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Fluidity of ADC12 Alloy Based On Theoretical and Computational Fluid Dynamics

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Abstract: ***Fluidity is one of the important factors that play a role in the casting industry. The current paper focuses on understanding the fluidity behavior of the aluminium alloy ADC12 in a spiral shaped mold based on the theoretical and simulation results. The aluminium alloy is subjected to the heating temperature of 670 °c along with the die preheated to a temperature of 200 °c and is poured into the cavity as gravity die cast. This enables the molten metal to travel a certain distance till it reaches the solidus temperature and get solidified. The maximum distance the alloy travels ensures the fluidity of the aluminium alloy. This paper gives a comparison between the theoretical fluid dynamics value and the computational fluid dynamics value for validating the fluidity of the aluminium alloy. The entire process is done on the theoretical formulas and the simulation process is done using the ANSYS simulation software. The spiral test shows how a modeling approach will predict fluidity index, mold filling, fluid temperature and the distance travelled for a given spiral and complex shaped casting.***

Keywords*:* Simulation, Gravity die cast, solidus, ANSYS, Spiral test, Fluidity index

1. Introduction

Solidification is the process by which the metals and alloys are being produced from the melts. Often, the liquid metal is poured into the mold of the required shape to get the desired component which is done by the process known as casting. In the automobile industry Aluminium is the mostly used component for the manufacturing of the automobile parts. There is a greater demand for the aluminum alloys in producing thin walled casting components. The manufacturing plants are using significant amounts of primary, secondary and master alloys in order to produce automotive components with greater quality. The good quality of the casting directly depends on the melt quality of the metal. Hence there must be a thorough understanding of the melt quality to control and predict the actual casting characteristics. The production of thin wall castings is limited by the fluidity of the molten metal. It defines to the great extend the quality of casting.

Fluidity is the ability of the molten metal to flow a certain distance and fill the cavity of the mold thus measuring the distance travelled by the melt until it gets completely solidified. It is an important parameter while considering the quality of the aluminium cast. The fluidity is based on certain factors such as Pouring temperature, Metal composition, Heat Transfer to the surroundings, Viscosity of the liquid metal. As viscosity and its sensitivity to temperature increase [1], fluidity decreases. The increase in surface tension also affects the fluidity. Insoluble inclusions and other impurities in the molten metal tend to affect the fluidity. Fluidity decreases when molten alloys flow through mold materials of higher thermal conductivity with rough surfaces. The aim of the study was to develop a comprehensive test for determining fluidity.

The small cross section channel provides conditions for rapid cooling and large temperature gradient, which gives good fluid flow a mathematical model for estimating fluidity length was proposed by Flemings et al [2].The model provides the following equation for calculating

The flow length L_f:

$$L_f = \frac{A\rho V(f^{cr}_{s}H + C\Delta T)}{Sh(T - T_r)}(1 + \frac{\beta}{2})$$

Where

$$\beta = \frac{h\sqrt{(\pi\alpha\Delta y/V)}}{K}$$

2. Methodology

2.1 Fluidity Tests

The most used tests for measuring fluidity are the vacuum fluidity test and the spiral test. The first method measures the length of the metal flowing inside a narrow channel when sucked from a crucible by using a vacuum pump. The second method measures the length of the metal flowing inside a spiral shaped mold.

The aim of the study was to develop a comprehensive test for determining fluidity. Traditionally, the flow ability is measured using spiral test that has been designed of spiral contours[3]. The apparatus in spiral test setup consists of two parts: (i) spiral contour that is milled in the lower half mold and (ii) upper part of the mold which holds the runner and raiser. The total length of the spiral is 900 mm. The spiral groove is designed in the form of semicircle with radius 6 mm and depth of 3 mm. The initial die design of the Spiral contour was done in Pro- E software. Flow ability is determined through the flow length of an alloy in the milled spiral contour.

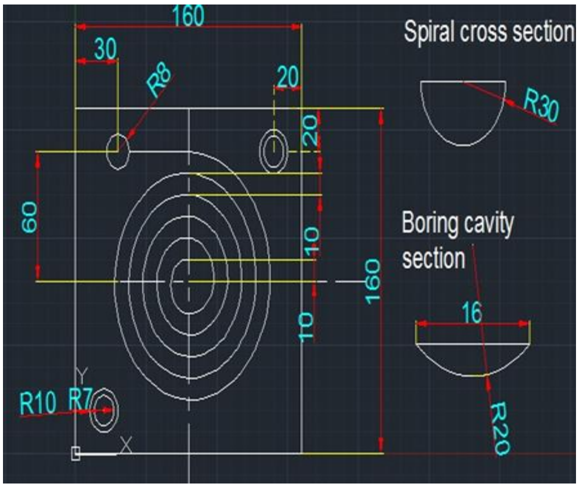


Figure 1: Spiral shape design

2.2 Theoretical Fluid Dynamics

Melt material: ADC12
Mold material: HDS H13
Chemical composition of ADC12 aluminium alloy (mass %)

