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Study of Process Parameters Effect on Surface Finish in Al-Alloy Sand Casting by Using Taguchi Method

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Abstract

The study aimed to find out the effect of sand casting parameters moisture content, mould preheat temperature, mould hardness and pouring temperatue on surface roughness of the cast parts and to achieve the optimal parameter values to producing minimum surface roughness.
In this study,Taguchi parameter design is adopted to achieve the optimal levels of process parameters (design parameters) that lead to low surface roughness. Three levels for each parameter is selected and the experiments are designed according to L9 orthogonal array and three trial for each experiment is conducted. Average values of Surface rougness and S/N ratio are tabulated and are also plotted for different control factors. The optimal parameters for sand casting of LM6 for better surface finish corresponds to a moisture content of 5%, mould preheat temperature of 200^{o}C, mould hardness 90 and mould preheat temperature of 670^{o}C. The S/N ratio table also shows that mould preheat temperature is the most significant factor that effect surface roughness and the other factors are found less significant.

Keywords: Sand Casting Process Parameters, LM6, Taguchi Method, Surface Roughness

1. Introduction

Sand casting is used to produce a wide variety of metal components with complex geometries. These parts can vary greatly in size and weight, ranging from a couple ounces to several tons. Some smaller sand cast parts include components as gears, pulleys, crankshafts, connecting rods, and propellers. Larger applications include housings for large equipment and heavy machine bases. Sand casting is also common in producing automobile components, such as engine blocks, engine manifolds, cylinder heads, and transmission cases.Casting as a process involves an interplay between so many parameters such as melting temperature of charge, the mould condition (temperature, moisture content, sand and type of binders used), pouring temperature, and the gating design (i.e. pouring speed, runner size and included gases), the casting size, the type of alloy.

Product Quality of a casting is a measure of its dimensional accuracy, surface finish and soundness, Morgen, 1982, [6]. Surface finish is the most desired characteristics to be on product surface. This is because surface finish is a predictor of the performance of a mechanical component, since irregularities in the surface may form nucleation sites for cracks or corrosion. The measure of surface quality can be done in terms of surface roughness.
There is no alternative to the intricacy; evidenced through sand casting as a production route, economical and poised for shorter runs. Quality of castings and parametric control there of is more important than that of die casting. With increasing demand for high-quality castings at close tolerances, a need however was felt to study ways to get the

optimal settings for main parameters to ensure better surface conditions. The effects of the selected process parameters on the surface roughness of al-alloy(LM6) sand castings and the subsequent optimal settings of the parameters will be accomplished using Taguchi's method.

2. Literature Review

The effect of pouring temperature and permeability of sand on the mechanical and metallurgical properties of aluminium alloy part produced through sand casting was investigated by Mahipal Singh et al[2]. Al-4%Si alloy was used as a molten metal and silica sand was used for preparing the mould. The pouring temperature ranges of 700^0C, 800^0C and 900^0C and permeability range of moulding sand 30 and 60 Darcy was considered. The mechanical properties of aluminium alloy casting studied were hardness and impact strength. The result showed that the selected parameters significantly influence the mechanical and metallurgical properties of aluminium alloy casting.

Guharaja, et. al., 2006, [1] made an attempt to obtain optimal settings of the green sand casting process in order to yield the optimum quality characteristics of the spheroidal graphite (SG) cast iron rigid coupling. The effect of selected process parameters i.e. green strength, moisture content, permeability and mould hardness and its levels on the casting defects have been accomplished using Taguchi's parameter design approach. The result indicated that the selected process parameters significantly affect the casting defects of SG cast iron rigid coupling castings.

From the analysis, by S. Guharaja, A. Noorul Haq , K. M. Karuppannan [1] it was proved that, by improving the quality by Taguchi's method of parameter design at the lowest possible cost, it is possible to identify the optimum levels of signal factors at which the noise factors effect on the response parameters is less. The outcome of this paper was the optimised process parameters of the green sand castings process which leads to minimum casting defects.

Muzammil, et al., 2003, [3] made a study for the optimization of a gear blank casting process by using Taguchi's robust design technique. Six control factors were considered , namely, clay content, moisture content, ramming, sand particle size, metal fluidity, and gating design. Each factor was assessed at three levels. The reduction in the weight of casting as compared to the target weight was taken to be proportional to the casting defects. An orthogonal array was constructed for the six factors undertaken, and performing 18 sets of experiments generated the data. The weights of the finished castings were obtained and signal to- noise ratios were calculated by using the nominal best approach of parameter design. The average values of signal-to-noise ratios for each factor at three levels were calculated and were plotted on the graph. Considering the maximum signal-to-noise ratios from the graph, the optimum levels of process factors in the type of task considered were obtained. A validation experiment was performed using the levels obtained. The weight of the castings produced was found to have a value close to the target value.

