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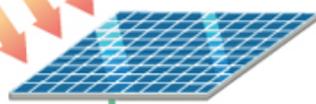
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It is a privilege to present this new edition of Element Magazine, a publication that reflects the strength, potential, and strategic direction of Pakistan's foundry industry. Today, our sector stands at a transformational point—where resilience meets innovation, and where the decisions we make today will define our industrial future for decades to come. Despite economic pressures and global challenges, Pakistan's foundry sector has demonstrated remarkable courage and capability. Our members have embraced new technologies, strengthened production efficiencies, and expanded their role in both local and international supply chains. This magazine captures these achievements and provides a roadmap for the opportunities ahead.

At PFA, our mission is clear: to modernize the foundry industry, promote technological excellence, and build partnerships that open new pathways for growth. We are committed to elevating our industry to global standards through training, knowledge exchange, and industry-driven initiatives that directly support our members.

I extend my sincere appreciation to the editorial team, contributors, and industry partners whose efforts have made this publication possible. Together, we will continue to push boundaries, unlock new opportunities, and strengthen Pakistan's position in the global industrial landscape.



## Sikandar Mustafa Khan

### President

Pakistan Foundry Association

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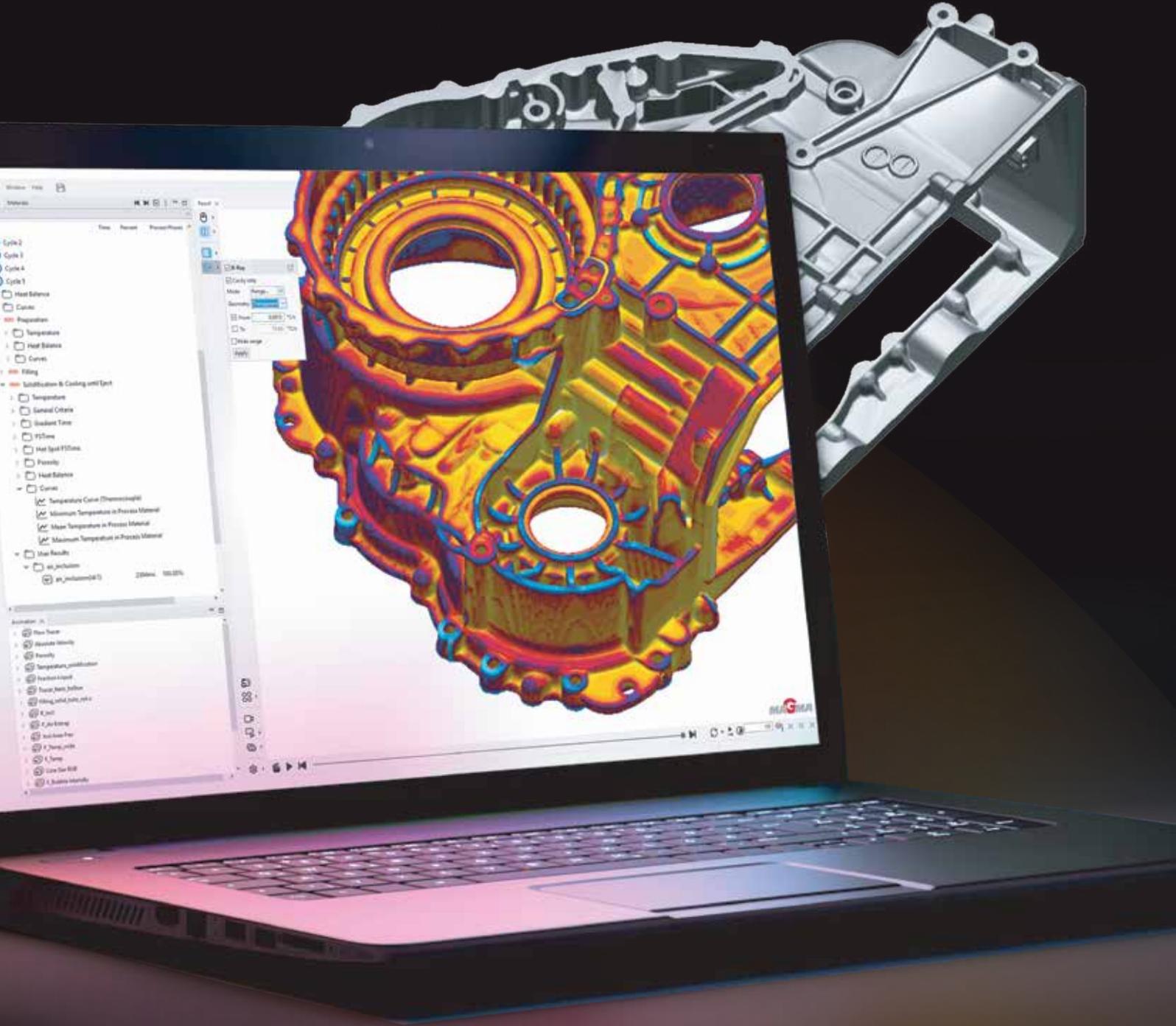
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# Efficiency of Solid Inclusion Removal from the Steel Melt by Ceramic Foam Filter: Design and Experimental Validation

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## Abstract

An investigation was performed to measure the efficiency of solid alumina inclusion removal by filtration during casting. A mold design was developed using modeling software to produce two castings that fill simultaneously, one with a filter and the other without a filter. The design avoided vortex formation and thus air entrainment, which helped to avoid reoxidation inside the mold cavity. Samples from these castings were analyzed utilizing an SEM/EDS system with automated feature analysis (AFA) to measure the efficiency of inclusion removal using a 20 ppi zirconia foam filter. This study also documents the occurrence of inclusion flotation and agglomeration in the ladle which, in turn, affects the removal efficiency of these inclusions by filtration in the mold.

**Keywords:** steel, non-metallic inclusions, ceramic filter, mathematical modeling

## Introduction

Non-metallic inclusions in steel can reduce mechanical properties, produce surface defects, affect machinability and increase scrap rate<sup>1</sup>. In foundry steelmaking, ceramic filters have been used to remove these inclusions for years. Several studies show that ceramic filters can effectively remove inclusions<sup>2-4</sup> from the steel melt. The melt flow rate inside the mold cavity influences the

inclusion removal by filtration. Higher flow rates<sup>4</sup> or melt velocities<sup>5</sup> through the filter lowers the inclusion removal efficiency ( $\eta$ ), which can be defined as:

$$\eta = \frac{C_i - C_o}{C_i} \quad \text{Eqn. 1}$$

where,  $C_i$  and  $C_o$  are the inclusion concentration in the steel melt at the inlet and at the outlet respectively. Filter geometry also plays an important role on inclusion removal. An increase in filter thickness<sup>6</sup> or aspect ratio<sup>7</sup> increases the inclusion removal efficiency due to an increased residence time in the filter. A direct comparison of filtered and unfiltered castings from the same heat having same inclusion content has not been studied extensively. The objective of the current study is to evaluate the effectiveness of solid alumina inclusions filtration from steel by comparing castings produced with and without a filter from the same heat. The study by Raiber et al.<sup>4</sup> has indicated that foam filters have a higher filtration efficiency compared to multi-hole filters and loop filters. Consequently, foam filters were selected for this study.

## Mathematical Modeling and Designing

A mathematical model was developed using computational fluid dynamics (CFD) simulations of fluid flow and heat transfer

during mold fill for a 316 stainless steel using MAGMA 5.3. The casting and rigging design is shown in Figure 1. Two modified Y-block castings are shown in vertically parted no-bake molds in Figure 1: one filtered (by a FOSECO STELEX ZR 10 ppi filter: 10 cm X 10 cm X 2.5 cm) and another unfiltered.

In the present CFD model, it has been found that a 25 ppi foam filter creates excessive resistance to liquid metal flow during mold fill and creates a risk of freezing during filling. For this reason, a 10 ppi foam filter was used to avoid excessive filling resistance and allow simultaneous filling of both the filtered and unfiltered castings. The size of the filter was selected to maximize the residence time in the filter, which increases the filtration efficiency. MgO stabilized zirconia foam filters were employed in our experiments, Figure 2, because they are chemically inert to molten steel.

