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Design and Analysis of Pressure Die Casting Die for Automobile Component

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DESIGNANDANALYSISOFPRESSUREDIECASTINGDIEFORAUTOMOBILECOMPONENT

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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, die casting machine, metal and die. Die casting differs from ordinary permanent-mold casting in that the molten metal is forced into the molds by pressure and held under pressure during solidification. The die casting machines are mainly categorized into two - hot chamber machines are used for alloys with low melting temperatures, such as zinc, and cold chamber machines are used for alloys with high melting temperatures, such as aluminium [1-2]. Most die castings are made from non-ferrous metals and alloys, but substantial quantities of ferrous die castings now are being produced. Because of the combination of metal molds or dies, and pressure, fine sections and excellent detail can be achieved, together with tong mold life. Die-casting dies are usually made from hardened tool steel they are expensive to make [3]. Semisolid die casting process used to improve the mechanical properties of aluminium alloy parts by substituting aluminium alloy for steel to improve the fuel efficiency parts and verified it by experiments [4]. The casting defects that existed include cold fills dross and alumina skins. The batches of specimen varying in runner and sprue design were analyzed. It was found that there were no significant variations in the fatigue strength between the acceptable and non-acceptable components [5]. The integrated system reduced the lead time and shortened the cycle time of die design resulting in an increase in productivity by integrating Computer Aided Design and Manufacturing system [6]. The conventional gating design, casting defects such as shrinkage and gas porosities was found in front axle housing a critical automotive component. This part is made out of spheroid graphite iron. A flawed gating system was considered to be the reason for improper fluid flow and melt solidification which in turn produced casting defects [7-8]. Computer aided die design system that comprises seven modules. The system proved useful to reduce the time required for the design of an ejector, die-base and gating [9]. The quality of the casting was reduced as the density decreases proportionally to the amount of porosity leading to higher rejection rates. It was found that there was non-uniform cooling of the component due to which the present design of the runner and gating system was studied thoroughly, and the flow simulation results had also proven the above said defects [10-11]. The objectives of this project is to design a die, develop tools and gating system to identify defects such as shrinkage cavities, gas defects, pouring material defects, mould material defects and take measures to minimize flaws by using Computer Aided Engineering software. This paper is organized based on different sections; the first section describes the literature survey, followed by problem formulation and objectives. The methodology are slated, the fourth section explores on design calculations for the automotive component, the design are analysed in this section, results and discussion is explained, and the concluding remark is given in this section.

II. Materials and Methods

The material to be used is ADC 12. This material is an international standard composition of aluminium die-casting alloys in Japan, and the composition of the material and properties are LM 24 in British standard, A 383 in American standard and DIN 226 in German standard. All these materials are to be used while

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designing the core and cavity after adding material shrinkage value to the component geometry. The core and cavity are the parts of the die that provide the internal and external shape of the component in which the core is the male part of the die and forms internal shape of the component, and the cavity is the female part of the die it forms the external shape of the component.

Table 1: Component Details

COMPONENT NAME	CYLINDER HEAD COVER
Quantity required	20,000 per month
Material	ADC 12
Density	2.7 g/cm3
Shrinkage	0.5%
Volume of the component	$217.553 cm^3 = 217{,}553\ mm^3$
Weight of the component	330.0 g
Projected area	$7900.0\ mm^2$
Draft angle	5 degrees
Function	Closing the top of the cylinder head

a) *Methods*

These are the following steps used while designing the component:

1. The component is identified and all relevant information required for design is collected.
2. The number of cavities is decided based on yearly requirement.
3. Identical components are grouped in the unit die.
4. The design calculations are done to find the suitable machine
5. Details of machine are collected
6. Component parting line was being decided based on part geometry, ejection, and aesthetics.
7. The runner, gate dimensions and type are selected based on the part geometry, cavity location.
8. The type of ejection will be selected based on aesthetics, parting line location, part geometry, etc.
9. The amount of heat being injected into the die will be calculated and the suitable cooling system is provided.
10. 3-Diamensional modelling of the die, gate design, and core cavity extraction will be conducted using Solidworks software by considering shrinkage of material.
11. Assembly and part drawings are to be made in 2-Diamensional using Solidworks software.
12. Part drawings will be carefully checked at the end and approved.

i. *Design Calculations*

➢ Number of Cavities

Production required per month: 20,000 per month (Die will be loading only for 5days)

Number of component per day: 4000

Number of shifts per day: 3

Number of shots per shift = 8 x 60 / Cycle time.

