Finest Design of Feeders for LM06 in Sand Casting: Comparative Study for Small Size Dumbbell Casting Through Software & Experiment Work

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Abstract
In the casting technology, defect free casting had been the primary goal since the inception of the technology. However in the present casting ground, emphasis on the exact and defect free casting has got greatly improved due to energy saving, environmental and economy considerations apart from the stringent product quality standard requirements. In order to achieve this level, computer simulation is certainly needed. FEM based simulation software is used to find solidification related defects specially shrinkage porosity very precisely. In the present work ANSYS, an FEM based versatile software has been used for hot spots identification in LM 06 dumbbells of different volumes in sand casting. The feeders have been designed and optimized by ANSYS 12.0 design optimizer tool & experiment. ANSYS has been used for transient thermal analysis and then optimization process has been performed. Path of two feeder optimization for sand casting on ANSYS have been investigated. Conductive and convective heat transfer has been taken in to concern. The whole process is performed using traditional modulus approach also. The results are compared with experimental out comes. The comparison reveals that ANSYS optimizer provides enhanced results for casting having two feeders. It saves material and energy thus resulting into economy and environmental benefits. The effect of increase of cast volume over feeder yield has also examined.

Keywords - *Sand Casting, LM06, Shrinkage porosity, Feeder design optimization, FEM Analysis with ANSYS.*

I. INTRODUCTION

Sand casting is the most extensively used process of manufacturing for both ferrous and non – ferrous metals, and accounts for approximately 90% of all castings produced [1]. In sand casting, sand mixed with binders and water is compacted around wood or metal pattern halves to produce a mould. The mould is removed from the pattern, assembled with cores and metal is poured in to the resultant cavities. After cooling, moulds are broken to remove the casting. After casting is removed from the sand moulds, sand mould is destroyed [2]. This leads to not only the loss of material but also to the loss of energy required for molding and remolding the material again and again. In fact the repeated molding-remolding consumes huge amount of fuel ultimately contributing to the global warming which is the greatest havoc for modern civilization. Hence the optimal design of feeder system must be seen not only from the material saving point of view, it must simultaneously be pursued from the environmental considerations too [16]. The modern casting processes not only require high precision and accuracy, they require energy efficiency and environmental consistency too. The present work is a determined step in this direction.

In sand casting, molten liquid metal is poured into a cavity which takes the negative shape of the object and the mould is made from sands. Heat removal is by heat transfer in sand mould, the governing equations for heat transfer are [3].

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial^2 x} \quad (1)$$

$$T(x,0) = T_0 \quad (2)$$

$$T(0,t) = T_M \text{ (Temperature at metal end)} \quad (3)$$

$$T(\infty,t) = T_0 \quad (4)$$

Finite Element Method (FEM) is an influential computational tool that is used to numerically solve many engineering problems. Most of the research on the area of casting processes modeling uses FEM as a solver to the casting process model. The numerical simulation of solidification process using either Finite Difference or Finite Element Methods (FDM/FEM) involves the following steps: [4]

1. Formulating an accurate mathematical model of the solidification process.
2. Specifying accurate values for thermal properties of material involved.
3. Performing the analysis to obtain the temperature history of casting and mould points.
4. Post – processing the results to visualize the solidification pattern and identify defects.

Feeders are designed to compensate the solidification shrinkage of a casting, and make it free of shrinkage porosity. Feeder design parameters include the number, location, shape and dimensions of feeder. Feed path and feeding distance influence the location and number of feeders. The volume of the feeders must be minimized to increase the yield. The criterion is given by for getting feeder yield C_{F3}:

$$C_{F3}=N_c v_c/\left(N_c v_c + \Sigma_i v_{fi}\right) \qquad (5)$$

Finite element analysis based software ANSYS 12.0 has been used. Modal of casting is done in Pro E wild fire and cylindrical feeders have been created in ANSYS modeling. Element selection and material property feeding is done latter. Convective load have been considered after proper meshing. Proper boundary values of temperature have been provided and then transient thermal analyses have been performed. DB log file has been assigned to ANSYS optimizer and then design variable, state variable and objective functions have been provided [5]. They are height of feeder, maximum temperature difference of feeder and respective casting zone, inverse of feeder yield respectively with suitable allowances and factor of safety. First order optimization has been performed through ANSYS 12.0.

In FEM, the field variables are the temperatures at all nodal points that vary with time .Thermal properties like thermal conductivity, density, specific heat also vary with temperature and hence the problem becomes non – linear transient in nature Galerkin's weighted residual approach has been reported[7]. The advantage of using FEM is the ability to handle complex boundaries, the ease in implementing boundary condition. But this method requires much stab for formulation of problem, data preparation and need long processing time [8].

