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# "Minimise the Nonfilling defect in the high pressure casting process component for an automotive application with metal flow simulation analysis".

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**Abstract*:*** The High pressure die casting process is the one of the vital leading casting process in the world to resolve the all engineering applications .The High pressure diecasting products are used in so many applications like, aerospace, automotive, domestic, agriculture and other engineering applications. In the High pressure diecasting process the scrap rate is nearly about 7% to 10 %.The scrap rate includes the rejections due to surface defect and internal defects. The surface defects can be visible and can be maximum resolved while process running time. In all surface defects the non-filling is one of the most repeated defects in all configurations of the castings. Some surface defects like coldshot, chipp off, crack, casting broken etc. can be eliminate at the process itself. But the surface defect like nonfilling defect can't able to resolve immediately. It needs some analysis like optimization of machine parameters and tool design concepts.

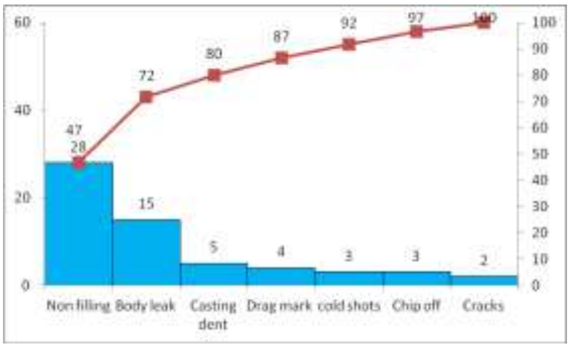
*Key words: Nonfilling, Machine parameters, Simulation flow analysis.*

## 1. INTRODUCTION

The High pressure diecasting process involves the high temperature of molten metal is injected in to the closed steel mould. Depending on the thickness of the casting it should be allow for the sometime (Min- 6sec Max-15sec) for solidification of the casting. Casting will be ejected after the mould opens and extractor will collect the casting. It required cool the high temperatures of the mould to the desired temperature value ($240^0$C).It supposed to cool the mould immediately before taking the next operation. Otherwise the casting will stick to the mould .For this purpose the mould is subjected cool under specialized chemical coolant mixed with RO water. The mould will cool with chemical coolant in some seconds (Min-4sec to Max-10 sec) with spray depends upon the casting area. After that next the cycle is repeats. The casting goes to further operation for removal burr and extra projected material.

## 2. EXPERIMENTAL

In present high pressure diecasting process the rejections are contributing at very high cost. The rejection percentage is up to 9 % and it is the very huge loss to the organisation .These rejection are due to nonfilling 5% ,the body leak 3% and the remaining are the surface defects .The surface defects are contributing up to 1% only .The nonfilling defect also known as one of the surface defect. Some of the surface defects can be reduced in the process itself by modifying the process parameters like the metal temperatures, pressures and velocities. The contribution of the rejection details are shown in the Pareto analysis. The contribution of the rejection details of one batch quantity (500 no's) are shown in the Pareto analysis




Graph 1.0 Diecasting defects Pareto analysis

The above Perato analysis shows the 72% overall casting rejection due to the Nonfilling and the Body leak defect. In which 47% of the casting defects shows the nonfilling defect [1] and 25% of the casting defect shows the Body leak. The rest of the defects are contributing the casting surface defects like dent, drag mark, colds shut and chip off etc. The aim of this Pareto analysis is to minimise the nonfilling defect. The below figure shows the nonfilling defect casting:


Fig: 1.0 Nonfilling defect

In order to minimise the above casting defect the flow simulation method has been initiated to check the flow of the metal temperatures at the different location and to identify the defect location in the casting. During this analysis four flow simulation metal flow paths are identified. The simulation flow path means the runner design only. Four runner design models are identified in this simulation model. In these four models the runner cross section is different and area of metal flow path is different. One of the widely used simulation model in the casting process is MAGMASOFT (Computer simulation) [2]. Several modules are available in this model is molten metal flow in sand casting, permanent mould casting (GDC) and Pressure diecasting also.

