International Journal of Engineering Technology, Management and Applied Sciences

www.ijetmas.com May 2015, Volume 3 Special Issue, ISSN 2349-4476

Analysis and Optimization of Investment Castings to Reduce Defects and Increase Yield

Arunkumar P[1], Anand.S.Deshpande[2], Sangam Gunjati[3]

[1] Associate Professor, Mechanical Engineering, KLS Gogte Institute of Technology, Karnataka, India,

[2] Principal, KLS Gogte Institute of Technology, Karnataka, India,

[3] PG Student, Mechanical Engineering, KLS Gogte Institute of Technology, Karnataka, India,

Abstract

Simulation techniques have been widely used in foundries and metal casting industries. It simulates the real casting phenomenon and gives a virtual casting process as molten metal flow in the mould cavity with respect to time and direction. It shows the virtual process of casting like mould filling, solidification, cooling and also predicts the location of internal defects. With the help of casting simulation, casting process method and design optimization is possible. Casting simulation is used in the production of reliable, economical and accurate cast components. Reliability of casting component can be improved with the help of casting simulation software.

In this paper, the casting simulation, its importance and application has been highlighted with the help of a case study on an investment casting. This casting provided by a local foundry has a shrinkage defect issue and low yield problem because of its design. An attempt has been made to eliminate the defect and suggest an optimized design providing higher yield.

Keywords: casting simulation, optimization, investment casting.

1. INTRODUCTION

Casting simulation is used to simulate the real casting phenomenon using a computer program. The simulation program is consists of set of mathematical equations [1]. Casting process simulation has become an indispensable tool in the production of economical and high performance cast components. Its application by experienced and knowledgeable operators leads to reduced castings defects, casting yield improvement, and reduced trial and error iteration in development of a casting optimization. Increasingly casting simulation is being used as a collaborative tool between component designers and casting producers to reduce lead times, to develop casting friendly component designs and to produce better castings.

Casting simulation should be used when it can be economically justified for quality enhancement by predicting and eliminating internal defects like porosity, yield improvement and rapid development [2].

- Quality improvement: Improvement in quality improves the reliability of casting and reduces the excess cost of defective casting and other resources cost. The quality improvement can be obtained from simulation.
- Yield improvement: With simulation technique, the casting process and method are optimized in short time. And also the casting process is optimized there will be very lesser wastage thus it results in yield improvement, reduces the effective melting cost per casting, and increases the net production capacity.
- Rapid development: Simulation of casting is virtual process so there is no scrap material and other wastages. Casting through virtual trials eliminates the wastage of production resources, and gives opportunity to foundry to take high order.

The most useful casting simulation programs available in India are AUTOCAST, MAGMA, ProCAST, Solidcast and Z-Cast. In the current work Z-Cast and Solidcast have been utilized for analysis and optimization.

The main inputs for the casting simulation process are:

- The geometry of the mould cavity (3D model of the casting, feeders, and gating channels).
- Thermo-physical properties (density, specific heat and thermal conductivity of the cast metal as well as the mould material, as a function of temperature).
- Boundary conditions (i.e. the metal mould heat transfer coefficient, for normal mould as well as feed aids including chills, insulation and exothermic materials).
- Process parameters (such as pouring rate, time and temperature) [2].

2. LITERATURE REVIEW

Casting simulation includes mould filling, solidification, grain structure, stresses and distortion. It requires solid models of product and tooling (parting, cores, mould layout, feeders, feed aids and gates), temperature-dependent properties of part and mould materials, and process parameters (pouring temperature, rate, etc.). The simulation results can be interpreted to predict casting defects such as shrinkage porosity, hard spots, blowholes, cold shuts, cracks and distortion. The inputs however, require considerable expertise and may not be easily available to product designers. Hence substantial work had been reported on casting simulation by using different casting simulation software's.

Prabhakara Rao et.al [3] have studied on the simulation of the mould filling solidification of casting of green sand ductile iron casting sand concluded that the use of casting simulation software like Procast can able to eliminate the defects like shrinkage, porosity etc. in the casting. It also improves yield of the casting, optimize the gating system design and the mould filling.

