

A Literature Review Design Optimization of a Die Casting Mold for Aluminum Alloy Components

Divya Rajesh Chaware, Dr. S.N. Waghmare

Divya Rajesh Chaware, M tech. Student, Department of Mechanical Engineering Design,
Priyadarshinin College of Engineering Nagpur-440019

Dr. S.N. Waghmare, Assistant Professor in Department of Mechanical Engineering , Priyadarshini
College of Engineering Nagpur – 440019

Email ID: subhashwaghmare1981@gmail.com , chawaredivya1@gmail.com

Abstract:

Die casting is a common manufacturing process for making complex aluminum alloy parts with high precision and good surface finish. However, the quality and performance of the final casting depend significantly on the design and thermal behavior of the die mold. In this study, we design and optimize a die casting mold for an aluminum alloy component to improve casting quality and reduce defects like porosity, shrinkage, and incomplete filling. The design process starts with creating a 3D model of the mold cavity, gating system, and cooling channels using CAD software. This is followed by thermal and flow analysis with simulation tools like ANSYS and ProCAST. The optimization looks at factors such as gate velocity, runner dimensions, cooling channel layout, and die material selection. This helps achieve a uniform temperature distribution and efficient solidification.

The results show that a better gating and cooling system improves heat dissipation, reduces cycle time, and strengthens the mechanical integrity of the casting. This study offers useful insights for creating high-performance die casting molds for aluminum alloy parts. It helps boost productivity and energy efficiency in the manufacturing sector.

Keywords: Die Casting, Aluminum Alloy, Mold Design Optimization, Cooling Channel Design, Simulation

1. OVERVIEW OF THE PRESENT RESEARCH WORK

The present research work will try to address the issue of the need to enhance the quality, effectiveness, and efficiency of aluminum alloy components made via die casting technique. Die casting is widely used in manufacturing automobile parts and components, aerospace industry, and consumer products because of its ability to manufacture components with close-to-net shape and high-quality surfaces. Despite these advantages, die casting process is quite sensitive to the issues related to mold design and temperature regime, leading to poor quality of manufactured components.

The goal of the present study is to create an optimized die casting mold using modern approaches and techniques. The research will start with the geometrical modeling of the die cast structure using specialized software. Such critical parts of the mold as cavity, gating

system (sprue, runner, and gate), overflow wells, vents, and cooling passages will be included in the model based on design guidelines and equations.

Numerical simulations for analysis and optimization of the design are done utilizing ANSYS and ProCAST software, which provide an integrated approach to analysis of fluid dynamics, heat transfer and solidification processes. Analysis of molten metal flow dynamics involves study of velocity profile, intensity of turbulence, and air entrapment during injection. At the same time, analysis of temperatures, cooling rates and solidification times is conducted in order to understand what is happening at the casting-mold interface.

Parametric optimization is the core of this project. Various factors, including gate velocity, runner cross-sectional area, ingate location, diameters and spacings of the cooling channels, coolant flow rate and die material properties are varied. Effects of these factors on quality of castings and their susceptibility to defects are studied. Optimization procedures based on iteration of the design and simulations are performed to determine optimal values of the parameters ensuring defect-free castings.

Thermal management gets special attention since uniform heating inside the die is critical for controlled solidification. The research examines new cooling channel designs to get rid of hot spots and minimize thermal gradients. Good heat removal not only improves the quality of the castings but also shortens the cycle time, thus boosting productivity.

It can be seen from the findings that the optimization of the gating system considerably increases the quality of melt flow, minimizing turbulence and air entrapment, whereas a better cooling system ensures proper solidification and stress relief. Consequently, the number of defects, like porosity and shrinkage, gets substantially reduced.

2. INTRODUCTION

Die casting is one of the most efficient and precise ways to manufacture metal parts with complex shapes and excellent dimensional accuracy. It works by forcing molten metal, usually a non-ferrous alloy like aluminum, under high pressure into a steel mold cavity called a die. This method allows for mass production of parts that have a great surface finish, a high strength-to-weight ratio, and limited machining needs. As a result, it is commonly used in the automotive, aerospace, electronics, and consumer product industries.

Aluminum alloys are some of the most widely used materials in die casting. They have a great mix of properties, including being lightweight, resistant to corrosion, having high thermal conductivity, and offering good mechanical strength. However, the performance and quality of aluminum die cast parts are greatly affected by the design of the die and its related systems,

particularly the gating system, cooling channels, and venting mechanism. Poor design can result in defects such as porosity, shrinkage cavities, cold shuts, and thermal stresses. These issues can harm the mechanical performance and dimensional accuracy of the casting.

