A Study on Wet Reclamation To Reduce Environmental Pollution in Foundry Industry

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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 this paper, the design of experiments (DOE) technique is used for experimentation of the specimen core of sodium silicate binder with CO_2 gas. Taguchi based L27 orthogonal array is used for the experiment purpose and analysis is carried out with the help of Minitab software for Analysis of variance (ANOVA) and analysis of mean plot.

This paper introduces a Green Manufacturing in foundry. A number of initiatives are being taken by companies in India in the areas of regulation and reduction of green house gases, discharge of pollutants and emissions, hazardous waste management, and energy conservation to pave the way for a cleaner and greener environment for sustainable development. Manufacturers are able to save costs on the final product by reducing energy and materials wastes.

The process parameters selected are: % of Sodium Silicate, % of coal dust, Sand Particle Size (No), Mixing Time (Mins), Weight of CO_2 Gas (sec) and Cooling time of poured metal (Mins). A confirmation run is used to verify the result, which indicated that this method is more efficient in determining the best casting parameters.

Key words: Used Core Sand, Wet Reclamation, Taguchi Design, Green Manufacturing

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List of Abbreviations :

DOE – Design of Experiments

OA – Orthogonal Array

S/N – Signal to Noise

ANOVA – Analysis of Variance

DOF – Degree of Freedom

SS – Sum of Square

MSS – Mean Sum of Square

P – Percent Contribution

CI –Confidence Interval

1. INTRODUCTION

Globalisation impacts and its associated demands in competitive environment have created a need for managers in manufacturing sectors to take decisive actions, responsive to environmental changes, and implement strategies that continually improve quality, capability and process efficiency. The efficiency in continually improving the quality of products and its processes could be seen in term of cost reduction, improvement of customer satisfaction as well as minimize the environmental impacts.

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Green Manufacturing is generically defined as elimination of waste by redefining the existing production process or system. Companies take their problem solving approach to the next level and develop innovative techniques towards effective solutions. Such solutions result in cost savings from reduced work handling, effluent control, process automation, etc. All these efforts are applications of green manufacturing.

Green Manufacturing addresses process redundancy, ergonomics and cost implications due to faulty methods of producing goods. Faster and cheaper are no longer the only two criteria in manufacturing a product or evaluating an existing process line. Several other factors such as materials used in manufacturing, generation of waste, effluents and their treatment (or possible elimination), life of the product and finally treatment of the product after its useful life are all important considerations.

Green Manufacturing organizations manufacturing products using materials and processes that minimize negative environmental impact, help in the reduction of green house gases (GHGs), conserve energy and natural resources, improve safety for consumers, communities and employees and at the same time increase profitability of their organizations as a whole.

One key principle of Lean production is the reduction of wasted materials and labor in a continuously improving culture. Lean companies naturally tend to be Green. Lean manufacturers were transcending to a more Green state as a result of their commitment to Lean production. Variables in the study were numerous, including measures of Green Management System, Green Waste Reducing Techniques, and Green Results as first defined by Melnyk, et al. This makes a very powerful statement that Lean companies are embracing Green objectives and suggests that Lean manufacturers are transcending to Green manufacturing as a natural extension of their culture of continuous waste reduction, integral to world class Lean programs.

The Taguchi method is powerful problem solving technique for improving the quality of the product and also productivity. A large number of experimental investigations linking green sand casting parameters with casting quality have been carried out by researchers and foundry engineers over the past few decades.

This paper summarizes the following:

i) Improving quality of green sand casting through process control. Keeping the effects of uncontrolled parameters at a minimum level.
ii) Analysis and select the most significant parameters that affect quality characteristics.
iii) Select an appropriate orthogonal array and suitable levels of parameters.
iv) Analysis the data using Minitab and generate interaction graphs and response graphs.
v) Decide on the optimal settings for the control parameters.
vi) Validate the optimum setting levels in reducing the levels of the Quality Characteristics (Casting Defects) .

Foundry industry is a mother industry for all the other engineering and automotive industries.

The Indian foundry industry producing 10 million tonnes of castings annually and ranked 3rd in the world. Foundry industries are also known as hazardous and polluting industries since

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they generate large amount of solid wastes, toxic effluents, flue gases, thermal emissions and noise. Sand is the basic molding material used in the foundry. Huge requirements of molding sand in foundries world over focused the attention of foundry men on effective utilization of molding sand. Figure 1 Shows the usages of used foundry core sand.

