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# THE IMPACT OF PRESSURE DIE CASTING PROCESS PARAMETERS ON MECHANICAL PROPERTIES AND ITS DEFECTS OF A413 ALUMINIUM ALLOY

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The objective taken in consideration towards this research is to bring about a model that consisting of an effective process that helps in developing towards the map process parameters of quality characteristics of a diesel engine head of aluminium alloy. Multi response optimization was carried out to predict and analyze the mechanical properties of A413 aluminium alloy that was produced utilizing the pressure die casting process. The injection pressure (A) Kgf/cm$^2$, shot velocity (B) m/s and furnace temperature (C) °C were taken in selection as the parameters that were influenced the output responses such as micro-hardness (MH) and surface roughness (Ra). The value of 0,607 was met at a high desirability in the objective of multi response optimization.

*Key words:* casting, injection pressure, microstructure, surface defects, mechanical properties

## INTRODUCTION

In recent trends, pressure die casting is considered as one of the most cost effective and fastest method in the production of components [1]. Aluminium alloys have a wide range of application in aerospace, automobiles, train due to its excellent physical characteristics such as lighter strength, stiffness and wear resistance. Aluminium alloy also possess god mechanical properties with accuracy [2]. During the commercial production, it is necessary for the manufacturer to monitor the process and set desired parameters in order to achieve benefits. The selection of casting process parameters such as injection velocity, pouring temperature, furnance temperature and pressure are based on the experience and trial and error method [3-4].

Various attempts have been done by the researchers to study the effect of process parameters in improving the quality of the products [4]. Application of intensification pressure improves the mechanical properties such as hardness, strength and surface roughness up to 65 % comparing to gravity die casting [5-7]. Achieving maximum hardness determines the quality of sound casting [8]. In the research of casting, researchers have made an attempt to analyze and identify the effect of process parameters using statistical regression based techniques such as design of experiment, Response Surface Methodology (RSM) and Taguchi [9-10]. Still an optimization based on desirability function approach with RSM is considered as best approach for multi response optimization to optimize process parameters [11-12].

The literature review reveals that several theoretical and experimental works has been done on optimization of pressure die casting process. But influence of casting process parameters of A413 alloy has not been reported to improve the mechanical properties such as Micro-Hardness and surface roughness using PDC.

## EXPERIMENTAL METHODOLOGY

The experiment was conducted in A413 aluminium alloy and their compositions are listed in Table 1. The gaseous mixture of $SF_6$ (0,5 vol.%) and $CO_2$ (99,5 vol.%) was used in melting the alloy. To produce diesel engine head the mold is preheated to a temperature range of 155 °C to 285 °C and velocity in the range of 0,4 to 0,6 m/s using a 380t-IDRA pressure die-cast machine with 900 KN injection force. The experimentation cost and time increased as the number of parameters increased. Experimental selection was done by design matrix to perform fifteen sets of diesel engine head on a three-factor central composite face centered design (CCF) using design expert V.11 with different process parameters, shown in Table 2. For each set of process parameter three to five pars were casted. The casted diesel engine head is shown in Figure.1

Table 1 **A413 alloying elements / wt. %**

| Al | Cu | Si | Fe | Zn | Ni | Sn | Mg |
|---|---|---|---|---|---|---|---|
| Bal | 1,0 | 11,0-13,0 | 2,0 | 0,5 | 0,5 | 0,15 | 2,0 |

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Table 2 **Casting process parameters**

| Casting parameters | Units | levels | | |
|---|---|---|---|---|
| | | -1 | 0 | 1 |
| A | Kgf/cm² | 175 | 200 | 225 |
| B | m/sec | 0,4 | 0,5 | 0,6 |
| C | °C | 650 | 675 | 700 |

## MEASUREMENT OF MICRO-HARDNESS AND SURFACE ROUGHNESS

The polished surface of 10 x 10 x 10 mm cut section of casted diesel engine head was used to measure MH using Vickers micro-hardness tester with application of 500 g load ($HV_{500}$) for 5 to 10 seconds. The Micro-Hardness (MH) values were recorded for each sample at three different positions. Surface roughness of the each sample was measured using Surf tester-SJ-210 with measuring force 4mN and tip radius of stylus about 2 micrometers. Experimental values were recorded and are presented in Table 3.

