DESIGN OPTIMIZATION OF GATING SYSTEM AND CASTING SIMULATION FOR CAST IRON

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Abstract: Metal casting is one of the basic manufacturing processes. The gating and riser system design plays an important role in the quality. Due to the lack of existing theoretical procedures the designing processes are normally carried on a trial and error basis. The casting produced by foundry with internal shrinkage as a major defect was analyzed and identified that gating and feeding system reduced defect and increase yield. Many casting defects, which cannot be eliminated by changes to tooling and process parameters, can be attributed to poor design of the part with respect to manufacturability. One such common defect is shrinkage porosity at casting junctions. The defects can be predicted by casting solidification simulation, and corrected by minor modification to part design. Finally, a more reasonable gating system was obtained by analysis of drawing and method effective calculations. In the current global competitive environment there is a need for the components in short lead time. Defect free castings with minimum production cost have become the need of foundry.

***Index Terms* - Casting, Different Defect, Optimized Gating System, Simulation**

I. INTRODUCTION

Casting is a manufacturing process in which a liquid material is usually poured into a mold, which contains a hollow cavity of the desired shape, and then allowed to solidify.

The solidified part is also known as a casting, which is ejected or broken out of the mold to complete the process.

It is the process of manufacturing in which molten metal is poured in the cavity, known as mold cavity, so that solidified metal takes the shape of the cavity. The solidified metal is called Casting and the process is called Casting Process.

Mold cavity is prepared by patterns. It is always larger in size than the actual casting.

Some of the metal casting processes and materials used in ancient times are still in used today the most commonly used resources are grey iron, ductile iron , aluminum , steel , copper , zinc.

The major casting process used in manufacturing industry are the following Investment casting, centrifugal casting , rapid casting , die casting , lost-wax casting , sand casting , lost-foam casting , glass casting , centrifugal casting , slip casting.

Figure 1.1 Casting Process

II. RESEARCH METHODOLOGY

1. Manual Gating system and Riser Designs for casting
2. Generate model of EP-20.
3. Analysis the casting product using click2cast.
4. Find suitable data for casting like temperature, filling rate.
5. To maximize productivity rate in EP-20 casting.

III. GATING SYSTEM DESIGN

1. Pouring Cup & Pouring Basin

Any one of these is necessary so as to direct the flow of the molten metal from pouring ladle to the mold cavity. Pouring Basin, in addition to this, provides better slag trap and smooth cavity filling properties i.e. reduces turbulence and vortexing at the sprue entrance. Pouring cup is *funnel shaped cup* at the top of the sprue.

2. Sprue

It is tapered (and not parallel which causes higher mold erosion) with its bigger end at the top to receive the liquid metal. The smaller end is connected to the runner. It will thus allow continuous feeding of molten metal into mold cavity. Round sprue has minimum surface exposed to cooling and offers lowest resistance to flow of metal. There is less turbulence in a rectangular sprue.

3. Gate

It is a channel which connects runner with the mold cavity. Runner connects sprue base with the gates. Molten metal enters the mold cavity through gates. It should feed *liquid metal* to the casting at a rate consistent with rate of solidification. A small gate is used for casting which solidifies slowly and vice-versa. More than one gate may be used to feed a fast freezing casting. A gate should not have sharp edges. There are varieties of Top, Bottom & Parting line gates which are used in practice.