Si	Fe	Cu	Mn	Mg	Zn	Ni	Sn	Al
11.62	0.88	2.89	0.34	0.21	0.93	0.05	0.02	Bal

The fluidity of the aluminium alloy can be theoretically derived by

$$L_f = \frac{A\rho V(f^{cr}_s H + C\Delta T)}{Sh(T - T_r)}(1 + \frac{\beta}{2})$$

Where

$$\beta = \frac{h\sqrt{(\pi\alpha\Delta y/V)}}{K}$$

A [mm^2] mold surface area
a [mm] channel radius
B constant
C [kJ/kgK] specific heat
$f_s$critical fraction solid
g [m/s^2] acceleration of gravity
H [kJ/kg] heat of fusion
h [W/m^{2}K] heat transfer coefficient
K [W/mK] thermal conductivity
Lf [mm] fluidity length
S [mm] circumference of the mold channel
T_{liq} [K] liquidus temperature
T_m [K] melt temperature
T_r [K] room temperature
t_f [s] solidification time
t_s [s] solidification time
ΔT [K] temperature interval
v [mms-1] velocity of metal flow
Δy [mm] choking range
α [m^2/s]Thermal diffusivity of mold

Cross section area:
Semi-circle area = $\pi/8D^2$
Diameter = 6mm
$A = \pi/8 \times .006^2$
$= 1.414*10^{-5}m^2$
Flow velocity:
$V = (2gh)^{.5}$ m/sec
h =.05m
$v = (2 \times 9.81 \times 0.05)^{.5}$
= 0.99m/sec

Circumference of the mold channel:
$S = \pi D/2$
$= \pi \times 0.006/2$
$= 9.425 \times 10^{-3}$m
Density:
$\rho = 2670$ kg/m^3
Specific heat:
C = 960 J/kg k

Critical fraction solid:
$f_s^{cr} = 30\%$

Heat of fusion:
$H = 528 \times 10^3$ J/kg
Temperature interval:
ΔT = 65 K
Melt temperature T_m = 853K

Room temperature T_r = 308K

Heat transfer coefficient:
h = 3500Wm^{-2}K^{-1}

Thermal conductivity:
K_{mould}= 28.6 Wm^{-1}K^{-1}
K_{melt}= 121 Wm^{-1}K^{-1}

Choking range:
Δy = 50 mm

Thermal diffusivity of mold:
$\alpha = 8.42 \times 10^{-6}$m^2/s

2.3 Computational Fluid Dynamics (Numerical Methods and Simulation)

The investigations carried out in the present work consisted of both numerical simulations and experimental fluidity tests. ANSYS Fluent commercial software package was used for numerically simulating the fluid flow of molten metal into spiral-shaped molds [4]. ANSYS Fluent software helps to solve the problems in fluid flow and the impact of fluid flows in our product.The computational fluid dynamics method consists of the following procedure

Step [1] Preprocessing : Geometry definition, Cad clean up, Fluid domain extraction, Surface and volume meshing, Mesh quality checkup, process parameters definition, simulation/solution of the governing equations, and evaluation of the results. The geometry and mesh used for the simulations are shown

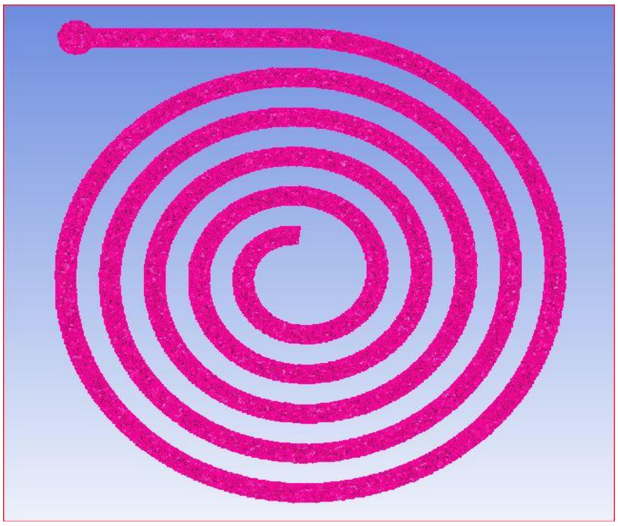


Figure 2: Meshing- CFD pre process

Step [2] solving: Firstly, the investigation focused on the mesh generation to achieve optimum simulation condition. Thereafter, simulations were carried out to evaluate the velocity, influence of heat transfer coefficient, casting temperature, and coherency temperature on the fluidity of the ADC12 alloy. An automatic method was used for the mesh generation and a mesh size of about three millions control volumes and hundred thousand metal cells(i.e. the number of mesh elements that lied within the melt). The filling process was dependent on the metals static pressure, which was calculated from the geometry of the equipment and experimental conditions. The stop criteria were based on the coherency temperature. The following material details of the aluminium alloy were to be given as an input.