Table 3 **process parameters and their responses**

| A / Kgf /cm² | B / m/sec | C / °C | MH / $HV_{500}$ | Ra / µm |
|---|---|---|---|---|
| 225 | 0,6 | 650 | 116 | 1,26 |
| 225 | 0,4 | 700 | 116 | 0,95 |
| 175 | 0,6 | 700 | 115 | 0,9 |
| 175 | 0,4 | 650 | 112 | 0,42 |
| 175 | 0,5 | 675 | 117 | 0,8 |
| 225 | 0,5 | 675 | 122 | 0,98 |
| 200 | 0,4 | 675 | 119 | 0,83 |
| 200 | 0,6 | 675 | 125 | 1,21 |
| 200 | 0,5 | 650 | 116 | 0,71 |
| 200 | 0,5 | 700 | 116 | 1,21 |
| 200 | 0,5 | 675 | 123 | 0,54 |
| 200 | 0,5 | 675 | 121 | 0,9 |
| 200 | 0,5 | 675 | 120 | 1,11 |
| 200 | 0,5 | 675 | 120 | 0,7 |
| 200 | 0,5 | 675 | 122 | 0,9 |

## RESULTS AND DISCUSSION

### Statistical analysis

Comparing all other parameters, the F-statistical value is recognized to be of injection pressure which has a better influence on the Micro-Hardness. The values of injection pressure A(13,99), shot velocity B(5,79) and furnace temperature c (10,42). The injection pressure A (5,4), shot velocity B (6,7) and furnace temperature C (7,5) carries out indication that the F-statistical value which is furnace temperature, has a great influence on the surface roughness comparing to all other parameters. The $R^2$ (0,96) and predicted $R^2$ (0,88) value of Micro-Hardness and $R^2$ (0,90) and predicted $R^2$ (-1,2) value of surface roughness shows the closeness of how the data are fitted in regression line. The advanced regression models are portrayed in Equation 1 and 2.

$$HV = - 3269,64 - 1.01 * A – 315,14 * B + 10,52 * C – 0,30 * A * B + 0,003*A * C + 0,50*B * C – 0,0029* A^2 * 67,64 * B^2 - 0,0085 * C^2 \quad (1)$$

$$Ra = - 4,52200 + 0,007133 * A + 1,95000 * B + 0,004467 *C \quad (2)$$

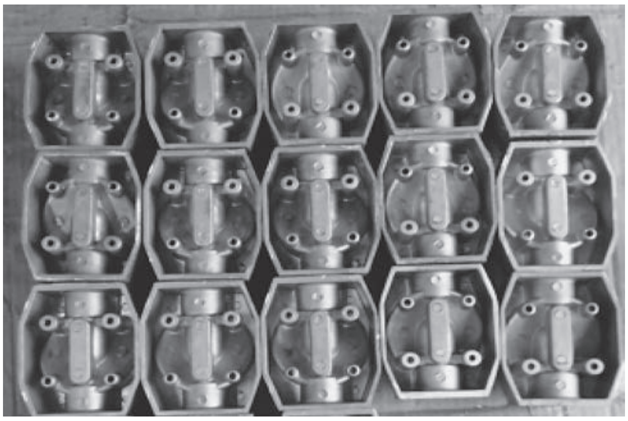

**Figure 1** Diesel engine head

### Microstructure of casted A413 aluminium alloy

Utilizing the metallurgical microscope carried out for microstructural examinations. Emery papers were grounded as the specimen samples and polished samples carried color tint that was etched with Weck's reagent. When the furnace temperature is taken in low to reading of 650 °C including the lower injection pressure of 175 Kgf/cm², the second phase particles are bit higher than those of a higher furnace temperature that has 700 °C and the injection pressure 175 Kgf/cm² shown in Figure.2. Taking high shot velocity 0,6 m/sec and injec-

