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Reduction of Shrinkage Defect in Globe Valve Casting By Redesigning of Gating System Using Simulation

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Abstract- *Investment casting is a manufacturing process to make complex geometrical parts of metal materials in mass production. But many times different types of defect occur such as shrinkage type defect. These defects can be minimized by appropriate changes in gating system. Existing gating system is critical to improve casting quality and productivity. It is necessary to improve casting gating systems based on analytical design of gating system and casting simulation with the goal of improving casting quality such as reducing casting shrinkage defects and increasing casting yield. Globe valve component is used for the experiment for gating system evaluation. First the existing design of globe valve gating system simulation has been done on simulation software. Then after by analytical design, redesigning of gating system design has been done and then after again re-simulation of the new gating system design has been done in software. Final this will be implemented in the industries. Both the results are match with each other.*

Keyword-*Investment Casting; Gating System; Shrinkage Defect; Solidification; Simulation*

I. INTRODUCTION

Investment casting is one of the oldest metals forming process and it is also known as "lost wax" casting. Investment casting process is capable for making millions of parts per year. The volumetric contraction accompanying solidification of molten metal manifests in defects like shrinkage cavity, porosity, centerline shrinkage, corner shrinkage and sink. These defects can be minimized by designing an appropriate feeding system to ensure directional solidification from thin to thick sections in the casting, leading to feeders. Major parameters of a feeding system include: feeder location, feeder shape and size, sleeves and covers, feeder neck shape and size, chills, and fins. The effect of these parameters on directional solidification by mapping the temperature gradients between the hot spot in the casting and hot spot in the feeder [1] Casting simulation can minimize the wastage of resources required for trial production. In addition, the optimization of quality and yield implies higher value-addition and lower production cost, improving the margins. Simulation programs are fast, reliable, and easy to use. This has been achieved by integrating method design; solid modeling, simulation and optimization in a single software program, and automating many tasks that otherwise require computer skills. [2]

II. LITERATURE REVIEW

Investment casting has been a widely used process for centuries. It is known for its ability to produce components of excellent surface finish, dimensional accuracy and complex shapes. In previous year trial and error method was adopted to reduce the internal defects occurred during solidification process. Now a day's Casting simulation has become a powerful tool to visualize mould filling, solidification and cooling, and to predict the location of internal defects such as shrinkage porosity, sand inclusions, and cold shuts. It can be used for troubleshooting existing castings, and for developing new castings without shop-floor trials. Shrinkage defect is one common defect which is shown after solidification. In investment casting process some parameters such as feeder location, feeder shape, feeder size etc. have to be considered to reduce shrinkage defect or method design is also one of the most important factor for shrinkage defect. Simulation software accurately locates all the hotspot with their size without any trail on shop floor.

III. PROBLEM DEFINITION

In one of the casting foundry industry, they are facing the shrinkage defects produce in globe valve casting product. These defects are occurring at a time of solidification process. This defect can be seen after machining the component. From surveying whole process of investment casting in casting company found a reason for defects in casting product. Many researchers reported that about 90% of the defect in casting is due to wrong design of gating & risering system and only 10% due to manufacturing problems. Company is manufacturing globe valve part in which they have found shrinkage defect after machining process. Due to shrinkage defect parts are rejected so that it is necessary to reduce the rejection by reducing the shrinkage defect.

Defect produce in the globe valve is shown in figure.

Figure 1. Defective Globe Valve

3.1. Part Information

Below table is shows the detail about globe valve body component.

1	Material Grade	AISI 304SS-(CF8)
2	Casting weight	12.00 kg
3	Layout weight	26.50 kg
4	Number of part	1
5	Pouring Temperature	1520-1540 deg. Celsius
6	Function of part	Globe Valve Body
7	Pouring Time	10 S
8	Chemical Composition	19% chromium
		0.08% Carbon
		9% nickel
		1.5%manganese
		1% Silicon
		0.045% Phosphorus

Table 1. Information of part

Most of the parts having shrinkage defect and due to this the rejection ratio is high. So that it is necessary to reduce the defect to improve the quality and productivity of casting product.

IV. EXISTING GATING SYSTEM DESIGN & SIMULATION

In Investment casting process most of the small parts are assemble in a tree type structure. But some of the parts that cannot be form into a tree type structure because of their heavy weight and complex geometric shape. Those kinds of parts are making as separate parts.

