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Calculation and Simulation of Aluminium Alloy Flange Reducer Cast using Resin Sand Mold

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Abstract

One of the causes of defects in casting is due to poor gating system design. In conventional casting methods, the gating system design process is carried out by trial and error to find the best design results. Computer modeling and simulation offer process design in a much faster time, and at much less cost, compared to conventional methods. The gating system design approach with a combination of well calibrated simulation software can avoid defect before casting. Casting simulation helps to visualize the phenomena of filling, molten metal solidification, and shrinkage porosity. The resulting casting simulation can be displayed in graph variants at specific nodes with line graphs or numerical numbers manually. This study discusses the simulation of casting a flange reducer from aluminum alloy material using a resin sand mold. The initial dimensions of the gating system used are sprue of 14.5 x 8.4 x 180 mm, runner 147 x 10 x 5.5 mm, ingate 80 x 10 x 5.5 mm with a bottom gate channel system. Total of dominant porosity that occurs using the initial gating system is 65.31 % and show the undirectional solidificiation behavior. After modifying the gating system and increasing the riser size, the simulation results show directional solidification behavior starting from the thinnest part to the thickest part and ending at the riser. The shrinkage porosity can compensate with the total of porosity is 57.60 % at the riser. Modification of the channel system is required to obtain a sound casting or porosity free.

Keywords: Casting simulation; flange reducer; gating system; resin sand; shrinkage porosity

1. Introduction

Sand casting is a manufacturing process for making complex shapes from metal materials in mass production. There are two successive main stages, the filling process, and the compaction process, in foundry production. In the filling process, a gating system was designed consisting of a pouring cup, runner, sprue, sprue well, and in-gate to guide the filling of molten metal. The riser system is used to compensate for the shrinkage caused by the solidification of the casting [1]–[3].

The flange is the most important component in the piping system. Flange reducers are used to make reductions in pipe diameter. Flange reducers are most often used in installations with limited space [4]. In general, aluminum is widely used in foundry because it is relatively low cost and easy to form. When casting aluminum, several factors affect its quality. It is undeniable that many types of defects occur in the sand casting process, such as porosity and incomplete filling. Shrinkage porosity is probably the most common phenomenon in the foundry, and it is difficult to eliminate it [5, 6].

In conventional methods only use the identified experience to design the gating system or by trial and error. Whereby doing manual calculations and directly apply them. If a defect occurs with this system, then the gating system is modified according to the position and level of the defect. This trial method is continuously until the defects in the casting are reduced. This trial and error method is considered to be ineffective and efficient so that it can cause the relationship between the dealer and the customer to be damaged because it requires and consumes more time and effort [7].

The use of calculation and simulations in sand casting has become a powerful tool for analyzing mold filling, compaction, and cooling, as well as for imagining the location and type of internal defects. Casting simulation helps optimize casting process design and improve casting yield. This simulation plays an important role in overcoming casting defects that occur during the casting

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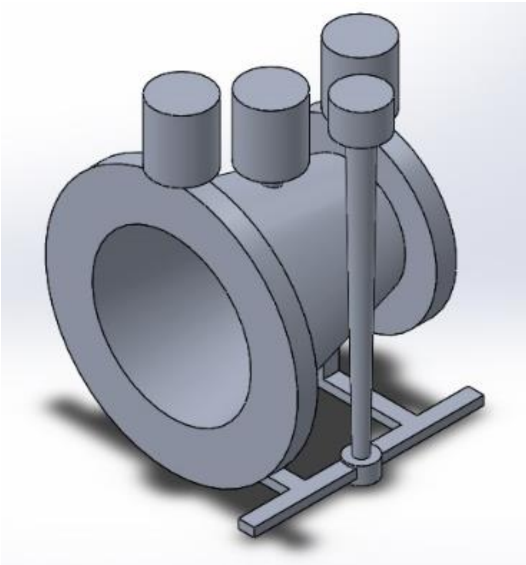


Figure 1. 3D Model gating system

process [8]–[11]. The calculation carried out in the casting process is then simulated using Procast software to optimize the results of the casting to be carried out.

2. Research Methodology

The method used in this study is an experimental method, which is a method used to predict the mechanism of compaction of aluminum alloys, analyze the results, and optimize casting parameters to achieve good properties of a material by experimentation using software simulations.

