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Numerical Simulation and Preliminary Experimental Verification of AISI 1040 Flat Bar Steel Casting to Investigate the Effect of Riser Design on Shrinkage

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Abstract—Producing *a defect-free casting for a critical application is a challenging job mainly due to two factors. Primarily due to trial and error approach towards the design of riser, runner, gates, sprue, mold cavity, core and chapstics. The other factor is not being able to maintain a good quality of the melt. Defects are the results of a merger of several causes. In this study, the authors have chosen to use a FEM based commercial software to design riser and employ chills to eliminate or minimize the shrinkage defects. The use of chills promoted directional solidification such that the shrinkage cavities moved along the solidification front and away from casting into the riser. Study is made on use of blind riser, open riser and their influence on shrinkage porosity.*

Keywords*-Numerical simulation, shrinkage porosity, solidification time, chills, cause-effect diagram*

I. INTRODUCTION

Casting is the traditional process for centuries. Cast products possess the risk of failure due to likely presence of shrinkage porosities, blowholes, pinholes, segregation and hotspots unless heat flow and fluid flow are properly managed. These defects can be reduced in various ways but modern approach like numerical simulation predicts to find the defects in casting before manufacturing the cast product. Making a casting involves use of a mold box, electric furnace, molten alloy, where as the numerical simulation requires only simulation software. It helps in predicting the location of shrinkage porosity in a casting. Simulation can be carried out any number of times without wasting metal or energy.

Mining operations of coal, iron, bauxite and asbestos require material handling equipment to transport raw materials from underground to surface [1-3]. Drilling, dozers, conveyor belts are used in the mining process. A flat bar scraper is a AISI 1040 steel casting mounted on a conveyor system to scrape off the mass containing coal particles get stuck to the conveyor belt [4-6]. It has been learnt from the user of this casting that frequent premature failures occur due to presence of severe shrinkage porosity. In order to minimize shrinkage porosity, riser and chill are designed such that unidirectional solidification is promoted.

II. METHODOLOGY

Numerical simulation of casting has been carried out using a commercial finite element based software. A geometrical model using CATIA V5 was prepared which contains sand mold with runners, gate, riser and chill. The geometrical model includes 6 risers, casting, sprue, sand mold box, different types of chills, different types of risers and with different materials of chills employed. Sprue base diameter is 32 mm, top diameter is 90 mm and height is 135 mm. 3Dimensional 8,27,026tetrahedra element sand 1,11,886 nodes have been created.

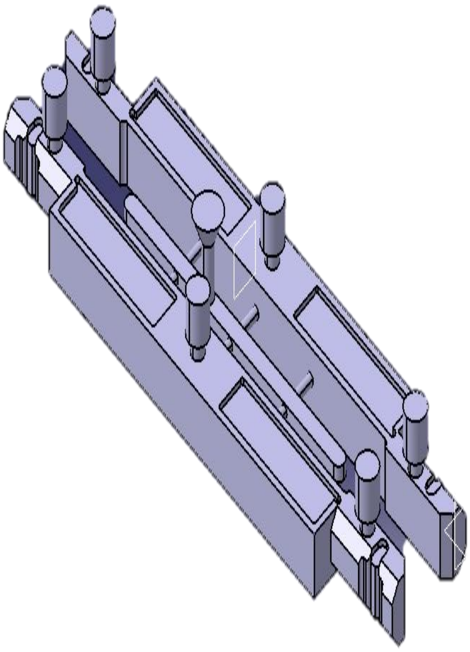

Figure 1(a). Geometrical model of Flat bar scrapper with 6 risers and sprue

Figure 1(b). Flat bar casting with 6 risers and sprue

A. Input Parameters

After meshing successfully input parameters like material of the casting, type of mold, insulation, chill and material of the chill have been assigned.

B. Initial and Boundary Conditions

Initial conditions: At time, t = 0; mold temperature is 30 ^{0}C, pouring temperature is 1580 ^{0}C. Thermal boundary conditions: Convective heat transfer coefficient at the interface between mold wall/ambient. Material Specifications: temperature dependent density, specific heat and thermal conductivity of material of the mold and material of the casting have been assigned from the materials property library of the software.

III. RESULTS AND DISCUSSION

The initial simulation run for the casting was carried out based on the exact dimensions of the mold, riser, gating. The simulation results have shown shrinkage porosity beneath the sprue as exhibited in Figure 2. The shrinkage is attributed to high temperature, longer solidification time as communicated by authors [7-8].

