OPTIMIZATION OF PROCESS PARAMETERS TO MINIMIZE THE DEFECTS IN AL-ALLOY CASTING

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ABSTRACT: This paper is focused on minimizing the defects in Al-Mg alloy castings in green sand casting process by optimizing the casting process parameters. Several process parameters contribute to these casting defects. Literature review reveals that moisture content, binder percentage and pouring temperature are among the most influencing parameters which contribute to the casting defects like sand drop, blow holes, scabs, and pinholes. In this paper these three process parameters are optimized by using the Taguchi's design of experiment method. The Taguchi approach is used to capture the effect of signal-to-noise ratios of the experiments based on the orthogonal array. Robust design factor values were estimated from the signal-to-noise calculations.
Keywords: Green sand casting, Casting defects, Design of Experiments, Parameter optimization, Taguchi method.

I. INTRODUCTION

Foundry deals with the process of making castings in moulds formed in either sand or some other material. Casting is an old production technique in which cavities are made into a porous and refractive material by a pattern and then liquid metal is poured in the mold to get the required product. Green sand casting is the most widely used casting process because of the wide variety of castings can be manufactured with respect to size, low cost of raw material, possibility of recycling the molding sand. Green sand casting process is a versatile process because it can be used for casting of most metals with high melting point temperatures like copper, cast iron. Several types of defects may occur during casting, considerably reducing the total output of castings. Defective castings lead to tremendous loss of productivity. Casting defects may be defined as those characteristics that create a deficiency or imperfection contrary to the quality specifications imposed by the design and the service requirements [1]. Defects in casting may be of three basic types, major defects that cannot be rectified, resulting in rejection of casting and total loss, second is defects that can be remedied but whose cost of repair may not justify the salvage attempt and third one is minor defects, which allow the castings to be economically salvaged and leave a margin of profit. The price of the finished product depends on the production cost, which is influenced by rejection or rework. It is necessary to improve the quality of castings without increase in price. By applying a disciplined approach to understand nature of the defect and mechanism of defect formation and controlling process parameters rejections can be reduced[2]. Attention to quality assurance can reduce wasteful rework. Timely implementation of modified techniques based on the quality control research is necessary to avoid defects in products [3]. In this paper four process parameters (moisture content, green compressive strength, mould hardness and permeability) are optimized in order to minimize the defects like blow holes, pinholes, scab, drop in the Al-Mg alloy casting. In the casting process every process parameter generally has influence on the more than one defect. As we increase the value of any parameter it may reduce the occurrence of a defect but at the same time it has an adverse effect on some other defect and it increases the tendency of occurrence of that defect. That's why we need to optimize the process parameters in order to obtain a casting having minimum defects. Moisture is added in the casting sand because it is necessary for the binding of sand particles to the clay particles. Moisture activates the clay to perform its function, but at the same time it reduces the permeability of the sand which may result in the blowholes defect in the casting. Permeability is a property of sand which allows the gasses to pass through the sand mold, as we increase the value of permeability it reduces the defects like blow holes and pin holes but the strength of the mold is reduced simultaneously, which can give rise to the defect like sand drop. Increasing green strength reduces the defect sand drop but the permeability also decreases. So these parameters have to be optimized so that a casting with minimum defects can be produced. In the past various researchers have shown interest in this field and have done useful work in optimizing the factors in various types of processes. Rasik upadhyay[4] optimized the sand parameters of the castings manufactured in iron foundry. By using Taguchi method he maximized the signal to noise ratio and minimized the noise factors. The process parameters considered were moisture, sand particle size, green compressive strength, mould hardness, permeability, pouring temperature, pouring time and pressure test. Lakshmanan Singaram[5] considered parameters like green strength, moisture content, permeability and mould hardness. The result of his research was the optimized process parameters of the green sand casting process. It improved the the process performance, reduced process variability and the casting defects were minimized. Uday A. Dabade and Rahul C. Bhedasgaonkar [6] Applied Taguchi method to analyze and optimize the selected process parameters. By taguchi method the percentage rejection of castings due to sand related defects is reduced from 10% to 3.59%. Taguchi method can be efficiently applied for deciding the optimum settings of process parameters to have minimum rejection due to casting defects. B. Senthilkumara, S.G. Ponnambalam, N. Jawahar[7] optimized the parameters like pouring temperature, carbon equivalent and gating system to minimize the Pull down defects in iron casting. The parameters were analyzed using 'Design of Experiments'. ANOVA analysis was done for robust design factor values obtained from S/N ratios. It was identified that the optimized values increased the acceptance percentage from 86.22% to 96.17%. G.P. Syrcos[8] analyzed various significant process parameters of the die casting method of AlSi9Cu13 alloy. He attempted to obtain optimal settings of the die casting parameters, to get the optimal casting density of the AlSi9Cu13 alloy casting. The process parameters were: piston velocity, metal temperature, filling time and hydraulic pressure. Satish kumar,Arun Kumar Gupta, Pankaj Chandana[9] analysed different parameters of pressure die casting to minimize the casting defects. Pressure die casting is generally applied for casting of aluminium alloy. They optimized the parametes such as solidification time, molten temperature, filling time, injection pressure and velocity of plunger. A 2.352% reduction in defects has been identified after adopting the optimized parameters. G.O. Verrana, R.P.K. Mendesb, L.V.O. Dalla Valentina[10] discissed the application of design of experiments method for analyzing the three injection parameters slow shot, fast shot and upset pressure on the quality of die casting SAE 305 alloy parts. The quality of die casting parts were assessed by quality image analysis and density measurements. Results were evaluated using variance analysis.

