage losses.

• Regular maintenance helps to minimize friction losses, heat losses and extends a motor’s life. The motor should be lubricated and cleaned periodically.

• Motors should be rewound only by a qualified person. This will minimize losses in the rewound motor.

• Every time a motor is rewound, its efficiency drops by 2%.

• Motors frequently drive variable loads such as pumps, hydraulic systems and fans. In these applications, the motors’ efficiency is often poor because they are operated at low loads. It is appropriate to use a variable speed drive (VSD) with the motor.

• Check motor for over-heating and abnormal noises/sounds, sparking and ensure proper bedding of brushes.

• Tighten belts and pulleys to eliminate transmission losses.

• Install capacitors across motors with a high rating to reduce the distribution losses. Apart from electric motors, diesel generator (DG) sets are also installed in a majority of foundries, as a source of back up power. Tips to monitor/improve the performance of DG sets are highlighted below:

• The performance of the generator set is monitored in terms of the SEGR (Specific Energy Generation Ratio), which is the ratio of units of electricity generated (in kWh) per unit of diesel consumption (in liters).

• Conduct regular SEGR trials to monitor the performance of the generator. Contact the manufacturer for overhauling if the operating value of SEGR is less than 80% of the designed value at optimum load.

• The SEGR value drops significantly at a loading of below 60%. Try to optimally load the DG sets.

• Ensure that the air intake to the generator is cool and free from dust. Warm air can seriously decrease the generator’s performance on account of a reduction in volumetric efficiency.

• Clean the air filters regularly.

• Unbalanced loads on A.C. generators lead to an unbalanced set of voltages and additional heating in the generator. When motors, for example, are fed with an unbalanced set of voltages, additional losses occur in the motors. Hence, the load on A.C. generators should be balanced as far as possible.

• DG sets require regular and periodic maintenance for efficient running. Carry out maintenance once in a month covering the following points.
- Check the level and appearance of lubricant oil. Top up or change the lubricant oil periodically as per the manufacturer’s guidelines.
- Clean the radiator fans and heat exchanger.
- Check the belt condition. Loose or damaged belts will lead to high coolant temperatures.
- Optimize the operating frequency of the generator.

4.5.0 Conclusions:
Amongst the different industrial sectors, casting/foundry sector appears to be one of prime importance and all the relevant aspects have been considered in this Chapter. The work was divided into three parts as under:
1) Optimization of casting process parameters using fuzzy logic
2) Optimization of casting process parameters using Taguchi Method
3) Energy conservation opportunities in foundries.
The various conclusions drawn are as under:

4.5.1 Optimization of Casting Process Parameters Using Fuzzy Logic:
Improper process selection can lead to increase in complexity of production, increase in production time as well as increased cost of production. What is required is Design for production. Design for production takes in to account the various manufacturing processes available for manufacturing the component using the best design and best process for ease of manufacture at economical price without affecting the function of the component. In case of casting also, there are large numbers of processes to select from. Choosing the right manufacturing process for making a component is required at early stages of design. The casting processes have different characteristics. Similarly the component to be produced also has its own characteristics that are user defined. A novel approach can be to create the database for various process parameters for each process. The requirements of the product are then checked against the process parameters of each and every process and then we can have on our hand the compatibility of various processes for the given component. Weightage can be given to various parameters in terms of their importance and the best process can be identified for a particular component.
The database can be fed in to a computer program and what we get is computer assisted process selection using fuzzy logic, which will save the time, improve the quality and reduce the cost of the casting.
The knowledge base construction involved the conversion of the knowledge acquired into If-Then rules followed by coding these rules using the development tool. The resulting system is a ‘goal oriented’ system, that is, all the rules in the knowledge base are evaluated until all the possible outcomes are analyzed.. A suitable flow chart indicating the decision route and various levels of casting process selector can e used to prepare the fuzzy logic application for casting process selection. Various tables have been described in this case study for various parameters to be considered in selection of the casting process.
It can be concluded as under:
Manual process of selecting the casting methods has some drawbacks. For example, it is difficult to accept that a wall thickness of 3.49mm would imply complete incomaptibility where as 3.51 mm would imply complete compatibility. Four limits for each criterion are considered because in practice the process characteristics also depend on the equipment, manpower, skill, quality management practices and other company decisions. This can be captured in a band of values for each process capability characteristics. These models have the capability of recognizing, representing, manipulating, interpreting, and utilizing data and information that are vague and lack certainty. The limitation of this approach is, when there is no result that can meet the initial requirement, the system does not suggest to the user how can change the input value to have results. Nevertheless the fuzzy logic technique is more suitable in selection methodology for casting process because the capability of each process different from one foundry to another.