= 8 x 60 /0.5

= 960 shots

Number of component per shot = 4000/ (3x960)

= **1.0**

Hence we have to use a **single cavity** die.

➢ Tonnage Requirement

Projected area of the component = $7900 mm^2$

Projected area including overflows and feed system

= 7900 x 1.5

= $11850 mm^2$

Specific Injection pressure = 600 kgf/cm2 = 600 x 10-2 kgf/ mm2

Total force acting on the die plate = Projected area x Injection Pressure

= 7900x 600 x 10-2

= 47400 kgf

= 47.4 T

Considering machine efficiency of 80%, Locking tonnage required = 47.4 x 1.2

= **57T**

Hence according to locking tonnage ranges, we can select **80 T** machine.

➢ Shot Weight

Component volume = $217{,}553\ mm^3$

Volume of component + Volume of overflow and feed system (excluding Biscuit)

= 217,553 x 1.2

= $261{,}063.6\ mm^3$

Actual shot volume = $261{,}063.6 + \pi d^2 h/4$

Where **h** is biscuit thickness, and **d** is the plunger diameter Stroke length for 80 T machine = 250 mm

Effective stroke length = 250 – biscuit thickness

= 250 – 25

= 225 mm

Assume fill ratio = 0.50

Volume delivered by machine

$= \pi d^2 \times (225/4) \times 0.5$

$261{,}063.6 + \pi d^2 \times (225/4)\ 0.5 = \pi d^2 \times (225/4)$

$261{,}063.6 = 88.40625\ d^2$

$d^2 = 2953\ mm^2$

d = 54.3 mm

Available plunger sizes in **80 T** machines are 35, 45, and 55 mm Hence we can select **55 mm** plunger tip

Shot volume $= 261{,}063.6 + \pi d^2\ h/4$

$= 261{,}063.6 + \pi\ (54.3)^2 \times 25/4$

$= 261{,}063.6 + \pi\ (54.3)^2 \times 25/4$

$= 261{,}063.6 + 57{,}900.97$

$= 318{,}964.57\ mm^3$

Shot weight = Shot volume x density

$= 318{,}964.57 \times 2.7 \times 10^{-3}$

= 861.2g = **0.9kg**

- Fill Ratio

$$\text{Fill ratio} = \frac{\text{Shot sleeve volume}}{\text{Metal volume}}$$

318,964.57 = π (55)2 x (225/4) x y y = **0.6**

This value for fill ratio is acceptable for the process

- Fill Time

$$\text{Fill Time} = \frac{K[Ti - Tf + sz]\ T}{[\ Tf - Td\ ]}$$

Where

k empirically derived constant = 0.0346

Ti, Temperature of molten metal as it enters the die = 6500c

Tf, Minimum flow temperature of metal = 5700c

Td, Temperature of die cavity surface just before the metal enters = 2000c

S, percent solid fraction allowable in the metal at the end of filling = 30%

Z, Units conversion factor = 3.8

T, casting wall thickness = 3 mm

$$t = \frac{0.0346[650 - 570 + 30 \times 3.8] \times 3}{[570 - 200]}$$

= 0.054 second

= **54 milli seconds**

ii. *PQ2 Calculations*

Maximum (Hydraulic) Accumulator Pressure = 150kgf/cm2

Diameter of (hydraulic) cylinder = 130 mm

Plunger diameter = 55 mm

Dry Shot Velocity (DSV) = 4.5 m/sec

- Maximum Static Metal Pressure

$$= \frac{\text{MAP} \times (\text{Cylinder Dia})^2}{(\text{Plunger Dia})^2}$$

$= 150 \times (130)^2/(55)^2$

= **838.02kgf/cm2**

- Dry Shot Flow Rate

$= (\text{Plunger Dia})^2 \times \pi \times DSV/4$

$= (55)^2 \times \pi \times 4.5 \times 103/4$

= 10,692,618.75 mm3/sec

= **10,692.62 cm3/sec**

- Max. Metal Pressure (lines)

