Simulating the effect of gating design and pouring temperature on LM4 casting quality

Ganesh P. Borikar
MIT, Research Center,
Savitribai Phule Pune University
Pune, Maharashtra-38, India
ganesh.borikar@mitpune.edu.in

Sandip T. Chavan
MIT, Research Center,
Savitribai Phule Pune University
Pune-38, Maharashtra, India

Mahesh L. Kulkarni
JSPM Narhe Technical campus
Savitribai Phule Pune University
Pune-38, Maharashtra, India

ABSTRACT

Today sand casting is used enormously due to its inherent advantage of no size and shape limitation and low cost. However the major issue of defect and yield need to be addressed further. The appropriate control over process parameters and design of gating system can resolve the stated problem to greater extent. The defects like distortion, porosity and cold shut /mis-run are very much dependent on melt temperature, solidification rate and design of gating system.

In present case attempts have been made to control the process by studying the effect of pouring temperature and gating system design. A commercial software AutoCAST-X1 is used for the purpose. It shows that to obtain uniform cooling and directional solidification towards feeder, use sprue position at center and side feeder should be used as in present case of cylindrical shaped hollow stepped casting of LM4 alloy. As gating ratio and melt pouring temperature is increased, shrinkage porosity and cold-shut defects are minimized to greater extent. The best gating ratio designed is 1:3:3 and pouring temperature of 682 °C for LM4 alloy.

Keywords: *Gating ratio, Melt pouring temperature, Feeder design, Direction solidification, Liquid fraction.*

1. INTRODUCTION

Conventional method of casting is based on experience and thumb rules. It consists of a number of steps from pattern making to fettling and inspection on shop floor. It is time consuming and the process itself consists of lot of parameters. Although lot a of research work is done on sand casting to get a sound casting free from defects is still a challenge. Virtual casting process using simulating software helps in speeding casting process design. It provides defect free casting to customer from the very first time and in less lead time.

Ravi[1] has worked on feeding analysis and optimization work using simulation.Feedability analysis is based on location of hot spots, feed paths and temperature gradient in solidification simulation. Khandelwal[2] et.al.investigated the flowability of ZA 8 and LM6 alloy through thin sections to understand the manufacturability limits for a particular combination of geometric, material and process parameters.The effect of shape of flow path, length and thickness combination of casting geometry for particular alloys and mould material need to be studied further to understand process capabilities.

Savithri[3], et.al.performed work on obtaining simulation results of temperature distribution and solidification time at different locations in mould for single cavity and multi-cavity layout with cube shaped casting.Omer[4], et.al. worked on factors affecting microporosity on A360 Al-alloy casting by using Taguchi method. The effect of mould filling flow, filtration, solidification time, melt hydrogen level, and melt with Strontium (Sr) addition parameters were investigated. Vosniakos[5], et.al. the studied evolution of solidification process of solid cylinder of pure aluminium A199.5, since it affects microstructural properties and formation of defects.

Murat [6], et.al. in their study investigated effects of change of casting dimensions on casting soundness for sand cast A360 Al alloy. Initially simulation runs on different scaled models was performed using simulation software Solid CAST to observe soundness in form of shrinkage porosity.

Santhi[7], et.al. had studied to predict porosity in US A356 and US 413 aluminium alloys for cylindrical shape casting using FDM software. In this different geometry effect need to explored further.

It is observed through referred literature (2-7) that, effect of gating system design and melt temperature on casting quality, defects, microstructure and yield are not yet defined as standard procedure for casting design. In the present work, the effect of gating system design and melt temperature on casting is studied. The casting design, metal flow and thermal analysis is carried out using AutoCAST-X1 simulationsoftware to predict direction solidification, hotspot-shrinkage porosity and cold shut.

2. DESIGN OF GATING SYSTEM AND MOULD LAYOUT

The selected casting component is cylindrical stepped hollow shape as shown below in Fig.1 Design of gating system consist of design of pattern, design of sprue with sprue well, layout of runner and gate, design of feeder, mould design, to estimate solidification time and yield.

Casting process used is sand casting and casting material used is LM4 alloy (Al-Si12) of which composition is provided in Table1.

Table1. Composition of alloy LM4

Al	Cu	Mg	Mn	Si	Zn
86.05	1.00	0.10	0.35	12.00	0.5

Pattern is designed with consideration of shrinkage allowance, machining allowance and draft allowance for external surface and internal bore/cavity. From the model of pattern mass properties are obtained. Design of sprue, gating system and feeder[8,9,10,11] gives

Wt. of casting =368 gm., Pouring time= 1.51 sec.