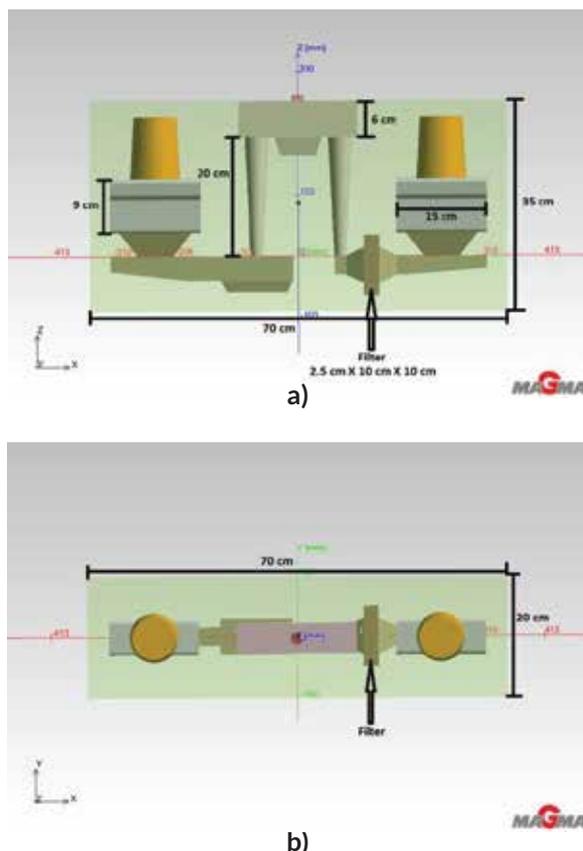


Figure 1. MAGMA 5.3 drawing of mold and rigging system: (a) front view and (b) top view

Both sides of the castings were designed to be filled by a common pouring cup so that the

physical properties and composition of liquid steel remain same for both the sides. By characterizing the samples from both these sides, a direct comparison can be made between the filtered and non-filtered castings and the effectiveness of the zirconia filter on inclusion removal can be determined. A dam is attached under the pouring cup to reduce the melt velocity and air entrapment. Bottom filling has been adopted to minimize the reoxidation of the melt.

The dimension of the mold is 70 cm x 20 cm x 35 cm. To minimize the back pressure during pouring two separate sprues are fed from a single pouring cup to fill the two castings simultaneously. Sprue diameters were also optimized to minimize air entrapment during mold filling. The dimensions of the sprues, gates, castings and risers from both sides are same, although the runners are different to adjust the liquid metal flow rate and ensure a simultaneous filling in the mold cavities for both sides. Hence, the gating ratios are different for both sides: 1:2:3.8 (with filter) and 1:2.6:3.8 (without filter). This design also minimizes vortex formation inside the mold. Filling velocity, time and temperature were predicted for this design using the mold filling and solidification software as shown in Figure 3. Solidification parameters were also evaluated by the software to ensure that the castings were sound.

The castings were predicted to be free of porosity.

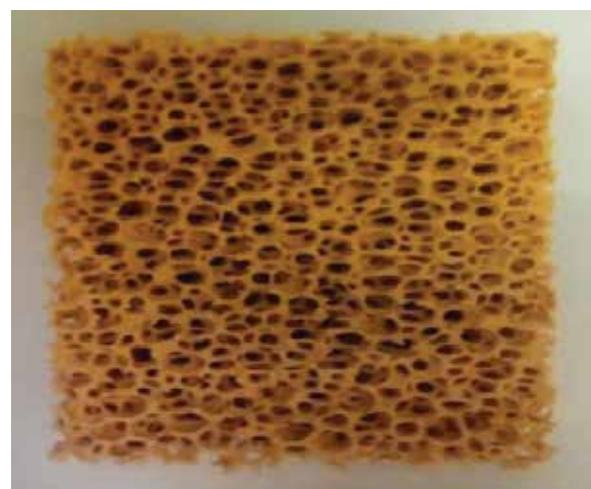


Figure 2. Zirconia foam filter: 10 ppi (10 cm X 10 cm X 2.5 cm).

Decreasing the velocity inside the mold cavity decreases the turbulence created by the liquid metal during filling which in turn decreases reoxidation of the melt. For steel, the recommended maximum velocity to minimize surface turbulence is less than 0.45 m/s.

For this mold design, the minimum filling time was found to be 9 s. Below this, a separation of metal stream was observed at the entrance of the castings. This type of discontinuity in the liquid can entrain air and create reoxidation inclusions. With this minimum pouring time, a moderate pouring rate of 2.9 kg/s was targeted for the mold.

The metal flow patterns during filling are different for the two different gating systems (with and without filter). The side without the filter initially showed a higher velocity as no filter was present to restrict the flow of the melt. To compensate for this, a sprue well was added to the side without the filter as shown in Figure 1. The metal entering the runner has a lower velocity than in the sprue. For most of the pouring time, the velocity in the runner is less than 0.4 m/s. At the gate, the liquid metal changes its direction and due to a sudden release in pressure, the velocity increases.

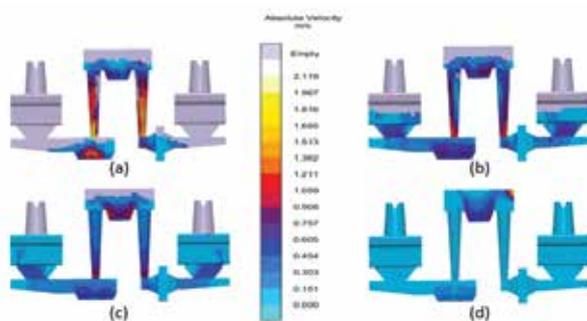


Figure 3. Absolute velocity of the steel melt at: (a) 25% (b) 50% (c) 75% and (d) 100% filling of mold.

The volume of the gate is small compared to the overall volume of the mold cavity. Therefore, the risk of air entrainment in gates is minimal. In the casting, the absolute velocity decreases and is less than 0.45 m/s at all times during the fill as shown in Figure 3. Tracer particle tracking in the filling and solidification software also demonstrates that minimal vortexing is generated in the mold during the filling.

The filling time for these two sides are designed to be the same to avoid any back pressure generation at one side of the mold during the filling and to ensure that steel from the ladle reaches both molds simultaneously. To match the filling times, the gating ratio on the side without the filter was adjusted to balance the fill times. As shown in Figure 4.(a), both the sides are filled at the same time. The pouring temperature was set to 1550°C and the temperature during filling has also been modeled as shown in Figure 4.(b). The minimum steel temperature predicted during filling is 1502°C which is higher than the liquidus temperature of 316 stainless, 1371-1399°C, depending on the specific composition of the steel.

Lowering the pouring rate or increasing the pouring time to greater than 9 s gives lower velocities inside the mold cavity. However, longer filling time can also cause air entrainment into the liquid metal stream during pouring, which would interfere with the experimental objectives. Slow filling can also create a temperature drop and premature solidification inside the mold cavity before completion of filling. This may result cold shuts or misruns. Therefore, for experimental studies these two opposing factors were always considered and in the current study the pouring time was maintained below 15 s, which shows a slower filling (than that of minimum pouring time) with lower filling velocities below the critical value of 0.45 m/s to avoid any premature solidification.

## Experimental Procedure

Three molds were prepared from a 3D-printed pattern as shown in Figure 5.(a). The patterns for the design were 3D-printed with acrylonitrile butadiene styrene ((C<sub>8</sub>H<sub>8</sub>·C<sub>4</sub>H<sub>6</sub>·C<sub>3</sub>H<sub>3</sub>N)<sub>n</sub>) polymer. All the parts were finish sanded with emery paper and glued into the mold box (Figure 5.(a)). Before molding, the mold box along with the 3D-printed parts are coated with a release agent, ZIP-SLIP® LP 78 and then allowed to dry for 24 hours.

To fit the risers into the mold cavity, cylindrical cores were added. Using these patterns, no-bake sand molds were constructed to carry out the experiments as shown in Figure 5.(b).

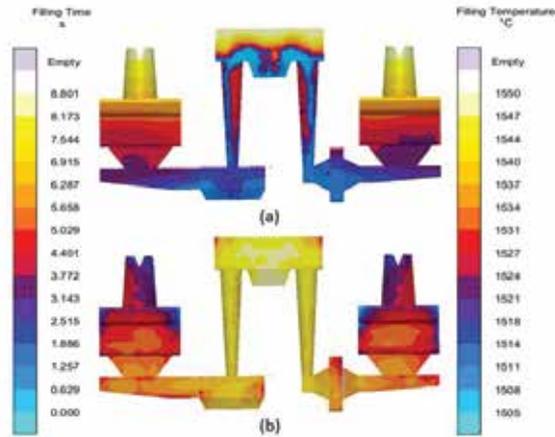


Figure 4. (a) Filling time and (b) filling temperature at the end of filling of the steel melt at different positions.

