Response Optimization of Sand Casting Parameter on Impact Strength of Cast Product

Mahipal Singh¹, Rajeev Rathi²*, Anil Kumar³
¹,²,³Assistant Professor, Department of Mechanical Engineering, Lovely Professional University, Punjab, India-144401

Abstract

Sand casting had become one of the largest casting processes in the production environment due to its ability to produce a wide variety of ferrous and non-ferrous components in order to satisfy customer needs and fulfillment. There are numerous casting techniques worldwide, including the casting of sand. More than 70 percent of casts are only treated with sand casting and the remaining casting processes are also shared. In the sand casting process which pours molten metal temperature and sand permeability, the mold hardness is essential to the sand casting process in order to achieve the desired product quality. Aluminum (6061) recently played an important role in the aerospace, automotive, production and marine sectors among other aluminum alloys, which were available worldwide.

Keywords: Sand Casting, Response surface methodology, Impact strength, Optimization.

1. Introduction

The main purpose for every foundry company is production of high quality metal castings with minimal rejections so that they could satisfy needs and requirements of customer in the global market (Narayanaswamy. C & NatarajanK, 2016) (Ishfaq K. et al., 2020). The growth of foundry industries depends upon skilled and experienced workers and techniques used by them in casting. It is been one of the oldest and cheapest processes in any manufacturing industry among other manufacturing processes like forging, machining and welding which manufactures ferrous and non-ferrous by obtaining a metal object according to pattern prepared on solidification of the molten metal (G. Mahesh, 2017) (Zheng, J et al., 2020). According to Foundry Informatics Centre, in the World Casting Census December 2017, India ranks the Second Largest Casting Manufacturers in the World reported 5.4% increase in production to 11.35 million metric tons whereas China being First Largest Casting Manufacturers in the World reported a 5.4% increase since 2015 putting its total production at 47.2 million metric tons. (http://www.foundryinfo-india.org/profile_of_indian.aspx)

1.1 Sand Casting

Among most of the casting processes available worldwide, 70% of the castings are prepared only through sand casting process (Anil Rathore&Prof.F.Ujjainwala (2017). Selection of Sand Casting process among the other casting processes is due to its Easy Development of Patterns, Excellent Geometrical Dimensions, Higher Rate of Production and Lesser Solidification Time (G. Mahesh et.al, 2017)(Prabhakar, A. et al., 2020). The various components of sand casting are shown in figure 1 and also process of sand casting when the mould is opened and closed. The various components of sand casting process involves Ladle, Molten Metal, Cope, Drag, Pouring Cup,
Sprue, Parting Line, Runner, Gates, Chaplets, Cavity, Core, Riser. Casting is known as one of the oldest processes for the production of metallic components. The first metal casting was done during the period of 4000-3000 BC using stone and metal moulds (Goyat R. et al. 2016, Goyat R. et al. 2019). The molten metal in casting is poured into a cavity; later the molten metal takes the shape of the cavity after solidification and then removing the solid component as the molten metal solidifies (Sulaiman, S., & Hamouda, A. M. S, 2004). This process of casting starts as following:

- Placing a pattern with a desired shape in the sand to make an imprint.
- Incorporating a Gating system.
- Pouring of the molten metal to fill the mould cavity.
- Allowing the molten metal to cool till it solidification.
- Breaking off the sand mould and removing the casting.

![Figure 1. Sand casting mould](image)

1.5 Casting Defects

The defects in the casting include blow holes, mismatch, misrun, micro porosity, penetration, shrinkage, inclusions, flash or fin, crushes, run out and drop. These casting defects do not occur accidentally but through error practices in step by step operations involved in the process of casting that leads to defective parts after the casting process, which is the big problem faced by the casting industry. (Narayanaswamy.C & Natarajan.K 2016; Kamble.B.S. 2016). Figure 2 shows various defects in the sand casting process.
2. Literature Review

