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Parametric Optimization of CO_2 Mould Made of Reclaimed Sand for Better Collapsibility

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Abstract: Inherent drawback of CO_2 moulding i.e Poor knockout property made the subject of moulding sand reclamation more prominent. In the present paper it is attempted for optimization of the process parameters of CO_2moulding process made of reclaimed sand for better knockout property. Retained compression strength after exposing the mould to 1000^0C for ten minutes and cooling to room temperature is considered as measure of knockout property or collapsibility. Taguchi method is employed for the purpose. % of Sodium silicate, percentage of coal dust, mixing time and interaction between sodium silicate and mixing time have significant effect on the collapsibility.
Keywords: Sodium silicate, Optimization, Collapsibility, Reclaimed Sand

I. Introduction

Even after evolution of several types of moulding processes sand moulding has lion share in production of castings across the world. Storage space occupied by the spent moulding sand awaiting disposal, cost of carrying huge heaps of knocked out sand to a faraway dump yard and the stern pollution norms to dump the spent sand and pursuit of man to utilize natural resources in best possible way the subject of moulding sand reclamation has gained importance.
Due to its ability to produce harder moulds,CO_2moulding process is widely used for casting variety of metals and alloys and especially high-density alloys like steels. The method has not only cured the headache of foundrymen caused by the management in planning a regular and streamlined production of castings at a low rejection rate. The process can serve as an inexpensive substitute for dry sand moulding .In early days, application of CO_2 process was limited only to cores. However now that when it is used for mould making, reclamation of CO_2 moulding sand cannot be ignored. Inherent drawback of CO_2mould is its poor collapsibility [1], hence the subject of reclamation of CO_2moulding sand has gained prominence. Warnen[2] reported easy shakeout of self-setting silicates as compared to CO_2 hardened sands .Hence breaking the lumps of knockout CO_2sand and their reclamation is to be considered carefully .There are basically three methods of foundry sand reclamation namely wet reclamation, thermal reclamation and dry reclamation .Selection of appropriate method of reclamation depends on nature of binder between sand grains. In CO_2mould, the binder bridge between sand particles i.e silica gel is a brittle porous mass [3].It is a well –known fact that brittle materials are fractured easily under the influence of mechanical forces. Hence, a mechanical dry reclamation process is appropriate choice for reclaiming CO_2moulding sands. In fact Liedel[4], Polasek et al[5]advocated for dry reclamation for silicate-bonded sands.

1.1Need of present Investigation:

It is necessary to build moulds of good quality for obtaining sound and defect-free castings. Considerable amount of literature on strength of sands bonded with sodium silicate is mostly directed towards control on a day-to-day basis rather than towards understanding the basic phenomena involved [3]. To have the best possible mould characteristics, a stringent control is to be exercised over the process parameters of CO_2moulding.In many instances it is difficult to perceive the trend of change of mould properties with respect to change in the process parameter values. Hence there is a need to optimize the process parameters of CO_2moulding process .Few of the earlier investigations on CO_2process utilizing fresh silica sand [6] attempted in this direction but not considered the aspect of knockout property of the mould made of reclaimed CO_2sand.To address this collapsibility problem, in the present paper it is attempted to optimize the process parameters of CO_2moulding process with reclaimed CO_2moulding sand for minimizing the collapsibility problem or improving knockout property. Taguchi method is a well-established statistical technique that aids in formulating a suitable experimental design matrix. Further it helps in systematic analysis of the results and in turn arriving at meaningful conclusion with minimum amount of experimentation. Hence, Taguchi method is employed for the purpose in the present investigation.

1.2 Response Characteristics

The response characteristic considered in the present study is knockout property i.e collapsibility .During pouring and solidification process of molten metal in the mould.theCO_2 mould is subjected to heating and cooling. Compression strength of the mould after heating and cooling cycle is called retained strength. Retained compression strength is a measure of collapsibility of the mould [7].The quality characteristic for retained strength (Collapsibility) is "Smaller the better". Petrzela'swork [8] towards improvement of collapsibility of chemically bonded sand moulds emphasized to concentrate separately on the two high retained strength peaks of mould below 593.3^0C and above 765.6^0C.Krishna Murthy [7] quoted that the retained strength after standard sand specimen is heated to a temperature of 1000^0C for a period of 10 minutes and cooled to room temperature is a measure of collapsibility. So in the present investigation, retained compression strength after heating and cooling cycle is considered as measure of

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collapsibility. As retained compression strength is more, collapsibility is less

