EFFECT OF PROCESS PARAMETERS IN DIE CASTING PROCESS ON SOLIDIFICATION

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Abstract--

With the increasing power of computer hardware and software, computational simulation and visualization are becoming increasingly important tools to understand and improve industrial processes, such as metal casting. Computer-aided visualization is increasing the power of all of the tools available to the solidification process engineer including previous literature, mathematical modeling, laboratory experimentation and online measurement of the casting processes. Die casting is a metal casting process that is characterized by forcing molten metal under high pressure into a mold cavity.

In this thesis, main emphasis will be on the optimization of process parameters in High pressure die casting. A case study of EMF load cell is considered where the flow simulations results are analyzed for optimization. An analytical approach is discussed by using software ANSYS Fluent to analyze the behavior of molten metal at different stages of time by observing the results of temperature variations, pressure variations and liquid fractions by applying the input parameters molten metal temperature, die temperature and velocity of flow. The model of the component with spreader design, runner design, gate location and overflows is done in 3D modeling software Pro/Engineer.

Key words—Die casting, Solidification**,** Optimization, Die temperature, Molten metal temperature, Liquid fraction.

I. INTRODUCTION

Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable molds called dies. The die casting process involves the use of a furnace, metal, die casting machine and die. The metal typically a non-ferrous alloy such as aluminum or zinc is melted in the furnace and then injected into the dies in the die casting machine. There are two main types of die casting machines **-** hot chamber machines (used for alloys with low melting temperatures such as zinc) and cold chamber machines (used for alloys with high melting temperatures such as aluminum). The differences between these machines will be detailed in the sections on equipment and tooling. In both machines, after the molten metal is injected into the dies, it rapidly cools and solidifies into the final part called the casting.

II. LITERATURE REVIEW

Mohammad Sadeghi et.al.[1] have been investigated effect of die temperature and melt temperature on casted component of A380 alloy casting by using high-pressure die casting is optimized by experimental observation and numerical simulation. Ladder frame (one part of the new motor EF7) with a very complicated geometry was chosen as an experimental sample. Die temperature and melt temperature were examined to produce a sound part. Die temperatures at the initial step and the final filling positions were measured and the difference between these values was calculated. ProCAST software was used to simulate the fluid flow and solidification step of the part, and the results were verified by experimental measurements. It is shown that the proper die temperature for this alloy is above 200°C.

In the paper by Rajesh Rajkolhe et.al.[2] Foundry industries in developing countries suffer from poor quality and productivity due to involvement of number of process parameter. Even in completely controlled process, defect in casting are observed and hence casting process is also known as process of uncertainty which challenges explanation about the cause of casting defects. In order to identify the casting defect and problem related to casting, the study is aimed in the research work. This will be beneficial in enhancing the yield of casting. Beside this, standardization (optimization) of process parameter for entire cycle of manufacturing of the critical part is intended in the proposed work. This study aims to finding different defects in casting, analysis of defect and providing their remedies with their causes.

In the paper by Bodhayana M.R et.al.[3] Die casting is a versatile manufacturing technique in which molten metal is poured into die. The die consists of core and cavity, an impression is formed when these core and cavity are closed together. This impression forms the shape and size of the component. The main challenge in die casting is design and manufacturing of die. Integration of design and analysis yields to better results. Die casting is often encountered with many problems, few of such problems are blowholes, improper filling, scratch marks, weld lines, cracks, cold shut, porosity, blisters, ejector pin marks, etc. Usually these defects are caused due to improper design of dies, or due to incorrect parameters such as injection pressure, cycle time, cooling circuits and other such parameters.

In the paper by Quang-Cherng Hsu et.al.[4] Die casting process is significantly used in the industry for its high productivity and less post machining requirement. Due to light weight and good formability, aluminum die casting plays an important role in the production of transportation and vehicle components. In the current study of die casting for Automobile starter motor casing, the following issues are focused: shot piston simulation, defect analysis, and, finally, the use of the Taguchi multiquality analytical method to find the optimal parameters and factors to increase the aluminium ADC10 die casting quality and efficiency. Experiments were conducted by varying molten alloy temperature, die temperature, plunger velocities in the first and second stage, and multiplied pressure in the third stage using L_{27} orthogonal array of Taguchi method.

