International Journal of Mechanical Engineering and Applications
2022; 10(4): 53-58
http://www.sciencepublishinggroup.com/j/ijmea
doi: 10.11648/j.ijmea.20221004.12
ISSN: 2330-023X (Print); ISSN: 2330-0248 (Online)

Design and Process Optimization in Die Casting Through Conformal Cooling

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To cite this article:
Boopathy Janarthanam, Rushikesh Nanasaheb Patil, Mayur Laxmanrao Jadhav. Design and Process Optimization in Die Casting Through Conformal Cooling. *International Journal of Mechanical Engineering and Applications*. Vol. 10, No. 4, 2022, pp. 53-58.
doi: 10.11648/j.ijmea.20221004.12

Received: June 9, 2022; **Accepted**: July 12, 2022; **Published**: August 17, 2022

Abstract: This study aims to implement the conformal cooling in die casting dies to reduce the cycle time and rejections due to shrinkage porosity. In this paper we have done a flow simulation between conventional cooling and conformal cooling to optimize the cooling time/solidification time reduction and shrinkage porosity reduction in die casting parts where the thick mass area/high wall thickness occurs. In die casting process cycle time Solidification time plays a vital role. In order to optimize the die casting process cycle time, conformal cooling design needs to be introduced in the dies at the thick mass area /variable wall thickness where we are not having any scope in modification of product design to reduce the wall thickness of the part to avoid shrinkage porosity/high solidification time. Apart from solidification/cooling time we can reduce the Shrinkage porosity defect by optimizing the cooling channels from conventional cooling i.e. At which the cooling lines can be manufactured through conventional machining process to conformal cooling i.e. At which the cooling lines are manufacturing through 3D Printing process. Normally in the die-casting process the cavity area solidifies first after that the runner, overflows and biscuit solidifies. Soldification depends upon the thick mass area, where ever thick mass area is there then the solidification is complex.

Keywords: Conformal Cooling, Cooling Time, Solidification Time, Cycle Time Optimization, Shrinkage Porosity, Additive Manufacturing, Die Casting, Simulation

1. Introduction

Recent innovations in the die casting industries is to focus on reducing the Manufacturing cost & to increase product quality. So far in die casting industries Traditional/conventional cooling design is used in dies for cooling the component as well as tool. In conventional cooling there is a constraint for profiled areas where we can't able to provide cooling efficiently with respect to the product/process requirement. In order to overcome this conformal cooling's has been used, where we can optimize the cooling as per the product/process requirement. Conformal cooling can be manufactured through additive manufacturing process. Additive manufacturing of construction materials has been one of the emerging advanced technologies that aim to minimize the supply chain in the construction industry through autonomous production of building components directly from digital models without human intervention and complicated formworks. The Die casting process is particularly inadequate when the product is molded in die casting equipment, there is inadequate material input, the mold temperature changes, molten metal cleanliness check the casting pressure and cooling conditions change and the site works randomly change the standardized working conditions as a result manufacturing site suffering from increasing defect rates [2].

1.1. Die Casting

The Die casting die has four basic functions, those are to hold the molten in the shape of the desired casting, provide a means for the molten metal to get into the space, remove heat from the molten metal to solidify the desired shape, provide for the removal of solidified casting [4], Die casting is a metal casting process that is characterized by forcing molten metal under high pressure into a cavity, the high pressure die-cast process is used to produce parts from aluminum, magnesium, copper and zinc. Parts produced by this process conform accurately to the die size, have favorable mechanical features, and are low in cost. This process also enables production of parts with complex shapes. This production process thus has a wide range of applications in a variety of industries like aircraft and automobile industries and electrical appliance manufacture etc. In foundry operation, the surface of the molten material is always in motion owing to charging, fluxing, degassing, skimming, transferring and mold filling [5], High pressure die casting is an important process in the manufacturing of high volume and low cost automotive components [7]. In Die casting it was found that the charge temperature, Injection Pressure and injection velocity were important parameters for controlling the length, porosity and degree of crystallinity in the as-cast samples [8]. Also it is almost impossible to produce defect free casting [12].