Choke area = 155 mm^2,Sprue height = 42 mm

Sprue well diameter =24 mm, Gating ratio= 1:3:3

- Use of parting gating, with two runners and gates,
- Feeder diameter = 30 mm, qty. 1 no.

SPRUE POSITION AND TOP/SIDE FEEDER LAYOUT

Effect of sprue position at center of component and at side of component is studied by flow and solidification simulation using AutoCAST-X1 with FLOW+ Module for hotspot positions and directional solidification.

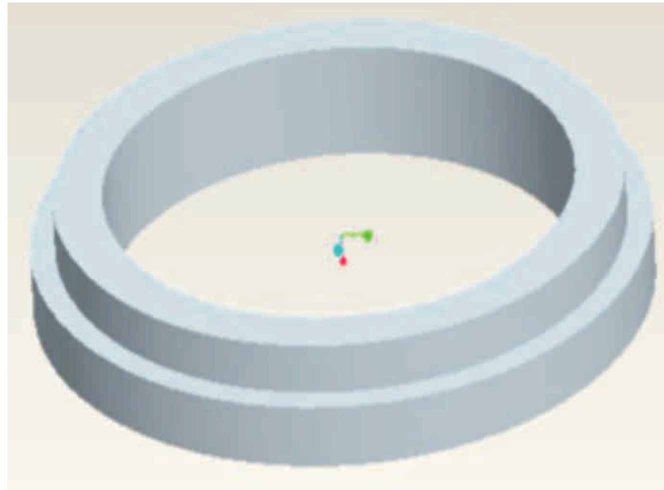


Fig.1Component geometry

CENTER SPRUE AND SIDE SPRUE:

i. Position of sprue at center of component and two symmetrical runners with gate gives flow and solidification simulation as shown in Fig.2a) provides more equal distributed cooling of component(temp. of 559.5°C and 560.7°C).

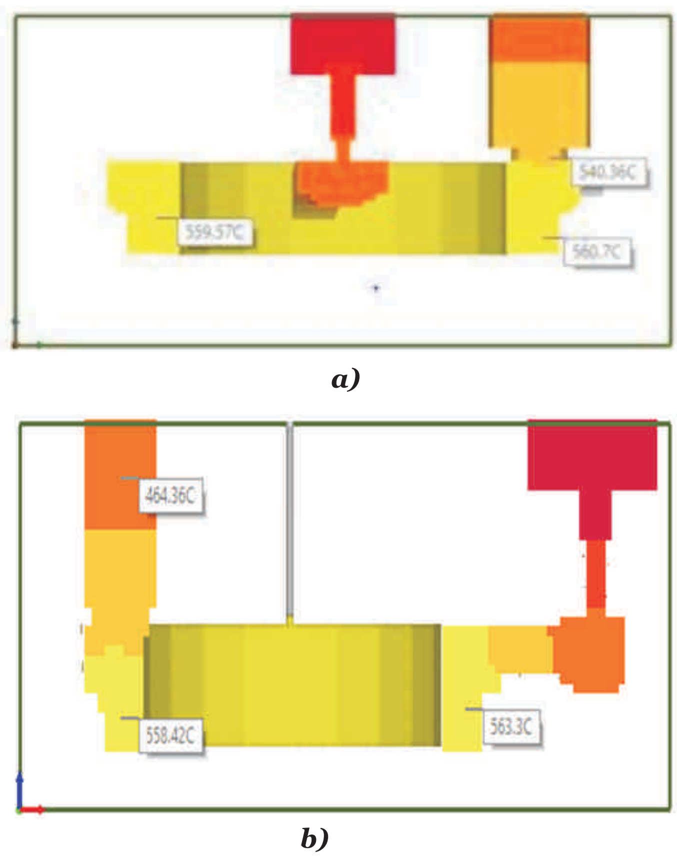


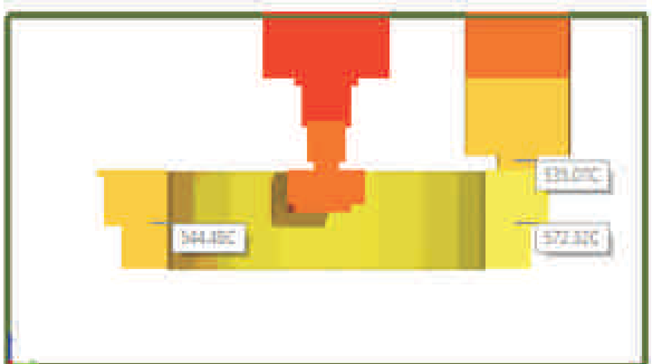
Fig. 2 Solidification of casting with sprue position a) at center and b) at side.