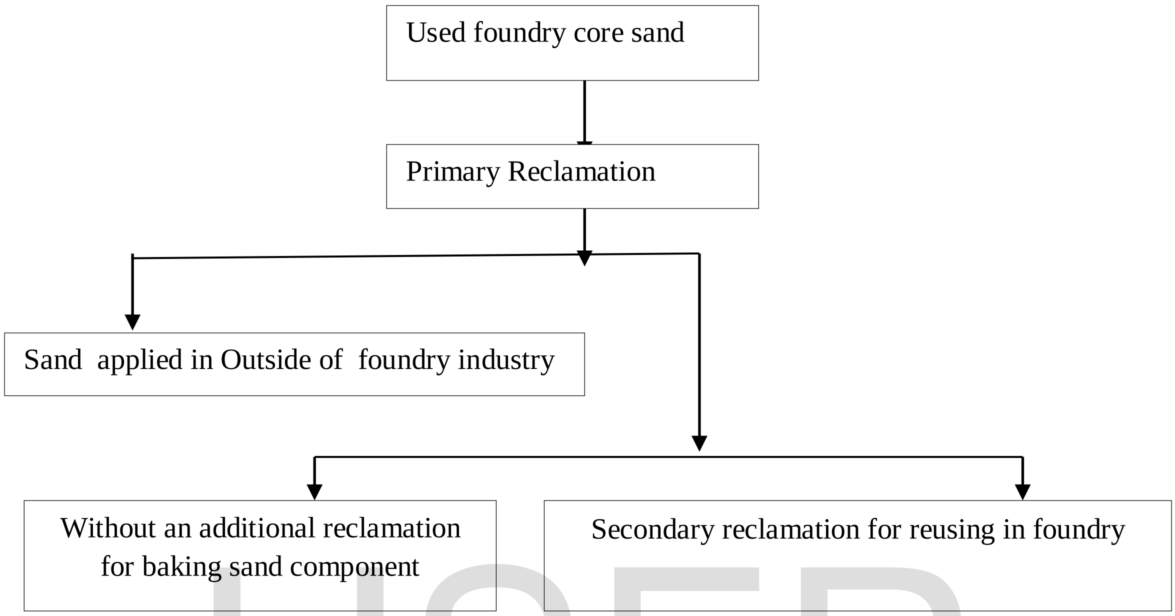

Figure 1 : Usage of used foundry core sand [1,2]

PROBLEM OVERVIEW

Green Sand :

Green Sands are produced by binding silica sand with clay (bentonite), coal dust or substitutes and water. They are normally used in re-circulating systems and can therefore also contain burnt fines, coke residues and residual clays (both active and 'dead').

Definition of AFS Division – Committee for sand reclamation," Sand Reclamation is the physical, chemical or thermal treatment of refractory aggregate to allow its reuse without significantly lowering its original useful properties as required for the application on hand". Sand Reclamation aims at restoring original screen analysis, removing accumulated coatings of binders , and removing excess fines, dust and other impurities. For good quality castings, it is necessary to retain physical properties, chemical characteristics and thermal properties.

After Sand reclamation 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 molding 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. Sand recycling has been done by several units and waste sand is being used constructively for manufacturing bricks by adding cement etc.

The incentive for sand reclamation in the foundry industry is growing due to a number of reason :

- 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.
- Sand is a crucial raw material for the foundry industry. But after repeated use, it becomes unfit for reuse at the foundries. This sand however, can be put to alternative use by other industries.
- The foundry industry needed to find solution to sand dumping.

Every reclamation system has 5 basic steps:

1. Shake out – Separating the casting from the mold and/or sand from the flask.
2. Crushing or lump reduction – Attrition or reduction of material by rubbing action.
3. Cooling
4. Scrubbing
5. Classification – sand screen analysis

Need for reclamation:

- Lack of sand availability is a constraint for foundries.
- 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 dissoluable sodium silicate and ester in the used core sand.

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Major Challenges in Foundry Industries:

1. Skilled Manpower.
2. Good quality power at competitive rates.
3. Sand availability due to mining and environment issues.
4. Slowdown in demand.

Advantages of sand reclamation unit:

1. Reduction of waste disposal costs, decline of waste amount.
2. Considerable reduction of new sand amount.
3. Less transport cost.
4. High plant reliability.

2. Literature review

Literature review on Green Manufacturing:

Congbo et al.(2010) described Green manufacturing (GM) is a kind of modern manufacturing mode with the full consideration of resources consumption and environmental impact.

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Ahmed.M.Deif et al.(2011), developed a system model for green manufacturing based on Green Stream Mapping and Impact Analysis through questionnaire Green Culture assessment is done. Improvement plans are suggested. The model which can capture various planning activities to migrate from a less green for the new green manufacturing paradigm into a greener and more eco-efficient manufacturing.

Madhuri Srinivas et al. (2011) listed a number of Green initiatives are being taken by Indian companies in the large scale and the small and medium scale sector in the areas of regulation and reduction of greenhouse gases, discharge of pollutants and emissions, hazardous waste management, and energy conservation to pave the way for a cleaner and greener environment for sustainable development.

R. Masike,M.J.Chimbadzwa (2013) developed a model for Cleaner Production options which enable the efficient use of resources and improve the environmental performance of foundry companies.

Kannan Govindan et al (2014) analyzed the drivers of green manufacturing from various literatures , industrial managers and expert opinions and to analyze them with fuzzy Multi Criteria Decision Making (MCDM) tool Analytic Hierarchy Process (AHP) approach to validate the results.

Suresh Prasad and S.K.Sharma (2014) integrated two strategies, namely lean and green manufacturing and offered simultaneously in the operation management to reduce both waste and pollution.

Literature review on Reclamation:

J. Danko et al. (2010) described the main use of wet reclamation has been for sodium silicate bonded sands, where the whole of the binder residues can be effectively removed.

Silvia Fiore et al. (2010) says that the efficiency of a wet treatment process for the reclamation of waste sands coming out from different foundries and moulding procedures was evaluated.

Fan Zitian et al. (2014) says that the waste resin bonded sand was first reclaimed by a thermal method and the waste clay bonded sand was reclaimed by a wet method. The optimized wet reclamation process of the waste clay bonded sand was achieved by investigating the effects of wet reclamation times, sand- water ratio and pH value on the residual sand characteristics. Composite reclaimed sand from wet-thermal reclamation could replace new sand to make cores or moulds.