N. Ducic et al. (2017) implemented Genetic algorithm to optimize the geometry of the gating system maximizing the rate of filling. Rahaini Mohd Said et al. (2017) conducted $2^k$ Factorial design with 16 levels of optimised process parameters. Optimal Green sand composition are 100g silica sand, 21g bentonite, 6.5g water and 6g coal dust getting optimum permeability number of 598.3GP minimizes occurrence of defects by improving quality of sand casting. Mugeriet al. (2017) proposed the technique of Magma soft simulation to minimize the defects in casting by considering filling temperature and pressure with 5 test samples of different wall thickness. Sanitas A & Coniglio N (2017) viewed that correlation between molten metal temperature and casting roughness values of Zr refined ZE41 Mg alloy cast in 3D printed Furan sand moulds. Roughness value drops when temperature of molten metal is 908K and solid fraction of 0.22. Mold Cavity filled at last has lowest roughness values. Misal Gandhi & Dr. Piyush Jain (2017) discussed that imposing Mechanical Vibrations, cooling rate increases at the top, middle and bottom area. Joseph B & Reyaz H (2017) concluded that Chromium is used as a substitute to titanium. Microstructure and mechanical properties were studied increasing addition of chromium to 0.23%. Casting with 0.20% chromium gave highest mechanical properties showing high hardness and UTS of 57HB and 229Mpa than compared to titanium. R. SrivathsanIyer et al. (2017) proposed Analysis of Variance (ANOVA) on grey cast iron castings to show the effect of process parameters like Moisture Content, Clay Content, and Green strength on Surface Roughness and Brinell Hardness. G. Mahesh et al. (2017) performed Design of Experiments using Taguchi Method for optimization of vent hole angle and vent hole diameter at 780 °C Pouring Temperature for Aluminium (6063) using sand casting process. Anil Rathore & Prof. F. Ujjainwala (2017) proposed L4 orthogonal array and Taguchi method for optimization of process parameters like Pouring Temperature 1390-1420 °C, Pouring Time 13 seconds for grey cast iron. Narayana Swamy C & Natarajan K (2016) carried out the study of various casting defects for one year from...
April 2014 to March 2015 in Ammarun Foundries, Coimbatore saying that the percentage of these casting defects vary from 12.87% to 15.02%.

BhushanKamble (2016) carried a research on various casting defects and their causes. He concludes that rejection in casting just won’t happen usually but due some wrong steps taken in the cycle of manufacturing a casting product which can result to about nearly 50% of rejections if not controlled. Himanshu.KB.Ravi. (2016) showed effect of molding parameters on mechanical properties is done by Taguchi method. Optimization of mould parameters have been considered such as curing time 4h, 2.4% binder and 40 GFN gives highly dimensional quality parts. V.M.Mohammedet al. (2016) applied Taguchi’s method to sand casting process with optimised parameters reduces rejections in Al-Si alloy casting also by setting the parameters like Pouring temperature 690°C and Holding time 4min if are optimised reduces the rejections in casting. Narayanaswamy, C & Natarajan, K. (2016) carried out experiments by FMEA Techniques, ANOM and setting of process parameters is done to minimize casting defects. Optimum parameters like pouring temperature 1460°C, inoculants 0.3, moisture content 3.1%, and Sand binder ratio 60:0.1 were observed.

3. Methodology
3.1. Materials

Aluminium Alloy 6061 which was developed in 1935 is a versatile heat treatable extruded alloy containing silicon and magnesium as major alloying elements. It has excellent welding characteristics, relatively high strength, better workability and higher resistance to corrosion. The Chemical Composition of Aluminium Alloy 6061 is shown in table 1. From table, it is observed that the Silicon (Si): 0.4% - 0.8%, Magnesium (Mg): 0.8 – 1.2%, Iron (Fe): Max 0.7%, Copper (Cu): 0.15% - 0.4%, Manganese (Mn): Max 0.15%, Chromium (Cr): 0.04% - 0.35%, Zinc (Zn): Max 0.25%, Titanium (Ti): Max 0.15%, Other Elements not more than 0.05%, Remainder Aluminium (95.85 – 98.56%).

<table>
<thead>
<tr>
<th>Element</th>
<th>Si</th>
<th>Mg</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Other</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount</td>
<td>0.4-0.8</td>
<td>0.8-1.2</td>
<td>Max 0.7</td>
<td>0.15-0.40</td>
<td>Max 0.04-0.15</td>
<td>Max 0.35</td>
<td>Max 0.25</td>
<td>Max 0.15</td>
<td>Max 0.05</td>
<td>95.85-98.56</td>
</tr>
</tbody>
</table>

3.2 Experimental Methodology

The current research work carried out by experimentation work and optimization of sand casting parameters for better results. Sand casting process is used for experimental work and optimization of parameters is done with the help of ANOVA approach in MINITAB software. The flow chart of current study is shown in Figure 3. Methodology is a theoretical and systematic analysis of methods that are applied in a particular field of research. It is a combination of principles and theoretical analysis associated with the branch of research study. It
comprises concepts such as qualitative and quantitative techniques, theoretical model and phases offering an understanding of which method are to be used. The experimental works are having the combination of pouring temperature, permeability of sand and mould hardness. The range of input variable of sand casting process with proper combination at pouring temperature of 650, 700 and 750 °C are shown in figure 3, 4 and 5 respectively.

Figure 3: Experimental methodology at pouring temperature of 650 °C

Figure 4: Experimental methodology at pouring temperature of 700 °C
The range of Pouring Temperature was selected as (650-750°C), Permeability Number as (30-60) and Mould Hardness Number as (60-80) as shown in table 2.

