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INVESTIGATING THE EFFECT OF CROSS SECTION OF GATING SYSTEM BY CFD SIMULATION IN COOLING OF ALUMINUM ALLOY IN A PERMANENT MOULD CASTING

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ABSTRACT

Casting is the process of producing metal/alloy component parts of desired shapes by pouring the molten metal / alloy into a prepared mould (of that shape) and then allowing the metal/ alloy to cool and solidify. A mould cavity must be filled with clean metal in a controlled manner to ensure smooth, uniform and complete filling, for the casting to be free of discontinuities, solid inclusions and voids. This can be achieved by a well-designed gating system**.** In this paper, CFD models illustrating the effect of cross sections of gating on cooling of Aluminum alloy in a permanent mold casting are presented. For this purpose, circular and square cross sections were incorporated. Same hydraulic radius was assigned for each of the cross section of gating systems. Different parts of the mold pattern i.e. sprue; basin, riser etc were designed for each cross section by maintaining same hydraulic radius. Bottom gating system is used for its low gas entrapment and less surface defect characteristics. By analyzing it has been observed that circular cross section the cooling is more rapid than the square cross sections.

Keywords: CFD Simulation, Gating System, Permanent Mould, Cross-Section

1. INTRODUCTION

Instead of using sand as the mold material, a metal is used as a mold. Typically cast iron or Meehanite (a dense cast iron) is used as the mold material and the cores are made from metal or sand. Cavity surfaces are coated with a thin layer of heat resistant material such as clay or Sodium silicate. The molds are pre-heated up to 200 ºC (392 ºF) before the metal is poured into the cavity. The cavity design for these molds does not follow the same rules for shrinkage as in sand casting molds, due to the fact that the metal molds heat up and expand during the pour, so the cavity does not need to be expanded as much as in the sand castings. However, care has to be taken to ensure proper thermal balance, by using external water cooling or appropriate radiation techniques. A mould cavity must be filled with clean metal in a controlled manner to ensure smooth, uniform and complete filling, for the casting to be free of discontinuities, solid inclusions and voids. This can be achieved by a well-designed gating system. The first step involves selecting the type of gating system and the layout of gating channels: the orientation and position of sprue, runner and ingate(s). The most critical design decision is the ideal filling time, based on which the gating channels are designed.

In the conventional casting processes, the casting defects are controlled by the correct gating system design because of the chock in the system. On the other hand, the casting defect locations are affected by the gating system as it controls the melt entrance into the mould [1-3]. The main objective of a gating system is to lead clean molten metal poured from ladle to the casting cavity, ensuring smooth, uniform and complete filling. Clean metal implies preventing the entry of slag and inclusions into the mould cavity, and minimizing surface turbulence. Smooth filling implies minimizing bulk turbulence. Uniform filling implies that all portions of the casting fill in a controlled manner, usually at the same time. It was observed that the surface defects for bottom gating system are very less compared to other gating systems and for top gating system surface defect is much higher and bottom gating system with one runner has very negligible surface defect. The mathematical description of casting is very difficult because of a lot of parameters mentioned above and appearing processes e.g. thermal, hydrodynamic, solidification, Segregation of particles. These processes affect each other. Moreover, the existence of solid particles has additional influence on the behavior of the materials during the process and complicates the mathematical description. At present there exist theories which, more or less precisely, describe the behavior of the composite in the centrifugal casting process [4-7]. The description presented by them is often incomplete and refers only to some chosen elements of the process. In this paper a CFD simulation were calculated based on different gating systems.

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2. SIMULATION SEQUENCE

In this study, the design was done by Autocad and the CAD file was transferred to ANSYS ICEMCFD in **.ACIS** format for mesh generation and analysis purposes. The different flow sequence is shown in Figure 1.

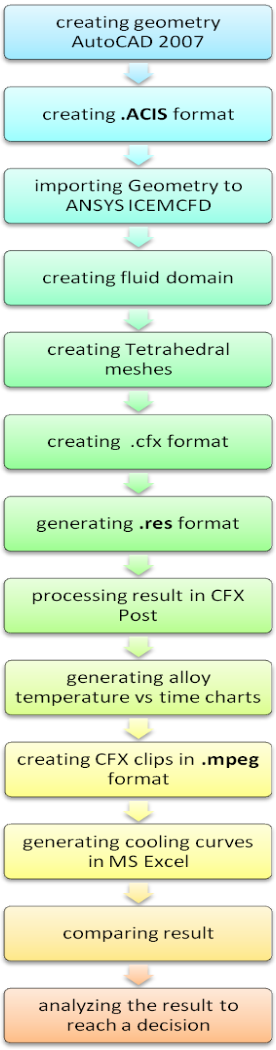

Fig 1. Flow chat for analysis the sequence

3. DESIGNING THE MODEL

The various section of sprue, choke area, risers etc are designed for the circular and square cross section of the gating systems [8]. Same hydraulic radius was assigned for each of the cross section of gating systems. Different parts of the mold pattern i.e. sprue; basin, riser etc were designed for each cross section by maintaining same hydraulic radius. The different gating systems are shown in Figure 2.

