Process Parameter Optimization for Sand Inclusion Defect in Furan No-Bake Casting by Grey Relational Analysis

Shailee G Acharya*, Manojkumar V Sheladiya** and Ghanshyam D Acharya***

Occurrence of defect in any process is the ultimate limitation of the process. Furan No-Bake (FNB) casting process also faces the same problem. To find and minimize the conditions for acquiring least casting defects is very critical. Trial-and-error method was the normal method for minimizing defects. But due to disadvantages like being expensive, time-consuming and uncertainty involved in the process, this method costs too much to the industry. The goal of an organization is to optimize the usage of resources to improve productivity. In this paper, Grey Relational Analysis (GRA) has been applied to minimize the FNB casting defects for optimizing the process parameters of FNB casting process. The process parameters are selected on the basis of rigorous research and on the basis of data collection and survey from different industries. The highest and lowest values of different process parameters were collected from Krislur Castomech Pvt. Ltd. — a foundry in Bhavnagar district of Gujarat, India. The main casting defect considered to minimize is sand inclusion.

Keywords: Sand inclusion, Furan No-Bake (FNB) casting, Grey Relational Analysis (GRA)

Introduction

Furan type resin binders were introduced in the 1950s as an acid catalyzed no-bake furan binder system. In the 1980s, furan resin became the largest resin binder consumed, and presently, it is the largest selling no-bake system. Furan No-Bake (FNB) is a simple two-part binder system made up of an acid catalyst and a reactive type resin (http://www.mancusocemicals.com/wp-content/uploads/2013/05/Furan-Binder-Use.pdf). It can be utilized for making all types of metal castings in all sizes. The amount of no-bake binder is taken usually 0.7%-1.0% based on sand and the levels of catalyst vary from 30% to 35% based on binder weight. FNB castings are in a trending demand of global industries due to extreme unique properties of high resistance to minimize the defects in sand/metal interface, excellent dimensional...
stability and superior shakeout with thermal or mechanical reclamation (Sarkar, 2014; and Pathak et al., 1998). These properties of material are constantly being optimized. The results of research on FNB with topics from base, i.e., properties of recycling, can be found and analyzed in a varied range of publications available worldwide (Andrade et al., 2005). Due to the development of modern technologies, industries are striving for quality and its development. FNB casting is a form of casting and also it possesses certain casting defects. These castings are termed in different forms by different researchers. There are multiple factors that play a role in contributing to cast defects, so it is impossible to eradicate such defects. However, minimization of certain defects is possible. In current times, casting defects are analyzed by certain tools like design of experiment and through rules, historical data analysis, Ishikawa charts, etc. The analysis of the casting data is done with certain optimization tools like ANOVA or Taguchi method. These methods have given satisfactory results (Lalwani et al., 2008). However, to save time and money, the concept of simulation is growing globally nowadays (Dabade and Bhedasgaonkar, 2013; and Ireland et al., 2002).

Grey Relational Analysis (GRA) is a promising tool for multiobjective optimization. GRA is very helpful for engineering applications and designs because it is user-friendly and finds the best solution or design available globally. The steps involved in GRA are: grey relational generating; reference sequence definition; grey relational coefficient calculation and grey relational grade calculation. GRA is highly unique compared to most of the optimization methods used traditionally. Translation of performance of all alternatives into sequence is the main procedure of GRA. The step is known as grey relational generating. Based on these sequences, a reference sequence (ideal target sequence) is defined. Then the calculation of grey relational coefficient between all comparability sequences and the reference sequence is needed. The grey relational grade between the reference sequence and every comparability sequences is calculated based on these grey relational coefficients. If a comparability sequence translated from an alternative has the highest grey relational grade between the reference sequence and itself, that alternative will be the best choice. The best choice among all alternatives will be based on comparability sequence translated from an alternative, which has the highest grey relational grade between the reference sequences. The procedure of grey relational analysis is shown in Figure 1.
2. Materials and Methods

