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Optimization of The Gating Design For AA2024 Base Alloy Casting using Numerical Method

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Abstract

Aluminum alloys are widely used engineering materials in a various field. AA2024 alloy is one of the most used alloys in the aerospace as well as automobile industry. At the time of the casting of the alloy, casting defects like porosity, shrinkage, etc. are induced in the alloy. The casting defects can be minimized by optimizing the gating system or by changing the composition of the material. In the present study, the simulation of casting process for optimizing the gating system was done with help of numerical method. Three different gating system designs (i.e., Top Gating design, Bottom gating design and anti-gravity gating design) were simulated for the casting process and the results of the simulations were interpreted. The anti-gravity gating system design was found out to be the best design which exhibits casting with minimum defects.

Keywords: *AA2024, Gating System design, Numerical method, Solidification.*

1.0 Introduction

Casting is the simplest and most adaptable manufacturing method, in which metal product is created by melting and pouring metal into molds. The integrity of cast components is directly influenced by the casting design, specifically the gating design [1]. As every liquid melt necessary to fill the casting cavity must be introduced through the gating system, its design has long been acknowledged as one of the critical aspects in deciding casting quality [2]. Even though there are basic casting design principles and empirical models for the gating ratio, pouring time, and gating system dimensions, there are considerable differences in empirical rules due to the differences in casting parameters used by various researchers [3] [4]. A well-designed gating system should fill the mold cavity fast yet quietly, with minimal turbulence; encourage directional solidification; and reduce air aspiration, decreasing re-oxidation and slag formation during the filling process [5]. Prior to the entry of molten metal into the cavity, it should also prevent mold erosion and make slag entrapment easier in the gating system [6]. If the casting process is not performed properly, light metals such as aluminum castings are more susceptible to flaws such as porosity and oxide inclusions [7] [8].

Shaik Mozammil et al. [9] have reported that the experimental and numerical findings indicate that the parting line gating system is best suited for producing minimal porosity values. It has also been shown that as the pouring temperature rises, porosity increases. Pouring time is found to play a crucial factor in the finding. Ali Kheirabi et al. [10] have reported that even nonpressurized and bottom-gating systems do not guarantee a surface turbulence-free state in casting; hence, the correctness of any traditional gating

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system design should be verified using simulation. Enesi Y. Salawu et al. [11] has studied the effect of different number of runners and ingates in the gating system designs to determine the casting productivity. The results stated that 3 runner top gating system took less pouring time than three runners bottom gating system results in discharge of molten metal at higher rate. As the molten metal enters the mold cavity with high velocity, turbulence is created which further creates gas entrapment and gives defects like porosity, etc. [12]. M. Bruna et al. [13] reported that reoxidation is a major cause of decreasing structural uniformity in aluminum alloy castings. The simulation results for the oxide films were interpreted and the optimized gating system was recommended. AA2024 is an aluminum alloy contains copper as the main ingredient and most often used in forging and rivets for the aerospace sector. Due to its high strength and fatigue resistance, AA2024 is widely used in aircraft, especially wing and fuselage structures under tension [14]. The AA2024 composite can also be used as an alternative to the insulation of electrical wires instead of pure aluminum. It is observed from the literature that the work on optimization of gating system design for the casting of AA2024 alloy by using numerical method is not yet done.

In the present study, the optimization of different positions of the ingate were done for AA2024 with the help of numerical method. Three 3D CAD models were made with different positions of the ingate. The design of the gating system was done based on the ten principles of John Campbell for casting process [4]. The design of the gating system is made in such a way that the liquid metal has to be enter mold cavity with less turbulence so that minimum porosity defect occurs.

2.0 Material and Methods

The material chosen for the simulation of the casting process is AA2024. The composition of the material is given in Table 1.

2.1 Modelling of The Casting Part

A CAD modelling software was used to model the casting part and the mold. SolidWorks software was used for the modelling. Three different models were made with different gating system. The three different gating system designs are top gating system, bottom gating system and anti-gravity gating system. Figures 1, 2 and 3 give the representation of the three gating system designs which were modelled for the simulation using SolidWorks modelling software. The designs differ from each other on the basis of the position of ingates of the gating system.