Steel heats were prepared in a 200 lbs coreless induction furnace under argon cover. Figure 6.(a) shows a photograph of the induction furnace and three vertically parted molds prior to casting. 176 lbs (80 kgs) of 316 stainless steel charge stock was induction melted under a continuous argon gas flow (15 SCFH). At 1548oC, a chemistry sample was taken. At 1644oC the steel melt was tapped into a preheated teapot-style ladle as shown in Figure 6.(b and c).

Because the objective of this study was to understand the efficiency of filtration of solid inclusions, aluminum was used as the deoxidizer (0.1wt% of the melt). The deoxidizer was submerged into the ladle with a steel rod and then vigorously stirred. After the addition of deoxidizer, another chemistry sample was taken from ladle before pouring. Finally, the molten metal was poured into three molds at 1554oC.

Inclusion floatation in the ladle during teeming was studied using three molds (Figure 6.(a)) that were filled from a single ladle. The metal from the inclusions in the resulting castings and gating systems, the extent of inclusion floatation and agglomeration in the ladle could be determined.

## Results

Castings from the three different mold sets were examined thoroughly and no blow-holes, pin-holes, surface cracks, misruns or cold shuts were found. Chemical analysis of the samples taken during experiments was carried out using optical emission arc spectroscopy and LECO combustion method (CS 600 and TC 500). The chemistries of the melt before and after deoxidation are shown in Tables 1 and 2, respectively. It can be observed that aluminum content in the ladle is increased by 0.1% due to the addition of deoxidizer in the melt.

To characterize the inclusion population of the castings, samples were taken from different position of the castings as shown in Figure 7. A scanning electron microscope, SEM, (ASPEX PICA 1020) with energy dispersive X-Ray spectroscopy, EDS, and automated feature analysis



(a)



(b)

Figure 5. (a) 3D-printed patterns in a wooden flask and (b) corresponding half of a vertically parted no-bake sand mold.

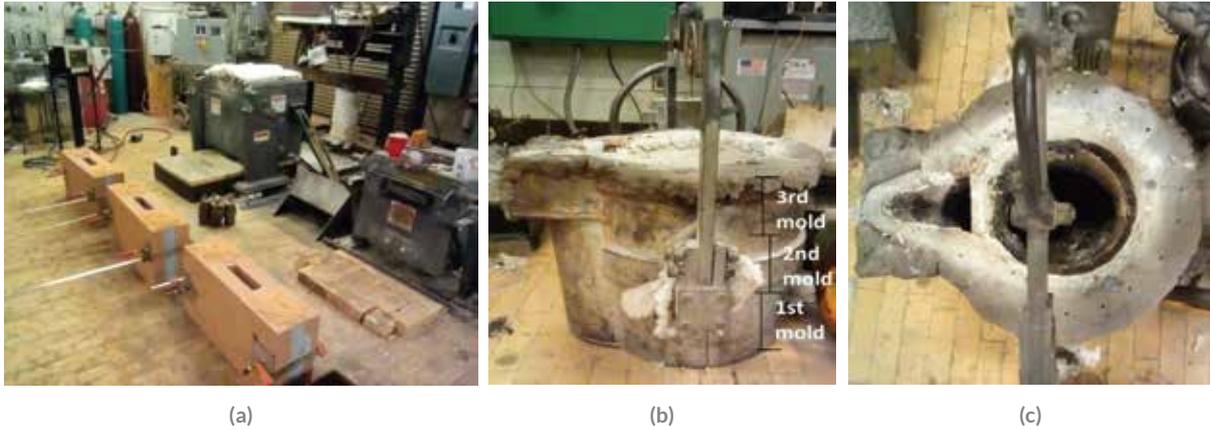


Figure 6. (a) Three mold sets, (b) 200 lbs teapot ladle (side view) and (c) 200 lbs teapot ladle (top view).

Table 1. Melt composition before 0.1 wt% Al addition (sample taken from furnace).

C	Si	Mn	Al	Cr	Ni	Mo	Cu	Ti	N	P	S	O
0.063	1.37	0.51	0.013	18.57	9.03	2.47	0.24	0.012	0.063	<0.0016	0.0039	0.0354

Table 2. Melt composition after 0.1 wt% Al addition (sample taken from ladle during pouring).

C	Si	Mn	Al	Cr	Ni	Mo	Cu	Ti	N	P	S	O
0.084	1.40	0.52	0.12	18.67	9.00	2.47	0.23	0.014	0.085	<0.0016	0.0044	0.0188

(AFA) was utilized to characterize the composition, size, and distribution of inclusions. The effect of the filter can directly be compared from samples 5 and 6. Sample 5 corresponds to the inclusion population of incoming liquid stream, whereas sample 6 is from the outgoing liquid stream after the filtration. From the other samples, the effect of runner design (comparing sample 6 to 4)

and floatation (comparing sample 4 to 2) can be determined. Metallographic specimens were prepared by sectioning and polishing utilizing standard metallographic techniques. Samples from positions 1-6 were prepared for metallography and inclusion analysis.

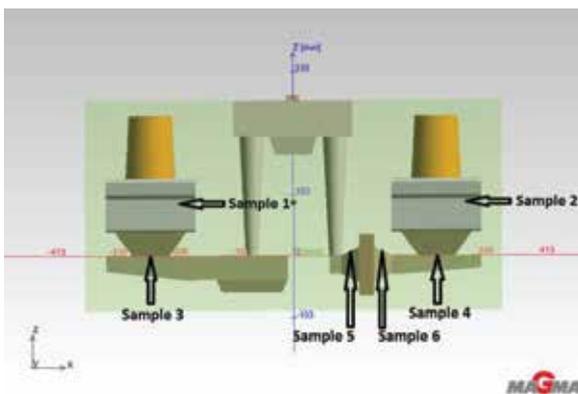


Figure 7. Sampling positions for metallography and inclusion analysis.



(a)

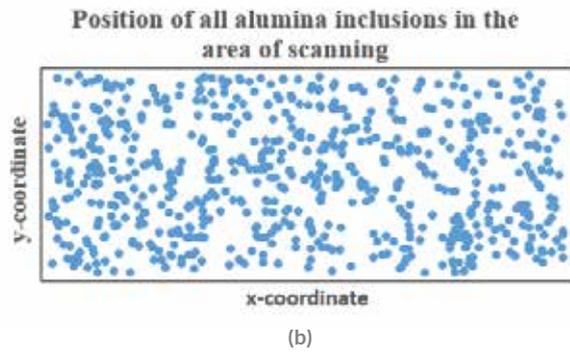


Figure 8. (a) Inclusions found by optical microscopy (Sample 3, third mold) and (b) cluster analysis using SEM/EDS data (Sample 3, third mold).

Before performing the inclusion analysis, the samples were examined under an optical microscope. From this study, it was observed that the inclusions were randomly distributed. The SEM/EDS AFA study also showed that the inclusions in the sample were uniformly distributed. A representative figure is shown here for sample 3 from the third mold set (Figure 8).

Total oxygen content of samples 5 and 6 from molds 1 and 3 was calculated from the total amount of oxide inclusions as determined by inclusion analysis. These values were then compared with total oxygen contents determined by combustion method (Figure 9). In both of these analyses the total oxygen content was decreased from sample 5 to sample 6 and this was expected as alumina inclusions were removed by the filter. As for both the techniques, the trends are similar and analysis of inclusions by the SEM/EDS AFA technique can be considered reliable.

The inclusion populations were measured for all the samples along with their chemistry, position, and size. For all the samples, alumina, manganese sulfide (MnS) and some complex inclusions (mainly MnS that heterogeneously precipitated on preexisting alumina) have been observed as shown in Figure 10.

A joint ternary diagram is presented in Figure 11 and shows the nominal chemistry and size distributions of the different types of inclusions. Manganese sulfide inclusions were mainly observed near the grain boundaries of the castings and these were formed during and after solidification. The size of this type of

inclusion formation strongly depends on the solidification rate of the castings, which is a

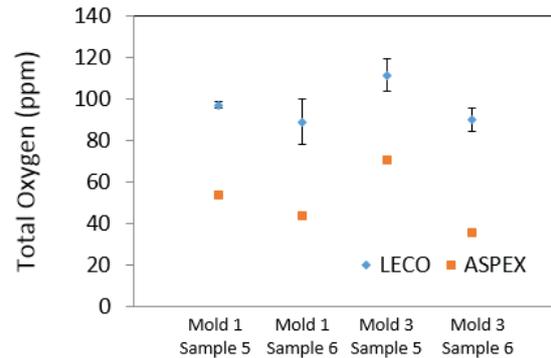


Figure 9. Total oxygen measured at different sampling positions with LECO and ASPEX.

