ENHANCING STRUCTURAL INTEGRITY OF COMPLEX DIE-CAST HOUSINGS THROUGH DESIGN AND PROCESS OPTIMIZATION

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Abstract
The increasing demand for lightweight, high-performance components in automotive, industrial, and consumer electronics sectors has intensified the need for structurally robust and geometrically complex die-cast housings. However, the intricate geometries, thin-wall features, and rapid solidification dynamics inherent in die-casting introduce challenges including porosity, warpage, cold shuts, and localized stress concentrations. This study presents an integrated design–process optimization framework aimed at enhancing the structural integrity of complex die-cast housings. The research combines Design for Manufacturability (DFM) principles, structural and thermal simulations, and statistical process optimization to achieve improved reliability and performance. A detailed finite element analysis (FEA) is conducted to assess the influence of critical design parameters such as rib configuration, wall thickness transitions, filleting, and gating placement on stress distribution and mechanical strength.

Keywords: *aluminum alloy; gearbox housing; mold design; process optimization.*

INTRODUCTION

The rapid advancement of automotive, aerospace, industrial automation, and consumer electronics industries has driven the need for lightweight, compact, and highly reliable components. Among various manufacturing technologies, high-pressure die casting (HPDC) has emerged as a leading process for producing complex housing structures due to its high dimensional accuracy, excellent surface finish, short cycle times, and ability to create thin-walled geometries. Complex die-cast housings used extensively in engine control units, transmission systems, electric vehicle power electronics, pump bodies, and structural enclosures—must withstand demanding mechanical, thermal, and environmental loading conditions. Consequently, ensuring high structural integrity has become a critical objective for manufacturers and design engineers. Despite its benefits, the die-casting process presents considerable challenges that can compromise the performance and durability of complex housings. The combination of intricate part geometries, rapid filling, high solidification rates, and multi-directional heat flow increases the risk of casting defects such as porosity, cold shuts, shrinkage cavities, hot spots, incomplete filling, and warpage. These defects adversely affect structural strength, fatigue life, leak tightness, and functional reliability. Moreover, highly complex housings often include sharp transitions, varying wall thicknesses, rib-reinforced features, deep pockets, and internal channels that further intensify mechanical and thermal stresses both during casting and in service. As a result, achieving optimal structural integrity requires a balanced interplay between part design and process parameter selection. Modern die-casting practices increasingly rely on advanced digital tools—including finite element analysis (FEA), computational fluid dynamics (CFD), and casting simulation software such as MAGMA, ProCAST, and FLOW-3D—to predict defect formation, thermal gradients, stress distribution, and filling behavior. Simultaneously, design methodologies such as Design for Manufacturability (DFM), Design for Casting (DFC), and topology optimization have become essential to improving part strength while ensuring ease of casting. However, many industrial approaches still treat design optimization and process optimization as separate activities, resulting in sub-optimal performance outcomes. A more holistic, integrated framework is required to bridge this gap. This research explores the synergistic relationship between design features and die-casting process parameters, aiming to systematically enhance the structural integrity of complex die-cast housings. By combining simulation-driven design refinement, statistical process modeling, and experimental validation, the study seeks to identify the optimal combination of geometric design modifications and process settings that minimize casting defects and maximize mechanical robustness. Key variables such as rib structure, fillet radius, wall thickness uniformity, gating system configuration, melt temperature, injection velocity, intensification pressure, die temperature, and cooling channel placement are examined in detail.

DIE CASTING

Castings are density, high-volume, metalwork goods manufactured and are used Thouse, commercial and industrial in thousands of clients. Diecasts are important components car toys. The components can be simple as sink complicated as connector housing. The earliest case die was injected into the middle of the 1800s instead of gravity casting. The first manually operated machine for the type of casting was issued a patent for Sturges in 1849. The method for the next 20 years was limited to printer types, but production of the other forms began to grow towards the century's end. By 1892 phonograph and cash registry components included consumer applications; in the early 1900s industrial production of many kinds of components began. Different compositions tin and plum were first casting alloys but their use declined after In 1914, the introduction of zinc and aluminium alloys. Many new alloys were created and made accessible in 1930's quickly followed by magnesium and copper alloys. Since the first injection operation for low pressure, advances like high pressure casting achieve 4500 livres per square inch casting and semi-solid die casting, casting process advanced.