<table>
<thead>
<tr>
<th>SN.</th>
<th>Input Parameters</th>
<th>Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Level 1</td>
</tr>
<tr>
<td>1.</td>
<td>Pouring Temperature(°C)</td>
<td>650</td>
</tr>
<tr>
<td>2.</td>
<td>Permeability (Darcy)</td>
<td>30</td>
</tr>
<tr>
<td>3.</td>
<td>Mould Hardness (Number)</td>
<td>60</td>
</tr>
</tbody>
</table>

Sand Mould Preparation

Sand casting is an oldest method of manufacturing a component by pouring molten metal in cavity as per required of design of component. The runner and riser are fitted in cope and venting is done for proper solidification of molten metal. This is shown in figure 6 & 7.
The three sand moulds with low permeability of sand are shown as figure 8.

Similarly, three more sand moulds were prepared by using medium permeability of sand and mould hardness Number of 70 for the manufacturing of casting with different pouring temperature (650, 700, 750 °C) as shown in figure 9 and figure 10.
The pouring of molten aluminum material in the sand mould is shown in figure 11.

Figure 11: Pouring of molten material at pouring temperature of 650°C at high permeability of sand mould with mould hardness number 80

Figure 12: Pouring of molten material at pouring temperature of 650°C at low permeability of sand mould with mould hardness number 60
The pouring of molten metal at 700 °C in the sand mould with high permeability of sand is shown in figure 13. The pouring temperature is kept same and the permeability of sand mould is decreased from 60 to 30. Then pour the molten material with 700 °C pouring temperature in the sand mould which having low permeability of silica sand and this is shown in figure 14.

Figure 13: Pouring of Molten material at Pouring Temperature of 700 °C in High Permeability of sand mould

Figure 14: Pouring of Molten material at Pouring Temperature of 700 °C in Low Permeability of sand mould

4. Result and Discussion

4.1. Main Effects Plot for the Effect of Pouring Temperature and Permeability on Impact Strength

In the figure 14, it is shown that impact strength decreases with increase in pouring temperature and permeability.

Figure 14: Main Effects Plot for the Effect of Pouring Temperature and Permeability of sand on Impact Strength

4.2. Interaction Plot for the Effect of Pouring Temperature and Permeability on Impact Strength

From figure 15, it is observed that high impact strength can be achieved at a pouring temperature 650 and permeability of sand 30.
4.3. Contour Plot for Effect of Pouring Temperature and Permeability on Impact Strength

From figure 16, it is shown that Impact strength decreases with increase in pouring temperature and permeability of sand.

4.4. Response Optimization for Pouring Temperature and Permeability on Impact Strength

<table>
<thead>
<tr>
<th>Response</th>
<th>Goal</th>
<th>Lower</th>
<th>Target</th>
<th>Upper</th>
<th>Weight</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Strength</td>
<td>Maximum</td>
<td>2.4</td>
<td>6.2</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Solution

<table>
<thead>
<tr>
<th>Solution</th>
<th>Pouring Temperature</th>
<th>Permeability</th>
<th>Impact Strength</th>
<th>Composite Desirability</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Multiple Response Prediction

<table>
<thead>
<tr>
<th>Variable</th>
<th>Setting</th>
<th>Fit</th>
<th>SE Fit</th>
<th>95% CI</th>
<th>95% PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pouring Temp.</td>
<td>650</td>
<td>6.20</td>
<td>0.0914</td>
<td>(5.9202, 6.5020)</td>
<td>(5.7756, 6.6466)</td>
</tr>
<tr>
<td>Permeability</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.5 Optimization Plot for effect of Pouring Temperature and Permeability on Impact Strength

In the given figure 17 it is shown that the optimal values of permeability of sand are 30 and optimal mould hardness number is 60 and best fit of impact strength is 6.20 Joule/mm²

![Optimization Plot](image)

Figure 17: Optimization Plot for effect of Pouring Temperature and Permeability of sand on Impact Strength

