Die design and optimization of cooling channel position for cold chamber high pressure die casting machine

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Abstract. A well-designed gating system for pressure die casting has always been of great importance to achieve good quality castings. However, the cooling system employed in the die and its position has found to have a significant impact on the generation of stresses in the die. High stress concentrations contribute to the erosion of cavity surface thereby affecting the tool life and casting quality. The objective of this research work is to design a die and to analyse the effect of positioning of the cooling channels on the generation of stresses on the cavity surface. In this study, a runner gate system is designed for an ADC 12 aluminium alloy component that is to be cast on a Cold Chamber High Pressure Die Casting (HPDC) machine. Stress analysis and optimization of the cooling channel position of the die is carried out using ANSYS Workbench. Flow simulation of the optimized design is carried using MAGMA software to understand the effect of cooling channel position on the flow characteristics. The results demonstrate the impact of cooling channel position on the stresses generated in the die and prove to be valuable in designing the die. Defect inspection and testing of porosity is carried out on the castings produced with the optimized design in operation to check if they are acceptable.

Keywords. Cooling channels, die design, flow simulation, high pressure die casting, porosity, radiography.

1. Introduction

The High Pressure Die Casting (HPDC) operation is widely employed for large scale production of non-ferrous castings that have complex shapes and requirement of high quality and dimensional accuracy. The Cold Chamber HPDC process is a pressure die casting process where the injection mechanism is not submerged in the melting furnace and rather is transferred by means of a ladle into the shot hole of the machine. The molten alloy is then pushed into the die by means of a hydraulically operated plunger. The process has advantages of minimizing the contact time between the molten alloy and components of injection mechanism thereby increasing their life. However, air entrainment due to high speed injection can result in porosity in the castings that is a common problem.
The cast alloy selected is ADC 12 aluminium alloy that is to be cast on 160 T Cold Chamber HPDC machine. Minimum flow temperature of the alloy is 580 °C and it enters the die at a temperature of 660°C. Low density, good corrosion resistance, high thermal and electrical conductivity, high dimensional stability and good castability are some of the characteristics of ADC 12. Aluminium die casts have often found applications in automobile products that suffer repeated loading and thermal cycling. Compared to other cast alloys, ADC 12 is found to have less casting defects. It has high production rate, good mechanical properties and ability to form intricate shapes. B. Vijaya Rammath et al. studied the occurrence of various defects in ADC 12 such as misrun, cold shuts, shrinkage porosity that were produced with an existing flat gate system. A modified spoon-fed gating system design was proposed that overcame the drawbacks of the flat gate system. Process parameters like fill velocity, fill time and metal pressure were considered for process optimization and flow analysis using Rotork Flow 3D software [1].

In high pressure die casting operation, the most commonly employed hot work tool steels are H11 and H13. The material selected for the die is H13 which has good resistance to thermal fatigue, erosion and wear. The production cost of castings is highly dependent on life of the die which is affected by its design, heat treatment, material and various other casting parameters. The thermo-mechanical stresses generated on the die during operation, when exceeded beyond the strength of tool steel are one of the major causes of die failure [2]. Damjan Klobcar et al. analysed the influence of aluminium alloy die casting parameters, die material and die geometry on the in-service tool life. An immersion test apparatus was developed and the die casting was simulated for the special test specimens prepared of the die materials with Finite Element Method used for computation of transient stresses. Maraging steel was found to produce lower stresses and was considered superior material for die casting dies compared to other hot work tool steels [3].

A well-designed gating system for die casting has always been of great importance to achieve good quality die castings. Numerical simulation has achieved great attention and has proved to be a cost-effective way in the optimization of runner gate design. B. H. Hu et al. investigated the effect of split gate system on the filling pattern. Numerical simulation was carried out that showed the continuous gating system provided homogenous mould filling compared to the split gate system. A series of short shot experiments were carried out to validate the simulation results [4]. In die casting operation, porosity is a serious problem as it is invisible and cannot be identified visually. Kulkarni Sanjay
Kumar et al. studied and examined the effect of die casting process parameters such as first phase speed, second phase speed, first phase length and injection pressure on porosity in SAE 380 aluminium alloy using Taguchi method. Of all the parameters, he found that higher level of injection pressure has most significant effect on porosity in castings and the injection pressure stage is more important than other parameters in the die casting operation [5].

