Prediction of Shrinkage Porosity Defect in Sand Casting Process of LM25

Abstract: In the present worldwide and aggressive environment, foundry commercial enterprises need to perform productively with least number of rejections and create casting parts in shortest lead time. It has become extremely difficult for foundry industries to meet demands of defects free casting and meet strict delivery schedules. The process of casting solidification is complex in nature. Prediction of shrinkage defect in metal casting is one of the critical concern in foundries and is one of the potential research areas in casting. Due to increasing pressure to improve quality and to reduce cost, it is very essential to upgrade the level of current methodology used in foundries. In the present research work, prediction methodology of shrinkage porosity defect in sand casting process of LM25 using experimentation and ANSYS is proposed. The objectives successfully achieved are prediction of shrinkage porosity distribution in Al-Si casting and determining effectiveness of investigated function for predicting shrinkage porosity by correlating results of simulating studies to those obtained experimentally. The real-time application of the research reflects from the fact that experimentation is performed on 9 different Y junctions at foundry industry and practical data obtained from experimentation are used for simulation.

Keywords: LM25, porosity, sand casting, shrinkage

1. INTRODUCTION
Casting defects result in increased unit cost and lower morale of shop floor personnel. Casting defects can be classified as:

(i) Misruns (due to rapid solidification in the runner),
(ii) Cold shuts (due to rapid solidification before complete filling of the mold),
(iii) Blow holes (due to gaseous entrapments),
(iv) Shrinkage cavity (due to lack of riser system),
(v) Micro-porosity (due to localized solidification shrinkage),
(vi) Hot tearing (due to the delayed cooling contraction).

Porosity in aluminum alloys is a well-known defect, which can cause cosmetic problems and
reduce the ductility and fatigue performance of cast parts. Porosity can be categorized by either its formation mechanism as hydrogen and shrinkage induced or by its size as macro porosity and micro-porosity. Macro-porosity refers to pores with a diameter in the millimeter to centimeter scale. The other category micro porosity refers to porosity in castings that is relatively small in scale, with a radius less than 500 µm. Micro porosity in Al-Si casting is one of the most unfavorable defects responsible for high scrap loss in the production of commercial castings and severely prevents their widespread use in many critical load-bearing conditions. The damaging effects of micro porosity are lack of pressure tightness, limited strength, variable fracture toughness and notable reduction in ductility as well as lower fatigue resistance.

Prediction of micro porosity amounts in casting is significant from practical and scientific point of view. The formation of micro porosity during solidification is a very complicated process, involving heat, mass and fluid flow. It has been basically accepted that micro porosity in cast aluminum silicon alloys is a result of two main factors: hydrogen rejection due to a drastic reduction in the solubility from liquid to solid phase, and/or the volume contraction coupled with poor inter dendritic feeding during mushy zone solidification. Enormous experimental research from various renowned authors reveal the fact that solidification conditions have a strong impact on porosity formation. Therefore, it is believed that some thermal parameters (e.g. thermal gradient (G), cooling rate (R), solidification time, and solidification velocity (Vs)) or their combinations may be used for determining the porosity level in castings. These thermal parameters or their combinations are termed criteria function. By a series of theoretical and mathematical analysis of experimental data, the percent porosity can be calculated directly from the derived equation. Since the solidification parameters can be simulated by computer modeling, the criteria function method seems to be a practical way for casting producers to predict an appropriate solidification condition necessary to control porosity under a required critical level.

2. LITERATURE REVIEW

In the investigation of simulation and experimental results of thermal analysis in sand casting process, a simulation model of 2-ingate mould and 3-ingate mould of sand casting was developed, references were taken as the concentration on chosen nodes and the change of temperature in the casting sand with time was monitored. In the thermal analysis results, the experimental temperature curves were found generally higher than modeling for mould because of the trapped air and porosity of the sand mould [1].

It was outlined that copper chills have the greater cooling effect, ranging from 4 to 8 kW/m²K depending on the size; aluminum chills range from 3 to 6 kW/m²K, gray cast iron ones range from 1 to 2 kW/m² K, while studying the investigation on the heat transfer coefficient (HTC) during sand casting of A356 aluminum alloy, presented by reconstructing the whole cooling process with many kinds of chills, different in size and materials [2].

