# OPTIMIZATION OF POROSITY OCCURANCE IN PRESSSURE DIE CASTING BY TAGUCHI METHOD

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**Abstract:**
*High-pressure die casting (HPDC) is particularly suitable for high production rates and it is applied in several industrial fields; actually, approximately half of the world production of light metal castings is obtained by this technology. An overview of the actual status of HPDC technology is described in the current work, where both critical aspects and potential advantages are evidenced. In the current study of die casting for Automobile starter motor casing, the following issues are focused: shot piston simulation, defect analysis, and, finally, the use of the Taguchi mutuality analytical method to find the optimal parameters and factors to increase the aluminium ADC10 die casting quality and efficiency. Experiments were conducted by varying molten alloy temperature, die temperature, plunger velocities in the first and second stage, and multiplied pressure in the third stage using L9 orthogonal array of Taguchi method. After conducting a series of initial experiments in a controlled environment, Response for Signal to Noise Ratios L9 Orthogonal array for developing a robust performance for pressure die casting processes. The appropriate multivariable linear model is a useful and efficient method to find the optimal process conditions in pressure die casting associated with the minimum shrinkage porosity percent.*

*Key words: High-pressure die casting, Signal to Noise Ratios, L9 Orthogonal array*

## 1.0 INTRODUCTION

High-pressure die casting (HPDC) is particularly suitable for high production rates, and it is applied in several industrial fields; actually, approximately half of the world production of light metal castings is obtained by this technology. [1,2] In the HPDC of aluminium alloys, cold-chamber die casting machines are typically used, in which the metal injection system is only in contact with the molten metal for a short period. Liquid metal, maintained in a holding furnace at a desired temperature, is generally ladled (or metered with some other method) into the shot sleeve for each cycle. [3] Several operations are involved in the whole HPDC process, from the spraying and blowing out the die to the opening and closing of the die, even if the main steps are the filling of the shot chamber, the injection of the metal into the die, the solidification and the further extraction of the casting (Fig. 1). Therefore, the HPDC is a complex process, not only due to the phase transformation the metal undergoes when solidifying in the die

- The production of high-pressure die castings begins by first pouring liquid metal into a steel shot sleeve. A piston accelerates quickly and transports the molten metal into a steel die, resulting in metal velocities between 30 m/s and 60 m/s (i.e., approximately 100–200 km/h).
- The subsequent extremely short filling time (50–100 ms) guarantees the perfect filling of complex-shaped castings with thin wall thickness, such as ribs, before metal solidification.
- During the solidification, the metal contracts, leaving eventually shrinkage porosity in the casting.[4]
- The process tries to overcome these physical phenomena by pressing

liquid metal into the die using several atmospheres (up to 120 MPa).


**Figure 1: The process chain of HPDC.**

## 2.0 LITERATURE REVIEW

Although the physical phenomena leading to defects in castings have been identified as mentioned in this review the elimination of defects in the final cast product remains a challenging task. This is because of the fact that there are various process parameters associated with surface turbulence or melt quality. Several approaches on defect analysis have been established in the past: historical data analysis, cause effect diagrams, if-then rules, Design of Experiments (DoE) and trial and error [5]. The DoE method is an effective tool for reducing foundry defects by optimising various process parameters and can be used to establish a relationship between various input variables (factors) and an output variable (response). Dabade et al. [6] proposed a method combining DoE and numerical simulations to obtain the optimal process parameters for a cast iron component in order to reduce defects. Guharaja et al. [7] optimised the process parameters of a green sand-casting process (green strength, mould hardness, moisture content and permeability) using the Taguchi's optimisation method to minimise defects in spheroidal graphite cast iron rigid coupling castings. In a similar study, Kumar et al. [8] analysed different process parameters of pressure die casting of aluminium alloys to reduce defects to a minimum using Taguchi's method. Five different parameters (solidification time, molten metal temperature, injection pressure, filling time and velocity) were selected while three different levels were chosen for each of these parameters. Experiments were subsequently conducted using different combinations of the process parameters as per the Taguchi's orthogonal array and the parameters were optimised for minimal casting defects. Besides DoE, Artificial Neural Networks (ANNs) have also been used for detecting the root cause of defects in castings. Perzyk et al. [9] trained an ANN using the simulated annealing algorithm in order to efficiently detect the root cause of gas porosity defects in steel castings.