$$= \frac{\text{Density} \times Gv^2}{2g \times Cd^2}$$

Where

Gv is maximum gate velocity = 400cm/s (recommended)

g is acceleration due to gravity = 981 cm/sec

Cd is coefficient of discharge = 0.4

$$= \frac{2.58 \times (4000)2}{2 \times 981 \times (0.4)2}$$

= 131,498.5 gf/cm2

= **131.5 kgf/cm2**

- Min. Metal Pressure (lines)

$$= \frac{\text{Density} \times Gv^2}{2g \times Cd^2}$$

Gv is the minimum gate velocity = 2500cm/s (NADCA recommended)

$$= \frac{2.58 \times (2500)2}{2 \times 981 \times (0.4)2}$$

= 51,366.6 gf/cm2

= **51.4 kgf/cm2**

- Flow rate (fill rate), Q

(A theoretical minimum fill rate that can be used to produce the highest quality casting)

= Volume (casting and overflow) of metal (passing) through Gate /Fill time

= 261,063.6 / 0.054

= 4,834,511.111 mm3 /sec

- Runner Design

Runner Area (A) = 1.3Ag

= 69 x 1.3

= 86.7 mm2

Depth (D) = $\sqrt{(A/0.8)}$

= 10.42mm

Width = 2D = **20.84 m**

P-Q^2 GRAPH

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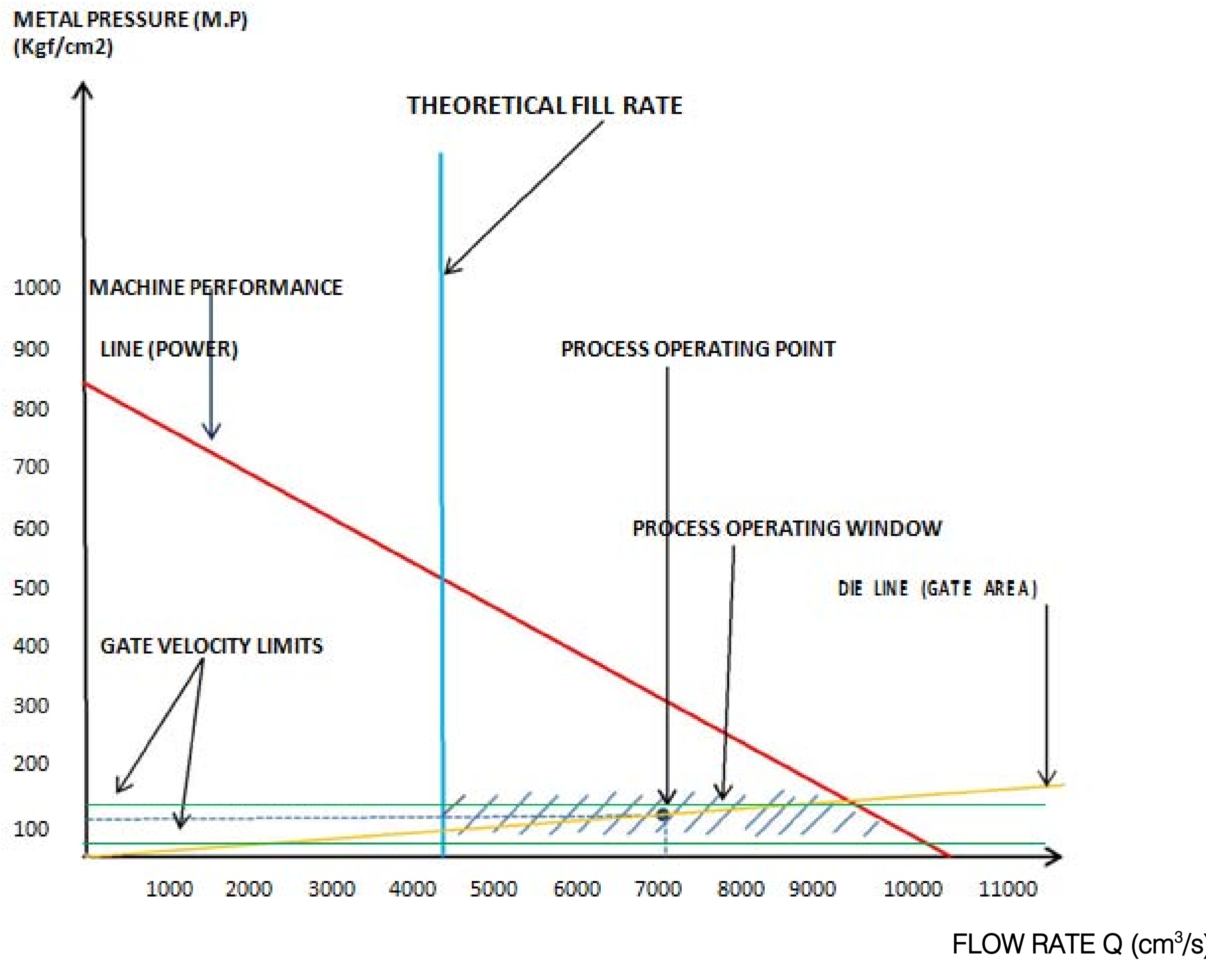

