International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 23513-23522

http://www.ripublication.com

Parameter Optimization for Insert Blowhole Defect in Piston Die Casting through DOE

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Abstract

This paper discusses the application of a design of experiments (DOEs) experimental method for analysing the influence of three ring carrier parameter (Alfin insert temperature, Die tilting angle and Insert dipping time) on the internal quality of Piston die casting LM13 alloy parts. At an initial stage, the experimental methods applied on the manufacturing process are outlined. A trial design was followed: it employed different combinations of Ring carrier parameters and aimed to assess the presence of Insert hole defect in the Piston casting parts. The quality assessment of the die casting parts was based on Visual inspection. The results obtained were evaluated by using variance analysis, which assessed how the variation in the three different parameters influenced the integrity of the components.

Index Terms— Design of experiments, Aluminium die casting, piston

I. INTRODUCTION

In Aluminium die casting processes, there are parameters with differential levels of adjustment, which influences the final characteristics of the pistons. To optimize the die casting process, the trial and error method is used to identify the optimal parameters to manufacture a quality piston. However, this method requires extensive experimental work and results in more time and money. Thus, design of experiments

(DoE) appears to be an important tool for continuous and rapid improvements in quality (Coleman and Montgomery, 1993). These experimental methods may be employed to solve problems related to a manufacturing process, to tryout a process for substituting another one, to develop different products and to understand the influence of different factors on the final quality of a product under consideration. The design of experiments (DOEs) is an experimental technique that helps to investigate the optimal combinations of process parameters, changing quantities, levels and combination of these in order to obtain results statically reliable. It is a systematic route that may be followed so as to find solutions to industrial process problems with greater objectivity by means of experimental and statistical techniques (Coleman and Montgomery, 1993; Antony et al., 1998; Steinberg and Hunter, 1984). The aluminum die casting process is impacted by several parameters. When properly ascertained and adjusted, they result in an improvement in quality of the die casting parts. Usually, the main controlled variables for insert hole defect are Insert temperature, die tilting angle and insert dipping time as well as chemical composition and liquid metal temperature. According to Taguchi (1993), the parameters which exert a great deal of influence on the die casting process can be adjusted to different intensity so that some settings can result in robustness of the manufacturing process.

Syrcos (2003) conducted a study in which the die casting parameters were divided into four categories as follows:

1. Die casting machine-related parameters;
2. Shot sleeve-related parameters;
3. die-related parameters;
4. Cast metal-related parameters.

The following paragraph presents some concepts of experimental design applied to the die casting process (Coleman and Montgomery, 1993):

Response variables are the dependent variables, which undergo changes when they go through different process parameters. In the experiments, there may be one or more response variables, in this case, porosity ratings and density of the casting. Control factors are the selected independent variables of the experiment, which have different effects on the response variables when adjusted to different levels. According to Juran et al. (1951), they can be subdivided into:

- Quantitative control factors (injection pressure, piston speed and temperature) and
- Qualitative control factors (die casting machine, operator and aluminum alloy).

Noise factors are the variables, which influence the response variables. They may or may not be known. Special care should be taken to prevent the noise factors from interfering in the experimental results.

Factor levels are the intensity to which the control factors are adjusted in a particular experiment. They can be identified as Insert Temperature (A), Die tilting angle (B), and Insert dipping time (C). Treatments: each experimental run is a treatment, that is, a combination of factor levels (die casting parameters). Experimental matrix is the matrix composed of control factors with different levels for each treatment given. Repetition is the reproduction of the selected combination under the same experimental conditions. According to Coleman and Montgomery (1993), repetition makes it possible to estimate the experimental error, which is used to define whether the differences in the control variables are significant. In this paper, the methodology DOE is employed to study the influence of some machine parameters on the quality of die casting parts, using the LM13 aluminum alloy. Recent publications present further information on the results obtained in this research (Mendes, 2005; Verran et al., 2006).