M. Venkata Ramana (2015) described need of sand reclamation because of the increased cost of core sand and Dumping of the used core sand causes environmental pollution.

M.VenkataRamana (2015) developed a 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.

Literature review on Taguchi Method:

Sushil Kumar et al.(2011) says that the quality can be improved by Taguchi's method of parameter such as moisture content, pouring temperature, green compression strength, mould hardness vertical and horizontal. Design at the lowest possible cost and also optimize the process parameters of the green sand castings process which lead to minimized casting defects.

Kumarvadivel et al. (2013) analyzed a various critical process parameters and the interaction among them is carried out with the help of Taguchi method of experimental design. Using the response surface methodology to complement the results obtained by the Taguchi approach, a significant reduction in casting defects is obtained, and it has been validated and confirmed by PWA.

Rajesh Rajkolhe, J.G. Khan (2014) identify a blowhole and sand drop are a kind of defect occurring in casting. Sand particle size, mould hardness, green compression strength and permeability are more significant factors. The identified factors were analyzed using 'Design of Experiments' approach. 'Signal –to –Noise' ratio was estimated.

Prasan Kinagi, Dr.R.G. Mench(2014) developed a Design of experiments and FMEA techniques are combined to analyze casting defects like cold shut and blow hole.

Dr.K.H.Inamdar (2014) optimized casting process parameters of mould hardness, moisture content (%), permeability number and Green compression strength (gm/cm^2) using Taguchi method.

Saravan kumar et al. (2015) analyzed the suitable process parameters in casting industry to produce defect free casting.

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Methodology

The following are the steps in this research.

Deciding the process parameters and fixing their levels for conducting the experiments

↓

Deciding experimental design matrix

↓

ANOVA Analysis

↓

Confirmation experiments to validate the obtained optimum condition

3. Foundry Production process

The major steps of process are mould sand preparation, charge preparation followed by melting, pouring, knockout and finishing. The steps are explained below.

1. **Mould sand preparation**. Fresh sand is mixed with bentonite and other additives and mixed in muller to make green sand.

2. **Moulding.** The mould sand is pressed by machines or manually on the pattern to make the mould. Then the upper and lower halves of mould are assembled together to prepare the complete mould.

3. **Charging.** The charged metallic such as pig iron, scrap, foundry returns and other alloys are weighted and charged in the furnace for melting.

4. **Melting.** The metal charge is melted in either a cupola or induction furnace.

5. Pouring. After melting, the molten metal is transferred and poured into the moulds using ladles operated either manually or with cranes.

6.Knock-out. The moulds are left to cool for certain time after which the castings are knocked-out from the mould either manually or using a machine.

7.Finishing. The finishing operation which involves removal of runners/ risers, shot blasting and cleaning of castings.

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Figure 2: Foundry flow chart

(ii) Moulding and core preparation

Preparation of the mould is an important process in casting industry. The mould is divided into two halves - the cope (upper half) and the drag (bottom half), which meet along a parting line. Both mould halves are contained inside a box, called a flask, which itself is divided along this parting line. The mould cavity is formed by packing sand around the pattern (which is a replica of the external shape of the casting) in each half of the flask. The sand can be packed manually, but moulding machines that use pressure or impact to pack the sand are commonly used. Cores are placed inside the moulds to create void spaces.Cores are baked in ovens which are usually electrical fired.

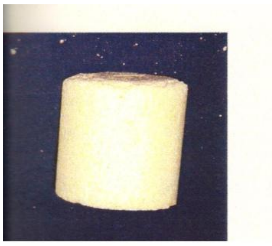

Figure 3 : AFS standard sand specimen (2 inch X 2 inch)

(iii) Sand preparation

Some foundries have installed a sand plant for sand preparation. The sand plant consists of sand muller, sand mixer, conveyor s, bucket elevators, knockout and sand sieve. Electricity is used to run these machines. Sand mixers have typical batch size of 200 to 1000 kg. The connected load of these mixers is in the range of 10 to 100 kW.

