Effect of Water Mass Flow Rate, Die Materials and Die Geometry on Thermal Profile of Pressure Die Casting Die

Krishna Patel, Chinmay Desai

Abstract— In casting processes, pressure die casting processes widely used for nonferrous alloys, which have wide applications in current industrial scenario. Nonferrous alloys should be casted by another processes but only PDC process provides qualitative casting with highest production rates. These can achieved only after proper temperature distribution is achieved in die as well as in casting parts. It was very difficult to predict temperature distribution for new geometry of die/casting and new advanced material of die. In current scenario trial/error and experience of workers play vital role to getting proper temperature profile of die. These methods are time consuming and also wasting of energy. i.e. heat energy required to melt materials, material cost, heating-cooling works etc. These activities overall increased individual product cost. Thermal profile of new die/casting, new geometry and new die materials can be achieved by ANSYS fluid flow fluent. In order to understand the effect of water flow rates on die thermal profile, a 3D solid modelling has been developed and employed for this study. Analysis work can suggest optimum water mass flow rate for particular geometry and for particular die materials. Various die materials and geometry gives different thermal profile according to provided water mass flow rates. To optimize water mass flow rate for specific die geometry and die materials these results can be employed.

Index Terms— Pressure Die Casting, Mass flow rate, Die material, Die geometry.

1. INTRODUCTION

Pressure die casting is a metal casting process which is characterized by forcing liquid metal under pressure into a mould cavity. Non-ferrous metals, specifically zinc, copper, aluminum, magnesium and tin-based alloys were casted by pressure die casting processes. There is two types of machine named as hot and cold chamber pressure die casting machine. In both types of machine pressure as well as temperature ranges are different.[1].

Pressure die casting process produced casting parts with highest dimensional accuracy at lowest cost, because of molten metal is injected into a die at high pressure, cooled by specific cooling rate with respect to part application. Rate of heat extraction from die directly reflects the mechanical properties of nonferrous alloy castings. Different sets of thermal conditions are used for the solidification processes of molten metal and cooling of PDC die. Thermal sets would vary depending on the casting processes used. [2][3] Thermal control is imperative to a good end result in pressure die casting. Additive manufacturing enables the use of cooling channels that follow the shape of the mould cavity and give fast and uniform cooling, usually called conformal cooling channels.[4]

Three dimensional nature of heat transfer between die and molten/liquid/solid metal is complicated system. Cooling or solidification of nonsymmetrical components are more complicated to predict as compared to symmetrical components.[5] The heat transfer between the melt and the die is resisted by the formation and growth of an interfacial gap between the cast and the mold.[6] It was very difficult to find out heat transfer coefficient for pressure die casting process, due that experimental work was not done up to the mark.[7][8]

Some researchers were approached for using of CFD tools to simulate cycle of die casting process. The study did not covered pressure die casting thermal system.[9] Additionally concluded from literature, generally 2 D modelling for solidification related works only carried out. Very few works involved with 3-D solidification modelling. [10] When molten metal is converted into solid metal, there is maximum probability to getting defects in final products due to changes in heat transfer rate at die and metal interfaces.[11] This is due to difference of cooling rate at various sections of casted parts. These variation in cooling rate responsible for macroscopic and microscopic variations in casted parts. Also different contraction rate provide different microscopic structure in casted parts.[12]

Normally, pressure die casting mold temperature is adjusted based on the experience of operators.[13] Mass flow rates of water or cooling agent through internal water cooling channels are generally run with fluctuated flow rates through each cooling channels. Due to this phenomena die casting industries were generally got various defects named as: poor filling, cold shuts, soldering etc. Some researcher also worked on the effect of die surface temperature distribution on casting quality. It has been observed that casting defects, such as porosity, hot tearing and hot spots are seen in casting due to uneven temperatures distribution in the die.[14], [15] This was seen due to localized fluctuation in cooling rate. This formation can be handled by manually only. Based on workers experience cooling rate should increase or decrease. Trial and error methods were used to control cooling rate of pressure die casting mold. Water or coolants run through cooling channels at maximum and minimum mass flow rate

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but it was difficult to reduce probability of getting defects in dies.[16] Nowadays energy conservation related works are undergoing throughout the world, also works related to productivity of PDC industries are required.[17][18]

This work describe procedural steps for die thermal analysis. Also covered effect of various water mass flow rate on die materials and die geometries. Also discusses formative results obtained with the ANSYS R18.2, R19.1 Academic during the analysis which was carried out with a fluid flow fluent tool.