This software allows the turbulent filling of the molten metal into the mould. The complete mould model is put into the one MAGMA FLOW analysis tool for checking the metal temperatures at different locations and analyse the defect occurrences. During this flow simulation [3] analysis we can find out the metal temperatures at each location from start point (runner) to the end level ( chill vent).The metal temperature in the mould should be different at the each location while metal flowing time with different colour codes .The metal temperatures are varying at different location depends upon the metal speed, component profile, wall thickness of the casting and distance from the metal entry .If metal temperature is less means there will a chance of casting defect at the location.

### 2.1. The simulation methodology is having the following phases [4]:

#### 2.1.1 Machine capacity calculation:

Depending on the casting configuration and area of the component the machine capacity to be finalized. This is to be completed before going to the simulation analysis. Machine tonnage is defined in the terms of tonnage like 800T, 900T. etc. The machine capacity depends up on the area and profile of the casting.

#### 2.1.2. Mathematical Calculation:

The complete 3D-model dimensions are required for the all segments of the mould. Dimensions of casting include core and cavity, runner, in gates, overflows and channels. The 3D model also consists of die segments including cooling or heating lines .These are all need to be synchronized for the mathematical calculations. During this calculation plunger tip size and chamber dimensions to be added.

#### 2.1.3. Model preparation:

The 3D Model is prepared based on component drawing. The shot model to be prepared includes core and cavity side, runner, gate design, overflows as well as of die segments including cooling and heating lines.

#### 2.1.4. Input interface and Execution of the process parameters:

Present days the parameters will be interface by the machine capacity itself. All parameters are inbuilt in the software according to the machine capacity. If enter the machine tonnage the parameters will be displayed on the screen with min and max range. It will depend up on the casting weight, thickness and area of the casting. During interface the simulations with input parameters, first go with low level next go with medium and go for higher level of range in the final stage. All these stages are verified until get the final model. Run the model by parameter change and verify the temperature changes at location. It is called as one iteration. For each iteration it takes 15 hours to 20 hours to get the final result. It supposed to do more iteration to get the final model. During execution meshing process to be carried out to get high accuracy of the simulation. Meshing is the process of in which the continuous geometric space of an object is broken down into thousands or more spaces to properly define the physical shape of the object.

**2.1.5. Evaluation of the result:** After meshing, the results are evaluated to get the final model. During this final model we can find out the following results:

- At the each location Metal temperatures, Pressures and velocities along with the plunger travel length.
- Flow of molten metal direction through the mould.
- Total time taken to fill the molten metal in the mould

- First and last filling area in the mould
- Too early and too fast filling areas in the mould
- Solidification process time and phases of solidification
- The formation of microstructure and properties
- The formation of residual stress and distortion
- Possibility of blow hole and shrinkage formation
- Shot curves formation.

**2.2 Runner design for the simulation models:**

Total 18 cycles (stages) collected with each model about the filling position of the molten metalTotal 18 cycles (stages) collected with each model about the filling position of the molten metal.

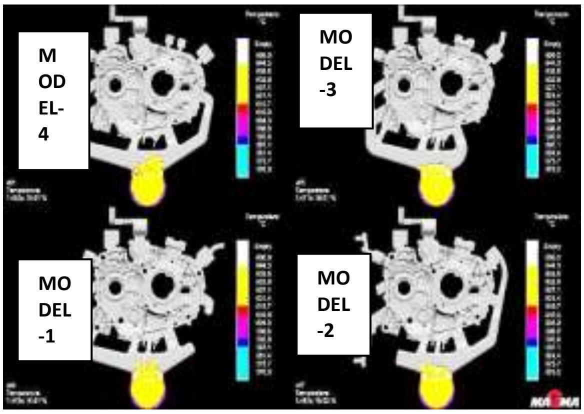



Fig: 2.0 The runner design models in four types for the simulation model

The above model shows the runner design models in four types for the simulation model. Model is designed for the four types of the flow analysis in the automotive component. During the flow analysis the runner design have modified with different location of metal inputs to the casting. Here only the metal input locations have been changed in the flow analysis. During the simulation model the metal has been flowing into the mould cavity in three phases by the machine injection system in which it is also called three phases of shot [5] applications. On the first, slow approach phase the metal is bought up to the gate and in a second phase, it is pushed into the die cavity in a short filling time with high injecting speeds. In the third phase (Multiplication pressures) [6], the casting is consolidated under high pressure, which is created with the aid of an intensifier control system. Against the shot phases, the simulation flow of molten metal as shown in the models at different stages. Each stage of the simulation model consists of the molten metal fill time and percentage volume of metal filled in the mould.