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Figure 4: Sand Preparation

3.1 Types of Reclamation

There are two types of foundry sand reclamation

i) Dry Reclamation

ii) Wet Reclamation

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

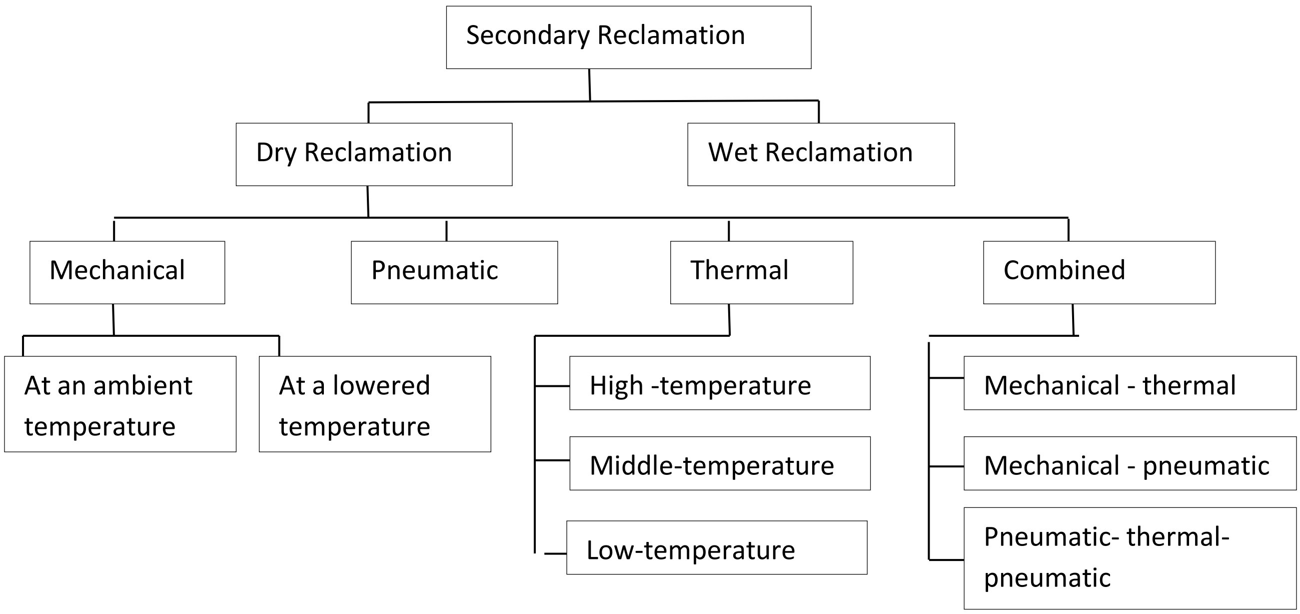
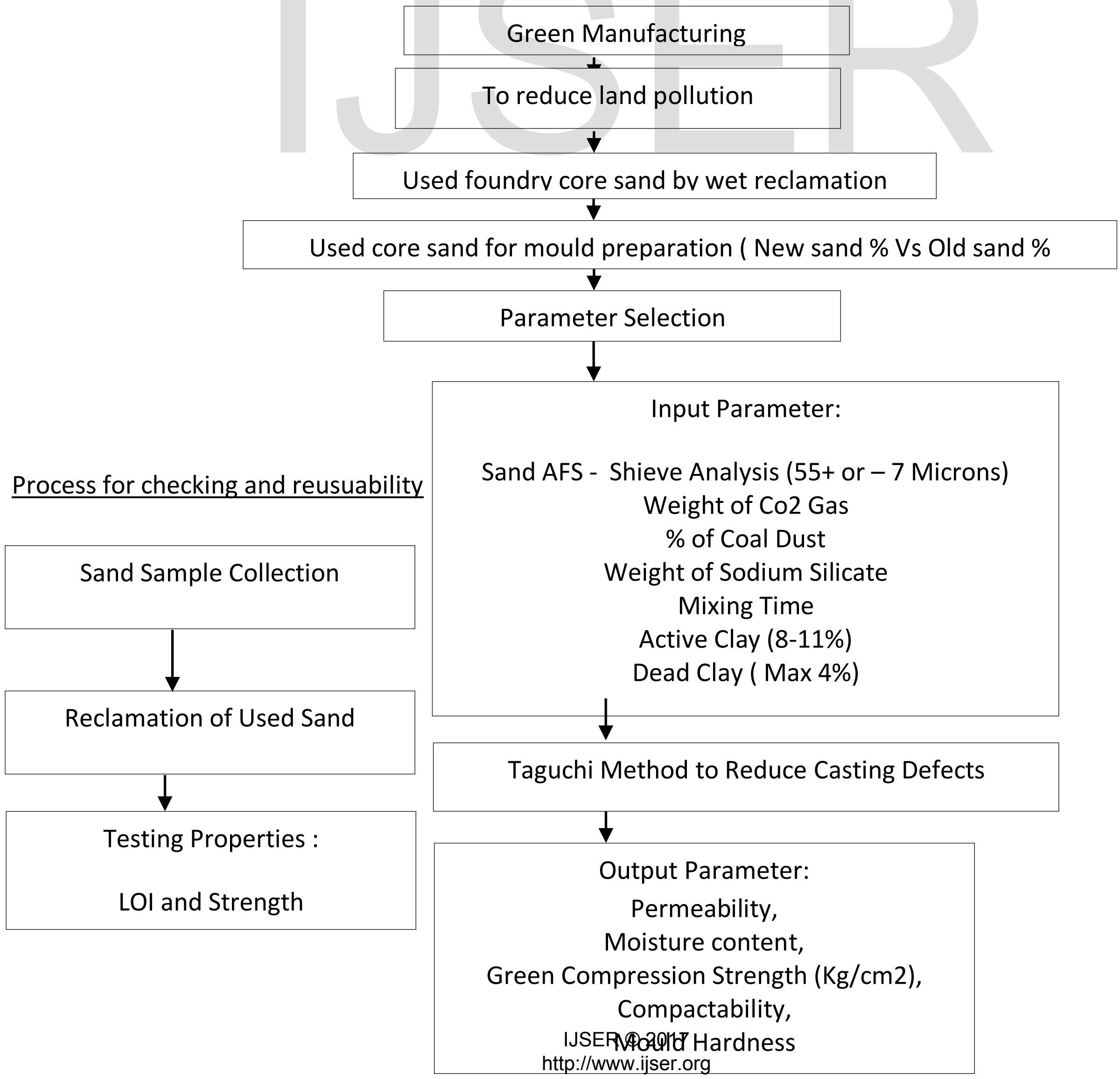


Figure 5: Types of Reclamation Process

Used Foundry Core Sand Wet Reclamation Flow Chart



Selection of Input Parameters :

The following factors are consider in this reclamation techniques.

