Analysis and Simulation of Die Filling in Gravity Die Casting using MAGMA Software

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***Abstract*—This paper explains the application of Magma Software to model the filling of gravity die casting and using it to check the defects present, if any. The simulation results demonstrate the filling of the die cavity and show how the filling process would actually take place. A die used for making spanner castings is used in this research. This paper discusses about various parameters such as cavity fill time, percentage of air entrapment in the mould after filling and cooling, velocity of metal, solidification time of metal and shrinkage porosity. The effects of these parameters on the die castings are also discussed in this paper.**

Keywords—Casting simulation, casting defects, air entrapment, shrinkage porosity,solidification tim,MAGMAsoft.

INTRODUCTION

Designing a new mould is often most expensive single investment in product development so we have to find out where the problems may arise before we manufacture the mould or die. For this we need a simulation software.[5] The primary purpose of the simulation software is to predict the various casting defects such as air entrapment, residual stresses, distortion, shrinkage porosity, etc. for a given die design. Then the casting simulation software can be used as a virtual shop floor of a casting plant to simulate various gating design options to optimize the design and to increase the yield and reduce rejections. Computer simulation of casting is based on the concept of mathematical modeling of manufacturing processes. In any mathematical model, the physical reality is idealized and approximated. As a result, there will be certain deviations between practical/field/plant observations and modeling or simulation results. However, by having a proper understanding of modeling procedures, and the physical reality, this gap between physical reality and simulation results can be minimized[6].

The casting simulation technology has sufficiently matured and has become an essential tool for casting defect troubleshooting and method optimization. It enables quality assurance as well as high yield without physical trials.[3] Productivity is improved, higher value castings can be taken up, and internal knowledge can be preserved for future use and training new engineers[2].

Therefore the MAGMA software is used for simulation of the filling in of the gravity die casting and various parameters are calculated in this process. Proper analysis of these parameters helps us to find out the defects in the die design and make changes in the design accordingly.

Physical steps in Gravity Die Casting process:

The various steps which are involved in the production of castings with the help of die are as follows:

1) Melting and alloying
2) Transportation of hot melt
3) Closure of the dies
4) Pouring of the hot metal into the die cavity
5) Removal of air from the die cavity
6) Heat transfer (loss) during flow
7) Heat transfer with phase change(Solidification)
8) Solid state heat transfer
9) Residual stress formation and distortion
10) Component ejection
11) Machining

In this paper, analysis of steps 4 to 8 have been carried out using MAGMA software. Firstly, the design of the component of which the castings are to be made is given to the die or mould design department. This design is in the form of a CAD model. With the help of this model, the designers design the die which would be used in the production of the castings. They make necessary changes a in the die based upon the design of the component. In Gravity die casting process gate is made for pouring the molten metal into the die and risers are also provided in the die. The blue part which is shown the figure is the required component and the rest of the parts which are generated due to gate and riser systems can be removed in the machining process.

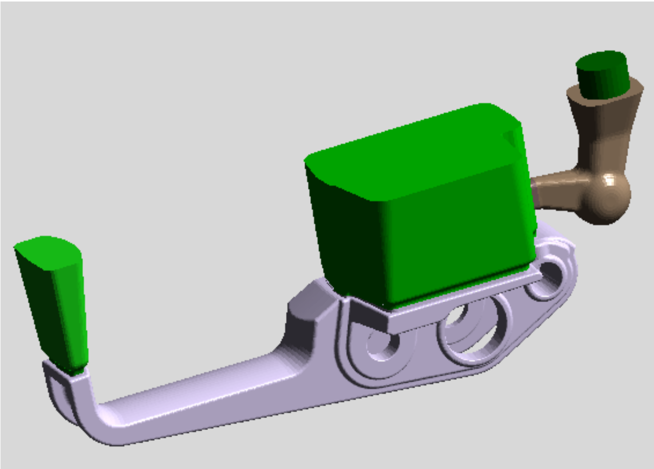

Fig. 1. CAD model prepared of the spanner

Pre-processing:
It is a general terminology used for all simulation model setup related activities. In this stage the physical reality is translated to computer simulation model. This is a key stage and has many steps:

1) *Meshing:*

Meshing is used to define the continuum solid to what are called nodes and elements. All the flow and heat transfer equations are solved at these nodal points. Type and number of elements (mesh points) is the choice that the engineer has to make. For larger number of elements, result is higher computational effort and time where as less number of elements might result in unrealistic geometry.