Present Die Casting

Die casting is a premium procedure. The industry's margins are typically very low and many die castings companies to consider it to be the number one priority for lowering costs. Many of the axles are also conscious of their possible damages to the environment. The issue is that the environmental burden of this commonly-used procedure cannot be measured and quantified by precise tools. For market members to receive widespread approval, Environmental advantages must be linked cost advantages. whether by tax code that penalises bad environmental activities cost benefits less resources (energy, water, aluminium, et cetera.). Many businesses want well-off businessmen offer priority to the economy when cost benefits are also provided. Clean water is perhaps the world's most valuable substance. At current, water restrictions exist in the region where this study has been performed, Victoria, though water reservoirs have a capacities of 40 per cent. The casting method is heavily dependent on water for heat transfer general material process.

LITERATURE REVIEW

Y. H. Chen (2000) Present a methodology for selecting the computer aided die and mould design division direction. The proposed methodology determines first the minimum boundary box of the moulding portion. Three pairs of potential separation directions for the option of an optimum partition path are subsequently considered. The separation line is calculated by using the part-slicing algorithm in all three possible dividing path pairs. Criteria including undercut, drawing, planned area and flatness are then used to measure each parting line by means of a fluctuating weighted sum system. To choose the best dividing path, the fuzzy weighted sum method is used.

Manas Dash et al. (2001) The impact alloying factor on AlSi casting alloy feeding characteristic has been identified. During solidification they categorised various feeding mechanisms as liquids, mass feeds, dendritic feed, and solid feeds. The dissertation was carried out by ANOVA and concluded as follows. Qualitative and quantitative research. Iron and silicone alone have little connection to porosity; however they make up intermetallic ones that influence feeding mechanism with their morphology. In the absence of Mn, the duration of Al5FeSi needles increases, while Fe material increases refrigeration intensity decreases, while Mn's influence is the other way around. Al5FeSi compound severely impedes the cross-dendritic direction liquid surge. Fe and Si along with Mn Al15 (MnFe)3 Si2 are Chinese. This morphology blocks feeding and causes porosity to shrink.

Siekanski and Borkowaski (2003) Various quality management tools have been used by in the study of casting defects in order to increase component casting quality. For the interpretation of data is used Ishikawa diagram and Pareto diagram. With the aid of the Ishikawa schema, the analysis of different defeats and their reasons for concord may be fulfilled. The diagram of Ishikawa helps one analyse failure analysis for up to five separate causes. Pareto diagram demonstrates isolation of the principal casting defect such as displacement, missed running, homogenous shaggy, despair shrinkage, hot crack etc. On the basis of this diagram, it has been inferred that the quantity of infringement during processing is largely determined by employee behaviours linked to incompetence and non-compliance with procedural recommendations of technical processes.

Carlos Esparza et al (2005) Recommended his quest method for optimal gating device configuration. A numerical optimization technique based on gradient-searing is used to achieve the ideal configuration of a conventional gating device used to produce aluminium parts for this severe activity. It is a modern use of the combination of non-linear techniques of optimization and a functioning simulator and is based on a preferential approach towards a scientifically based quest for improved techniques to take the mathematical construction of the problem into consideration. The simulator uses the CFD Analytical Algorithm and end-volume strategy. Two design variables using a direct gradient optimisation (SQP) algorithm have solved the 2D and 3D gate modelling issue. The results show very clearly the effectiveness of the approach proposed to classify high-quality castings in comparison to current business practises.