As a result, die casting mold design optimization is important to ensure that the filling will be uniform, solidification will be controlled, and heat transfer will be efficient. Computer-aided engineering (CAE) tools allow engineers to model the casting simulation by making predictions about flow, temperature differentials, and cooling capacity before actually producing the die. The virtual optimization step minimizes trial-and-error in the creation of the die, resulting in saved time and cost while enhancing casting quality.

In this research, a die casting mold of an aluminum alloy part is designed and optimized using CAD and simulation tools. The research focuses on improving thermal performance, controlling casting defects, and optimizing gating and cooling system design to achieve uniform temperature distribution and efficient cycle times. The anticipated outcome of this research understanding is to develop a tangible systematic approach to advancing mold design efficiency, improving part quality, and reducing production costs in aluminum die casting.



2. MECHANICAL DESIGN OF DIE CASTING MOLD

The structure of the die casting die may affect dimensional accuracy of the cast product, its strength characteristics and efficiency of the entire process. The die design must provide good fluidity of molten metal, proper cooling and durability of the die under cyclic loads.

2.1 Structure of Die Casting Die and Its Arrangement

Normally, a die casting die consists of two parts.

- Fixed die or cover die - installed on the stationary part of a die casting machine.
- Moving die or ejector die - mounted to the moving platen and containing an ejector mechanism.

The shape of the cavity is determined from 3D drawings of the product and must account for the following parameters:

- Evenness of wall thickness of the product.

- Angles at walls to make the ejection easier (usually, in range 1-3).

2.2 Materials Used for Molds

Materials for molds have to endure high temperatures, pressures, and thermal fatigue. Some of the materials used are:

- Steel H13: High thermal resistance and strength
- Dievar Steel: Increased thermal fatigue resistance

The basic criteria for materials include:

- Very high hardness (≈ 45 -50 HRC)
- High thermal conductivity
- Corrosion resistance

2.3 Gating System Design

The gating system controls the flow of molten aluminum into the mold cavity. It consists of:

- Sprue
- Runner
- Gate

Design considerations:

- Minimize turbulence and air entrapment
- Maintain laminar flow
- Optimize gate velocity (30–60 m/s typical for aluminum)

The cross-sectional area of the gate is calculated based on flow rate and filling time to ensure complete cavity filling without defects.

2.4 Cooling System Design

Effective cooling plays an important role in:

- Cycle time reduction
- Solidification control
- Minimizing residual stresses

Cooling passages are provided:

- Near hot spots
- Evenly distributed
- Maintaining uniform temperature of mold (generally 150-250°C)

Thermal analysis through simulation software like ANSYS facilitates effective design of cooling passage positions and diameters.

2.5. Ejector System Design

The ejector system is used for removing the solidified casting without any damage. The ejector system comprises:

- Ejector pins
- Ejector plates
- Return pins

Design criteria:

- Even distribution of ejector pins
- Do not place ejector pins on sensitive areas
- Enough force for overcoming adherence and contraction

2.7. Structural Design and Strength Analysis

High injection pressures (up to 100 MPa) should be able to sustain the mold. Structural design involves:

- Adequate back plates
- Ribs for reinforcement
- Proper calculation of clamping force

Stress analysis ensures:

- Absence of yielding in mold material
- Deformation within acceptable limits

3. THEORETICAL ANALYSIS

The theoretical evaluation of the design of the die-casting mold helps in comprehending the behavior of aluminum metal when it fills, cools, and solidifies. It helps form the basis of designing the mold geometry, gating system, and temperature control.

3.1. Fluid Flow Analysis

Molten aluminum flow within the mold cavity is guided by fluid mechanics principles. Optimum flow guarantees filling without turbulence and air pockets.

Continuity Equation

Mass balance is shown as:

$$A_1 V_1 = A_2 V_2$$

A = Area

V = Velocity of liquid metal

This equation aids in the design of runner and gate sizes for optimal flow.

Reynolds Number

Fluid flow characteristics (laminar or turbulent) are calculated based on:

$$Re = \frac{\rho V D}{\mu}$$

ρ = Density of liquid aluminum

V = Velocity

D = Hydraulic diameter

μ = Dynamic viscosity

In die casting, moderate turbulence is permitted; however, high turbulence causes porosity.