In the paper by Sandeep.V. Chavan et.al.[5] the casting defect analysis and optimization using computer aided casting simulation technique plays vital role in manufacturing of metal parts and determining various casting defects. In pressure die casting, we require a quality die to prevent unfilled phenomena, weld lines, deflection and air traps and provide two overflows for filling thin section of existing part. The gating system is very critical to a die-casting die, but designing the gating system is an iterative process that can be very time-consuming and costly. The aim of this work is, (a) to identifying the best gate location for the component taking into consideration the flow balance and to avoid differential Clamp force and pressure, (b) to optimize the model of gate location, (c) Study the causality of the defects arrive and their solutions, (d) commenting on simulation results and selecting best suitable gate design for manufacturing the final part and (e) to validate the proposed approach.

In the paper by Javed Gulab Mulla et.al.[6] Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable moulds, called dies. The die casting process involves the use of a furnace, metal, die casting machine, and die. The metal, typically a non-ferrous alloy such as aluminium or zinc, is melted in the furnace and then injected into the dies in the die casting machine.

In the paper by A. P.Wadekar et.al.[7] Gravity die casting is used to manufacture the complex metal components where there is a need for high structural integrity. The casting defects that are caused by molten metal include air entrapment, porosity, and shrinkage. But the control of casting defects has been based on the experience of the foundry engineers. This paper describes these defects in casting with the help of computer aided simulation. These are demonstrated using a simple two dimensional example which contains the essential features of compressor housing.

In the paper by Ferhathullah et.al.[8] This paper deals with elimination of defects in aluminium alloy castings produced by gravity die casting process. The main intention of work is to investigate the defects and improve quality of a gravity die cast component using Computer Aided Casting Simulation Software. In this study an industrial gravity casting die is used which was producing defective components. The die and components produced by the die are studied to eliminate the defects using virtual simulations. The defects in the components are identified to be solidification shrinkage, cracks, unfilled riser and incomplete mould cavity. The reasons for the defects are analyzed as either improper selection of process parameters, or improper design of gating and risering system.

In the paper by M. MUHIC et.al.[9] Die-casting dies are exposed to high thermal and mechanical loads. Thermal fatigue cracking of dies due to thermal cycling may importantly shorten the life-time of the die. Cracks degrade the surface quality of dies and consequently the surface of castings. In this study, thermal fatigue cracking of dies was analyzed during the process of die casting aluminium alloys.

In the paper by B. Vijaya Ramnath et.al.[10], A well - designed runner and gating system is very important to produce good quality die castings by providing a homogenous mould filling pattern. Flow analysis of the component is done in order to visibly analyse the cavity filling process. In this study, a Commutator End (CE) bracket, a cold chamber die casted product was chosen. Initially when the component was casted numerous defects such as Cold shuts, Misrun, Shrinkage porosity and Gas porosity were found. This in turn led to rejection of number of components.

III. PROPOSED WORK

The 3D model of component Base Plate of Load cell is modelled in 3D modelling parametric software Creo 2.0. The component Base Plate of load cell is one of the part used in the Gold weighing machines. The component material is Aluminum 413.0-F Die Casting Alloy.

The molten metal flow behaviour is analyzed using analysis software ANSYS Fluent. FLUENT can be used to solve fluid flow problems involving solidification and/or melting taking place at one temperature (e.g., in pure metals) or over a range of temperatures (e.g., in binary alloys).

The main inputs to be provided for analysis are

1. Thermo physical properties such as density, specific heat, thermal conductivity, die material and temperatures.
2. Boundary conditions such as inlet velocity, fill time, die temperature and molten metal temperature

PROPERTY	VALUE
Density (Kg/mm^3)	2660
Specific Heat (J/Kg K)	963
Thermal Conductivity (W/mK)	120
Viscosity (Kg/m s)	0.00296

Pure Solvent Melting Heat (J/Kg)	0.389
Solidus Temperature (K)	847
Liquidus Temperature (K)	855