Gunasegaram, D.R. (2009) Utilizing an immersive computer simulation system to assist in determining the time pressure applied during the filling of a low-pressure cast iron in order to eliminate filling faults while maintaining production. In low-pressure casting method, the pressure needed to fill a casting may be divided into two steps. The first move is to add pressure to the molten metal in order to lift it. The upward tube to the casting grid varies from casting to casting as volume of molten metal in the oven decreases. The second step is to press molten metal into the die cavity, ensuring that there is minimal turbulence that fill model is right to avoid gas trapping because the die cavity is now productive. One of the primary objectives of this analysis is to fine-tune the filling simulation process in order to accurately forecast the occurrence of petrol.

Methodology

We reviewed the current die and analysed it during the design, which gave us a deeper understanding of die. The issue at the die was that only the upper portion was first filled in the low part of the product. This allowed the molten metal to solidify and thus left unfilled gaps in the die and refused further pieces. The commodity had jet marks because of the greater risk of product rejection. While jet markings on the product's surface can be cleaned and discarded, the strength of the product has been compromised if the jet marks are greater. The die was often damaged by wear and tear. We assumed a 45m/s gate speed in the operating window In order to explain who is correct, we attempted to change runner styles such as fans and tangent runners. The research considers Filling Time, solidification, intake speed, mould degradation, air traps, cold shutter, etc. some of the parameters. We used analytic tools to compare these parameters of the current die and iterations in the software.

Results

The cast is cast metal, in which metal molten is crushed under great pressure into mould hole. During this technique, mould cavity is sculpted using two harded tools manufactured in stainless steel in same way as injection mould. The majority of nonferrous methods used in casting are nonferrous metals, such as zinc, copper, aluminium, and magnesium. The hot or cold chamber machine is utilised depending on kind of metal that has been cast. Taguchi is widely recognised method which provides trustworthy, efficient efficient way to process optimisation. The Taguchi technique is widely used in engineering and the science community as technique for designing and manufacturing goods that are minimally vulnerable to different variance triggers and deliver high-quality, developing, and produced products with low development costs.

According to the selected experiment design, experiments are conducted. The influence of different parameter levels has been simulated. The simulations were done in cast programme from Quik. A fine mesh component involved was first created in Visual Viewer applications prior to the start of the simulation. For the simulation this meshed component has been used. The emphasis was to verify the distribution temperature, fill period and overall porosity shrinkage. Quik cast is software for casting simulation and method assessment. It addresses the fundamental elements of every casting method, including filling, solidification and creation of porosity. It contributes to full manufacturing approach which offers practical forecasting at any stage casting phase. The app will minimise costs and reduce time in face of challenges encountered by every casting industry. It may be used in early stages such as construction of mould and method and also for evaluation of component efficiency. The period measured as seen in the table below is when the procedure is carried out.