1.3 Taguchi's Method

Taguchi method uses Signal to Noise ratio (S/N ratio) to compare the results[9].Goal of Taguchi method is to choose control factors that provides not only the desired result but also to direct a process that is less sensitive to noise. Although noise can't be eliminated its effect can be minimized

S/N ratio = -10 log(MSD)

MSD = Mean Square deviation of the results of replications of an experimental trial combination

II. Objective and Methodology

2.Objective :

Main objective of investigation is to optimize the process parameters of CO_2moulding process (With reclaimeCO_2moulding sand) for better knockout property

3. Methodology:

- Determining the process parameters and their levels.
- Selection of a suitable experimental design matrix.
- Building up of gassing arrangement.
- Conducting experiments as per the experimental plan.
- Analysis of results for optimum condition.
- Confirmation of optimum condition.

3.1 Determining the process Parameters and Their Levels

The process parameters considered are percentage of sodium silicate, quantity of CO_2 gas (gassing time), mixing time of the sand mix and percentage of coal dust.

Usual percentage of sodium silicate used in the process is 3% to 6%.Now the levels of sodium silicate considered are 4% and 6% with respect to the quantity of reclaimed CO_2moulding sand. Along with sodium silicate the responsible agent for the formation of silica gel is CO_2 gas. Under gassedCO_2 mould results into inferior mould hardness and other properties. At the same time, over gassing also leads to reduction of the strengths of the mould. Chemical requirements of CO_2 gas for reacting with Na_2O of sodium silicate is estimated to be 10 kg per 100 kg of silicate used. However in shop floor conditions, a quantity up to 40 kg per 100 kg of silicate should be considered ideal[7].These levels of quantity of CO_2gas required for preparing standard AFS sand specimen are appropriately converted into gassing time by maintaining fixed flow rate of CO_2 gas. Hence quantity of CO_2 gas factor is termed as gassing time in the foregoing sections of this article and levels of gassing time obtained are 13 seconds and 30 seconds. Time of mixing of sand and sodium silicate plays an important role for uniform coating of sodium silicate over sand grains and in turn the ability of formation of silica gel bond among sand grains. Too high a mixing time leads to overheating of the sand mix and affects bonding properties. Generally the mixing times employed are 5 to 10 minutes. In the present work two levels of mixing time 5 minutes and 10 minutes are considered. Coal dust is one of the important breakdown agents that impart ease of collapsibility to the mould. Maximum of 2% coal dust is generally used[7].The two levels of coal dust considered are 0% and 2%.Process parameters their designations and their levels are shown Table-1

3.2 Selection of a Suitable Experimental Design Matrix

Four factors at two levels and effect of two interactions between sodium silicate, gassing time and sodium silicate, mixing time are planned to be studied

Hence, an L_8 array having seven degrees of freedom is suitable for the purpose. Experimental design matrix (L_8 array) along with responses is shown in Table-2 Number of replications of each experimental trail combination is to be decided based on noise factors. Generally for better results each experimental trail combination is replicated for three times.

3.3 Building up of gassing arrangement:

To facilitate supply of exact amount of CO_2 gas for preparing standard AFS sand specimen, a simple experimental setup is built up. Gassing arrangement setup shown in Fig:1 consists of i) CO_2 gas cylinder ii) Rota meter iii) Nozzle iv) Pressure gauge and v) Hose pipe. Apart from monitoring the pressure of CO_2 gas, the exact quantity of gas supplied to the mould can be metered with the help of Rota meter attachment to the cylinder

Table-1: **Description of factors and their levels**

S.No	Factor Name	Level-1	Level-2
1	Percentage of Sodium Silicate (SS)	4%	6%
2	Gassing time in seconds(GT)	13Sec	30 Sec
3	Mixing time in minutes (MT)	5 Minutes	10minutes
4	Percentage of coal dust (CD)	0%	2%