The amount and size of the porosity in a solidified casting was predicted by computation of the micro-/macro-scale gas species transport in the melt, coupled with simulation of the feeding flow and calculation of the pressure field. The comparisons with previous experimental measurements conclusively showed that pore growth can indeed be limited by finite-rate diffusion of hydrogen [3].
Experiments under unidirectional solidification in a device cooled with water, and Zn-1%Al and Zn-2%Al (wt%) alloys were solidified in a vertical upward (0º), inclined at 30º and 45º to the vertical and horizontally upward (90º to the vertical) were performed. The position of the transition from columnar-to-equiaxed structure (CET) through macro- and micro analysis and significant thermal parameters by recording temperature-time data were determined. The length of the columnar zone is larger in the case of the samples solidified at 0º respect to the vertical axis than in the tilted samples for approximately the same cooling rate. Minimal and critical gradients and recoalescence or thermal arrest were observed in the transition zone. The angle of inclination of the columnar grains and dendrites with the longitudinal axis of the alloy sample coincides approximately with the angle of inclination of the furnace. In the three directions (0º, 30º and 45º), the micro porosity due to shrinkage during solidification of the samples occurred at approximately the same position [4].

The application of two equivalent pore size definitions (i.e. maximum Ferret diameter and (Area)1/2) were combined with the EVS approach in terms of predicted critical pore sizes and fatigue strengths were observed. X-ray computed tomography and the finite element method were used to investigate the stress concentration. The result reflected that the estimated critical pore sizes of four casts AlSi7Mg according to the largest ferret diameter parameter showed a better correlation with the experimental long life fatigue strengths than the (Area)1/2 parameter. It is confirmed that metallographic and the EVS approach combine into a reliable quality inspection technique are suitable for the industrial environment [5].

The sand and method related defects in green sand casting were analyzed by combination of design of experiments and computer assisted casting simulation techniques. Taguchi method based L18 orthogonal array was used for the experimental purpose and Minitab software was used for analysis of variance (ANOVA) and analysis of mean (AOM) plot. ANOVA results showed that the selected process parameters significantly affect the casting defects and rejection percentage. For shrinkage porosity analysis, use of casting simulation technique by introduction of a new gating system was designed and solid model was developed for four cavities mould. Number of iterations using casting simulation software was performed for mould filling and solidification analysis to reduce the level and intensities of shrinkage porosities in cast component. The result of Taguchi optimization method showed that the % rejection of castings due to sand related defects is reduced from 10 % to a maximum up to 3.59 % [6].

The effect of mild steel chills on steel casting in sand mould to minimize shrinkage defects was investigated, in which chill distance, chill thickness, pouring temperature and pouring time parameters were considered to minimize the shrinkage defects using Taguchi L16 orthogonal array design matrix for experiments. The staistical analysis tool showed that chill thickness has contribution of 92.68% in formation of shrinkage cavity [7].

The shrinkage porosity defect of a component leading to premature failure was studied and an attempt was carried out for entire methoding, simulation and optimization in Auto CAST X software which is based on Vector Gradient Method (VGM). All parameters were set properly in Auto CAST X software to shift the shrinkage porosity to the feeder. It was observed that solidification simulation enables visualization of the progress of freezing inside a casting and identification of the last freezing regions or hot spots. Auto CAST-X software placed feeder at last solidifying region. The study showed that simulation can be of great use in optimizing the feeder dimensions and increasing the feeding efficiency of the casting. Both macro porosity and micro-porosity were identified as 4.47 cm$^3$ with 100% quality [8].
An attempt was made to redesign and develop a casting free from shrinkage defect. Methoding and simulation of the component under study was subjected to high amount of shrinkage defects, which is the major cause for the rejection in the foundry. It is also having very low yield of 45% as per the foundry information. Understanding of the casting phenomena to identify the location and extent of internal defects, ensuring defect-free casting was provided by the computer simulation, which is based on Gradient Vector Method (GVM) and computes temperature gradients (feed metal paths) inside the casting and follows them in reverse manner to identify the location and extent of shrinkage porosity. This method is much faster than finite element or finite volume method and also more accurate [9].

The filling process and solidification of Al based alloy linkage by suction casting by numerical simulation was studied and the shrinkage defect was predicted using FEM software ProCAST. This simulation analysis indicated that by increasing graphite suction diameter, the pouring temperature is conducive to cold traps and reduce water shortage defects. The reduced heat transfer coefficient can result in good quality castings [10].