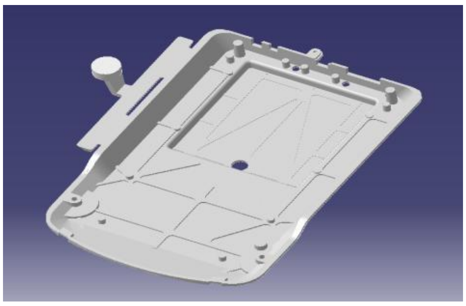
Properties of molten metal is Aluminium 413.0-F Die Casting Alloy

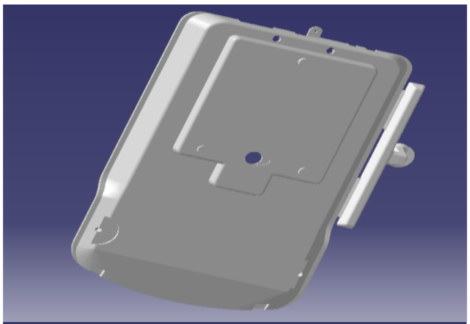
PROPERTY	VALUE
Molten Metal Temperature (K)	1033
Velocity (m/s)	55
Fill Time (Secs)	8, 10, 12
Die Temperature (K)	393, 423, 523

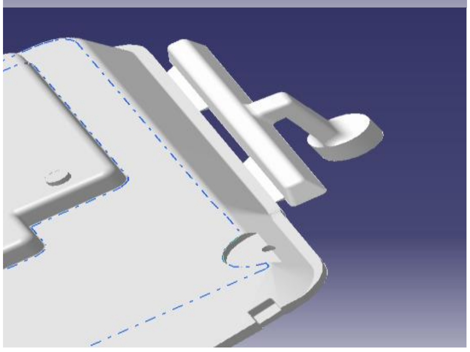
Input parameters and there levels

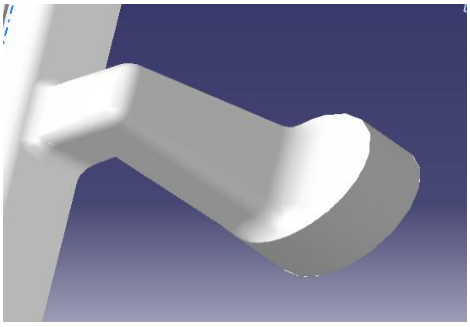
The input parameters which effects the flow behavior of molten metal considered in this analysis are molten metal temperature die temperature and velocity of flow fill time. In these parameters, the molten metal temperature and velocity of flow are kept constant. The die temperature and fill time are varied.

IV. 3D MODELS OF COMPONENT BASE PLATE









RESULT & DISCUSSION

The molten metal flow behavior after analysis is investigated by extracting the outputs temperature distribution during filling pressure and liquid fraction. The Table specifies the different cases performed in the analysis. The following are the figures of the specified outputs at different cases.

FILL TIME	DIE TEMPERATURE (K)		
	CASE A	CASE B	CASE C
12	393	423	523
10	393	423	523
8	393	423	523

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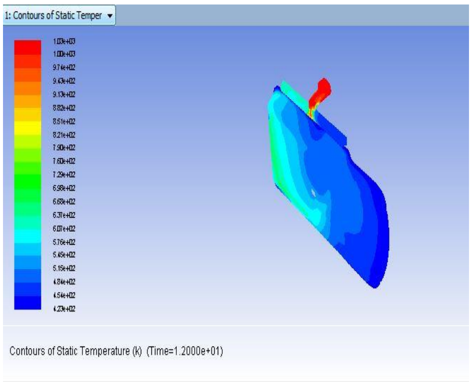
Control factors and their levels