Table 1: ADC12 properties

Density of molten alloy(kg/m3)	2670
Liquidus (°C)	515
Solidus (°C)	580
Viscosity of liquid metal (Pa s)	0.03
Specific heat (J/kg k)	960
Velocity (m/s)	0.99
Heat of fusion (J/kg)	528000

Step [3] post processing: In this, the results can be plotted for the values of the fluid flow, temperature distribution over the fluid domain, velocity magnitude, and liquid fractions of the contours and thus the overall result can be generated.

3. Result

Thus the fluidity of the ADC12 alloy predicts well with the theoretical and computational results and found to be varying slightly with the experimental results around ±491 mm.

3.1 Theoretical Fluid Dynamics

Constant:

$B = h/K \times (\pi\alpha\Delta y/v)^{.5}$

$= 3500/28.6*(3.14 \times 8.42 \times 10^{-6} \times .05/.99)^{.5}$

$= 0.142$

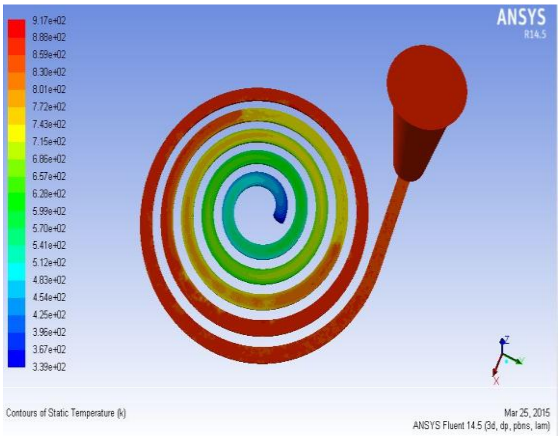
Fluidity:

$L_f = 0.494$ m

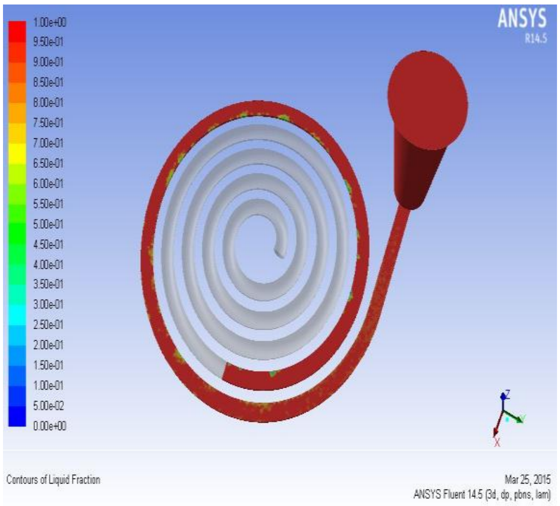
Thus the maximum fluid length that the molten metal can travel is 494 mm. Thus the fluidity of the molten metal increases with increase the temperature.

3.2 Computational Fluid Dynamics

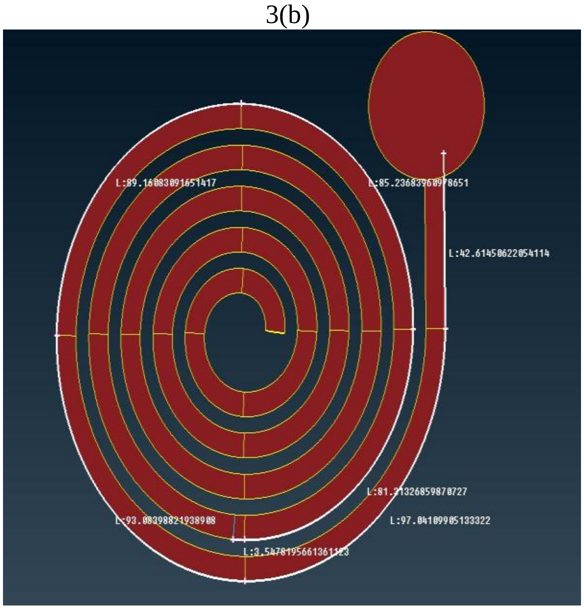
Investigations on the simulation process shows that the maximum distance travelled by the alloy is around 491mm.



3(a)



3(b)



3(c)

CFD RESULT
Fig 3(a) temperature distribution
Fig 3(b) liquid fraction at flow path
Fig 3(c) Flow length

4. Conclusions

This investigation has led to the following conclusions:

- Thus the theoretical fluid dynamics and computational fluid dynamics method enables to identity the fluidity of the ADC12 alloy.
- The simulation predictions fit well with the theoretical results and, therefore, numerical simulations can be a useful tool for predicting the fluidity of Al alloys.
- Thus the Spiral test setup ensures the fluidity of the molten metal to the greater extent and helps in ensuring the purity of the molten metals.
- Increasing the casting temperature increases the fluidity length of the ADC12 alloy.

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