II. METHODOLOGY

In this paper Taguchi's Design of Experiment method is used to optimize the influencing parameters. Design of Experiments is a series of tests in which changes are made to input parameters to identify the effect on the response variables. DOE can be used to study the effect of outcome of multivariable [11]. By using Taguchi's experimental design we can design products which are easy to manufacture, have better performance and can be designed, developed and produced in less time. These experiments are applied in a sequence. A screening experiment is performed first to identify the most influencing factors [12]. Further experiments are conducted to determine adjustments required for these critical variables to improve the parameters. The Taguchi method can be applied by using eight experimental steps that can be grouped into three major categories as follows : Planning the experiment: (1) Identifying the main function of casting process. (2) Identifying the quality characteristic to be observed and the objective function to be optimized. (3) Identify the control factors and their alternate levels. (4) Identifying the noise factors and the testing conditions of the process. (5) Designing the matrix experiment and define the data analysis procedure. Performing the experiment (6) conducting the matrix experiment. Analyzing and verifying the experimental results (7) Analyzing data, determining the Optimum levels for the control factors, and predicting performance under these levels (8) Conduct the verification experiment.

A. Selection of control factors of process parameters

From the literature survey it is identified that following factors are among the most influencing factors for casting defects:

- Moisture content
- Binder percentage
- Pouring temperature

B. Selection of level for the factors

The levels of experiments are selected after the screening experiment. To include the non linear effects, minimum three levels for each parameter should be considered[13]. The designation of parameters and values of signal levels are shown in Table 1.

Table 1.Control factors of process parameters and their levels

Factor Designation	Control factor	Range	Level 1	Level 2	Level 3
A	Moisture (%)	3.5-4.5	3.5	4	4.5
B	Binder (%)	7-10	7	8.5	10
C	Pouring Temp. (^{0}C)	740-880	740	800	880

C. Selection of orthogonal array

In full factorial design of experiment the number of experiments to be performed for four factors and three signal levels are 81. A process gives the best output when all the factors operate at optimum levels. If n signal levels are selected with m factors, the total number of experiments possible is 'nm'. When number of controlling factors and level is large, the number of experiments to be conducted is large. Taguchi suggested the use of orthogonal arrays to reduce the number of experiments without affecting the quality of research. Orthogonal array is the basis for conducting fractional factorial experiments. Orthogonal arrays are selected according to the number of controlling parameters and the number of signal level under each parameter[14]. Table 2 shows standard 'L-9' orthogonal array used for the four factors each set at three levels. The experimental orthogonal array having the levels of the factors assigned to columns is shown in Table 3.

Table 2.Orthogonal array L 9 (3^4)

Trial no.	A	B	C
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

Table 3.Experimental orthogonal array

Trail no.	A Moisture content (%)	B Binder (%)	C Pouring Temperature (0C)
1	3.5	7	740
2	3.5	8.5	800
3	3.5	10	880
4	4	7	800
5	4	8.5	880
6	4	10	740
7	4.5	7	880
8	4.5	8.5	740
9	4.5	10	800

III. RESULTS AND DISCUSSIONS

The experiments were conducted thrice for the same set of parameters using a single-repetition randomization technique [15]. Casting defects that occur in each trial experiment were found and recorded. The average of the casting defects was determined for each trial condition as shown in Table 4. The casting defects are the "lower the better" type of quality characteristics. S/N ratios were computed for each of the 18 trials and the values are given in Table 4. The average effect of factors is shown in Table 5.