3d modeling of flange reducer is done with the help of Solidwork software. The 3D geometry of the flange reducer with a gating system using Solidwork is shown in Fig. 1. The material chosen for the flange reducer is A 356.0 with dimensions 101.60 mm x 50.80 mm x 127 mm The modeling consists of determining the bottom gating system.

In performing the calculation of the channel system, initial data is needed which will be used to determine the dimensions of the channel system. Mathematically the calculation of the channel system is as follows [12, 13]:

- Determine volume of cast object (*V*)
- Determine dominant thickness of cast (*t*)
- Determine depth of metal in pouring basin (*b*)
- Calculation mass of object cast, the equation is shown as:

$$W = V \, x \, \rho \quad (1)$$

where:

W = Mass of cast object (gr)
V = Volume of cast object (cm^3)
ρ = Density of aluminium (gr/cm^3)

- Calculation of pouring volume, Qp (m^3) is shown as:

$$Qp = \frac{Wp}{\rho} \quad (2)$$

where:

Qp = Pouring volume (m^3)
Wp = Pouring weight (kg)
ρ = Material density (kg/m^3)

- Calculation of pouring time, tp (s) according by Nielsen as follows:

$$tp = 0.32 \, x \, t \, x \, Wp^{0.4} \quad (3)$$

where:

tp = Pouring time(s)
t = Dominant thickness of cast (mm)
Wp = Mass of cast object (gr)

- Effective sprue height H (mm) use bottom gate as:

$$Effective\ sprue\ height = h - \frac{p}{2} \quad (4)$$

where:

ESH = Effective sprue height (mm)
h = Height of sprue (mm)
p = Cast height (mm)

- Determine the area of the bottom sprue (choke area) as:

$$As = \frac{W}{\rho \cdot tp \cdot c\sqrt{2 \cdot g \cdot H}} \quad (5)$$

where:

A_B = Area of the bottom sprue (mm^2)
W = Mass of cast object (kg)
ρ = Liquid metal density (kg/m^3)
tp = Pouring time (s)
H = Effective height of descending channel (m)
g = gravitational acceleration (9.81 m/s^2)
c = Efficiency factor of channel down (0.88)

- Determine the diameter of the bottom sprue (choke area) as:

$$D_B = \sqrt{\frac{4 \, x \, A_B}{\pi}} \quad (6)$$

where:

D_B = Diameter of the bottom sprue (mm)
A_B = Area of the bottom sprue (mm^2)

- Determine the area of the top sprue, as:

$$A_A = A_B \sqrt{\frac{h}{b}} \quad (7)$$

where:

A_A = Area of the top sprue (mm^2)
A_B = Area of the bottom sprue (mm^2)
h = Height of sprue (mm)
b = Depth of pouring basin (mm)

- Determine the diameter of the bottom sprue, show:

$$D_A = \sqrt{\frac{4\, x A_A}{\pi}} \tag{8}$$

where:

D_A = Diameter of the top sprue (mm)
A_A = Area of the top sprue (mm^2)

- Determine of ingate use the ratio of American AFS horizontal gating system between choke area : runner area : gate area = 1:4:4, then the runner is equal to four times the choke area and the gate area is equal to four times the choke area.

- Determine *well base area* (mm^2), the equation is shown as:

$$\textit{well base area} = 5 \times A_B \tag{9}$$

- Determine well base diameter (mm), the equation is shown as:

$$d = \sqrt{\frac{4 \times \textit{well area}}{\pi}} \tag{10}$$

- Determine *well base depth* (mm) is shown as:

$$\textit{Well base depth} = 2 \times \textit{runner depth} \tag{11}$$

Generally casting simulation software has three main parts, namely:

- Visual Mesh: the program reads the geometry and generates a mesh.
- Visual Cast: addition of boundary conditions and material data, filling, and temperature calculation.
- Visual Viewer: show simulation result data.

During the casting simulation process, compaction and porosity are checked and the gravity sand casting process is optimized by modifying the gating system. The elements that are taken into account in the flange reducer casting process are pouring cup, sprue and sprue base, in gate, riser, which are designed using solidworks software. The initial dimensions of the duct system used are sprue of 14.5 x 8.4 x 180 mm, runner 147 x 10 x 5.5 mm, in gate 80 x 10 x 5.5 mm. and the location of their respective molds. From the dimension size data, it will be used to build a 3D simulation model using computer simulation software.