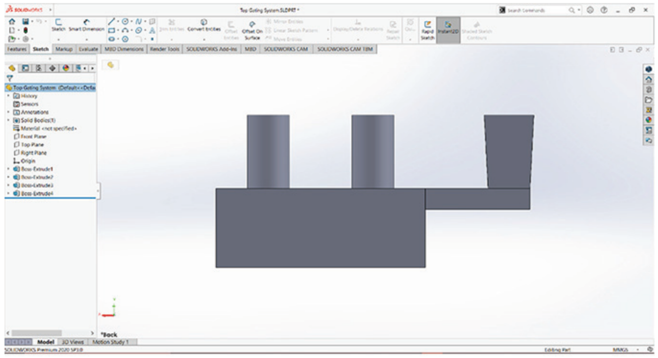

Figure 1: Top gating system

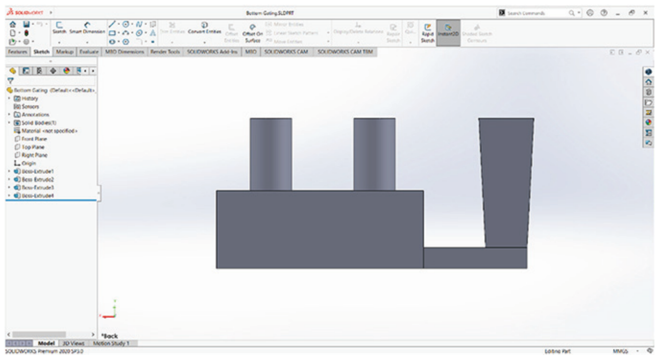

Figure 2: Bottom gating system

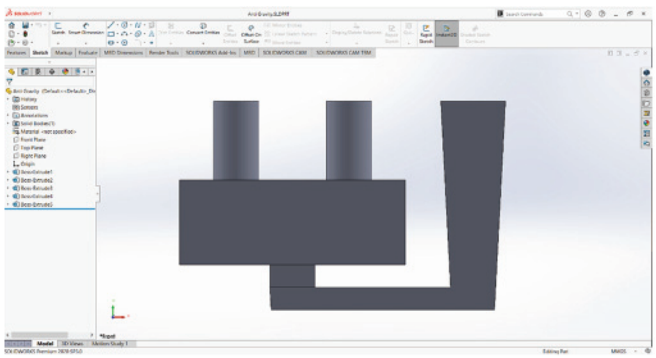

Figure 3: Anti-gravity gating system

Table 1: Composition for AA2024 base alloy [15]

Alloy Cu	Mg	Mn	Si	Zn	Fe	Cr	Ti	Other	Al	
AA2024	4.14%	1.45%	0.49%	0.15%	0.07%	0.26%	0.1%	0.15%	0.05%	Bal.

The dimensions of the casting part considered for the study was 200mm × 100mm × 75 mm and the dimension of the ingate was 40mm × 20mm. Two risers were given for the mold cavity and the dimensions of the risers having the diameter of 40mm and height of 70mm. The inlet dimensions of the pouring basin were 47.34mm × 47.34mm.

2.2 Simulation of Casting Process

The prepared models were then imported to the ProCAST simulation software in iges format from Solidworks. After importing the 2D and 3D meshing of the models were done. The elements formed after meshing the part in 2D meshing were 18694 elements, whereas for 3D meshing were 129179 elements for the simulation of casting process. The parameters chosen for performing the casting process are given in Table 2:

Table 2: Parameters used for simulation work

Parameter	
Material	AA2024
Temperature of Melt	730°C
Permanent Mold	H13 (Chromium hot work tool steel)
Heat transfer coefficient	h=750 W/(m^2°C)
Type of casting	Gravity die casting
Mass flow rate	0.5m/s

3.0 Results and Discussion

The simulation process was done with the help of a simulation casting software. The results for the total shrinkage porosities and solidification temperature were interpreted for all the three different gating system designs. Graphs for percentage total shrinkage porosities against percentage solidification were plotted. There were six distinct nodes chosen for plotting the graphs. These nodes were selected in the areas where the porosities are visible in the simulation results. Figures 4, 5 and 6 give the representation of the nodes selected for plotting of the graph.

The Figures 7, 8 and 9 indicate the graphs for all the three gating system designs. In the top gating system, the graph shows high percentage of total shrinkage porosity at the selected nodes, and 83% of shrinkage porosity was found at node one. While in bottom gating system, the maximum per cent of shrinkage porosity was also found at node one i.e., 97% total shrinkage porosity. The graph for anti-gravity gating system showed maximum % of total shrinkage porosity at node six. The maximum % of total shrinkage porosity was found out to be only 19%. The reason for the lower total

