



Experimental Study and Effects of Process Parameters of LM24 Aluminium Alloy in Cold Chamber High Pressure Die Casting

Vikas Gulia

Assistant Professor, Mechanical Engineering Department,
Symbiosis Institute of Technology, Symbiosis International University,
Pune, Maharashtra, India.

Abstract: High Pressure Die Casting is best suited for mass production runs and can produce the least expensive parts. Thus the objective of this study was to evaluate the effects such as thermal characteristics (temperature of the molten metal), injection pressure of the molten metal, type of coating (Oil + graphite coating, Dycote + graphite coating, Dycote coating), and the type of cooling (air cooling, water cooling and oil cooling) on density, hardness and surface roughness of the material using design of experiments. Experiments in industrial environment were conducted for producing wire clamp using commercially treated LM24 Al alloy. Results of this study showed increase in hardness with the use of dycote coating. Oil cooling enhanced the hardness. Increase in injection pressure resulted in increase in density of LM 24. It was observed that a high injection pressure was most prominent in casting of aluminium alloys. Further it was concluded from the microstructure analysis, that the crack propagation was observed in some samples which have low injection pressure i.e. pressure also affects the microstructure of LM24. The study suggests the different combination of process parameter which helps the product to sustain in the market.

Keywords: LM 24 Al Alloy; High Pressure Die Casting; Dycote coating; Design of Experiments.

I. Introduction

In High pressure die casting, molten metal is to be injected in die at high pressure and velocity [1]. It is an economical and a proficient method for producing intricate components requiring high dimensional accuracy, repeatability and low surface roughness. It is best suited for the mass production; least expensive parts can also be produced from this process. High pressure die casting have many other applications like transmission cases, mobile housings, laptop housings, motor housings, engine heads, cylinder heads, steering wheels, aircraft and marine. High pressure die casting process has various machining parameters, i.e., temperature of molten metal, injection pressure of the molten metal, type of coating and type of cooling etc., which affect the performance parameters (i.e., hardness, surface roughness, impact strength and density of the material). Coating of the die plays a vital role in the field of die casting; it improves the quality of die casting, enhances the life of die and it prevents the molten metal stick out on the die casting surface [2]. Many studies have been conducted in high pressure die casting of different alloys. In High pressure die casting process, the quality characteristics are affected by various factors and process parameters. Dargusch et al. determined the influence of process variables on the quality of high pressure die casting machine with the help of in-cavity pressure sensors. They found that when the injection pressure was increases then the porosity of the part was decreases, and porosity was increases when the casting velocity was increases [3]. Maleki et al. examined the influence of pressure and die temperature on the microstructure of LM 13 aluminium alloy which is casted from squeeze casting. They find from their results the grain size will be decreases during solidification under the application of pressure [4]. Abtan and Ghilaim investigated the effect of applied pressure to eliminate the porosities that formed during the squeeze casting process and pressure die casting process. The results showed that the values of hardness and density in pressure die casting were lower than the squeeze casting samples. They also conclude that the mushy zone of molten metal represents the optimum region to enhance the mechanical properties by injected pressure [5]. Mitterer et al. found that the hard coatings based on carbides or nitrides of transition metals may protect the surface of the die steel erosion and soldering of the aluminium and also improve the thermal cracking resistance. Salas et al. discussed about the coating on H13 steel substrates and try to improve the tribological performance of die casting dies for aluminium alloys [6]. Rosso et al. concluded that if the samples are coated with ZrO₂ and WC-Co with silicon resin reached 45000 cycles without any cracks any damage and their surface was still in excellent condition and increased roughness [7]. Zhang et al. investigated the aluminium oxide particles (Al₂O₃) were to improve the microstructure of LM24 and also increase the tensile strength and yield strength of this kind of alloy. They investigated that with the addition of 0.1% Sb in LM24/Al₂O₃ alloy then the