A. Formulae for flow rate calculation

FR X 2 = WEIGHT

$\sqrt{WEIGHT}$ X 2 = FT_1

Where,

FT= Initial fill time in seconds

FR= Initial flow rate as calculated, Kg/sec

T = Temperature given to the casting, ^{0}C

WEIGHT= Multiplied value with flow rate

FT_1= Final fill time after calculation in seconds

FR_1= Final flow rate of simulated value in Kg/sec

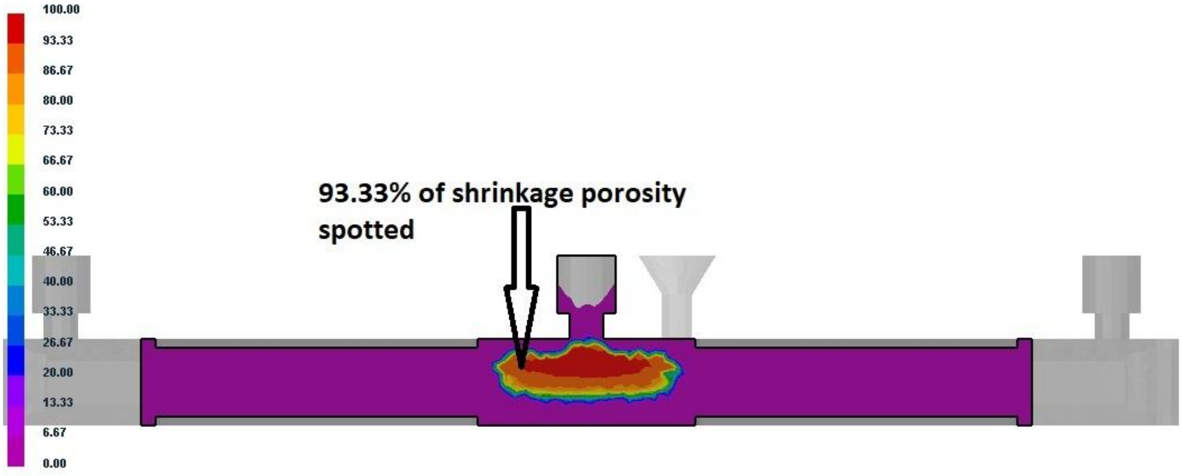

Figure 2. shrinkage spot formed inside the scrapper casting of 93.33%

Flow rate calculation of type 1 riser

Initial fill time assumed (FT) = 2 sec

Temperature given to the casting (T) = 1550 ^{0}C

Flow rate for the given input data (FR) = 108.8171 Kg/sec

FT = 2 Sec	FT1 = 29.50 Sec
T = 1550 ^{0}C	T =1550 ^{0}C
FR= 108.8171 Kg/sec	FR1= 7.3764 Kg/sec

Calculations

108.8171 X 2 = 217.6342

$\sqrt{217.6342} = 14.75$

14.75 X 2 = 29.50 (FT1)

In order to minimize or eliminate shrinkage from the casting, three types risers have been designed.

IV. EFFECT OF THREE TYPES OF RISERS

Risers with three different dimensions have been modelled using CATIA V5 software. The type-1, has 6 risers each of dimensions 67.5 mm diameter, 67.5 mm height.

Table 1. Type 1 Riser dimensions of scrapper

	Height(mm)	**Diameter(mm)**
Type 1 riser	67.5	67.5

This is the exact geometric model of the casting the present day industry is implementing. It is clear from the Figure 3 that shrinkage porosity is severe beneath the sprue.