Shamasunder [4] has discussed the steps which is involved in simulation the possible sources of errors and care to be taken during the casting process simulation. According to him the designer needs to have full confidence in the casting simulation tool. This can come only by experience and usage of the tool to mimic effect of various process parameters. With the advances in technology and proper care in modeling, it is possible to simulate the defects generated during casting before the casting is practically produced. They presented different case studies using ADSTEFAN software.

Maria [5] have observed that the application of casting simulation has been most beneficial for avoiding shrinkage scrap, improving cast metal yield, optimize the gating system design, optimizing mould filling, and finding the thermal fatigue life in permanent molds. Several case studies demonstrate the benefit of using these tools under industrial conditions. Nowadays, the foundries that cover around 90% of the production of the cast machine components use casting simulation as an everyday tool like Procast. Simulation resulted in gating system and molding changes that significantly reduced the weight of the total casting. Maintaining casting quality, the yield has been substantially increased. Some experiments were carried out under foundry conditions to compare the results.

B.Ravi [6] has discussed on the basics of casting simulation. 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 costly shop-floor trials.

3. METHODOLOGY

Fig 1 shows a flowchart for the Methodology of Casting analysis and optimization, in which 3D CAD and simulation tools are utilized to improve the system design of the casting.

The drawing provided by the customer is converted into a CAD model using CAD software. The analysis is then carried out and the defects like shrinkage, porosity etc are noted. The redesign and optimization of the gating system is then taken up based on the optimization results. The CAD model is redesigned and simulated. The analysis results are compared with previous results and the defects are checked. If the defects are reduced or are found to be in the gating system rather than casting body, the optimization results are accepted as successful and the new design is finalized. This step usually takes much iteration in practice. The finalized design is then sent for production.

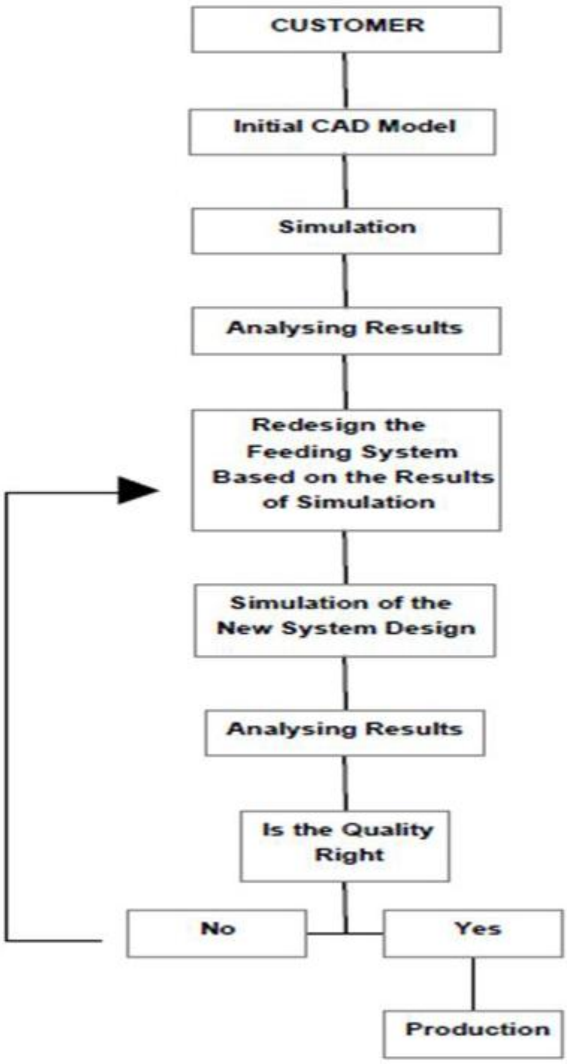

Fig 1: Methodology of Casting analysis and optimization

4. THE INVESTMENT CASTING MODELS

The globe valve body is an important component that cannot be made using sand casting process. This part (shown in Fig 2) has been taken for the work and will be made using Investment Casting (IC) process. The CAD model has been made in the modeling package CATIA V5 R16. The part drawing has been provided by the local industry which is making the actual model (in wax) using investment casting process. The industry has been facing shrinkage ad low yield problems in their casting. In this paper, the work done to analyze and optimize the casting has been discussed in the following pages.