Most of the research work is found to be made on optimization of runner gate system using various simulation tools and analysing the effects of various casting parameters on the filling operation and formation of defects. Failure of dies is a common problem but very less literature is found on analysing die failure in the design stage. Analysis of the cooling system and its effect on the generation of stresses on the tool during operation has been rarely published. This paper discusses the effect of cooling channel position on the stress generation in the die that can be optimized in the design stage itself so as to improve die life and achieve good quality castings.

2. Design of runner gate system

2.1. Component

The runner gate system is designed for an automobile component SRE Bracket. The material of SRE Bracket is ADC 12 aluminium alloy. The weight and density of the component is 265 gm and 2.7 gm/cm$^3$ respectively. The 3D model of the component is created using NX software and is shown as follows.

![Figure 2. Model of SRE Bracket.](image)

2.2. Cavity fill time

One of the best-known formulas for determining the die cavity fill time is that given by NADCA fill time equation by J. F. Wallace and E. A. Herman: the equation takes slightly different forms in different literature.

The equation for fill time is

$$t = K \left( \frac{Ti - Tf + SZ}{Tf - Td} \right) \times T$$

(1)
Where, \( t \) = maximum fill time in seconds

\( K \) = empirically derived constant related to thermal conductivity of die steel, sec/mm

\( T \) = characteristic thinnest average wall thickness of the casting in mm.

\( T_f \) = liquidus temperature, °C.

\( T_i \) = metal temperature at the gate, °C.

\( T_d \) = die surface temperature just before the shot, °C.

\( S \) = percent solids at the end of fill, %.

\( Z \) = solid unit conversion factor, related to the width of solidification range.

\[
t = 0.0346 \left( \frac{660 - 580 + 15 \times 3.8}{580 - 180} \right) \times 3.5
\]

\( t = 41 \text{ milli-sec} \)

The part of the equation between the brackets sets a relation between the consumable heat during the cavity fill time and the temperature difference between the minimum flow temperature and die cavity surface temperature. Constant \( K \) relates this to the die material thermal conductivity and constant \( T \) to the average wall thickness of the casting.

### 2.3. Gate velocity

The gate velocity has an influence on the casting mechanical properties and on the surface quality. High gate velocity produces higher mechanical properties and less porosity than lower gate velocity. New HPDC machines are capable of producing gate velocities up to 100 m/s, but the die erosion starts to increase already around 40 m/s. Thus, higher velocity range from 40 m/s to 100 m/s is not very practical.

Gas porosity can be reduced without raising the gate velocity by designing the gate and runner system to maintain smooth, continuous flow profiles and by designing the casting so that no backflow occurs. Backflow can occur if there are protrusions on the flow of the metal.

The gate velocity can be chosen depending on the type of application and material of casting from the following table.

| Alloy   | Gate Velocity range (m/s) | Recommended gate velocities |
|---------|---------------------------|-----------------------------|
|         | Decorative parts | Engineering parts | Pressure Tight Parts |
| Aluminium | 20 - 60 | 20 | 40 | 60 |
| Zinc     | 30 - 50 | 30 | 40 | 50 |
| Magnesium| 40 - 60 | 40 | 50 | 60 |
| Copper   | 20 - 50 | 20 | 35 | 50 |

Therefore, from the alloy type and application of SRE Bracket we have, Gate velocity, \( V_g = 40 \text{ m/s} \).
2.4. \( PQ^2 \) analysis