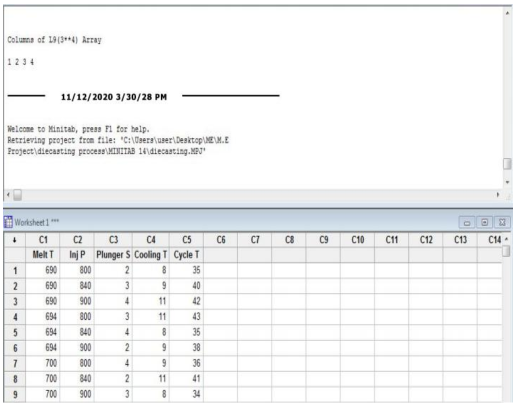


Figure: 6.1 L9 Process parameters 9 level chart

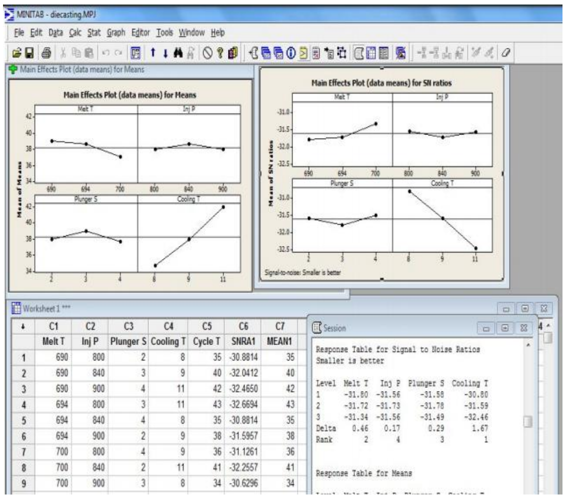
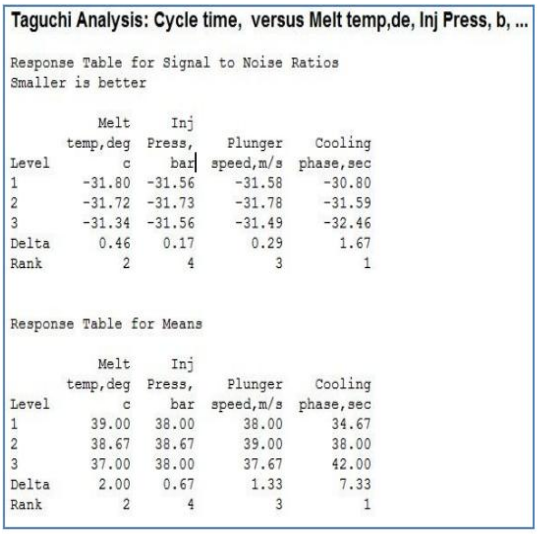


Figure: 6.2 Result table



Taguchi Analysis: Cycle time, versus Melt temp,de, Inj Press, b, ...

Response Table for Signal to Noise Ratios
Smaller is better

Level	Melt temp,deg c	Inj Press, bar	Plunger speed,m/s	Cooling phase,sec
1	-31.80	-31.56	-31.58	-30.80
2	-31.72	-31.73	-31.78	-31.59
3	-31.34	-31.56	-31.49	-32.46
Delta	0.46	0.17	0.29	1.67
Rank	2	4	3	1

Response Table for Means

Level	Melt temp,deg c	Inj Press, bar	Plunger speed,m/s	Cooling phase,sec
1	39.00	38.00	38.00	34.67
2	38.67	38.67	39.00	38.00
3	37.00	38.00	37.67	42.00
Delta	2.00	0.67	1.33	7.33
Rank	2	4	3	1

Figure: 6.3 Response table for SN ratio & Means

From delta temperatures for melting, injecting pressure and lounging pace, cooling stage, it can be infer that, compared to melting temp, injection pressure and plunger speed, the cooling pressure and plunger speed, the cooling process is the most affected. Chart reveals that the optimal solution is provided by the value that the SN ratio is greater, that is to say -30.6296.

Table: 6.1 Optimum solution

	C1	C2	C3	C4	C5	C6	C7
	Melt	In	Plunge	Cooling	Cycle	SNRA	MEAN1

	T	j P	r S	T	T	1	
1	690	800	2	8	35	-30.8814	35
2	690	840	3	9	40	-32.0412	40
3	690	900	4	11	42	-32.4650	42
4	694	800	3	11	43	-32.6694	43
5	694	840	4	8	35	-30.8814	35
6	694	900	2	9	38	-31.5957	38
7	700	800	4	9	36	-31.1261	36
8	700	840	2	11	41	-32.2557	41
9	700	900	3	8	34	-30.6296	34

Applying DOE using Taguchi optimized level has been found out with particular combinations for cycle time.

Table: 6.2 DOE result table

Melt. Temp	Inj Pre	Plung Speed	Cool Time	Cycle Time	SNR	Mean
700	900	3	8	34	-30.629	34

Experiment on the handle bar part name-house (2W/motor cycle) was administered

The name BAL 15324 of the above described parameters with a substantial cut back in the initial setup period in addition to the fair quality of the product was found to be satisfactory for the range value provided for the parameters.