IJETMAS

www.ijetmas.com May 2015, Volume 3 Special Issue, ISSN 2349-4476

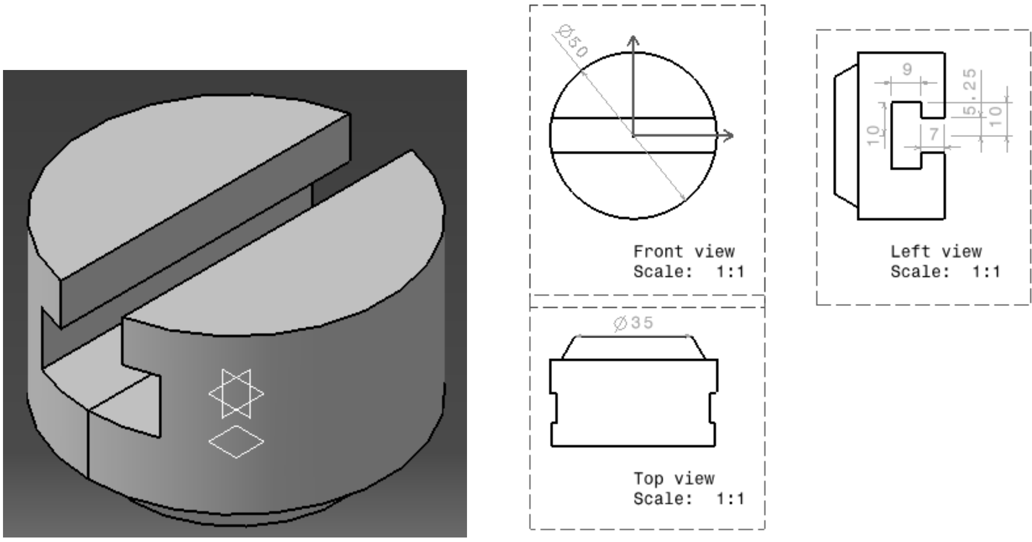

Fig 2: CAD and drafted model of Globe valve body

5. EXISTING DESIGN OF IC MODEL OF GLOBE VALVE

The CAD model has been made in the modeling package CATIA V5 R16. The design of gates, Sprue etc has been made in consultation with the industry. This is an initial design and will be modified if shrinkages are found in the casting during analysis in Solidcast software. Currently the gates are rectangular in cross-section. The Sprue is 40mmX40mm in cross section. The cup has a 60mm lower diameter and 75 mm upper diameter with a height of 50mm. The distance between the Sprue and casting is 40mm. The ingates are suitably designed to fit onto the Sprue and casting. The existing IC design has been shown in Fig 3.

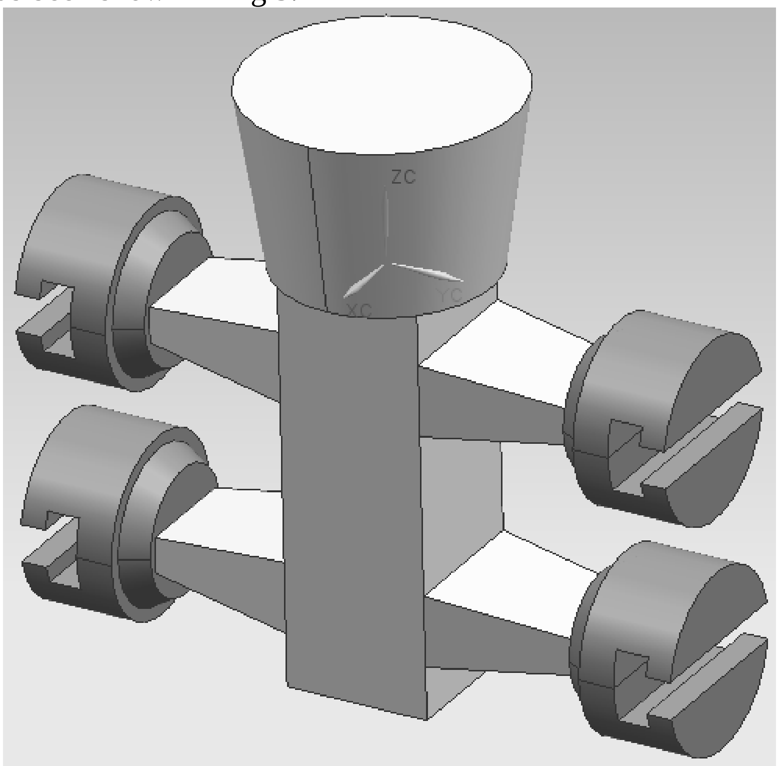

Fig 3. Existing IC model of globe valve

The IC model for the globe valve shown above is complete with cup, Sprue and gates. Some of the data gathered from the industry for analysis purpose are as follows:

