International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 07 Issue: 06 | June - 2023 SJIF Rating: 8.176 ISSN: 2582-3930

OPTIMIZATION OF COOLING RATE IN PRESSURE DIES CASTING WITH TIME DOMAIN

Mohammedojer Mohammedhabib Kushkiwala

G..TU. M..E. (Production) Scholar, Department of Mechanical Engineering, Ahmedabad Institute of Technology, Ahmedabad, Gujarat, India. ojer99@gmail.com

ABSTRACT:-

In order to supply previously adjusted technological parameters impacting cast quality in pressure die casting, this study discusses solutions for optimising and managing the casting regime. This study specifically demonstrates the benefit of combining new items with cutting-edge software in comparison to traditional methods. An costly and time-consuming travel is needed to complete the previous, standard procedure of concurring new products. Modern software implementation shortens the time needed to complete a new product, improves process control, boosts quality, and lowers new product cost. The risks and extremely difficult working conditions at foundries make this a difficult profession, and there aren't many people who fit this description working there. the resolution to these issues

KEYWORD:-Pressure die casting, input variables, as well as numerical casting simulation

1.1 INTRODUCTION:-

A variety of processes are used in the manufacturing industry to produce a finished product. These processes are quite complex in nature and demand high conformity to tolerances. Due to recent advances in computing hardware and software it is possible to simulate the physics of the process using numerical simulations. These simulations map the input to output process parameters and thus can be used to estimate the final product quality. Development of real-time data acquisition systems has facilitated the measurement of parameters during physical experiments. In order to increase the simulation accuracy, there is a need to couple experimental data with numerical simulations. Moreover in the industrial environment, controlling the process parameters tightly is often costly and time consuming.

Die casting is an important manufacturing process used when high production rates and complex geometries are required to be manufactured. The die is generally made out of steel consisting of two halves which are separated along the parting line and held in place by multiple ejector pins. Cooling lines are designed in the die to flow a coolant, typically water. The mold cavity is sprayed with a lubricant which helps to control the die temperature and also reduces the sticking of the molten metal to the die during the removal. Then, the two die halves are closed and liquid metal is filled in the cavity. The owing coolant maintains temperature of the die and extracts heat from the molten metal. After solidification, the two halves are separated by sliding along the ejector pins. The last step is shakeout in which the scrap (gates, runners etc.) are separated from the casting and the casting is further cooled to room temperature either by quenching in water or leaving open to air.

1.2 Research Gap

1. Experimental investigation on process parameters like Pouring rate, Cooling Time, Cooling rate and environment was done separately.
2. Most of the research papers depicted the relationship based on Separate Parameters.
3. Hence, more development of statically modelling of Time domain based research was rarely found in literature survey.

1.3 Problem statement

From the literature review, it is found that the pressure die casting literature is the lack of comprehensive investigation and statistical modeling that integrates the effects of multiple process parameters (pouring rate, cooling time, cooling rate, and environment) on the time domain. Existing studies have predominantly examined these parameters individually, resulting in a fragmented understanding of their combined influence. To address this gap, this research aims to develop a holistic statistical modeling framework that considers the combined effects of these parameters, enabling a more accurate understanding of the time domain in pressure die casting. By achieving this objective, the study seeks to contribute to improved process prediction, optimization, and control in the field of pressure die casting. So, after referring literature review, this thesis has been carried out and the dissertation title is taken as **"Optimization of Cooling Rate in Pressure Die Casting With Time Domain"**

1.4 Objective

- To find optimum parameters like Pouring rate, Cooling Time, Cooling rate based on real-time data.
- To carry out experimental work according to the Design of Experiments.
- To develop relationship between actual timings and optimized time with using Taguchi method and ANOVA method.
- To predict relatable cooling extensions using the real-time data.