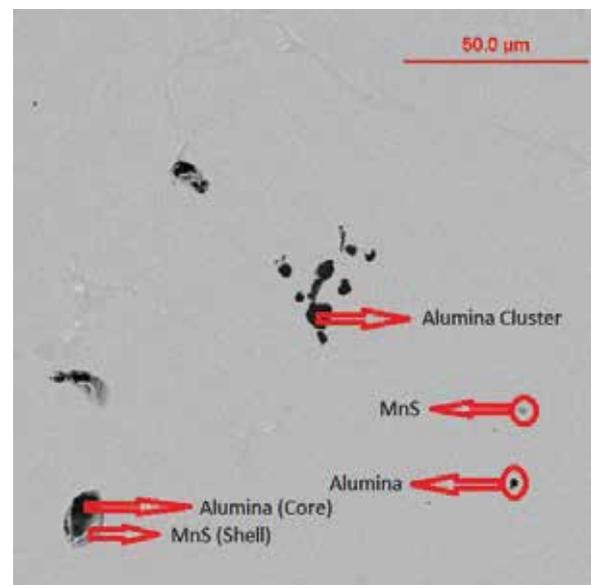


Figure 10. Backscattered electron image of different inclusions observed in this analysis.

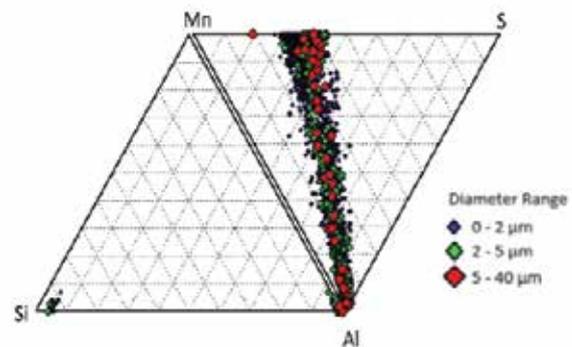


Figure 11. Joint ternary diagram of the inclusions observed for Mold 1, Sample 1.

variable parameter at different positions. MnS inclusions were also associated with alumina inclusions, sometimes forming complex inclusions which can interfere with the statistical analysis of the oxide inclusions

Of Interest That Were Present In The Melt. To Solve This Problem, A Threshold Filter Was Applied To Only Consider The Inclusions With High Al Content. For Aluminum Content  $\geq 90\%$ , All The Inclusions Were Considered As Pure Alumina. Considering This Assumption, Area Fraction Of The Alumina Inclusions (In Ppm) Was Calculated (Figure 12).

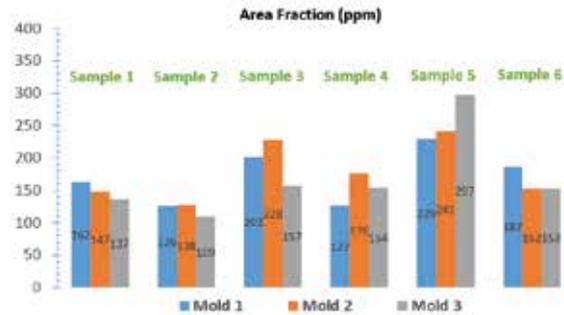


Figure 12. Area fraction of the alumina inclusions for Samples 1-6 for all three molds.

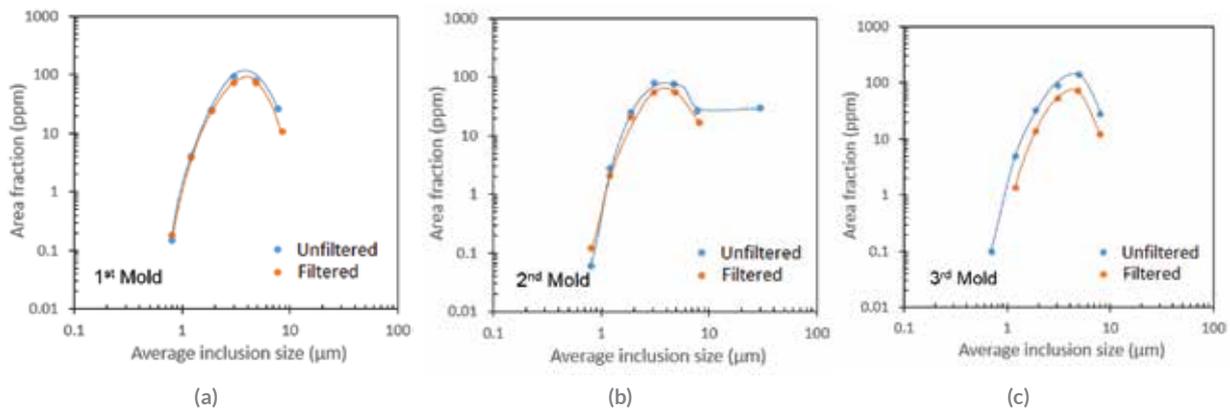


Figure 13: Size distributions of alumina inclusions before and after filtration. Samples 5 & 6 indicate removal of inclusions from the: (a) first mold, (b) second mold and (c) third mold.

## Discussion

Comparing Unfiltered And Filtered Samples 1 & 2, 3 & 4 And 5 & 6 For All The Mold Sets, It Can Be Observed That Solid Alumina Inclusions Can Effectively Be Removed After Filtration As Shown In Figure 12. It Can Also Be Observed That The Incoming Steel Before Filtration (Sample 5) Contained A Greater Number Of Alumina Inclusions When Compared To The Other Samples Collected. For All The Three Molds, The Area Fraction (In Ppm) For Sample 5 Of Third Mold Shows The Highest Value (297 Ppm) Followed By Second Mold (241 Ppm) And Third Mold (229 Ppm). This Is To Be Expected As Alumina Inclusions Are Lighter Than The Steel Melt And Have A Tendency To Float Towards The Top Of The Teapot Style Ladle. Size Distribution Of Alumina Inclusions From Just Before The Filter (Sample 5) And Just After The Filter (Sample 6) Are Shown In Figure 13 For The Different Molds That Were Poured. From The Size Distribution Analysis Of These Inclusions, It Can be determined that mold 3

shows the maximum number of larger inclusions (5-10 µm), followed by mold 2 and mold 1. This is anticipated, as alumina inclusions tend to agglomerate and float to the top of the ladle. Therefore, the last metal poured should contain the steel with the highest oxide content.

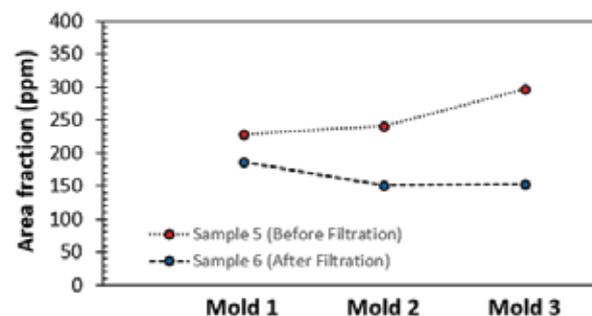


Figure 14. Area fractions of the alumina inclusions for Samples 5 (before filtration) and 6 (after filtration) for all three molds.

Comparing the area fractions of Sample 5 and 6 for all three molds (Figure 14), it can be seen that for mold 3, the inclusion removal is a maximum of 48% followed by mold 2 at 37% and mold 1 at 18%. The increase in incoming inclusion content with time is a direct result

of the floatation and agglomeration of alumina inclusions in the ladle with time. In addition, the filtration efficiency (Figure 14) improves with ladle hold time and increasing incoming inclusion content. Also, it appears that the top of the ladle contains a higher concentration of slightly larger alumina inclusions, which have a better chance of being captured by the filter and removed.

The filtration efficiency numbers reported in this study are somewhat lower than the 68% efficiency reported in a previous study by Raiber et. al.4. However Raiber's experiment employed a finer 25 ppi foam filter and calculated the efficiency using measurements of total oxygen content. Differences in mold setup, orientation of the filter, composition of the filter, alloy composition and the initial inclusion concentration may also explain the differences in observed filtration efficiency. Considering sample 6 (just after the filter), mold 1 has the highest inclusion content, 187 ppm, compared with mold 2 at 152 ppm, and mold 3 at 153 ppm. This is because the alumina inclusions entering the filter are slightly smaller and at a lower incoming inclusion concentration.

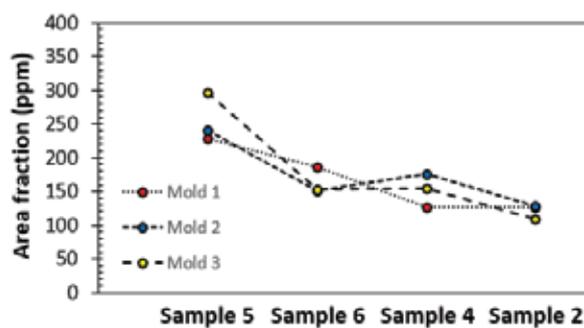


Figure 15. Area fractions of the alumina inclusions for Samples 5, 6, 4 and 2 for all three molds.