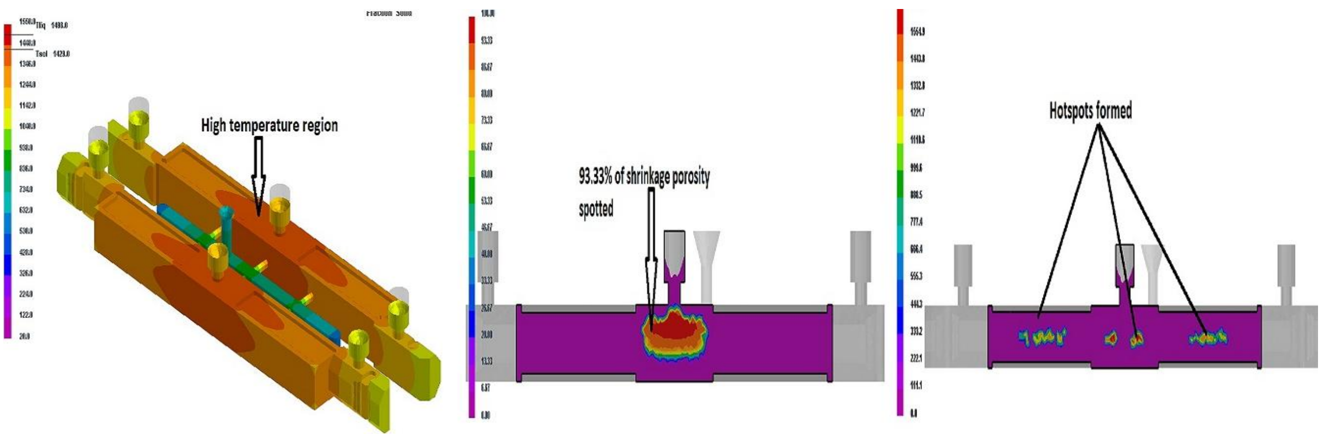

Figure 3. Simulation results of casting showing temperature profile, shrinkage porosity and hotspots of type 1 riser

In type-2 riser dimensions of only central riser have been changed while dimensions of the remaining risers were maintained constant. Central riser diameter is increased to 110 mm and height is maintained the same as that of type-1. The simulated results are given in Figure 4.

Table 2. Type-2 Riser dimensions of scraper

Central riser		**Left and right risers**	
Height(mm)	**Diameter(mm)**	**Height(mm)**	**Diameter(mm)**
67.5	110	67.5	67.5

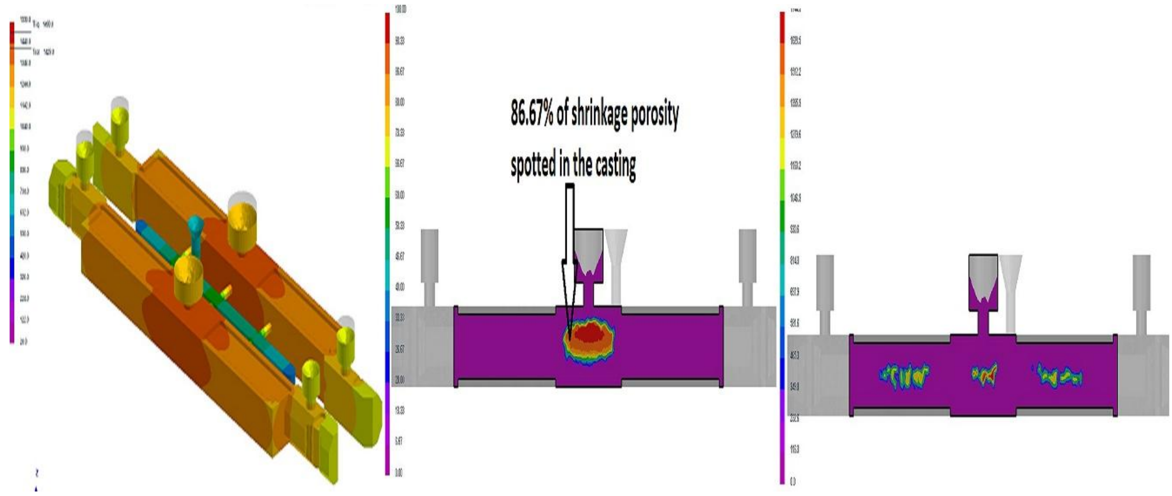

Figure 4. Casting simulation results of type 2 riser showing the temperature profile, shrinkage porosity and hotspots.

The type-2 riser did not alter the amount of shrinkage when compared with the type-1 riser, therefore, the riser has been redesigned as explained below.