1.5 Research Methodology

1.5.1 Selection of material

In this work Aluminium 6063 is selected as material because of its number of advantages and applications. It is very lightweight alloy, offers good strength, excellent thermal conductivity, corrosion resists, etc

1.5.2 Mechanical Properties and composition of Aluminium 6063

Mechanical Properties of Aluminium 6063

1. 310 MPa Tensile Strength
2. 276 MPa Tensile Yield Strength
3. 207 MPa Shear Strength
4. 96.5 MPa Fatigue Strength
5. 68.9 GPa is the modulus of elasticity
6. 26 GPa Shear Modulus
7. Poisson's ratio of 0.33
8. elongation of 12–17%;
9. Brinell hardness of 95
10. Density 2700 Kg/m3 = 2.7 g/cm3
11. 588 °C melting point

Aluminium 6063's chemical composition is as follows:

1. Aluminium, Al - **97.9%**
2. Magnesium, Mg - **1%**
3. Silicon, Si - **0.60%**
4. Copper, Cu - **0.28%**
5. Chromium, Cr - **0.20%**

Cooling Methods for Casting Process

Many kinds of die casting moulds encompass water-cooling channels to reduce the accumulation of heat within the mould during casting and solidification. Soldering between Al molten metal and die steel mould can be prevented by improved water-cooling channel configuration and quantity.

The reference example is a common, uncooled sand mould with a cooling time of around 210 minutes measured until the casting accomplishes its desired temperature of 300 °C.

To aid in solidification in a particular area of a metal casting mould, a device termed to as a chill is utilised. The thickness of the casting is often what determines how quickly the metal in the mould cools.

There are Four Types of Chillers like Air-Cooled, Water-Cooled, Used, and Custom Chillers

1.5.4 Selection of variable process parameters

The factors that directly affect cooling rate improvement include pouring temperature, filling time, die temperature, and injection pressure. As a consequence, For the purpose of experimentation, the process parameters pouring temperature, filling time, die temperature, and injection pressure were chosen.

- **Pouring temperature:** Pouring temperature refers to the temperature at which molten material is poured into a mold during a casting process. It is a crucial parameter that significantly influences the solidification behaviour, microstructure, and overall quality of the cast product.
- **Filling time:** During a casting or moulding process, the term "filling time" describes the amount of time it takes for molten material to entirely fill a mould cavity. It is a significant factor that has an immediate impact on the final product's quality, dimensional correctness, and overall integrity.
- **Die temperature:** Die temperature is a term used to describe a die's temperature in a variety of manufacturing processes, particularly in the context of metal forming and die casting. When processing a material, the die temperature is crucial for shaping and hardening it.
- **Injection pressure**: Injection pressure refers to the amount of pressure applied to inject molten material into a mold cavity during the injection molding process. It is a critical parameter that plays a significant role in the quality, dimensional accuracy, and performance of the molded product.

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1.6 Design of Experiment.

1.6.1 Methodology

1. Optimum Parameter Using Industrial Problem.
2. Calibrated Equipments.
3. Absolute Experimental Reading.
4. Analysis of the data at real time.
5. Comparisons based on software.
6. Findings Evaluation
7. Conclusion

1.6.2 Design of Experimentation

- Industrial Problem Formulation
- Data of Temperature
- Data compilation
- Data Processing
- Analysis using array
- Software based comparison
- Conclusion

1.6.3 Taguchi approach to DOE

Taguchi method is somewhat different than other methods of DOE. This approach is often used to identify the best conditions, evaluate each parameter's unique impact, and estimate performance under the most favorable conditions. Taguchi approach either uses ANOVA or S/N ratios to achieve the optimal values. Using Minitab software, the trials are created using the L9 orthogonal Taguchi method. For each experiment, are petition was performed, therefore total of 36 specimens were printed using an FDM 3D printer.

Steps included in the Taguchi approach are,

1. Selection of factors
2. Selection factor interactions
3. Selection of the levels of each factor
4. Selection of an orthogonal array
5. Assign columns
6. Conduct tests
7. Analyze results
8. Confirmation experiment
9. Assess risk

1.6.4 Selection of process parameters and their levels

Parameter Destination	Process parameters	Range
A	Pouring temperature(0C)	650 - 750
B	Filling time (ms)	40 - 130
C	Die temperature(0C)	180 - 260
D	Injection pressure(bar)	120 - 240

Table-1 Parameters for Design

Throughout the experiment, the additional parameters remained constant.. The range of the pouring temperature was chosen to be between 650^0C and 750^0C, the filling duration to be between 40 and 130 (ms), the die temperature to be between 180^0C and 260^0C, and the multiplied injection pressure to be between 120 bar and 240 bar. The parameters chose for the casting process and their ranges.