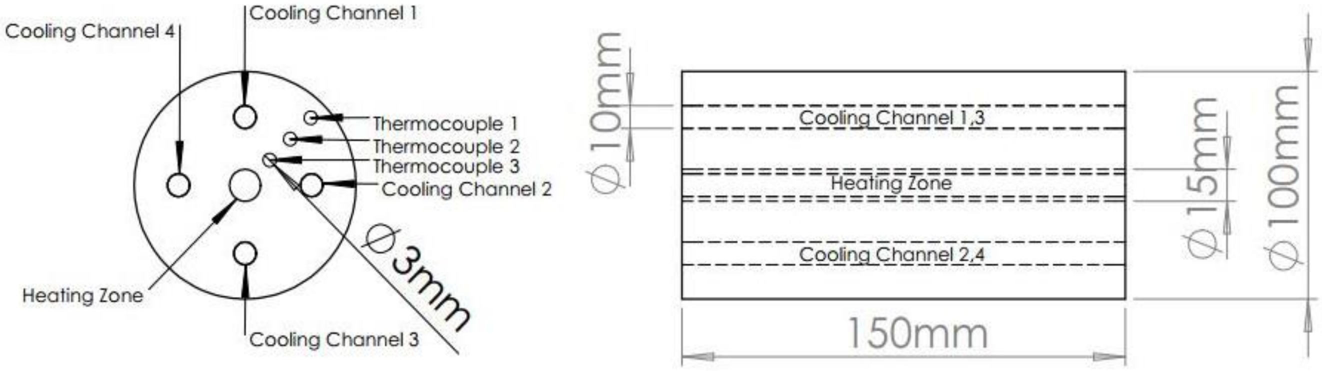

Figure 1 Pressure Die Casting Die Specimen Geometry-1

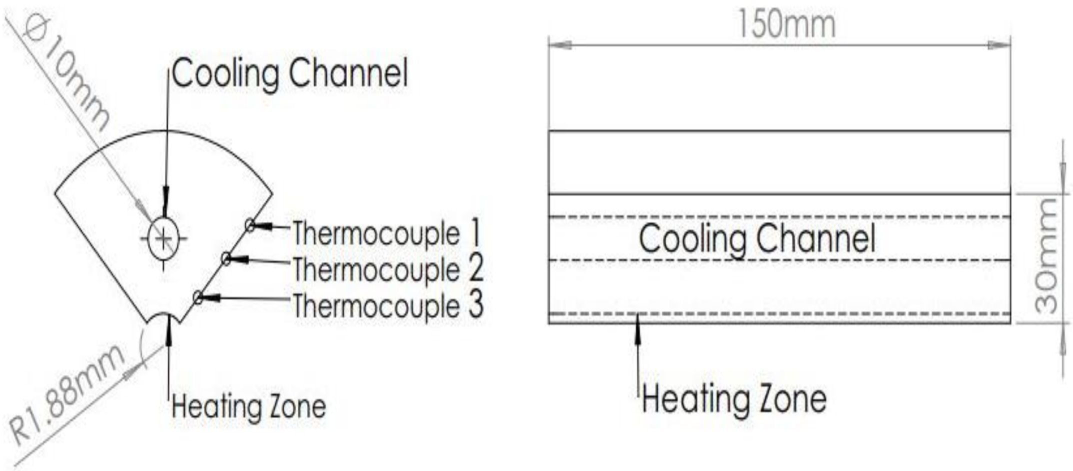

Figure 2 Pressure Die Casting Die Specimen Geometry-2

II. DESIGN AND GEOMETRY OF DIE

The initial stages was the design of the two numbers of dies with cooling channels that followed the similar profile of the PDC die cooling system. 2D and 3D CAD model was created using Autodesk Fusion 360 software. Die, supporting structure and test rig dimensions were finalized after literature and PDC work related company survey. According to requirement of thermal analysis of die of pressure die casting each parts of test rig are designed. Flow diagram of particular test rig was also designed. Figure 1 shows pressure die casting die specimen with geometry number 1. Figure 2 shows pressure die casting die specimen with geometry number 2.