Table 3. Dimensions of the Type-3 Riser

Central riser		**Left & right risers**	
Height, mm	Diameter, mm	Height, mm	Diameter, mm
110	102.5	110	102.5

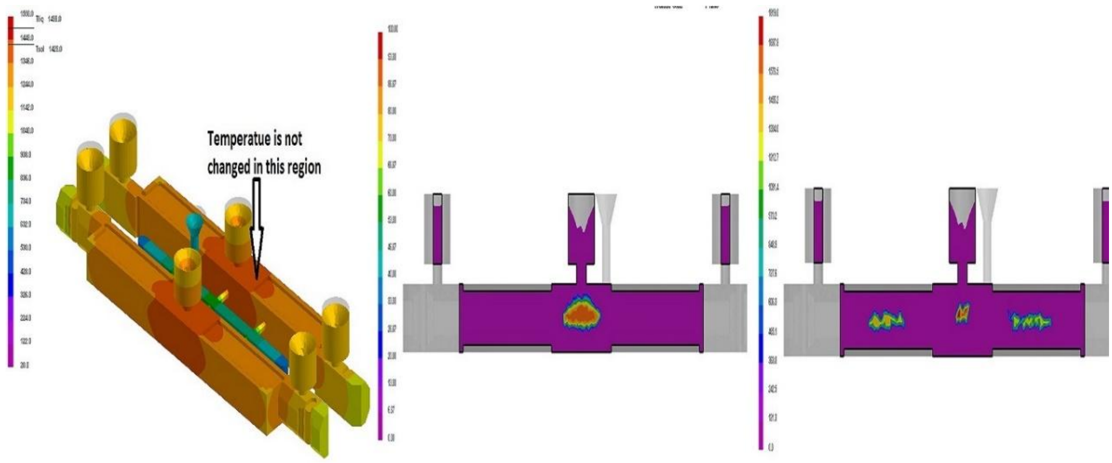

Figure 5. Simulation results of type 3 riser showing temperature profile, shrinkage porosity and hotspots

In type-3 riser system, dimensions of all risers have been maintained constant as shown in the above Table 3. Simulation studies have been carried out by incorporating the type-3 riser system and results are shown below in Figure 5.Comparing to previous versions of riser this type-3 riser exhibited somewhat less amount of shrinkage, however, shrinkage defect is still present. Other researchers [9-11] have also reported similar results in nonferrous alloy castings. A chill is proposed to be incorporated to promote directional solidification.

A. Adding of copper chill and its effect on the shrinkage porosity

A copper chill has been modeled such that its surface is in contact with casting. The copper chill of 1492 x 125 x 20 mm has been incorporated into the mold and simulated. The 20 mm thick chill has shown slight decrease of shrinkage porosity. In order to eliminate the shrinkage porosity completely the thickness of the chill has been increased from 20 mm to 40 mm to 60 mm. The simulation studies have clearly revealed that by incorporating chill together with all risers of same dimension have totally eliminated the shrinkage porosity and hotspots. After adding chill to the scrapper, the simulation results revealed no shrinkage as shown in the Figure below. However, some recent studies [12-14] revealed opposite results

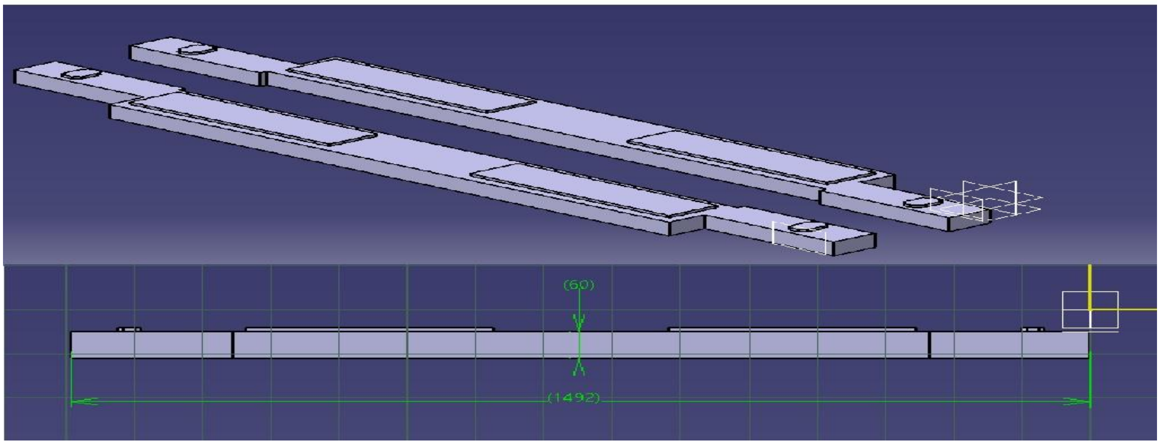

Figure 6. Designed copper chill of dimension 1492 X 125 X 60 mm

as their model has some vacant spaces between the chill and the mold wall leading to lower heat transfer coefficient.