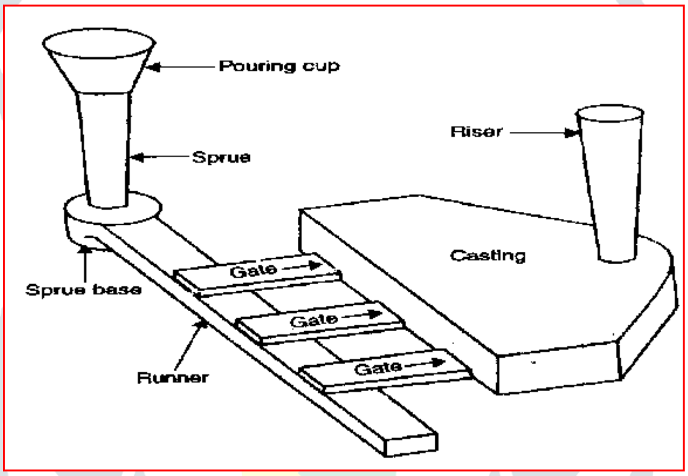

Fig. 3.1 Elements of Gating System

4. Governing Equations

First equation is Reynold's equation which gives the value of a dimensionless number which indicates whether flow of fluid is turbulent or not. Generally, turbulent flow occurs if the value of Reynolds's number exceeds the value 4000.

$$Re = \frac{\rho V D}{\mu}$$

Continuity equation of fluids is very important as it is used for designing the sprue. This law holds good for only those ducts, tubes or channels which run full.

$$Q = A_1 V_1 = A_2 V_2$$

Bernoulli's equation is also very useful in the gating system design. This is because it is used to find out the velocity of the molten metal at sprue base, given the height of the sprue.

$$\frac{V_1^2}{2g} + h_1 + \frac{P_1}{\rho g} = \frac{V_2^2}{2g} + h_2 + \frac{P_2}{\rho g}$$

Note that this equation is written neglecting the loss of head during the flow.
By manipulating this equation, we get

$$V_2 = \sqrt{2gh_s}$$

Another important equation is Darcy- Weisbach equation. It is basically an equation of loss of head during fluid flow through pipes due to friction.

$$h_f = \frac{fLV^2}{2gD}$$

Choke: It is that part of gating system which possesses smallest cross- sectional area. In pressurized gating system, gate serves as choke. So, very high velocity will lead to excessive mold erosion and turbulence in the fluid flow.

Area of the Choke is calculated by using modified form of Bernoulli's equation.

$$C_A = \frac{W}{c\rho t\sqrt{2gH}}$$

Pouring Time: Selection of optimum pouring time is major problem in foundries. Some empirical formulas are setup to find the pouring time for a particular size & shape of the casting. Here, only Grey Cast Iron is taken into consideration.

For Castings weighing more than 1000 lbs

$$\text{Pouring time} = \text{K}\left[0.95 + \frac{\text{T}}{0.853}\right]\sqrt[3]{\text{w}} \quad \text{seconds}$$

For Castings weighing less than 1000 lbs

$$\text{Pouring time} = \text{K}\left[0.95 + \frac{\text{T}}{0.853}\right]\sqrt{\text{w}} \quad \text{seconds}$$

Where K= Fluidity factor

$$= \frac{\text{Fluidity of specific iron}}{40}$$

IV. FEEDING SYSTEM

Feeding system includes Risers or Feeders, Feed-aids & Neck connection. Risers or Feeders are used to compensate the liquid metal for Liquid to Solid shrinkage. It is extremely useful to avoid the hot spots and hence shrinkage defects in the castings. Always feeders must solidify at last. This is only possible if Modulus of the feeder is larger than Modulus of the castings. Feed-aids include Sleeves, Chills, Padding, Fins, Exothermic materials, etc.These are extensively used in foundries as they improve the yield by improving the effectiveness of the risers. Neck is the connection between the Riser and Casting. Typical figure for this is shown as fig. 4.1