3. Results and Discussion

3.1. Channel System Planning

3.1.1. Cast Material

- Material type = A356.0
- Densty = 2,685 kg/m^3
- Liquidus = 613°C
- Solidus = 548°C

3.1.2. Specimen

- Volume of cast object (*V*) = 537,949.92 mm^3
- Dominant thickness (*t*) = 20 mm
- Depth of metal pouring basin (*b*) = 20 mm
- Mass of cast object

The equation of cast object mass is shown as:

$$\begin{aligned} W &= V \times \rho \\ &= 537.949 \times 2,685 \\ &= 1,444.39\ gr = 1.444\ kg \end{aligned}$$

- Calculation pouring volume, Qp (m^3) is shown as:

$$\begin{aligned} Qp &= \frac{Wp}{\rho} \\ &= \frac{1.442}{2,685} \\ &= 0.000537\ m^3 \end{aligned}$$

- Calculation pouring time, tp (s). according by Nielsen as follows:

$$\begin{aligned} tp &= 0.32 \times t \times Wp^{0.4} \\ &= 0.32 \times 20 \times 1.157 \\ &= 7.4\ \text{sec} \end{aligned}$$

- Determine *effective sprue height*, H (mm) use bottom gate

$$\begin{aligned} \textit{Effective sprue height} &= h - \frac{p}{2} \\ &= 180 - \frac{161,6}{2} \\ &= 99.2\ mm = 0.0992\ m \end{aligned}$$

- Determine area of the bottom sprue, A_B (mm^2)

$$\begin{aligned} As &= \frac{w}{\rho \cdot tp \cdot c\sqrt{2 \cdot g \cdot H}} \\ &= \frac{1.444}{2,685 \cdot 7.4 \cdot 0.88\sqrt{2 \cdot 9.81 \cdot 0.0992}} \\ &= \frac{1.444}{17,484.72 \cdot 1.395} \\ &= 5.92 \times 10^{-5} m^2 = 59.2\ mm^2 \end{aligned}$$

- Determining the diameter of the bottom sprue:

$$\frac{1}{4}\pi d^2 = 59.2$$

$$D_B = \sqrt{\frac{4\times A_B}{\pi}} = \sqrt{\frac{4\times 59.2}{\pi}} = \sqrt{\frac{236.8}{3.14}} = 8.7\ mm$$

- Area of the top sprue A_A (mm^2):

$$A_A = A_B\sqrt{\frac{h}{b}} = 59.2\sqrt{\frac{180}{20}} = 177.6\ mm^2$$

- Determining the diameter of the top sprue:

$$\frac{1}{4}\pi d^2 = 177.6$$

$$D_A = \sqrt{\frac{4\times A_A}{\pi}} = \sqrt{\frac{4\times 177.6}{\pi}} = \sqrt{\frac{710.4}{3.14}} = 15.04\ mm$$

- Determining ingate

The ratio of AFS horizontal gating system 1:4:4 can be obtained as:

$$Area\ ingate = 4\times A_B = 4\times 59.2 = 236.8\ mm^2$$

$$Then\ size\ ingate = L\times T = 20\times 11.84 = 236.8\ mm^2$$

- For a channel system that uses two ingates then:

$$R1 = R2 = runnerarea;$$

$$2 = 118.4 : 2 = 59.2\ mm^2$$

$$Then\ size\ ingate = L\times T = 10\times 5.92 = 59.2\ mm^2$$

- Determining *Well base area* :

$$Well\ base\ area = 5\times A_B = 5\times 59.2 = 296\ mm^2$$

Table 1. Result of dimension of calculation the gating system

Part of gating system	Dimensions
Volume of cast	537,949.92 mm^3
Dominant thicknest	20 mm
Depth of metal pouring basin	20 mm
Pouring volume	537,000 mm^3
Pouring time	7.4 second
Effective sprue height	99.2 mm
Area of the bottom sprue	59.2 mm^2
Diameter of the bottom sprue	8.7 mm
Part of gating system	Dimensions
Area of the top sprue	177.6 mm^2
Diameter of the top sprue	15.04 mm
Area ingate	236.8 mm^2
Size ingate	20 mm x 11.84 mm
Well base area	296 mm^2
Well base diameter	19.4 mm
Well base depth	11.84 mm