ii. Position of sprue at side of component and one runner connecting to body of component results in the flow and solidification simulation as shown in Fig.2 b), the considerable temperature difference in the component is observed which is (temp. of 563.3°C and 558.4°C).

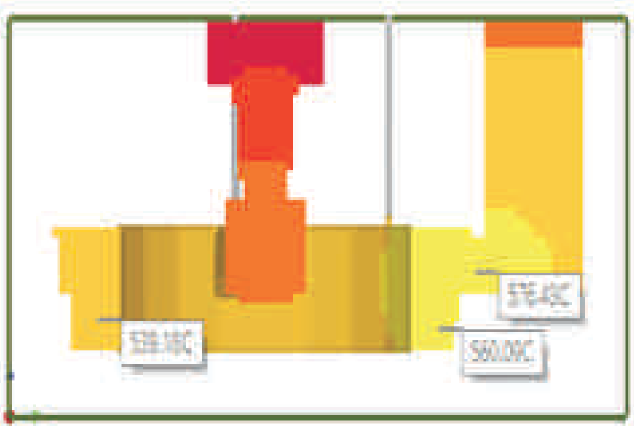
TOP AND SIDE FEEDER:

Casting solidification is analysed for top feeder and side feeder in gating system design. Casting simulated with top feeder is shown in Fig.3. Temperature distribution in part and in neck of feeder is 572.3°C and 535.0°C whereas in case gating design with side feeder, temperature in casting section to feeder neck to feeder increases (560.0°C to 576.4°C) and also side feeder feeds melt in more laminar way.Thus in present case side feeder is selected for further casting study in terms of temperature distribution, solidification time, liquid fraction, hotspot, shrinkage porosity and cold shut in casting.

Gating system components are redesigned with center sprue and side feeder to get more uniform cooling and shrinkage porosity free casting.



a)



b)

Fig.3 Solidification of casting with a) top feeder and b)side feeder.

The partial directional solidification is obtained with single side feeder. Two side feeders along with copper sleeve(2.8mm thick) results in complete directional solidification from part to feeder neck to feeder(Fig.4.) is used in further study.

3. EFFECT OF GATING RATIO

By keeping all other process parameters constant, gating ratio and melt temperature are varied to study its effect on casting.

With the above design configuration (Fig.4) the effect of variation of gating ratio i.e. 1:2:2, 1:3:3 and 1:4:4 on casting quality is explored with melt pouring temperature at 680°C.

Gating system with 1:2:2 gating ratio:simulation result obtained is as shown in Fig.5 below.

It is observed that the feeder is feeding to complete casting and the sequence of solidification is part-neck of feeder and lastly, feeder (Fig.5a)). As per liquid melt flow, it gets disconnected from feeder at one stage and due to that it is possible to have shrinkage porosity at that positions (Fig.5 b)).It results in fill time of 1.51 second and solidification time of 1.73 minute.Casting doesn't show possibility of cold-shut.

Gating system with 1:3:3 gating ratio:

Solidification simulation results obtained with gating ratio of 1:3:3 are as shown in Fig.6.It shows that, casting solidification takes place from part towards feeders and liquid fraction reduces during solidification process. This indicate lower liquid fraction at few positions.