## 3.0 RESEARCH METHODOLOGY

High pressure die casting for nonferrous casting applications is increasingly used in the foundries today as an economically viable casting process. High pressure die casting (HPDC) process has been widely used to manufacture a large variety of products with high dimensional accuracy and productivities. It has a much faster production rate in comparison to other methods and it is an economical and efficient method for producing components with low surface roughness and high dimensional accuracy. All major aluminium automotive components can be processed with this technology. High Pressure Die Casting process is rapid and depends on many factors. So, to capture the problem it requires a lot of time and experience including testing and simulation. The conventional trial and error-based die design and process development is expensive and time consuming. Such a procedure also might lead to higher casting rejections. The HPDC castings production process has many defects, such as shrinkage porosity, misrun, cold-shut, blister, scab, hottear. Several previous studies of defects in aluminium alloy by the method of HPDC and disability solutions However, the study to optimize aluminium alloy casting process in the condition of production casting factory is essential. This study focused on analysis of shrinkage porosity defect with mold design and put into production casting by foundry factory conditions.

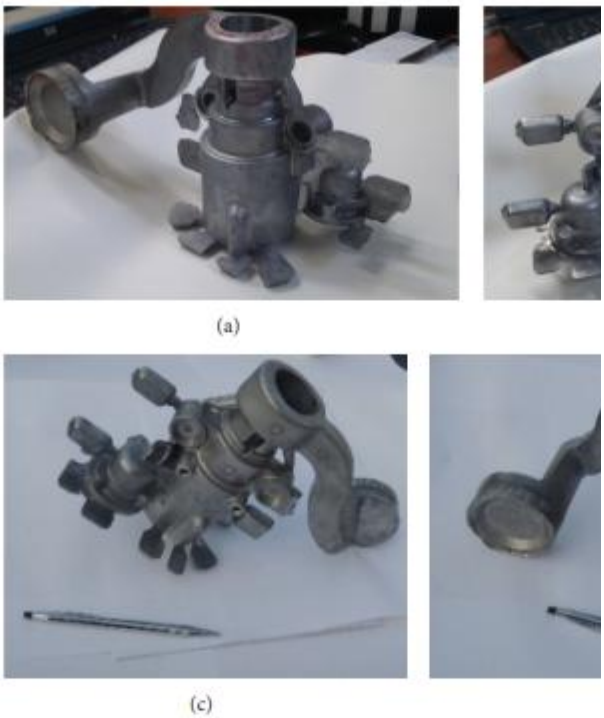


**Figure 2: Casting image.**

porosity percent is costly and time consuming, because many experiments are necessary to find the optimal parameters. Taguchi method is one of the efficient problems solving tools to upgrade the performance of products and processes with a significant reduction in cost and time involved. Taguchi's parameter design offers a systematic approach for optimization of various parameters with regard to performance, quality, and cost.

**Table 1: Chemical composition of the alloy ADC10 used in the experiment**

| Element | Si | Fe | Cu | Mg | Mn | Ni | Zn |
|---|---|---|---|---|---|---|---|
| wt% | 7.5~9.5 | 1.3 | 3.0~4.0 | 0.1 | 0.5 | 0.5 | 3 |

The die casting part product of this study is provided through aluminium die casting factory, so the casting body no changes. A major factor in the successful development of castings is the design of the die and design of gates, biscuit, and runner system. A well-designed gating and runner system should avoid turbulence in metal flow and to reduce incidence of inclusions and air entrapment in the casting. The die design is required to avoid solidification related defects like shrinkage, micro-porosities, hot-tear and so forth. Die design process is very much dependent on the experience and skill of the design engineer. The die for this study is the result of collaboration between the foundry factory and Department of Mechanical Engineering-National Kaohsiung University of Applied Sciences The die casting is designed in CATIA V5R19 software, shown in Figure 3. Moreover, the die casting material selection is very important. The nature of the material will directly affect the quality of the casting and die casting parameters configuration, this study selects casting material as the aluminium alloy.