1.2. Shrinkage Porosity

Porosity can be generally categorized as gas porosity, Inclusion, shrinkage porosity and hot tears [6] Shrinkage porosity is one the defects found in aluminum products produced through High pressure die casting process. In Aluminum casting as a product requirement we are getting thick mass/ variable wall thickness, Due to the variable wall thickness/thick mass area irregular voids will get generated inside the casting, which called as shrinkage porosity, Such type of defect effect the inter molecular integrity of casting component due to which it fail to resist pressure, stress, impact testing for the required structure, Normally Shrinkage porosity defect will happen at the time of solidification phase at the thick mass area where we can't able to introduce runner gate. Figure 1 shows the cut section of aluminum part with shrinkage porosity defect. In India many foundry have followed conventional and manual process, Foundry industry suffer from poor quality and productivity due to large number of process parameters combined with lower penetration of automation. [15]

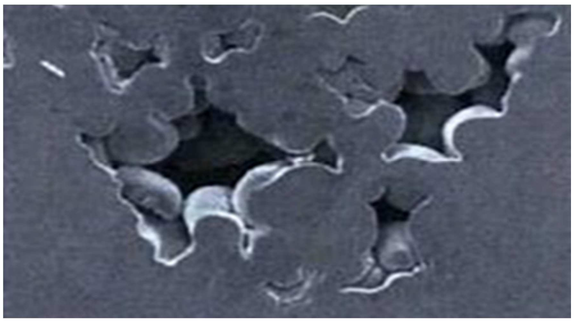

Figure 1. *Shrinkage porosity defect.*

1.3. Additive Manufacturing

Additive Manufacturing technique has prompted the development of conformal cooling, however the accessible cases that include full details of the experiments are limited [1] 3D printing, or additive manufacturing, is the construction of a three-dimensional object from a CAD model or a digital 3D model. The term "3D printing" can refer to a variety of processes in which material is deposited, joined or solidified under computer control to create a three-dimensional object, with material being added together (such as plastics, liquids or powder grains being fused together), typically layer by layer, One of the key advantages of 3D printing is the ability to produce very complex shapes or geometries that would be otherwise impossible to construct by hand, including hollow parts or parts with internal hollow arrangements/cooling arrangements with spiral profile or the profile we need to reduce weight & further improvement projects, Additive manufacturing offers high-freedom in the design processing of components with complex internal structure [3]. SLS Technology adopt the principle of discrete stack forming to make the forming entering the part interior: thereby the internal CCC can be arranged [10].

2. Problem Statement

In the Outer Case Cover aluminum component which is manufactured through high pressure die casting process, we have done a study for reducing the shrinkage porosity & Cooling/solidification time reduction by introducing the conformal cooling design.

3. Design & Analysis – Conventional Cooling

3.1. Outer Case Cover Full Shot Design

The below mentioned design is the conceptual full shot design with runner and overflows to meet the standard requirement for high pressure die casting process.