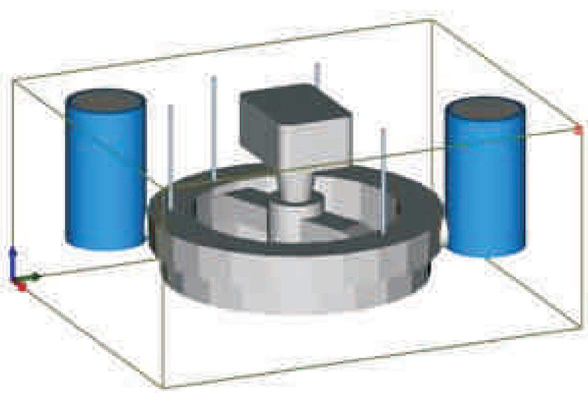
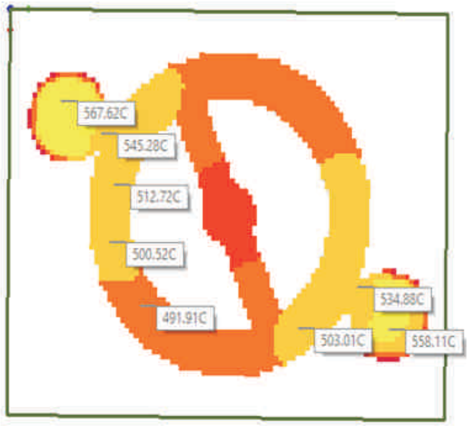
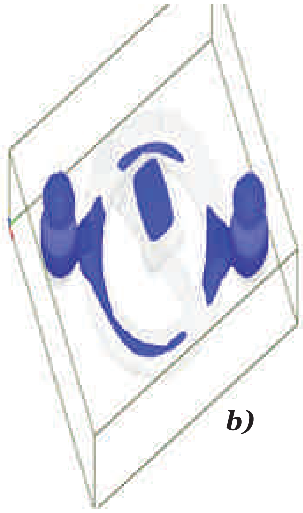


Fig.4 Design with two side feeders and sleeves



a)



b)

Fig.5 Solidification for gating ratio of 1:2:2, with a) temperature distribution and b) liquid fraction.

It is having fill time of 1.51 second and solidification time is 1.74 minute. However possibilities of hot spot exist at lower level than earlier case of gating ratio 1:2:2. Casting does not have the possibility of cold-shut.

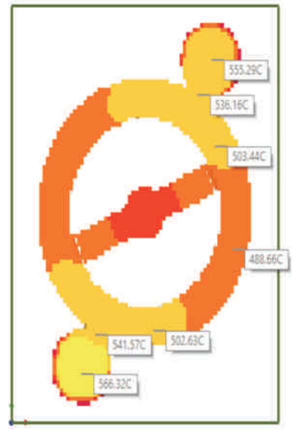
Gating system with 1:4:4 gating ratio: simulation results obtained with gating ratio of 1:4:4 are as shown in Fig.7 below.

With gating ratio of 1:4:4, Fig.7 a) shows temperature rise towards feeder neck to feeder.

Casting cooling takes place from this part towards feeders and liquid fraction is approximately nil (Fig.7b) during solidification. This shows almost no chances of hotspot and shrinkage porosity.

4. EFFECT OF MELT TEMPERATURE

The cast aluminium alloy LM4 is having liquidus temperature of 582°C and solidus temperature of 574°C



a)

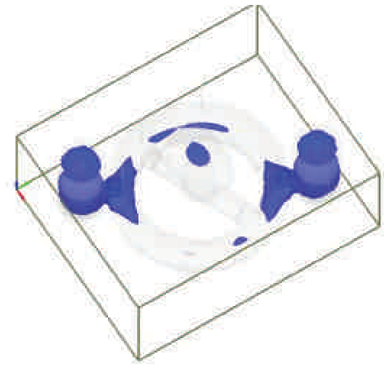


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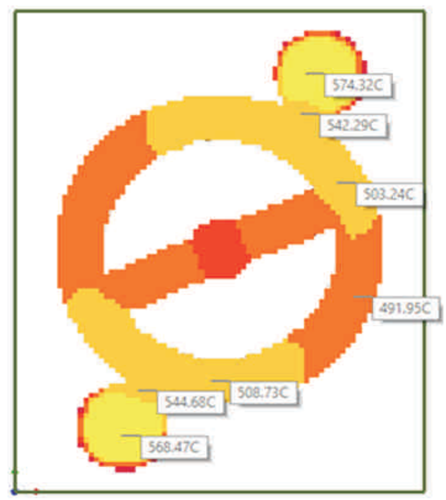
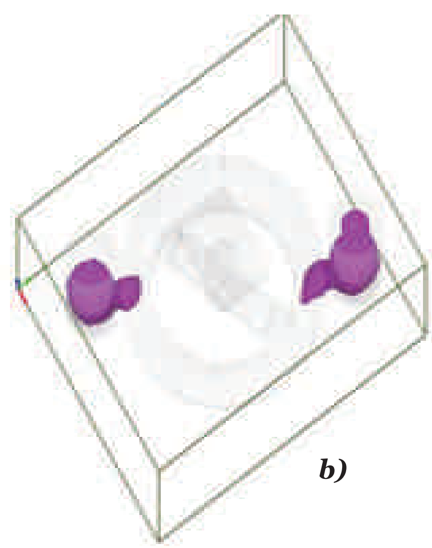
Fig.6 Solidification for gating ratio of 1:3:3with a) temperature distribution and b) liquid fraction.