Figure 2.1 : P-Q2 Diagram

From PQ2 graph,

P = 91.5 kgf/ cm2

Q = 7,255.7 cm3/sec

Therefore $A_g = Q/ C_d\sqrt{(p*2g/\rho)}$

$= 7255.7/0.4 \sqrt{(91.5 \times 2 \times 981/2.58)}$

= 0.6877 cm2

= 69 mm2

Therefore area of the gate = 69 mm2

Gate thickness = 3mm (will produce atomization)

Gate length hence = 23mm

iii. *Cooling Calculation*

Heat input = hGn

h is the heat factor = 145 Kcal/kg for Aluminum

n is the number of shots = 120 per hour

G is weight of casting, overflow and feed system

= 705g

= 0.705kg

Therefore Heat input = 145 x 0.705 x 120

= 12,267 kcal/hr

50 % of heat is lost by convection to atmosphere and by spray cooling

Heat accumulated = 12,267 x 50/100

= 6,133.5 kcal/hr

Heat removing capacity = 35 kcal/hr

Length of cooling line = 6,133.5/35

= 175 mm

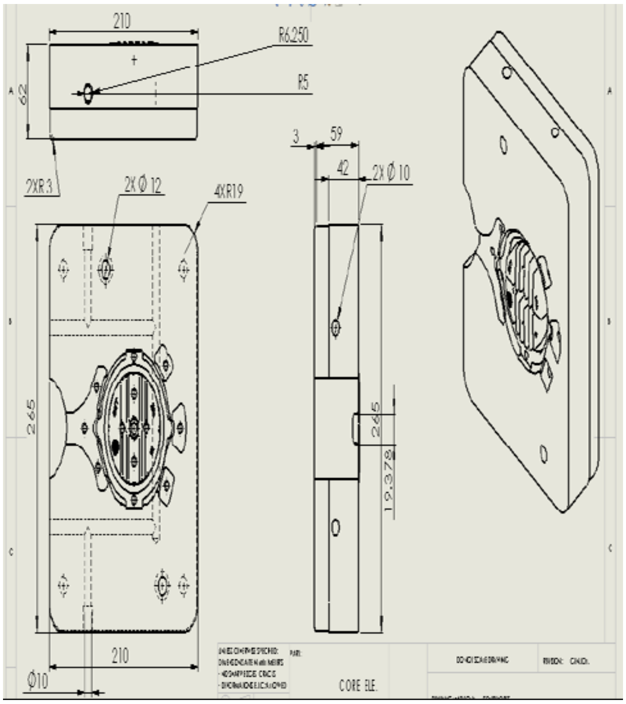

Figure 2.1.1 : Core Insert

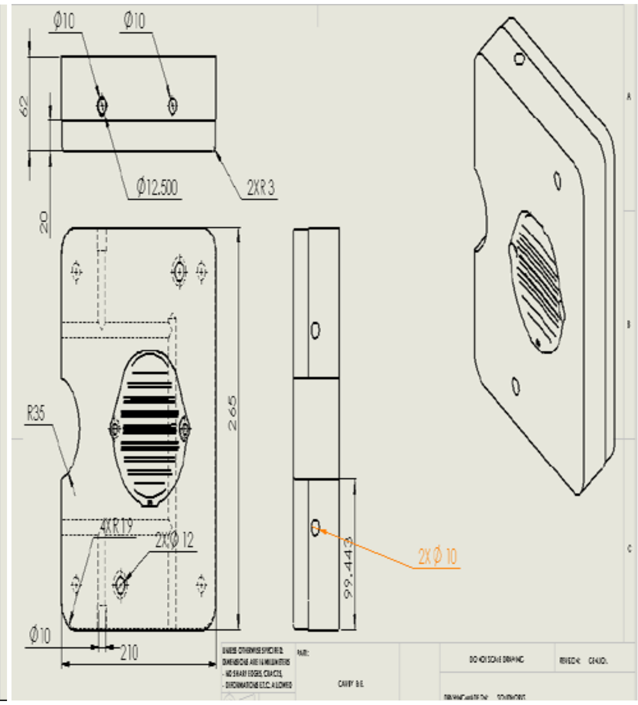

Figure 2.1.2 : Cavity Insert

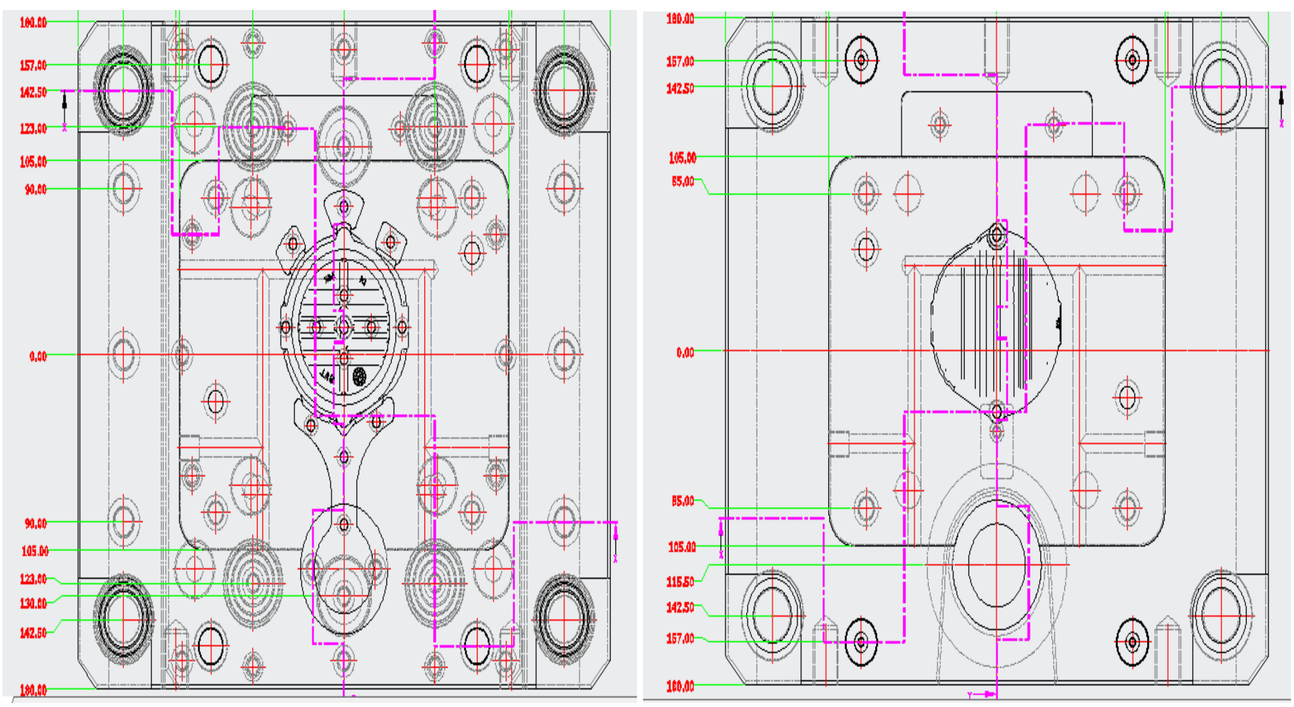

Figure 2.1.3 : Tool Cavity & Core Assembly

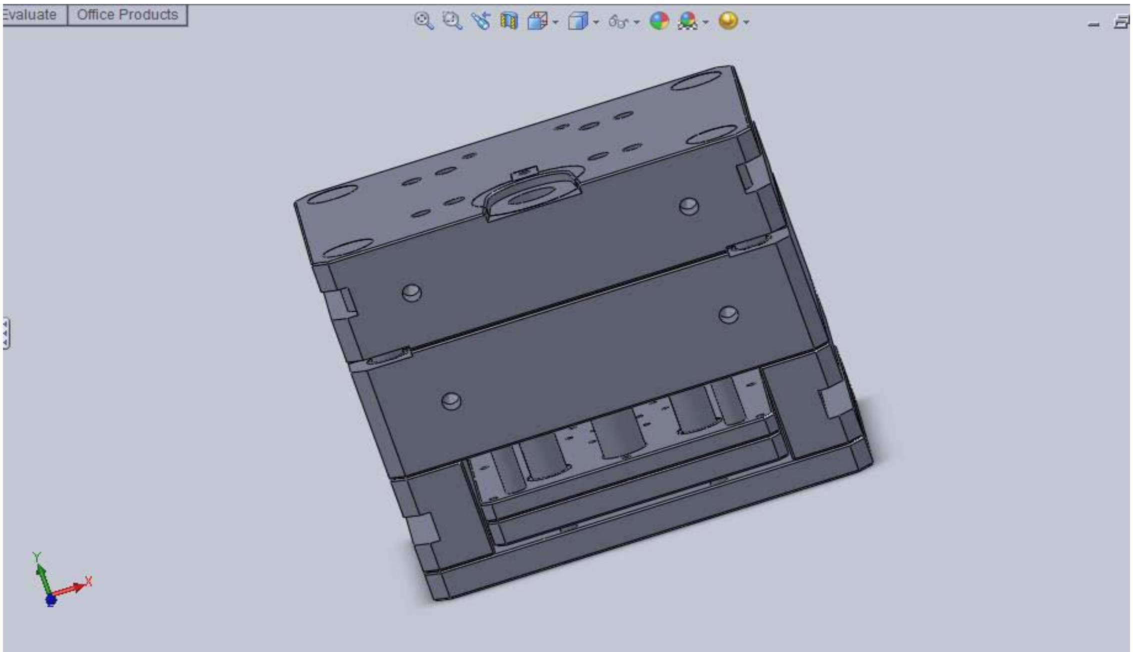

Figure 2.1.4 : Assembled Die Tool

III. Analysis

A comprehensive analysis of each factor entering in the die casting process is needed to be done since each factor is susceptible to affect the ready casting in a negative way. The die casting technology makes the thin-walled castings having a high dimensional and geometrical precision. These are to handle the whole die casting process to control all aspect associated with the process to prevent wastage while casting. The geometrical, structural, dimensional and superficial requests are considered as a waste if the casting which doesn't fulfil the factors to be considered. In this case, a short with vertical and horizontal part ribs arrangement was considered in which the 3Dflow behaviours was analysed. The following results at the different filling time were observed when the process started.