- Well base diameter*:*

$$d = \sqrt{\frac{4\times well\ area}{\pi}} = \sqrt{\frac{4\times 296}{3.14}} = 19.4\ mm$$

- Determining *Well base depth*:

$$well\ base\ depth = 2\times runner\ depth = 2\times 5.92 = 11.84\ mm$$

3.2. Simulation Result and Analysis

3.2.1. Solidification

Solidification is the time in every second the reducer flange becomes completely solid, from the time of the end of pouring to the point of solidification. Solidification time is proportional to the ratio of volume to the surface area [14, 15]. After the molten metal is poured into the mold cavity, the compaction of the flange reducer begins. Solidification in the casting process is generally complex, where physical, thermal, and metallurgical phenomena occur simultaneously.

To obtain good casting quality, directional compaction is required. Solidification is the result of heat transfer from the internal casting to the external environment [9]. The actual solidification of the metal begins at a liquidus temperature of 613 °C. Metal solidification ends at a solidus temperature of 548 °C.

Figure 2 shows that the solidification times at different time stages have been displayed in various colors, which helps to locate the isolated areas of molten metal in the casting and gives an overview of the directional compaction in the various areas of the flange reducer.

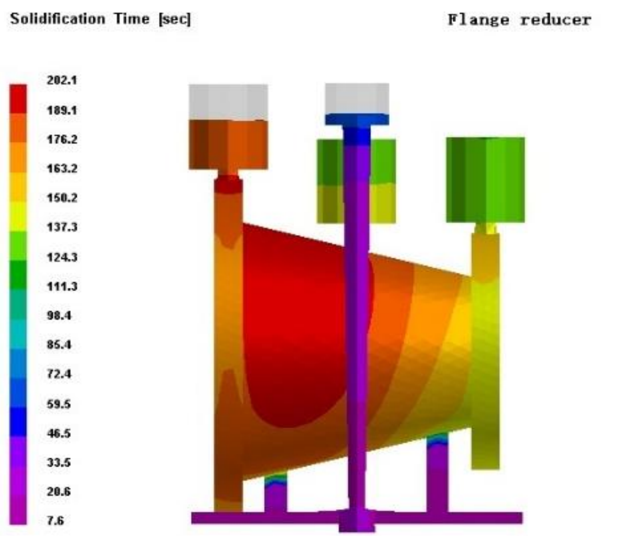


Figure 2. Initial gating system solidification time

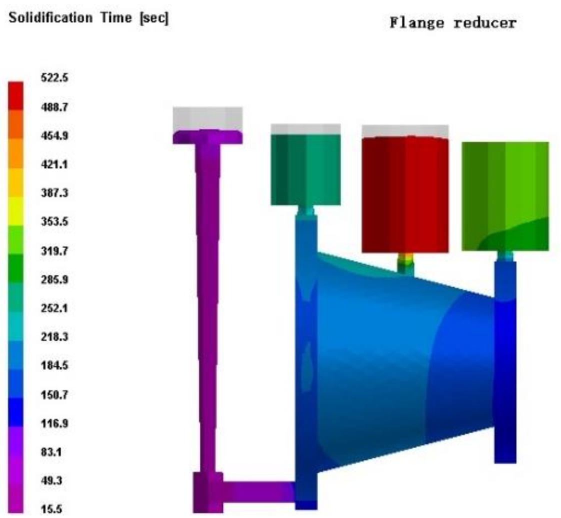
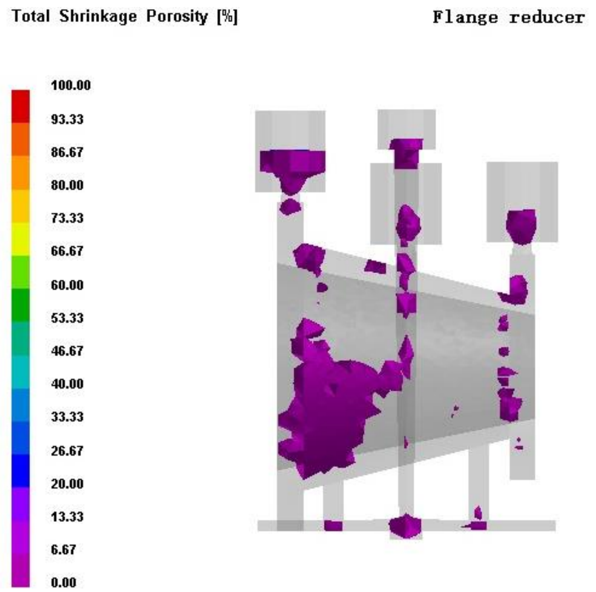
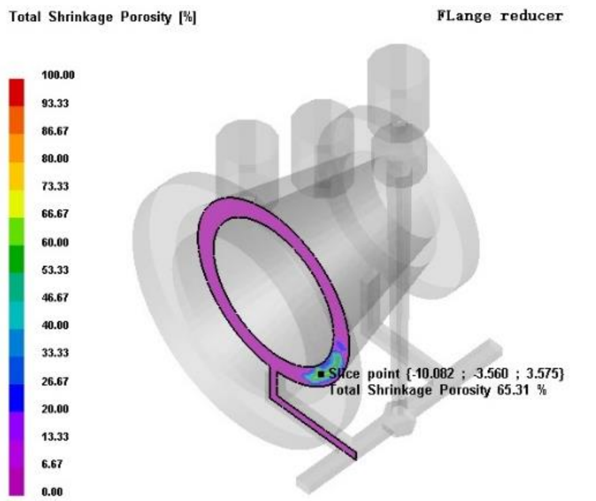