a)



b)

Fig.7 Solidification for gating ratio of 1:4:4, with a) temperature distribution and b) liquid fraction.

with difference of only 8°C. To find the effect of melt temperature on casting, the melt pouring temperature is increased in steps of 30°C, and observations are made for temperature of 612°C, 642°C, 672°C, 682°C, 702°C, 732°C. The response is measured in terms of hot spots/shrinkage porosity, solidification time(cooling effect / temp.) and cold-shut defect occurrence. The simulation outcome for melt temp. 612°C, 642°C is as shown in Fig.8

The simulation outcome for melt temperature 672°C, 682°C are as shown below in Fig.9 a), and Fig.9 b).

When the component is cast with melt pouring temperature of 672°C and 682°C, further reduction in liquid fraction is continued. The simulation figures 9 (a,b) shows that defect-free casting can be obtained for pour temperature of 672°C . At higher power temperature of 6820C also, porosity and hot spot defects are absent, as shown in figure 9 (c,d). In case of melt with temperature 702°C and 732°C, during casting solidification no hot spot/shrinkage porosity positions were found. Hence behavior for liquid fraction is not shown separately. So it is checked for its temperature distribution and that the part is cooling towards feeder is confirmed. The simulation outcome for melt temperature 702°C, 732°C is as shown in Fig.10. It doesn't include hotspot output for above temperature.

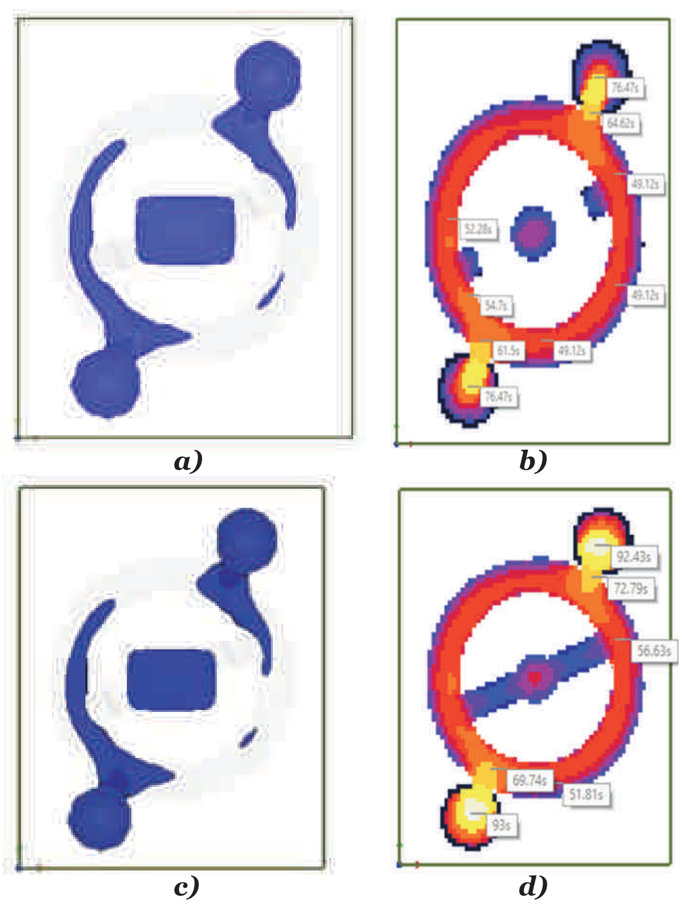


Fig.8 Casting poured with melt temperatureof 612°C, results in a) hotspot b) solidification time for different positions; Casting with melt temp. 642°C shows, c) hotspot d) solidification time.