In geometry 1 die design, there is four water cooling channels are provided. In geometry 2 die design, there is one water cooling channel provided. In that channels water passed and absorbed heat available inside the die. At various mass flow rates water passed through four channels and one channel for geometry-1 and geometry-2 respectively. Different three thermocouple (indicated in geometry-1 and geometry-2) holes indicated in the both die design. In geometry 1. For the heating purpose, drill is provided in center of die with 15 mm diameter. This drill is provided to place cartridge heater which is used to increase die temperature up to 500 °C. The holes are provided to attach thermocouples (“k” Type) and that attachments are capable to measure temperature up to 800 °C. 3 mm diameter holes are provided for the provision of it. Die should directly fixed in supporting rack. Supporting rack should be openable, due that die can easily fix and unfix in supporting structure. Four separate pipes with ID 12 mm is directly attached with die cooling hole for supply of water inside die.

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III. METHODOLOGY OF ANALYSIS

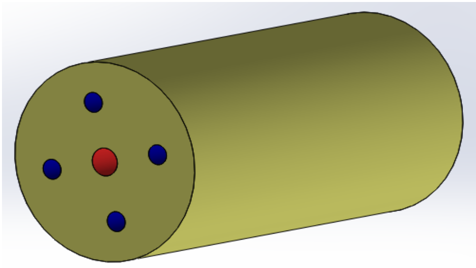

Figure 3 3-D Model of PDC Die

The dimensional computational based model created from specification. ANSYS R18.2, R19.1 (Academic) software used to create the 3-dimensional computational model. PDC Die are generated by importing coordinate of data and extruded in span wise direction by span length. Full computational domain is shown in figure 3. Heat was applied from red color zone, water mass flow rate applied from blue color as per figure 3. Solid model of geometry-1 and geometry-2 was transfer to meshing module of software. Figure 4 shows meshing of die for geometry-2. Also meshing was finalized for geometry-1 after considering grid independency study.

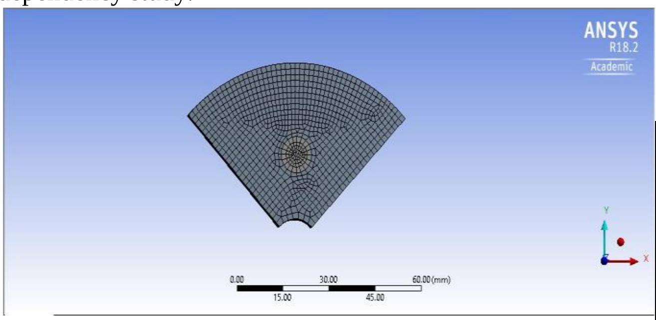

Figure 4 Meshing of Die for Geometry-2

Computational Approach:

CFD tools provide the solutions of fluid flow solving basics fluid flow equations. This problem was structural and well defined, due that the CFD tools can understand and analyses the results, usually all CFD tools processed through three functional levels as follows: Pre-processor, Solver, and Post-processor.

Pre-processor: This is the first step to convert the geometric model in to mesh model, which is understood by CFD tools and gives results. All the flow equation as shown here are in differential form. All CFD tool converts these differential equations in difference form to carry out solution. For that first step is to discretize the domain into sub domains of small size. CFD gives only the approximate solution of actual problem. Solution also depends on quality and density of meshes. Accuracy of solution increases with mesh density, but computational effort increases with mesh density. Solver and post processor: Different meshed sized were consider for this study. Solutions with different meshed sized also analyzed. After consideration of grid independency test final mesh size, quality, numbers of elements and numbers of nodes finalized. Table 2 shows details of mesh sized which were consider for this work. After considerable reasons 1 mm fine mesh size finalized. Table 3 shows details of parametric conditions which were applied to mesh model for this work. Apart from table 3 parameters, analysis also done for other parameters. Geometry-1 takes 7 to 8 hours for complete calculations. There were 2 different materials selected for study. Also 2 geometries selected for study purpose. For each parameters die starting temperature and water Intel temperature was fixed to 623 K and 300 K respectively. Mass flow rate of water change for various parameters through changing velocity directly. Same parametric conditions applied for both OHNS, H-13 die materials and different geometries as per figure 1 and figure 2.