Figure 3. Gating system solidification time after modification



(a)



(b)

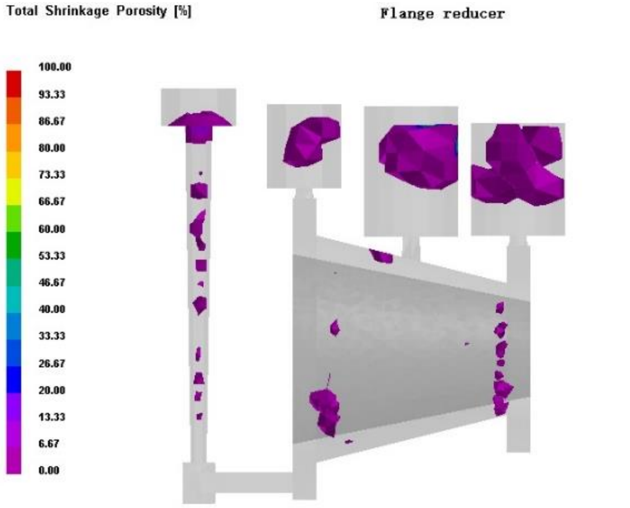
Figure 4. (a) Total shrinkage porosity (b) Slice point major shrinkage porosity on initial gating system

Figure 2 shows a plot of the initial gating system compaction time where the compaction results are less than perfect, the red gradient shows the last part of the compaction process. Figure 3 shows the compaction of the flange reducer with a modified gating system where the compaction takes place in a directed manner, starting from the thinnest part to the thickest part and ending at the riser.

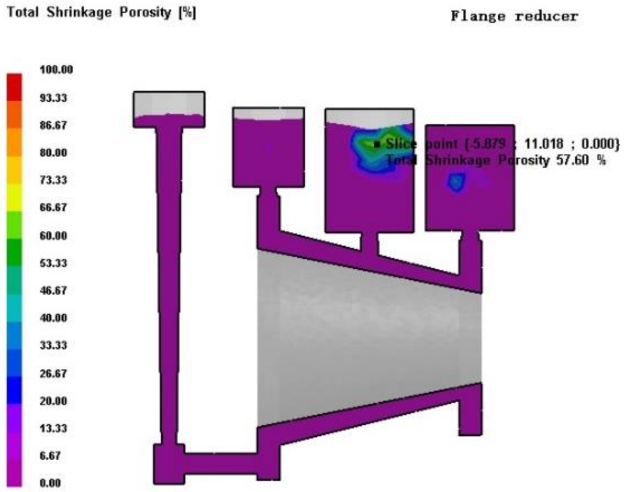
3.2.2. Porosity

Shrinkage porosity defects are voids within components that can cause the material to weaken and if placed on the surface can deteriorate its aesthetic qualities and corrosion resistance. Porosity shrinkage occurs during the solidification phase of the material, which begins with the mold filling phase and ends when each part of the material is completely compacted. The cause of porosity is material shrinkage [9], [16].