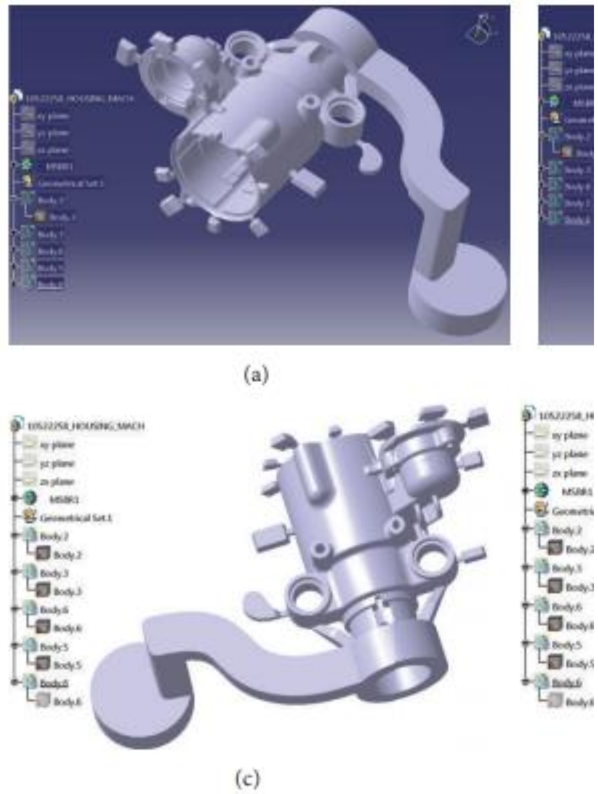


**Figure 3: Part product is designed by CATIA software**

In this case, holding furnace temperature, die temperature, plunger velocity in the first stage, plunger velocity in the second stage, and multiplied pressure in the third stage were selected as the most critical in the experimental design. The other parameters were kept constant in the entire experimentation. The range of holding furnace temperature was selected as 640~700∘ C, the range of die temperature as 180~260∘ C, the range of plunger velocity in the first stage as 0.05~0.35 m/s and in the second stage as 1.5~3.5 m/s, and the range of multiplied pressure in the third stage was chosen as 200~ 280 bars.

**Table 2: The parameter and its value at three levels.**

| Process parameters | Parameters range | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Holding furnace temperature (∘ C) | 640~700 | 640 | 670 | 700 |
| Die temperature (∘ C) | 180~260 | 180 | 220 | 260 |
| Plunger velocity, 1st stage (m/s) | 0.05~0.35 | 0.05 | 0.2 | 0.35 |
| Plunger velocity, 2nd stage (m/s) | 1.5~3.5 | 1.5 | 2.5 | 3.5 |
| Multiplied pressure (bars) | 200~280 | 200 | 240 | 280 |

**Table 3: Experimental layout using an L9 orthogonal array**

| Trials | Holding furnace temperature, A | Die temperature B | Multiplied pressure |
|---|---|---|---|
| **1** | **1** | **1** | **1** |
| **2** | **1** | **2** | **2** |
| **3** | **1** | **3** | **3** |
| **4** | **2** | **1** | **2** |
| **5** | **2** | **2** | **3** |
| **6** | **2** | **3** | **1** |
| **7** | **3** | **1** | **3** |
| **8** | **3** | **2** | **1** |
| **9** | **3** | **3** | **2** |