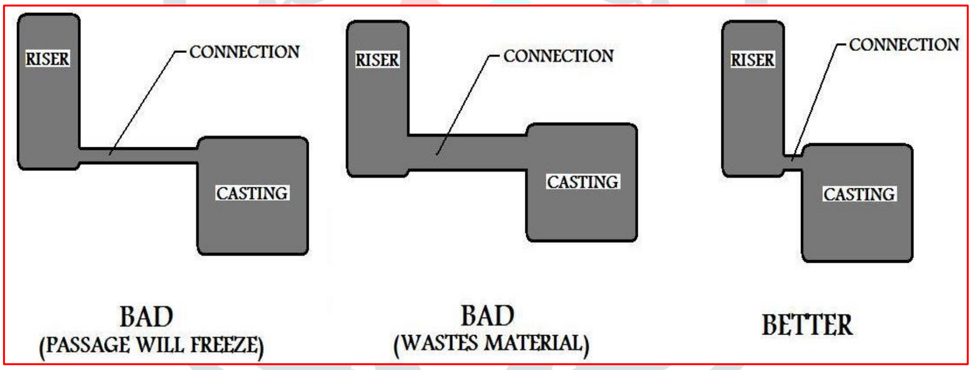

Fig. 4.1 Feed aids & Neck Connections

V. METHODS OF RISER DESIGN

1. **Chorine's Rule:**

It states that freezing time is proportional to $(V/A)^2$. It means if metal in riser has to remain liquid for a longer time, V/A should be large or A/V should be small. According to this rule, riser should be cylindrical (round) rather than square or rectangular of equivalent mass. Spherical risers are the best by this criteria but due to difficulties in molding, feeding and fettling, they are not practicable.

$$t_{\text{freezing}} \text{ or } t_{\text{solidification}} = k\,(\text{Volume/Surface Area})^2$$

According to thisrule,

$$Ts_{\text{sphere}} > t_{s\ \text{cylinder}} > t_{s\ \text{bar}} > t_{s\ \text{plate}}$$

2 **Modulus Method:**

Modulus is nothing but ratio of Volume and Surface area.

Empirically $_{\text{feeder}} \geq 1.2$ M $_{\text{casting}}$

After this, appropriate h/d ratio is assumed & dimensions of riser are calculated.

3 Caine's Method:

It is based on an experimentally determined hyperbolic relationship between relative volumes and relative solidification rates of riser and casting to produce shrinkage free castings.Reason for taking Surface area to Volume ratio is that, surface area represents the heat dissipation and the volume (within which mass of liquid is present), represents quantity of heat.

Relative freezing time

$$\left(\frac{A}{V}\right)_{casting} > \left(\frac{A}{V}\right)_{riser}$$

$$\left(\left(\frac{A}{V}\right)_{casting} \Big/ \left(\frac{A}{V}\right)_{riser}\right) > 1 \text{ or } x > 1,$$

$$\text{where } x = \text{freezing ratio}$$

$$(x-1) > 0$$

Quantity of metal required

For compensating shrinkage

$$\left(\frac{V_r}{V_c}\right) > b \text{ or } y > b,$$

$$\textit{where, y is contraction ratio}$$

$$(y-b) > 0$$

So, Caine's Equation:

$$(x-1)(y-b) > 0$$
$$\Rightarrow (x-1)(y-b) \geq a$$
$$\Rightarrow x \geq \left(\frac{a}{(y-b)}\right) + c$$

Where

a= freezing chara. Constant
b= liquid- solid shrinkage
c= relative freezing rate of

Riser& casting

Caine's curve is basically a hyperbola having specific values of constants a, b and c as discussed above. It is shown in fig. 5.1

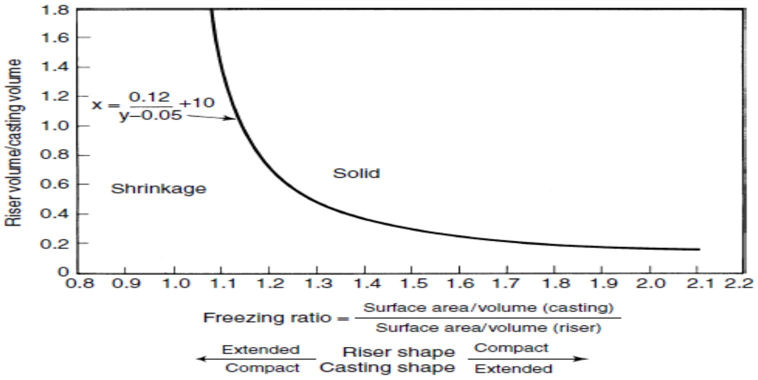

Fig. 5.1 Caine's Curve

4 NRL (Naval Research Laboratory) Method:

A further and simplified development of the Caine's approach was that of Bishop, who used the concept of a **shape factor** to replace the surface area to volume ratio used in the earlier relationship.