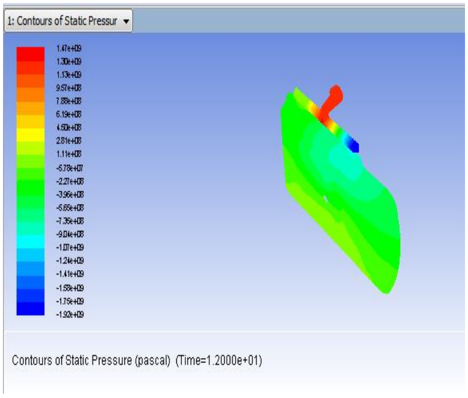
Type 1: FILL TIME – 12Secs

CASE A – DIE TEMPERATURE – 393K

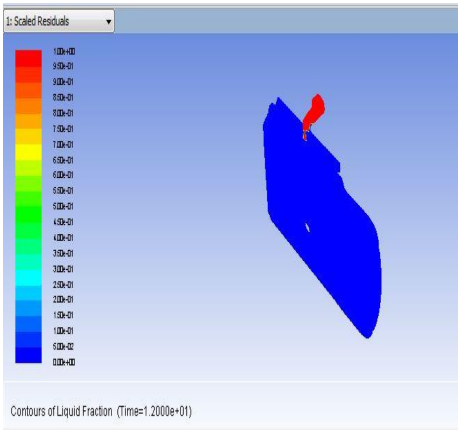
Static Temperature



Static Pressure



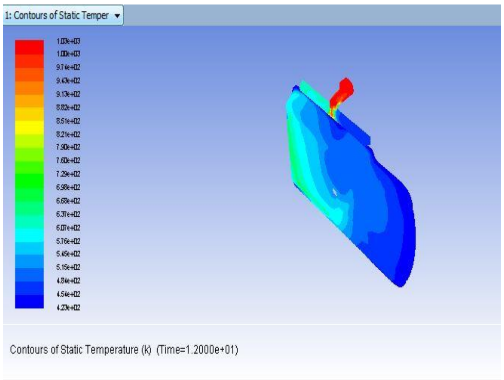
Liquid Fraction



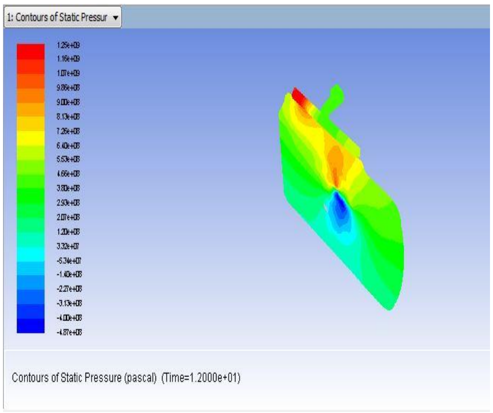
Type 1: FILL TIME – 12Secs

CASE B – DIE TEMPERATURE – 423K

Static Temperature



Static Pressure



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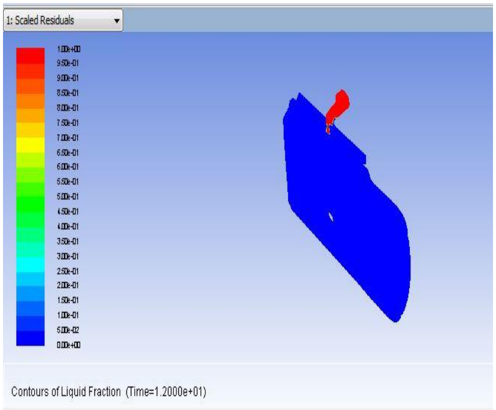
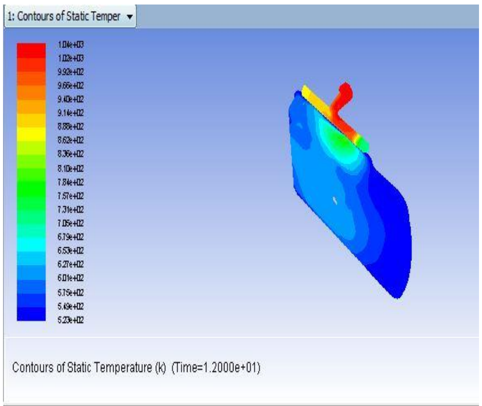
Liquid Fraction

