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Taguchi Based Parameter Optimization of CO_2 Core Process for Maximum Core Hardness

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Abstract: Adoption of greener engineering processes like sand reclamation reduce the consumption of natural resources and pollution, thereby certainly improve the environment. The wet reclamation process consists of soaking, washing, solar drying and sieving of used core sand is studied in the paper. In this paper the Design Of Experiments (DOE) techniques is used to analyze the specimen core of sodium silicate binder with CO_2 gas. Four process parameters like % of Sodium Silicate, Mixing Time, CO_2 Gassing Time, % of Coal Dust are considered. Taguchi based L8 orthogonal array was used for the experiment purpose and analysis was carried out with the help of Minitab software for analysis of mean plot & Main Effects plot for signal to noise ratio.

Key words: Used Foundry Core Sand · Taguchi Design

INTRODUCTION

Foundry industries are also known as hazardous and polluting industries since they generate large amount of solid wastes, toxic effluents, flue gases, thermal emissions and noise. Sand is the basic melding material used in the foundry. Huge requirements of melding sand in foundries world over focused the attention of foundry men on effective utilization of melding sand. Figure 1 shows the usages of used foundry core sand.

Reclamation is a Process of removing the adhesive binder coatings from sand grains. After Sand used core sand regains its original condition and can be reused again and again, with minimum addition of new sand. Sand reclamation is the physical, chemical or thermal treatment of used core sands so that they can be safely re-used in place of new sand in melding and core making mixes. Green foundry adopt environment- friendly technology like reduction in energy consumption in the process, consumption of less fossil fuel or electricity with minimum emissions and usage of natural resources efficiently by recycling and reusing of waste. The basic reasons for reclaiming used sand are:

- Economical, as all the foundries wanted to reduce the total sand cost which includes purchase cost, freight cost and disposal costs.
- Environmental, as it is difficult to dispose of great quantities of used material into the ground.
- Technical, as reclaimed sand is in such a state as to be suitable for reuse with any binder system with no defects on the castings.

Every reclamation system has 5 basic steps:

- Shake out – Separating the casting from the meld and/or sand from the flask.
- Crushing or lump reduction – Attrition or reduction of material by rubbing action.
- Cooling
- Scrubbing
- Classification – sand screen analysis

Need for Reclamation:

- The increased cost of core sand [3]
- Dumping of the used core sand causes environmental pollution [3]
- The disposal of waste foundry sand has become one of the most pressing problems for the foundry due to environmental regulations.
- Used core sand dumping in valleys, rivers and lakes caused the water and soil , even the ground water pollution due to the presence of the dissoluble sodium silicate and ester in the used core sand, [4, 5]

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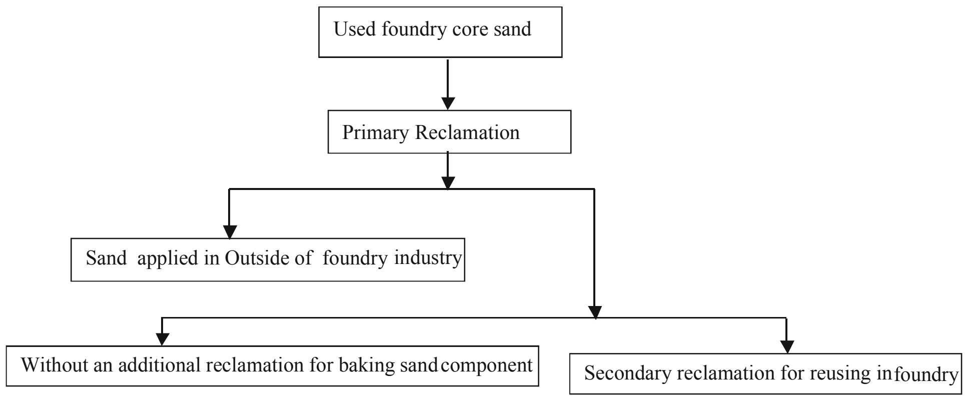


Fig. 1: Usage of used foundry core sand [1, 2]