tensile strength and yield strength are increased by 16 MPa and 52 MPa than that of LM24 alloy [8]. Syrcos analyzed the several important process parameters of AlSi9Cu13 aluminium alloy of the die casting method. Process parameters are as follows: metal temperature, piston velocity, filling time and hydraulic pressure. The effect of entire process parameters on the density and following optimal settings of the parameters have been dexterous using taguchi technique. The results show that the selected parameters importantly affect the density of AlSi9Cu13 aluminium alloy castings [9]. Penghuai Fu et al. have studied about the influence of process parameters i.e pressure holding time, die temperature, holding pressure, filling time and casting temperature on microstructure, density and mechanical properties of low pressure die casting. They also concluded that when the filling time is increased then the grains become coarser and also leading to lower density and mechanical properties (yield strength, ultimate tensile strength and elongation), with increase in casting temperature then the grains become coarser and mechanical properties reduced [10]. Lalit Kumar et al. investigated that the influence of injection pressure of the molten metal, cooling medium, coating type and pouring temperature on hardness of the material, density of the material and the surface roughness of the material. They have worked on material LM6 aluminium alloy on high pressure die casting machine [11]. Prabhu et al. prepared lead samples in high pressure die casting D250 machine. They discussed about the parameters which affecting the defects in high pressure die casting process such as injection pressure, pouring temperature, cooling medium and pouring time. They used taguchi technique. Various parameters affecting defects i.e bubble, blow hole and flash defect shown by the signal-to-noise ratio graph. They concluded that the pouring temperature plays a major role in the blow hole defect but cooling medium, tool temperature and cooling time plays minor role in the blow hole defects [12]. El-Mahallawy et al. studied the influence of velocity and pressure high pressure die casting on the thermal conditions and on the casting properties. Two gate velocities of the liquid 40 and 80 m/s were used for die filling and pressure 30 and 70 MPa [13]. With respect to the literature survey, it is perceived that less attention was given on casting of LM 24 aluminium alloy and subsequent analysis of gaps the present work aims to investigate the effect of various process parameters such as temperature of the molten metal, injection pressure of molten metal, coating and cooling type in a High Pressure Die Casting Process on the properties of cast aluminium alloy LM24.

II. Methodology

The experiments were conducted on high pressure die casting machine to evaluate the influence of main process parameters i.e., injection pressure, temperature of molten metal, coating type, cooling type after solidification on the quality of the final product. Raw material was melted in the crucible on temperature 665 °C, which was made up of Sic. Then molten metal was ready for pouring after 1 hour 30 minutes. Firstly machine was started empty without any pouring of metal to heat up the dies for better accuracy of dimensions. The entire machine set up was operated on standard conditions except injection pressure, because the injection pressure was varied at 170, 180, 190 kg/cm² as per experimental design. Some other factors were also varied as per experimental design, which is Pouring temperature of molten metal, Cooling medium of the cast product (Oil [transformer] cooled, water cooled, air cooled) and Coating type (oil +graphite, dycote +graphite, dycote coating). Dycote was made up from silicate, soft stone powder and water. High pressure die casting experimental machine is shown in Fig. 1. Experiments were performed using HPDC for LM24 aluminum alloy as specimen material. LM24 chemical composition consists of several elements, i.e., 6.50 % Si, 0.590 % Fe, 2.41% Cu, 0.161 % Zn, 0.234% Mn, 0.157% Mg, 0.0118% Cr, 0.0565 % Ti, 0.00036 % B, 0.00068 % Ca, 0.00510 % Co, 0.00079% Na, 0.00040% P, 0.00727 % Pb, 0.00010% Sb, 0.00905 % V, 0.00279 % Zr and 89.80 % Al. LM 24 has an excellent casting features and is very easy to cast than other aluminum alloys having more silicon content. Experiments were conducted on different pouring temperature of the molten metal i.e (725°C, 750°C, 775°C).The molten metal was poured into the injection chamber in the shot sleeve with the help of pouring ladle. After pouring the molten metal into the injection chamber the plunger pushes the molten metal in the direction of dies and after applied some force like 170 kg/cm² the plunger comes back to its original position. After few seconds dies were opened by the operator to push the button of die open on control panel. When the dies were open then after solidification of metal the ejectors were ejects the casted part, and after that casted part was drop in air or water or oil as per the experimental requirements. This entire experimental process was conducted at the D-217, S.L Castings and Allied industry, Focal point, Patiala. The main aim of the study is to evaluate the main effects i.e injection pressure of the molten metal, pouring temperature of molten metal, type of coating (oil+ Graphite coating, Dycote + graphite coating, dycote coating) and type of cooling(oil cooling, water cooling, air cooling) on substrate, material impact strength, material density, material surface roughness, material hardness. Taguchi technique has been used in this paper to obtain the optimum parameter setting. This is efficient method to obtain the effect of considered parameters. A set of process parameters is given in Table I. Before going to conduct the experiment, Raw material (LM24) was put in to the crucible and leave for melting at up to 665 °C for about 1 hour 30 minutes. Pit furnace achieved maximum temperature of about 11000C.