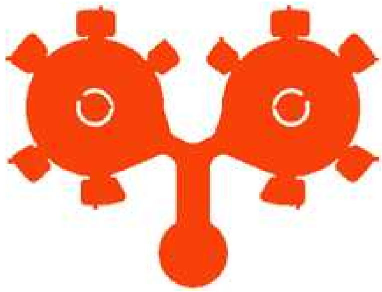

Figure 2. *Conceptual full shot design .*

3.2. Outer Case Cover Design with Conventional Cooling

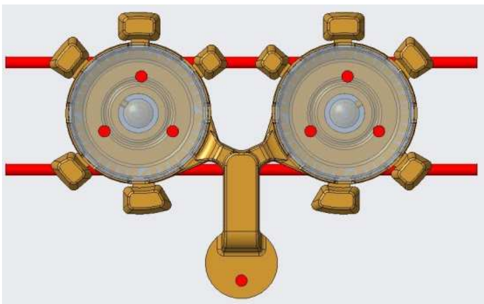

Figure 3. *Conceptual full shot design with conventional cooling.*

Figure 3 denotes the full shot design with conventional cooling, in standard Die casting die consists of Fixed Half and moving half which in general terms we say as core and cavity, apart from the core & cavity there are many parts in die casting tool assembly/ As a general practice in high pressure die casting cooling's will be provided in the core and cavity die parts in terms of channel cooling or spot cooling based on the part requirement. In outer case cover die also at the Fixed side Channel cooling has been Considered and at the moving side center bunk, spreader/Diffuser spot cooling has been considered has highlighted in the picture (Red color). For all the Channel cooling's in and out water passage line will be provided separately but in Spot cooling the in & out flow will be in the same hole which will be controlled in cooling bubblers. In Figure 3 only Die cooling lines with full shot has been shown with hidden core and cavity parts for better understanding of channel cooling & Spot cooling lines .

3.3. Outer Case Cover Simulation Analysis with Conventional Cooling

Generally in die casting runner design process after completion of runner design it will be validated through simulation software in terms of metal filling, air entrapment, shrinkage porosity, Pressure, velocity, solidification & Temperature, as per our study requirement we need to analyze the shrinkage porosity & solidification.

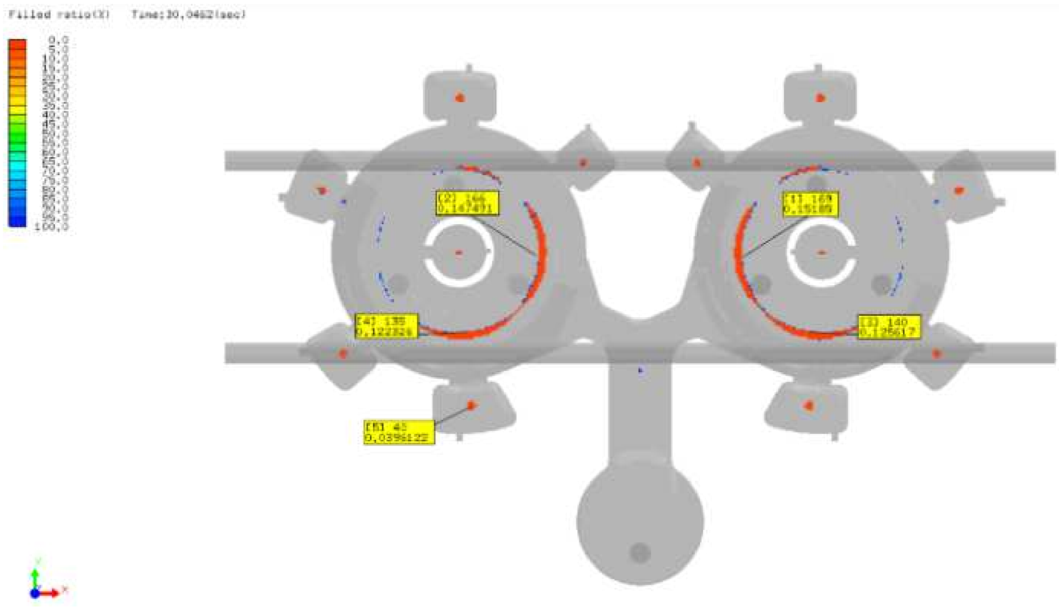

Figure 4. *Simulation results– Prediction of Shrinkage porosity.*

In Figure 4 it shows the analysis of outer case cover shrinkage porosity results, Red color shows the presence of shrinkage porosity and volume of shrinkage porosity has been highlighted in yellow color dialogue box, Based on the results it is observed that shrinkage porosity varies from 0.12 to 0.15.

