Optimization of Performance of Aluminum Dross Crusher by using Design of Experiments

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ABSTARCT

During the various steps of Aluminum and its alloy production huge amount of dross is floating on the liquid molten aluminum. Drossing is the formation of aluminum oxide and other oxides which accumulate on the melt surface. Recovery of aluminum from the dross is a challenging task. Aluminum dross crusher is used to accelerate the recovery rate of aluminum from its dross. In this paper, an attempt has been made to optimize the performance of aluminum dross crusher by optimizing certain parameters affecting the performance of aluminum dross crusher by design of experiments method such as Taguchi method. Selected process parameters are: blade profile of stirrer, speed of rotation and duration of rotation of shaft. The response variable is the recovery rate of Aluminum in %. L_9 orthogonal array is used for experimentation and ANOVA is performed by Minitab 16. The results indicates that the performance of dross crusher can be improved and optimized by getting the optimum settings of process parameters by using Taguchi optimization method.

Keywords- Aluminum dross, Dross crusher, Recovery rate, Design of experiments, Taguchi method.

I. INTRODUCTION

During re-melting, refining, and casting process of aluminum alloys and scraps, aluminum dross, primarily oxides and nitrides of aluminum and entrapped metallic aluminum is generated at the surface of the molten metal resulting from its uncontrolled reaction with the furnace atmosphere at elevated temperatures [1]. When the aluminum is maintained at molten state in a furnace for purpose such as casting, dross is formed at the surface of the molten bath. This dross or skim, which is periodically removed, may contain more than 50% of free aluminum metal in the form of very small droplets entrapped in aluminum oxide and other impurities [2]. Melting down with minimum dross formation occurs when the charge is protected from combustion products and melting is rapid [3]. Oxides of aluminum form quickly on the surface of the molten bath, making a thin, tenacious skin that prevents further oxidation as long as the surface is not disturbed [4].

Recycling of aluminum dross is one of the most challenging tasks in die casting processes since it is difficult to separate the oxides from metallic aluminum even at a high temperature. Oxidized metal must be removed from the melt. If it contains in the molten metal, the castings will contain harmful inclusions [5].

In a typical recovery process, the dross is normally melted at high temperatures in a furnace. However, at elevated temperatures, free metallic aluminum in the dross is easily susceptible to oxidation and, moreover, commonly tends to ignite and burn in the presence of air to emit toxic gases. The burning of the aluminum can decrease substantially the amount of aluminum recovered. The dross as a by-product not only brings huge waste, but also produces pollution to the environment. Also, due to high market demand for cost saving on die castings, the recovery of aluminum dross becomes critical for die casters. However, recovery rates of the dross are often unknown to die casting shops since most dross is presently recycled externally and aluminum content in the dross depends on the practice of molten metal processing.

II. ALUMINUM DROSS CRUSHER

So, in order accelerate the recovery rate of aluminum from aluminum dross, special purpose aluminum dross crusher has been fabricated in our earlier research paper and as shown in Fig. 1.

As it involved rapid rotary motion huge amount of heat from the high temperature molten aluminum dross is evolved into the atmosphere. Because of high temperature aluminum particles which were sticked to the dross will separate out. As the rotary motion progresses more quantity of aluminum particles will lose out from the dross. However, density of aluminum dross is lower than aluminum; we can easily separate out optimized amount of liquid aluminum.

Fig.1. shows the set up for aluminum dross crusher. The recovery rate of the recycled metal was determined based on weight measurements.

From the experiments and analysis it was found that, the recovery rate of aluminum from its dross by using aluminum dross crusher can be increased or accelerated by using optimum profile of the blades of stirrer, keeping optimum speed of rotation of shaft to which blades are attached and rotating the shaft for optimum duration.

Therefore, in this paper, an attempt has been made to optimize the performance of aluminum dross crusher by optimizing certain parameters affecting the performance of aluminum dross crusher by design of experiments method such as Taguchi method.

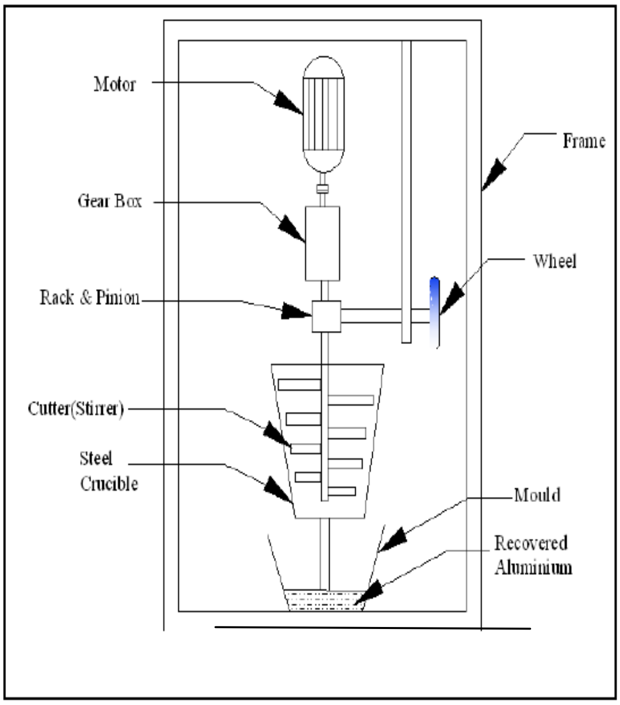


Fig. 1 Aluminum dross crusher [6]