1.6.5 Selection of Orthogonal array

There are several orthogonal arrays, and each one is dependent on the number and degree of the process parameters. Based on the degree of freedom, which can be calculated with the following equation, an orthogonal array is selected.

DOF is equal to [((Average Number of Levels for Each Factor-1)*(No. of Factor)] + [Interaction freedom degree] +1

The research will focus on three process parameters, each of having three levels and a 9 DOF. As a consequence, Taguchi's L9 orthogonal array been chosen.

Exp. No	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table-2 Orthogonal Array

1.6.5 Experimentation

All the experiments are carried out according to the selected L9 orthogonal array and their results are evaluated further.

1.6.6 ANOVA (Analysis of Variance):

A statistical test called an ANOVA is used to examine the total number of parameters produced by an orthogonal array.. ANOVA table with the parameters listed below,

1. Degrees of freedom(DF)
2. Sum of squares(SS)
3. Means squares (MS)
4. F-value
5. P-value

The total sum of squares helps the total deviation from the mean. Mean squares indicate an estimate of the population variance. It may be calculated using the inverse value of the degrees of freedom to the suitable sum of squares. The F-value identifies the parameter that impacts a given respond to the most. A higher F-value yields a factor that is more significant. The calculated probability is expressed by the P-value. Significant factors are those that have a P-value that is below.

1.7 Selection of process parameters and their levels

Parameter Destination	Process parameters	Range	Level 1	Level 2	Level 3
A	Pouring temperature(0C)	650 - 750	650	700	750
B	Filling time (ms)	40 - 130	40	85	130
C	Die temperature(0C)	180 - 260	180	220	260
D	Injection pressure(bar)	120 - 240	120	180	240

Table-3 Design Parameters with their levels

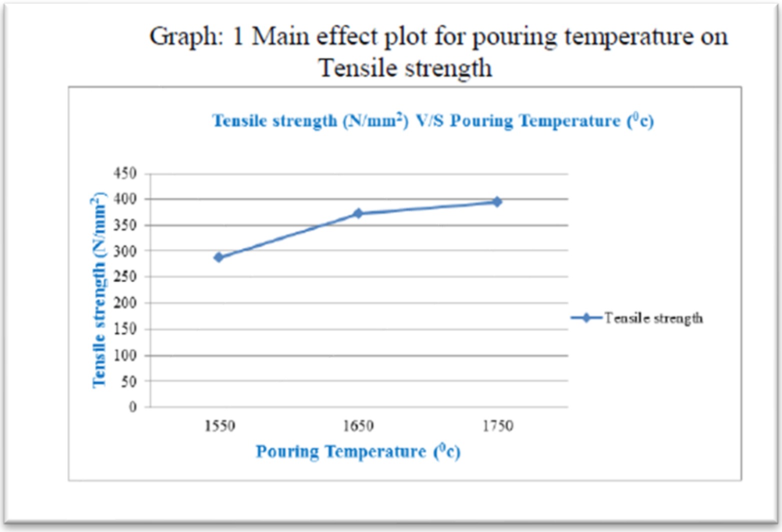

Fig-1 Graph-1 Main effect plot for pouring temperature on Tensile strength

To create a main effect plot for pouring temperature on tensile strength, different temperature levels (low, medium, and high) are considered. At low temperature (1550°C), the tensile strength is around 290 N/mm^2. At medium temperature (1650°C), it increases to about 375 N/mm2, and at high temperature (1750°C), it reaches around 400 N/mm^2. The plot reveals any systematic trend, with rising values from left to right indicating an increasing temperature effect. Variability in tensile strength can be assessed by observing the dispersion of data points.