Table I Levels and values of the process parameters

FACTORS	Level-1	Level-2	Level-3
Injection pressure of the molten metal kg/cm ² (A)	170	180	190
Pouring temperature of the molten metal (B)	725 °C	750 °C	775 °C
Type of coating (C)	Dycote +graphite	Oil + graphite coating (transformer oil)	Dycote coating
Type of cooling (D)	Air cooling	Water cooling	Oil cooling

The pit furnace which was used for melting metal is available at S.L Castings & Allied industry Focal Point, Patiala (shown in Fig.1a). The temperature of the molten metal can be varied and these variations in the melting temperature can be measured by the pyrometer indicator.

Figure 1 Pit Furnace



The effect of various process parameters has been studied using Taguchi technique after the machining of die cast parts. The Taguchi approach decreases the variation of the process parameters by using the robust design of experiment. The main aim of this technique is to make goods of high quality with less cost in manufacturing industries. Taguchi technique proposed the orthogonal arrays. The full factorial design is referred as the technique of finding and investigating all favorable conditions in experiment involving multiple factors investigate only fraction of all the combinations. Where there are advantages there are disadvantages also. These techniques are widely used but there are some disadvantages like this technique is so time consuming and costly, if the no. of variables are large. They must need strict mathematical treatment in the design of experiment and to analyze the results. In this design contribution of each factor is determined and generally this is not permitted so that's why to simplify and to systematize the fractional factorial design taguchi technique has been proposed to overcome the limitations. In the current experimental work, L9 orthogonal array is used for conjoining the four process parameters in the design of experiment, and each process parameter is changed at three different levels as given in Table I. In this study four process parameters have taken in cold chamber die casting process. For the four sets of input parameters there are eight degrees of freedom. Once the degree of freedom is known, the next step is to select the particular orthogonal array to fit the specific task. The degrees of freedom should be greater than or less than equal to those process parameters for orthogonal array. L9 orthogonal array with nine rows and five columns was used in this study. Each cold chamber die casting parameter which was assigned to a column and nine cold chamber die casting parameters were tested. Therefore by using orthogonal array only nine experiments are requires analyzing the entire casting parameters. The layout of L9 orthogonal array of selected parameters is shown in Table II. The parameters that influence the output can be categorized in two categories, controllable factors and uncontrollable factors. The control factors that may contribute to reduced variation can be quickly identified by looking at the amount of variation present in response. The uncontrollable factors are the sources of variation often associated with operational environment. For this experimental work, response characteristics have given in the Table 3.

Table II L9 Orthogonal Array

Trial No.	Pouring temp. °C	Injection pressure, kg/cm ²	Coating type	Cooling medium
1	725	170	Oil+Graphite	Air
2	725	180	Dycote+Graphite	Water
3	725	190	Dycote	Oil
4	750	170	Dycote+Graphite	Water
5	750	180	Dycote	Oil
6	750	190	Oil+Graphite	Air
7	775	170	Dycote	Oil
8	775	180	Oil+Graphite	Air
9	775	190	Dycote+Graphite	Water

Table III Response Characteristic

Response name	Response type	Units
Impact test	Higher is better	Joules
Density	Higher is better	gm/cm ³
Hardness	Higher is better	HRB
Surface Roughness	Lower is better	Microns