4.5.2 Optimization of Casting Process Parameters Using Taguchi Method:
Sand casting is used to manufacture complex shapes of various sizes depending upon the customer requirements. The basic requirements casting are pattern making, preparing a mold, pouring a molten metal, cooling of mold, shakeout, fettling. The main causes of rejection in castings are due to improper pattern, improper gating system, improper control of sand parameters, improper molten metal composition. The process parameters of the sand casting can be listed as follows:
- Sand particle size
- Moisture percentage in sand
- Green compression strength
- Mould hardness
- Permeability
- Pouring temperature of molten metal
- Pouring time of molten metal in mold
- Pressure test
The objective of this study is on optimizing the process parameters of sand casting process including optimum levels using the Taguchi. The relevant detailing with respect to selection of experimental orthogonal array has been done and experiments were conducted with the objective of optimizing sand casting process parameters. All the experimental results have been tabulated and considering the factors and the interactions, the performance of the expected optimum is also estimated. The main objective of the study was to reduce the variation and getting close to the target. After implementation of Taguchi method in the foundry a reduction of 37.66 % in variation was observed. This was due to the improved signal to noise ratio from -15.544 to -9.689. The improved standard deviation was 0.788 from the current standard deviation 1.547.

The summary of optimum conditions and concluding remarks are as under:
The optimum conditions for the factors computed are:
- Moisture (%) – Level 1 – Minimum 3.5
- Green compression strength (g/cm²) – Level 1 – Minimum 900
- Permeability – Level 2 – Minimum 185
- Pouring temperature (deg. Celsius) – Level 3 – Maximum 1420

The improvement expected in minimizing the variation is 37.66 percent which means reduction of casting defects from present 6.16 percent to 3.84 percent of the total castings produced in the foundry. This also reflects that by using Taguchi method the factor levels when optimized will result in reduction of casting defects and increase the yield percentage of the accepted castings without any additional investments. A usage of quality tools like Pareto chart is useful for finding the major defects in the daily operations of foundry. Quality of castings can be improved by aesthetic look, dimensional accuracy, better understanding of noise factors and the interaction between variables, quality cost system based on individual product, scrap reduction, reworking of castings and process control.

4.5.3 Energy Conservation in Foundry:
The most commonly used furnace in foundries is Cupola followed by the Induction furnace. Up to 50% of the foundry’s total energy consumption is accounted by Cupolas only. For efficient cupola operation guidelines and tips have been given for making the bottom sand base of the cupola, preparation of the coke bed, charging, melting, tapping and slagging.

Similarly the important energy saving measures in Induction Furnaces have been discussed.

Energy saving measures in other important operations have also been discussed for the following:
- Energy Savings in the Mould and Core-Making Process and Heat Treatment
- Energy Savings in the Machine Shop
- Energy Savings in the Compressed Air System
- Energy Savings in the Electrical Distribution System
- Energy Savings in Electrical Utilities – Motors and DG Sets

Following are some important observations w.r.t. annual savings due to energy conservation measures (ECM):
- Use of divided cupola blast (DCB) instead of conventional cupola can result in annual savings of Rs 22 lakhs for annual molten metal capacity of 3000T.
- Decreasing the melting temperature from 1550º centigrade to 1480º centigrade can result in annual savings of Rs 3 lakhs for annual molten metal capacity of 3000T.
- Decreasing core shooter die temperature from 345º centigrade to 320º centigrade can result in annual savings of Rs 75000 for annual molten metal capacity of 3000T.
- By replacing conventional motors (15kw) by energy efficient motors can result in annual savings of Rs 3.8 lakhs for use of 10 motors for 12 hrs for 300 days.
- By using VFD and start stop mode for compressors of 260 cfm can result in annual savings of Rs 1 lakhs for use at 0.8 X 12 hrs for 300 days.