1. Material grade with chemical composition
   Mild steel. Composition- C: 0.25% Si: 0.6% Mn: 1.2% Ph & S: 0.04%
2. Weight of casting and total liquid metal
   Density = $7.85X10^{-6}$ kg/mm^3, Weight of casting = 0.369 kg,
   Weight of total liquid metal (with rectangular ingates) = 5 kg
3. Tapping/pouring temperature
   Tapping: 1660 ^{0}C Pouring: 1630-1640 ^{0}C
4. Type of moulding sand used:
   Primary coating: Zircon sand / Zircon flour / Colloidal silica
   Backup coating: Molochite sand / Molochite powder / Colloidal silica
   Mold temperature: 800 ^{0}C during pouring
5. Number of cavities: 4
6. Pouring time: 15 to 30 seconds

A basic casting analysis followed by a flow analysis has been carried out on the IC model taking into consideration the above mentioned data. The results of the analysis have been discussed here on.

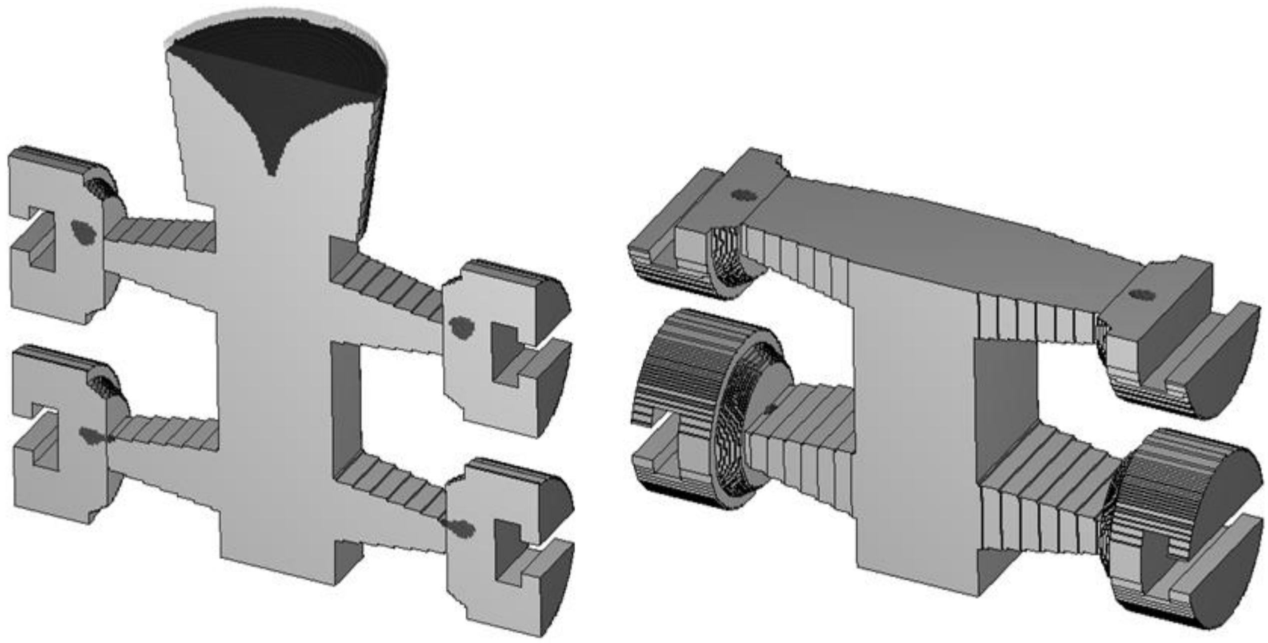

Fig 4. Shrinkage observed in casting cross section at 100% solidification

The Niyama Criterion

The Niyama Criterion is a function based on Temperature Gradient and Cooling Rate. The criterion was developed by Dr. Niyama, a Japanese researcher studying shrinkage prediction in steel. Niyama found that the Temperature Gradient divided by the square root of the Cooling Rate corresponded to the presence of shrinkage porosity in steel castings. The lower the value, the higher the probability of shrinkage. If this number were 1 or above there will be little or no shrinkage porosity in the castings. Niyama has been used extensively for shrinkage prediction in castings, until the use of more advanced calculations such as the Material Density Function.