The \( PQ^2 \) Analysis is based on knowing the pumping rate capability of a die casting machine. It is used to predict what happens when a die is put on the machine. To achieve good quality castings, the gating system must be matched to the machine characteristics so as to have correct pressure and flow rate. This analysis takes into consideration both the die casting machine and the die characteristics that help to evaluate the performance of the die on the selected machine. The machine’s characteristic curve describes how much pressure \( (P) \) the machine applies to the metal at a given flow rate \( (Q) \). \( PQ^2 \) analysis matches the selected gate velocity to the HPDC machine plunger hydraulic system. Using these, the runner gate system can be designed to be hydraulically and thermally efficient so that they give minimal mixing of air-metal and minimal re-melt. The value of Metal Pressure \( (P) \) can be calculated using the equation as follows

\[
P = \left( \frac{\rho}{2g} \right) \times \left( \frac{V_g}{C_d} \right)^2
\]

Where, \( P = \) metal pressure, kg/m\(^2\)
\( \rho = \) density of the cast alloy kg/m\(^3\)
\( V_g = \) gate velocity, m/s
\( g = \) gravitational acceleration, m/s\(^2\)
\( C_d = \) coefficient of discharge

\[
P = \left( \frac{2700}{2 \times 9.8} \right) \times \left( \frac{40}{0.3} \right)^2
\]

\[
P = 4.32 \times 10^6 \text{ kg/m}^2
\]

The metal pressure creates a breaking force \( F \), which is proportional to the projected area of the cavity \( A \) and is calculated as,

\[
F = P \times A
\]

Where, \( F = \) breaking force, kg
\( P = \) metal pressure, kg/m\(^2\)
\( A = \) projected area of the die cavity, m\(^2\)

\[
F = 4.32 \times 10^6 \times 268 \times 10^{-4}
\]

\[
F = 115.776 \times 10^3 \text{ kg}
\]

\[
F = 115.776 \text{ T}
\]

\[
F < 160 \text{ T}
\]

The breaking force is less than the machine tonnage capacity. “\( PQ^2 \) check is OK”.

Therefore, the die can be operated on the selected 160 T machine.
2.5. Gate parameters

2.5.1 Gate area. It represents cross sectional area of the gate and can be determined as follows

\[ A_g = \frac{V_{\text{part}} + V_o}{V_g \times t} \]  

(4)

Where, \( A_g \) = gate area, mm\(^2\)
\( V_{\text{part}} \) = part volume, mm\(^3\)
\( V_o \) = overflows volume, mm\(^3\)
\( V_g \) = gate velocity, m/s
\( t \) = fill time milli seconds

Overflow volume, \( V_o \) is accounted to be 10% of the part volume

\[ A_g = \frac{98148.1 + 9814.81}{40 \times 41} \]

\[ A_g = 65.8310 \text{ mm}^2 \]

\[ A_g = 66 \text{ mm}^2 \text{ (approx.)} \]

2.5.2 Gate height The gate height can be calculated as a fraction of the average wall thickness

\[ H_g = \frac{n}{3} \sim \frac{n}{4} \]  

(5)

Where, \( H_g \) = gate height, mm
\( n \) = average wall thickness, mm

\[ H_g = \frac{3.5}{3} \sim \frac{3.5}{4} \]

\[ H_g = 1.2 \text{ (approx.)} \]

The user can however interactively choose another suitable value of gate height that fulfils the gating requirements. The gate height is found to be dependent on selected gate velocity and alloy density as given by the equation

\[ V_g^{1.707} \times H_g \times \rho \geq J \]

Where, \( \rho \) = alloy density
\( J \) = constant, 998000 for aluminium, magnesium and zinc alloys.