In general, FEM is preferred as it allows a wider choice of element shapes and better accuracy, while FDM based simulation programs are faster and easier to execute. Recent advances have been in the areas of automatic preprocessing (mesh generation), adaptive re-meshing for better accuracy in critical regions, heat transfer models for considering the effect of variable air gap and mould coatings, convective and radiation heat transfer and improving the efficiency of computation[9]. Feeder optimization has been performed using topology optimization [10], poison equation approximation [11] and genetic algorithm [12].

P. Prabhakara Rao gives advantages of computer simulation based design enumerated. The procedures thus described have been demonstrated with the above case study of application of Pro CAST simulation at G.S. alloy Foundry. It is demonstrated that the foundries can derive mileage by resorting to FEM simulations of the casting process for process development and optimization. [13]

The application of casting simulation software in the foundries not only minimizes the wastages of resources required for final castings, but also improves / enhances the quality and yield of castings, which implies higher value addition and lower production cost. The experimental study represents the effect of sizes of risers and necks on the solidification behavior of the aluminum alloy castings. The simulated results are more or less similar with experimental results. [14]

The application of computer aided method, solid modeling, and casting simulation technologies in foundries can able to minimize the bottlenecks and non value added time in casting development, as it reduces the number of experiment casting required on the shop floor. In addition, the optimization of riser neck reduces or completely removes the incidence of shrinkage defect in the casting. The application of casting simulation software based on finite element method and vector element method shows good results and matched with the experimental results. [15]

II. DATA COLLECTION

Multi feeder optimization has been performed on a dumbbell casting of Aluminium-06. Two feeders have been considered. The calculated volume of dumbbell casting = 10.87×10^{-06} m^3, Surface Area of dumbbell casting = 12.98×10^{-2} m^2 through Pro-E wildfire 3.0.

Feeders can be optimized by modulus approach. The thickest section has highest value of modulus [1]. The optimization can be performed on ANSYS12. [5]

III. FEEDER OPTIMIZATION

The use of negative of the gradient vector as a direction for minimization was first made by Cauchy in 1847. In this method we start from initial trial point X1 and iteratively move towards the optimum point.[4]

The method of steepest descent may appear to be the best unconstrained minimization technique since each one-dimensional search starts in the best direction. Design optimization works entirely with the ANSYS Parametric Design Language (APDL) and is contained within its own module. Design optimization is largely concerned with controlling user-defined, APDL functions/parameters that are to be constrained or minimized using standard optimization methods (e.g., function minimization, gradients, design of experiments).The independent variables in an optimization analysis are the design variables. [4], [6]

IV. OPTIMIZATION OF DUMBBELL CASTING WITH SOFTWARE APPROACH AND EXPERIMENTAL INVESTIGATIONS

For preventing shrinkage porosity defect, two over size cylindrical feeders are designed for checking in ANSYS 12.0 design optimization tool for dumbbell casting of LM06. The optimized feeder design has been checked on shop floor sand casting experiment.

The process of analysis of this case with Design optimizer of ANSYS 12.0 (An FEM Based general purpose software) has been search out for two feeders. Here we have taken height of feeders as a design variables, State variable S1 = FT1-CT1 (always positive), State variable S2 = FT2-CT2 (always positive) with suitable allowances and factor of safety so that hot spot must not remain in casted part because hot spot leads to shrinkage porosity defect. It must be in respective feeder. FT denotes maximum feeder temperature for respective zone; CT denotes maximum casting temperature of catchment area. Following are the graphs as a result of feeder design optimization process with first order optimization. Figure1 is showing the temperature according to cooling. It can be seen that higher temperature are with feeders as compare to casing. This assures that the shrinkage porosity will be in feeders only. The values in temperature scale in degree Celsius.

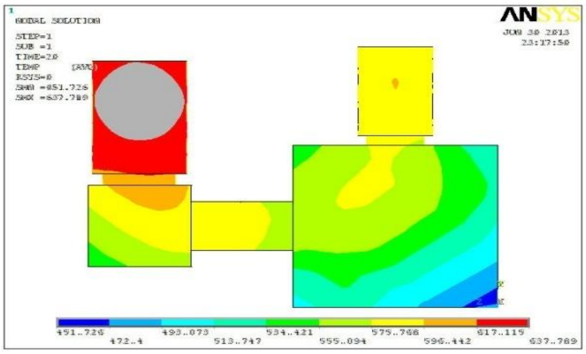

Figure 1: At Centre Plane of Dumbbell Shape Casting With Optimized Feeders

With the help of graph in figure 2, it is clear that during the design optimization process the maximum temperature of feeder number 01 remain higher than the corresponding casting catchment area. The X-axis is showing the number of iteration and the Y-axis is showing the temperature in degree Celsius.