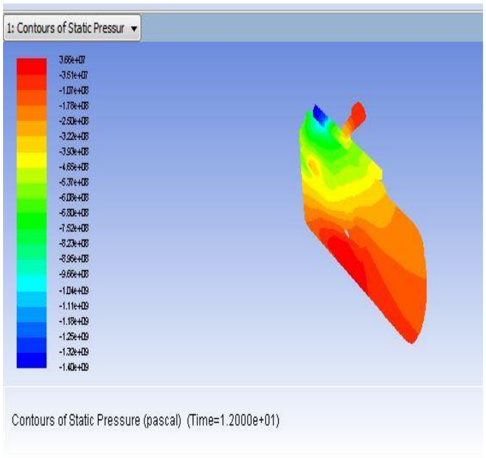


CASE C– DIE TEMPERATURE – 523K

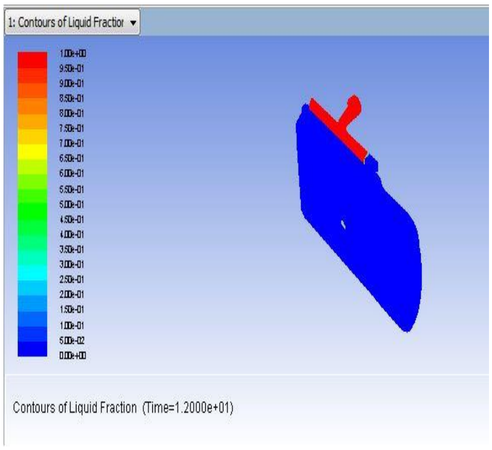
Static Temperature



Static Pressure



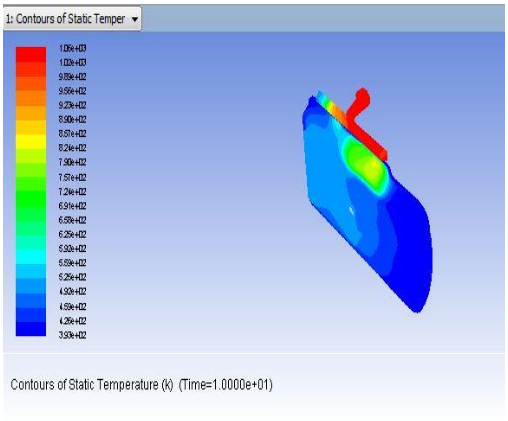
Liquid Fraction



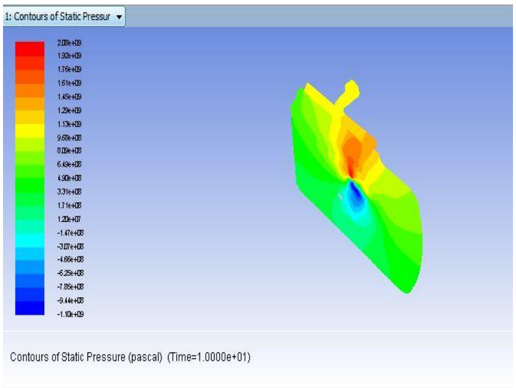
FILL TIME – 10Secs

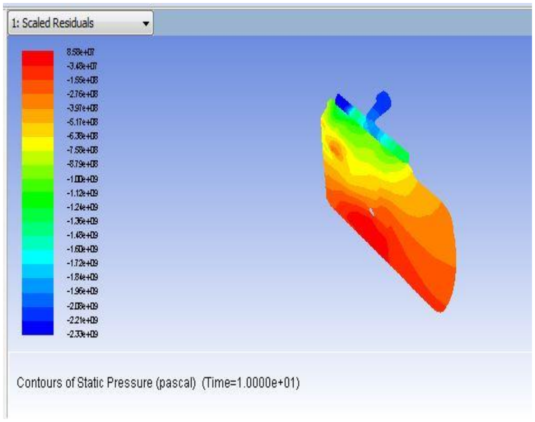
CASE A – DIE TEMPERATURE – 393K

Static Temperature

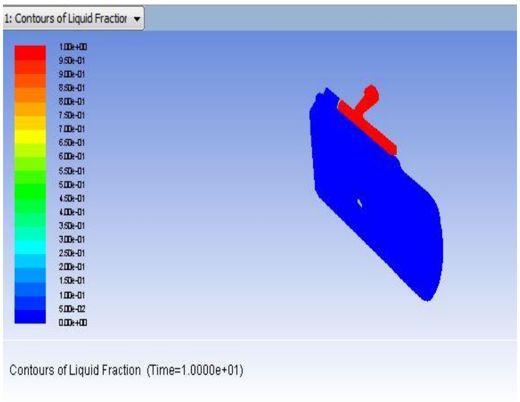


Static Pressure

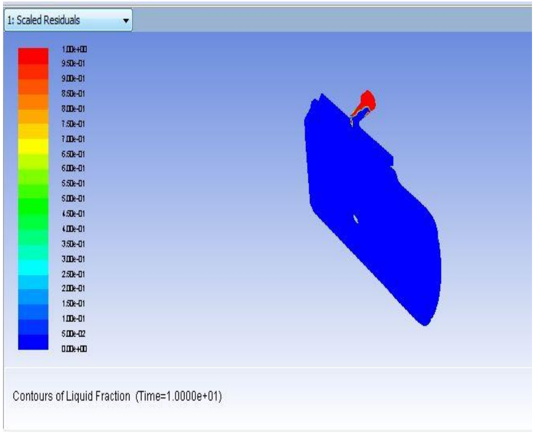




Liquid Fraction

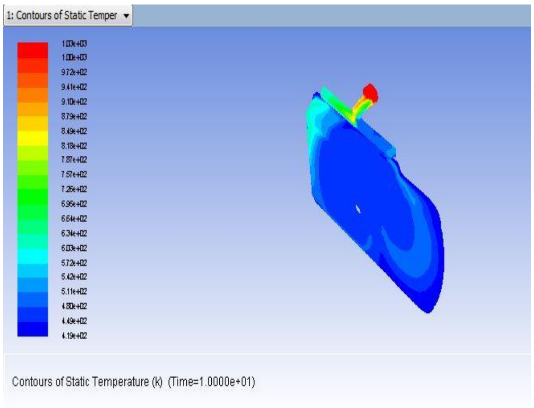


Liquid Fraction



CASE B – DIE TEMPERATURE – 423K