**2.3 First phase (S1) velocity or slow shot speed:**

The metal flows from the starting point of the mould i.e. origin of gate level with the low speed. The low speed velocity is called the 1st phase speed. In this approach the piston is moving at the slow speed of 0.18 m/sec until the metal reaches up to the gate through the runner. It is also called of the slow approach phases or First phase (S1) approach. The thermal flow analysis in the four models during the first dispalcement is shown in following figure.

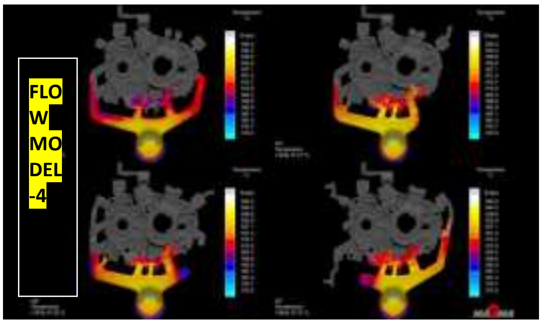



Fig:3.0 Metal flow during Firsr phase

**2.3 Second phase (S2) High Velocity**:

The flow starts from the nozzle to the top point of mould with high velocity. It is called the second phase velocity. When the molten metal is reached the gate, the high velocity valve is activated then molten metal is pushed into the die cavity in a short period of filling time (in milli seconds) with high speed .The velocity of the molten metal at this stage is 3.35m/sec. This phase is also called S2 approach. After completion of the second phase the third phase approach will start. The flow analysis in the second phase ending to third phase is as follows:

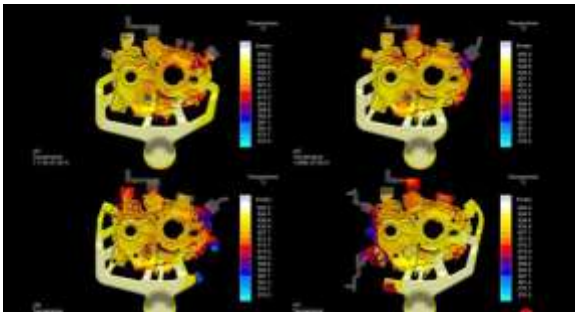


Fig 4.0 Metal flow during second phase

In above second phase the molten metal flows into the mould cavity with high velocity at a speed of 3.5 m/sec.The above thermal image show the metal temperatures in complete mould in the four simulation models. The filling time (Filling process) [7] will be different at each model of flow analysis while flowing the molten metal with different runner cross sectional areas. This is because of the metal flow path is different at each model. During the second phase the metal will fill in the entire cavity up to the overflows. During this stage the thermal stresses [8] are developed in the mould cavity. Gate velocity [9] will be different at each model and it depends upon runner design. In reality this velocity has to be calculated utilizing (the $PQ^2$ diagram) [10].

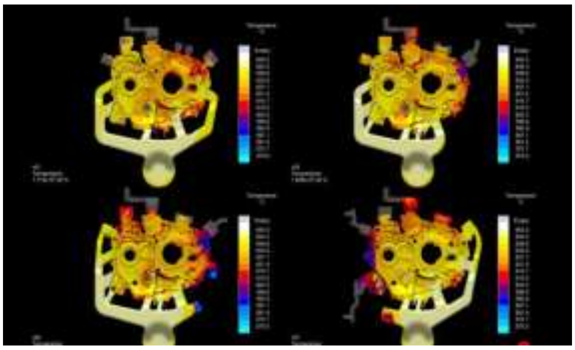


Fig 5.0 Metal flow during third phase

**2.4 Third phase (S3) or Intensification pressure:** In This phase the pressure acts after the cavity filling is completed. The hydrostatic pressure is applied to the casting before solidification. In this stage the casting will get more compactness. In the third phase the casting is consolidated under high pressure, which is created with the aid of an intensifier control system. Here 250 $Kg/cm^2$ pressure is acting on the casting .The pressure applied in this phase is called multiplication pressure. The figure 5.0 shows the simulation of intensification pressure acting position.