From Sample 4 to Sample 2, a drop can be seen in the area fraction of the inclusions for mold 2 (27%) and mold 3 (29%). This is due to the floatation of the inclusions towards the risers during filling (Figure 15). For mold 1, the inclusions are slightly smaller and they are not as likely to float. It can also be observed from Sample 5 and Sample 2 that the area fraction of the inclusions decreased by 45%, 47% and 63%, respectively for mold 1, mold 2 and mold 3 (Figure 15). This decrease indicates that the overall decrease in

inclusion content is the result of a combination of filtration and floatation of the inclusions inside the mold cavity. It also suggests that the larger inclusions are more likely to be removed by the combination of filtration and floatation.

## Conclusions

A mold design and an appropriate rigging system has been designed using mold filling and solidification software to study the filtration efficiency of solid alumina inclusions removal by a ceramic foam filter. This design employs two Y-block castings in the same mold, one with and other one without a filter in the runners. In this current design, liquid steel fills the mold cavity from the bottom with minimum vortex formation and turbulence, which reduces air entrainment. CFD modeling of the test configuration shows that for both of the castings, filling time is matched for both sides. Misruns and cold shuts were avoided. An experiment with three different mold sets has been carried out using three molds that were filled from a single heat to observe the effects of inclusion stratification in the ladle at the same time that the filtration efficiency is evaluated. From this experiment, the following conclusions can be made:

1. Stratification of solid alumina inclusions was observed in the ladle due to floatation of inclusions towards the top of the ladle after aluminum killing. Using a bottom pour 'teapot' ladle, successively teemed molds were observed to have increasing incoming inclusion concentrations.
2. Zirconia (10 ppi) foam filters effectively remove the alumina inclusions from steel melt. In this experiment, mold 3 had the highest incoming concentration of inclusions and also the highest overall inclusion removal efficiency (48%) by filtration.
3. Floatation of inclusions (5-10  $\mu\text{m}$ ) inside the mold cavity also contributed to inclusion removal. Molds 2 and 3 showed the removal of inclusions due to floatation in the mold cavity, whereas mold 1 did not.

4. Both Filtration And Floatation Mechanisms Appear To Play An Important Role For Inclusion Removal. The Combined Effect Is Larger Than Filtration Alone. In This Study, The Highest Combined Inclusion Removal Efficiency Observed In Mold 3 Was 63%, With Filtration Accounting For 48% Of The Removal Efficiency.

## Future Work

Filtration Of Solid Alumina Inclusions Was Considered In This Study. Future Experiments Utilizing The Same Mold And Casting Design Will Be Conducted To Study The Removal Efficiencies Of Liquid Manganese-silicate Inclusions And Liquid Calcium-modified Alumina Inclusions.

Examination Of The Filter Media By Metallographic Methods Is Planned To Observe The Inclusion Attachment Mechanisms And The Distribution Of The Inclusions Through The Body Of The Filter For Both Liquid And Solid Inclusions.

Notch Toughness Of Filtered And Unfiltered Castings Will Be Evaluated In These And Future Trials Using Charpy V-notch Testing.

The Effects Of Different Filter Orientations And Filter Types On Inclusion Removal Efficiency Will Also Be Investigated.

## Acknowledgments

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The foundry industry in Pakistan has long been perceived as a domain reserved for established family enterprises, with limited entry points for fresh entrants. Yet, the founder of Lahore Casting saw beyond these conventions. Drawn to the field by an intrinsic fascination and recognizing Pakistan's vast market potential—bolstered by a population that serves as our greatest strength—he took the leap. Starting with modest resources in Lahore, the company began operations in a landscape rife with challenges, including unreliable market credit systems and a scarcity of skilled labor. These hurdles, however, only fueled the drive to innovate and adapt.

In just six to seven short years, Lahore Casting has transformed into a reliable source for customers seeking high-quality ferrous castings. What began as a small-scale venture has expanded into a powerhouse, serving diverse sectors with precision-engineered products. Their portfolio now includes a wide array of auto parts, agricultural implements, industrial castings, and specialized components for Pakistan's defense forces. This rapid ascent is not merely a story of growth but one of strategic foresight. By addressing the inefficiencies in the supply chain—where a significant portion of mechanical parts are imported from China, leading to frustrating time lags and a lack of direct manufacturer-buyer connections—Lahore Casting carved out a niche. They bridged this gap, offering localized, efficient solutions that have empowered local industries and reduced dependency on foreign imports.

Today, Lahore Casting's expertise spans an impressive range of materials, including mild steel castings, spheroidal graphite iron castings, manganese steel castings, and wear-resistant high chrome castings. These products are crafted with meticulous attention to quality, ensuring durability and performance that meet international standards. Their client list, now surpassing 300 esteemed partners, extends not only across Pakistan but to markets around the globe. This global footprint is a reflection of their commitment to excellence, where optimism, innovation, and continuous development form the core pillars of their philosophy. In an industry that demands resilience, Lahore Casting has emerged victorious, turning potential obstacles into stepping stones for success.



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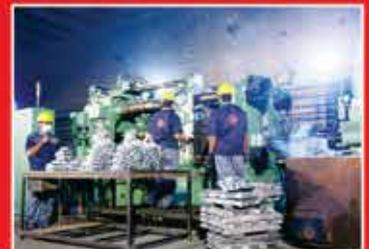


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# Application of Casting Simulation for Sand Casting of a Crusher Plate

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## Abstract

Sand casting technologies have now emerged as practical and commercial ways of manufacturing high integrity near net shape castings. A variety of castings have found their way into general engineering applications, primarily in the areas of cement industries for crushing components and load bearing structures. Castings that serve these specific applications have to achieve the quality requirements of superior mechanical properties and zero-porosity. To achieve these objectives within a limited time frame in a product development process, CAD technologies combined with process simulation tools are increasingly used to optimize form filling and solidification of the cast parts. This paper discusses a newly developed simulation tool and its application to a crusher component that was prototyped via sand casting route. Results of casting trials showed a high level of confidence in the simulation tools.

**Keywords:** Numerical simulation, steel castings, mould filling, and solidification of CO<sub>2</sub> sand castings.

## Introduction

ProCAST is a three dimensional solidification and fluid flow package developed to perform numerical simulation of molten metal flow and solidification phenomena in various casting processes, primarily die casting (gravity, low pressure and high pressure die casting) and sand casting. It is particularly helpful for foundry applications to visualize

and predict the casting results so as to provide guidelines for improving product as well as mold design in order to achieve the desired casting qualities (Campbell et al, 2004). Prior to applying the ProCAST extensively to create sand casting and die casting models for the simulation of molten metal flow (mold filling) and solidification (crystallization in the process of cooling). The cast and mold design of the experiment is transformed into a 3D model and imported into ProCAST to conduct the sand casting process simulation. Sand casting is the casting process that has the longest history (Ravi et al, 2005). Sand casting still accounts for the largest tonnage of production of shaped castings. This is due to the fact that sand casting is economical and possesses the flexibility to produce castings of any material and the weight of castings can be range from tens of grams to hundreds of tons. Conventional sand casting is not a precision process and requires after-cast machining processes and surface finishing producing the required dimensions and surface quality. However, advanced high technology sand casting process (improved sand quality and mold rigidity) enables this method to produce higher precision cast products with better as-cast surface finishing that reduces the cost of after-cast touch-up. This will enhance the capability of sand casting to produce „near-net-shape products and improve its competitiveness (Ravi et al, 2008). Most sand moulds and cores are made of silica sand for its availability and low cost. In the present work simulation of mould filling solidification of alloy steel castings are carried out.

## 1.1 Casting process modeling

An engineer designing the particular production technology of a casting has certain possibilities of interfering with the process of solidification and cooling – among others through proper designing of technological allowances, internal and external chills, distribution and magnitude of riser heads, assuming optimum temperature of pouring and chemical analysis of the alloy, and finally through a suitable selection of sand mix. The process of designing the technology of a casting production can be expanded, modernized and improved through utilization of the possibilities offered by the introduction of numerical methods in the calculation of solidification and cooling of metal in a mould (Guharaja et al, 2006). Generally the simulation software has three main parts shown in Figure1.

Pre-processing: the program reads the CAD geometry and generates the mesh,

Main processing: adding of boundary conditions and material data, filling and temperature calculations,

Post processing: presentation, evaluation.