Table 1 Meshing Properties

Parameters	Dimension 1,2,3,4			
Mesh Size	0.75mm	1mm	1.25mm	1.5mm
Mesh Quality	Fine	Fine	Fine	Fine
No. of Nodes	6,46,051	3,74,352	2,59,728	2,40,818
No. of Element	6,76,540	3,52,300	2,40,611	1,87,576

The mesh model was import to ANSYS fluid flow fluent for computing simulation. Solver shows variation of different parameter with iterations. Simulation stops either after defined no. of iteration or on satisfying convergence criteria. At end of run it generates the results which is use for post processing of results. Associated momentum, energy, conversion of mass and mathematical formulation of fluid flow equations are used to computing this models and give appropriate results.

Table 2 Parameter Table

Zone Name	Boundary Condition				
	Specifications	Water Inlet Velocity	Die Starting Temp.	Time (Sec)	Die Materials
Parameter - 1	Coupled Wall	0.25 m/sec	623 K	18	OHNS
Parameter –2	Coupled Wall	1 m/sec	623 K	18	OHNS
Parameter –3	Coupled Wall	2.5 m/sec	623 K	18	OHNS
Parameter –4	Coupled Wall	0.25 m/sec	623 K	18	H-13
Parameter - 5	Coupled Wall	2.5 m/sec	623 K	18	H-13

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IV. RESULT AND DISCUSSION

Heat transfer coefficients of the mold can be studied by using the ANSYS analysis model. Different mass flow rate of water applied to die materials and geometries. At starting, it was observed that the die heat transfer coefficients change according to the die surface temperature, when the starting temperature and the mass flow rate of cooling water remain fixed. Then after, it was observed initial mass flow rate of water affects the heat transfer coefficients. Figure 5 shows die temperature distribution after 18 sec at the end of cycle with parameter 1 (0.0785 kg/sec mass flow rate). Overall temperature of die was not reduced up to mark, as we compare 0.7853 kg/sec water mass flow rate. Figure 6 indicate temperature versus time graph for 0.0785 kg/sec water mass flow rate. It shows gradual downward flow from 623 K temperature to 560 K in 18 second span. Figure 7 shows temperature versus time graph for 0.0785 kg/sec water mass flow rate at various three locations on die.

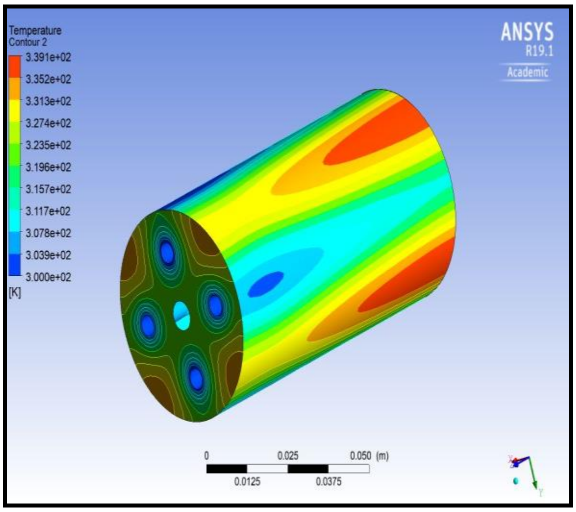

Figure 5 Die Temperature Distribution Parameter-1

It shows very little variation of temperature at different locations of die. It shows clashing of temperature line to each other. Overall volume average temperature and temperature at three locations (Th-1, Th-2, and Th-3) of die remains near about to same.