Table 1: Selection of Input Parameters

S.N	Parameters	Range	Level 1	Level 2	Level 3
1	% of Sodium Silicate	4-6%	4	5	6
2	Sand Particle Size (No)	50 -60	50	55	60
3	Mixing Time (Mins)	5-10	5	7.5	10
4	Weight of CO_2 Gas (sec)	13-30	13	22	30
5	Cooling time of poured metal (Mins)	45-60	45	52.5	60
6	% of coal dust	0-2%	0	1	2

Selection of Output Parameters :

Table 2: Selection of Output Parameters

S.No	Parameter	Range
1	Green Compression Strength (g/cm2)	1000-1200
2	Moisture content (%)	3-4
3	Permeability Number	140-190
4	Mould Hardness	85-95
5	Compactability	

Table 3 : Orthogonal array setting

Experiment No	% defects in experiment			Average
	Trial 1	Trial 2	Trial 3	
1	6.345	6.190	6.200	6.245
2	6.297	6.277	6.227	6.267
3	6.864	6.584	6.844	6.764
4	6.356	6.426	6.586	6.456
5	6.685	7.074	6.869	6.876
6	6.475	5.255	7.305	6.345

7	7.887	8.226	7.848	7.987
8	5.925	6.325	6.725	6.325
9	6.460	6.244	6.334	6.346
10	7.536	7.753	7.670	7.653
11	7.924	7.994	8.034	7.984
12	6.690	6.736	6.863	6.763
13	8.260	7.252	8.356	7.956
14	7.232	7.210	7.251	7.231
15	7.750	7.600	7.675	7.675
16	7.604	7.294	8.964	7.954
17	8.260	7.438	7.780	7.826
18	7.160	7.180	7.164	7.168
19	6.145	6.440	6.450	6.345
20	7.206	7.232	7.600	7.346
21	6.570	7.320	7.110	7.000
22	6.656	7.056	7.156	6.956
23	7.850	7.460	7.952	7.754
24	7.200	7.320	8.940	7.820
25	7.574	7.967	7.750	7.764
26	7.245	6.840	6.750	6.945
27	8.756	7.756	6.756	7.756

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Table 4 : L 27 Orthogonal Array

% of sodium silicate	Sand Particle Size	Mixing Time	Weight of Co2 Gas	Cooling time	%of coal dust
1	1	1	1	1	1
1	1	1	1	2	2
1	1	1	1	3	3
1	2	2	2	1	1
1	2	2	2	2	2
1	2	2	2	3	3

1	3	3	3	1	1
1	3	3	3	2	2
1	3	3	3	3	3
2	1	2	3	1	2
2	1	2	3	2	3
2	1	2	3	3	1
2	2	3	1	1	2
2	2	3	1	2	3
2	2	3	1	3	1
2	3	1	2	1	2
2	3	1	2	2	3
2	3	1	2	3	1
3	1	3	2	1	3
3	1	3	2	2	1
3	1	3	2	3	2
3	2	1	3	1	3
3	2	1	3	2	1
3	2	1	3	3	2
3	3	2	1	1	3
3	3	2	1	2	1
3	3	2	1	3	2

4. Results and Discussion

Table 5 : Minitab worksheet

% of sodium silicate	Sand Particle Size	Mixing Time	Weight of Co2 Gas	Cooling time	%of coal dust	Trial 1	Trial 2	Trial 3	% of rejection Mean	S/N Ratio
1	1	1	1	1	1	6.345	6.190	6.200	6.245	-15.9106
1	1	1	1	2	2	6.297	6.277	6.227	6.267	-15.9412
1	1	1	1	3	3	6.864	6.584	6.844	6.764	-16.6041
1	2	2	2	1	1	6.356	6.426	6.586	6.456	-16.1993
1	2	2	2	2	2	6.685	7.074	6.869	6.876	-16.7467
1	2	2	2	3	3	6.475	5.255	7.305	6.345	-16.0486
1	3	3	3	1	1	7.887	8.226	7.848	7.987	-18.0477

1	3	3	3	2	2	5.925	6.325	6.725	6.325	-16.0212
1	3	3	3	3	3	6.460	6.244	6.334	6.346	-16.05
2	1	2	3	1	2	7.536	7.753	7.670	7.653	-17.6766
2	1	2	3	2	3	7.924	7.994	8.034	7.984	-18.0444
2	1	2	3	3	1	6.690	6.736	6.863	6.763	-16.6028
2	2	3	1	1	2	8.260	7.252	8.356	7.956	-18.0139
2	2	3	1	2	3	7.232	7.210	7.251	7.231	-17.184
2	2	3	1	3	1	7.750	7.600	7.675	7.675	-17.7016
2	3	1	2	1	2	7.604	7.294	8.964	7.954	-18.0117
2	3	1	2	2	3	8.260	7.438	7.780	7.826	-17.8708
2	3	1	2	3	1	7.160	7.180	7.164	7.168	-17.108
3	1	3	2	1	3	6.145	6.440	6.450	6.345	-16.0486
3	1	3	2	2	1	7.206	7.232	7.600	7.346	-17.321
3	1	3	2	3	2	6.570	7.320	7.110	7.000	-16.902
3	2	1	3	1	3	6.656	7.056	7.156	6.956	-16.8472
3	2	1	3	2	1	7.850	7.460	7.952	7.754	-17.7905
3	2	1	3	3	2	7.200	7.320	8.940	7.820	-17.8641
3	3	2	1	1	3	7.574	7.967	7.750	7.764	-17.8017
3	3	2	1	2	1	7.245	6.840	6.750	6.945	-16.8334
3	3	2	1	3	2	8.756	7.756	6.756	7.756	-17.7928