3.2 Heat Transfer Analysis

Heat transfer plays a critical role in solidification and cooling of the casting.

Fourier's Law of Heat Conduction

$$q = -kAa \frac{dT}{dx}$$

Where:

- q = Heat transfer rate
- k = Thermal conductivity
- A = Area
- $\frac{dT}{dx}$ = Temperature gradient

This equation is used to design cooling channels and predict heat dissipation.

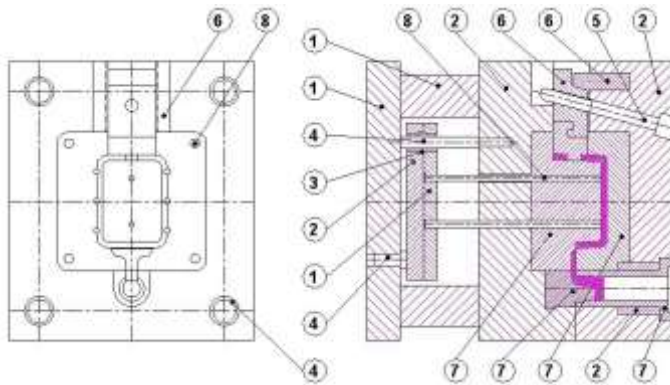
Newton's Law of Cooling

$$q = hA(T_s - T_f) \quad q = h A (T_s - T_f) \quad q = hA(T_s - T_f)$$

Where:

- h = Heat transfer coefficient
- T_s = Surface temperature
- T_f = Fluid temperature

This helps in estimating heat loss from mold surfaces.



4. SIMULATION TECHNIQUES

Filling velocity simulation is a very important part of the die casting process study since it enables us to evaluate the filling process and the dynamics of molten aluminum during its entry into and filling of the mold cavity. During high-pressure die casting, the metal enters the mold cavity at very high velocities, which have a big impact on the quality of the produced item. Incorrect flow can cause several defects, such as porosity and cold shut defects, among others.

4.1 Filling Velocity Simulation in Die Casting

The velocity fill simulation is one of the most important elements in designing the die casting mold since it analyzes how the melted aluminum will flow while filling the cavity. The figure below is a simulated velocity of the melted metal in the die casting process using casting simulation software such as MAGMASOFT or Autodesk Moldflow.

The simulation will help in recognizing any serious problems relating to flow such as:

- ☐ High velocity areas (which usually occur near the gates), causing erosion of the surfaces of the mold or defects due to turbulence.
- ☐ Low velocity areas, where the filling process may fail because solidification is already happening.
- ☐ Unbalanced flow, where one area fills much faster than the other, causing weld lines.

4.2 Solidification Simulation

One of the essential factors in the modeling of the casting process is simulating the process of solidifying metal as it turns from liquid to a solid. One of the major issues with HPDC is that

solidification plays a pivotal role in creating a casting that has a high strength, low porosity, and no leakage.

4.2.1 Solidification Theory:

Solidification in casting occurs in three stages:

1 Liquid Phase ($f_s = 0$)

- ☐ Entire metal is in molten state
- ☐ Heat transfer occurs mainly through convection

2 Mushy Zone ($0 < f_s < 1$)

- ☐ Coexistence of liquid and solid phases
- ☐ Dendritic structure forms
- ☐ Feeding becomes restricted

3 Solid Phase ($f_s = 1$)

- ☐ Fully solidified structure
- ☐ No further fluid flow possible
- ☐ Residual stresses develop

4. Model Description:

The analyzed component consists of:

- ☐ A central block (housing)
- ☐ A cylindrical section
- ☐ A connecting arm with varying thickness

The geometry includes sharp transitions and thick sections, which strongly influence heat dissipation and solidification behavior.

5. CHALLENGES AND FUTURE TRENDS

1. Problems Associated with Mechanical Design of Die Casting Mold

While there have been developments in the field of die casting technologies, a number of problems still exist regarding mechanical design and optimization of molds used to manufacture aluminum alloy parts.

5.1.1 Thermal Fatigue and Mold Breakage

Repetitive heating and cooling of die casting mold results in:

- Development of thermal fatigue cracks
- Wearing off surfaces
- Shortening of mold lifetime

High thermal gradients cause stresses, which cause gradual deterioration of mold material in critical areas like gates and sharp edges.