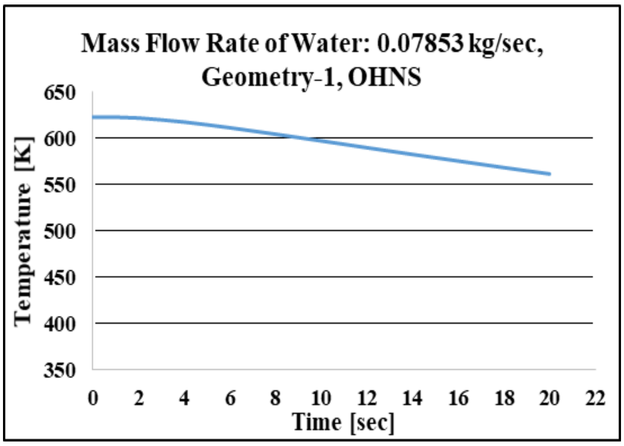

Figure 6 Temperature vs Time for Parameter-1

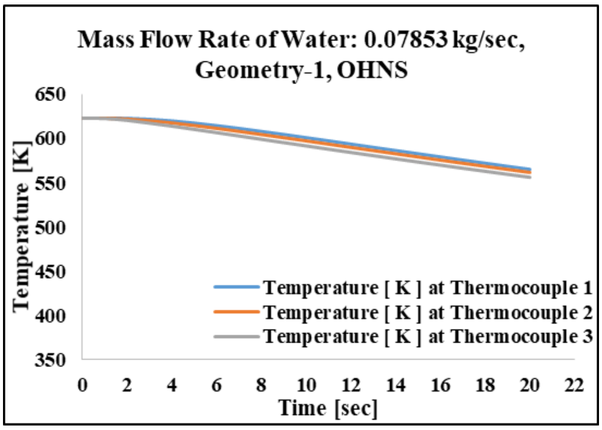

Figure 7 Temperature vs Time (Thermocouple 1, 2, 3) Parameter-1

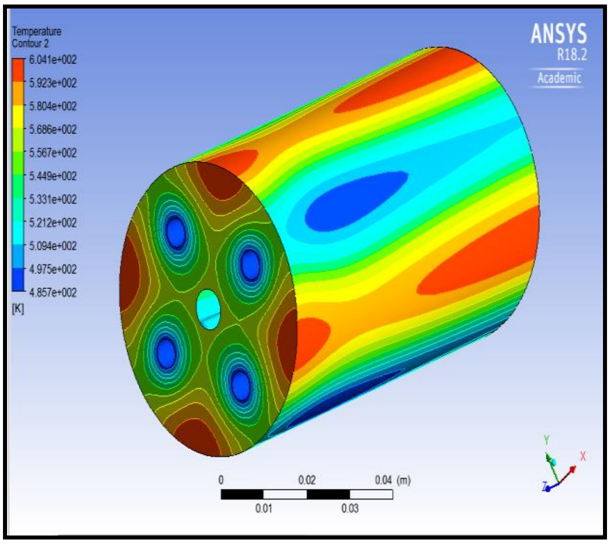

Figure 8 Die Temperature Distribution Parameter-2

Figure 8 shows die temperature distribution after 18 sec at the end of cycle with parameter 1 (0.3141 kg/sec mass flow rate). Figure 9 indicate temperature versus time graph for 0.3141 kg/sec water mass flow rate. It shows gradual downward flow from 623 K temperature to 552 K in 18 second span. Figure 10 shows temperature versus time graph for 0.3141 kg/sec water mass flow rate at various three locations on die. Its indicate difference of temperature at various locations of die. Overall volume average temperature and temperature at locations Th-1 and Th-2 of die remains near about to same. There is large difference in overall volume average temperature and temperature at locations Th-3 of die, which is nearer to cooling channel of die.