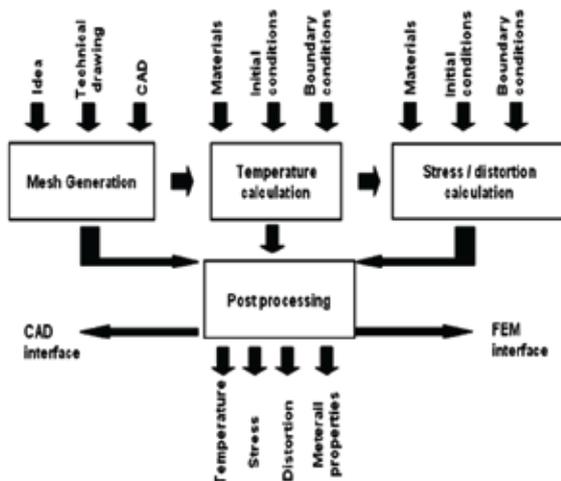


Fig.1. System of simulation

Figure 2 shows the flow chart in which the 3D CAD and simulation tools are utilized to improve the casting process design. Computer simulation based on the design procedures described above have been implemented with one case study. Let's

consider a crusher plate casting for the present study (Figures.3 &4. Shows the 3D model&3D model of sand block). Used in cement industry made of IS 1030 alloy steel. During simulation of the casting process, mould filling and solidification are examined and sand casting process are optimized.

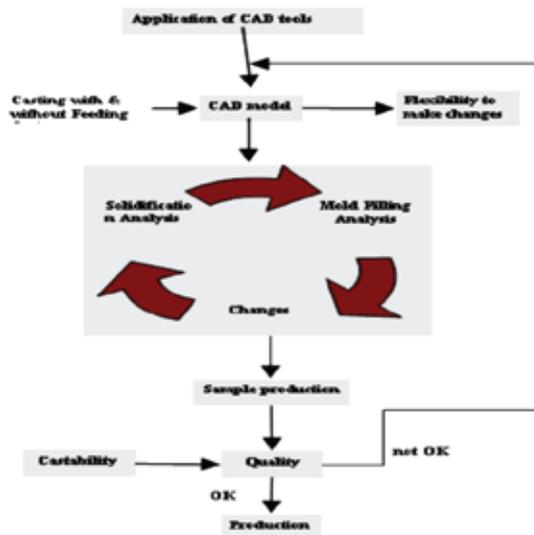


Fig.2. Flow chart for improvement of the casting system design

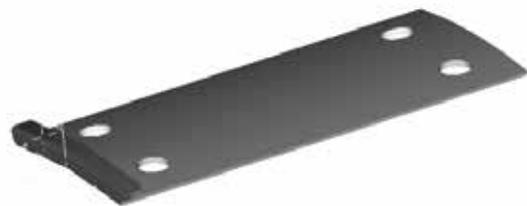


Fig.3 3D model of Crusher plate References

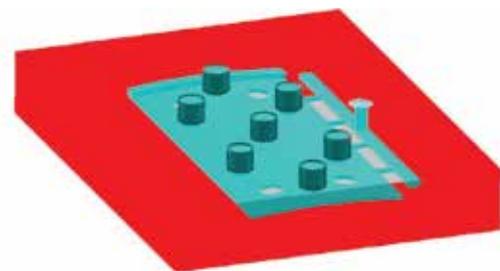


Fig.4 3D model of sand block

## 2. Methodology

The purpose of this paper is to simulate the mechanism of the solidification of alloy steel sand castings, and analyze the results to give some aspects of logical thoughts for experiments designation, and to optimize the casting parameters in order to achieve better

properties of steel castings (Moreira et al, 2003). The procedures were mainly divided into three stages. They were Simulation Preparation, Computer Aided Simulation on ProCAST, and Analysis. Each stage contained several steps. Researcher followed this operation flow to try and examine different influencing factors, such as molten metal temperature, mould material, inlet velocity, substrate pre-heating temperature, and radiation. In the first stage, observation of fluid flow was most important because all the model construction, parameters designation, and questions description are based on observing substantial experiments. The purpose of this stage was to gather more data for simulation experiments, and all the material properties, mould properties, relationships between materials and surroundings are needed. In addition, the second stage was the simulation by ProCAST, and this stage was totally under computer operation, including model construction, input factors setting, problem solving, result obtainment (M.R Bharkudarov et al, 2005). Finally, the final stage was to show the results of simulation, to build a data base and to analyze, then to find out a persuasive conclusion that would improve the manufacturing of alloy steel sand casting Figure. 5 is the procedure graph showing the entire methodology followed for the present work. And, succeeding this section, the substantial software.

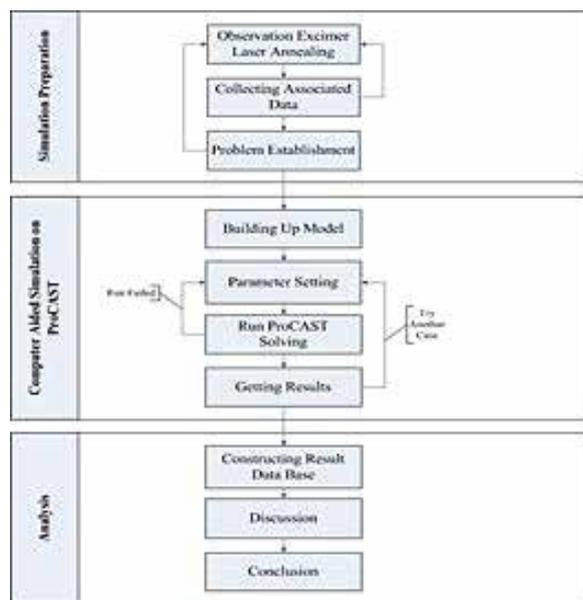


Fig.5 Methodology

## 2.1 ProCAST Working Flow

ProCAST is a modular system and allows the coupling of various modules. Based on Finite Element technology, ProCAST provides a complete solution covering a wide range of simulation. The purpose of this stage is to generate a finite element model, to setup the calculation, to run the analysis and, to interpret the results. The primary working flow of ProCAST was divided into three main parts, to begin with: “Pre-Processing”; in addition: “Solving” to run the analysis; and finally was the step “Data Output” to interpret the results and each step includes several sub-steps. The principal process of ProCAST is indicated in Figure.6

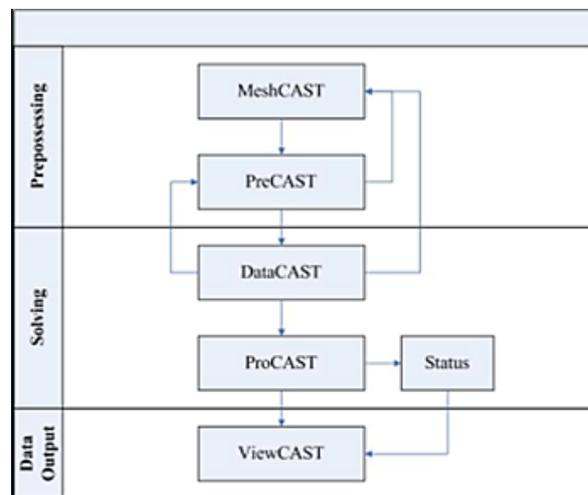


Fig. 6 ProCAST Working Flow

## 3. Case Study

A case study was conducted to verify the use of ProCAST in an industry casting environment. The selected case study was a plate casting made from alloy steel by the GS alloy steel Castings limited, Surampalli, Krishna (Dist); Andhrapradesh. The tests conducted in this case study used ProCAST to find potential defects in the casting at different locations and compare them with the real casting design and to find possible outcomes and modifications attempted to improve the existing casting design. The modification of existing Riser and Gating Design were changed to improve the existing casting design, riser, and gating systems with improved yield for the casting from scratch and compare the calculated dimensions and

resulting simulations with the existing casting design, material for casting IS1030 alloy steel chosen Chemical composition given Table.1;and mould material is Silica sand.