Product Quality of a casting is a measure of its dimensional accuracy, surface finish and soundness, Morgen, 1982, [6]. It depends upon the quality of various constituents of green sand and structural properties of green mould, Berth, 1990,[4]. It is also influenced by the metal or alloy, in terms of their castability. Charnnarong Saikaew and Sermsak Wiengwiset, 2012, [5] studied Optimization of molding sand composition for quality improvement of iron castings. The aim of this research was to optimize the proportion of bentonite and water added to a recycled sand mold for reducing iron casting waste using the following analysis techniques: a mixture experimental design, response surface methodology, and propagation of error.

An aggregate view of such studies makes a case for deploying Taguchi method for surface finish analysis. The metal-casting process, in general,involves a large number of parameters affecting the quality of the products. The variation in the quality of the product by uncontrollable factors (noise factors) can be estimated by Taguchi's approach of determining the signal-to-noise (S/N) ratio.

3. Design of Experiment

The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varied

. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources.

The general steps involved in the Taguchi Method are as follows:

1. Define the process objective, or more specifically, a target value for a performance measure of the

process. The target of a process may also be a minimum or maximum. The deviation in the performance characteristic from the target value is used to define the loss function for the process.
2. Determine the design parameters affecting the process. Parameters are variables within the process that affect the performance that can be easily controlled. The number of levels that the parameters should be varied at must be specified. Increasing the number of levels to vary a parameter at increases the number of experiments to be conducted.
3. Create orthogonal arrays for the parameter design indicating the number of and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameters and the levels of variation for each parameter, and will be expounded below.
4. Conduct the experiments indicated in the completed array to collect data on the effect on the performance measure.
5. Complete data analysis to determine the effect of the different parameters on the performance measure.

3.1 Process Parameters of Green Sand Castings

The process parameters that may influence green sand casting defects can be listed in five categories asfollows :
1. Mould-machine-related parameters
2. Cast-metal-related parameters
3. Green-sand-related parameters
4. Mould-related parameters
5. Shake-out-related parameters

Out of the above parameters the revieved literature identifies moisture content , mould preheat temperature, mould hardness and pouring temperature may considerably affect surface roughness. The aim of this study is to find out the effect of sand casting parameters like moisture content, mould preheat temperature, mould hardness and pouring temperatue on surface roughness of the cast parts and to achieve the optimal parameter values to producing minimum surface roughness.
In this study, Taguchi parameter design will be adopted to achieve the optimal levels of process parameters (design parameters) that lead to low surface roughness.

3.2 Selected Control parameters and their Response for Analysis

From the literature reviewed the response selected is surface roughness which is a major quality considerations for silumin alloys having very less or no copper content which make them difficult to machine after being casted so the surface finish shoud be imparted while casting. The process parameters which are found to have greater impact on surface roughness of sand casting of Al-alloy and which are considered for present study are

a) moisture content
b) mould preheat temperature
c) mould hardness d) pouring temperature

Table-I Control parameters and their proposed levels

Designation	Main Parameters	Level I	Level2	Level3
A	Moisture content	3%	4%	5%
B	mould preheat temperature	100^{0}C	150^{0}C	200^{0}C
C	mould hardness	70	80	90
D	Pouring temperature	750	710	670

3.3 Selection of material to be casted

On the basis of the literature reviewed the material selected to be casted was Aluminium Casting Alloy LM6 (AL - Si12)

Chemical composition

Copper	0.1 Max
Magnesium	0.10 Max
Silicon	10.0 - 13.0
Iron	0.6 Max
Manganese	0.5 Max
Nickel	0.1 Max
Zinc	0.1 Max
Lead	0.1 Max
Tin	0.05 Max
Titanium	0.2 Max
Aluminium	Remainder

3.4 Methodology

Taguchi recommends the achievement of a robust process or product design. A robust process or product is one whose response is least sensitive to all noise factors. The aim is fulfilled by considering the “signal-to-noise” ratio (S/N ratio) as the measure of performance. Of course, a mathematical analysis is available to support the above. However according to it, each product or process performance characteristic would have a target or nominal value. The parameter design of the Taguchi method involves determining the design parameter's settings for a product or a process so that the product's response has the minimum variation and its mean is close to the target. Experimental design is used in this method to arrange the design parameters and noise factors in the orthogonal arrays. The signal-to-noise (SN) ratio is computed for each experimental combination. Next, SN ratios are analysed to determine the optimal settings (i.e. control factors and their levels) of the design parameters.