- For example, for trial no. 1 , the
- S/N ratio is : = -10 log [($\sum y^2_i$)/n]
- S/N ratio = - 10 log [($6.345^2+6.190^2+6.6^2$)/3]

= - 10 log [(117.01)/3]

=-10 log 39

= -15.91

ANOVA analysis:

Analysis of variance (ANOVA) is an analytical method to square the dispersion of specific number. ANOVA is widely used for determination of percentage contribution.

Table 6 : ANOVA Table for StDevs (From General Linear Model)

Factor	Degree of Freedom (DOF)	Adj. Sum of Square (SS)	Adj. Mean Sum of Square (MSS)	F ratio	Percentage of Contribution of Factor (P)
% of Sodium silicate	2	4.3414	2.17072	6.61	74.10
Sand particle size	2	0.8157	0.40786	1.24	13.90

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Mixing Time	2	0.0166	0.00832	0.03	0.33
Weight of Co2 gas	2	0.2885	0.14423	0.44	4.93
Cooling Time of poured metal	2	0.1571	0.07853	0.24	2.69
% of Coal dust	2	0.2370	0.11850	0.36	4.05
Error	14	4.5964	0.32831		
Total	26	10.452			100

3.3 Percentage of Contribution of Factors: (unit in %)

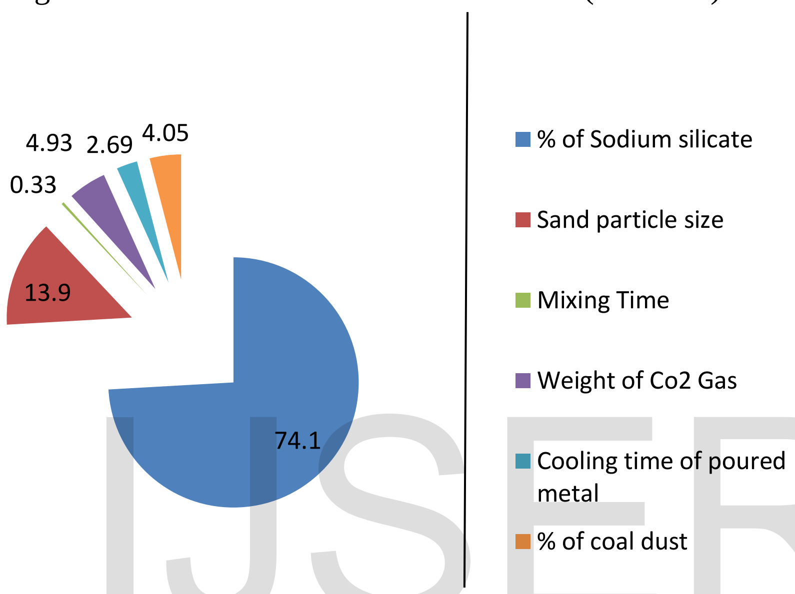

Figure 6: Percentage of Contribution of Factors

Figure 7: Main Effects Plot for Means

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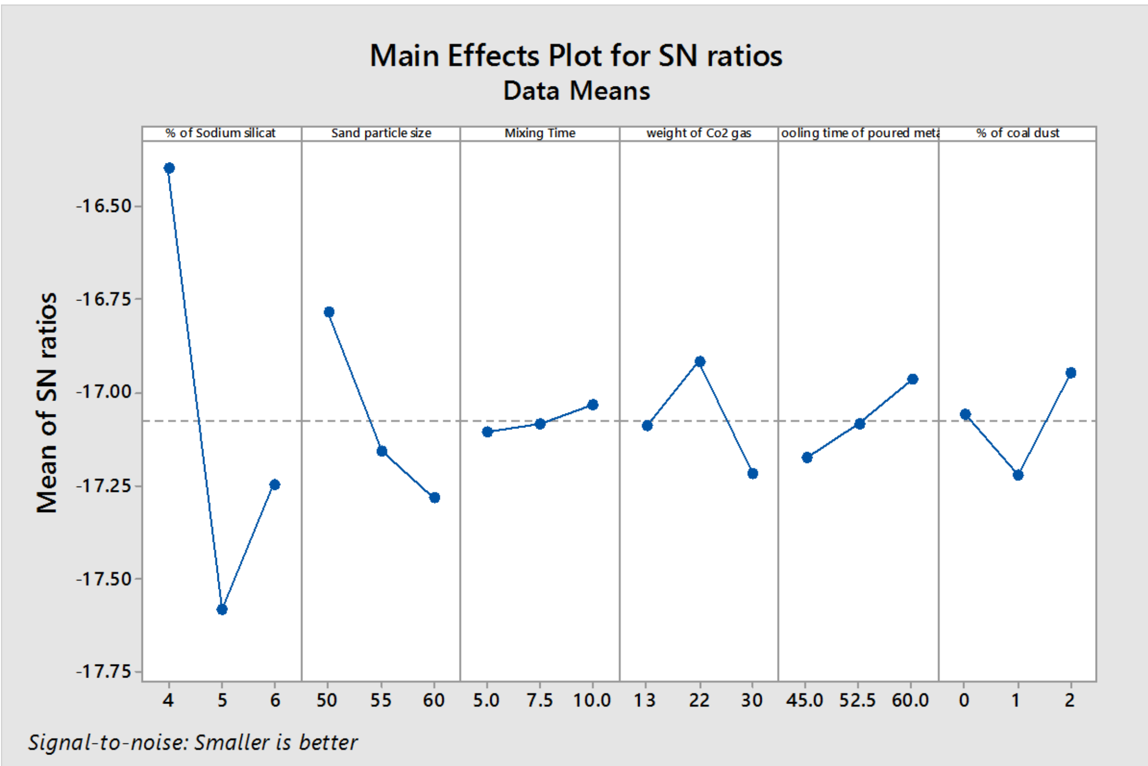