The shape factor

$$S = \left(\frac{L+W}{T}\right)$$

Where L, W and T are the length, breadth and thickness of the section concerned.

General Procedure:

I. Calculate shape factor for critical section.
II. Derive the value of $V_{riser}/ V_{casting}$ from the NRL graph as shown in fig. 5.2
III. With known $V_{casting}$, V_{riser} can be found out.
IV. Various alternative h/d combinations are selected.

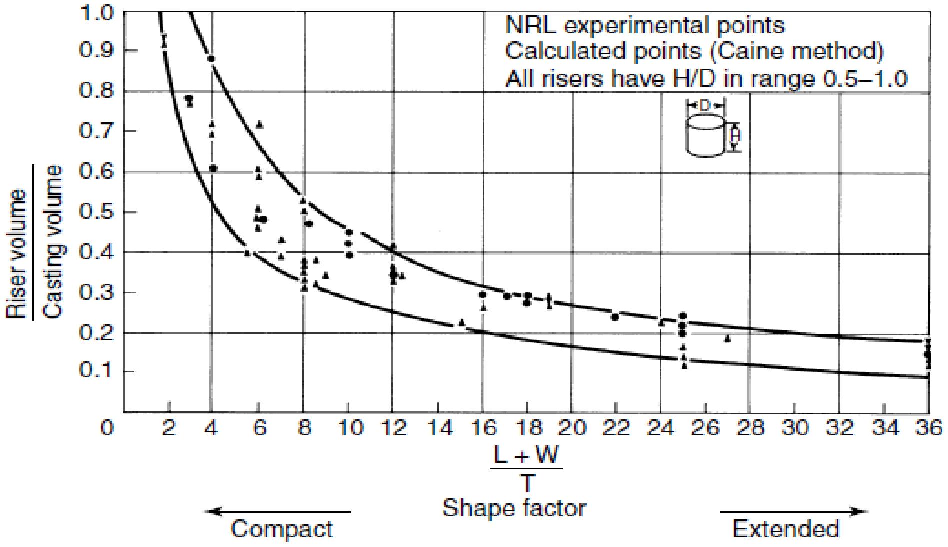

Fig. 5.2 NRL Graph

VI. CALCULATION

1. *GATING SYSTEM:*

Essential Input Parameters:-

Density of Gray Cast Iron, ρ= 7.1 gm/cm^3

Average section thickness, T= 15 mm

Fluidity of Gray Cast Iron= 30 inch

Weight of casting, W= 240 kg

Nozzle coefficient, c = 0.9

Gating Ratio= 1:4:4

Effective Head, H= 462.5 mm

Cross section of runner and in gate = Rectangular

Ratio of height to width for runner = 1:2

Ratio of height to width for in gate = 1:2

No. of in gates = 4

Calculated parameter

Pouring time :-

$$k\left[0.95+\frac{T}{0.853}\right]\sqrt{w}\ \text{sec.}$$

$$= 0.95\left[0.95+\frac{15}{0.853}\right]\sqrt{240}\ \text{sec.}$$

$$= 28.328\ \text{sec.}$$

Choke area:-

$$C_A = \frac{W}{cpt\sqrt{2gH}}$$

$$C_A = \frac{240}{0.9 * 7.1 * 28.329\sqrt{2 * 9.81 * 462.5}}$$

$$C_A = 440.138\ \text{mm}^2$$

Diameter at top of pouring cup = 150 mm

Diameter at top of down sprue = 90 mm

Diameter at sprue base = 75 mm

Area at sprue base

$$A = \frac{\pi}{4}D^2$$

$$A = \frac{\pi}{4}75^2$$

$$A = 4417.86\ \text{mm}^2$$

Dimension of runner:-
Height = 23.5 mm and width = 47 mm

Area of one gate = 276.12 mm^2

Dimension of gate:-
Height = 11.75 mm and width = 23.5 mm

Gating ratio :- 1:4:4
(Chock area = runner = gate)