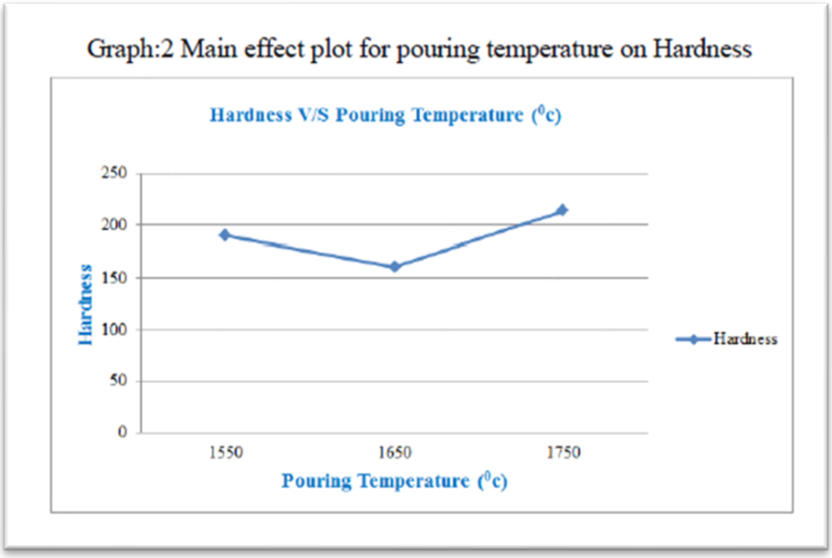

Fig-2 Graph-2 Main effect plot for pouring temperature on Hardness

The graph illustrates the relationship between pouring temperature (low, medium, high) and hardness values. Each point represents the average hardness for a specific pouring temperature level. At a low pouring temperature of 1550°C, the hardness value increases to around 190 N/mm^2. In contrast, at a medium pouring temperature of 1650°C, the hardness value decreases to approximately 150 N/mm^2. Finally, at a high pouring temperature of 16500°C, the hardness value increases to around 220 N/mm^2.

1.8 Results and Analysis

After performing the experiments, the experimental data are analysed in Minitab software. The results are analysed using S/N ratio, main effect plot, regression analysis and Analysis of Variance (ANOVA), contour plot sand bar charts. The optimum set of process parameters and also the most influential process parameter are obtained using ANOVA in the context of the properties and printing time. Validation of all the results is performed at the end of this chapter.

Trial no	Repetition 1	Repetition 2	Repetition 3	Average	S/N ratio
1	0.538	0.502	0.466	0.5018	5.9748
2	0.466	0.573	0.538	0.5257	5.5542
3	0.323	0.358	0.394	0.3584	8.8832
4	0.394	0.358	0.394	0.3823	8.3430
5	0.538	0.502	0.430	0.4898	6.1628

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6	0.430	0.430	0.394	0.4182	7.5661
7	0.394	0.358	0.430	0.3943	8.0604
8	0.251	0.215	0.287	0.2509	11.9514
9	0.394	0.358	0.323	0.3584	8.8832

Table-4 Experimental Results

Factor	Level 1	Level 2	Level 3	L 2-L 1	L 3-L 2
A	0.4620	0.4301	0.3345	-0.0319	-0.0956
B	0.4261	0.4221	0.3783	-0.0040	-0.0438
C	0.3903	0.4221	0.4142	0.0318	-0.0079
D	0.4500	0.4460	0.3305	-0.0040	-0.1155