III. Result and Discussions

The effect of various input parameters i.e. thermal characteristics (temperature of the molten metal), injection pressure of the molten metal, type of coating (oil+ graphite coating, dycote + graphite coating, dycote coating), and the type of cooling (air cooling, water cooling and oil cooling). The four responses were selected for experimentation namely, surface roughness, density, hardness and impact strength. The experiment was conducted using LM24 aluminium alloy. The assignment of factor was carried out using statistical software MINITAB 17. All the factors were varied at three levels. The degree of freedom required for the experiment was calculated to be 8, thus orthogonal array that can be used should have degree of freedom (DOF) less than or equal to 8. L9, which can accommodate factors with 3-levels, was thus used for conduct of experiments to measure four responses namely the surface roughness, density, hardness and impact strength. After conducting the 9 trials the mean value for all the above factors are tabulated. For the analysis of result Analysis of Variance (ANOVA) was performed.

A. Analysis of Variance- Impact Strength

ANOVA analysis showed that Cooling (F value 6.54547) was the only factor that significantly affects the impact strength. All other factors, namely, pouring temperature, Injection pressure and coating were found to be insignificant. ANOVA analysis is shown in Table IV.

Table IV Analysis of Variance for means of Impact Strength

Factors	DOF	Seq SS	Adj MS	F	% contribution
Pouring Temperature	2	1.6086	0.8043		
Injection Pressure	2	8.1947	4.0973		
Coating	2	21.9288	10.9644		
Cooling	2	39.6650	19.8325	6.54547	75.25
Total	8	71.3971			

ANOVA analysis showed that Cooling (F value 6.54547) was the only factor that significantly affects the impact strength. All other factors, namely, pouring temperature, Injection pressure and coating were found to be insignificant. For S/N ratio of impact strength at 95% confidence interval Other than pouring temperature, all other factors, namely coating, cooling and injection pressures were found to be significant in affecting impact strength. According to F-test, Cooling was observed to be the most significant factor affecting the impact strength. It is concluded that highest impact strength was observed when cooling type Oil is used and pressure was kept at 180 kg/cm². In S/N ratio highest impact strength was observed when coating type dycote was used and pressure was kept at 190 kg/cm². The best value impact strength was observed with the 95% confidence level was 3.676 ±1.6342 micron.

B. ANALYSIS OF VARIANCE- SURFACE ROUGHNESS

The results were analyzed using ANOVA for identifying the significant factors affecting the surface roughness. ANOVA results for the mean surface roughness at 95% confidence interval are given in Table V. The variation data for each factor was tested for F value to find significance of each factor. The principle of F-test is that the larger the F values for a particular parameter, the greater the effect of performance characteristics due to the change in that process parameter. ANOVA analysis showed that injection pressure (F value 9.55395) was the only factor that significantly affects the surface roughness. All other factors, namely, pouring temperature, coating and cooling were found to be insignificant.

Table V Analysis of Variance for means of Surface Roughness (Ra)

Factors	DOF	Seq SS	Adj MS	F	% contribution
Pouring Temperature	2	0.013067	0.006533	3.5455	25.6821
Injection Pressure	2	0.019467	0.009733	9.55395	56.9575
Coating	2	0.010867	0.005433	2.02554	11.6249
Cooling	2	.000800	.000400	1.85892	8.3844
Total	8	.044200			
E pooled	2	0.006109	0.24854		

ANOVA analysis showed that injection pressure (F value 9.55395) was the only factor that significantly affects the surface roughness. All other factors, namely, pouring temperature, coating and cooling were found to be insignificant. ANOVA results for S/N ratio of surface roughness at 95% confidence interval. Other than cooling, all other factors, namely coating, pouring temperature and injection pressures were found to be significant in affecting surface roughness (Ra). It is concluded that lowest roughness was observed when injection pressure was kept at 190 kg/cm². In S/N ratio lowest roughness was observed when injection pressure was kept at 190 kg/cm²,

and cooling type air cooling was used as they reduce the variation and improve the surface finish. The best value of surface roughness was observed with the 95% confidence level is 0.3366 ± 1.066 micron.