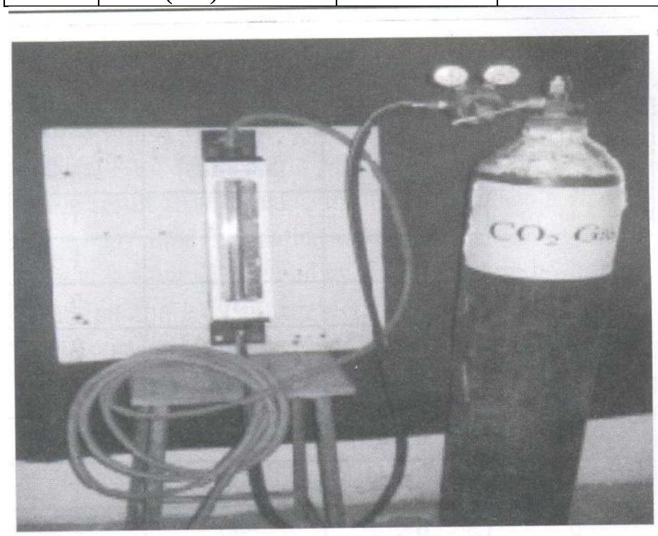

Fig1: **Gassing Arrangement**

3.4 Conducting experiments as per the experimental plan.

As per the experimental plan shown in Table-2 sand mixes are prepared with reclaimed moulding sand.CO_2moulding sand is subjected to dry reclamation with impact and attrition for a reclamation time of fifteen minutes. In the total mixing time initially dry mixing is carried for one minute and remaining mixing time is continued with the addition of sodium silicate. Standard AFS sand specimens of 2X2' size are prepared from the prepared mix in a split specimen tube.The specimens are gassed using the gassing arrangement and special gassing attachment as per the gassing time specified in the L8 array (Table2) Retained compression strength after exposing the sand specimen to 1000^0C for 10 minutes and cooling to room temperature (Collapsibility) are determined and the results are tabulated in Table-3

Results & Analysis

3.5 Analysis of results for optimum condition.

Average valuesand S/N ratio values of results of replications of each experimental trial combination are found out and the results are shown in Table-3. Response graphs are drawn to determine the effect of each factor on the response characteristic .From Fig.2 it can be observed that percentage of sodium silicate and coal dust are the important factors to be controlled to have higher Collapsibilityi.e. lower retained strength .Irrespective of type of quality characteristic Optimum condition of factors is decided basing on the higher value of S/N ratios of the levels considered .From the response graphs, the optimum condition is observed to be 4% SS,30 Sec gassing time (SSxGT) second level, 5 minutes mixing time (SSXMT) first level ,2% CD Effect of each factor on the collapsibility can be determined using response graphs but the significance of various factors and interactions can be ascertained through analysis of variance (ANOVA) and F-test. Analysis of variance of the experimental results is given in Table-4. Percentage contribution of each factor and interaction on collapsibility are shown in Fig.3. Optimum condition for: Smaller the better type characteristic of retained strength (collapsibility) is given in Table-5

Table-2 :L8 Orthogonal Array with actual values of Factor Levels

Trail No	SS (1)	GT(2) (seconds)	SSX GT 1X2	MT(3) (minutes)	SSXMT 1X4	Unused column	CD (7)
1	4%	13	1	5	1	-	0%
2	4%	13	1	10	2		2%
3	4%	30	2	5	2		2%
4	4%	30	2	10	1		0%
5	6%	13	2	5	1		2%
6	6%	13	2	10	2		0%
7	6%	30	1	5	2		0%
8	6%	30	1	10	1		2%

Table-3: Experimental Values of Retained Compression Strength

Trail No	Collapsibility (Retained Strength) (Kg/cm$^{2)}$			Average	S/N Ratio
	R1	R2	R3		
1	1.88	1.92	1.72	1.86	-5.395
2	1.86	1.81	1.97	1.88	-5.489
3	0.4	0.41	0.32	0.376	8.431
4	2.76	2.89	3.17	2.939	-9.382
5	3.12	3.26	8.16	3.18	-10.051
6	6.01	5.86	5.74	5.87	-15.375
7	4.92	4.99	5.25	3.053	-14.575
8	2.89	2.98	2.98	2.95	9.378

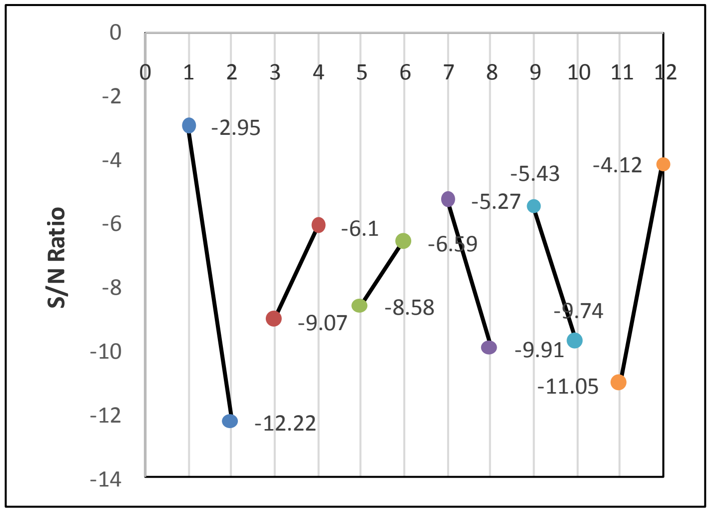

Fig .2 : Response Graphs

Table-4 : Analysis of Variance (ANOVA)