Figure 8: Main Effects Plot for SN ratios

Taguchi Design

Taguchi Orthogonal Array Design

L27(3^6)

Factors: 6
Runs: 27

Columns of L27(3^13) Array

1 2 3 4 5 6

Taguchi Analysis: % of rejection versus % of Sodium silicate, Sand particle, Mixing Time, ...

* NOTE * Unable to perform linear model analysis.

Response Table for Signal to Noise Ratios
Smaller is better

Level	% of Sodium silicat	Sand particle size	Mixing Time	weight of Co2 gas	Cooling time of poured metal	% of coal dust
1	-16.40	-16.78	-17.11	-17.09	-17.17	-17.06
2	-17.58	-17.16	-17.08	-16.92	-17.08	-17.22
3	-17.24	-17.28	-17.03	-17.22	-16.96	-16.94
Delta	1.18	0.50	0.07	0.30	0.21	0.27
Rank	1	2	6	3	5	4

Response Table for Means

Level	% of sodium silicate	sand particle size	Mixing Time	weight of Co2 gas	Cooling Time of poured metal	% of coal dust
1	6.623	6.930	7.195	7.178	7.257	7.149
2	7.579	7.230	7.171	7.035	7.173	7.290
3	7.298	7.341	7.135	7.288	7.071	7.062
Delta	0.955	0.412	0.060	0.252	0.187	0.227
Rank	1	2	6	3	5	4

General Linear Model: % of rejection versus % of sodium silicate , sand particle, Mixing Time, ...

Method

Factor coding (-1, 0, +1)

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Factor Information

Factor	Type	Levels	Values
% of sodium silicate	Fixed	3	4, 5, 6
sand particle size	Fixed	3	50, 55, 60
Mixing Time	Fixed	3	5.0, 7.5, 10.0
weight of Co2 gas	Fixed	3	13, 22, 30
Cooling Time of poured metal	Fixed	3	45.0, 52.5, 60.0
% of coal dust	Fixed	3	0, 1, 2

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
% of sodium silicate	2	4.3414	2.17072	6.61	74.10
sand particle size	2	0.8157	0.40786	1.24	13.90
Mixing Time	2	0.0166	0.00832	0.03	0.33
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% of coal dust	2	0.2370	0.11850	0.36	4.05
Error	14	4.5964	0.32831		
Total	26	10.452			100

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.572987	56.03%	18.34%	0.00%

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	7.167	0.110	64.99	0.000	
% of sodium silicate					
4	-0.543	0.156	-3.49	0.004	1.33
5	0.412	0.156	2.64	0.019	1.33
sand particle size					
50	-0.237	0.156	-1.52	0.150	1.33
55	0.063	0.156	0.40	0.692	1.33
Mixing Time					
5.0	0.028	0.156	0.18	0.860	1.33
7.5	0.004	0.156	0.03	0.978	1.33
weight of Co2 gas					
13	0.011	0.156	0.07	0.944	1.33
22	-0.132	0.156	-0.85	0.412	1.33
Cooling Time of poured metal					
45.0	0.090	0.156	0.58	0.571	1.33
52.5	0.006	0.156	0.04	0.971	1.33
% of coal dust					
0	-0.018	0.156	-0.12	0.909	1.33
1	0.123	0.156	0.79	0.444	1.33

Regression Equation

```
% of rejection = 7.167 - 0.543 % of sodium silicate_4
+ 0.412 % of sodium silicate_5
                 + 0.132 % of sodium silicate_6 - 0.237 sand particle size_50
                 + 0.063 sand particle size_55 + 0.174 sand particle size_60
                 + 0.028 Mixing Time_5.0 + 0.004 Mixing Time_7.5 -
 0.032 Mixing Time_10.0
                 + 0.011 weight of Co2 gas_13 - 0.132 weight of Co2 gas_22
                 + 0.121 weight of Co2 gas_30
+ 0.090 Cooling Time of poured metal_45.0
                 + 0.006 Cooling Time of poured metal_52.5
                 - 0.096 Cooling Time of poured metal_60.0 - 0.018 % of coal dust_0
                 + 0.123 % of coal dust_1 - 0.105 % of coal dust_2
```

```
Fits and Diagnostics for Unusual Observations

           % of                  Std
Obs   rejection     Fit  Resid  Resid
  7       7.987  6.958  1.029   2.49  R

R  Large residual
```