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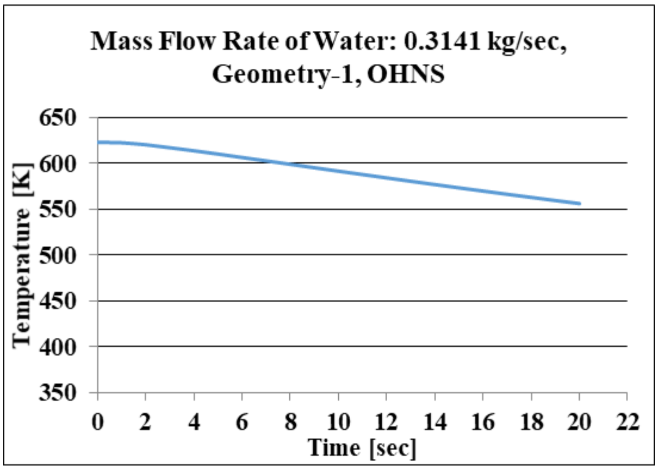

Figure 9 Temperature vs Time for Parameter-2

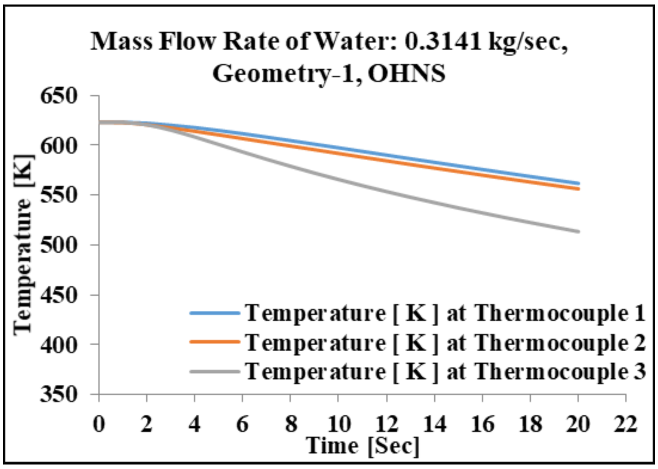

Figure 10 Temperature vs Time (Thermocouple 1, 2, 3) Parameter-2

Figure 11 shows die temperature distribution after 18 sec at the end of cycle with parameter 1 (0.7853 kg/sec mass flow rate). Figure 12 indicate temperature versus time graph for 0.7853 kg/sec water mass flow rate. It shows gradual downward flow from 625 K temperature to 540 K in 18 second span. Graph shows temperature remains steady up to 3 seconds. After that downward trend was start. It remains in downward trend till the supply of water stop. Figure 13 shows temperature versus time graph for 0.7853 kg/sec water mass flow rate at various three locations on die. It shows wide temperature variation at different locations of die. Temperature distributions at various locations of die clearly separated. Overall volume average temperature and temperature at locations Th-1, Th-2 and Th-3 of die clearly differentiate. In fact at Th-1 location, temperature was less than the overall volume average temperature. There is large difference in overall volume average temperature and temperature at locations Th-3 of die, which is nearer to cooling channel of die. Figure 14 shows die temperature distribution after 18 sec at the end of cycle with parameter 1 (0.7853 kg/sec mass flow rate). Geometry 2 was selected for this study. H-13 die materials cooling time was less as compared to OHNS die material.