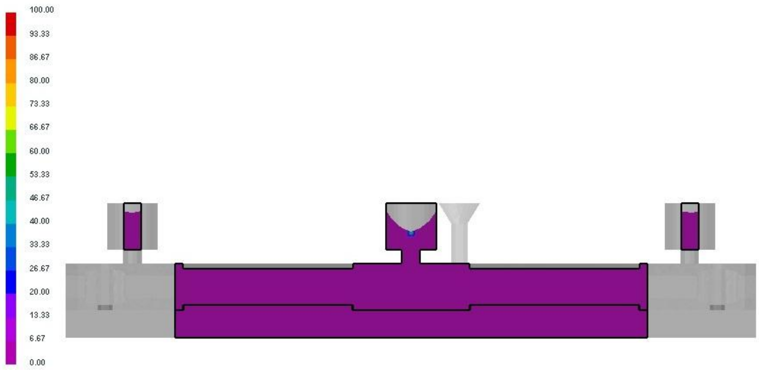

Figure 7. shrinkage porosity totally diminished to 0% after adding the copper chill

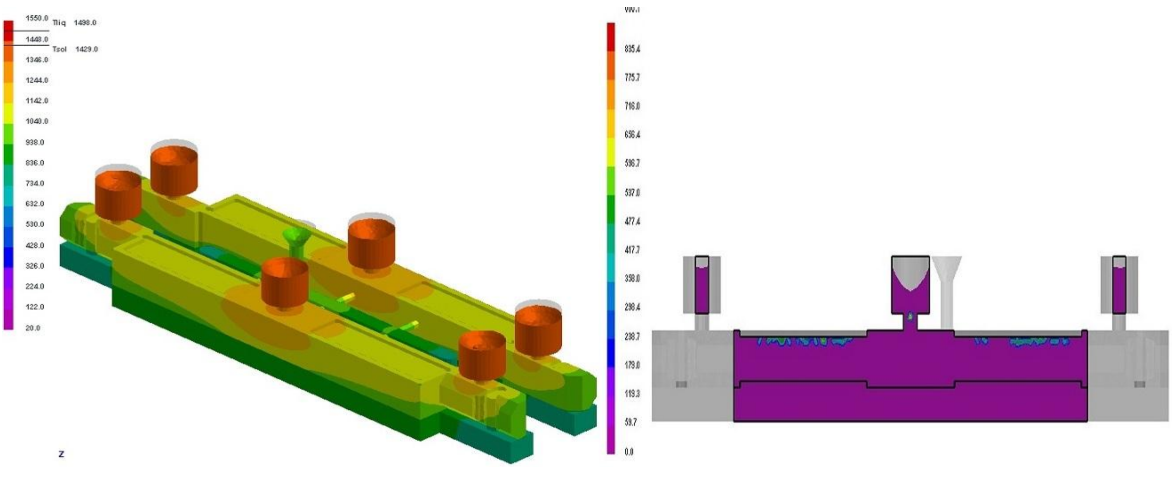

Figure 8. simulation results of scrapper showing the temperature and hotspots

V. CONCLUSION

Using FEM based commercial software risers and chills have been designed to successfully eliminate the defects that are generated in the casting. Temperature profile in type-1 riser exhibited longer solidification time compared to other types of risers. The temperature recorded in the type-1 riser has been 1488 °C, where as in type-3 riser 1346 °C.

Shrinkage porosity in type-1, 2, and 3 risers have been found to be respectively 93.3%, 86.67% and 80%. Thus type-3 riser in combination with 60 mm chill has been selected to be the mold configuration to eliminate shrinkage porosity successfully.

Hotspots in type-1 riser found to be 1555 seconds where as in type-3 riser it has been least compared to other type-2 the amount present is 1213 seconds.

A. After employing the chills in the mold

When copper chill of dimensions 1492 x 125 x 60mm used with the scrapper casting in combination with type-3 riser resulted in 1142 ^{0}C temperature leading to zero percentage of shrinkage porosity in the casting. Hotspots also reduced significantly from 1213 to 477seconds.Thus 60 mm thickness copper chill eliminated porosity defect in the scrapper casting of AISI 1040 steel.

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