However, a large number of different S/N ratios have been defined for a variety of problems, with the problem under study for minimizing Surface Roughness,

S/N ratio $(\eta) = -10 \log10(1/n\sum y_i^2)$

where n = number of replications

This is termed a smaller-the-better type problem where minimization of the characteristic is intended.

Another major tool used in robust design is orthogonal array, which is used to study many design parameters by means of a single response. An orthogonal array may contain both an inner array (control array) and an outer array. The inner array represents control factors involving a number of variables under the control of the experimenter. Each experimental run of the inner array is replicated according to the outer array, which is another design array based upon a certain number of noise variables for which the experimenter either cannot control directly or chooses not to control.

3.5 Selection of Orthogonal array

There are 4 parameters, and each one has 3 levels. The highest number of levels is 3, so we will use a value of 3 when choosing our orthogonal array, we found that the appropriate orthogonal array is L9.

In conformance with Process parameters selected at respective levels as tabulated in table-1, following experiments were conducted in the metal casting laboratory.

Table-.2 L9 Orthogonal array showing designed set of experiment

Experiment	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

4. Result and Discussion

In order to optimize the process parameters of sand casting process, 9 sets of experiments were conducted using L9 orthogonal array and in each experiment set, three trial were carried out. The responses of each experiments and their S/N ratio are shown in table-3 below.

Table-3 Experimental matrix for responses(surface roughness) and S/N Ratio

Experiment	A	B	C	D	Surface Roughness(μm) Trial-1	Trial-2	Trial-3	S/N Ratio
1	3	100	70	750	6.8	6.9	7.1	-16.82
2	3	150	80	710	6.46	5.78	5.83	-15.60
3	3	200	90	670	5.32	5.55	5.20	-14.58
4	4	100	80	670	6.76	6.8	6.92	-16.68
5	4	150	90	750	6.32	5.68	5.83	-15.48
6	4	200	70	710	5.22	5.65	5.16	-14.56
7	5	100	90	710	6.55	6.7	6.72	-16.46
8	5	150	70	670	6.12	5.48	5.73	-15.23
9	5	200	80	750	5.36	5.20	5.12	-14.36

The mean response refers to the average value of the performance characteristic for each parameter at different levels. The average values of surface roughness and S/N ratio for each parameter at levels 1, 2 and 3 were calculated and are given in Table-**4**.

The variation of surface roughness and S/N ratio at different levels of each control factors are being plotted and shown in figures-1(A,B,C,D**)**for moisture content, mould preheat temperature, mould hardness and pouring temperature respectively.

Table-4 average values of surface roughness and S/N Ratios

Factors	Level-1		Level-2		Leve-3	
	Surface Roughness	S/N ratio	Surface Roughness	S/N ratio	Surface Roughness	S/N ratio
A	6.10	-15.67	6.04	-15.57	5.89	-15.35
B	6.81	-16.65	5.91	-15.44	5.31	-14.50
C	6.02	-15.54	6.03	-15.55	5.99	-15.51
D	6.03	-15.55	6.01	-15.54	5.99	-15.50