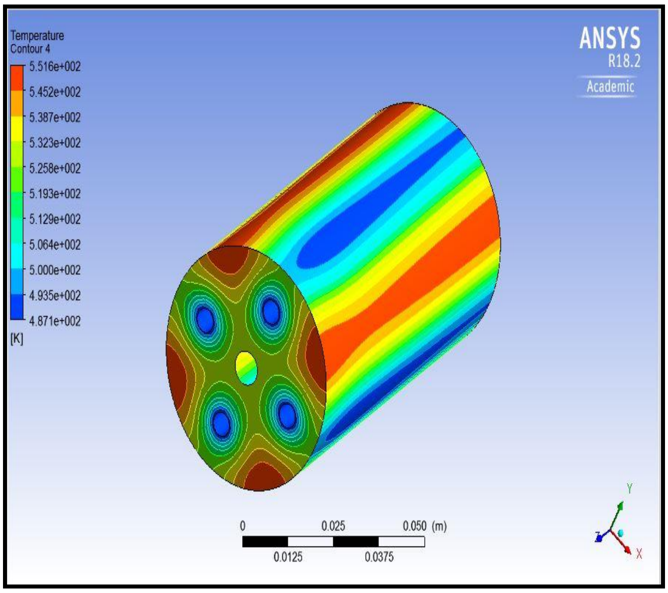

Figure 11 Die Temperature Distribution Parameter-3

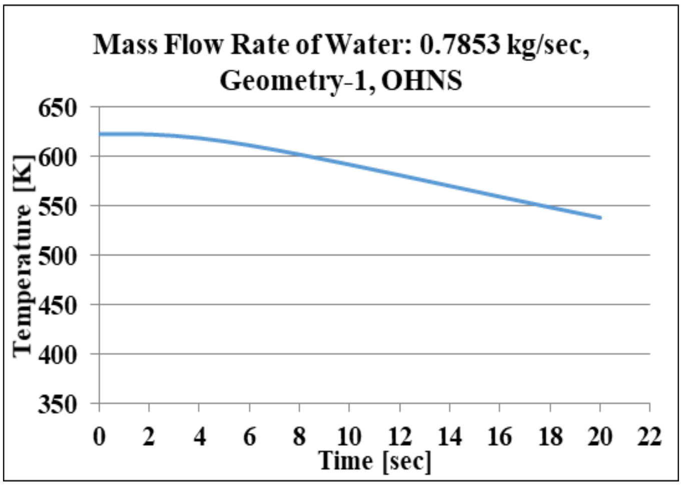

Figure 12 Temperature vs Time for Parameter-3

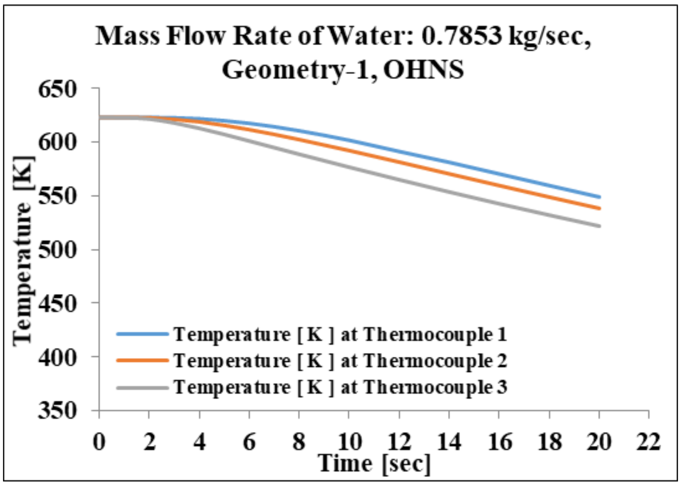

Figure 13 Temperature vs Time (Thermocouple 1, 2, 3) Parameter-3

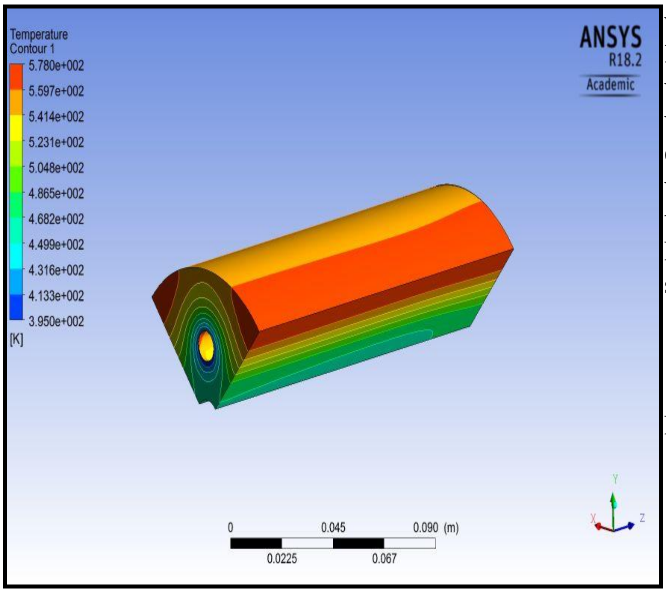

Figure 14 Die Temperature Distribution Parameter-5

Figure 15 indicate temperature versus time graph for 0.7853 kg/sec water mass flow rate. It shows gradual downward flow from 625 K temperature to 525 K in 18 second span. Figure 16 shows temperature versus time graph for 0.7853 kg/sec water mass flow rate at various three locations on die.