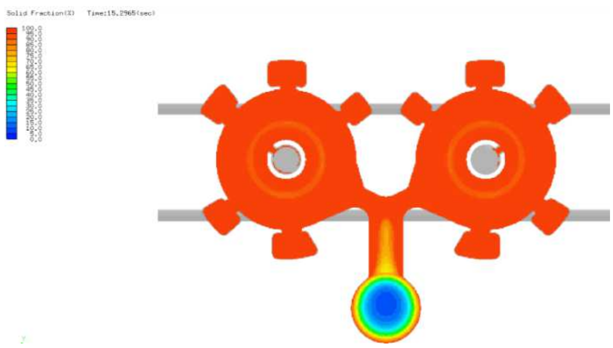

Figure 5. *Simulation results – solidification/cooling time.*

Figure 5 shows the solidification results of outer case cover part with conventional cooling in the left hand side there is a scale which denotes the solidification % where the red color denotes the complete solidification of the component, as per the simulation results it shows it taken around 15.29 sec for solidification of component area.

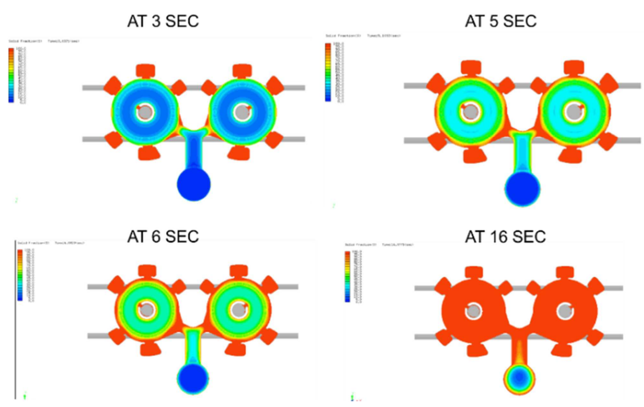

Figure 6. *Simulation results–cooling time with respect to time.*

In Figure 6 it shows the solidification of the outer case cover part with respect to time 3 sec, 5sec, 6sec & 16 Sec. At 3 sec 10% of cavity has been solidified at 5, 6 sec 30-65% Solidification done & Finally at 15.29 sec cavity has been solidified 100%, The process of casting solidification is complex in nature [14], In the cooling phase heat transfers between the molten material inside the cavity and the cooling fluid flowing through the cooling channels in the die until ejection temperature is achieved and part is stable enough for ejecting. [13]

4. Design & Analysis–Conformal Cooling

4.1. Outer Case Cover Design with Conformal Cooling

To overcome the shrinkage porosity issue and reduction in Solidification time, the cooling circuit has been changed from spot cooling to conformal cooling to increase the effectiveness of the cooling.

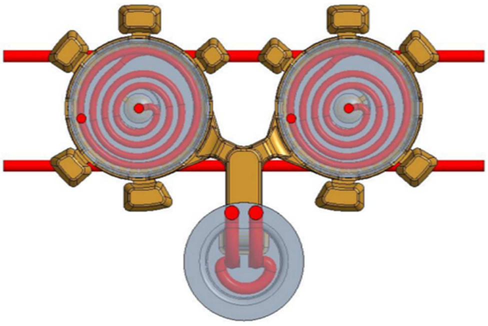

Figure 7. *Conceptual full shot design with conformal cooling.*

Figure 7 shows the full shot design with conformal cooling, Conformal cooling channels are a series of cooling channels that are equidistant from the mold cavity surfaces [9], An effective cooling system can rapidly and uniformly remove heat from molds, but product must be uniformly cooled in mold to minimize shrinkage [11], the conformal cooling has been implemented in the center bunk i.e Core & diffuser to increase the cooling effectiveness nearer to the cavity throughout the surface whereas in spot cooling it is not possible to cool the entire surface.