The Niyama Criterion has been extended to alloys other than steel. Niyama is basically a prediction of directional solidification. Poor directional solidification is represented by a value of 0, good directional solidification by higher values.

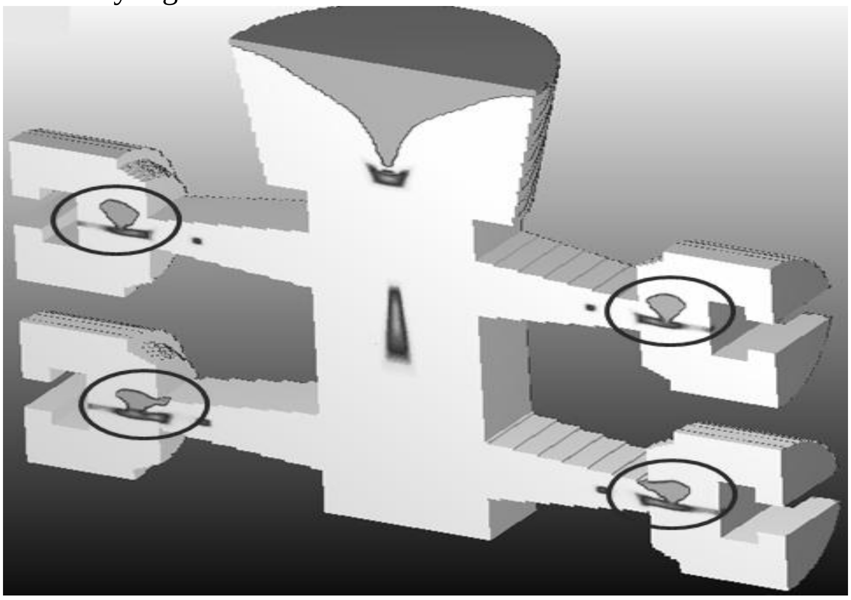

Fig 5. Micro Shrinkage observed in casting cross section as per Niyama criteria

The Fig 4 shows a clear shrinkage problem in the castings which is as claimed by the industry. This is further strengthened by the presence of micro shrinkage in the casting as per the Niyama criteria shown in Fig 5.

The yield is calculated to be around 30% with the existing design of gates & Sprue. Hence this design needs to be modified to eliminate the shrinkage and also to increase the yield. The discussion in the next section highlights the optimization and redesign of IC model.

5. OPTIMIZED DESIGN OF IC MODEL OF GLOBE VALVE

The optimized CAD model has been made in the modeling package CATIA V5 R16. The Sprue is 40mmX40mm in cross section. The cup is 60mm lower diameter and 75 mm upper diameter with a height of 50mm.

The gating design has been changed from rectangular cross section to circular cross section. The diameter of ingate at Sprue is 40mm and diameter of ingate at casting is 30mm. The distance between the Sprue and casting is 40mm. The optimized IC model has been shown in Fig 6.

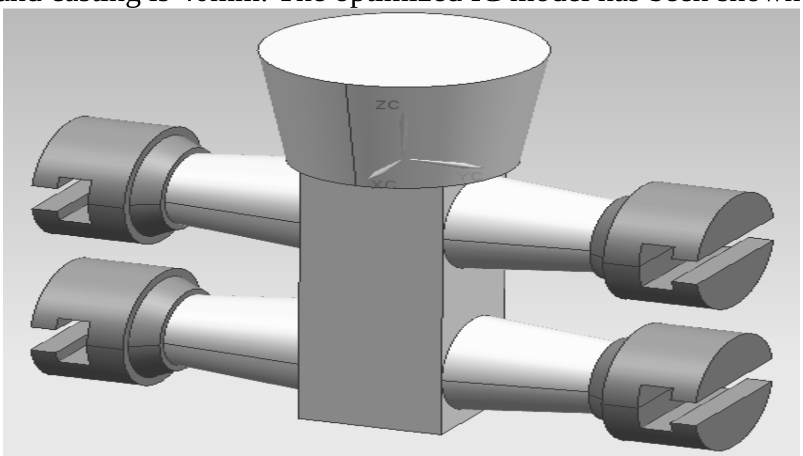

Fig 6. Optimized IC model of globe valve

The IC model for the globe valve shown above is complete with cup, Sprue and gates. The data gathered from the industry for analysis purpose is same as given in the previous section. However due to the circular cross section of the ingates in the new design, the weight of total liquid metal (with circular ingates) is 5.549 kg.