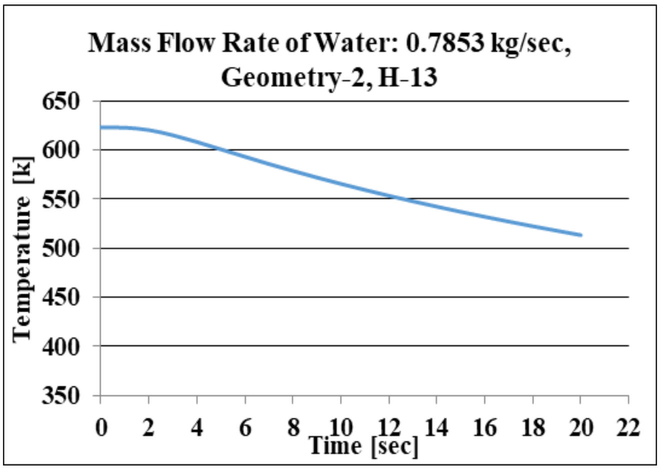

Figure 15 Temperature vs Time for Parameter-5

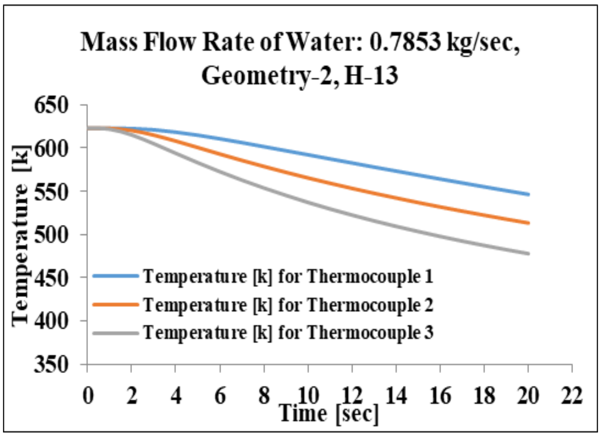

Figure 16 Temperature vs Time (Thermocouple 1, 2, 3) Parameter-5

Temperature distributions at various locations of die clearly separated as seen for OHNS materials also. If water mass flow rate was appropriate, it was possible to achieve variation in temperature at different portion or location of die. Result also shows temperature variations in inlet and outlet water temperatures. At different mass flow rates variation of water temperature clearly separated. This results can be employed for study of new die material, new cast material as well as new geometry of die. Due to this it was expected that these results and analysis technique will be enormously helpful in find out optimum cooling water processing time for specific die geometry and die materials.

V.CONCLUSION

Based on present research following broad conclusions have been reported:

- Computational fluid dynamics of pressure die casting mold using ANSYS useful to determine optimum cooling time for specific die geometry and die materials.
- A CFD thermal analysis method suitable for pressure die casting mold has been developed. It was observed that h (convective heat transfer co-efficient) can be determine using CFD tool.
- As mass flow rate of water increases, the outlet water temperature reduces to reach its original temperature in the lessor period of time. However the die temperature does not reach to steady state because the die temperature required for next cycle is above 400 K to 500 K according to its applications.
- An increase in velocity of water reduces the overall temperatures of PDC mold, however further increment in mass flow rate may not always reduce the temperature in accordance with the similar profile by velocity of water.
- H-13 die materials gives better productivity as compared to OHNS, because of its cooling time was less.
- This CFD tool is also capable to measure a temperature variation with respect to time at any point and portion of die, this was very difficult in actual PDC machine.
- Thermal profile of die change as per changing of its geometry. Geometry-2 take less simulation time as compare to geometry-1.

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