2. *FEEDING SYSTEM:*

Input parameter:-
Volume of casting $V=33.80*106\ mm^3$
Surface area of casting $A=3.45*106\ mm^2$

Existing method of feeding at time cost:-
Numbers of feeders = 10
Modulus of casting Mc = 9.8 or 10
Modules of riser:-

$$\begin{aligned} Mr &= 1.25*Mc \\ &= 1.25*10 \\ &= 12.5 \end{aligned}$$

VII. SOLIDIFICATION SIMULATION FOR PROPOSED METHOD& ITS OPTIMIZATION:

Need of changing the existing method for EP20 can be visualized from the results of simulation of that existing method.
Fig. shows the complete assembly of EP20 casting along with existing method used in Fine Cast.
Temperature scale used for the results is as per fig. 7.1
After simulating this whole assembly, the result obtained is as shown in fig. 7.2 to 7.10

Fig. 7.1 Temperature scale

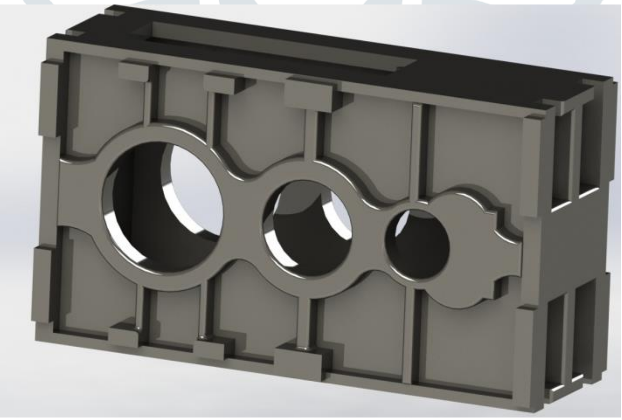

Fig. 7.2 Model of EP-20

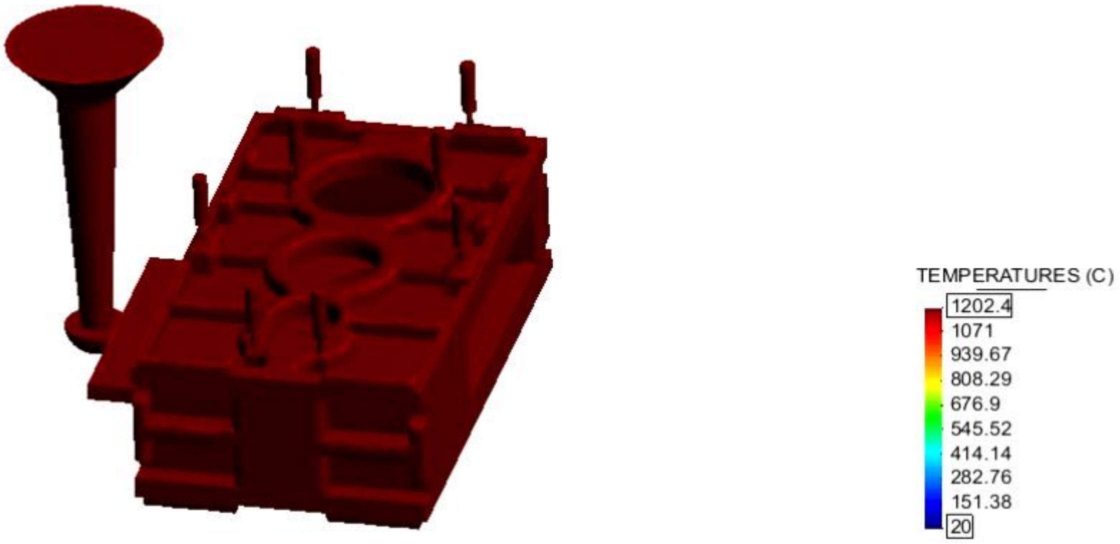

Fig. 7.3 Temperature at 1200 °C of EP-20

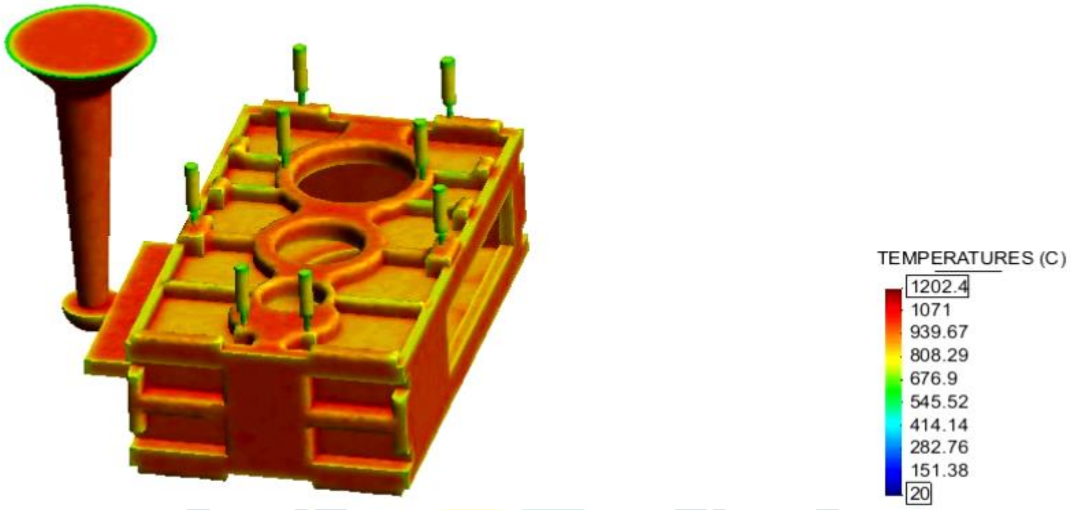