C. ANALYSIS OF VARIANCE- DENSITY

The results were analyzed using ANOVA for identifying the significant factor affecting the performance measures. ANOVA for the mean density at 95% confidence interval is given in Table VI. ANOVA table shows that injection pressure (F value (35.541) is the only factor that significantly affects the density. All other factors, namely, Pouring temperature, Coating and cooling type were found to be insignificant.

Table VI Analysis of Variance for Means density

Factors	DF	Seq SS	Adj MS	F	% contribution
Pouring Temperature	2	0.000082	0.000041	3.2154	2.560521
Injection Pressure	2	0.005831	0.002915	35.54125	82.04531
Coating	2	0.000004	0.000002	1	7.805711
Cooling	2	0.000022	0.000011	2.54587	7.603973
e-pooled	2	.000001	0.000045		
Total	8	0.005983			

ANOVA table shows that injection pressure (F value (35.541) is the only factor that significantly affects the density. All other factors, namely, Pouring temperature, Coating and cooling type were found to be insignificant. ANOVA results for S/N ratio of density at 95% confidence interval. Except injection pressure all other factor namely Coating, Cooling and Pouring temperature are found to be insignificant. According to F-test injection pressure was observed to be the most significant factor affecting the density, followed at small level by temperature 775 °C. It is concluded that highest density was observed when injection pressure was kept at 190 kg/cm² and Pouring temperature 775 °C is used. The best value for the density was observed with 95% confidence level is 2.697 ± 0.0509 g/mm³.

D. ANALYSIS OF VARIANCE- HARDNESS

The results were analyzed using ANOVA for identifying the significant factor affecting the performance measures. The analysis of variance (ANOVA) for the mean hardness at 95% confidence interval is given in Table VII. ANOVA table shows that coating (F value 16.926) and cooling (F value 6.9568) are the factor that significantly affects the hardness, whereas pouring temperature and Injection pressure factor was found to be insignificant.

Table VII Analysis of Variance for Mean Hardness

Factors	DF	Seq SS	Adj MS	F	% contribution
Pouring Temperature	2	9.3764	4.68821	3.4487	10.71756
Injection Pressure	2	4.3468	2.17341	2.6548	4.5654
Coating	2	19.5983	9.79914	16.926	69.2366
Cooling	2	17.1083	8.55414	6.9568	16.2365
e-pooled	4	3.254	1.2785		
Total	8	53.6838			

ANOVA table shows that coating (F value 16.926) and cooling (F value 6.9568) are the factor that significantly affects the hardness, whereas pouring temperature and Injection pressure factor was found to be insignificant. ANOVA results for S/N ratio of hardness at 95% confidence interval. Except pouring temperature and injection pressure, all other factors are significant. According to F-test coating was observed to be the most significant factor affecting the hardness, followed by cooling according to F-test. It is concluded that higher hardness was observed when Coating Type Dycote was used and pouring temperature was kept at 7750C and for cooling oil cooling was used during casting because these decrease variation. The best value of hardness was observed with 95% confidence level is 105.66 ± 1.7299 HBN.

IV. Conclusion

This study experimentally investigated the effect of cold chamber die casting process parameters on the properties of casted LM 24 aluminium alloy. Further the component PG Clamp a product of P.S.P.C.L, Punjab which is originally made from LM6 was made out of LM24 aluminium alloy. Following conclusions are drawn out from this study:

- Dycote coating was increased the hardness as compared to dycote + graphite coating and oil + graphite coating.
- Oil cooling was also increased the hardness. Increase the injection pressure density is increased and the density value of LM 24 is greater than LM6.
- Surface finish, Hardness, Impact strength of LM24 is extremely good as compared to LM6.
- It was concluded that the high injection pressures was most prominent in casting of aluminium alloys and Water cooling is least preferred from oil cooling and air cooling.
- It was concluded from the microstructure analysis, the crack propagation was observed in some samples which have low injection pressure i.e. pressure also affects the microstructure of LM24. Porosity of LM24

was less as compared to LM6 at the same pressure conditions because pressure mainly affects the porosity of the aluminium alloy. It is recommended using the LM24 instead of LM6 to D-217 focal point, Patiala, because I got better results in favor of LM24.

V. References

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