For minimizing the performance characteristic, S/N ratio is calculated by using the following formula:

$$S/N = -10 \log_{10} (1/n) [\Sigma_i^n (y_i)^2]$$

Table 4.Casting defects values and signal-to-noise ratio against experimental trial numbers

Trial no.	Percentage defects in experiment			Average	S/N ratio
	Repetition 1	Repetition 2	Repetition 3		
1	5.42	5.08	4.36	4.954	-13.93
2	4.56	6.40	5.16	5.374	-14.69
3	3.67	4.11	4.55	4.110	-12.30
4	6.25	5.89	7.32	6.480	-16.27
5	4.87	5.72	5.54	5.370	-14.63
6	5.13	5.65	6.12	5.640	-15.03
7	3.93	5.22	5.03	4.727	-13.55
8	7.24	6.56	6.31	6.701	-16.54
9	4.33	5.73	5.88	5.314	-14.58

Table5.Average values of S/N ratios at different levels and their main effects

Columns	Factors	Level 1	Level 2	Level 3
1	Moisture (%)	**-13.64**	-15.32	-14.89
2	Binder (%)	-14.58	-15.28	**-13.97**
3	Pouring Temperature	**-14.38**	-14.42	-15.03

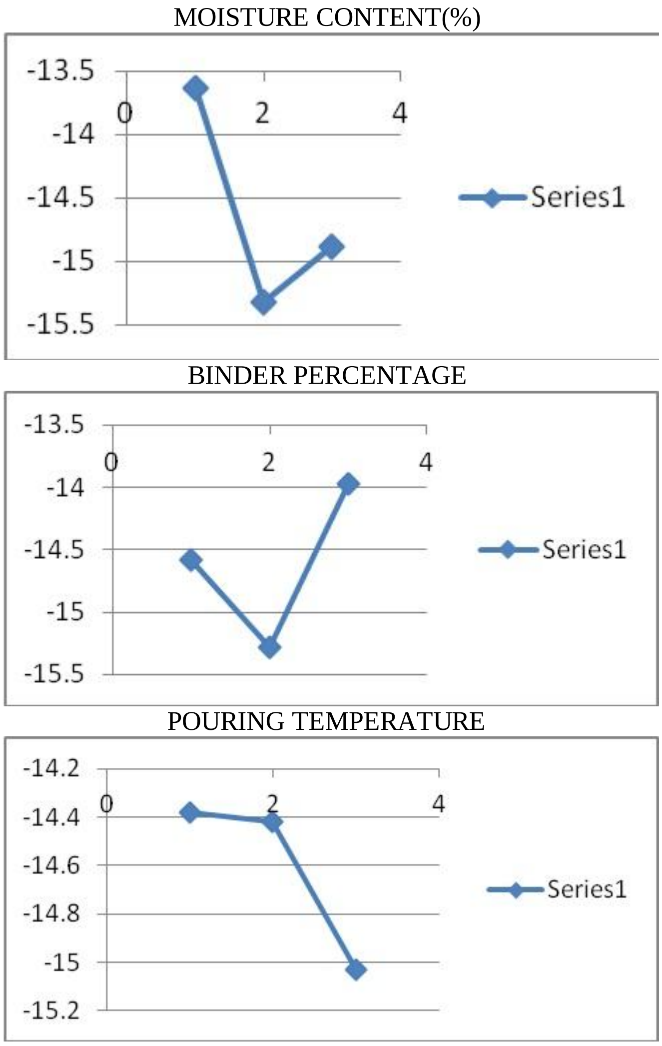

Fig. 1. Average values of S/N ratio of each parameter at levels 1-3

Table6. Robust design optimum value of factors for minimization of defect

Factor	Level	S/N ratio	Optimum value
Moisture (%)	1	13.433	3.5
Binder (%)	3	13.786	10
Pouring Temperature	1	14.186	740

IV. CONCLUSIONS

In this research work process parameter optimization for controlling the defects in Al-Mg alloy casting was considered. The conclusions are following:

- Contributing parameters identified were moisture content, binder percentage and pouring temperature. These parameters were analyzed with three signal levels for each parameter.
- Robust design factor values were estimated from S/N ratios and tabulated in Table 6.
- The optimum values for the process parameters

computed are:

- Moisture content – Level 1 – 3.5%
- Binder percentage – Level 3 – 10%
- Pouring Temperature – Level 1 – 740 0C
- This result reflects that by using Taguchi method the factor levels when optimized will result in reduction of casting defects and increase the yield percentage of the accepted castings without any additional investments.

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