5.1.2 Porosity and Shrinkage Formation

The most important problem associated with die casting process is:

- Formation of gas porosity as a result of air entrapping
- Development of shrinkage pores because of inadequate solidification

Porosity negatively impacts mechanical properties and causes defects. To produce defect-free castings, gating and cooling processes should be optimized properly.

5.1.3 Complicated Geometry and Flow Characteristics

Today many components are characterized by:

- Small wall thickness
- Complex shape
- Inhomogeneous dimensions

As a result, there might occur:

- Non-homogenous flow of metal
- Turbulent and non-complete filling
- Poor solidification

Special methods need to be developed when designing molds of complicated shape.

5.1.4 Limitations of Conventional Cooling Channels

Traditional cooling channel configuration may lead to:

- Poor heat removal from molds
- Development of hot spots in particular areas
- Increased cycle time

5.2 Future Directions

To address current constraints, certain innovative technologies and approaches have emerged that are expected to influence the future of die casting mold optimization.

5.2.1 Advanced Simulation and Digital Twin Technology

- Simulation model application to anticipate casting behavior
- Digital twin for ongoing evaluation and optimization

- Integration with CAE software (e.g., ANSYS, MAGMASoft)

These innovations facilitate:

- Faster iterative design cycles
- Decreased experimentation
- More precise identification of defects

5.2.2 Additive Manufacturing for Mold Construction

- Creation of conformal cooling channels via 3D printing
- Intricate internal structures unattainable through conventional machining techniques

Advantages:

- Even cooling
- Shorter manufacturing times
- Superior casting outcomes

5.2.3 Intelligent Molds and Internet of Things (IoT)

Instrumentation within molds for the detection of:

- Temperature
- Pressure
- Stress

Data gathering and feedback regulation

These developments result in:

- Preventive maintenance
- Minimized downtimes
- Better process management

5.3 Objective

The primary goal of this project is to design and optimize a die-casting mold for aluminium alloy components with the aim of enhancing casting quality, reducing defects, and optimizing thermal performance, using a model-based simulation approach.

1. To design a 3D model of the die casting mold for an aluminum alloy component using CAD software, incorporating essential features such as cavity, gating system, runner, and cooling channels. Define the boundary conditions as per references.
2. To perform thermal and flow analysis of the die using simulation tools (e.g., ANSYS or ProCAST) to evaluate temperature distribution, metal flow behavior, and solidification characteristics. Optimize the wheel design if possible by changing material grade or Material.

3. To optimize the gating and cooling system design parameters—including gate size, runner dimensions, and cooling channel layout—to achieve uniform filling and efficient heat dissipation.
4. To analyze the effect of design modifications on casting defects such as porosity, shrinkage, and incomplete filling through simulation-based evaluation.
5. To minimize cycle time and improve die life by ensuring uniform temperature distribution and reducing thermal stresses in the mold.
6. To provide design recommendations for an optimized, cost-effective die casting mold that ensures high-quality aluminum alloy components with improved mechanical and surface properties

6. METHODOLOGY

The approach utilized in this project uses a systematic method that combines computer-aided design (CAD), simulation-based analysis, and optimization to create a viable die casting mold for manufacturing aluminum alloy components. The overall process is divided into actionable steps that start with selection of components and concludes with final validation of the optimized design.

1. Choice of Component and Material

A component made of aluminum alloy was chosen based on industry relevance, geometric complexity, and the ability to manufacture using the die casting process. The selected material was aluminum alloy (e.g. Al–Si or Al–Si–Cu series) based on the notable castability, strength-to-weight ratio, and thermal conductivity. The material properties (density, specific heat, thermal conductivity, and melting temperature) were taken into consideration for accurate simulation and analysis.

2. Die Casting Mold Design

The die casting mold was designed with the aid of 3D modeling software (AutoCAD/Creo/SolidWorks). The mold design included:

- Cavity and core design
- Gating and runner system
- Sprue and overflow
- Ejection pin and vents

Each design parameter, including the gate dimensions, runner length, and the diameter of cooling channels, were selected based on standard die casting design recommendations and the volume of molten metal necessary to fill the cavity.

3. Meshing and model Preparation

The CAD model was imported into simulation software (ANSYS/ProCAST) for meshing. A fine tetrahedral or hexahedral mesh was established to properly capture the flow and thermal gradients within the mold cavity. Boundary conditions such as mold wall temperature, injection pressure, and cooling channel flow rate were defined.