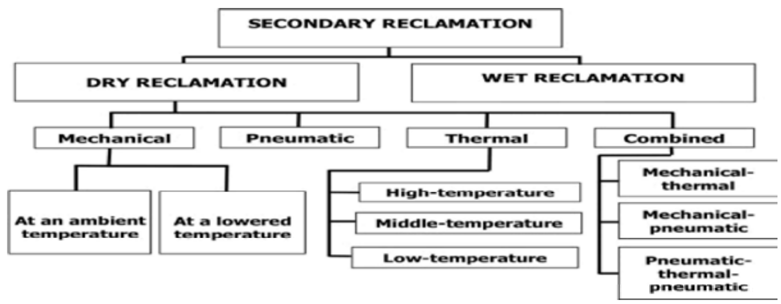


Fig. 2: Secondary Reclamation [7, 8]

Types of Reclamation Process: There are two types of foundry sand reclamation as shown in the Figure 2.

- Dry Reclamation
- Wet Reclamation [6]

The type of reclamation adopted for a specific core sand depends on the type of binder coating that is adhered to the sand.

Taguchi Method: Taguchi approach is suitable in using experimental design for

- Designing & developing products/processes so as to be robust to component variation.
- Designing products/processes so as to be robust to environmental conditions and
- Minimizing variation around a target value.

Conventional full factorial experimentation causes lot of time and money to arrive at optimum process parameter values [9]. Design of experiments is highly useful in planning the experiments systematically and also helps in drawing a meaningful conclusion [10].

MATERIALS AND METHODS

The following are the steps in this research.

- Deciding the process parameters and fixing their levels for conducting the experiments
- Deciding experimental design matrix

The factors and their levels were decided based on the discussion with the experts working in the foundry. Has *et al*. [11] have optimized the process parameters of CO_2 casting process such as weight of CO_2 gas, mould hardness, sand particle size and percentage of sodium silicate, sand mixing time, pouring time, pouring height, pouring temperature and cooling time of poured metal using design of experiments method such as Taguchi Method. Dr. K.H. Inamdar [12] have optimized casting process parameters of mould hardness, moisture content (%), permeability number and Green compression strength (gm/cm^2) using Taguchi method. Sushi Kumar *et al*. [13] have applied design of experiments such as Taguchi method for optimization of the process parameters such as moisture content, pouring temperature, green compression strength, mould hardness vertical and horizontal.

This research conducted experiments with 4 parameters namely, % of sodium silicate, mixing time, gassing time and Percentage of Coal Dust. This silica gel combination of CO_2 and Sodium Silicate is used to interfacial bond between sand grains. Generally 4% to 6% sodium silicate as a weight of sand is used [14, 15].

Specifications of sodium silicate binder;

(I)Water soluble alkali as Na $_2$O =12%
(II)Water soluble Silicates as SiO_2=28%
(III)Modulus ratio of SiO2: Na $_2$O=2.2
(IV)Invert sugar=5%
(V)Total Solid content=45%
(VI)Specific gravity =1.55 gm/cc

Mixing Time is Silica sand along with additives , if any, is to be dry mixed in a sand mixer for about one minute and then mixing is to be continued by adding required quantity of sodium silicate. Mixing ensures uniform coating of sodium silicate binder over sand grains, which in turn affect bond strength during curing with CO_2 gas. If mixing time is too low sodium silicate will not be mixed properly. Too long mixing times i.e. over mixing make the sand dry and the bond strength development during curing process is improper and hence affects mould characteristics .Generally 5 to 10 minutes of mixing time is employed on the shop floor. In this experiment three levels of mixing time i.e. 5 minutes and 10 minutes are considered. Gassing Time is an estimation of chemical requirement of CO_2 gas to react with Na_2O is 10 kg for 100kg of sodium silicate [14]. In practical, 40 kg of CO_2 gas per 100kg of sodium silicate are used. So in this work two levels of CO_2 gas i.e. 10kg/100 kg of sodium silicate and 40 /100kg of sodium silicate are used. For the preparation of AFS standard sand sample of 2 inch X 2 inch the above two levels of CO_2 gas are appropriately converted in to gassing time by maintaining uniform flow rate of CO_2 gas with the help of a specially made arrangement shown in Figure 3.The two levels of gassing time observed are 13 seconds and 30 seconds. To improve the knockout properties coal dust is added to sand mix [14] because of poor collapsibility in CO_2 Mould. Generally up to 2% of coal dust is added. Two levels of coal dust i.e. 1% and 2% are considered in this work.