Fig. 7.4 Temperature at between 939.67 to 808.29 °C of EP-20

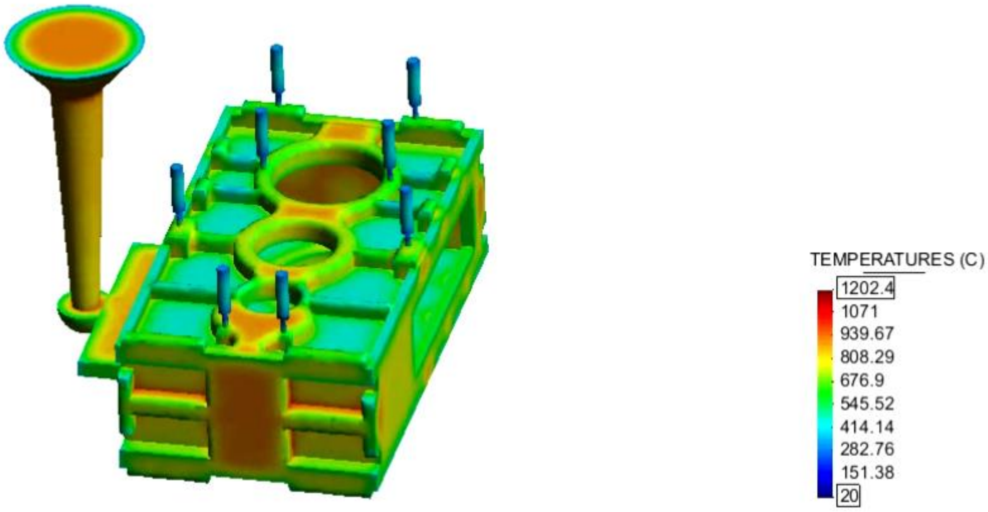

Fig. 7.5 Temperature at between 808.29 to 550 °C of EP-20

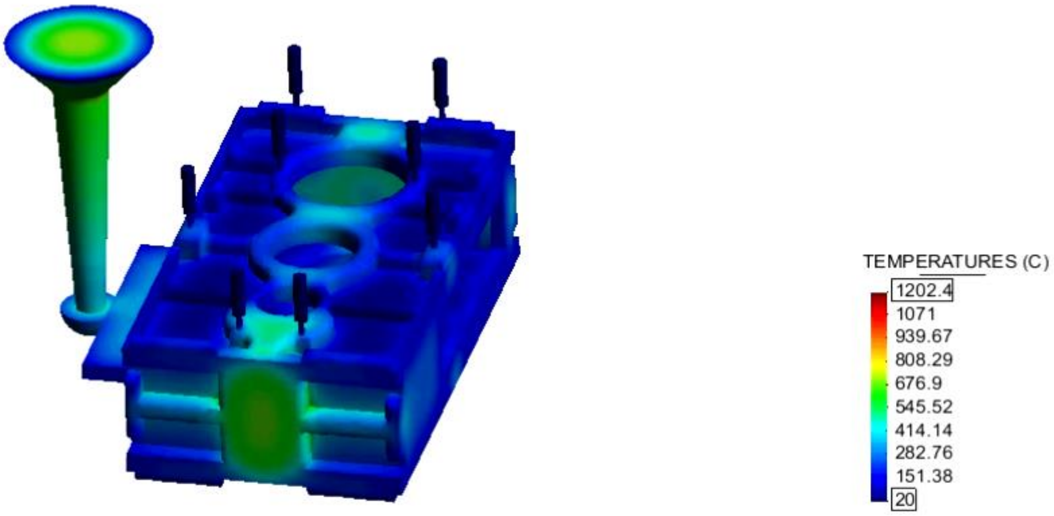

Fig. 7.6 Temperature at between 450 to 100 °C of EP-20

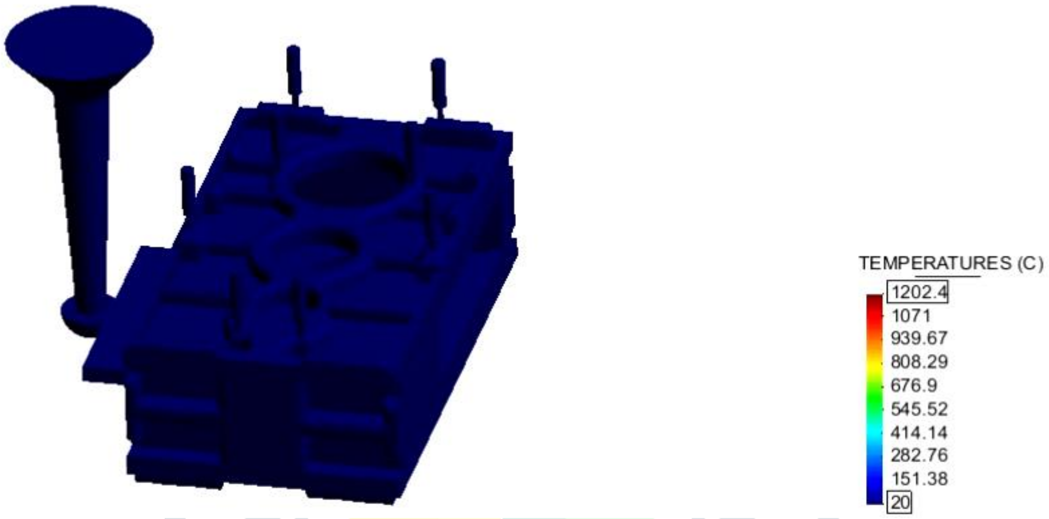

Fig. 7.7 Temperature at between 20 °C of EP-20

The temperature distribution shown in every result can be interpreted in the context of figure 7.1
The simulation is performed by considering Fine mesh size of molding sand.