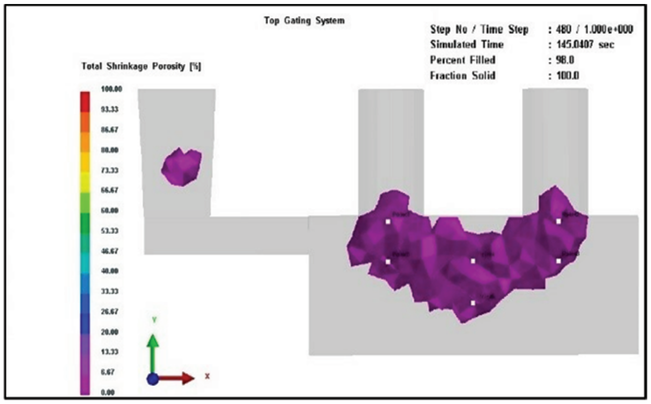

Figure 4: Nodes selection for plotting of graph for top gating system design

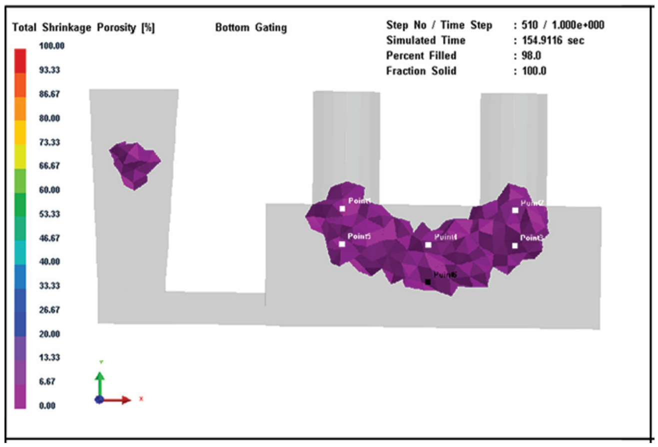

Figure 5: Nodes selection for plotting of graph for bottom gating system design

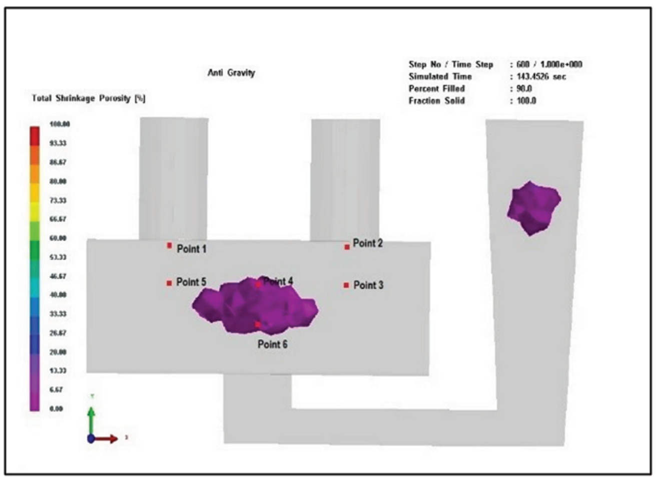

Figure 6: Nodes selection for plotting of graph for Anti-Gravity gating system design

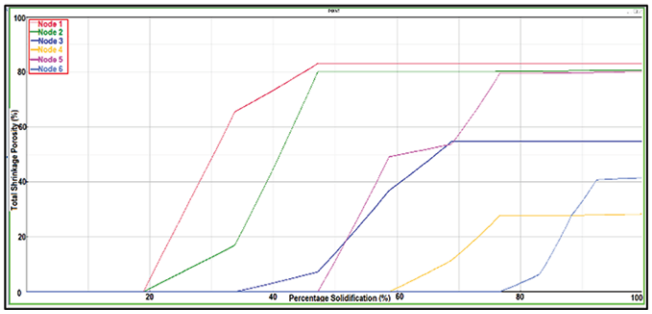

Figure 7: Graph plot for % Total Shrinkage Porosity vs % solidification % solidification

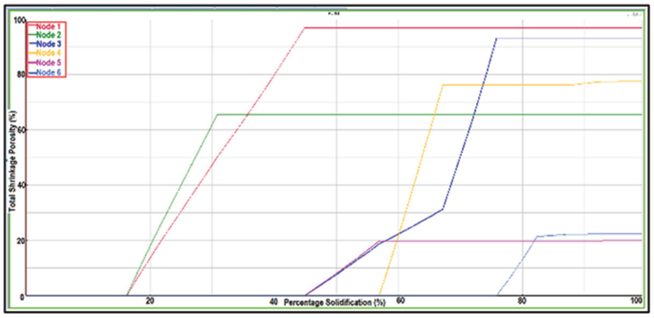

Figure 8: Graph plot for % Total Shrinkage Porosity vs% solidification for Top gating system

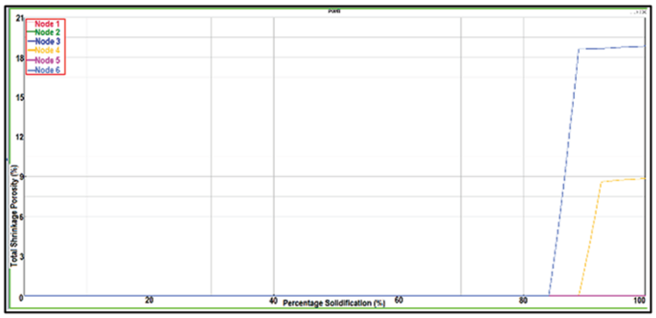

Figure 9: Graph plot for % Total Shrinkage Porosity vs % solidification for Anti-gravity gating system

shrinkage porosity is because lowest turbulent flow of the anti-gravity gating system compared to other two gating system designs.