Experiments were performed at a foundry named Krislur Castomech Pvt. Ltd. located in Bhavnagar, Gujarat. FNB mold system was used as sand binder to produce grey cast iron electric motor body. The samples as per IS: 1918-1966 were produced by changing the percentage of resin, catalyst and temperature. The data was collected for sand inclusion defect from the rejected casting possibly due to quality of mold in terms of strength. From the base of root-cause analysis, the testing like sieve analysis, scanning electron microscopy, energy dispersive spectroscopy, loss of ignition and pH test were performed on sand and the specimen was found in limit as per the Indian Standard (IS, 1966). The pouring height, flow rate of molten metal and pouring time are considered constant. Experiments were performed with instruments like sand binder mixer, mold boxes, hammer, calibrated compressive strength testing machine, etc. Figure 2 shows the samples of test specimen for compressive, tensile and transverse strength prepared as per standard and tested in universal strength machine, as shown in Figure 3 (Acharya et al., 2017; 2016a and 2016b).

Figure 2: Samples of Test Specimen for Compressive, Tensile and Transverse Strength

Figure 3: Broken Specimen in Compression Test
Table 1 shows the selected value of input variables. Experimental data is shown in Table 2 at different resins, catalyst and temperature level for tensile, compressive, transverse strength and scratch hardness.

<table>
<thead>
<tr>
<th>Levels of Experimental Factors</th>
<th>Resin (g)</th>
<th>Catalyst (g)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
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<td>30</td>
</tr>
<tr>
<td>2</td>
<td>0.85</td>
<td>45</td>
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</tr>
<tr>
<td>3</td>
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<td>55</td>
<td>45</td>
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</tbody>
</table>

**Table 2: Experimental Data for Sand Inclusion Defect**

<table>
<thead>
<tr>
<th>Run No.</th>
<th>Input Variables</th>
<th>Output Variables</th>
<th>Comp. (kg/cm²)</th>
<th>SH</th>
<th>Tensile (kg/cm²)</th>
<th>Transverse (kg/cm²)</th>
</tr>
</thead>
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<td>Catalyst</td>
<td>Temperature (°C)</td>
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</table>

3. Results and Discussion

3.1 Grey Relational Analysis

The details of the proposed GRA procedure are:

3.1.1 Grey Relational Generating

The influence of some attributes can be neglected when the units in which performance is measured are different for different attributes. The large range of some performance attributes may lead to non-selection of it. In addition, if the directions and goals of these attributes are different, it will cause incorrect results in the analysis (Huang et al., 2003). Therefore, for every alternative processing of all performance values into a comparability sequence, a process analogous to normalization, is essential. This processing is called grey relational generating in GRA. For a grey problem, if there are m alternatives and n attributes, the ith alternative can be expressed as $Y_i = (y_{i1}, y_{i2}, \ldots, y_{in}, \ldots, y_{im})$, where $y_{ij}$ is the performance value of attribute j of alternative i. The term $Y_i$ can be translated into the comparability sequence $X_i = (x_{i1}, x_{i2}, \ldots, x_{in}, \ldots, x_{im})$

$$X_j = \frac{y_j - \min\{y_{ij}, i=1,2,\ldots,m\}}{\max\{y_{ij}, i=1,2,\ldots,m\} - \min\{y_{ij}, i=1,2,\ldots,m\}}$$
for \( i = 1, 2, \ldots, m \) \hspace{1cm} \text{and} \hspace{1cm} j = 1, 2, \ldots, n \hspace{1cm} \ldots(1)

\[
X_{ij} = \frac{\max\{y_{ij}, i = 1, 2, \ldots, m\} - y_{ij}}{\max\{y_{ij}, i = 1, 2, \ldots, m\} - \min\{y_{ij}, i = 1, 2, \ldots, m\}}
\]

for \( i = 1, 2, \ldots, m \) \hspace{1cm} j = 1, 2, \ldots, n \hspace{1cm} \ldots(2)

\[
X_{ij} = \frac{|y_{ij} - y^*_j|}{\max\{y_{ij}, i = 1, 2, \ldots, m\} - \min\{y_{ij}, i = 1, 2, \ldots, m\}}
\]

for \( i = 1, 2, \ldots, m \) \hspace{1cm} j = 1, 2, \ldots, n \hspace{1cm} \ldots(3)

For the-larger-the-better attributes, Equation (1) is used; for the-smaller-the-better attributes, Equation (2) is used; whereas for the-closer-the-better, Equation (3) is used (Table 3).