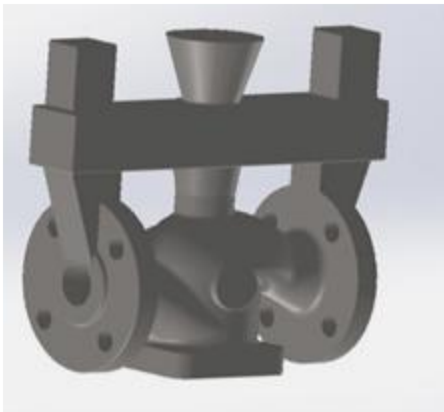

Figure 2. Existing design method

Figure shows that the existing method design of globe valve. Design containing separate gating system for manufacturing globe valve body part. From the literature survey, it comes to know that most of the shrinkage defects are comes from the wrong method design or inadequate gating system design. By changing method design and/or minor modification in method design, shrinkage defect can be minimized up to certain level.

Calculation of initial gating system

- Pouring time (t) = (2.4335-(0.3953) logW) $\sqrt{W}$=10s
- Average filling rate = Weight of casting /Filling time = 1.198 kg/s
- Initial pouring rate = 1.5 x Average pouring rate = 1.797 kg/s
- Runner Volume =width of runner x height of runner x length of runner= 10.04 X $10^5 mm^3$
- Casting modulus = Casting volume/Surface area = 4.48 mm
- Layout modulus = 9.9 mm
- Feeder modulus = 6.72mm
- Freezing ratio (k) = m_f/m_c
  =1.49
- Casting Yield = (weight of actual casting/ weight of poured metal) x 100
  = 45.38%

Here above analytical calculation is for existing gating system design. Here we can see that the weight of the method is more than the weight of the casting. Also the casting yield is also low. If casting yield is improve some minor percentage, and then weight of the method will be less. Benefits of the high casting yield is less pouring time, less pouring material, less machining process, etc.

4.1. Simulation

As discuss earlier, parts having shrinkage defect at the end of process. So it is necessary to reduce this defect before the shop floor trial. These types of defect can be easily identified by the simulation software before the shop floor trial. The entire study has been carried out SoftCAST 3.5 software and finally validate with experimental trial.

SoftCAST is based on the radically new Vector Method for casting solidification analysis. Unlike the Finite Element Method (volume elements) and the Boundary Element Method (surface elements), it uses vector elements to analyze the progress of solidification inside a 3D casting model. This greatly increases the computation speed without compromising the accuracy of results. [12]

Input: - The main input to SoftCAST is a solid model of the cast component, which can be created using a commercial 3D CAD system and imported in an industry-standard .STL format. Other inputs include cast metal, mold type and process parameters.

Output: - The following some main results are provided in this work after solidification analysis:

• Location of the hotspots or last freezing zones

• Refined temperature profiles of solidification on any cross-section

• Information on geometry modulus, significant modulus at any zone, yield

• Automated report generation

General Flow Work of Simulation: -

- Step: 1 Converting a .STL file into .SDF format
- Step: 2 File load (Casting)
- Step: 3 File Load (Method Layout)
- Step: 4 Select section for temperature map
- Step: 5 Computations of Temperature Map and Hot Spot
- Step: 6 SoftCAST Analysis Results

Hotspot: -

The most important information generated by a SoftCAST simulation is the location of the hotspots. Hotspots are the last freezing zones in a casting. SoftCAST accurately locates all hotspots in the casting, and displays them in order of their intensity (low to high intensity scale).A relative scale is used to show the hotspots at different temperature intensity bands or levels (from level 1 to level 9). Level 9 is the highest relative temperature intensity level. If any hotspot is located in the major intensity level (7 to 9), it will show the possibility of shrinkage defect. [12]Here the intensity level 8 and level 9 is shown in below figure.