2.6. Runner parameters

2.6.1. Runner Area. The ratio of runner area to gate area varies with part design and usually ranges from 1.1 to 1.4 \( A_g \). A larger ratio of 1.6 is used in the case of small parts in multi cavity gating system design. The type and cross section shape of the runner chosen is tangential and trapezoid respectively.

\[ A_r = 1.1 \ A_g \text{ to } 1.6 \ A_g \]  

(6)

The default value to calculate runner area is
\[ A_r = 1.4 \ A_g \]

\[ A_r = 92.1634 \text{ mm}^2 \]

2.6.2. Runner Height The runner height is calculated from the equation as follows and the runner width \((W_r)\) is taken twice of the runner height \((H_r)\)

\[ H_r = \sqrt{\frac{A_r}{1.6}} \sim \sqrt{\frac{A_r}{2}} \quad (7) \]

\[ H_r = 7.5896 \sim 6.7883 \text{ mm} \]

\(H_r = 7.5 \text{ mm (approx.)}\)

Therefore, we have the width of runner as \(W_r = 15 \text{ mm}\)

The various constants and assumptions used in the calculations are as given below

**Table 2. Constants and Assumptions**

| Constants and Assumptions                  | Value           |
|--------------------------------------------|-----------------|
| Empirically derived constant, \(K\)        | 0.0346 sec/mm   |
| Temperature of molten metal as it enters the die, \(T_i\) | 660 °C          |
| Min flow temperature of metal (liquidus), \(T_f\) | 580 °C          |
| Temperature of die cavity surface just before metal enters, \(T_d\) | 180 °C          |
| Percent solid fraction allowable in metal at the end of filling, \(S\) | 15%             |
| Units conversion factor, \(Z\)             | 3.8             |
| Coefficient of discharge, \(C_d\)          | 0.3             |
| Acceleration due to gravity, \(g\)         | 9.8 m/sec\(^2\) |

3. Cooling system of the die

Cooling system employed in the die is line cooling which covers large surface area of the die unlike spot cooling. Cooling channels are employed in the die to maintain its temperature during operation. As internal cooling is very important, the cooling channels are placed in the high temperature regions in the vicinity of the cavity surface. They also facilitate proper solidification of the cast part after complete filling of the die cavity. If the cooling channel is placed too close to the cavity surface, the surface temperature becomes too low and low strength between the channels and the cavity surface likely results in cracking.

Hot phase of the die casting cycle is characterized by generation of high compressive stresses on the surface that get additionally increased by filling pressure of the die. Compressive stresses suppress the crack nucleation and growth which is favourable if no plastic deformation occurs. Local plastic deformations occur as a consequence of exceeding stresses beyond the yield strength of the die material which are expressed on specific locations as stress concentrators, notch effects, sharp transitions and large mass changes of the tool. High tensile stresses are produced during the cold phase that which are increased by plastic deformation of the surface material of the die. Due to cyclic loading operation of the die, low cycle fatigue occurs when the stresses exceed beyond the yield
strength or ultimate tensile strength of the material at working temperature that result in nucleation and initial crack growth [6].

In die designing, the designer can intentionally challenge the distance of cooling channels from cavity surface based on some experience. The cooling channel distance from die cavity surface is usually kept twice of its diameter. However, this position does not always prove efficient in controlling the stresses developed in the die. Suitable stress analysis is carried out to optimize the cooling channel position so as to have acceptable stresses in the die. The standard cooling channel diameter taken in the research work is 8 mm and they are placed at a distance of 16 mm from the cavity surface. This positioning of cooling channels based on experience is used in the existing model.

4. Stress analysis and optimization of cooling channel position

A steady state thermo mechanical analysis of the existing model is carried out on ANSYS Workbench 14.5. The shot model of the casting with the cooling channels and the existing die assembly model used for analysis are shown in figure 3 and figure 4 respectively. The modelling of gating system and the die halves is done using NX software.