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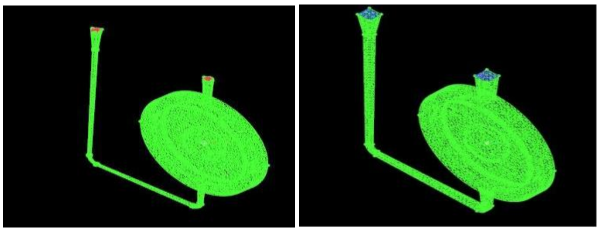

(a) Circular cross section (b) Square cross section

Fig 2. Different cross sections used in the simulation

3.1 Formulas Governing Sprue Design

The cross sectional area and the height of the sprue was found out using Eq. (1).

$$\frac{A_1}{A_2} = \sqrt{\frac{h_1}{h_2}} \qquad (1)$$

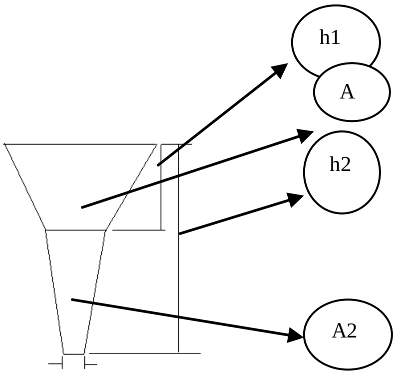

Fig 3. Different parts of sprue design

3.2 Choke Design

Depending upon the Bernoulli’s equation the choke diameter was calculated using Eq. (2).

$$C_d = \frac{\mathbf{W}}{\mathbf{n.d.t}\sqrt{\mathbf{2gh'}}} \qquad (2)$$

3.3 Riser Design

Risers are reservoirs of molten material. They feed this material to sections of the casting to compensate for shrinkage as the casting solidifies. There are different classifications for risers. Riser design criterion considering the cooling of the casting was calculated using Eq. (3).

$$\left(\frac{Volume}{Area}\right)_{riser} = \left(\frac{Volume}{Area}\right)_{casting} \qquad (3)$$

Higher V/A indicates towards increased solidification time.

3.4 Mesh Generation

The different points on the model with the surfaces such as inlet, opening and wall were created followed by fluid domain. Tetrahedral meshes were generated in ICEMCFD for the mold cavity and pattern. The quality of the meshes and refinement of the mesh quality were done up to an optimum level. Mesh file in .cfx format was written at the end. The mesh sample is shown in Figure 4.

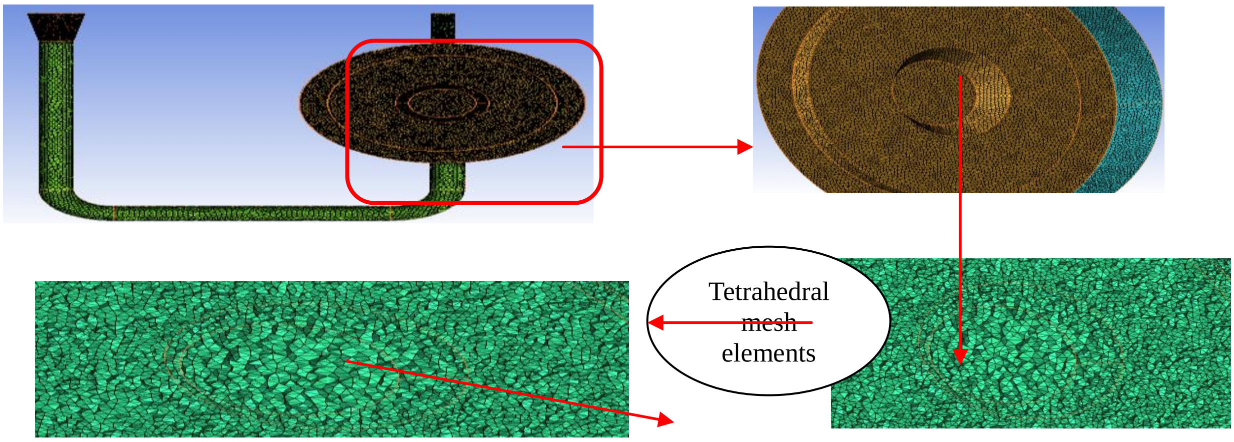

Fig 4. Tetrahedral mesh elements sample.