Residual Plots for % of rejection

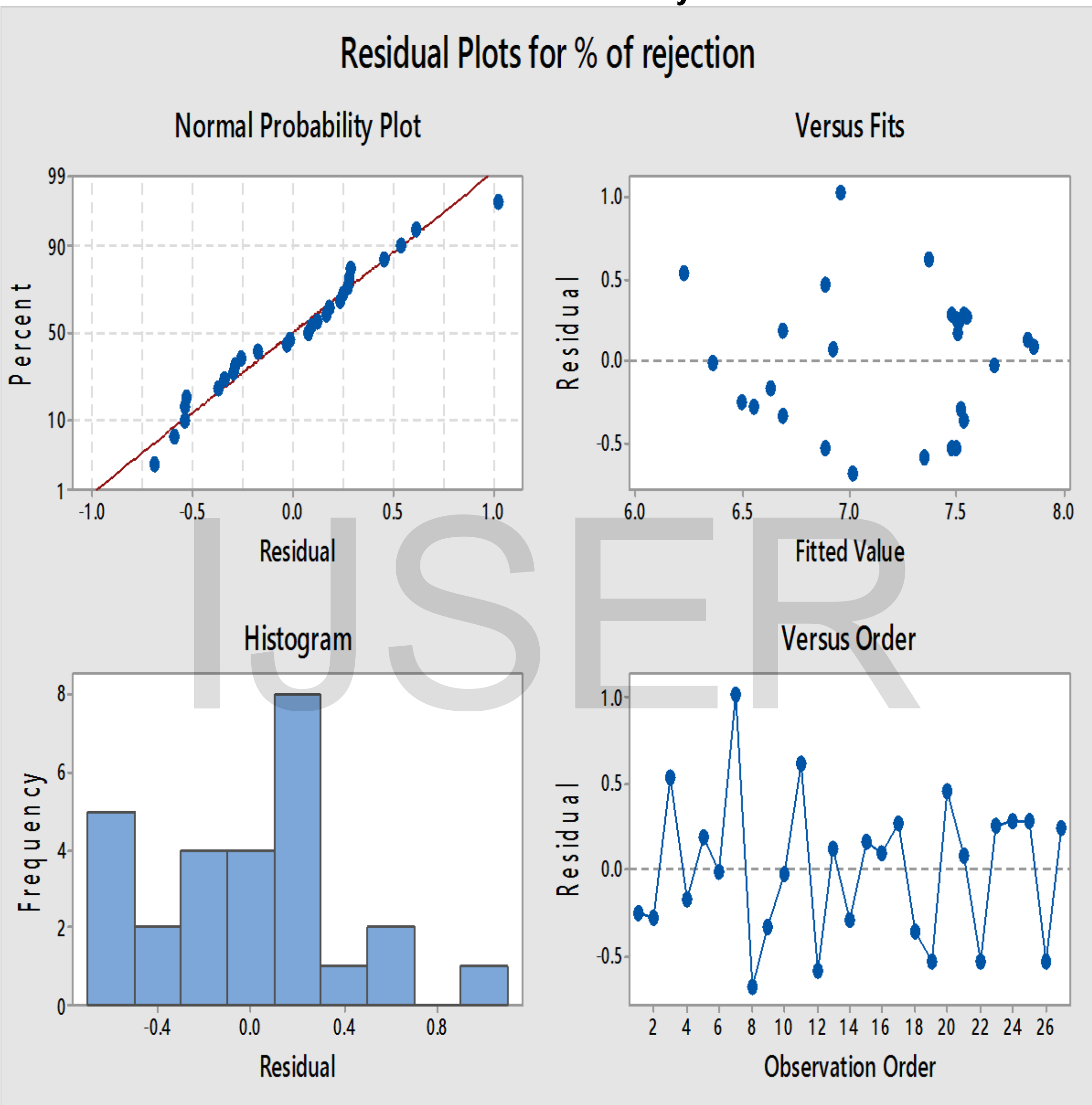

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Figure 9: Residual Plots for % of rejection

Table 7 : Robust Design Optimum value

S.N	Parameters	SNR	Level	Optimum Value
1	% of Sodium Silicate	-16.40	1	4
2	Sand Particle Size (No)	-16.78	1	50
3	Mixing Time (Mins)	-17.03	3	10

4	Weight of CO_2 Gas (sec)	-16.92	2	22
5	Cooling time of poured metal (Mins)	-16.96	3	60
6	% of coal dust	-16.94	3	2

5 Conclusion

S.N	Parameters	Level 1	Level 2	Level 3
1	% of Sodium Silicate	4	-	-
2	Sand Particle Size (No)	50	-	-
3	Mixing Time (Mins)	-	-	10
4	Weight of CO_2 Gas (sec)	-	22	-
5	Cooling time of poured metal (Mins)	-	-	60
6	% of coal dust	-	-	2

1. 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.
2. The analysis proves that by improving the quality of Taguchi's Method of parameter design at lowest possible cost, it is possible to identify the optimum level of signal factors at which the noise factor effect on the response parameter is less.
3. DoE is the technique which can be implemented in any processing industry. In India there are number of small scale industries which can implement such techniques to improve the yield, give standard process parameter and increase the effective capacity of the unit.

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