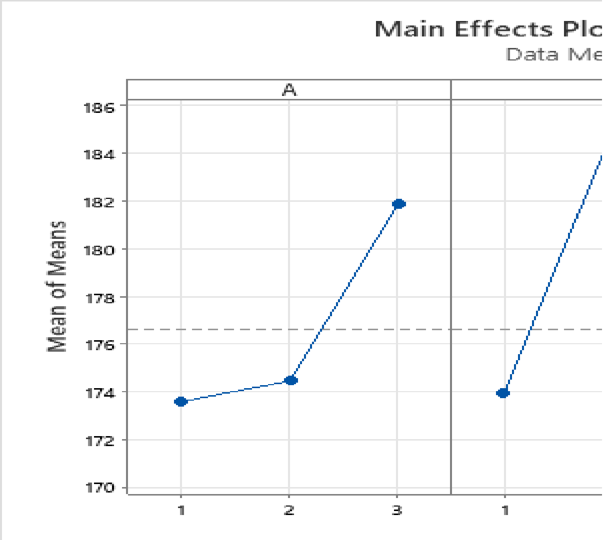


**Figure 4 : Response for Signal to Noise Ratios L9 Orthogonal array**

important output parameter (Shrinkage porosity). For selecting appropriate orthogonal array, degree of freedom (number of fair and independent comparisons needed for optimization of process parameters is one less than the number of levels of parameter) of the array is calculated. In the experimental layout plan with five factors and three levels using L9 orthogonal array, 9 experiments were carried out to study the effect of casting input parameters, shown in Table The input parameters are installed in the Pro CAST software to conduct 9 simulation experiments.

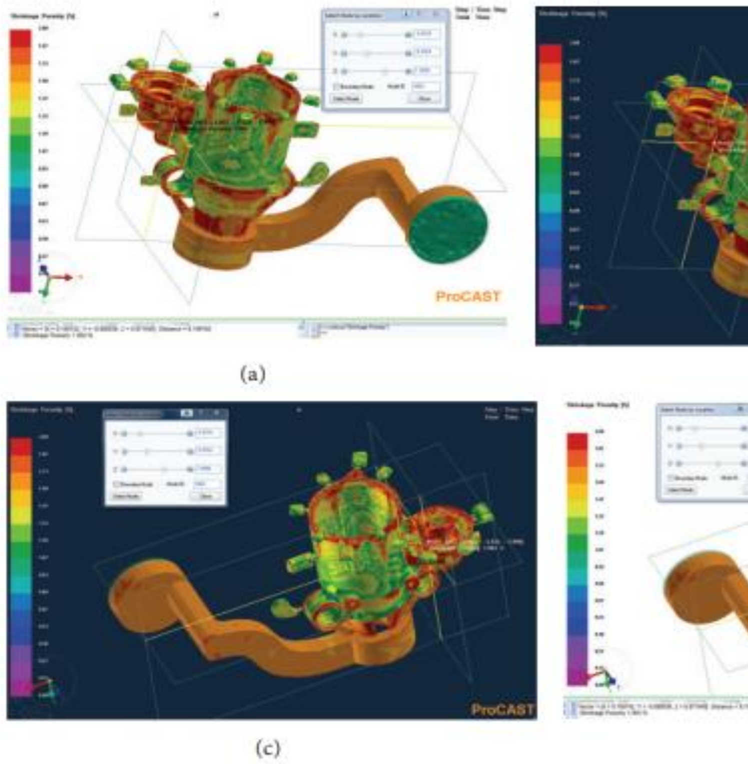


**Figure 5.: Casting measurement area**

Solid fraction may be available shrinkage prediction casting position, the present study is in accordance with the theory prediction of defect, and Pro CAST manual referred to in the final period of solidification. Shrinkage solid fraction prone is greater than 0.7, here as the reference value of 0.7 solid fractions. When the solid fraction area is below this value and the area around the solid phase rate is rather than this value, we can predict this area shrinkage porosity occurred. The challenge of leading HPDC to a ''zero-defect environment'' requires advanced engineering tools that can manage the complexity of the process. The identification of key variables, the knowledge of the variables–defects relationship, and the implementation of real time sensor device must be managed by these tools, with the capability to integrate all this information and to carry out reactive strategies to instantaneously balance the process in view of a zero-defect production.

## CONCLUSION:

Structural aluminium ADC10 parts used in the automotive industry are widely produced by the High Pressure Die Casting process, HPDC. The process is mainly used because of the high production rate and the possibility to manufacture complex parts with high requirements to shape and tolerances Mechanical properties of the cast parts are mainly affected by the grain size and porosity content. In order to obtain improved mechanical properties smaller grain size and low porosity content should be satisfied. The results of this thesis also indicate that dependency of mechanical properties to porosity are more dominant than the dependency of grain size. The model proposed in this paper gives satisfactory results in the optimization of pressure die casting process. The predicted values of the process parameters and the calculated are in convincing agreement with the experimental values. The experiments which are conducted to determine the best levels are based on "Orthogonal Arrays," and are balanced with respect to all control factors and yet are minimum in number. This in turn implies that the resources (materials, saving time, and money) required for the experiments are also minimized.

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