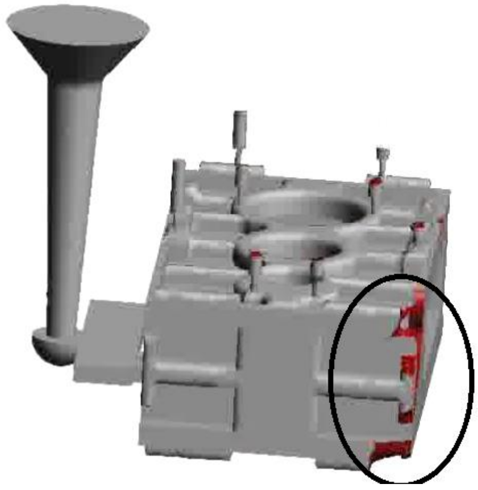

Fig. 7.8 shrinkage defect accruing in part

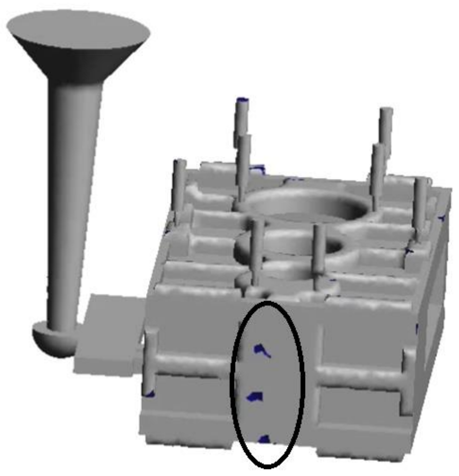

Fig. 7.9 Blow hole defect accruing in part

Fig. 7.10 Cold shuts defect accruing in part

The cold spots i.e. Blue locations indicates probable locations of occurring the cold shut. This is because; the blue regions are early freezing regions. Due to large temperature gradients, chances of induced residual stresses increase which may lead to cracking.

The problem of cold spot can be solved by performing very complex flow simulation process.

Other way of reducing or eliminating these problems is to analyze the past records to find out locations of these defects in previously cast EP-20.

After knowing these locations, appropriate amount of padding at appropriate locations so as to minimize temperature difference.

Padding may be base metal type or foreign material type.

This method is simply described as increasing the thickness of critical sections of the casting.

The problem of shrinkage can be solved by proper feeling of molten metal in gating system.

The blowholes produced due to moisture in the sand. It can be reduced by removing moisture from the sand.

Sometimes mismatch also occurs in the castings . This cannot be eliminated by any simulation software. This is because of the nature of defect i.e. Only because of foundry practice. It has large dependence on operator's accuracy in clamping mold boxes and location accuracy of pattern plates on molding machines.

VIII. CONCLUSION

EP 20 Casting produced is fails to provide the soundness frequently due to defects such as Shrinkage, Cold shut, Crack and Mismatch.

Out of these defects, Shrinkage, Cold shut and Crack can be reduced by optimizing the design of Gating and Feeding systems. Mismatch is the defect occurring due to operator error or pattern plate positioning error and cannot be reduced or eliminated with an aid of simulation software.

Since manual iterations for optimizing the design require huge amount of time and money, it is customary to use Casting Simulation Software for this purpose.

Simulation software gives the results for solidification simulation, flow simulation as well as coupled simulation by providing required inputs.

Flow simulation gives ideas about mold filling by which solidification time and mold filling time can be known. Also, flow related defects can be predicted and may be prevented. Flow related defects are cold shut, cracking, etc.

In short, simulation technique aims at improving casting yield as well as reduces rejections which ultimately lead to the higher profits

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