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Research Article

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_2 sand castings.*

1. 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.

1.1Casting 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.

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- 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.

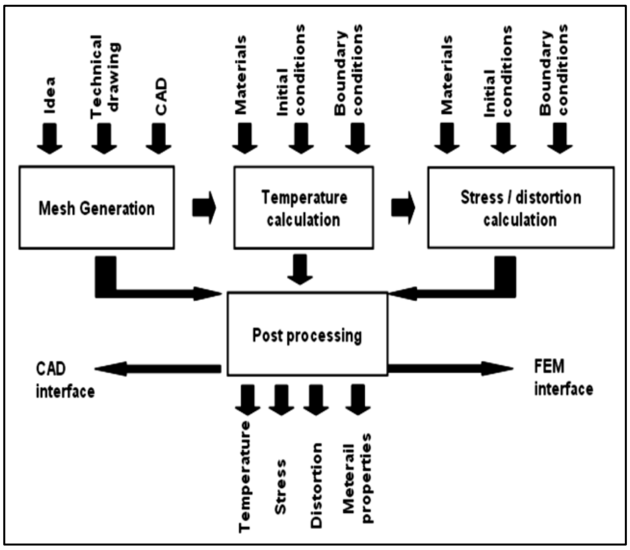

Fig.1.System of simulation

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.