Mesh size will also have an effect on accuracy results. For instance, in the sharp features region, it is better to have more number of elements.

2) *Material properties:*

Material properties of the melt and the die/mould have to be properly defined .One of the key issue is to get the temperature dependent thermo mechanical properties such as diffusivity, thermal expansion, viscosity, Young's modulus, etc. The temperature of solid and liquid determines the shrinkage porosity and has to be precisely defined. The software provides such data for different alloys and is stored in the simulation software itself, but still it is always better to get the values cross checked.

3) *Process definition*

Process definition includes inlet velocity, estimated filling time, pouring temperature, use of exothermic powders, coating cycles, etc.

4) *Boundary conditions:*

Boundary conditions are used to specify the process details such as temperature pressure, velocity, etc. The interference heat transfer resistance , convection heat transfer from die to surroundings, die cooling circuits are also included in the boundary conditions. The friction between the melt and the die surface also needs to be mentioned.

Cavity filling simulation:
Two options are available, coupled simulation and stand alone simulation. The hot spot of the component is first predicted by heat transfer analysis in the beginning of gating design.

The alloy used for making the castings is LM25 (AlSi10Mg). It is melted in a furnace and transferred near the die and poured into the mould manually. The pouring temperature is about 730^{o}C and the mould temperature is around 350^{o}C.The estimated fill time is 7 seconds. The further results show that this time is suitable and the pouring velocity does not cause any problem in causing any defects in the casting. Figures 2-5 show the screenshots of the alloy filling into the die cavity as shown in MAGMA software.