Table-5 Result Analysis using Taguchi Method

Graph: 3 Main effect plot for pouring time on Tensile strength

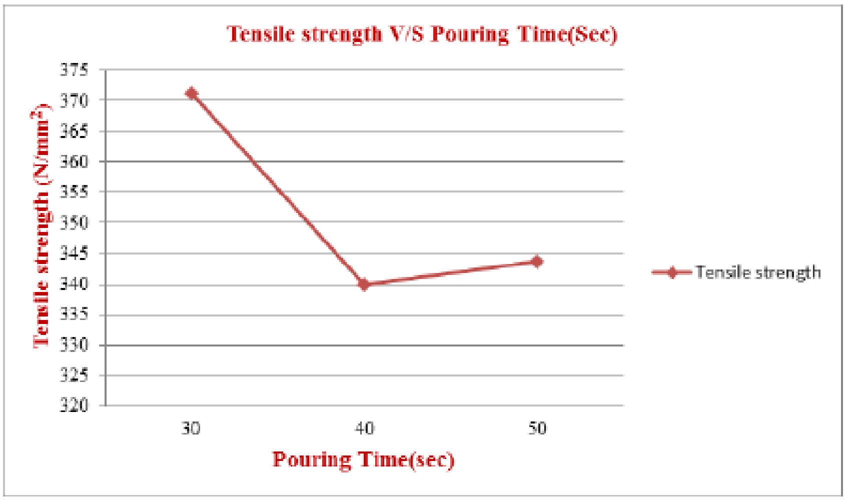

Fig-3 Graph-3 Main effect plot for pouring time on Tensile strength

The graph shows the relationship between pouring time (short, medium, long) and tensile strength values. At a short pouring time of 30 seconds, the tensile strength increases to around 375 N/mm^2. However, with a medium pouring time of 40 seconds, the tensile strength decreases to approximately 340 N/mm^2. For a long pouring time of 50 seconds, there is a slight increase in tensile strength to about 345 N/mm^2. The spread of data points indicates the variability in tensile strength.

Graph:4 Main effect plot for pouring time on Hardness

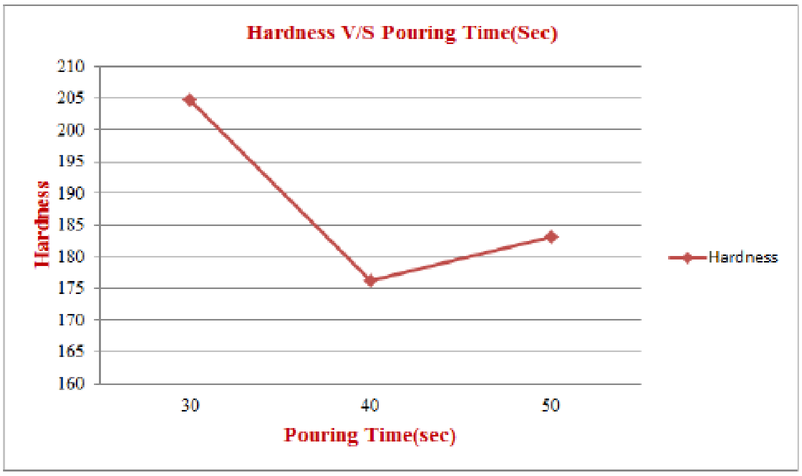

Fig.-4 Graph-4 Main effect plot for pouring time on Hardness

The graph shows the relationship between pouring time (short, medium, long) and hardness values. At a short pouring time of 30 seconds, the hardness value increases to around 205 N/mm^2. For a medium pouring time of 40 seconds, the hardness value decreases to approximately 175 N/mm^2. However, with a long pouring time of 50 seconds, the hardness value increases again to about 185 N/mm^2. The spread of data points indicates the variability in hardness.

Graph: 5 Main effect plot for cooling time on Tensile strength

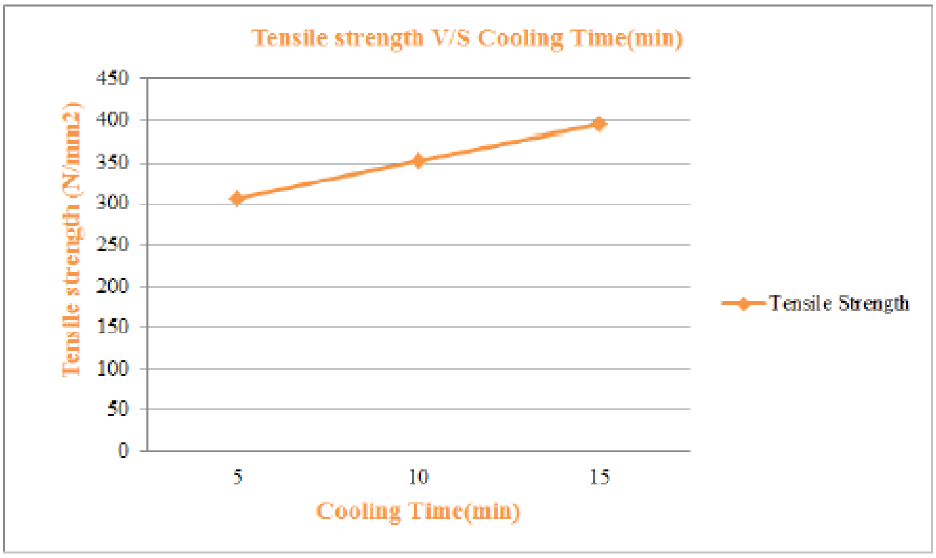

Fig.-5 Graph-5 Main effect plot for cooling time on Tensile strength

The graph displays the relationship between cooling time (short, medium, long) and tensile strength values. At a short cooling time of 5 minutes, the tensile strength increases to around 300 N/mm^2. For