Deciding Experimental Model

In this work --------4---------- factors are considered at ------2--------levels.

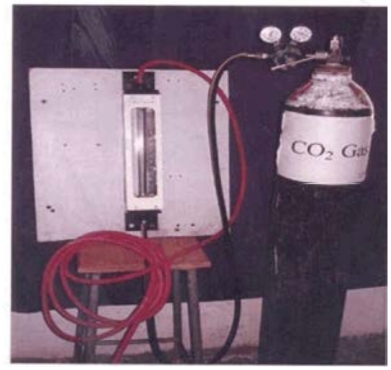


Fig. 3: Photograph of CO_2 gassing arrangement (Courtesy M. Venkata Ramana [16])

Table 1: Process Parameters and levels

Factors	Level 1	Level 2
% of Sodium Silicate	4%	6%
Mixing time (Min) (MT)	5	10
CO_2 Gassing time (sec)	13	30
% of Coal Dust (CD)	1%	2%

The number of experiments to be conducted for three factors and three levels under full-factorial testing is 16. Any process will give the best possible output when all of the factors operate at the optimum level. If 'm' factors are selected with 'n' levels, the total number of experiments to be conducted is 'n^m'. If the total number of factors and levels involved is greater, the number of experiments to be conducted becomes very large. Taguchi suggested the use of an orthogonal array (OA), which is the basis for conducting 'fractional factorial' experiments. The most suitable orthogonal array for experimentation is L8 array as shown in Table 2.

AFS standard specimen of 2 inch x 2 inch cylindrical shape are prepared as per Table 2.

Core hardness values are determined using scratch hardness tester.

Fig. 4: AFS standard sand specimen

Table 2: L8 Orthogonal Array

	%of SS	MT min	SS x MT	GT Sec	CD	SS X GT	Un used Column
1	1	1	1	1	1	1	
2	1	1	1	2	2	2	
3	1	2	2	1	2	2	
4	1	2	2	2	1	1	
5	2	1	2	1	2	1	
6	2	1	2	2	1	2	
7	2	2	1	1	1	2	
8	2	2	1	2	2	1	

Table 3: Experimental Values of Mould Hardness

	Mould Hardness (Scratch Hardness No)				
Experiment Trial No	a	b	c	Average Value	S/N ratio
1	74	73	72	73	37.26
2	65	64	67	65.33	36.29
3	73	70	70	71	37.02
4	71	73	74	72.66	37.22
5	81	80	79	80	38.06
6	77	78	80	78.33	37.87
7	82	81	79	80.66	38.13
8	76	78	77	77	37.72

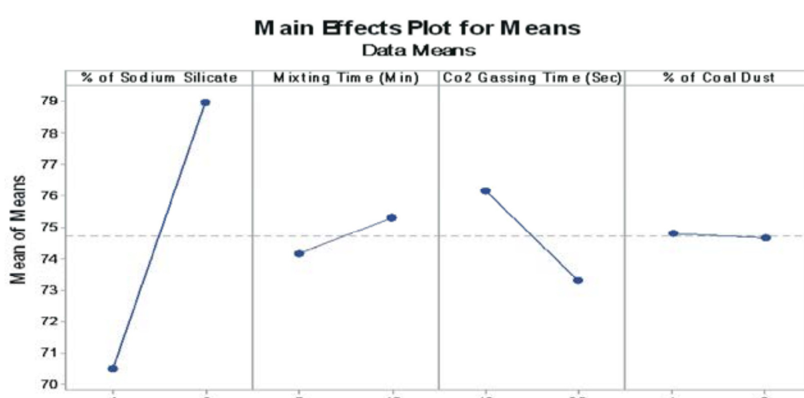
Quality Characteristic for core hardness is " Bigger the better type"
S/N ratio = -10 log (MSD)
where MSD = mean square deviation

MSD = [(1/y12 + 1/y22 + 1/y32 + ...]/n

Taguchi Analysis: Mould Hardness Versus % of Sodium Silicate, Mixting Time, CO_2 Gassing Time and % of Coal Dust Response Table for Means.