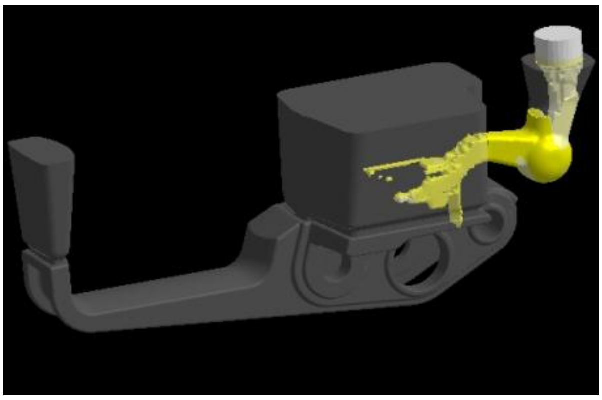

Fig. 2. Filling screenshot with temperature at 0.4 sec

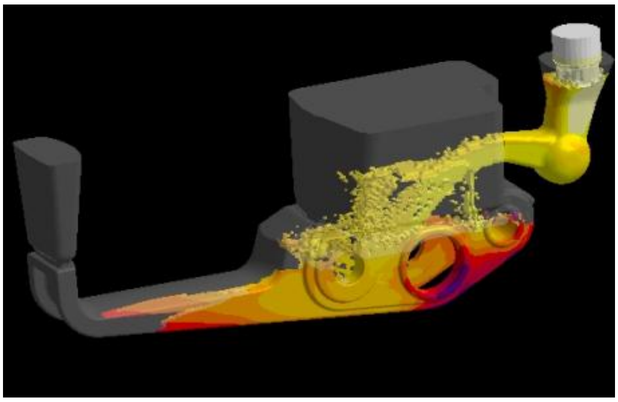

Fig. 3. Filling screenshot with temperature at 1.0 sec

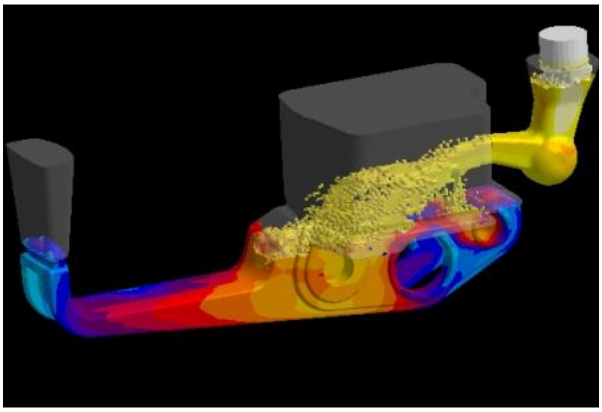

Fig. 4. Filling screenshot with temperature at 1.7 sec

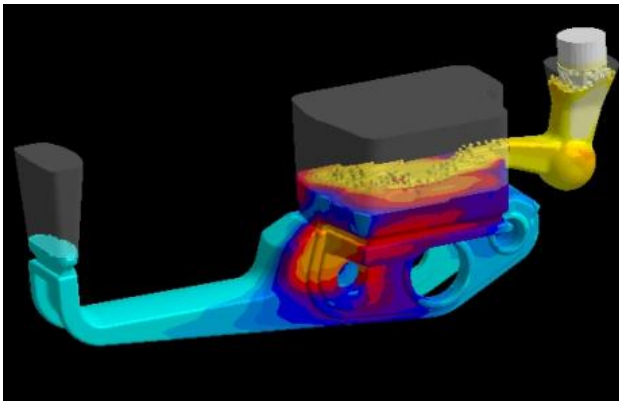

Fig. 5. Filling screenshot with temperature at 3.3 sec

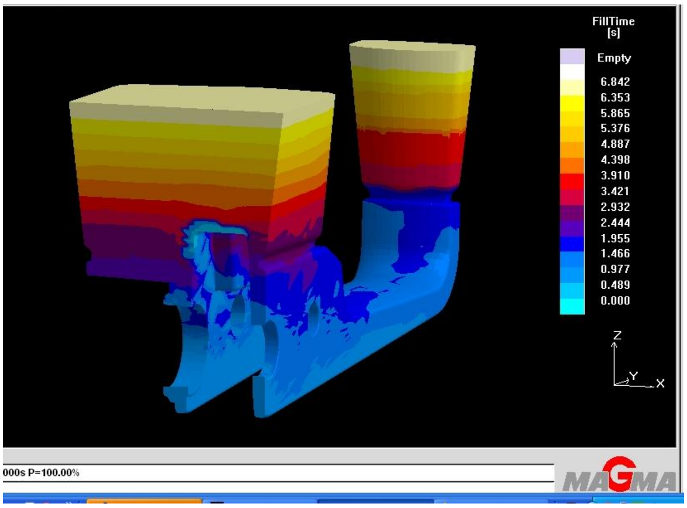

Fig. 6. Layer wise representation of filling time

The formation of various casting defects is directly related to the fluid flow phenomenon during the mould filling stage and in the cast metal [4]. The filling of the lower main part is less than 4 seconds and is evenly distributed. Hence we can infer that the estimated filling time is correct for this casting.

Solidification:

The rate of solidification greatly affects the mechanical properties such as strength , hardness, machinability, etc.[4]. For this particular die, the time required for solidification was around 170 second for the main part.In this time the spanner part had been solidified while solidification was going on in the gate and riser system. There was no hot spot generation which is good for the casting process. The total time required was about 200 second for cooling the entire casting. The total solidification time is also called as the die open time. After 200 seconds the die can be opened and the casting can be ejected from the mould. The MAGMA software gives layer by layer information regarding the solidification time required by a particular layer as shown in the fig().It can be inferred that the solidification rate is correct and doesn't affect the mechanical properties greatly.