Shrinkage porosity was predicted by computer simulation of the filling and compaction processes. Molten metal becomes solid when the heat in it is released and a phase change occurs from liquid to solid. As a result, porosity shrinkage occurs in the casting process. A shrinkage defect occurs when the feed metal is not available to compensate for shrinkage as the metal hardens. If the shrinkage porosity is small in diameter and confined to the center of a very thick section, it usually will not cause any problems [9]. Figure 4a shows the shrinkage porosity present in the simulation with the initial gating system. It has been observed that the shrinkage porosity is in the riser and flange reducer components with total porosity of 65.31% as shown in Figure 4b.



(a)



(b)

Figure 5. (a) Total shrinkage porosity (b) Slice point major shrinkage porosity on modified gating system

After the gating system is modified, the shrinkage porosity can be reduced in the flange reducer by providing the appropriate gate, the riser in the right location, and increasing the riser height as shown in Figure 5a The largest number of porosities is in Figure 5b Indicated on the riser of 57.60%.

4. Conclusions

a. The simulation software in foundry creates opportunities to prevent wastage of material, energy, cost, and time associated with casting trials to get good quality.
b. The gating system design approach with a combination of well calibrated simulation software can avoid defects before casting.
c. Casting simulation helps to visualize the phenomena of filling, molten metal solidification, and shrinkage porosity.
d. The resulting casting simulations can be displayed in graph variants at specific nodes with line graphs or numerical numbers manually.
e. Modifying the gating system can compensate for the shrinkage porosity.

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References

[1] C. M. Choudharia, B. E. Narkhedeb, and S. K. Mahajanc, “Methoding and Simulation of LM 6 Sand Casting for Defect Minimization with its Experimental Validation,” in *Procedia Engineering 97*, 2014, pp. 1145 – 1154.
[2] M. Iqbal, S. Patel, and G. Vidyarthee, “Simulation of casting and its validation by experiments,” *Int J Eng Sci Res Technol*, vol. 3, no. 8, pp. 55–56, 2014.
[3] V. M. Vasava and D. R. Joshi, “Identification of casting defects by computer simulation,” *Int J Eng Res Technol*, vol. 2, no. 8, pp. 2550–2555, 2013.
[4] R. A. Parisher and R. A. Rhea, “Pipe Drafting and Design,” in *Flange Basics*, 2012, pp. 56–78.
[5] J. Campbell, *Castings*. Oxford: Elsevier Science Ltd, 2003.
[6] F. Liu, “Optimized design of gating/riser system in casting based on CAD and simulation technology,” Worcester polytechnic institute, 2008.
[7] Ravi, “Casting method optimization driven by simulation,” *Indian Foundry Cong.*, vol. 57, pp. 70–74, 2009.
[8] K. S. Reddy, “Casting Simulation of Cast Iron Rotor-Disc using ProCAST,” *Int. J. Curr. Eng. Technol.*, vol. 4, no. 6, pp. 4091–4094, 2014.
[9] T. H. Hirigo and B. Singh, “Design and analysis of sand casting process of mill roller,” *Int. J. Adv. Manuf. Technol.*, vol. 105, no. 5–6, pp. 2183–2214, 2019.
[10] J. Jezierski, R. Dojka, and K. Janerka, “Optimizing the gating system for steel castings,” *Metals (Basel).*, vol. 8, no. 66, pp. 1–13, 2018.
[11] T. Roy, “Analysis of Casting Defects in Foundry by Computerised Simulations (CAE) - A New Approach along with Some Industrial Case Studies,” 2013.
[12] American Foundrymen’s Society Training & Research Institute, “Basic Principle of Gating and Risering, Golf & Wolf Roads Des Plainers Illinois,” 1972.
[13] J. R Brown, *Foseco Ferrous Foundryman’s Handbook*, 11th ed. Oxford: ButterworthHeinemann, 1994.
[14] M. C. Flemings, “Solidification processing,” *Metall. Mater. Trans. B*, vol. 5, no. 10, pp. 2121–2134, 1974.
[15] M. Mc Guinness and A. J. Roberts, “Efficient design of tall tapered feeders,” New Zealand, 2001.
[16] J. P. Anson and J. E. Gruzleski, “Effect of Hydrogen Content on Relative Shrinkage and Gas Micro-porosity in Al-7% Si Casting,” McGill University Canada, 2000.