**2.5 Filltime and fill ration of the models:**

Total 18 cycles (stages) collected with each model about the filling position of the molten metal

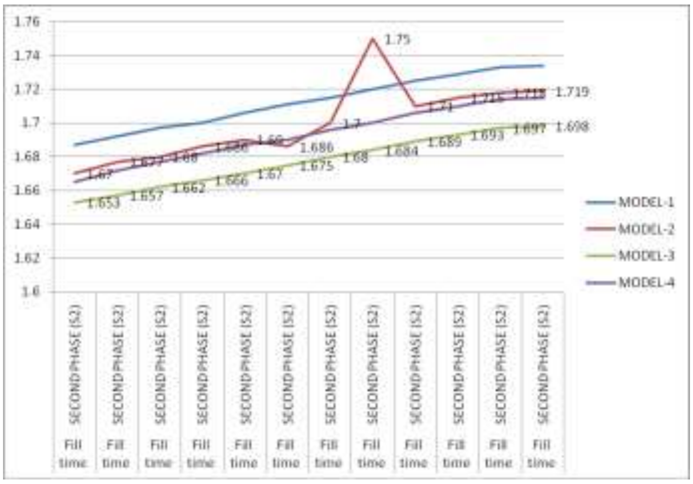
The following table shows the filling time and filling ratio of the four models at each stage. The first phase conditions about from stage-1 to stage-4. It is not considered due to low velocity of speed (0.18 m/sec). Second phase (stage 5-17) and third phase (stage-18) shot condition was displayed in the following table.

| | | | | | |
|---|---|---|---|---|---|
| STAGE-5 | Fill time | 1.687 | 1.670 | 1.653 | 1.665 |
| | Fill ratio | 47.000 | 47.000 | 47.000 | 47.000 |
| STAGE-6 | Fill time | 1.692 | 1.677 | 1.657 | 1.672 |
| | Fill ratio | 52.030 | 52.000 | 52.020 | 52.020 |
| STAGE-7 | Fill time | 1.697 | 1.680 | 1.662 | 1.677 |
| | Fill ratio | 57.030 | 57.010 | 57.000 | 57.030 |
| STAGE-8 | Fill time | 1.700 | 1.686 | 1.666 | 1.682 |
| | Fill ratio | 62.030 | 62.000 | 62.030 | 62.010 |
| STAGE-9 | Fill time | 1.706 | 1.690 | 1.670 | 1.687 |
| | Fill ratio | 67.010 | 67.000 | 67.010 | 67.020 |
| STAGE-10 | Fill time | 1.711 | 1.686 | 1.675 | 1.690 |

| | | | | | |
|---|---|---|---|---|---|
| | Fill ratio | 72.020 | 72.010 | 72.010 | 72.010 |
| STAGE-11 | Fill time | 1.715 | 1.700 | 1.680 | 1.696 |
| | Fill ratio | 77.010 | 77.000 | 77.000 | 77.010 |
| STAGE-12 | Fill time | 1.720 | 1.750 | 1.684 | 1.700 |
| | Fill ratio | 82.010 | 82.000 | 82.000 | 82.000 |
| STAGE-13 | Fill time | 1.725 | 1.710 | 1.689 | 1.706 |
| | Fill ratio | 87.000 | 87.000 | 87.000 | 87.000 |
| STAGE-14 | Fill time | 1.729 | 1.715 | 1.693 | 1.710 |
| | Fill ratio | 92.000 | 92.000 | 92.000 | 92.000 |
| STAGE-15 | Fill time | 1.733 | 1.718 | 1.697 | 1.714 |
| | Fill ratio | 96.010 | 96.010 | 96.000 | 96.000 |
| STAGE-16 | Fill time | 1.734 | 1.719 | 1.698 | 1.715 |
| | Fill ratio | 97.000 | 97.000 | 97.000 | 97.000 |
| STAGE-17 | Fill time | 1.735 | 1.720 | 1.699 | 1.716 |
| | Fill ratio | 98.010 | 98.010 | 98.000 | 98.000 |
| STAGE-18 | Fill time | 1.737 | 1.722 | 1.722 | 1.718 |
| | Fill ratio | 100 | 100 | 100 | 100 |