4. Flow and thermal Analysis

- Flow Analysis:

To investigate the flow velocity, pressure distribution and turbulence within the die, the filling of molten aluminum was simulated. A critical part of the filling simulation was determining appropriate cavity filling without air entrapment or cold shuts.

- Thermal Analysis:

A steady state and transient thermal analysis was undertaken to investigate the temperature distribution over the die during the casting and cooling stages. The analysis was used to identify areas prone to overheating or uneven solidification.

5. Design Parameters Optimization

The important parameters obtained from simulation were optimized to further enhance the performance of the dies:

- Modified gate and runner dimensions targeted for a balanced flow.
- Optimized channels targeted for uniform temperatures and minimized cycle time.
- Minimized thermal hotspots based on cooling path positions (and diameters)

7. LITERATURE REVIEW

1. Huang, Mingyu, et al. "Die casting die design and process optimization of aluminum alloy gearbox shell." *Materials* 14.14 (2021): 3999.

"Die casting process optimization for aluminum alloy products has received considerable attention in order to enhance quality and minimize defect occurrences. As such, the die casting process optimization for the aluminum alloy gearbox housing provides an exemplary case study that could be used for analysis purposes. By taking into consideration the nature of the gearbox, the first step is to establish the position of the parting line before proceeding to design the gating system using Unigraphics NX software. In order to improve the design further, computer simulations for the metal filling and solidification stages are done using MAGMASOFT software. This allows for the simulation of various gating systems, helping to choose the best design through the assessment of parameters like flow patterns, temperature gradients, and defect formation. Furthermore, a cooling system and core pulling system are designed.

2. Verran, G. O., R. P. K. Mendes, and L. V. O. Dalla Valentina. "DOE applied to optimization of aluminum alloy die castings." *Journal of materials processing technology* 200.1-3 (2008): 120-125.

“In this paper, we examine the use of a design of experiments (DOEs) methodology experiment in investigating the impact that three injection parameters (i.e., slow shot, fast shot, and upset pressure) have on the internal quality of die castings SAE 305 alloy parts. In this regard, the first step was to describe the types of experiments used during the manufacture of these products. We conducted an experiment where different levels of injection parameters were used to determine whether there was porosity in the parts obtained. For this purpose, the internal quality of die castings was measured using density tests and visual images. Analysis of Variance was used to analyze the results of this experiment.”

3. Adke, Mahesh N., and Shrikant V. Karanjkar. "Optimization of die-casting process parameters using DOE." *Int. J. Eng. Res. Gen. Sci* 3.2 (2015): 1314-25.
“The present paper highlights an optimization of die casting process parameters to optimize the cycle time level that would improve cycle time using Taguchi method for DOE. 20tonn AISic132 die casting machine capacity is used to measure the cycle time. Four machining parameters were considered such as melting temperature, Injection pressure, Plunger speed and cooling phase. Experiments were conducted on the basis of these parameters. The design of experiment with Taguchi orthogonal array having three levels and four process parameters was made through statistical software package Minitab version 15. Initially nine experiments were conducted.”
4. Tai, C. C., and J. C. Lin. "A runner-optimization design study of a die-casting die." *Journal of Materials Processing Technology* 84.1-3 (1998): 1-12.
“It is usual practice that the die caster conducts a die casting test prior to manufacturing the new castings. During the die-casting test process, the runner portion will always be corrected repeatedly; hence, there will be an increase in processing time and cost of processing. To address this issue, experimental investigations on the runner and die body portions were carried out separately in the current experiments. For the runner portion, various insert runner blocks were produced, and a die-casting test was designed through the experimental design approach.”
5. Gupta, Arun Kumar, et al. "Optimization of process parameters during pressure die casting of A380: a silicon-based aluminium alloy using GA & fuzzy methodology." *Silicon* 13.8 (2021): 2429-2443.
Pressure die casting process can be efficiently used for zinc, aluminum, magnesium, lead and tin-based alloys. Good surface finish, tolerances and dimensional accuracy could be achieved through optimization of important parameters of pressure die casting (PDC), like solidification time, melting temperature, fill up time, inoculation pressure and plunger velocity, etc. Moreover, by choosing optimum parameters of PDC, PDC defects, like flash, cold shut, porosity, misrun, etc. could also be minimized. Minimization of PDC defects through artificial intelligence approach involves genetic algorithm and fuzzy logic methodology. A380: Silicon-based aluminum alloy carburetor housing is used for the same. An experimental design method involving L18 orthogonal array Taguchi design approach has been employed to determine the percentage of defects per batch out of 500 pieces as fuzzy logic methodology knowledge base. For determining the degree of accuracy of prediction through fuzzy logic method, regression analysis is carried out.”