3. SET UP FOR EXPERIMENTATION ON LM 25

A casting junction is an abrupt increase in local thickness caused by meeting of two or more elements (walls) resulting in regions of high thermal concentration. Molten metal at the junction cools slowly, leading to shrinkage porosity defects. The size and extent of defect region depends on the thickness and number of elements, and the angle between them, all of which affect the rate of heat transfer from the casting. Chemical composition of LM 25 and nomenclatures of 9 different Y junctions used for experimentation are shown in Table I and Table II respectively.

For experimentation, LM25 is heated at 750°C, poured at three different temperatures under gravity and patterns are made from wood. Silica sand moulds are prepared using sand mix with a composition of 8% calcium based bentonite, 4% moisture (approx.) and 2% saw dust and coal powder are added. LM25 aluminum alloys are melted and as taken out as soon as the molten metal reaches a temperature of 750°C. The presence of oxides and coal ash in the surface of the molten metal are skimmed. Then the molten metal is poured into the mould cavity at a temperature of 750°C. Fig. 1 shows actual foundry set up used for experimentation. Size of moulding box used is 330 mm × 330 mm, pouring temperature used is 700°C, 725°C, 750°C. 9 different cavities are prepared with no feeder.

Table I. Chemical Composition of LM 25

| Sr. No. | Element | Weight (%) |
|---------|---------|------------|
| 1       | Copper  | 0.1 max    |
| 2       | Magnesium | 0.20-0.60 |
| 3       | Silicon  | 6.5-7.5    |
| 4       | Iron     | 0.5 max    |
| 5       | Manganese| 0.3 max    |
| 6       | Nickel   | 0.1 max    |
| 7       | Zinc     | 0.1 max    |
| 8       | Lead     | 0.1 max    |
| 9       | Tin      | 0.05 max   |
| 10      | Titanium | 0.2 max    |

Table II. Nomenclatures

| Nomenclature | Arm length (mm) | Angle (degree) | Width (mm) |
|--------------|-----------------|----------------|------------|
| Y-30-40-10   | 30              | 40             | 10         |
| Y-30-50-15   | 30              | 50             | 15         |
| Y-30-60-20   | 30              | 60             | 20         |
| Y-45-40-15   | 45              | 40             | 15         |
| Y-45-50-20   | 45              | 50             | 20         |
| Y-45-60-10   | 45              | 60             | 10         |
| Y-60-40-20   | 60              | 40             | 20         |
| Y-60-50-10   | 60              | 50             | 10         |
4. Prediction of Shrinkage Porosity Defect Sand Casting Process of LM25 Using ANSYS 15.0

Foundries explore different simulation software packages to reduce the need of trial and error experiments. However, there is always a difference in actual and predicted location of defects, especially for new materials, shapes and processes. The process of casting solidification is complex in nature and the simulation of such process is required in industries before parts are actually casted. In the present research work, shrinkage porosity defect is detected in sand casting process of LM25 using ANSYS 15.0. Data obtained from actual experimentation are used as input parameters for simulation as shown in Table III. Steady state thermal solution and transient thermal solution for Y-30-40-10 are shown in Fig. 2.

Table III. Input Parameters for Simulation

| Load condition | Reference Temperature | Initial condition of Metal (Pouring temperature) | Initial condition of sand | Load step | Time | Time step size |
|----------------|-----------------------|--------------------------------------------------|---------------------------|-----------|------|---------------|
|                | 300 K                 | 973/998/1023 K                                   | 300 K                     | 1         | 1000 | 1             |

Fig. 1. Experimental Set Up

(a). Wood Patterns  (b). Moulding Box  (c). Pouring of Metal
Fig. 2. Steady State Thermal Solution and Transient Thermal Solution for Part 1

5 CONCLUSION

It is reflected from experimental results that there are more chances of shrinkage porosity occurrence near the center of geometry for Y junction. It can also be observed that large amount of shrinkage porosity was formed near the center as found in simulation. However, the location of shrinkage porosity can vary according to geometric and thermal parameter change. In the present research work, ‘Y’ junction is used for prediction of shrinkage porosity, which may be extended for other junctions also.

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