![Figure 3. Shot Model with Cooling channels](image1)

![Figure 4. Existing Die assembly](image2)

4.1. Pre-processing

The step file of die assembly model created on NX software is imported in ANSYS. The assignment of materials made in analysis is as given below.

| Part                        | Material |
|-----------------------------|----------|
| Component                   | ADC 12   |
| Fixed side insert (FSI)     | H 13     |
| Moving side insert (MSI)    | H13      |
4.2. Processing

The loading and boundary conditions employed for analysis are given as follows

| Condition | Part          | Value            |
|-----------|---------------|------------------|
| Temperature | Casting      | 660 °C           |
|            | FSI           | 180 °C           |
|            | MSI           | 180 °C           |
|            | Cooling channel | 25 °C         |
| Loading    | FSI           | Fixed            |
|            | MSI           | 160 T            |

4.3. Post-processing

4.3.1. Existing Model

The cooling channel distance in existing model is 16 mm from cavity surface. The stress values obtained with the existing position of cooling channels from the analysis as shown in figure 7 and figure 8 are found to exceed the permissible limits. The yield strength and ultimate tensile strength of the tool being 1650 MPa and 1990 MPa respectively. Thus, keeping the distance of cooling channels from cavity surface twice as the used diameter is found to be inefficient from stress point of view. The positioning of the cooling channels from the cavity surface therefore needs to be optimized so as to have stresses produced within the permissible limits.

The temperature and stress results obtained on the Moving Side Insert (MSI) and Fixed Side Insert (FSI) of the existing model of the die are shown as follows.
4.3.2. Proposed model

Moving the cooling channels closer to the cavity surface were found to produce higher stresses and so decreasing the distance was not a solution. The cooling channels distance from cavity surface was then increased so that the stresses that were produced were in safe limits. After few trials, an optimum distance of cooling channels from the cavity surface was achieved that produced efficient results. The new proposed design of the die with optimized cooling channel position was found to be safe from stress point of view. The optimum cooling channel distance obtained was 20 mm from the cavity surface in FSI and MSI.

The stress and temperature results that were obtained from the proposed position were acceptable and are shown as follows.
5. Flow simulation

The proposed design of the die with optimized position of the cooling channels is validated by carrying out the flow simulation of the mould filling process. The simulation is done using the MAGMA Soft software. The input data used for simulation of the proposed design of die is as given below.

| Description                  | Value     | Description                  | Value     |
|------------------------------|-----------|------------------------------|-----------|
| Plunger diameter             | 50 mm     | Casting weight               | 265 gm    |
| Active sleeve length         | 285 mm    | Shot weight                  | 528 gm    |
| Slow phase length            | 206 mm    | Yield                        | 52 %      |
| Slow phase velocity          | 0.25 m/s  | Shot projected area          | 268 cm²   |
| Second phase velocity        | 2.2 m/s   | Molten melt temperature      | 660 °C    |
| Gate area                    | 66 mm²    | Casting pressure             | 800 kg/cm²|
| Fill ratio                   | 34%       | Vent area considered         | 8 mm²     |
| Gate velocity                | 40 m/s    | Machine tonnage              | 160 T     |
| Cavity fill time             | 41 milli-sec | Density of alloy           | 2.7 gm/cm³|

The filling simulation of the optimized model of gating system gave metal temperature during filling in liquids range thus ensuring complete filling of the mould cavity. With the optimized position of cooling channels, the filling of the cavity is found to be good. The other results of flow simulation obtained are explained as follows.
5.1. $PQ^2$ analysis

$PQ^2$ Analysis is used to match the target gate velocity with the capabilities of High Pressure Die Casting machine’s plunger hydraulic system.

From $PQ^2$ Analysis, the plunger size is found to be OK to fill the casting.

5.2. Switch over point during filling

At plunger position 206 mm, velocity changes from slow to fast. The switch over point occurs at 206 mm plunger position as shown below. The slow phase velocity being 0.25 m/s that increases to 2.2 m/s in the second phase.
5.3. Air entrapment result

Maximum air entrapment is found to be 15% which is in the acceptable range for any surface defect of casting.

Figure 15. Air entrapment result

5.4. Hotspot_FS result

The result shows local solidification time at different places. This is maximum 12 sec which is acceptable.