6. El Mehtedi, Mohamad, et al. "Design optimization of gate system on high pressure die casting of AlSi13Fe alloy by means of finite element simulations." *Procedia CIRP* 88 (2020): 509-514.
"Current diecasting industry trends prove that the proof-of-concept methods used by these companies nowadays are based on the Finite Element Method (FEM) simulation, not the traditional trial and error. Diecasting of aluminum is a rather complicated process, due to the difficulties associated with the mold filling. In this case, the FEM simulations play a significant role within the framework of the new approach to manufacturing and designing, providing virtually all phases of the casting process. In this work, FEM simulation of a thin panel component made from G-AlSi13Fe aluminum alloy (actually made in AA3004 sheet metal) was performed in order to optimize the design of its gates and runner system."
7. Syrcos, G. P. "Die casting process optimization using Taguchi methods." *Journal of materials processing technology* 135.1 (2003): 68-74.
In this research work, several important process variables in the die casting process of AlSi9Cu13 aluminum alloy have been studied. Efforts have been made to optimize the process variables so as to obtain optimum density for AlSi9Cu13 aluminum alloy castings. The important process variables under consideration include: Piston speed (first and second stages), Metal temperature, Filling time, and Hydraulic pressure. Influence of above mentioned process variables on the casting density and optimizing the process variables have been achieved through Taguchi's Methodology. It is concluded from the findings of the experiment that the chosen process variables have significant influence on the density of AlSi9Cu13 aluminum alloy castings.
8. Jin, Chul Kyu, Chan Hyun Jang, and Chung Gil Kang. "Die design optimization of die casting for fabrication of fuel cell aluminum bipolar plate with micro-channel through casting simulation and experimental investigation." *Journal of Mechanical Science and Technology* 27.10 (2013): 2997-3003.
Vacuum Die Casting requires us to have a die with good quality designs to avoid unfilled conditions, turbulence, and porosities in manufacturing fuel cell bipolar plates. Two kinds of geometric shapes have been used to design a die for thin plate die casting. Moreover, a new type of overflow system has been proposed based on numerical simulation and then applied practically by conducting the vacuum die casting tests. An optimized die design involves seven overflows in the cavity end while three overflows are placed in the cavity side wall. In our vacuum die casting test, the molten metal, which passes through the gate and reaches the side wall, entered the side overflow and did not have any turbulence. Also, partially solidified molten metal in the channel has been completely drained off by overflow without backflow. The validity of the new proposed overflow design has been confirmed by manufacturing a good quality product.
9. Nouri, Hossein. "Multi-objective topology optimization of aluminium die casting alloy connecting rod using the bacterial foraging algorithm." *International Journal on Interactive Design and Manufacturing (IJIDeM)* (2026): 1-19.
In this paper, we have performed a thorough investigation into multi-objective topology optimization of an ADC alloy connecting rod through a Bacterial Foraging Optimization algorithm. A basic model of a car engine connecting rod has been created

in which gradient-less multi-objective optimization based on BFO algorithm has been applied in order to optimize mass, minimizing the displacement and factor of safety maximizing frequency of the model. The manufacturing constraints for die casting process such as minimum wall thickness and draft angles have been incorporated through the use of penalty functions and directional density gradients. Validation of the results was done numerically by comparing with the famous SIMP algorithm. The paper includes the solid rod baseline, a number of parameter settings, as well as simulation results. Some of the results from our study include Pareto curve of the trade-off between mass and stiffness, mass and frequency, optimized design with dimension details, and comparison results that show reduction in weight of up to 30%, enhancement in frequency of up to 18%, while compliance and factor of safety improved by 25% and 18.5%. This work advances the field of topology optimization for die-cast assemblies by integrating a bio-inspired algorithm and practical manufacturing constraints, offering guidelines for lightweight and high-performance connecting rod designs.

10. Giarmas, Evangelos, and Dimitrios Tzetzis. "Optimization of die design for extrusion of 6xxx series aluminum alloys through finite element analysis: a critical review." *The International Journal of Advanced Manufacturing Technology* 119.9 (2022): 5529-5551.