The turbulence in the molten metal plays an important role for integrity of the cast components. The molten metal should not enter the cavity with turbulent flow or else it entraps air bubbles in the molten metal [4].

The Figures 10, 11 and 12 show the solidification temperature for all the three gating system designs. The liquidus temperature for all the three gating system designs was found out to be at 638.4°C, while the solidus temperature was found out to be 493.6°C.

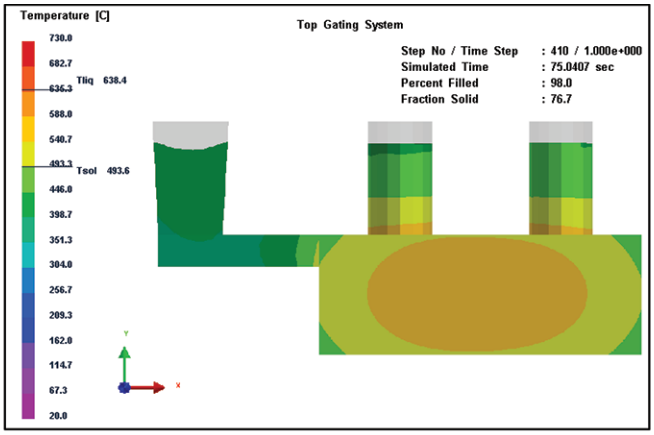

Figure 10: Simulated result for solidification temperature for top gating system

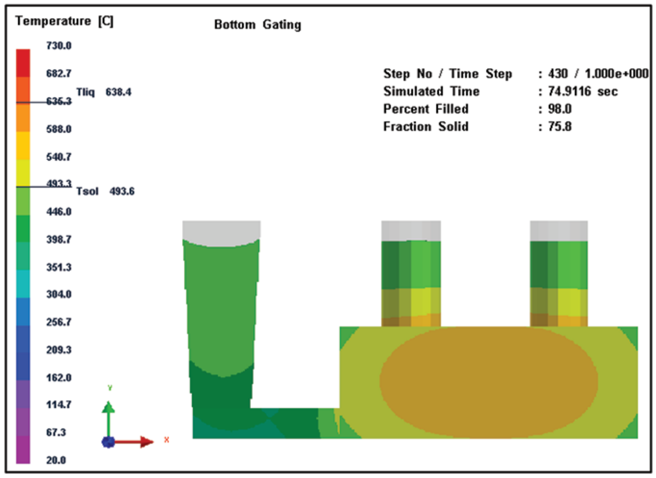

Figure 11: Simulated result for solidification temperature for Bottom gating system

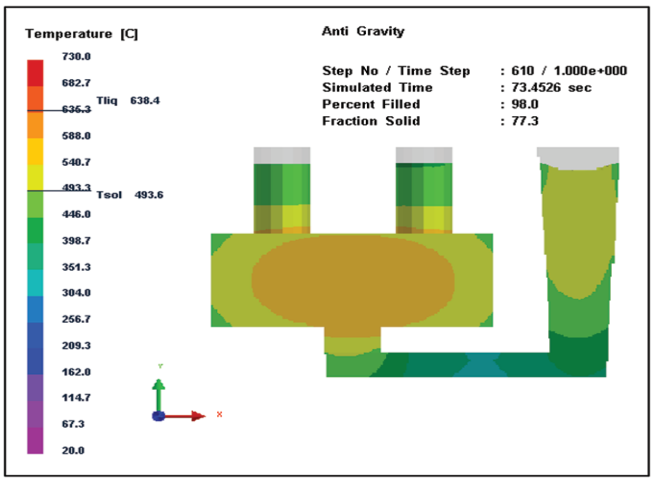

Figure 12: Simulated result for solidification temperature for anti-gravity gating system

4.0 Conclusions

In the present study, a simulations of casting process for three different types of gating system designs were done and the results for the total shrinkage porosity (%) and solidification temperature were interpreted. The following were the conclusions deducted from the study:

- The liquidus temperature was found out to be 638.4°C and the solidus temperature was found to be 493.6°C.
- The least percentage of total shrinkage porosity of 19% was found in the anti-gravity gating system design.

Hence, anti-gravity gating system is the best gating system design among the other two designs. Thus, it recommended that anti-gravity gating system design should be used for the casting of AA2024 alloy to cast a component with minimum defects.

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