Static Temperature



Static Pressure

The Input parameters:

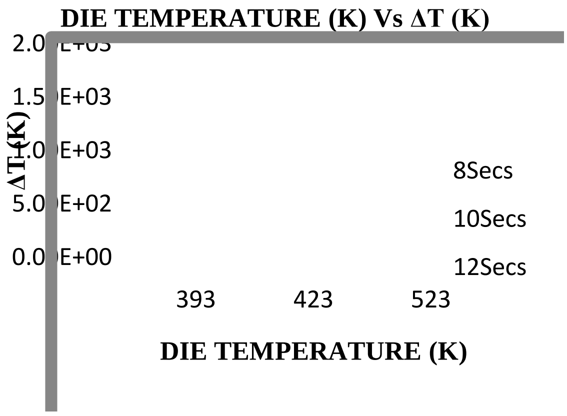
a) Molten Metal Temperature – 760^{0}C (1033K)
b) Input Velocity - 55m/s (typically 40–60 m/s for aluminium alloys, reference from [1])

FILLING TIME (Sec)	DIE TEMPERATURE (K)	STATIC TEMPERATURE (K)			PRESSURE (Pa)
		Min	Max	ΔT	
12	393	423	1003	580	$1.47e^{9}$
	423	423	1003	580	$1.25\ e^{9}$
	523	523	1004	481	$3.66\ e^{7}$
10	393	393	1006	613	$2.08\ e^{9}$
	423	419	1003	584	$8.58\ e^{7}$
	523	458	1003	545	$4.05\ e^{7}$

8	393	293	1003	710	2.44 e^9
	423	392	1003	611	2.93 e^8
	523	522	1003	481	8.64 e^7