<table>
<thead>
<tr>
<th>Comparability Sequence</th>
<th>Reference Sequence</th>
<th>Comp.</th>
<th>SH</th>
<th>Tensile</th>
<th>Transverse</th>
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Table 3 (Cont.)

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<th>Comparability Sequence</th>
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</tr>
<tr>
<td>No. 29</td>
<td>0.9945</td>
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</tbody>
</table>

3.1.2 Reference Sequence Definition

All performance values will be scaled into [0, 1] after the grey relational generating procedure using Equation (1), (2) or (3). For an attribute ‘j’ of alternative ‘i’, if the value $x_{ij}$ which has been processed by grey relational generating procedure is equal to 1 or nearer to 1, then the value is preferably compared to other alternatives. Which means the performance of alternative i is the best one for the attribute j. Therefore, an alternative will be a comparative better choice if all of its performance values are closest to or equal to 1. However, this kind of alternative does not usually exist. This paper then defines the reference sequence $X_0$ as $(x_{01}, x_{02}, \ldots, x_{0j}, \ldots, x_{0n}) = (1, 1, \ldots, 1, \ldots, 1)$, and then aims to find the alternative which comparability sequence is the closest to the reference sequence (Kuo et al., 2008; Tzeng et al., 2009; and Jayaraman and Mahesh, 2014).

3.1.3 Grey Relational Coefficient Calculation

Grey relational coefficient is used in determining how close $x_{ij}$ is to $x_{0j}$. The larger the grey relational coefficient, the closer $x_{ij}$ and $x_{0j}$ are; the grey relational coefficients can be calculated as:
\[
Y(x_{ij}, x_{ij}) = \frac{\Delta_{\text{min}} + \xi \Delta_{\text{max}}}{\Delta_{ij} + \xi \Delta_{\text{max}}}
\]

for \( i = 1, 2, \ldots, m \) and \( j = 1, 2, \ldots, n \)

In Equation (4), \( Y(x_{ij}, x_{ij}) \) is the grey relational coefficient between \( x_{ij} \) and \( x_{ij} \) and

\[
\Delta_{ij} = |x_{ij} - x_{ij}|
\]

\[
\Delta_{\text{min}} = \text{Min}\{\Delta_{ij}, i=1,2,\ldots,m; j=1,2,\ldots,n\}
\]

\[
\Delta_{\text{max}} = \text{Max}\{\Delta_{ij}, i=1,2,\ldots,m; j=1,2,\ldots,n\}
\]

\( \xi \) is the distinguishing coefficient, \( \xi [0, 1] \)

The purpose of the distinguishing coefficient is to expand or compress the range of the grey relational coefficient. For example, take the case where there are three alternatives, "a", "b" and "c". If \( \Delta_{ij} = 0.1, \Delta_{ij} = 0.4 \) and \( \Delta_{ij} = 0.9 \), it means that for attribute \( j \), alternative "a" is the closest to the reference sequence. After grey relational generating using Equations (1) to (3), \( \Delta_{\text{min}} \) will be equal to 1 and \( \Delta_{\text{max}} \) will be equal to 0. The grey relational coefficient results are described when different distinguishing coefficients are adopted (Figure 4) (Tzeng et al., 2009; and Jayaraman and Mahesh, 2014).