Grade 200-400W	
C	0.25
Si	0.6
Mn	1
P	0.040
S	0.035
Cr	0.35
Ni	0.40
Mo	0.15
Cu	0.40
V	0.05

Table1.I S1030Chemical Composition

## 4. Results and analysis

### 4.1 Mould filling

The Procast simulation solved for mould filling and solidification processes at the same time. The discussion about mould filling is solely based on ProCAST simulation results. The mould filling processes of the initial and modified gating systems are able to be visualized from Figures.4.1&4.2. It is found that for every succession of one second fraction of solid and temperatures are changing (encompasses pouring basin, sprue and runner system, gatings, casting and feeder) will be filled up. The melt was rising almost uniformly in the cavity of the mould until it was completely filled up. This is a good filling because it ensures the temperature distribution in the mould will be equal everywhere just after filling so that solidification rate will be fairly consistent throughout the casting. Equal rate of solidification will entail uniform shrinkage of the casting to minimize defects such as shrinkage cavities as a result of non-uniform cooling rate. The temperature distribution and fraction of solid also indicates that during

mould filling, cooling has actually started especially at the end of runner as shown from Figures.4.3&4.4. It can be seen that down sprue and feeder were filled up simultaneously since their dimensions and shapes are very similar. Though the down sprue is the entrance of the molten metal, it was not filled up or completely wetted during the mould filling of cavity. Generally, the mould filling is successful as a result of proper design of straight runner system. It can be seen that the straight runner and gatings were filled up with in the first few second.

### 4.2 Solidification & Various Gating Systems

Temperature contour of solidification and solid fractions:

For the cast material IS 1030 alloy Steel, solidification will start when the temperature drops below 1473°C, and fully completed beneath 1355°C. Solidification is a result of heat transfer from internal casting to external environment. The heat transfer from the interior of the casting has to go through the routes of (C.W Hirt. et al, 2007) 1. Internal liquid convection above liquidous temperature during mould filling.

2. The solidified metal conduction after complete solidification achieved throughout the bulk of casting.

3. The heat conduction at the metal –mould interface.

4. Heat conduction with in the sand mould.

5. Convection and radiation from mould surface to the surrounding.

In the present study we compare the solidification simulation results of the IS 1030 Steel plate castings at different time intervals and different gating systems as shown in the Figures.4.1&4.2. Solidification time is proportional to volume to surface area ratio (modulus of casting) (Viswanathan et al, 1998), therefore the faster solidification rate at the runner tip is expected. The mould cavity which is in the center sand mould as

comparatively has the longest solidification time. Since there are long list of possibilities for a gating system of a particular casting, various gating systems were tried and tested in the ProCAST software. One of those gating system with ingates settling all around the casting can be seen in the figure 4.1. Molten metal is poured at a temperature of 1600°C with a yield of 60%. A defect usually seen in plate castings is the free end distortion which is avoided through an improvised gating system. The main defect with this gating system is that the ingates solidify before the molten metal reaches the Mould thereby providing no inlet to the mould and leading to a partial filling for the casting. Higher stresses results due to filling pattern of liquid metal, in this case from both sides of gating system. The same is shown in the Time Vs Temperature graph in figures 4.5 & 4.6.

Moreover with such a gating system high turbulence is seen as in the figures 4.1 & 4.3. Hence, a remedy for such defect would have been to increase the temperature of the pouring molten metal so that the molten metal reaches the cavity and then solidifies. A Simulation at 2000°C is done and a defect free casting is obtained during the simulation processes. With higher stresses and high turbulence levels even a defect free casting would fail under high loading and hence, a check for stresses & turbulence is necessary. For molten metal to stay at a higher temperature, a Kalminex exothermic material used as sleeve. The comparison of stresses with the use of exothermic material is performed the casting with lesser stresses was observed with the use of the exothermic material as shown in the figures 4.2 & 4.3.

Accordingly, the turbulence levels are quite high in the initial gating system and the stresses in the casting are quite high after the solidification. A modified gating system is prepared and gating calculations performed with a yield of 80% using an exothermic material (Kalminex) as a sleeve. The molten metal is poured at 1600°C with the temperature and solidification behavior of the molten metal as shown in the figures 4.1 & 4.2. Once simulation is complete, a defect free casting is obtained with a yield of 80%. (which

is shown in comparison table.2). On comparison of the entire defect free castings yield, turbulence, effective stresses, flow, etc are to be taken into consideration such that a sound casting could be provided to the user. Stress analysis is performed on castings with no defects and results analyzed as shown in figures 4.5 and 4.6. A defect free gating system with perfectly sound casting was the one with the modified gating system. This Gating system has higher yield, lesser turbulence of flow during mould filling and lesser stresses and hence it has been chosen as the optimum gating system. Bar chart was plotted against yield and trails which is shown in Figure

#### 4.7 According to the result analysis obtained from the simulation.

Control points temperature time tracking  
The figure 4.1 & 4.2 shows the temperatures changes for the casting points. The fraction of solids and liquid metal in the mushy zone is a function of time and temperature. When the last drop of liquid metal is crystallized into solid, the solidification process is considered. Therefore the ProCAST simulation and experiment obviously differ from each other however, compared with other casting points. In a way the temperature range at the start of mould filling to the end is same in initial gating system. In the modified gating system the temperature variation between nodes at the start seems to be non-uniform but at the end of solidification it is uniform.

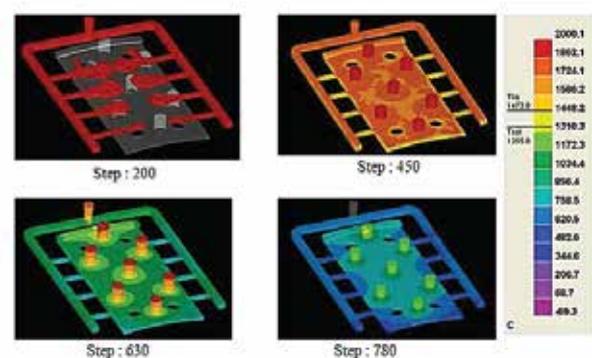


Fig. 4.1 Mould filling pattern and Temperature variations of initial gating system at various stages

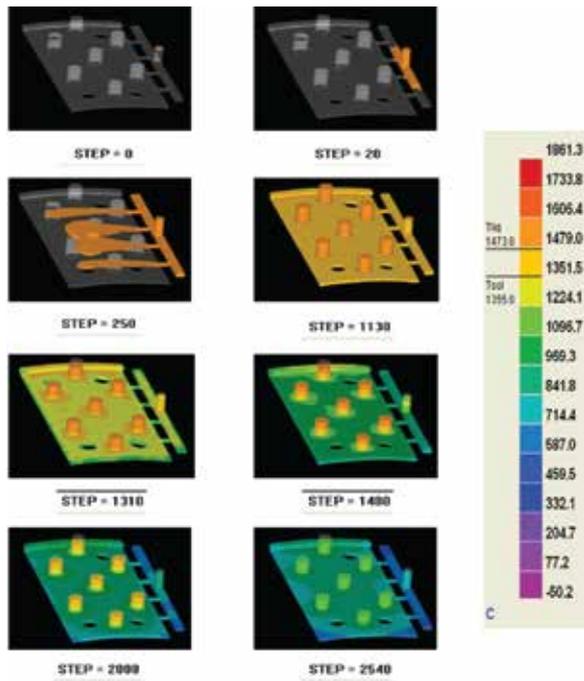


Fig.4.2 Mould filling pattern and Temperature variations of modified gating system at various stages.

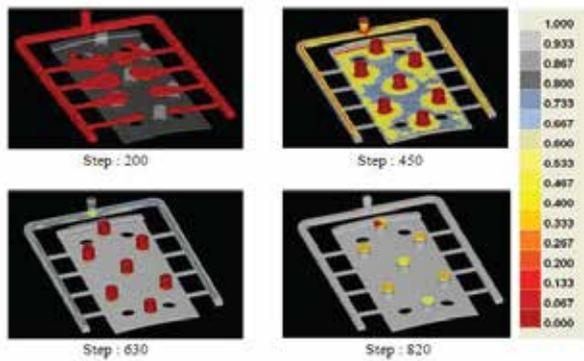


Fig. 4.3 Solidification Fraction of initial gating system at various stages

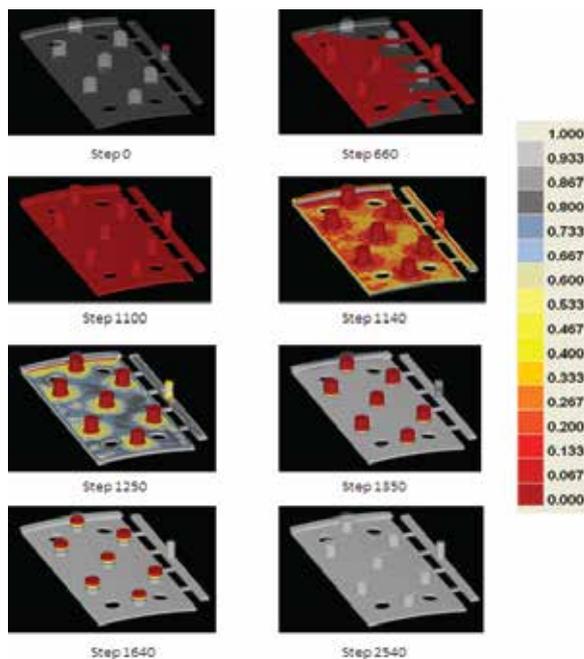


Fig. 4.4 Solidification Fraction of modified gating system at various stages.