Figure 16. Hotspot_FS Result
5.5. Shrinkage porosity

The shrinkage porosity is in the acceptable range. Porosity defects however cannot be completely avoided in die castings. They can be minimized by controlling process parameters like first phase speed, second phase speed, injection pressure and first phase length in operation.

![Figure 17. Shrinkage porosity result](image)

6. Defect inspection and testing

Porosity is the most common defect found in die castings that is of vital concern. The different types of porosities that occur in castings include gas porosity, flow porosity and shrinkage porosity. Gas and shrinkage porosity often occur together and are mostly confused with each other. Gas porosity occurs as round smooth wall shaped bubbles. It has different sources like trapped air, trapped steam, vaporized lubricant vent design, etc. which cannot be completely avoided but can be minimized if proper care is taken during design and die operation. Shrinkage porosity defects are voids that appear jagged and are irregularly shaped. Increasing the injection pressure produces less difference in the void size or visibility of porosity but shrinkage porosity is found to respond quite well to metal pressure applied at the right time and place [7]. Casting defects cannot be completely avoided but they can be minimized. The defective castings are re-melted and used again. Defects less than 1% of the production rate are acceptable in high pressure die casting.

The cavity pressure should be within the range needed to minimize shrinkage porosity. For pressure to be effective it has to be present when metal solidifies as metal cannot be pressurized before the end of stroke and it can have large porosities if it solidifies before the end of the stroke. Two metal pressures are important, one without intensification called as static pressure which is applied at the end of the stroke before the intensifier comes in and the second is intensified pressure which is about 2.5 to 3 times the static pressure. The magnitude of pressure applied during operation was obtained by trial and error and is in the range of 270 to 275 kg/cm² so as to keep shrinkage porosity at a minimum.
The castings manufactured in operation were inspected for porosity. The numbers of rejections due to porosity from the defect inspection sheet were found to be less than 1% of the production. The defects obtained were within acceptable limits. Table 6 gives the number of defects obtained in operation for five different heat loads.

### Table 6. Defect inspection sheet

| Heat load | Sr. no. | Production Qty. (per day) | No. of Defects | % Defects |
|-----------|--------|---------------------------|----------------|-----------|
| 1         | 1      | 700                       | 5              | 0.71      |
| 2         | 2      | 700                       | 6              | 0.85      |
| 3         | 3      | 750                       | 3              | 0.40      |
| 2         | 4      | 700                       | 3              | 0.42      |
| 5         | 5      | 700                       | 4              | 0.57      |
| 6         | 6      | 700                       | 6              | 0.85      |
| 3         | 7      | 690                       | 4              | 0.57      |
| 8         | 8      | 700                       | 4              | 0.57      |
| 9         | 9      | 700                       | 5              | 0.71      |
| 4         | 10     | 700                       | 6              | 0.85      |
|           | 11     | 670                       | 6              | 0.89      |
| 12        | 12     | 700                       | 5              | 0.71      |
| 5         | 13     | 700                       | 4              | 0.57      |
| 14        | 14     | 700                       | 5              | 0.71      |
| 15        | 15     | 700                       | 3              | 0.42      |

Defective casting samples were taken from different heat loads that were examined for the type and level of porosity. Five samples were taken, each from one of the five heat loads and were tested for porosity using radiography. The observations obtained from radiography are as given below.

### Table 7. Radiography Observations

| Sr. No | Film Size (in.) | Observations | Remarks  |
|--------|-----------------|--------------|---------|
| 1      | 6 × 7.5         | Shrinkage Cat. C | Level IV |
| 2      | 6 × 7.5         | Porosity Cat. A | Level II |
| 3      | 6 × 7.5         | Porosity Cat. A | Level II |
| 4      | 6 × 7.5         | Porosity Cat. A | Level III|
| 5      | 6 × 7.5         | Porosity Cat. A | Level II |

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Radiographic examination serves as a guide that enables recognition of discontinuities and their differentiation both as to type and severity level through radiographic examination. The results of radiography are compared with ASTM E505 standards. The reference radiographs as per ASTM E505 standard used for die castings are as shown in the figure below.