II. EXPERIMENTAL PROCEDURE

In the current work, the following die casting parameters were studied: Insert temperature, die tilting angle and insert dipping time. Fig. 1 presents the cause and effect diagram adapted from Syrcos (2003). This diagram is employed to identify the die casting process parameters that may affect the quality of the Piston casting part. The selected casting process parameters and their different levels are tabulated Table 1. The part, which was investigated, was a “Piston casting” of LM 13 alloy for IC engines (Fig. 2), which presented Insert hole defect problems and a high number of rejections. As for the quality assessment, a critical region of this part has been chosen, that is, there was a considerable amount of Insert hole defect. An experimental design was conducted and it employed factorial arrangements, that is, the design included all possible combinations of factors considering different levels. Table 2 shows the different levels in the form of actual values for each parameter investigated.

TABLE I.

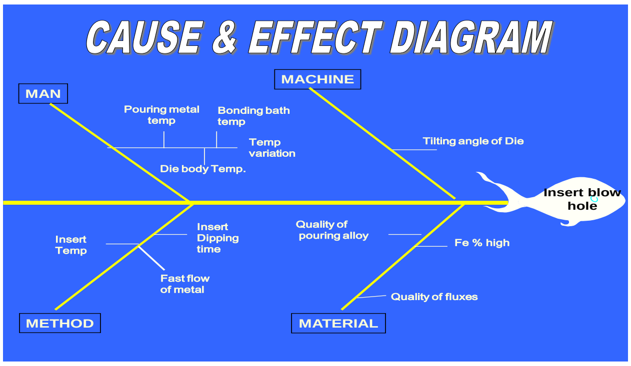
PROCESS PARAMETERS WITH THEIR DIFFERENT LEVELS

Process Parameter	**Level 1**	**Level 2**
A=Insert temperature °C	175-200	201-225
B=Tilting angle Degree	10-15	16-20
C=Dipping time +/- 10 Sec	100	150

TABLE II.

CONTROL FACTORS FOR EACH EXPERIMENTAL COMBINATION

Experiments	A=Insert temperature °C	B=Tilting angle Degree	C=Dipping time +/- 10 Sec
1	175-200	10-15	100
2	201-225	10-15	100
3	175-200	16-20	100
4	201-225	16-20	100
5	175-200	10-15	150
6	201-225	10-15	150
7	175-200	16-20	150
8	201-225	16-20	150



Definition of Insert blow hole

Fig.1 Cause and effect diagram

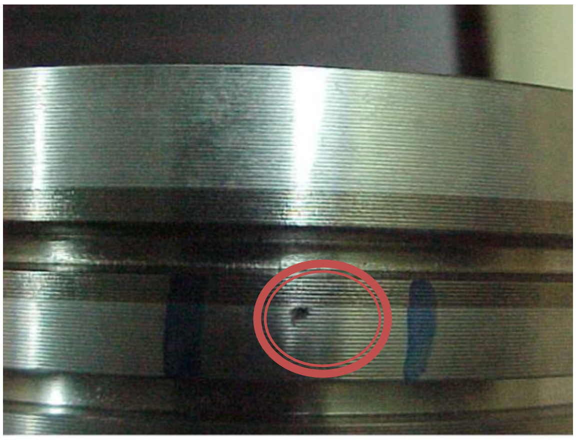


Fig.2 Insert blowhole is a casting defect – Seen as a small bubble like hole just below the Alfin insert or the machined surface of the piston.

III. RESULTS AND DISCUSSION

The average of 2 replication of different levels of control factors are shown in Table 3. It is possible to observe that the Insert temperature, Die tilting angle and insert dipping time for the different levels that were investigated; however, the effect of Insert temperature and die tilting angles have significant effect were observed in both levels. The quality assessment of the die casting Piston carried out by visually after the piston casting machined. The results of Insert blow hole are shown in Tables 4. The average values of Insert blow hole defect that the best results were obtained in experiment 8. Such results are related to High level of Insert temperature, Die angle and Insert dipping time. On the other hand, the worst results were obtained in experiment 2. Such results are related to High insert temperature with low die angle and insert dipping time. These findings are in agreement with theoretical and experimental predictions about the influence of the Insert temperature, Die tilting angle and insert dipping time on formation of insert blow hole. In order to study the significance of parameters a variance analysis (ANOVA) based on number of defect was performed, as shown in Table 6. From Table 6 it is possible to conclude, with 95% of confidence, that fast shot and upset pressure, as well as the interaction between these two factors affect the amount of porosity on the surface of the die casting part under study. The values of the F0 for each factor and their respective interactions are shown in Fig. 3.