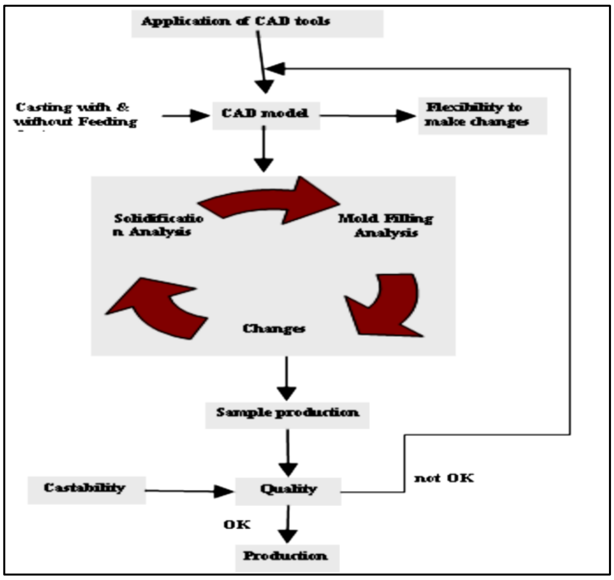

Fig.2. Flow chart for improvement of the casting system design

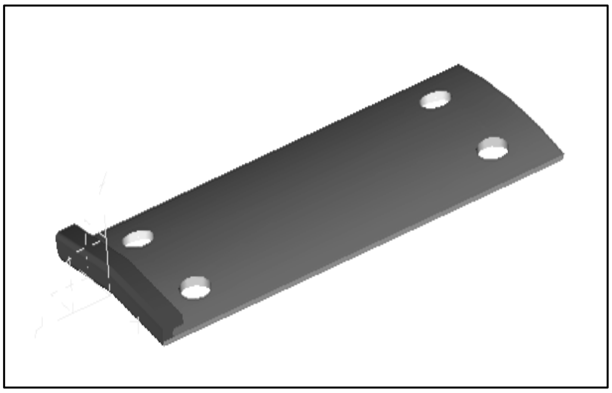

Fig.3 3D model of Crusher plate References

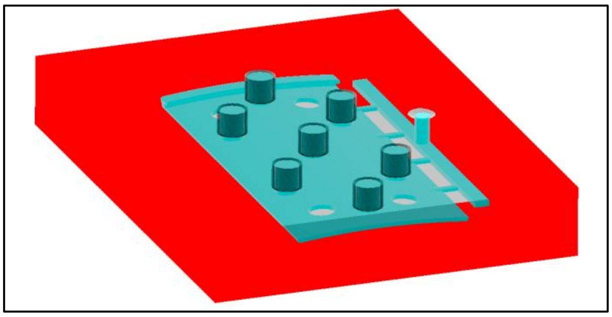

Fig.4 3D model of sand block

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

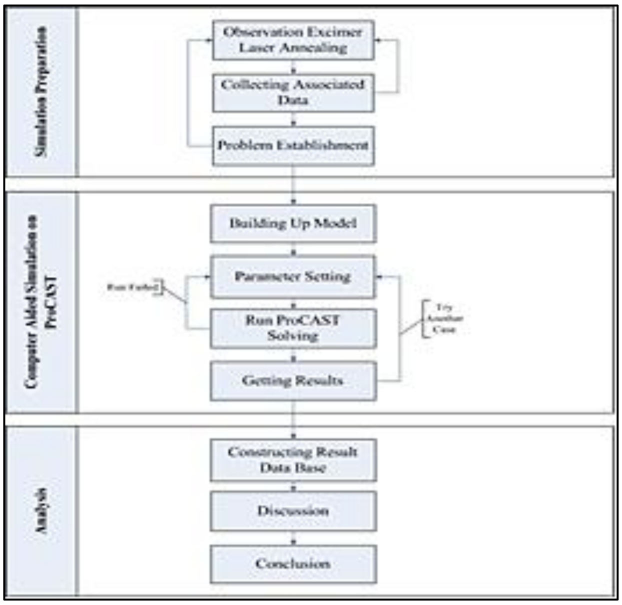

Fig.5Methodology

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

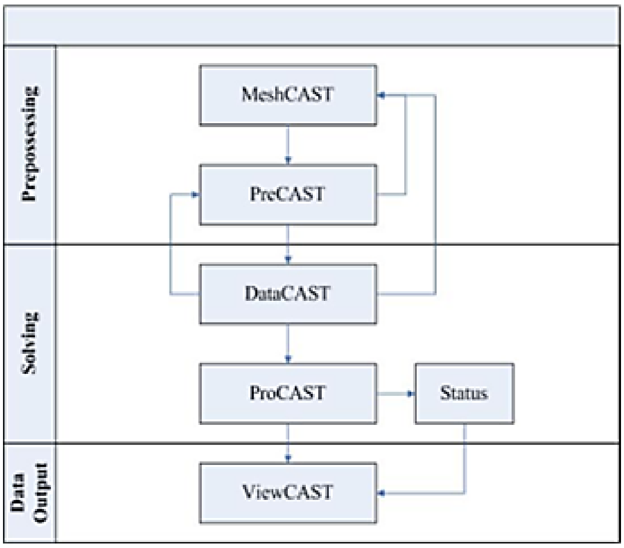

Fig. 6 ProCAST Working Flow

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.

Table1.IS1030Chemical Composition

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

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.

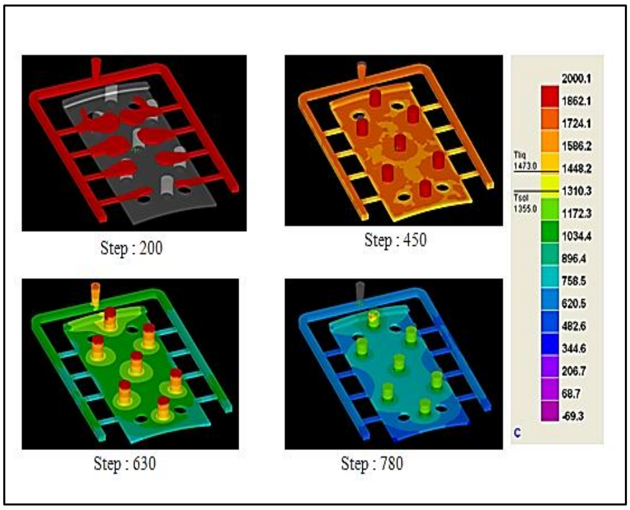

Fig. 4.1Mould filling pattern and Temperature variations of initial gating system at various stages