Table: 1 Fill time and fill ratio in simulation Model

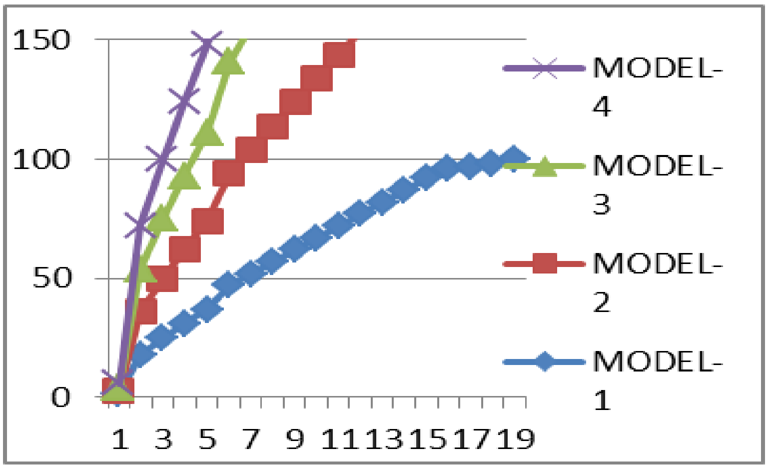
Note: 1. Fill time: Time required filling the molten metal in the mould .2. Fill ratio: Volume of metal filled in the mould in unit time.




Graph 2.0 The filling time in each model for each cycle in Second phase condition

In the above graph shows the filling time in each model for each cycle in Second phase. In the above Simulation the simulation model 3 is having the low filling time compared to the other models. Here filling time is important. If the filling time is more the molten metal will solidify before reaching the end point of the casting. There may be chances of the overlapping of the solidification layers and surface defects like non-filling defect. During this time the molten metal will solidify with fewer temperatures and there will be uneven solidification and chances internal defects also. The hidden air and gases inside the mould will not escape thought the mould timely. At the same time the molten metal temperature will not reach up to end point of the component profile. The above problems will be eliminating with the lower side of the filling time.

**2.6 Filling ratio evaluation**:




Graph 3.0 Fill ratios of the all simulation models

The above graph shows the fill ratio of the all simulation models. Here fill ratio means the area of molten metal filled in a unit time (fraction of seconds) inside the mould cavity. When compared to all simulation models the fill ratio of model- 4 is more compared to the other models

**2.7 Simulation model parameters comparison:**

The model-1 and model-2 are not considered due to the fill time is high and fill ratio is less in both models.

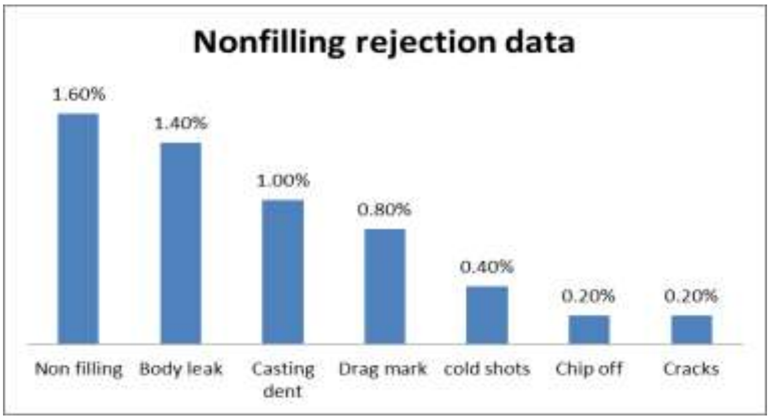
**2.7.1 Simulation Model-3:**

When compared to all fill times the Model-3 fill time is less. It is good for proper metal formation. But at end point of the over flows area the metal temperatures are very less ($592^0$C - $615^0$ C) compared to Simulation Model-4 .At the same time in Model-3 the metal temperatures are less ($598^0$ C -$615^0$C) at the chill vent areas also.