This paper describes the recent research progress of the die design and optimization for aluminum alloy with the 6xxx series using the finite element analysis. The die design and optimization have become very important in the manufacturing process of 6xxx series aluminum alloy, in order to produce high-quality products. Prior to the implementation of the finite element analysis (FEA) in the aluminum extrusion industry, many tests and designs had been done before producing acceptable products. The implementation of FEA plays a significant role in eliminating the trials and faulty extrusions and its usage is being used by almost all the manufacturers. The review highlights some studies that attempt to optimize the extrusion dies in terms of efficiency and how the most common defects can be avoided if the appropriate simulation is used. Some of the topics that have been discussed in this paper are flow optimization in extrusion die, flow balance in extrusion of complex aluminum profiles, spread extrusion die design, optimization of porthole extrusion dies, defects in front end and back end extrusions, die bearing geometry and surface defects, automated die design optimization and liquid nitrogen die cooling.

11. Ragab, Kh A., A. Bouaicha, and M. Bouazara. "Optimization of casting design parameters on fabrication of reliable semi-solid aluminum suspension control arm." *Journal of Materials Engineering and Performance* 26.9 (2017): 4450-4461.

The semi-solid casting technique is characterized by a high reliability of manufacturing solid aluminum mechanical parts that function continuously under dynamic load conditions in the control arm component of suspension systems in automobile vehicles. The performance of such a dynamic control arm depends on the characteristics of mold and gating systems, which have impact on fluidity of the semi-solid metal when filled in the mold cavity. In this connection, the current research is focused on improvement in mechanical performance of dynamic control arms, depending on material characterization and design optimization, manufactured from the A357 aluminum semi-solid alloys. The results of mechanical and design analysis, performed for suspension arms, reveal mechanical failures in unexpected weak points of the components.

According to the metallurgical analysis, the main cause is difficult flow of semi-solid metal through thin thickness of a complex geometry part.

12. Jeong, Seong Il, et al. "Mold structure design and casting simulation of the high-pressure die casting for aluminum automotive clutch housing manufacturing." *The International Journal of Advanced Manufacturing Technology* 84.5 (2016): 1561-1572.

The research targets at the mold design which relies on casting simulation and structural simulation of mold structure for the production of automotive clutch housing aluminum parts using the high-pressure die casting process. In order for the melt to flow into the mold and fill the mold up to the product section uniformly, the gate system containing five gates were established. MAGMAsoft software, the casting simulation, was applied in the prediction or prevention of casting defects which might happen during filling and solidification processes. The method for selecting appropriate casting equipment for clutch housing was provided in the research as well. The structural simulation of the mold base was carried out using ANSYS Workbench software in order to predict any possible damage that may happen to the most sensitive area of the mold during the process of mold design. During the shot test, totally five pieces of clutch housing parts were produced. These parts were all completely filled without surface defects. The spots of shrinkage porosity predicted in the casting simulation and those actually occurred were not the exact same but very similar. The value of hardness of the parts was about 84 HV regardless of position.

13. Sharma, Satpal. "Modeling and optimization of die casting process for ZAMAK alloy." *Journal of Engineering and Technology* 4.2 (2014).

Purpose of the experiment is to analyze effect of injection pressure of molten metal, hydraulic pressure, temperature of molten metal and cooling time on dimensional stability of the lock assembly of two wheelers. Material used for lock assembly is ZAMAK 3 (zinc, aluminum, magnesium and copper) alloy. Lock assembly is prepared using die casting technique. In order to study effect of process parameters i.e. injection pressure of molten metal, hydraulic pressure, temperature of molten metal and cooling time, RSM (Response Surface Methodology) with face center design is used. Experiments were performed randomly according to designed matrix. Three responses (shutter width, shutter thickness and shutter hinge length) have been considered for study. RSM models for each response are prepared. For each response analysis of variance is done in order to identify significant factors and their interaction. At the end optimization is done and optimization results are validated by performing experiments at optimum input levels. Comparison of experimental and modeled results revealed that there is error in the range of 2-8%.

14. He, Yuhang, et al. "Multi-objective optimization of the low-pressure casting of large-size aluminum alloy wheels through a systematic optimization idea." *Materials* 16.18 (2023): 6223.