Table 2 Comparison of Results

Trial No	POURING TEMPERATURE (°C)	EXOTHERMIC MATERIAL	TYPE OF SAND USED	MESH DISTORTION	STRESS	YIELD	GATING SYSTEM	FILL TIME (Sec)
	1800	NOT USED	SILICA SAND	NO DISTORTION	HIGH STRESS	71%	ORIGINAL	8
1	1600	NOT USED	SILICA SAND	N/A*	N/A*	60%*	INITIAL	5.9
2	1600	NOT USED	SILICA SAND	NO DISTORTION	HIGH STRESS	64%	INITIAL	6.1
3	2000	NOT USED	SILICA SAND	NO DISTORTION	HIGH STRESS	67%	INITIAL	6.3
4	2000	KALMINEX	SILICA SAND	NO DISTORTION	HIGH STRESS	67%	INITIAL	6.3
5	2000	KALMINEX	SILICA SAND	NO DISTORTION	HIGH STRESS	68%	INITIAL	6.7
6	1600	NOT USED	SILICA SAND	NO DISTORTION	MEDIUM STRESS	78%	MODIFIED	8.7
7	1600	KALMINEX	SILICA SAND	NO DISTORTION	LEAST STRESS	78%	MODIFIED	8.7
8	2000	KALMINEX	SILICA SAND	NO DISTORTION	HIGH STRESS	79%	MODIFIED	9.0

\*. Not applicable since there is an incomplete mould filling (defective)

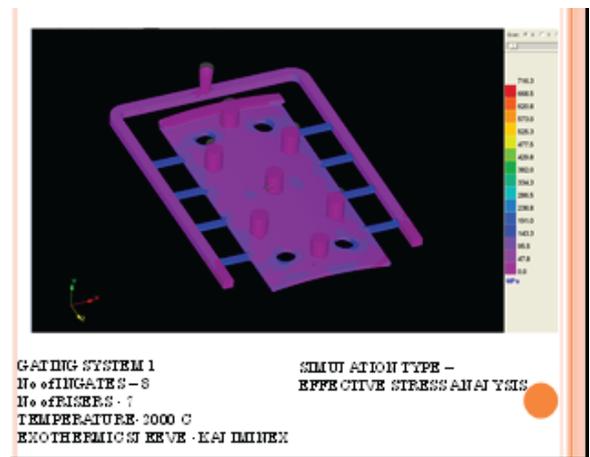


Fig. 4.5 Stress Analysis for initial gating system at step 2660 with KALMINEX at 2000°C

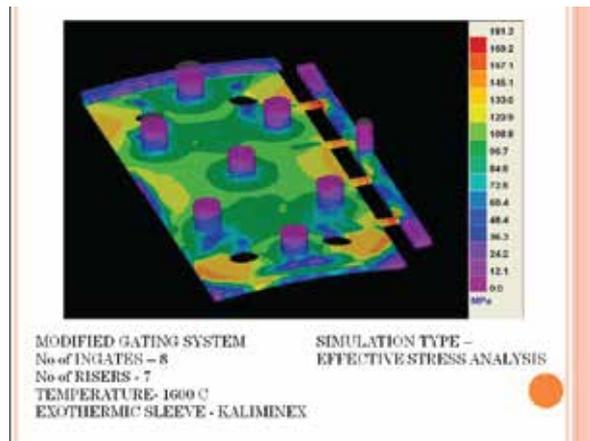


Fig. 4.6 Stress Analysis for modified gating system at step 2540 with KALMINEX at 1600°C

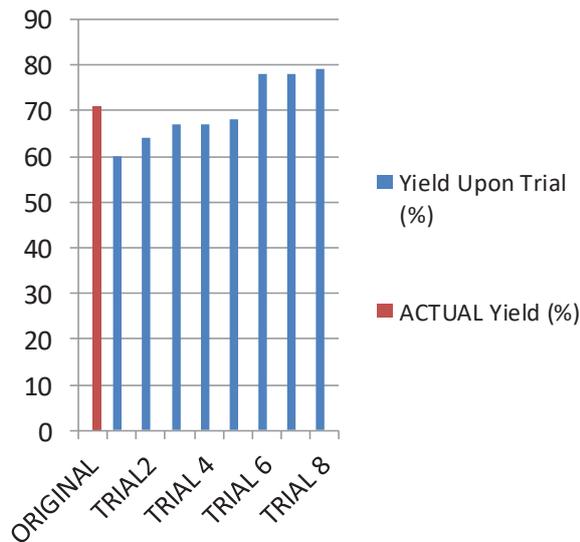


Fig.4.7 Bar Chart showing Yield Deviation in trials

## Conclusions

The main conclusions that can be drawn from this study are:

1. By using simulation software intelligently it is possible to help foundries reduce scrap rates even for defects which cannot be predicted
2. The utilization of the simulation tool to carry out filling and solidification analysis on a high integrity part is illustrated. The simulation tool was used to identify critical locations and filling pattern and solidification related problem areas in the casting.
3. Destructive testing of samples excised from the plate casting (not showed in this paper because of customer agreement) results that correlated well with the simulation based results.
4. Early analysis of the filling and mould design must be used in identifying problem areas in castings.
5. By moving the trial and error process into the virtual world and determine the cost of different design and process options.
6. By minimizing real world trial and error (and surprises) making castings right the first time.

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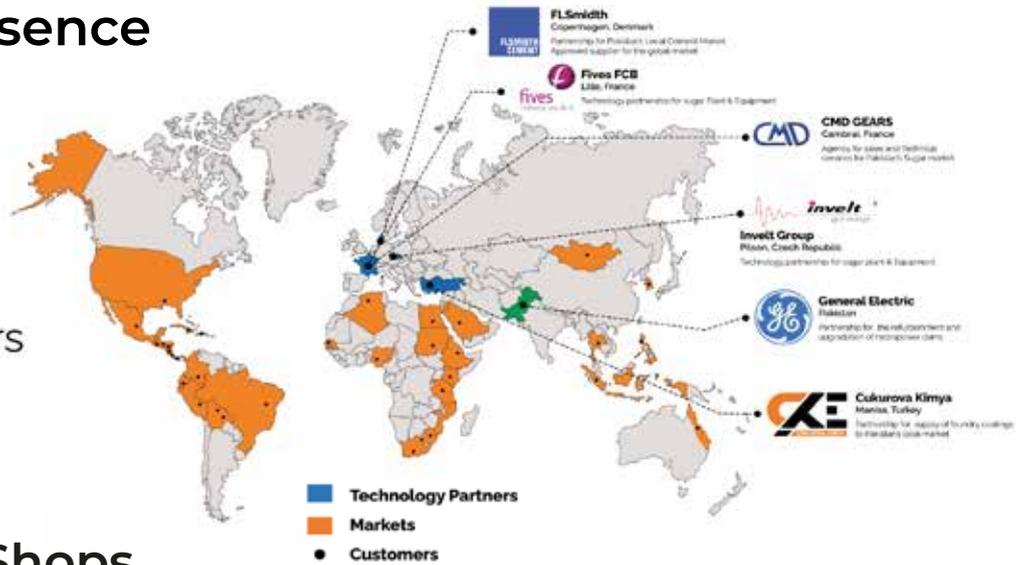
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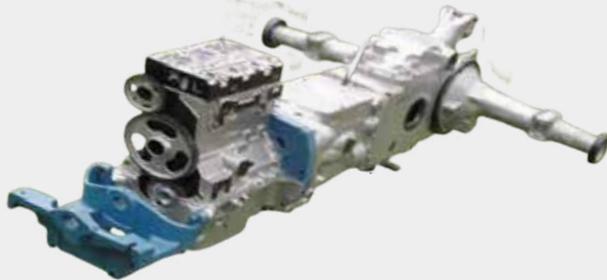


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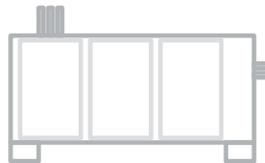
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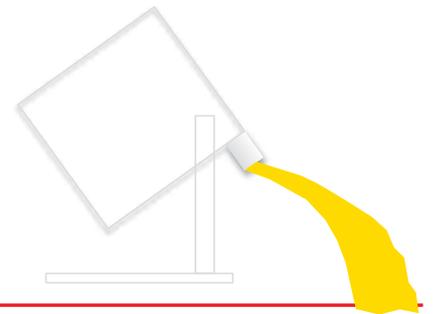
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