5. RESULT AND DISCUSSIONS

Positioning the sprue at the center of the casting provides melt flow at more equal rate and result in very close temperatures on both sides of sprue in the component as seen from Fig.2. It results in symmetrical cooling on opposite sides. In case when sprue location is at one side, it gives more difference in cooling rate at opposite position to sprue, results in different cooling rate. This happen as there is fall in temperature and increase in viscosity while melt reaches to opposite end. Hence sprue position at center of casting is used further.

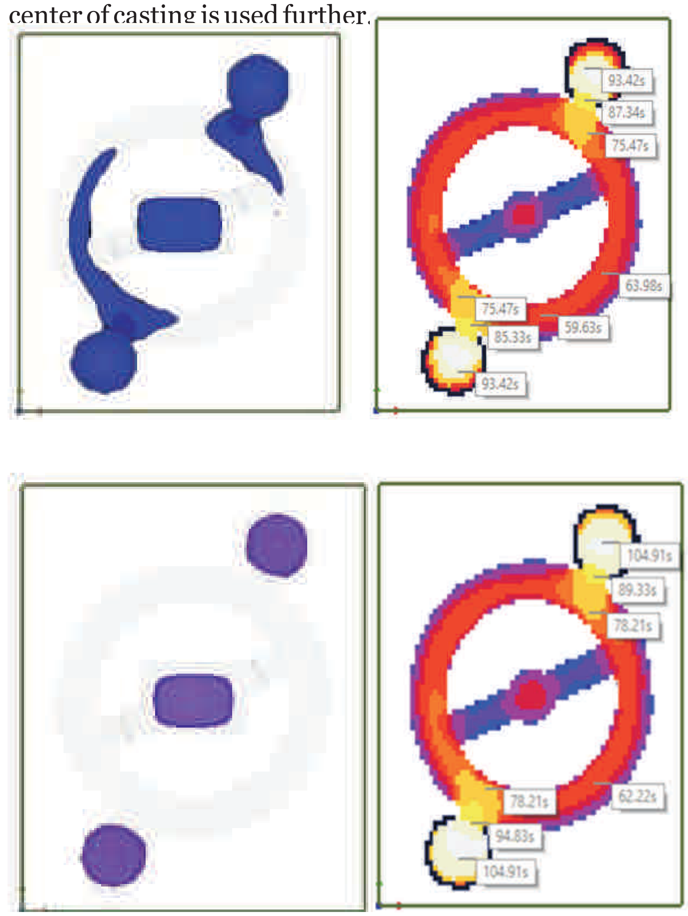
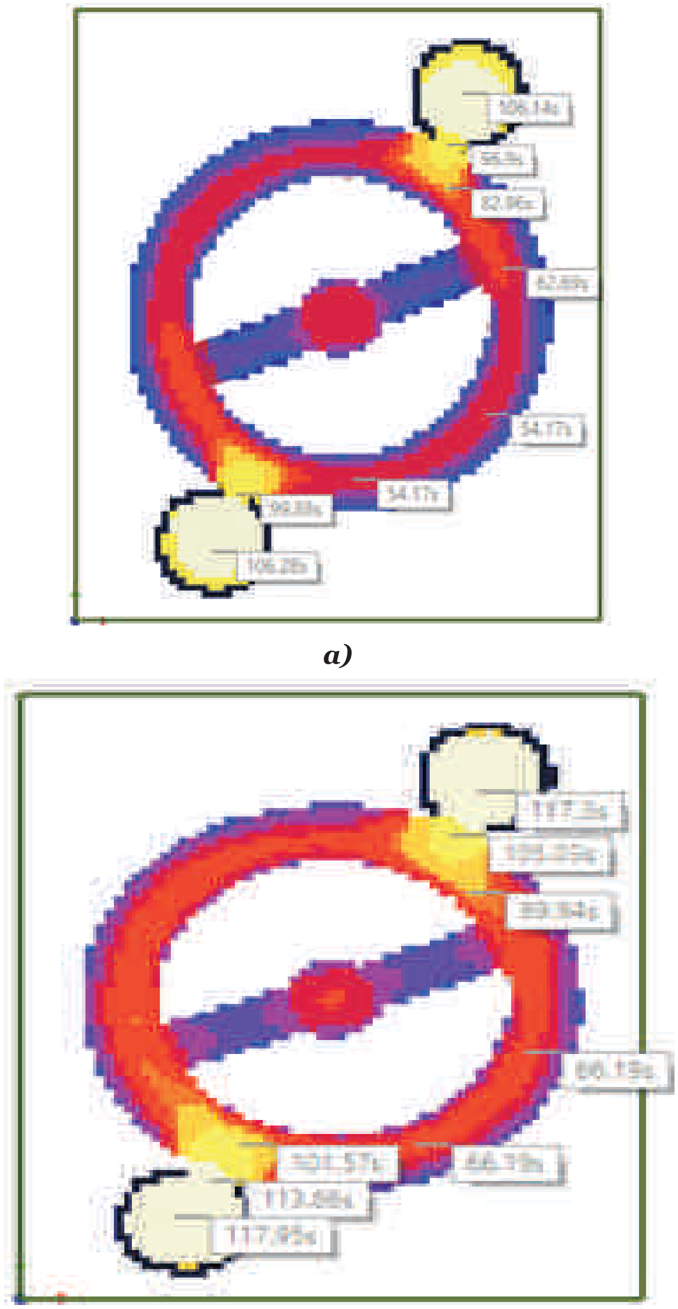