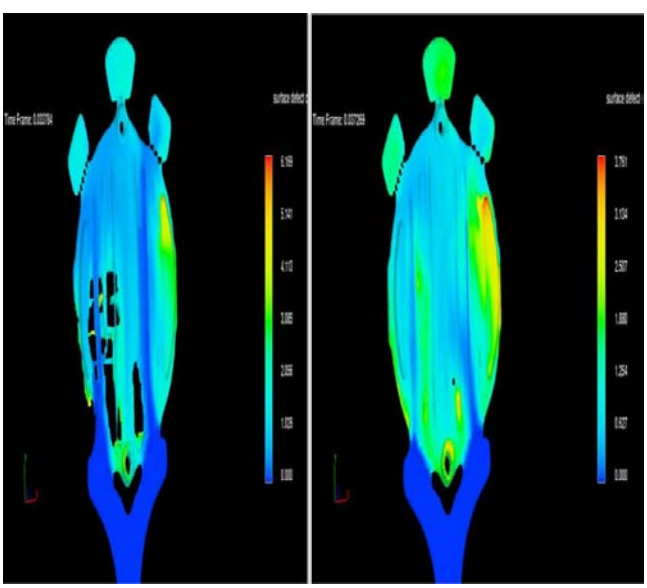

Figure 3.01 : Vertical Arrangements of Part

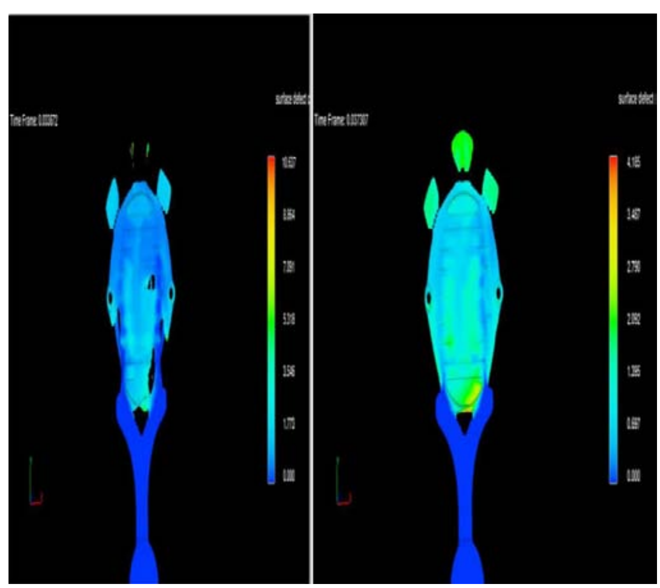

Figure 3.02 : Horizontal Arrangements of Part

IV. Results and Discussion

The process started at initial for both cases and terminated at 3.810 and 4.214 seconds for vertical arrangement and a horizontal one. The analysis shows that the air porosity defect rate is more in the vertical arrangement than the horizontal arrangement. The outstanding volume of the shot sleeve is filled with air. Both design and analysis research shows that the motion of the plunger, the shot sleeve dimensions and the initial amount of metal in the sleeve all affect the types of waves which are created during the process. The results summary of the tool design parameters which are the multiple functions of other design parameters upon which the design was made in Table 2 below.

Table 2 : Results Summary

NO. OF CAVITIES	1
TONNAGE REQUIREMENT	80 T
SHOT WEIGHT	0.9kg
FILL RATIO	0.6
FILL TIME	54 milliseconds
MAX. STATIC PRESSURE	838.02kgf/cm2
DRY SHOT FLOW RATE	10,692.62 cm3/sec
MAX. METAL PRESSURE	131.5 kgf/cm2
MIN. METAL PRESSURE	51.4 kgf/cm2
FLOW RATE	4,834.5 cm3/sec
METAL PRESSURE (P)	P = 91.5 kgf/ cm2
FLOW RATE (Q)	Q = 7,255.7 cm3/sec
GATE AREA	69 mm2
GATE LENTH	23mm
RUNNER SIZE	L=86.7 mm2, D= 10.42mm, W= 20.84 mm

V. Conclusions and Future Scope

The aim of this paper has been achieved successfully considering all the critical dimensions. The size of the component is essential to any die design because it gives the actual picture of what a die designer wanted to achieve. Careful gate calculations are made to avoid any turbulent motion of the material.

The filling pattern of the molten aluminium is shown, and melt enters the gate and starts filling the cavity after 0.5s. Then the rest of the mould cavities will be filled up. The simulation demonstrates the importance of calculating the filling of the casting in the aluminium casting process. Simulation gives actual valuable information to the manufacturer what will be the final quality of the product. In this research, few process parameters were considered in the analysis for optimization. But this work can be extended, and other parameters such as molten metal, speed, discharge pressure, temperature and cavity fill rate, cooling rate, pq^2 relations can be considered for the purpose of optimization.

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