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a medium cooling time of 10 minutes, it further increases to approximately 350 N/mm^2. At a long cooling time of 15 minutes, the tensile strength reaches about 400 N/mm^2. Higher point values indicate higher tensile strength at each cooling time level.

Graph: 6 Main effect plot for cooling time on Hardness

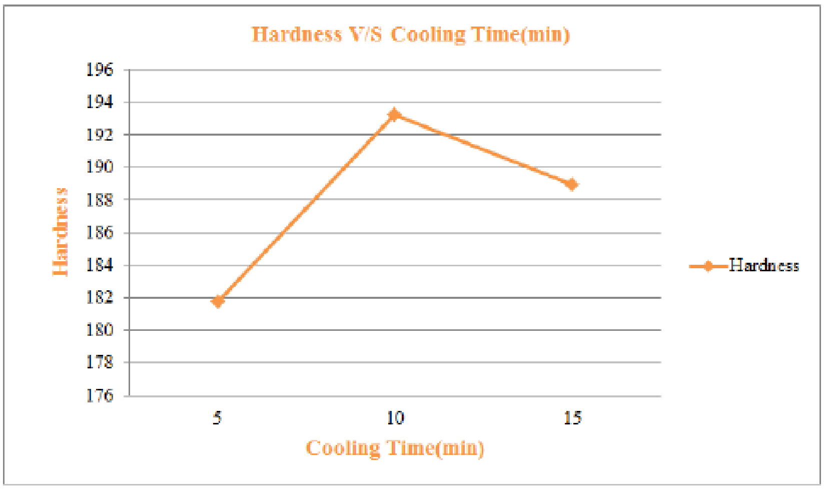

Fig. 6.2 Graph-6 Main effect plot for cooling time on Hardness

The graph shows the relationship between cooling time (short, medium, long) and hardness values. At a short cooling time of 5 minutes, the hardness value increases to around 182 N/mm^2. For a medium cooling time of 10 minutes, it further increases to approximately 193 N/mm^2. However, with a long cooling time of 15 minutes, the hardness value decreases to about 189 N/mm^2. The spread of data points indicates the variability in hardness.

- ## Conclusions

An experiment demonstrates that changes in the die casting process parameters have a substantial impact on the development of porosity in die castings of aluminium alloys. Porosity development in castings made of aluminium 6063 is affected by the pouring temperature, filling time, die temperature, and injection pressure.

Following are the parameters' percentage implications to the variations in casting porosity of aluminium 6063 castings:

Pouring temperature (%)	43.606
Filling time (%)	4.733
Die temperature (%)	4.730
Injection pressure (%)	46.931

Table-6 Variations in casting porosity of aluminium 6063

The following table indicates the ideal values of several die casting parameters for optimum casting density via porosity minimization:

Pouring temperature(0C)	750	(third level)
Filling time (ms)	130	(third level)
Die temperature(0C)	180	(first level)
Injection pressure(bar)	240	(third level)

Table-7 Ideal values of several die casting parameters for optimum casting density

- Future scope

- Future research can focus on finding the optimal combination of these parameters to achieve even lower porosity levels and improve the overall casting density.
- Developing mathematical models and simulation techniques can help predict the porosity formation during the die casting process.
- Exploring different material compositions and alloy modifications for aluminium 6063 can provide insights into reducing porosity formation.
- By analysing the internal structure and porosity distribution, advanced imaging techniques, such as X-ray or CT scanning, may be used to help design focused solutions for reducing porosity.
- concentrate on how the die casting process affects the environment. investigating environmentally friendly and sustainable die casting methods, such as using recycled materials.

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