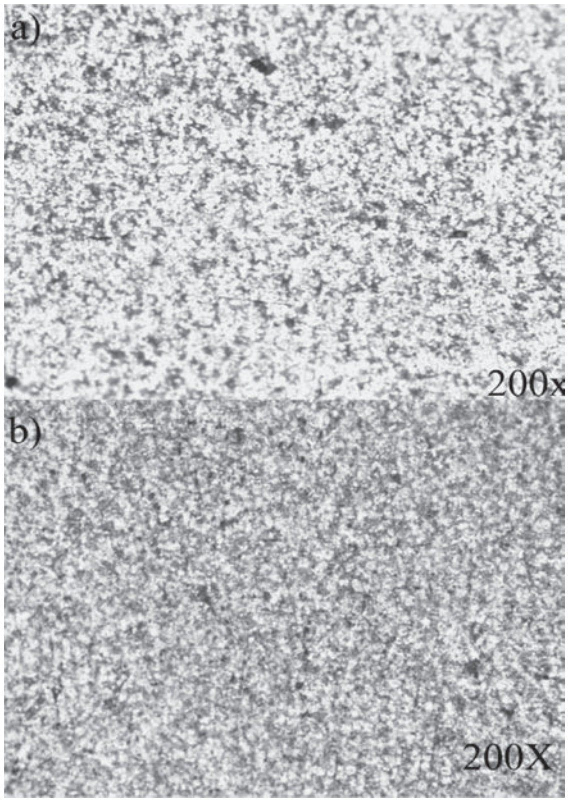


**Figure 2** Microstructure (200X) of A413 PDC casted diesel engine head at a) 225 Kgf/cm² b) 175 Kgf/cm²

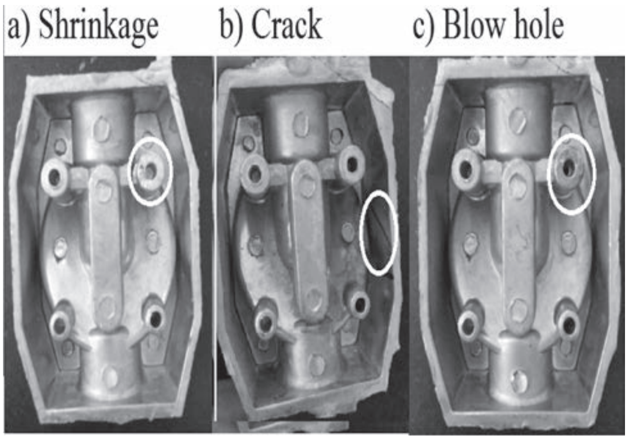


**Figure 3a-c** Casting surface defects

tion pressure 225 Kgf/cm², it is observed that the average grain size is reduced as shown in Figure 2b. With higher shot velocity, the average grain size is reduced shown in Figure 2b and the large grains that are portrayed in Figure 2a disappears. It is found that the optimum furnace temperature has and injection pressure increases with slight increase with density as in higher shot velocity and injection pressure as shown in Figure 2b. Thus better mechanical properties are got in result in relation to the finer grains and the increased density.

## Surface defects of casting

Shrinkage, crack and blow hole are shown in Figure 3a-c are considered as major surface defects. Hot cracks occur when the casting is hot and due to uneven cooling conditions. Shrinkage occurs when there is a change in fluidity of the melt during the misrun and cold shut. The decrease of pouring speed and furnace temperature affects the quality of the casting. Selection of casting process parameters are much more considered as improper selection leads to surface defect. The effective optimization methodology is required as an objective function to achieve the minimum value of the surface defects, surface roughness and maximum value of micro-hardness.

## Multi response optimization using Desirability function approach

Desirability function has been chosen for multi response optimization. The function of its desirability varies from 0 to 1 owing towards the nearness of the objective. The value near most to one is proficient. Notifying to be an evident from the Figure 4 perturbation of coded units versus Micro-Hardness, it is said that the maximum Micro- Hardness can be achieved in the range of 118 and 124 HV in order for casting process parameters in between injection pressure of 200 to 225 Kgf/cm², shot velocity of 0,5 and 0,6 m/s along with furnace temperature of 665 and 685 °C. Evidences from the Figure 5 perturbation of coded units versus surface