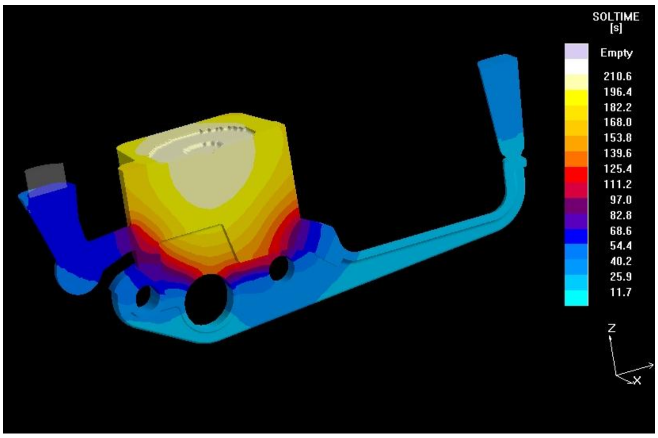

Fig. 7. Solidification time

Shrinkage porosity:

Shrinkage porosity is one of the most common defects to the rejection of aluminium castings. It can be described as internal cracks in the castings which come from several sources. The causes of shrinkage porosity are increased metal concentration at a specific region, complexity in casting geometry, poor gating and runner design, reduced metal volume during solidification. In this process the MAGMA software also gives the information about shrinkage porosity present in the casting after solidification. This shrinkage porosity is depicted by the means of layer by layer graph representation. For this particular die, there was no shrinkage porosity found in the required main casting part. There was porosity indicated in the gate and the riser but that parts are of no use as they would be removed off the main part after machining. It can be seen from the fig() that there is no shrinkage porosity present in the casting.

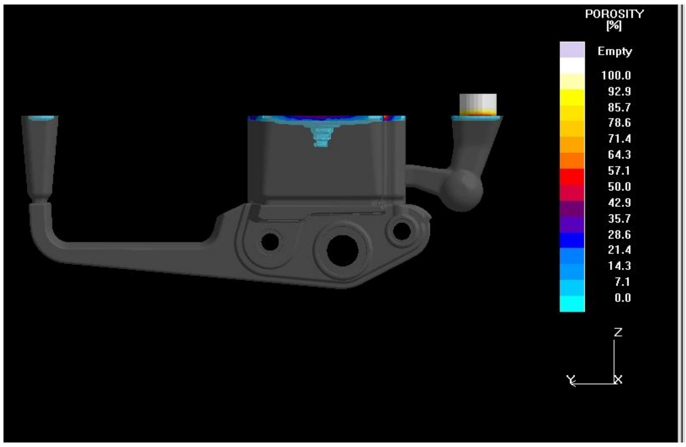

Fig. 8. Percentage of porosity

Gate inlet velocity and air entrapment:

MAGMA software also gives information about the velocity of molten metal in various regions while die cavity filling and the percentage of air entrapment [1]. The gate inlet velocity is the velocity of the molten metal when it enters into the main die cavity. This velocity is very important as the turbulence of the metal flow depends on this gate inlet velocity. For this particular process, the inlet velocity was found to be less than 1 m/s. At this velocity there is minimum turbulence and it does not cause any defects in the casting. Air entrapment is another important parameter. It describes the quantity of air bubbles present in the casting. In this experiment, there were no air bubbles present in the casting.

Post processing:

In this stage, the results of simulation are visualized. Casting simulation is a transient analysis process. This means, the solution results are available from the beginning of melt flow to the end till full solidification. These results have to be captured over specific number of time steps. This has to be properly set in the beginning of model set up. Typically 10-20 and in some cases even 100 steps are saved to get more detailed reports.

CONCLUSION

It can be concluded that the casting simulation has become a powerful tool to predict the location of defects and eliminate them by visualizing mould filling, solidification and cooling. It can be used to trouble shoot the existing castings or to develop a new castings without shop-floor trails by using fewer resources which reduces cost and time to market [2].

The simulation of cavity filling of the spanner die with the molten metal was carried out with the help of MAGMA software. The whole process was depicted as a movie clip in which how the actual physical process of die casting production would actually take place. Various other parameters were also analyzed. The pouring temperature, mould temperature both were correct. The gate inlet velocity, filling time, solidification time were all within limits. The shrinkage porosity was absent and there was no air entrapment. Hence we can infer that this simulation was successful and since no defects were found, this die design can be approved and used for making castings.

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