AVERAGE VALUES FOR THE PROCESS PARAMETERS INVESTIGATED

Treatment combination	A=Insert temperature °C	B=Tilting anglein Degree	C=Dipping time +/- 10 sec	IH defect (Replication-1)	IH defect (Replication-2)	Total in no's
-1	175-200	10-15	100	6	7	13
a	201-225	10-15	100	7	8	15
b	175-200	16-20	100	7	6	13
ab	201-225	16-20	100	4	5	9
c	175-200	10-15	150	11	10	21
ac	201-225	10-15	150	4	5	9
bc	175-200	16-20	150	6	5	11
abc	201-225	16-20	150	3	4	7

Effect of Inert temp			Effect of Tilting angle			Effect of Insert dipping time		
	High level-201-225	Low level 175-200		High level-16-20	Low level 10-15		High level-150 sec	Low level - 120sec
1	15	13	1	13	13	1	21	13
2	9	13	2	9	15	2	9	15
3	9	21	3	11	21	3	11	13

4	7	11	4	7	9	4	7	9
Total	40	58	Total	40	58	Total	48	50
X Bar	10	14.5	X Bar	10	14.5	X Bar	12	12.5
Effect	-4.5		Effect	-4.5		Effect	-0.5	
The interaction effect of Insert temp and Tilting angle			Interaction between Insert temp and Insert dipping time.			Interaction between Tilting angle and Insert dipping time.		
	High level-Insert temp-201-225	Low level-Tilting angle-10-15		High level-Insert temp-201-225	Low level-Insert dipping time 100 sec		High level-Tilting angle 16-20	Low level-Insert dip time 100 sec
1	15	13	1	15	13	1	13	13
2	9	15	2	9	15	2	9	15
3	9	21	3	9	13	3	11	13
4	7	9	4	7	9	4	7	9
Total	40	58	Total	40	50	Total	40	50
X Bar	10	14.5	X Bar	10	12.5	X Bar	10	12.5
Effect	-4.5		Effect	-2.5		Effect	-2.5	

MAIN EFFECTS AND INTERACTION- 2^3 DESIGNS

Treatment combination	**A=Insert temperature °C**	**B=Tilting angle in Degree**	**C=Dipping time +/- 10 sec**	**IH defect (Replication-1)**	**IH defect (Replication-2)**	**Total in no's**
-1	175-200	10-15	100	6	7	13
a	201-225	10-15	100	7	8	15
b	175-200	16-20	100	7	6	13
ab	201-225	16-20	100	4	5	9
c	175-200	10-15	150	11	10	21
ac	201-225	10-15	150	4	5	9
bc	175-200	16-20	150	6	5	11
abc	201-225	16-20	150	3	4	7

THE AVERAGE OF THE RESPONSE FOR THE FACTORS DUE TO EACH LEVEL

Insert temp lower level (A1)
A1=¼((1)+b+c+bc)= 14.5
Insert temp at higher level (A2)
A2=¼ (a+ab+ac+abc)= 10

Tilting angle at lower level (B1)
B1=¼((1)+a+c+ac)= 14.5
Tilting angle at higher level (B2)
B2=¼(b+ab+bc+abc)= 10
Insert dipping time at lower level (C1)
C1=¼((1)+a+b+ab)= 12.5
Insert dipping time at higher level (C2)
C2=¼(c+ac+bc+abc)= 12
Main The effect of Insert temp, Tilting angle and Insert dipping time.
Effect of Insert temp =A2-A1= -4.5
Effect of Tilting angle =B2-B1= -4.5
Effect of Insert dipping time=C2-C1= -0.5

Yates method is a statistical method to find out the hypothesis which can be used to find the significance difference if any among all factors.