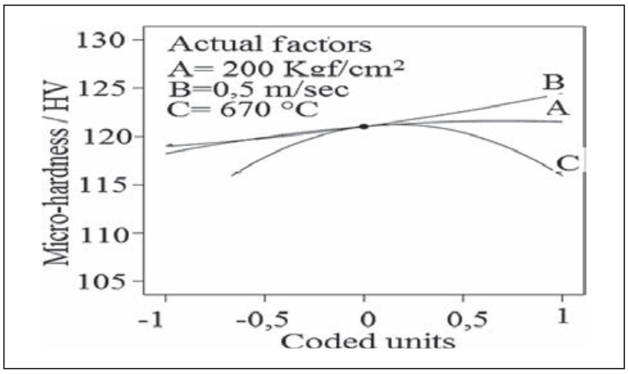


**Figure 4** Coded units versus micro-hardness

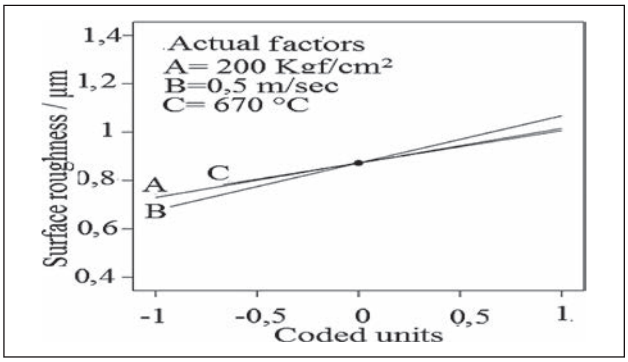


**Figure 5** Coded units versus surface roughness

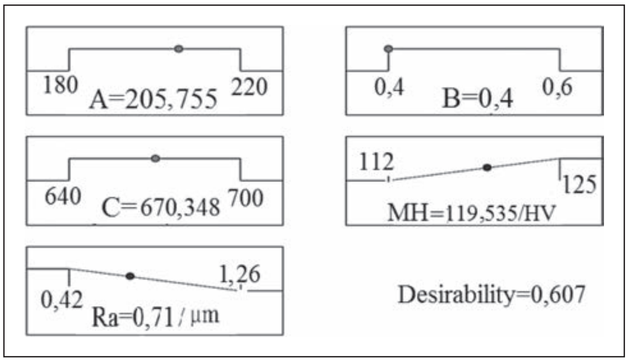


**Figure 6** Optimized result using desirability function

roughness is found to be a minimum in range of 0,6 to 0,8 μm towards casting process parameters that fall between injection pressure of 175 to 190 Kgf/cm², shot velocity of 0,4 and 0,45 and m/s including furnace temperature of 650 and 670 °C. The possibility of combination of casting process parameters is shown in the Figure 6 proves that maximum micro-hardness about 119,535 HV and 0,71 μm as minimum surface roughness could be achieved towards casting process parameters such as injection pressure is 205,755 Kgf/cm², shot velocity is 0,4 m/s and furnace temperature is 670,348 °C at highest desirability of 0,607.

## CONCLUSION

To conclude, it is noted that the present work is focused on modeling and optimization relating the high pressure casting process using desirability function approach. The design of experiments with CCF was utilized towards die casting process. In accordance to this, the following conclusions were found.

- The F-statistical values indicate that the highest F-statistical value that stand high in injection pressure and furnace temperature that has a great influence over the Micro-Hardness and surface roughness compared to all other parameters.
- Evidences from perturbation analysis of coded units versus surface roughness portays that minimum surface roughness can be attained in the range of 0,6 to 0,8 μm for casting process parameters found between injection pressure of 175 to 190 Kgf/cm$^2$, shot velocity of 0,4 and 0,45 m/s and furnace temperature of 650 and 670 °C.
- And also, it is evident from the perturbation analysis of coded units versus Micro-Hardness portays that the maximum Micro-Hardness can be achieved in the range of 118 and 124 HV for casting process parameters in between injection pressure of 200 to 225 Kgf/cm$^2$, shot velocity of 0,5 and 0,6 m/s and furnace temperature of 665 and 685 °C.
- The desirabilty at a high of 0,607 provides maximum Micro-Hardness about 119,535 HV and 0,71 μm as minimum surface roughness in the casting process parameters such as injection pressure is 205,755 Kgf/cm$^2$, shot velocity is 0,4 m/s and furnance temperature is 670,348 °C.

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**Note**: The responsible translator for English language is Mrs.Parvin, Dept. of Science, Peepal Prodigy Groups, Coimbatore, India.