Co2
Mixing Gassing

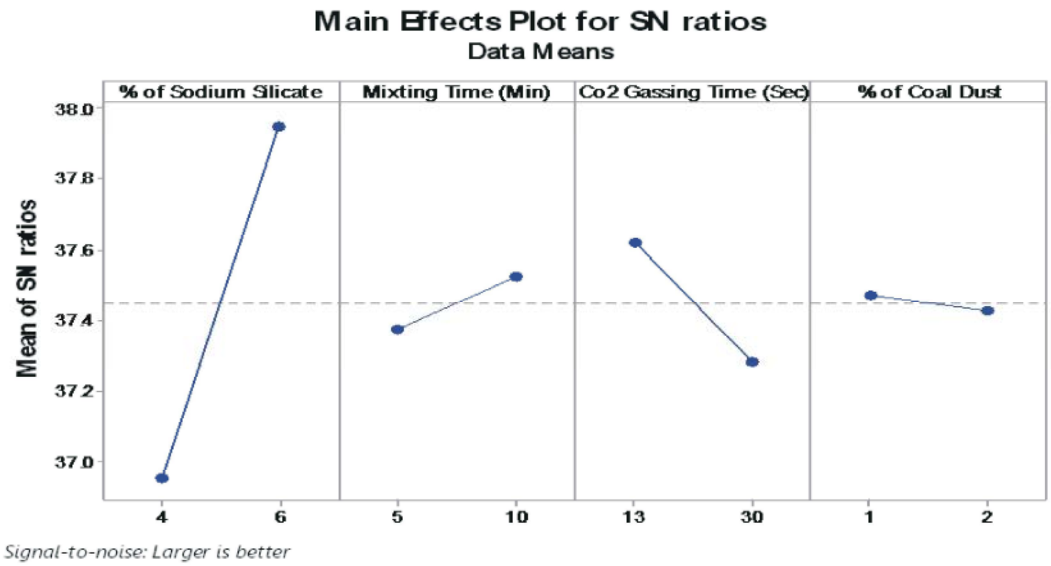
	% of Sodium	Time	Time	% of Coal
Level	Silicate	(Min)	(Sec)	Dust
1	70.50	74.17	76.17	74.83
2	79.00	75.33	73.33	74.67
Delta	8.50	1.17	2.83	0.17
Rank	1	3	2	4



Response Table for Signal to Noise Ratios
Larger is better

Co2
Mixting Gassing

	% of Sodium	Time	Time	% of Coal
Level	Silicate	(Min)	(Sec)	Dust
1	36.95	37.37	37.62	37.47
2	37.95	37.53	37.28	37.43
Delta	1.00	0.15	0.34	0.04
Rank	1	3	2	4



CONCLUSIONS

- Taguchi's method of optimization is simple and effective in terms of time and cost of overall manufacturing operation performed. It improves the overall quality of product and helps in development at all stages of product life cycle starting from design to finishing of product.

- The analysis proves that by improving the quality of Taguchi's Method of parameter design at lowest possible cast, it is possible to identify the optimum level of signal factors at which the noise factor effect on the response parameter is less.
- The result of this research is the optimized process parameters of % of Sodium Silicate, Mixing Time, CO_2 gas mixing time. Optimum values of Process Parameters are

% of Sodium Silicate	: 6 %;
Mixing Time	: 10 Minutes;
Quantity of CO_2 gas (gassing time)	: 13 Seconds.
% of Coal Dust	: 1 %

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