Yates has developed a systematic tabular method which is most expeditious, which when there are three or more factors.

Treatment combination	Replicate1	Replicate2	Total	Effect'(1)	Effect'(2)	Effect total-3
1	6	7	13	28	50	98
a	7	8	15	22	48	-18
b	7	6	13	30	-2	-18
ab	4	5	9	18	-16	2
			Total	98	80	64
c	11	10	21	2	-6	-2
ac	4	5	9	-4	-12	-14
bc	6	5	11	-12	-6	-6
abc	3	4	7	-4	8	14
Odds			58	48	36	72
Evens			40	32	28	-16
Total			98	80	64	56

ANALYSIS OF VARIANCE ANOVA FOR 2^3 FACTORIAL DESIGN.

Source of variation	Degree of freedom= N-1	Degree of freedom (DF)	Sum of squares	Mean squares
Between Treatments	7	7	67.75	9.678571429
Between Replicates	1	1	0.25	0.25
Error	7	7	3.75	0.54
Total	15	15	71.75	

Grand total	98
Correction factor	600.25
Total sum of odds	58
Total sum of evens	40
Treatment sum of square	67.75
Total sum of square	71.75
Total sum of replicate 1	48
Total sum of replicate 2	50
The Sum of squares due to replicate is	0.25
Error Sum of squares= (Total sum of squares -Treatment Sum of squares) - Sum of Squares due to replicate.	3.75
Mean squares between treatments= sum of square between Treatment / D.F=67.75 / 7= 9.68	9.68
Mean squares between Replicates= sum of square between Replicates / D.F=2.25 / 1= 2.25	0.25
Mean squares between Errors= sum of square between errors / D.F=3, 75 / 7= 0.54	0.54

The F Ratio = Treatment mean squares/Error mean squares =9.68/0.54=18.06 Which is Significant at 5% level based on 7 and 7 degree of freedom for F (test table value 3.79 for F 7, 7.)

Treatment combination	**Mean effect= taken from column effect3.**	**Mean effects**	**Sum of squares**	**F Ratio= sum of squares/Error mean square**	**F Calculated value**	**F table value**	**Significant**	**Effect**
1	$98/2^k r = 96/2^3 * 2$	6.125						G
a	-18/X	-2.25	20.25	20.25/0.54	37.8	3.79	Yes	A
b	-18/X	-2.25	20.25	20.25/0, 54	37.8	3.79	Yes	B
ab	2/X	0.25	0.25	0.25/0.54	0.5	3.79	No	AB
c	-2/X	-0.25	0.25	0.25/0.54	0.5	3.79	No	C
ac	-14/X	-1.75	12.25	12.25/0.54	22.9	3.79	Yes	AC
bc	-6/X	-0.75	2.25	2.25/0.54	4.2	3.79	Yes	BC
abc	14/X	1.75	12.25	12.25/0.54	22.9	3.79	Yes	ABC

Where X= Number of treatment = 8.
F (Calculated value) < F (Table value) = Accept the Null Hypothesis. There is no significant variance.
F(0.5)<3.79 so Two Factor interaction ab and c are having no significant for Insert blow hole defect.
F (Calculated value) > F (Table value) = Accept the alternative hypothesis and there is significant variance.

F (37.8,37.8,22.9,4.2,22.9) >3.79 So Factor a, b and two factor interaction ac and three factor interaction abc are significant for Insert hole defect
Even though the Two factor interaction bc are significant marginally.

IV. CONCLUSIONS

Based on the experiment result, the effect of high insert temperature and high die tilting angle gives good result of reducing insert hole defect in piston casting. But the effect of insert dipping time having only marginal effect to reduce insert hole defect in Piston casting. The interaction effect of high level of insert temperature and low level of die tilting angle giving significant effect on reducing insert hole defect.Finally we have implemented the insert temperature, Die tilting angle and Insert dipping time on higher level, the insert blow hole defect is come down to 1.42% from 2.57%

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