Fig.9 Casting poured with melt temp. 672°C,results into a) hotspot b) solidification time for different positions; Casting with melt temp. 682°C, shows c) hotspot d) solidification time for different positions.



a) *b)*

Fig.10 Casting poured with melt temp. 702°C, a) solidification time for different positions; Casting with melt temp. 732°C,b) solidification time for different positions.

Top feeder results in casting solidification with temperature in casting part higher than temperature in feeder neck (Fig.3). i.e. temperature gradient does not increase towards feeder neck. In contrast, in side feeder design, temperature gradient increases towards feeder. That results in directional solidification towards feeder. It is observed that side feeder work more effectively than top feeder.

Effect of gating ratio:

Fig.5 shows that with gating ratio 1:2:2, higher temperature gradient towards feeder is obtained, but still there is possibility of liquid fraction at three different positions in casting during solidification. It is due to insufficient melt feeding during metal shrinking.Fig.6 shows that when gating ratio of 1:3:3 is used, in addition to temperature gradient towards feeder, % of liquid fraction during solidification is reduced, but not removed. Here due to increase of gating ratio, more melt is fee during cooling process, but it is still insufficient.

Fig.7 shows that when gating ratio is increased to 1:4:4, more refined temperature distribution is observed during solidification. Liquid fraction problem is resolved completely. The possibility of hot-spot (shrinkage porosity) is almost nil. This happens as more quantity of melt is feed with respect to fill time. Quantity of metal shrinkage is equal to the amount of melt fed through feeder and gating system. At the same time it result in fall of yield by small percentage.

Effect of melt temperature:

In case of casting with melt pouring at 612°C(Fig.8. a and b),liquid fraction during solidification is more and overall, the component cools early due to high resistance to melt flow and loss of heat during the period of increase viscosity. With melt pour temperature 642°C (Fig.8 c and d), effect of liquid fraction slightly reduces and temperature level of component increases.

When melt with pour temperature of 672°C is used (Fig.9 a and b), liquid fraction further reduces with increase of temperature. At a higher pouring temperature of 682°C, about 100°C more than the melting temperature of the LM4, alloy, optimum distribution of temperature is obtained and the simulation figure shows that the casting is free from cold shut and porosity.

Fig.10 shows the simulation figure of the casting with melt pouring temperature of 702°C and 732°C, as temperature is more w.r.t. earlier cases, fluidity is increased and it feeds cavity without liquid fraction defect. But as good quality casting is obtained at 682°C pouring temperature, there is no need to go for higher temperature melt pouring. It may increase gas problem during process. So it is recommended to go for melt temperature of 682°C for obtaining casting with minimum defects.

CONCLUSIONS

The casting is designed with consideration of mould layout. AutoCAST-X1 with FLOW+ module is used to study the effect of gating design and melt pouring temperature on casting quality. By simulating castingprocess the results obtained are discussed and following conclusions are drawn:

i. Sprue position should be placed at center of hallow cylindrical shape casting, which gives more uniform cooling than placing it to one side of component.

ii. For feeder design, use side feeders instead of top feeders as it provides fine directional solidification from component to feeder neck to feeder during cooling.

iii. As gating ratio is increased, the liquid fraction during solidification reduces which makes casting more free from shrinkage porosity and cold-shut defects.

iv. As melt pour temperature is increased, hot spot/shrinkage porosity, cold shut defect formation possibilities are minimized to greater extent. It gives better results at 682°C melt poring temperature in present case for LM4 casting.

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