**2.7.2 Simulation Model-4**:

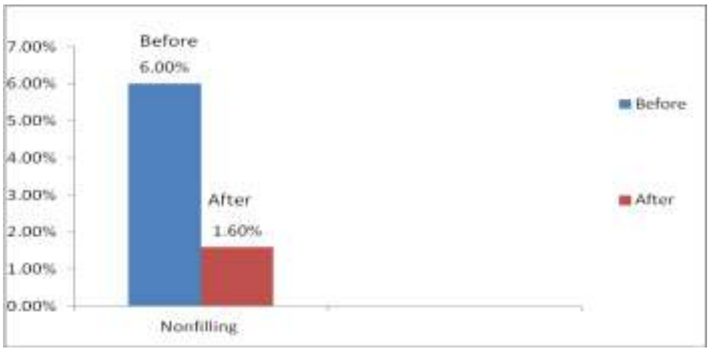
The fill time is almost equal in model-4 compared to model-3. The molten metal temperatures are high at chill vent and overflows area compared to model-3. If the metal temperatures are high then there will be increase in die temperatures. Due to this there is a chance of immediate casting formation and less chance in formation of surface defects. So At this stage the hidden gases in the mould cavity will escape through the cavity without remain in the die. The gases will escape before metal filling in the mould. Here metal temperature and mould temperature both are contributing to escape the internal hidden gases.If the metal temperatures are high then there will be less chance of formation of bubbles in molten metal while metal flowing and during the solidification time. Simultaneously there may be fewer chances of internal defects like blow holes, shrinkages formation. So it is recommended that model-4 is best suited for the mould maker to manufacture the mould.

The mould has been prepared as per the simulation model-4 only for the runner design. The dimensions are made as per the component drawing. Trials conducted for the dimensional inspection. After completion of dimensional inspection, 500 no’s of batch production planned for validation of the process rejection and productivity. The complete rejection trend with this simulation model-4 is as shown in figure




Graph:4.0 Non filling rejection data

**3.0 RESULTS AND DISCUSSION:**




Graph 5.0 Initial nonfilling and final nonfilling

The above graph shows the nonfilling defect rejection down trend .The nonfilling defect is reduced from the 6.0 % to 1.60% with the flow analysis method and practical experiments. Before the simulation methods the diecaster fine tunes the process parameters until get the new defect free casting from the machine and the mould. The entire calculations have been doing with manual methods and it is time taking process.

The diecasting experienced persons should be incorporated while preparing the simulation process design models. The designer will explain the model but the experienced person can find out actual root causes of defect and where it will occur during model preparation. If we use more mesh tool means more model accuracy will come. The metal temperature plays a vital role during the diecasting process .The most important step of the simulation model design is the choice of testing model. It is the most important tool to the diecaster. It reduces the rejection cost and increases the production time also. With this Simulation models the energy consumption of diecasting machine will reduce and eliminates the unscheduled machine downtime also. The information generated by the casting simulation is very importance to the designer. In the Present days so much simulation models are available. But it is constrain on price. MAGMA simulation method is available in present scenario.

**4.0 CONCLUSION OF THE FUTURE WORK:**

Simulation model is applicable to all diecasting industries. It will give good margins to the organisations. The wastage due to rejection cost will be equal to the simulation package. The Simulation in the design of high pressure diecasting is much less than in steel casting simulation. High quality of the castings can be produced. Simulation software does not give 100% results but it will give the information to the mould maker from the major mistakes. More importantly, mould flow simulation should be considered as necessity activity in any new project so that time, cost and quality requirements can be achieved. Waste in the sense rejections and machine breakdowns can be eliminated. Simulation model to be use in the new projects it will give saving in time, money and improves customer satisfaction.

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