![Reference Radiographs for Die Castings](image)

**Figure 18.** Reference Radiographs for Die Castings

As per ASTM E505 standards, the following descriptions are used in discontinuity identification and classification. These descriptions apply to these reference radiographs only:

**Category A (Porosity)** – Round or elongated, smooth-edged dark spots occurring individually distributed or in clusters.

**Category B (Cold Fill)** – A distinct, darkened line or band of variable length and definite smooth outline, usually continuous or interconnected.

**Category C (Shrinkage)** – Filamentary or jagged darkened areas, usually continuous or interconnected.
**Category D (Foreign Material)** – Isolated irregular variations in film density that are either lighter or darker than surrounding areas. They may indicate the inclusion of oxide or dross or metallic compounds of different density.

| Discontinuity                | Plate Thickness in. (mm) | Applicable casting Thickness in. (mm) |
|-----------------------------|--------------------------|---------------------------------------|
| Category A (Porosity)       | 1/8 (3.2)                | Up to 3/8 (9.5), incl                 |
| Category A (Porosity)       | 5/8 (15.9)               | over 3/8 to 1 (9.5 to 25.4) incl      |
| Category B (Cold Fill)      | 1/8 (3.2)                | up to 3/8 (9.5), incl                 |
| Category C (Shrinkage)      | 5/8 (15.9)               | over 3/8 to 1 (9.5 to 25.4) incl      |
| Category D (Foreign materials) | 0.200 (5.08)            | up to 1 (25.4) incl                   |

7. **Results and discussion**

Designers often produce a good quality part by following the best practices for designing the runner gate system, vents, overflows, etc., of the casting. The die designing is a very broad area to be studied and the process parameters have been found to have a significant influence on the formation of defects and ultimately the quality of the cast product. The positioning of the cooling channel has significant effect on the generation of stresses in the die. The existing model had cooling channels placed at a distance of 16 mm which was twice the diameter as per past experience. This model was analysed using ANSYS and resultant stresses were found to exceed permissible stress limits. A new model was proposed by optimizing the distance of cooling channels from the cavity surface so as to have permissible values of stresses. The optimized distance of cooling channels obtained was 20 mm from the cavity surface.

The proposed model with optimized cooling channel position was simulated to study its effect on the fill characteristics using MAGMA Soft software and the results obtained with the proposed design are acceptable from stress as well as filling point of view. Of the various defects that occur in castings, porosity is the most common. The defects produced in operation were inspected for porosity so as to check if they are acceptable in the optimized model. Five defective samples from five heat loads were tested using radiography to find porosity and the defect inspection sheet showed results in the acceptable range (< 1%).

8. **Conclusion**

Die erosion due stress concentrations during operation is a typical die failure mode and the positioning of the cooling channels is found to significantly impact the stresses generated on the die. The project work intended to design a die and optimize the cooling channel position to ensure that the stresses developed in the die are produced within permissible limits.

The investigation made was of line cooling used in the cold chamber machine die. A coupled structural and thermal analysis of the die was carried out of the existing design using ANSYS Workbench 14.0. As the existing design resulted in stresses beyond the permissible values, a new safe design was proposed with optimized position of cooling channels. The proposed design was simulated...
Using MAGMA Soft to understand its effect on the filling and solidification of casting and the fill results obtained were satisfactory.

A major challenge while designing a die is determining whether or not the final part has defects. A major portion of defects that occur in die casting have been found to be related with temperature fluctuations and stresses that are produced during the operation. The final cast products produced with the proposed design of the die were tested to observe the defects. The defects obtained were within the acceptable range.

Thus, this type of analysis could prove to be of value while designing the die and positioning of the cooling system. It not only helps in the prediction of stresses but also allows one to make the required modifications in the die accordingly. This type of analysis in the early design stage serves to improve the life of the die as well as the quality of the cast products.

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