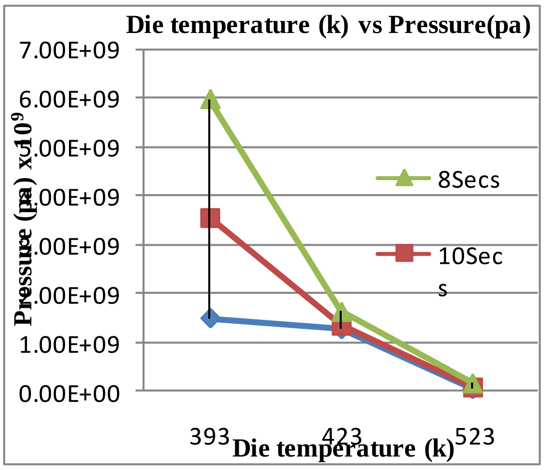
Results of Temperature Distribution and Pressure at different filling times and die temperatures

Graphs to compare temperature distributions and pressures with respect to die temperatures for different filling times



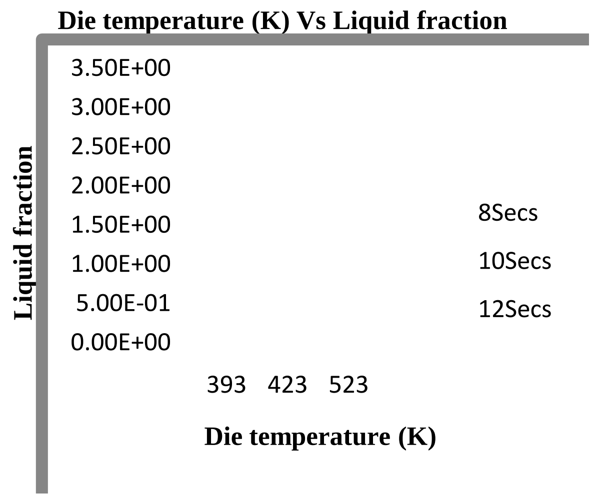
Die Temperature Vs Static Temperature

Temperature distribution in die casting is important as it plays a vital role in deciding the quality of castings. The die is preheated to 120°c, 150°c, 250°c (usually in die casting dies are pre heated from 150° to 300°c). Aluminium which is in the form of ingots is melted to around 760°c. and molten metal at around 760°c is injected in to the die using plunger (in case of hot chamber molten metal is directly fed into the dies) when the molten metal comes in contact with the dies which is at lower temperatures (around 120°c) tries to cool down due to high temperature difference.



Die Temperature Vs Pressure

Pressure is main parameter which decided the component quality. Solidification of molten metal at high pressure increases the mechanical properties such as impact strength, tensile strength and hardness. Material packing is one of main concern for component strength. Component will have higher strength and toughness when the metal is packed completely. This can be achieved when the pressure is optimum. As the pressure increases porosity decreases and pore size is shifted to smaller pores means molten metal can fill all corners of molten cavity and uniform strength can be achieved. Fine arrangement of molecules is achieved. Also if pressure is less, it leads to mixing of air and molten metal. Sufficient pressure is required to push the air out without mixing with the molten metal.



Die Temperature Vs Liquid fraction

Pressure is one of parameters which decided the component quality. Solidification of molten metal at high pressure increases the mechanical properties such as impact strength, tensile strength and hardness. Material packing is one of main concern for component strength. Component will have higher strength and toughness when the metal is packed completely. This can be achieved when the pressure is optimum. As the pressure increases porosity decreases and pore size is shifted to smaller pores. Fine arrangement of molecules is achieved. Also if pressure is less, it leads to mixing of air and molten metal. Sufficient pressure is required to push the air out without mixing with the molten metal.

CONCLUSION

In this thesis, the optimum filling time, injection pressure and die temperature for better solidification of the filling material are analyzed by taking the input parameters molten metal

temperature, velocity at spreader, injection time and die temperature.
Solidification analysis is done in ANSYS CFD.
From the results, the following conclusions can be made:

a) The better solidification occurs at 8secs injection time, 2.44 e^9 Pa pressure and 393^0C die temperature. Solidification of molten metal at high pressure and less die temperature increases the mechanical properties such as impact strength, tensile strength and hardness.

These parameters can be applied practically in experimental investigation. From this thesis, trial and error methods in manufacturing process of pressure die casting die methods can be avoided thereby reducing total cycle time and also material wastage in manufacturing process. The problems faced in the casting industry can be rectified by this method.

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