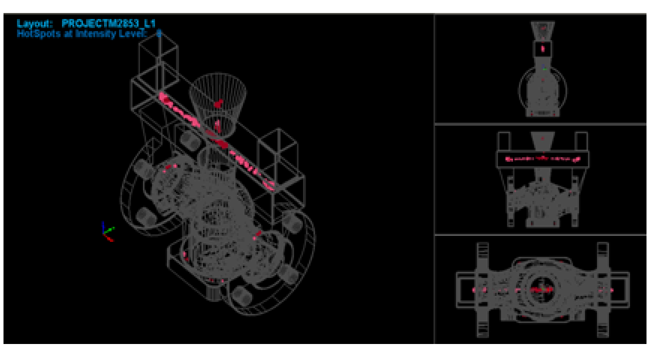

Figure 3. Major hotspot intensity level 8

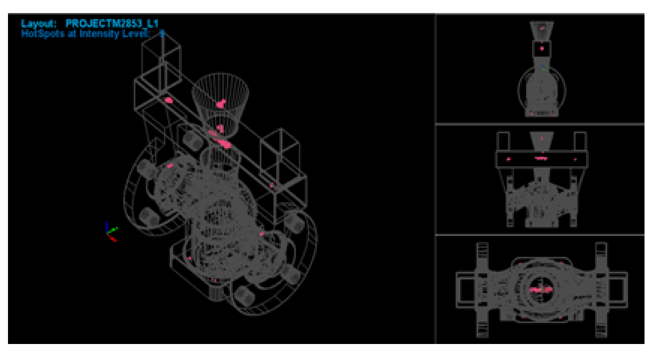

Figure 4. Major hotspot intensity level 9

From the figure 3 and figure 4, we can see that the hotspots are located in particular location. Hotspot is the last freezing zones, so that there is possibility of shrinkage defect after solidification. Ideally hotspot should come in the gating system/feeding system. If any hotspot located in the casting it will shows the possibility of the shrinkage defect.

Temperature Maps: -

Another result is generated by the software is Temperature Maps at different section of the casting part. The temperature maps within the casting, as seen through the section temperature analysis in SoftCAST, provide a wealth of information on temperature distribution, thermal gradients and moduli within the various sections. SoftCAST enables the user to take sections through the casting, in any of the three orthogonal planes: XY, YZ, or ZX.

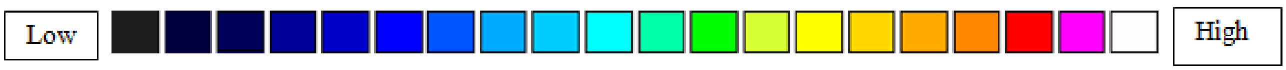

Figure 5. Relative temperature map scale

There are two options for viewing the section temperature maps, i.e. Global and Local comparisons. When viewed globally, we have a comparison of the temperatures in that section with that of the hottest point in the entire casting configuration. In the local comparison, all points in the section are compared with the hottest point within that section itself. [12] Here the section is compute globally at different section as shown in below figure.