In this paper, the low-pressure casting process parameters for manufacturing large-size aluminum alloy wheels were optimized systematically via numerical casting simulation, response surface methodology (RSM), and genetic algorithm (NSGA- II). The nonlinear relationship between input and output factors in relation to the critical casting parameters (pouring temperature, mold temperature, holding pressure, holding

time), and response indicators (volume fraction of defects, mean SDAS of spokes large plane) was constructed via the Box-Behnken design (BBD). A mathematical model was built via regression analysis. Then, the Isight 2017 Design Gateway combined with the NSGA-II algorithm was employed to enlarge the population and obtain the optimal solution of casting process parameters. The validity and prediction of the mathematical model were analyzed via ANOVA. Numerical simulation was applied to verify the optimal solution obtained above. To conduct systematic optimization of its low-pressure casting process, the mold cooling process parameters were modified in terms of the local solidification rate.

8. Conclusion

The current study has examined the problem of optimizing a mold design used in the casting of aluminum alloy parts. In this case, the primary goals were the improvement of the process quality, reduction of defect formation and increasing the productivity of production. For achieving these

goals, a combined approach has been applied including modeling and optimization. Firstly, the mold and the components geometry were created through UG software (Unigraphics NX). The complexity of the geometrical shapes, such as gates, cavities, and cooling systems could be accurately simulated through this process. Subsequently, the simulation of the flow pattern of molten metal filling the mold and solidification processes took place through MAGMASOFT software, which was able to visualize the fluid flow, temperature variation, and solid phase fraction during the whole casting process.

References

- [1] Huang, Mingyu, et al. "Die casting die design and process optimization of aluminum alloy gearbox shell." *Materials* 14.14 (2021): 3999.
- [2] Verran, G. O., R. P. K. Mendes, and L. V. O. Dalla Valentina. "DOE applied to optimization of aluminum alloy die castings." *Journal of materials processing technology* 200.1-3 (2008): 120-125.
- [3] Adke, Mahesh N., and Shrikant V. Karanjkar. "Optimization of die-casting process parameters using DOE." *Int. J. Eng. Res. Gen. Sci* 3.2 (2015): 1314-25.
- [4] Tai, C. C., and J. C. Lin. "A runner-optimization design study of a die-casting die." *Journal of Materials Processing Technology* 84.1-3 (1998): 1-12.
- [5] Gupta, Arun Kumar, et al. "Optimization of process parameters during pressure die casting of A380: a silicon-based aluminium alloy using GA & fuzzy methodology." *Silicon* 13.8 (2021): 2429-2443.

- [6] El Mehtedi, Mohamad, et al. "Design optimization of gate system on high pressure die casting of AlSi13Fe alloy by means of finite element simulations." *Procedia CIRP* 88 (2020): 509-514.
- [7] Syrcos, G. P. "Die casting process optimization using Taguchi methods." *Journal of materials processing technology* 135.1 (2003): 68-74.
- [8] Jin, Chul Kyu, Chan Hyun Jang, and Chung Gil Kang. "Die design optimization of die casting for fabrication of fuel cell aluminum bipolar plate with micro-channel through casting simulation and experimental investigation." *Journal of Mechanical Science and Technology* 27.10 (2013): 2997-3003.
- [9] Nouri, Hossein. "Multi-objective topology optimization of aluminium die casting alloy connecting rod using the bacterial foraging algorithm." *International Journal on Interactive Design and Manufacturing (IJIDeM)* (2026): 1-19
- [10] Giarmas, Evangelos, and Dimitrios Tzetzis. "Optimization of die design for extrusion of 6xxx series aluminum alloys through finite element analysis: a critical review." *The International Journal of Advanced Manufacturing Technology* 119.9 (2022): 5529-5551.
- [11] Ragab, Kh A., A. Bouaicha, and M. Bouazara. "Optimization of casting design parameters on fabrication of reliable semi-solid aluminum suspension control arm." *Journal of Materials Engineering and Performance* 26.9 (2017): 4450-4461.
- [12] Jeong, Seong Il, et al. "Mold structure design and casting simulation of the high-pressure die casting for aluminum automotive clutch housing manufacturing." *The International Journal of Advanced Manufacturing Technology* 84.5 (2016): 1561-1572.
- [13] Sharma, Satpal. "Modeling and optimization of die casting process for ZAMAK alloy." *Journal of Engineering and Technology* 4.2 (2014).
- [14] He, Yuhang, et al. "Multi-objective optimization of the low-pressure casting of large-size aluminum alloy wheels through a systematic optimization idea." *Materials* 16.18 (2023): 6223.