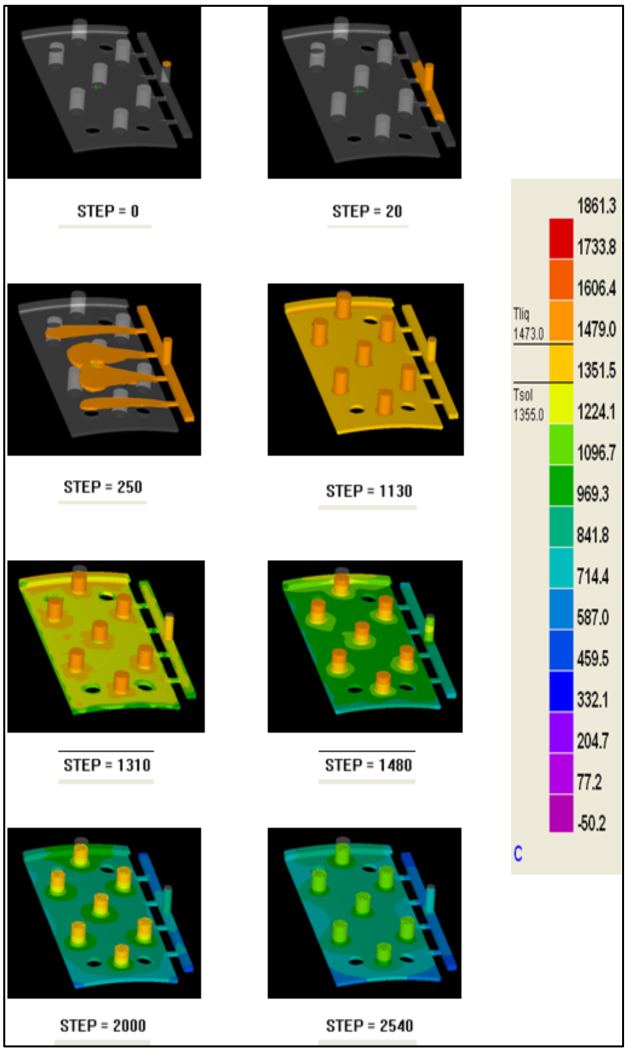

Fig.4.2 Mould filling pattern and Temperature variations of modified gating system at various stages.