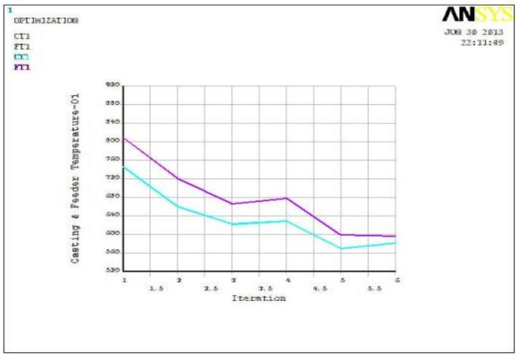

Figure 2: Feeder 01 Temperature Remained Higher than Corresponding Casting Zone 01 Temperature During Entire Optimization Process.

With the help of graph in figure 3, it is clear that during the design optimization process the maximum temperature of feeder number 02 remain higher than the corresponding casting catchment area. The X-axis is showing the number of iteration and the Y-axis is showing the temperature in degree Celsius.

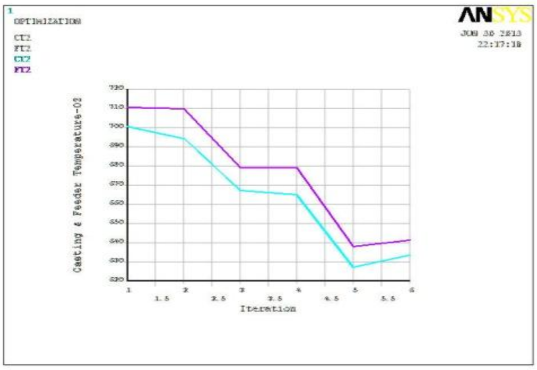

Figure 3: Feeder 02 Temperatures Remained Higher Than Corresponding Casting Zone 02 Temperatures During Entire Optimization Process.

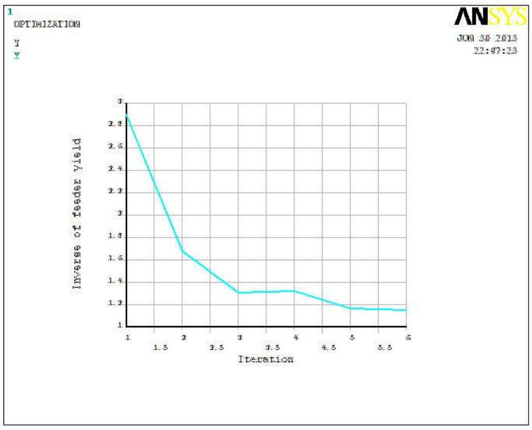

Figure 4: The inverse of Feeder Yield Decreasing with Respect to Number of Iteration.

The feeder yield= (Total Casting volume/ (Total casting volume + Total feeder volume)) which should be highest because feeders are not the part of casting. They have to re-melt after removal from casting cause time and fuel requirement ultimately leads to increased process cost.

The figure 4 is showing the graph of inverse of feeder yield during the optimization process. The feeder yield comes out with the help of ANSYS12 design optimizer is **86.88 %.**
The dumbbell designed by ANSYS 12 has been checked by experiment in foundry shop.

Figure 5: The Pouring Process of LM06 in the Dumbbell Casting Process with Suggested Cylindrical Feeders.

The figure 5 is showing the pouring of LM06 molten metal in the Dumbbell casting process with suggested cylindrical feeders by ANSYS 12 design optimization tool.

Figure 6: The Shrinkage Porosity Defect in the Feeder after Cutting it with Center Plane.

The figure 6 is showing that the shrinkage porosity defect is in the feeder which prove that the result of ANSYS 12 are true and could be used at practical level.

V. CONCLUSION

Feeder yield obtained comes out by ANSYS 12 design optimizer is equal to = **86.88 %.** The same design of feeders 1 & 2 has been used for experimental check which is clearly showing that the shrinkage porosity defect will be in the applied feeders and casting will remain defect free. So net advantage gained by ANSYS 12.0 design optimizer over modulus approach can be taken in use.

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