III. EXPERIMENTAL WORK

3.1 Design of Experiments

3.1.1 Strategy of experimentation

There are several strategies of experimentation which have been used by the researchers. The most widely used strategies for experimental analysis include:

1. Best-guess approach

In this approach an arbitrary combination of factors is selected, then tested and its influence on output response is observed. If this initial 'best-guess' does not produce the desired results, the researchers take another 'guess' at the correct combination of factor levels. This could continue for a long time without guarantee of success. Secondly, suppose the initial 'best-guess' produces an acceptable result, the researcher is now tempted to stop testing although there is no guarantee that the best solution has been found.

2. One-factor-at-a-time

This approach consists of selecting a starting point or baseline set of levels for each factor, then successively varying a factor over its range with the other factors being held constant at a baseline level. After all tests are performed, a series of graphs usually are constructed showing how the response variable is affected by varying each factor with all other factors held constant. The interpretation of these graphs is straightforward and easy to select the optimal combination of factor levels. However, this strategy fails to consider any possible factor interactions. One-factor-at-a-time experiments are always less efficient than other methods based on a statistical approach to design.

3. Statistically designed experiments

A correct approach to dealing with several factors is to conduct a statistically designed experiment such as a factorial experiment. In such experimental strategy, factors are varied together instead of one at a time. Such experimental designs based on statistical approach enable the researcher to investigate the individual effects of each factor (or the main effects) and to determine whether the factors interact. To assess the effect of input parameters on output response variables, large numbers of experimental runs are required and therefore, is a time consuming task. Various design of experiment (DoE) methods are widely used to overcome this problem. The application of DoE requires careful planning, prudent layout of the experiment, and expert analysis of results [7].

Therefore, considering the above aspects, the experiments were designed using Taguchi method-based design of experiments methodology as elaborated below.

3.2 Taguchi Method-Based Design of Experiments

Among the available methods, Taguchi design is one of the most powerful design of experiments method for analysis of the process or system. It is widely recognized in many fields particularly in the development of new products and processes in quality control.

Taguchi methods have been used widely in engineering analysis to optimize performance characteristics by means of settings of design parameters. Taguchi method is also strong tool for the design of high quality systems. To optimize designs for quality, performance, and cost, Taguchi method presents a systematic approach that is simple and effective. Taguchi method was developed by Taguchi. It involves the stages of system design, parameters design, and tolerance design. System design involves the application of scientific and engineering knowledge required in manufacturing a product; parameter design is employed to find optimal process values for improving the quality characteristics; and tolerance design consists of determining and analyzing tolerances in the optimal settings recommended by parameter design.

By applying Taguchi method based on orthogonal arrays, the time and cost of experiments can be reduced. Here, Taguchi method employs a special design of orthogonal arrays to learn the whole parameter space with only a small number of experiments. Taguchi recommends the use of the

S/N ratio for the determination of the quality characteristics implemented in engineering design problems. The S/N ratio characteristics can be divided into three stages: smaller the better, nominal the best, and larger the better type.

In addition to the S/N ratio, a statistical analysis of variance

(ANOVA) can be employed to indicate the impact of process parameters on the response variable. In this way, the optimal levels of process parameters can be estimated.

The salient features of the method are as follows:

– A popular off-line quality control method aiming to reduce variability in a process and the number of experimental runs required to gather necessary data.

– A simple, efficient and systematic method to optimize product or process to improve the performance or reduce the cost.

– It helps to arrive at the best parameters for the optimal conditions with the least number of analytical investigations.

– It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities.

Therefore, the Taguchi method has great potential in the area of low cost experimentation. Thus it becomes an attractive and widely accepted tool to engineers and scientists [8].

3.3 Steps in Taguchi based Design of Experiments

Taguchi method - based design of experiments involved following steps:

3.3.1 Definition of the problem

The statement of the problem is "Optimization of Performance of Aluminum Dross Crusher by using Design of Experiments."

3.3.2 Selection of response variables

Response variable selected is the recovery rate of aluminum from its dross and calculated by using formula:

Recovery rate (%) = $\frac{Weight\ of\ recovered\ Aluminum}{Dross\ weight}$ X 100

The recovery rate of Aluminum in % is the "larger the better" type of quality characteristic.

3.3.4 Selection of process parameters and their levels

In the present study, three process parameters were identified which affects the performance of dross crusher in terms of recovery rate of aluminum from its dross. These parameters are as follows:

1. Profile of stirrer blades
2. Speed of rotation of shaft on which stirrer blades are fixed
3. Duration of rotation of shaft

Various process parameters and their identified levels are shown in Table 1.