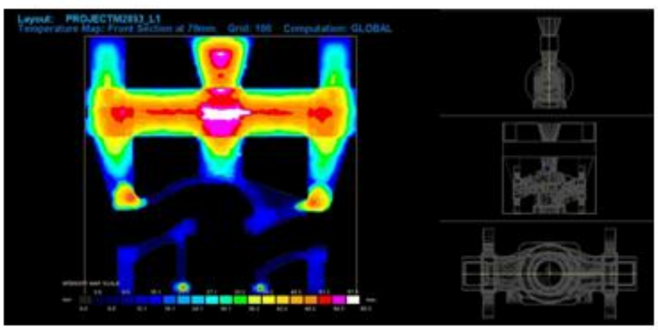

Figure 6. Temperature map at front section at 79 mm

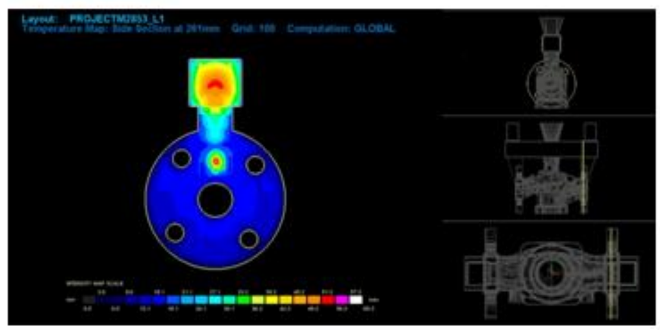

Figure 7. Temperature map at side section at 261 mm

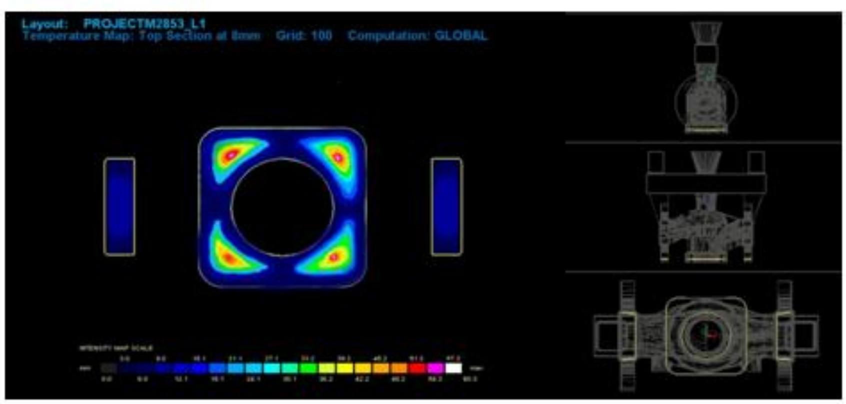

Figure 8. Temperature map at top section at 8 mm

Here form the section temperature map, we can see that the temperature distribution of whole casting part with gating system in a global view. In Temperature Map we can also see that the hottest point in the casting. It will occur in that area where the location of hotspot in major level 7, 8 and 9 is there.

From the above hotspot and temperature map result we can see that the both the results are shows the same results and if we compare simulation result with actual defective casting part, both the results are match closely. So that it is necessary to minimize shrinkage defect to improve casting quality and productivity.

V. MODIFIED GATING SYSTEM DESIGN & SIMULATION

It is necessary to take certain parameter for making a new gating system design. For those parameters such as, feeder location, feeder size, feeder shape, sleeve etc. should be taken for the new design. Out of this parameter three parameters are taken into account such as feeder location, feeder size and feeder shape. Based on these parameters new design is developed. Analytical design calculation for the new gating system is given below.

Calculation of Modified gating system

- Pouring time (t) = (2.4335-(0.3953) logW) √W= 9.4s
- Average filling rate = Weight of casting /Filling time = 1.2 kg/s
- Initial pouring rate = 1.5 x Average pouring rate = 1.8 kg/s
- Runner Volume =width of runner x height of runner x length of runner= 11.22 X $10^5 mm^3$
- Casting modulus = Casting volume/Surface area = 4.48 mm
- Layout modulus = 9.7 mm
- Freezing ratio (k) = m_f/m_c
  =1.8
- Casting Yield = (weight of actual casting/ weight of poured metal) x 100
  = 47.6%

From the above calculation it can be seen that casting yield is higher than the initial gating system design. So that method weight is less as compared to previous design. Here the design is based on modulus and the freezing ratio is 1.8. Ideally freezing ratio should be 1 to 2.3 for the optimum design of feeder design. Here the optimum value is 1.8 for the feeder design and based on that the design is created in 3D cad software.

Modified gating system design is shown in the below figure.

Figure 9. Modified system design

Here in the new modified design is based on three parameters such as feeder location, size and shape. Both Simulation result is shown in below figure as discuss as earlier.

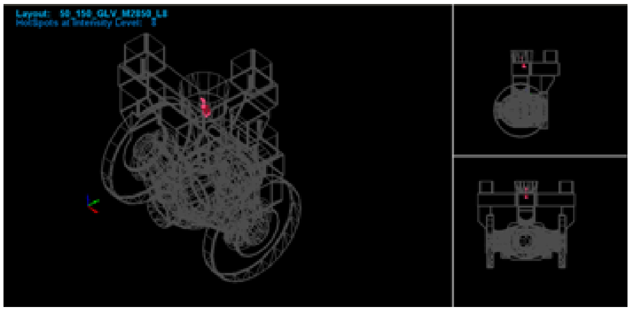

Figure 10. Major hotspot intensity level 8

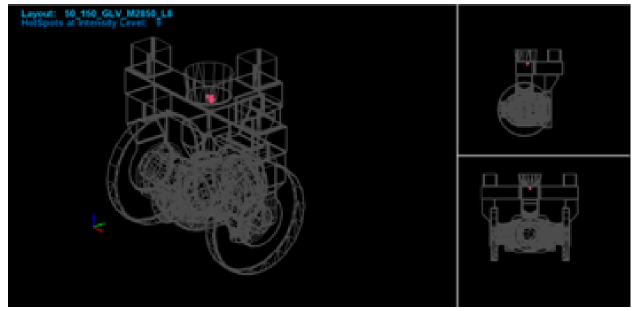

Figure 11. Major hotspot intensity level 9

From the above two hotspot result, we can see that the hotspot is completely shifted in to the gating/feeding system. Now there is no any hotspot location inside the casting part. So that, less chances of shrinkage defects inside the casting.