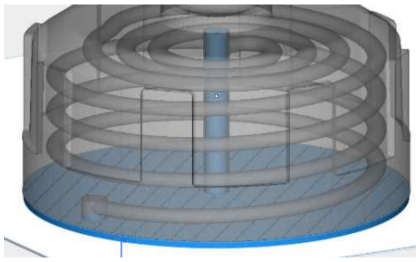

Figure 8. *Centre bunk with conformal cooling design.*

Figures 8 & 9 shows in mirror image of Centre bunk and spreader to view the conformal cooling circuit design easily.

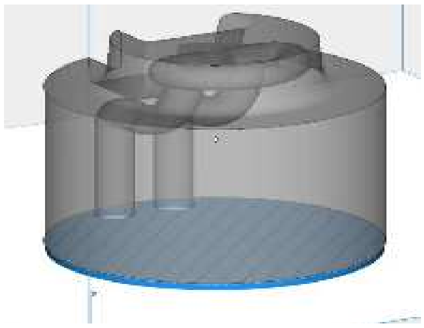

Figure 9. *Diffuser with conformal cooling design.*

4.2. Outer Case Cover Simulation Analysis with Conformal Cooling

The simulation for outer case component has done with center bunk and diffuser with conformal cooling design whereas in conventional the simulation executed with conventional cooling design.

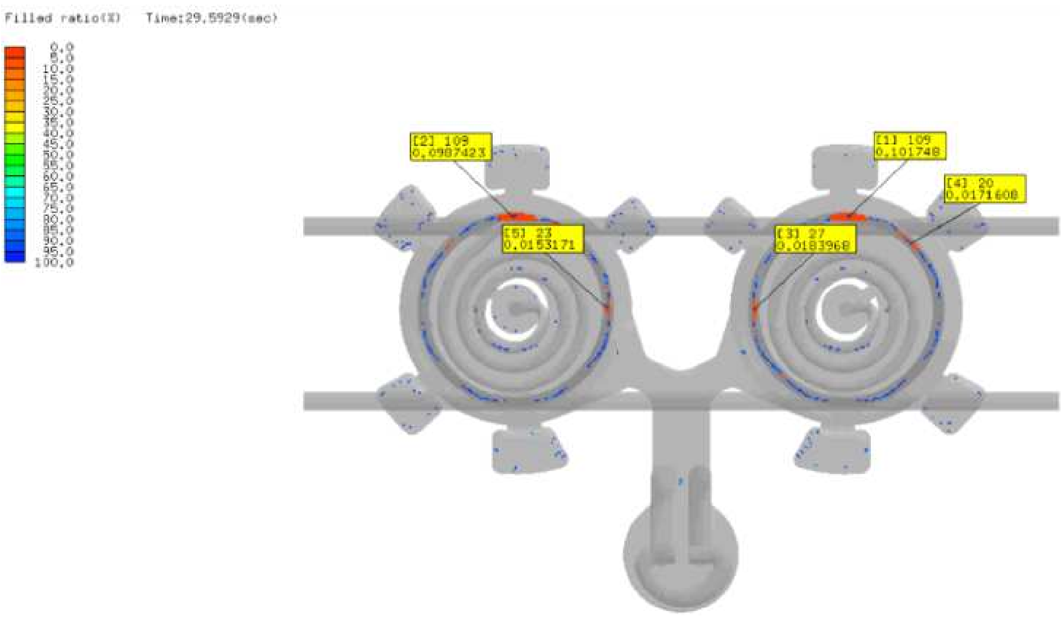

Figure 10. *Simulation results–Prediction of Shrinkage porosity.*

Figure 10 shows the analysis of outer case cover shrinkage porosity results, Red color shows the presence of shrinkage porosity and volume of shrinkage porosity has been highlighted in yellow color dialogue box, Based on the results it is observed that shrinkage porosity varies from 0.015 to 0.10.