Parameter designation	Process parameters	Level 1	Level 2	Level 3
A	Blade profile	Semi-circular	Rectan-gular	Truncated
B	Speed of rotation of stirrer (rpm)	40	55	70
C	Duration of rotation of shaft (minutes)	5	10	15

3.3.5 Selection of an orthogonal array

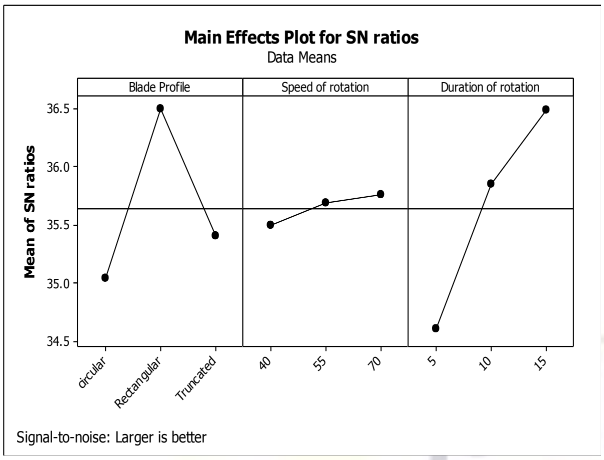
Table 1 Process parameters and their levels The number of levels for each control parameter defines the experimental region. We have three parameters at three different levels, from the table we has selected L_9 orthogonal array for the experimentation.

3.3.6 Conducting the matrix experiments

Nine experiments at different combinations of the levels of selected process parameters were performed and analysis of experimental results has been done as discussed below.

IV. ANALYSIS OF EXPERIMENTAL RESULTS

Average values of S/N ratios and means for each parameter at different levels and ANOVA for recovery rate of Aluminum in % including percent contribution at 95 % confidence limit are plotted with help of software Minitab 16 and shown in Fig. 2 and Table 2 respectively.



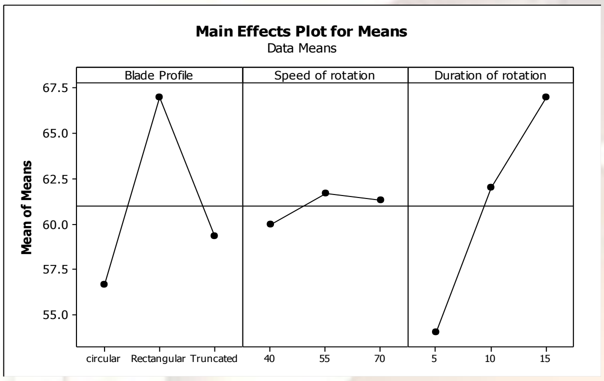


Fig. 2 Main effects plot for means and S/N ratio

For determining the recovery rate, the weight of aluminum dross has been kept constant such as 30 kg for each experiment of the selected orthogonal array. As their no exists the parameters interactions, so they are not considered for the analysis.

Table 2 ANOVA for recovery rate at 95 % confidence limit

Source	Degree of freedom	Sum of squares	Mean of squares	F ratio	P value	Percent contribution
A	2	172.67	86.33	4.25	0.191	36.27 %
B	2	4.67	2.33	0.11	0.897	---
C	2	258.00	129.00	6.34	0.136	54.20 %
Error	2	40.67	20.33			
Total	8	476.00				
	S = 4.50925 R-Sq = 91.03% R-Sq(adj) = 75.85%					

It is clear from Fig. 2 that the recovery rate of aluminum from its dross is maximum at the second level of parameter A (A2), the third level of parameter B (B3), the third level of parameter C (C3).

From the ANOVA table (refer Table 2) it can be concluded that, out of the three parameters considered, parameters A (blade profile) and C (duration of rotation of stirrer) are significant parameters which affects the response variable because % contribution of these parameters is more and parameter B (speed of rotation) is insignificant in determining the recovery rate of aluminum from its dross.

Confirmation Experiments

Three confirmation experiments were performed at the optimized settings of the process parameters, results of which are shown in Table 3. Prior to the application of Taguchi method, the recovery rate of aluminum form its dross was maximum of 60 % which is now increased upto 75 %.

Table 3 Results of confirmation experiments

Expt. No.	Recovery rate (%)
1	73
2	75
3	77
Avg. recovery rate : 75 %	

V. RESULTS AND CONCLUSIONS

In this paper, an attempt is made to improve and optimize the performance of aluminum dross crusher in concern with the recovery rate of aluminum from its dross by using design of experiments method such as Taguchi method.

The optimized levels of selected process parameters obtained by Taguchi method are: blade profile of stirrer (A): rectangular, speed of rotation (B): 70 rpm and duration of rotation (C): 15 minutes.

From these three parameters, the significant parameters are; blade profile of stirrer (A) and duration of rotation (C) at 95 % confidence level. As speed of rotation is insignificant in determining the recovery rate, so, it's any level between the specified range can be selected.

With Taguchi optimization method, the recovery rate in % of aluminum from its dross can be increased from 60 % of existing to maximum of 75 % with the optimized levels of the selected process parameters.

From the analysis, it is 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.

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