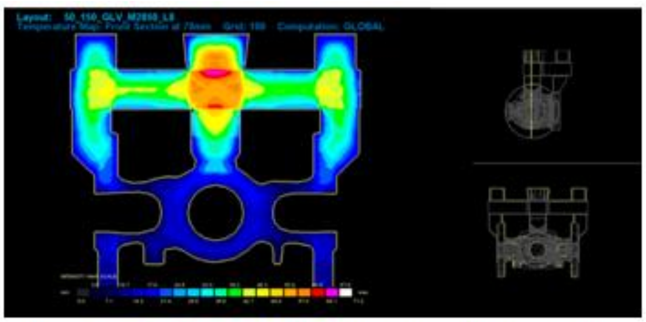

Figure 12. Temperature map at front section at 78 mm

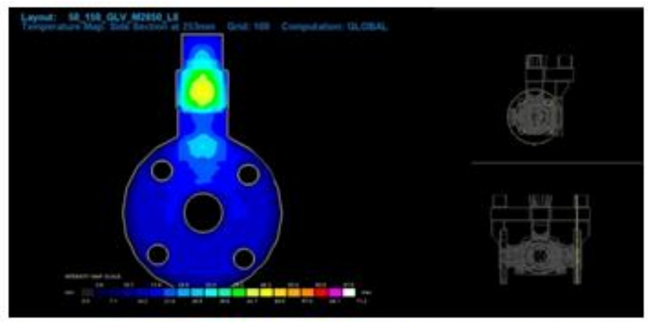

Figure 13. Temperature map at side section at 253 mm

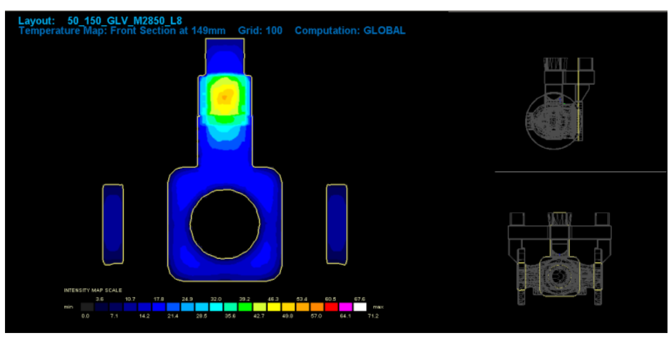

Figure 14. Temperature map at front section at 149 mm

In the temperature distribution map, hot zone is completely shifted in to feeding system as shown in above three different sections. So that last solidified zone is feeding system.

VI. EXPERIMENTAL VALIDATION

For the experimental validation first step is to making wax pattern of globe valve body. Second step is the making new wax method design of modified gating system. Then modified gating/feeding system is attached to the casting wax pattern. After that, follow the procedure of the investment casting process.

Figure 15. Modified gating system part

Figure 16. Back view of final part

Figure 17. Top view of final part

Figure 18. Bottom view of final part

Above figures shows the new gating system design and final casting part. Radiographic test were performed on final casting part. Result of radiographic test confirmed that there is no shrinkage defect in final casting part. By visual inspection, it has been observed casting part was defect free surface. Hence it was conformed that experimental result was confirmed to the simulation results.

VII. CONCLUSION

In this study, it was observe that simulation software is powerful tool to predict the shrinkage defect inside the casting parts. It helps to predict the shrinkage porosity defect inside the casting parts without shop floor trial. Casting yield improve up to some percentage, which indicates the new method design weight is less as compared to initial method and also shrinkage defect is also reduce to a minimum level. Proper design of feeding system helps to reduce the casting defect and give the sound casting. So from the whole study, simulation software helps to eliminate the shop floor trial, gives the accurate result related to shrinkage defect and assists to improve the casting yield.

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