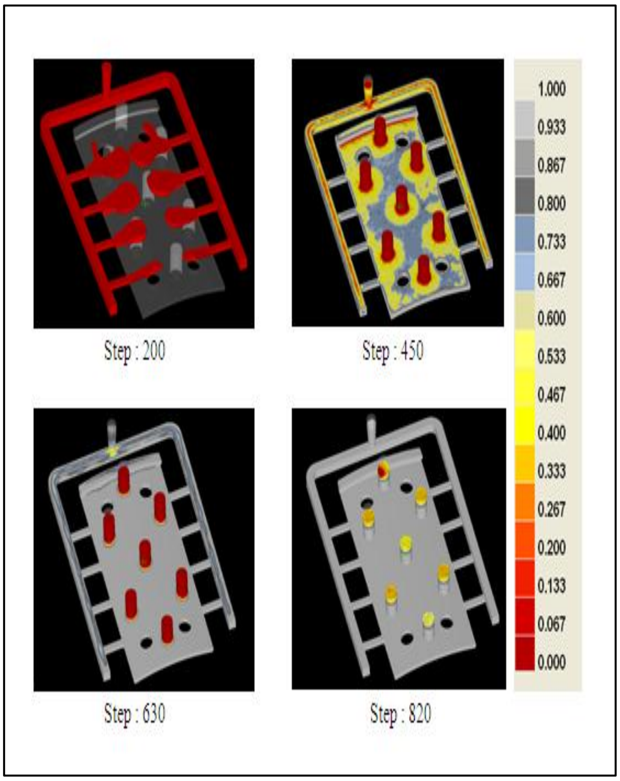

Fig. 4.3Solidification Fraction of initial gating system at various stages

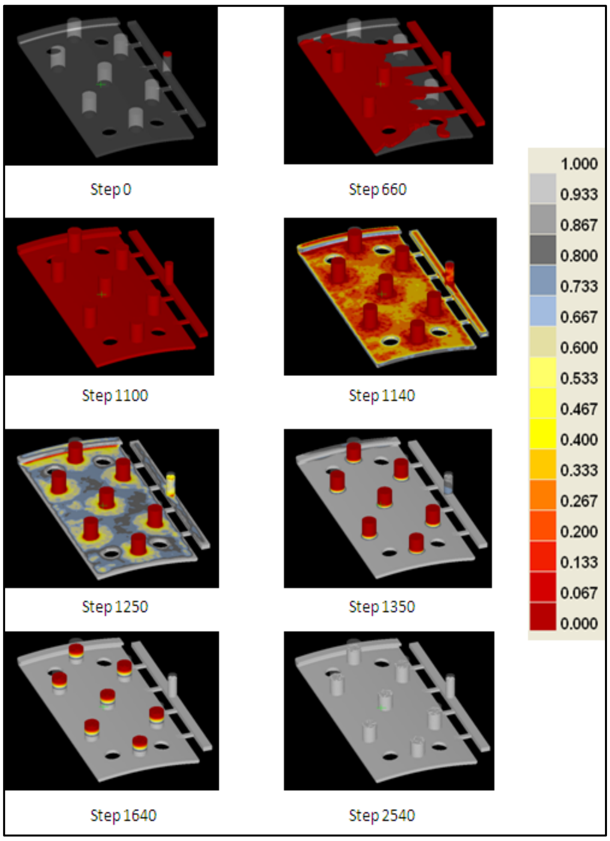

Fig. 4.4 Solidification Fraction of modified gating system at various stages.

Table 2 Comparison of Results

Trial No	POURING TEMPERATURE (^{0}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)*

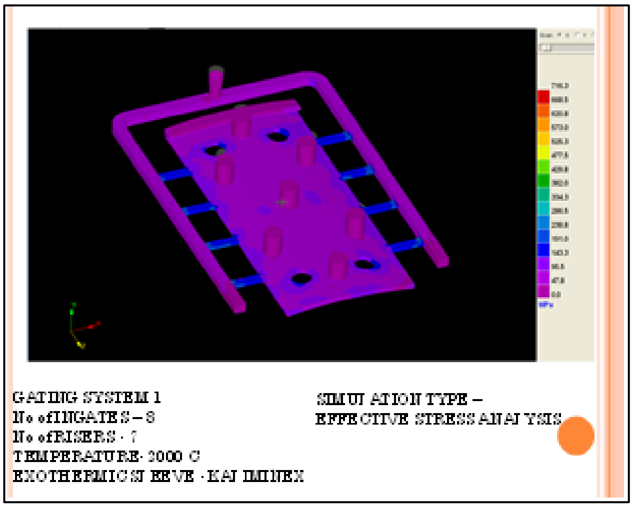

Fig. 4.5 Stress Analysis for initial gating system at step 2660 with KALMINEX at 2000°C

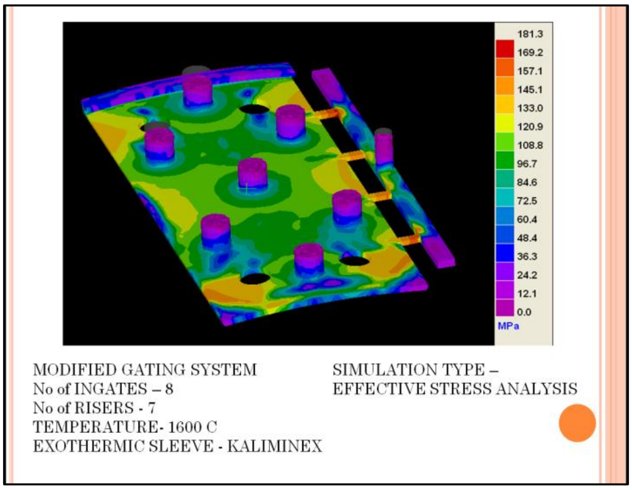

Fig. 4.6 Stress Analysis for modified gating system at step 2540 with KALMINEX at 1600°C

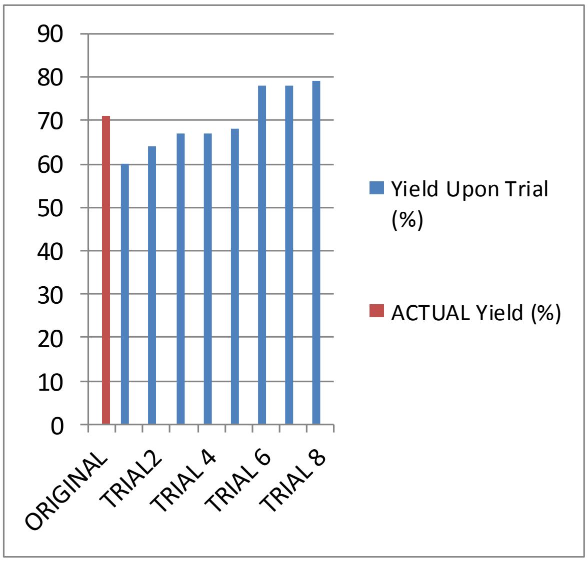

Fig.4.7 Bar Chart showing Yield Deviation in trials

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 our 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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