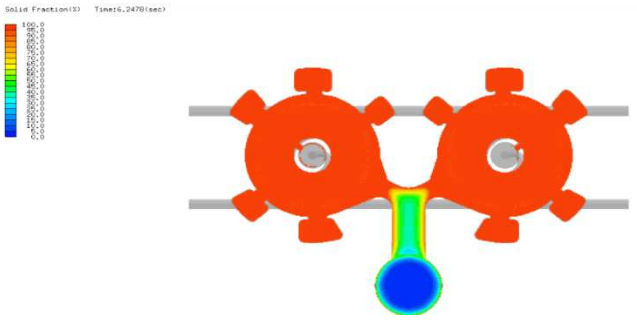

Figure 11. *Simulation results– solidification/cooling time.*

Figure 11 shows the solidification results of outer case cover part with conformal cooling in the left hand side there is a scale which denotes the solidification % where the red color denotes the complete solidification of the component, as per the simulation results it shows it taken around 6.24 sec for solidification of component area.

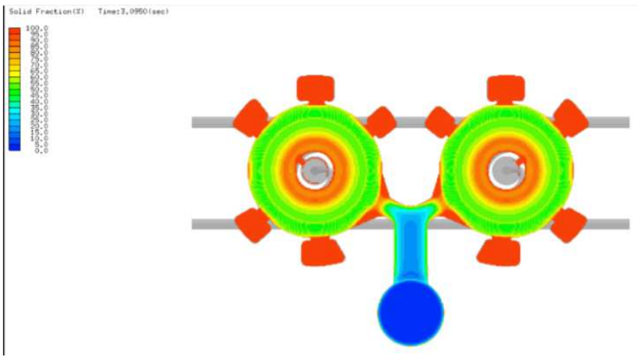

Figure 12. *Simulation results–cooling time with respect to 3 Sec.*

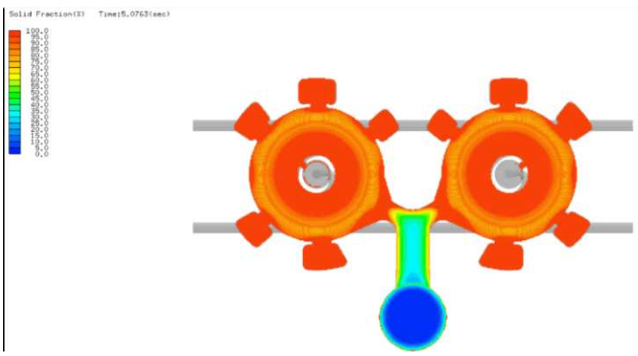

Figure 13. *Simulation results–cooling time with respect to 5 Sec.*

In Figures 12 & 13 it shows the solidification of the outer case cover part with respect to time 3 sec & 5 sec. At 3 sec 50% of cavity has been solidified at 5 sec 90-95% Solidification done & finally at 6.24 sec cavity has been solidified 100%.

5. Results & Discussion

Based on the above simulations results with respect to the conventional cooling and conformal cooling, in conventional cooling shrinkage porosity observed all over the circular area but in conformal cooling design only at the top area shrinkage porosity has been observed slightly, in terms of cooling time as per simulation in conventional cooling it takes around 15.29 sec in conformal cooling it takes around 6.24 sec. Research gap observed that to reduce the defects many research has done by modification in feeding system and modification in product design by reducing the wall thickness.

6. Conclusion

As per the simulation results with conformal cooling 90% of the Shrinkage porosity has been Reduced i.e. 0.12-0.15 to 0.015 to 0.1 & 40 % reduction in Cooling/solidification time i.e 15.29 sec to 6.24 sec with respect to conventional cooling design, Based on the simulation results conformal cooling has given better results than conventional cooling design. It has been observed that without changing the product wall thickness we can reduce the shrinkage porosity with the help of conformal cooling. Also research will be continued to optimize the die casting defects with help of conformal cooling.

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