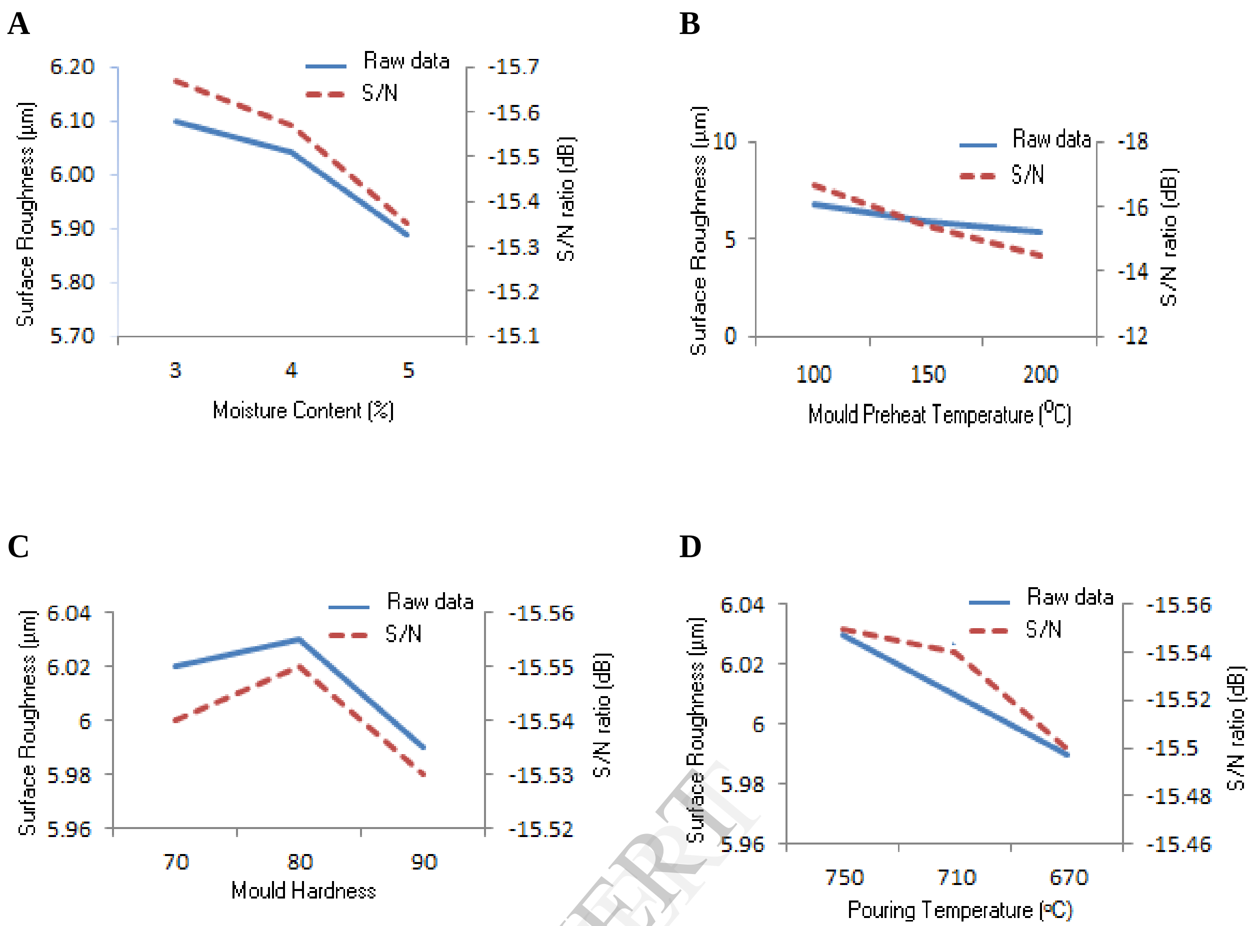

Figure-1.(A,B,C,D). Effect of process parameters on surface roughness (raw data) and S/N ratio (main effects)

It is clear from Figure-1.(A,B,C,D) that the surface roughness was the lowest at the third level of parameter A (A3), third level of the parameter B (B3), third level of the parameter C (C3) and the third level of parameter D (D3). The S/N ratio analysis also suggests the same levels of the parameters (A3, B3, C3 and D3) as the best levels for obtaining the favorable values of surface roughness of Al–alloy LM6 castings in sand casting process. Thus it is evident from the above graphs that the optimal parameters for sand casting of LM6 for better surface finish corresponds to a moisture content of 5%(level-3) , mould preheat temperature of 200°C(level-3), mould hardness 90(level-3) and mould preheat temperature of 670°C(level-3). Therefore the optimal setting of the control factors to achieve better surface finish for the the factors and there levels under consideration is A3,B3,C3,D3.

5. Conclusion

On the basis of the above experiments conducted and the analysis carried out many conclusions can be drawn and the few of them are

The Figure-1.(A,B,C,D) showing average values of surface roughness and S/N ratio for different control factors brings out the optimal setting for each control factors amongst the level selected for study. These optimal values for different control factors in order to produce better surface finish are moisture content - 5%, mould preheat temperature- 200°C, mould hardness- 90, and pouring temperature- 670°C.

On noticing the individual effect of each factor on surface roughness from the various graph plotted above we find that surface roughness decreases on increasing moisture content and mould preheat temperature and decreasing pouring temperature, where as it first increases and then decrease as the mould hardness is changed from 70 to 80 and then 80 to 90.

From the average values of surface roughness and S/N ratio we can see that there is high change in response(surface roughness) with changes in mould preheat temperature while the rest control factors effect less.

One can also notice the that mould preheat temperature is the only and most significant factor to impart better surface finish hence keeping the other factors constant at resulted optimal level, studies can be conducted only changing preheat temperature

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