4.6. Response Surface Methodology of Permeability and Mould Hardness on Impact Strength

4.6.1 Analysis of Variance for Effect of Permeability and Mould Hardness on Impact Strength

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F-Value</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>5</td>
<td>5.5478</td>
<td>1.10956</td>
<td>0.50</td>
<td>0.768</td>
</tr>
<tr>
<td>Linear</td>
<td>2</td>
<td>3.8083</td>
<td>1.90417</td>
<td>0.86</td>
<td>0.507</td>
</tr>
<tr>
<td>Permeability</td>
<td>1</td>
<td>3.5267</td>
<td>3.52667</td>
<td>1.59</td>
<td>0.297</td>
</tr>
<tr>
<td>Mould Hardness</td>
<td>1</td>
<td>0.2817</td>
<td>0.28167</td>
<td>0.13</td>
<td>0.745</td>
</tr>
<tr>
<td>Square</td>
<td>2</td>
<td>0.0494</td>
<td>0.02472</td>
<td>0.01</td>
<td>0.989</td>
</tr>
<tr>
<td>Permeability*Permeability</td>
<td>1</td>
<td>0.0356</td>
<td>0.03556</td>
<td>0.02</td>
<td>0.907</td>
</tr>
<tr>
<td>Mould Hardness*Mould Hardness</td>
<td>1</td>
<td>0.0139</td>
<td>0.01389</td>
<td>0.01</td>
<td>0.942</td>
</tr>
<tr>
<td>2-Way Interaction</td>
<td>1</td>
<td>1.6900</td>
<td>1.69000</td>
<td>0.76</td>
<td>0.447</td>
</tr>
<tr>
<td>Permeability*Mould Hardness</td>
<td>1</td>
<td>1.6900</td>
<td>1.69000</td>
<td>0.76</td>
<td>0.447</td>
</tr>
<tr>
<td>Error</td>
<td>3</td>
<td>6.6611</td>
<td>2.22037</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>12.2089</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.6.2 Main Effects Plot for the Effect of Permeability and Mould Hardness on Impact Strength

In the given figure 18, it is observed that the permeability of sand and mould hardness decreases with increase in impact strength.

![Main Effects Plot for Impact Strength](image)

Figure 18: Main Effects Plot for Effect of permeability of sand and Mould Hardness on Impact strength

4.6.3 Interaction Plot for Effect of Permeability and Mould Hardness on Impact Strength

Figure 19 is presenting that maximum impact strength can been seen at mould hardness number 60 and at a permeability of sand 30.

![Interaction Plot for Impact Strength](image)

Figure 19: Interaction Plot for the Effect of Permeability of sand and Mould Hardness Number on Impact Strength
4.6.4 Contour Plot for the Effect of Permeability and Mould Hardness on Impact Strength

Here in the given figure 20, the input parameters are pouring temperature and permeability of sand and the output response is Tensile Strength and it is shown that impact strength decreases with increase in permeability of sand and mould hardness number.

![Contour Plot of Impact Strength vs Mould Hardness, Permeability](image)

Figure 20: Contour Plot for the Effect of Pouring Temperature and Mould Hardness on Impact Strength

4.6.5 Response Optimization for Effect of Permeability and Mould Hardness on Impact Strength

<table>
<thead>
<tr>
<th>Response</th>
<th>Goal</th>
<th>Lower</th>
<th>Target</th>
<th>Upper</th>
<th>Weight</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Strength</td>
<td>Maximum</td>
<td>2.4</td>
<td>6.2</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Solution

<table>
<thead>
<tr>
<th>Solution</th>
<th>Permeability</th>
<th>Mould Hardness</th>
<th>Impact Strength Fit</th>
<th>Composite Desirability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>60</td>
<td>5.69444</td>
<td>0.866959</td>
</tr>
</tbody>
</table>

Multiple Response Prediction

<table>
<thead>
<tr>
<th>Variable</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability</td>
<td>30</td>
</tr>
<tr>
<td>Mould Hardness</td>
<td>60</td>
</tr>
<tr>
<td>Response</td>
<td>Fit</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permeability</td>
<td>30</td>
</tr>
<tr>
<td>Mould Hardness</td>
<td>60</td>
</tr>
<tr>
<td>Response</td>
<td>Fit</td>
</tr>
<tr>
<td>SE Fit</td>
<td>1.34</td>
</tr>
<tr>
<td>95% CI</td>
<td>(1.44, 9.95)</td>
</tr>
<tr>
<td>95% PI</td>
<td>(-0.68, 12.07)</td>
</tr>
</tbody>
</table>

4.6.6 Optimization Plot for Effect of Permeability and Mould Hardness on Impact Strength

In the figure 21 the optimal points for permeability of sand is 30 and for mould hardness number 60 at a best fit of Impact Strength at 5.69 Joule/mm².
5. Conclusion

The experimental investigation is used to predict ultimate tensile strength, impact strength and Rockwell hardness of Aluminum (6061) by sand casting process using Design of Experiments of Analysis of Variance (ANOVA) and Response Surface Methodology (RSM). The ultimate tensile strength is measured using Universal testing machine and Impact strength is measured using impact testing machine, Hardness using Rockwell hardness testing machine. Casting of Aluminum (6061) material is presented with enhanced mechanical properties and process parameters such as pouring temperature, permeability of sand and mold hardness affect the output response like tensile strength, impact strength and hardness.

References


https://me-mechanicalengineering.com/probable-causes-suggested-remedies-various-casting-defects