Minitab tools used the principal impact track for SN ratios. The results can be calculated by key effects plot before ANOVA is performed. The plot with key effects contrasts the means of various parameters to decide the optimal degree. Five parameters were used to monitor the temperature of the plunger velocity 1st and the temperature of the second stage die, temperature filling and intensifier strain. The first parameter of the 2nd stage dipping velocity has various means with regard to the object level; the mean values for dipping temperature, pouring temperature, 1st phase dipping velocity and the intensification pressure are of three degrees. The lower average values match the lower signal t noise ratio.

The debate:

The test carried out was based on the variety of components normally done by the firm. The tests considered satisfactory for the specified range of parameter values added to the new feature produced, complemented by a fair quality reduction in the initial time environment. By generating the part according to the findings defined by the analysis process (DOE/ Taguchi Methods), the theory must be tested without influencing the consistency norms adversely. During attempts to detect faults, visual examination is performed. Die validation of the process is impacted by the development of the test lot for defect-free components with the necessary physics and/or properties attributes.

The method of Taguchi has been implemented to optimise the die-casting operation parameters. The use of SNR has optimised four input parameters. For reducing cycle time, the smaller quality feature was used. For the prediction of a series of parameters that value a predicted cycle period, an orthogonal array L9 with four parameters and three levels was used. For these parameter sets 9 numbers of tests have been performed. For Melting Temple 700 deg C, Injection Pressure 900 bar, Plunger speed 3m/s & Colding period 8 sec. Experimental output values are used in Minitab software14 and software predicated. This proposed criteria for optimal porosity efficiency. For this collection of parameters and relative to a given value, a validation experiment was carried out. This experimental percentage value of porosity is far similar to the values defined. The results obtained with the help of optimum parameter combination validation experiments provide excellent agreement to the results given. The efficiency of the optimised model is superior to the initial and also demonstrates that the principle of taguchi parameter architecture is more effective and useful tools to reduce cycle time.

CONCLUSION

It helps in enhancing product quality and upgrade the yielding of casting, reduced cost and spare time among other optimization technique. Throughout the years, numerous design standards or optimization method has been developed and employed in the casting industry, yet the simulation has wide application among the others. Since simulation is easy to use, fast and having reliable result. It also enables to minimize the value-added time in casting development. In the long run, Casting Simulation is a single software program and having the ability to predict the internal defect of casting which helps to reduce the shop floor trials.

In conclusion, die casting is one of the most important technology in the system of metal shaping. The enhancement of the above casting method is of major concern to all production companies, to satisfy the requirements for higher accuracy, higher efficiency and competitiveness in the present scenario. The study was conducted by acknowledging the activities of previous writers while also taking account of the recent pattern and improving the method. This study focuses on the usage of high-quality instruments, the DOE Taguchi approach and optimization simulation. Both the above strategies were used in order to choose the parametric combination of the ideal casting method, to minimise the decrease percentage.

Usage of consistency instruments including Ishikawa diagram to analyse the causes of the defects and examine them. Generally, quality tools such as Ishikawa's diagram or histogram graph allow to establish that the key responsibility for defects lies in parameters such as plunger velocity 1st and 2nd step, strain, feed temperature and aluminium pouring temperature. Brainstorming and quality tools have allowed the value set of the parameters referred to in last paragraph to be established; • The use of experiment design and, in particular, the system Taguchi to optimise process parameters and to reduce time and time for the computers. Using Minitab programme, DOE was conducted using the parameters. The Taguchi approach was used to analyse the final parameter range, so its values were robust. • ANOVA was an effective mathematical method for determining the parameters that were very important in order to better develop. The most powerful parameter that could cause defects after DOE is crucial to decide. · Ray as a non destructive measuring tool, which detects non-compliances with the casting that is invisible to an individual's nude eye.

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