3.5 Optimum Melting and Pouring Conditions

The knowledge of melting temperature of metals and alloys is necessary to estimate their corresponding pouring temperature. Aluminum alloy casting has melting temperature of 660°C with its corresponding pouring temperature range between 700°C-750°C. In order to avoid rapid solidification, intercepted directional solidification and shrinkage of casting and mould warping, it is necessary to maintain an optimum temperature. The pouring temperature of 700°C for inlet temperature with a tolerance of 10°C has been taken. All the simulation parameters are furnished in Table 1.

Table 1: Simulation parameters

Para meters	**Value**
pouring temperature	700°C-750°C
Inlet temperature	710°C
pouring speed	2.6 cm/s
Pressure	1 atm

Pouring speed of molten metal, V may be defined as the flow of the metal per unit time. In determining the pouring speed, the parameter, V is expressed as the distance of the ladle above the pouring basin per unit time of pouring of the metal. This is expression is given in Eq. (4).

$$V = \frac{H}{t} \tag{4}$$

The different properties of molten aluminum alloy and the wall materials are shown in Table 2 and 3 respectively.

Table 2: Properties of molten Aluminum A356 alloy

Properties	**Values**
Molar Mass	26.98 g mol^{-1}
Density	2750 Kg m^{-3}
Specific heat capacity	1047 J Kg^{-1} K^{-1}
Dynamic viscosity	0.0025 Kg $m^{-1}s^{-1}$
Thermal conductivity	180 $Wm^{-1}K^{-1}$
Thermal co-efficient of expansion	$4x10^{-5}$ K^{-1}

Table 3: Properties of wall material (cast iron)

Properties	**Values**
Roughness	Smooth wall
Heat transfer co-efficient	50 W m^{-2} K^{-1}
Temperature	298 K

4. RESULT ANALYSIS

Six steps associated with the temperature gradient of alloy in the mould of circular cross section are shown in Figure 5. As the molten metal travels through the cavity the temperature rises. The blue region represents temperature around 298 K and the red region represents the temperature around 1000 K. The other values for each of the color are shown in the scale.

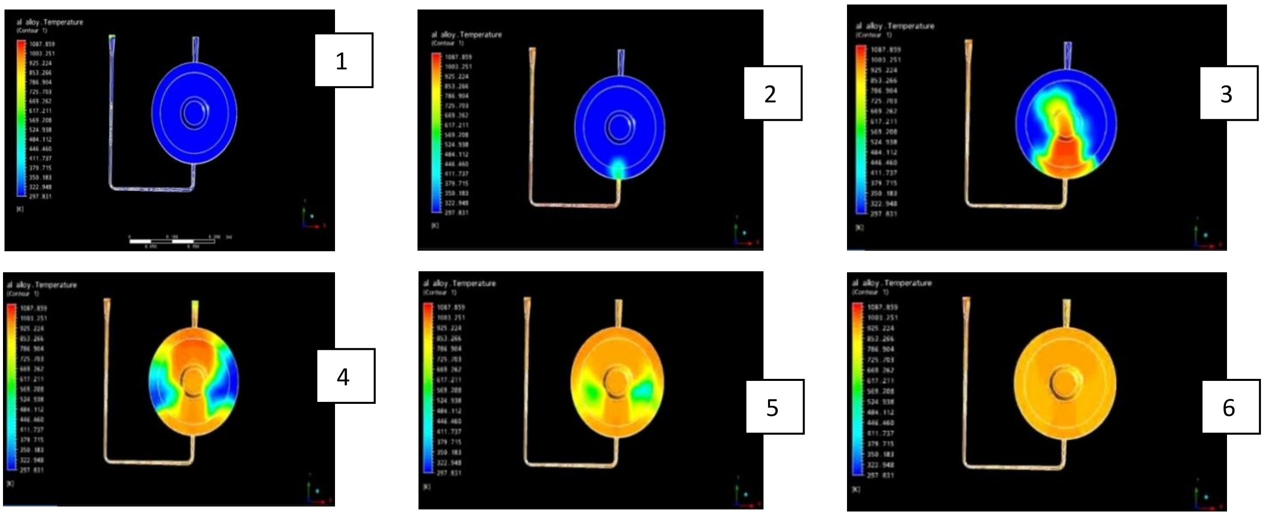

Fig 5. Filling up of circular mould pattern by showing temperature gradient.