### Figure 4: The Relationship Between Distinguishing Coefficient and Grey Relational Coefficient

The differences between \( Y(x_{ij}, x_{ij}), Y(x_{ij}, x_{ij}) \) and \( Y(x_{ij}, x_{ij}) \) always change when changed distinguishing coefficients are adopted. The rank order of \( Y(x_{ij}, x_{ij}), Y(x_{ij}, x_{ij}) \) and \( Y(x_{ij}, x_{ij}) \) is always the same irrespective of the distinguishing coefficients. The distinguishing coefficient can be set by the decision-maker judgment. The changed distinguishing coefficients produce different results of GRA. The distinguishing coefficient value is set as 0.5 primarily and other different distinguishing coefficients are then tested for analysis.
3.1.4 Grey Relational Grade Calculation

After calculating the entire grey relational coefficient $\gamma(x_0, x_j)$, the grey relational grade can be calculated as:

$$\Gamma(X_o, X_j) = \sum_{j=1}^{n} w_j \gamma(x_{y_j}, x_{y_j})$$

for $i = 1, 2, \ldots, m$ \hspace{1cm} \ldots(5)

In Equation (5), $\Gamma(X_o, X_j)$ shows grey relational grade from $X_o$ to $X_j$. It gives the level of correlation between the reference sequence and the comparability sequence. The weight of attributes $j$ which is usually decision-maker judgment or structure of the proposed problem is $w_j$. The grey relational grade indicates the degree of similarity between the comparability sequence and the reference sequence (Liang and Tsay, 2010). Therefore, on every attribute, the reference sequence indicates the better performance that can be achieved along with the comparability sequence. So, if highest grey relational grade is obtained by a comparative sequence with reference sequence for an alternative, which indicates comparability sequence similarity with reference sequence. It would be comparative better choice (Tzeng et al., 2009; and Jayaraman and Mahesh, 2014).

So, the better choice among all alternatives would be selected based on the similarities of comparability sequence with reference sequence. This is possible due to highest grey relational grade of comparability sequence with the reference sequence (Tzeng et al., 2009; and Jayaraman and Mahesh, 2014). Table 4 shows calculated grey relational coefficient and grey relational grade for 29 comparability sequences with rank.

<table>
<thead>
<tr>
<th>Experimental Run</th>
<th>Grey Relational Coefficients Value</th>
<th>Grey Relational Grade</th>
<th>Rank</th>
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Table 4 (Cont.)

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<td>0.6974</td>
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</table>

From Table 4, it can be concluded that the highest grey relational grade is 0.9216 for experimental run No. 29 which is assigned as rank 1. So the optimum parameter for the stated problem is described in Table 5.

Table 5: Optimized Parameters and Their Levels

<table>
<thead>
<tr>
<th>Experimental Run</th>
<th>Resin (g)</th>
<th>Catalyst (g)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 29</td>
<td>0.85</td>
<td>45</td>
<td>30</td>
</tr>
</tbody>
</table>

Figure 5 represents grey relational grade at different experimental runs. Figures 6, 7 and 8 show average grey relational grades versus level of resin, level of catalyst and sand temperature, respectively. Sand temperature plays a crucial role in the
strength of the mold as chemical reaction is taken place when resin react with catalyst while mixing with sand (Bobrowski and Grabowska, 2012).

**Conclusion**

It is evident from Figures 6, 7 and 8 that independent parameter resin, catalyst and temperature have the main effect on response variables. From Figure 6, it is concluded that as the resin increases from 0.7 to 0.85, average grey relational grade increases but decreases at 1.0. From Figures 7 and 8, it is concluded that as the level of catalyst and temperature increases from 1 to 2, response parameter increases but decreases at level 3.

The required range of compressive strength after 4 h of drying is 12 to 15 kg/cm² and as per binder supply and defect analysis it is acceptable. The range of variables stated in Table 5 will lead to economical use of binder and denotes a general range of temperature in Indian region. The less consumption of binder produces less emission of gases during pouring and produce less environmental hazard.

**References**


Reference #: 60J-2017-11-01-01