A basic casting analysis and later a flow analysis have been carried out on the IC model. The results of the analysis have been discussed here on.

The Fig 7 shows absolutely no shrinkage defect in the castings. Further the presence of micro shrinkage happens to be in the Sprue and not in the casting, as per Niyama criteria shown in Fig 8.

The yield is calculated to be around 27% with the new design of circular gates. This design is good as it eliminates the shrinkage defect. However the yield needs to be improved. The discussion in section 6 highlights the further optimization and redesign of IC model.

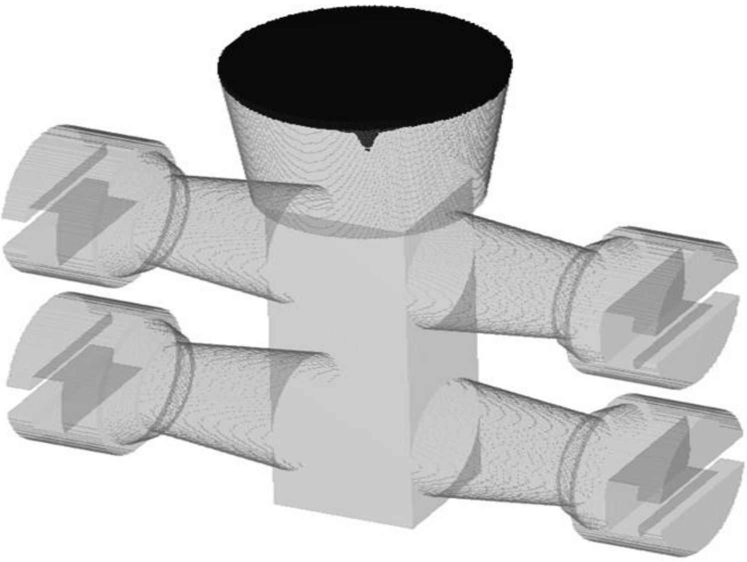

Fig 7. No Shrinkage observed in casting at 100% solidification

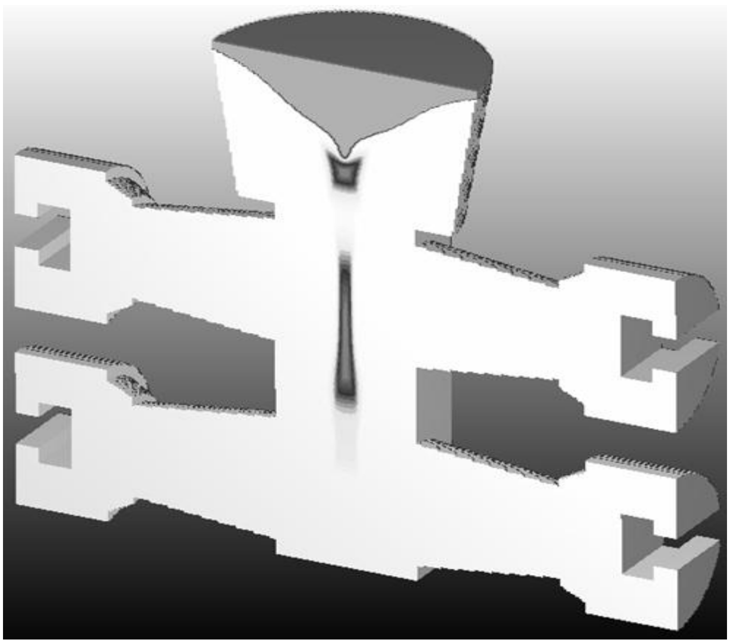

Fig 8. No Micro Shrinkage observed in casting cross section as per Niyama criteria

6. ANOTHER OPTIMIZED DESIGN OF IC MODEL OF GLOBE VALVE

The optimized CAD model has been made in the modeling package CATIA V5 R16. The gating design has been retained as circular in cross section.