From the Figure 5, it is observed that when the molten metal enters the mould cavity the temperature rises within the cavity around 980 K (shown by red color in 3rd step) and along with time the temperature drops down to around 923 K (6th step). It is also observed that the temperature increases rapidly in upward direction (3rd and 4th steps) within the cavity and the regions on the sides are heated later. Also the cooling begins first at the side regions (6th step) and then at upward and downward regions of the cavity.

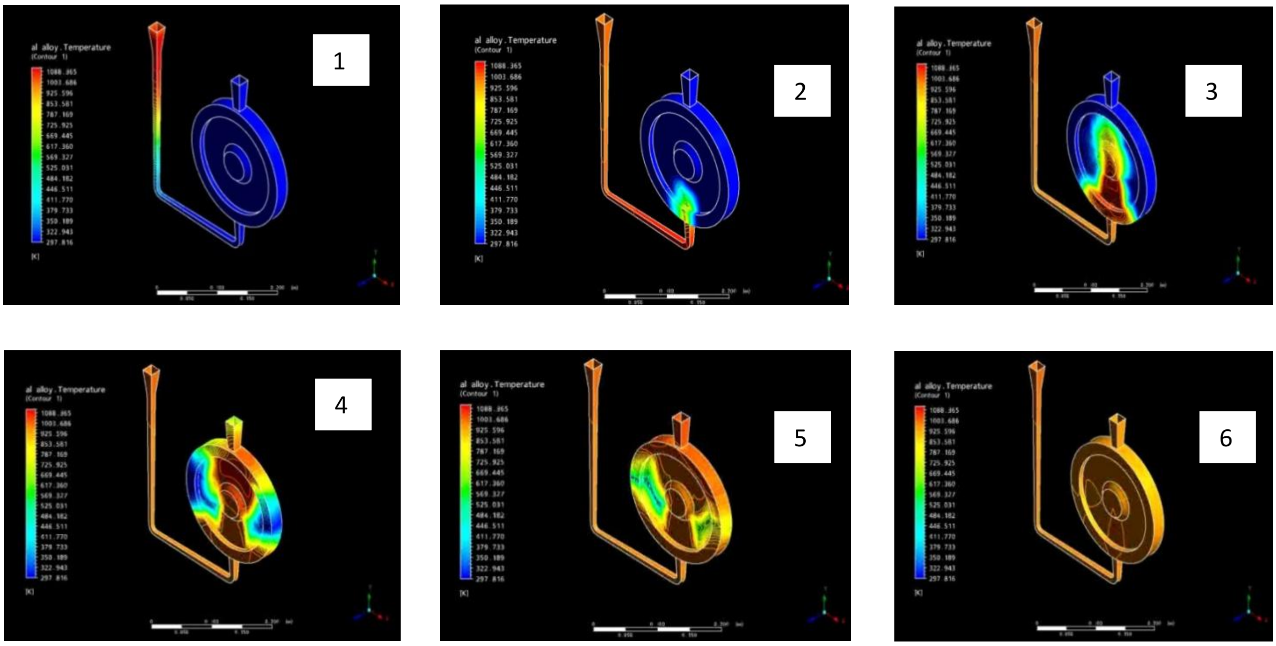

Fig 6: Filling up of square mould pattern by showing temperature gradient.

For the square cross sectional mould as shown in Figure 6, it has been observed that the temperature also rises to around 980 K and gradually drops down to around 920K. But from the solution it has been observed that for the same time limit the value of temperature corresponding to the circular cross section is lower than the value of the square cross sectional one. This implies that the solidification takes place earlier in circular cross section which leads to better surface quality casting product.

5. CONCLUSION

By analyzing the result it can be concluded that for circular cross sectional model the cooling is more rapid than square cross section model. More accurate results can be obtained by assigning higher time steps.

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7. NOMENCLATURE

Symbol	**Meaning**	**Unit**
A	Area	(m^2)
h	Height	(m)
C_d	Choke Diameter	(m)
W	Weight of the casting	(N)
n	Nozzle co- efficient (taken as 1)	
d	Density of liquid metal	(Kg/m^3)
t	Pouring time	(s)
g	Gravitational acceleration	(m/s^2)
h'	Effective liquid metal head	(m)
V	pouring speed	(m/s)
H	Height of ladle above pouring basin	(m)