Factor	DOF	SS	Variance	F-Ratio	Percentage of Contribution of Factor
SS	1	171.71	171.71	23.065	45.1
GT	1	17.656	17.656	2.371	4.63
SSXGT	1	7.962	7.962	1.069	2.1
MT	1	43.03	43.03	5.78	11.3
SSXMT	1	37.24	37.24	5.002	9.8
CD	1	96.056	96.056	12.903	25.2
Error	1	7.443	7.443		1.87
Total	1	381.101			100

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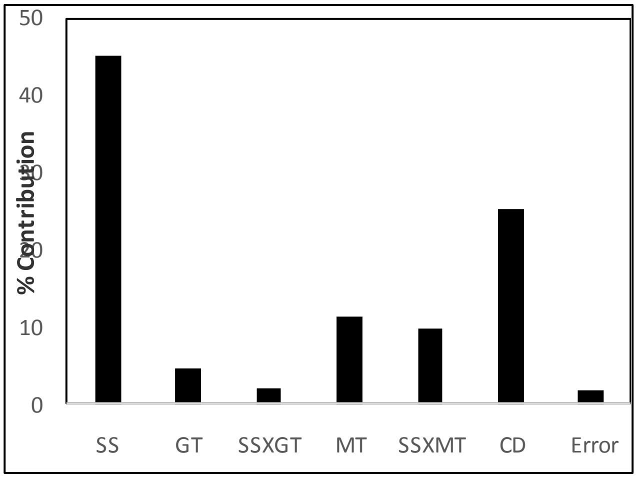

Fig-3 : Percentage contribution of each factor and interaction on Collapsibility (retained compression strength)

F-Test

F-test discriminates significant and insignificant factor. From the statistical F-tables ,F-ratio corresponding to degrees of freedom of factor '1' and error degrees of freedom '1' is 1.6 By comparing F-ratio values from the statistical table with the computed F-ratio, it can be observed that SS,CD,MT,(SSXMT),GT are significant, however the percentage contribution of GT on the result is very small. In fact when sodium silicate and mixing time interaction is significant the optimum levels of sodium silicate and mixing time are to be decided basing on the level of interaction .In the present case, there is no ambiguity because the interaction is at first level and optimum levels of sodium silicate and mixing time as per the response graph.(Fig.2) are already at level '1'

Out of all the significant factors sodium silicate has the highest percentage of contribution and next to that is coal dust .For better collapsibility the retained compression strength should be less and hence optimum level of sodium silicate is 4%. As coal dust is the breakdown agent added the optimum level of coal dust is 2%

Table-5: Optimum Condition

Factor Name	Level Descripton	Level Contribution
SS	4% [1]	4.632
GT	30 sec [2]	1.485
SSXGT	[2]	0.997
MT	5 min [1]	2.319
SSXMT	[1]	2.157
CD	2% [1]	3.465
		15.054

Result at Optimum condition:

Yopt= $\bar{T} + (\bar{SS}_1 - \bar{T}) + (\bar{CD}_2 - \bar{T}) + (\bar{MT}_1 - \bar{T}) + [(\bar{SS}_{1x}\bar{MT})_1 - \bar{T}$

=-7.592+4.362+3.465+2.319+2.157=5.161(S/N value)

Actual value =Yopt=0.55 kg/sq .cm

Range of Expected Result at Optimum Condition

C.I $=\sqrt{[F(l,n2)]XVe/Ne}$

At a confidence level of 90% C.I= ± 2.73
Range of result (S/N values) = 7.891 to 2.431
Range of result (Actual values) =0.303 to 0.76 kg/sq.cm

3.6 Confirmation Test

Conformation test is conducted at optimum condition obtained the result obtained is 0.36 Kg/Cm^2 which is well within the confidence interval of the expected result

.IV. Conclusion

Taguchi method has been successfully employed for optimizing the process parameters of the CO_2 moulding process. The optimum level of process parameters for maximizing the collapsibility i.e. minimizing the retained strength are 4% sodium silicate ,30 seconds gassing time ,5 minutes mixing time and 2% coal dust. Percentage of sodium silicate and percentage of coal dust has significant effect on the collapsibility. The result of the confirmation test is within the confidence interval of the predicted result

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