However the Sprue has been redesigned to 40mmX30mm in cross section. The cup has also been redesigned to 50mm lower diameter and 65 mm upper diameter with a height of 40mm. The ingates design has not been changed and they fit onto the Sprue and casting.

A basic casting analysis and later a flow analysis have been carried out on the IC model. The results of the analysis have been discussed here on.

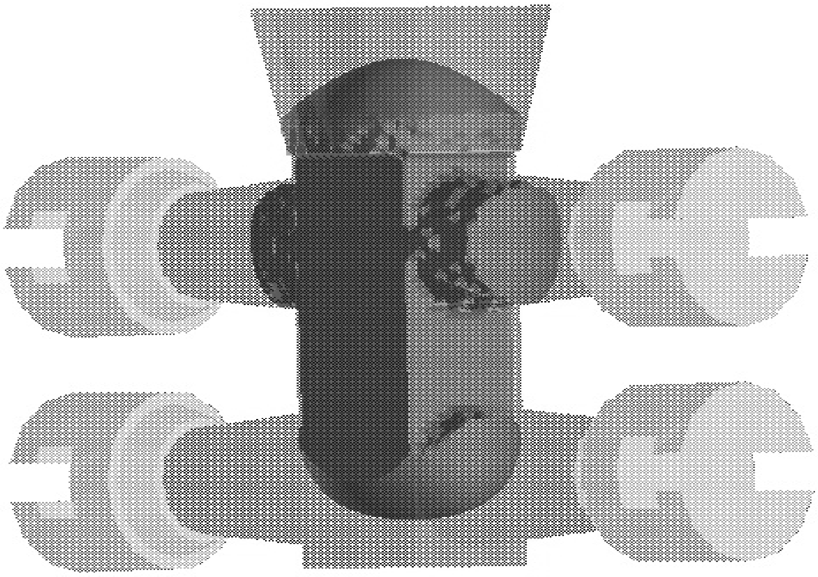

Fig 9. No Shrinkage observed in casting at 100% solidification

The Fig 9 shows absolutely no shrinkage defect in the castings. The yield is calculated to be around 32% with the new and optimized design using circular gates and Sprue. This design is good as it eliminates the shrinkage defect and provides a higher yield.

CONCLUSIONS

Casting simulation technology has become a powerful tool for casting defect analysis, prediction and method optimization. It has reduced the lead time for the sample casting and improved productivity. It helps in storing knowledge and results of software's for future use and also for training new engineers in the field of casting analysis. In the casting design process, the shrinkage defect predominantly occurs in most of the part. In practice, these defects are eliminated by iteratively designing gating system through experience and experiments, but it requires large number of shop floor trials, consuming huge amount of resources and time. This can be avoided by conducting trials on computer using casting simulation in order to reduce defects, increase productivity and yield. However in the current work the shrinkage in the casting has been removed and the subsequent iterations in the design have resulted in an increase in yield. This is acceptable by the company as the improved quality of the casting and increased yield is beneficial to them.

ACKNOWLEDGEMENT

We profoundly thank Prakash Iron Works for providing the drawings and details about investment casting parts. We also thank the Management, KLS Gogte Institute of Technology for providing the funds and infrastructure to setup Computer Integrated Manufacturing lab used in conducting the work.

REFERENCES

[1].B. Ravi, "Casting Simulation and Optimization: Benefits, Bottlenecks, and Best Practices", Indian foundry journal, 2008.

[2]. B. Ravi, "Casting simulation- best practices", 58th IFC, pp 19-29, 2010.

[3]. P. Prabhakara Rao, G.Chakaraverthi, "Application of casting simulation", International journal of thermal technologies, Vol.1,No.1, 2011.

[4].Shamasunder S., "To believe or not to believe Results of casting simulation software," ALUCAST, pp. 62-67, 2012.

[5]. Maria Jos Marques, "CAE techniques for Casting optimization", INEGI, pp 4465- 4591, 2006.

[6]. B.Ravi, "Casting simulation & optimization, benefits, bottlenecks & best practices".