Process Parameter Optimization of CO2 gas cured Sodium Silicate Moulding Process for better Compression Strength

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Abstract - As CO_2moulding process is used for casting alloys of high density, compression strength of mould should be possibly high. Present paper depicts optimization of process parameters of CO_2moulding process for better compression strength. Four process parameters are considered at two levels and Taguchi's L8 Orthogonal array is used .It is observed that percentage of sodium Silicate and mixing time are the significant factors that affect compression strength. Optimum values of process parameters for maximum compression strength, are obtained and these are validated through confirmation experiments

Keywords –Moulding ,optimization ,compression strength

I. INTRODUCTION

Out of all the sand moulding processes available, carbon dioxide moulding process has its own advantage by virtue of its high mould hardness. This CO2 gas cured sodium silicate process was first conceptualized in 1998.By 1956 this process has become popular for core making.

1.1 Bond formation in CO_2moulding process

In this process,moulding sand is mixedwith sodium silicate in a mixer and the mix is poured around the pattern in a moulding flask.The mix is loosely rammed around the pattern.Carbon dioxide gas is sent into the mould with the help of a nozzle at various locations of mould.This carbon dioxide is mixed with sodium silicate leading to formation of silica gel.

$Na_2Si\ O_3 + H_2\ O + CO_2 \text{---}\rightarrow Na_2CO_3 + SiO_2 + H_2O$- (1)

The binding power of sodium silicate can be attributed to three apparently different aspects of its nature.

i)It is very efficient wetting agent and hence a detergent. Vali [[1] quoted that sodium silicate is known to be more thorough wetting agent and detergent than powerful alkalis. When surface of sand grain is covered with sodium silicate, particles of impurities such as dust and grease will be dislodged from surface and be floated of

ii) Sodium silicate is a metastable compound and can be easily decomposed. Such decomposition product is monosilisic acid$Si(OH)_4$ and this monosilisic acid polymerizes into polysilisic acid and continue to high polymers as gels. This gel is able to adhere to cleaned surface of sand grains and thereby form bridge of multiple vanderwalls strength and thus can accomplish stitching action.

iii) Sodium silicate is one of the best industrial adhesive In CO_2 process strength development occurs due to change of phase of sodium silicate from liquid to solid state by loss of water and due to development of new products. This new product functions as bond between sand grains [2]

Atterton [3] cautions that equation (1) is over simplified. In fact water solution of sodium silicate reacts with CO_2 and produce mono silisic acid and sodium carbonate. This monosilisic acid polymerizes leading to formation of Si-0-Si linkage known as siloxane linkage. This siloxane linkage produces a gel when it grows randomly in three dimensions. Warrey [4] described gel as a loose network of colloidal particles interconnected at only few points. It is concluded that the primary responsible agent for strength development process of CO_2 gas cured silicate bonded mould is 'Silica gel'

1.2 Use of present investigation

By virtue of its high mould hardness, CO_2moulding process is used for casting alloys of high density. When high density alloy is poured in mould cavity, the mould should maintain higher compressive strength. According to the variation of different process parameters like percentage of sodium silicate, mixing time etc….Compression strength value will be varried. But our requirement is to obtain optimum values of process parameters for maximizing mould hardness .Previously optimization of process parameters of CO_2moulding process was attempted by M.VenkateRamanaetal [5] for better Tensile strength. As analysis is very difficult in conventional full factorial experimentation [6], Taguchi's orthogonal array is used to decide the experimental plan for the sake of optimization. Previously many researchers [7,8] used Taguchi technique for parametric optimization of various manufacturing processes.

2.0 Objective and scope of the present work

Present work is aimed at optimization of process parameters of CO_2 moulding process for maximizing compression strength of mould. Taguchi technique is used for the purpose. Scope of the present work includes fixing number of levels and level values for the identified process parameters, arriving at a suitable experimental plan depending on number of process parameters and their number of levels, Gassing arrangement setup preparation, experimental determination of compression strength and analysis of obtained compression strengths to determine optimum condition and validation of optimum condition through confirmation experiments..

2.1 Identification of process parameters

Mould properties of CO_2 mould are influenced by factors namely percentage of sodium silicate, quantity of CO_2 gas and mixing time [9]. Hence these three are considered as three factors. Usually to improve collapsibility of mould ,coal dust is added to mix. So percentage of coal dust is also included as one of the factors.

2.1.1 Percentage of sodium silicate

Main element in bond formation of CO_2mouldingprocesses is sodium silicate.Generally 3% to 6% of sodium silicate is used [7(10)] .So now two levels 4% and 6% are considered.

2.1.2 Quantity of CO2gas [CO2 gassing time]

During CO_2moulding process CO_2 gas is mixed with sodium silicate coat on sand grains and forms silica gel. This silica gel is prime responsible for strength development of bond between sand grains. Adequate supply of CO_2 gas is important criterion for development of compression strength of mould. Too low quantity of CO_2 gas leads to formation of mould of inferior compression strength. At the same time over gassing leads to formation of sodium bicarbonate, which in reduces strength of the mould. Hence adequate supply of CO_2 gas is the requirement. Chemical formula of reaction i.e. equation-1 indicates requirement of 10 kg of CO_2 gas per 100 kg of sodium silicate. But generally in shop floor, a quantity up to 40 kg of CO_2 gas per 100 kg of sodium silicate is used. Hence 10 kg and 40 kg per 100 kg of sodium silicate are considered as two levels. These two levels are suitably converted in to gassing time by maintaining uniform flow rate of CO_2 gas. The two levels of gassing time obtained are 13 seconds and 30 seconds.

2.1.3 Mixing Time

Uniformity of formation of silica gel on entire sand grain depends on degree of uniformity of coating of sodium silicate on sand grains. Too low mixing times lead to inadequate mixing and too high mixing time lead to heat generation. This generated heat, affects strength development process during bonding. Usually mixing time of 5 minutes to 10 minutes is employed. So two levels of mixing time 5 minutes and 10 minutes are considered in the present work.

2.1.4 Coal dust.

Though CO_2 mould is well known for its high mould hardness, it is suffering from a drawback of poor collapsibility.Generally, 2 percent coal dust is added to mix to enhance collapsibility [9] .So in present work two levels of coal dust i.e 0% and 2% are considered

2.2 Experimental plan:

Effect of four factors at two levels and two interactions namely sodium silicate versus gassing time and sodium silicate versus mixing time are proposed to be studied. Total no of degrees of freedom is '7' and hence L8 orthogonal array, that can accommodate four 2-level factors and three interactions is chosen. Experimental trials with actual level values of factors are given in Table-2

Table-1 Factors and their level

S.NO	Factor name	Level-1	Level-2
1.	Percentage of coal dust(CD)	0%	2%
2.	Percentage of sodium silicate	4%	6%
3.	Mixing time in minutes(MT)	5minutes	10minutes
4.		13seconds	30seconds

Table 2:L8 Orthogonal array with actual values of factor levels

Trail No.	SS (1)	GT (2) (Seconds)	SSXGT (1X2)	MT (4) (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%2
6	6%	13	2	10	2	-	0%
7	6%	30	1	5	2	-	0%
8	6%	30	1	10	1	-	2%

2.3 Gassing arrangement setup

The parameter, quantity of CO_2 gas is converted into gassing time by keeping constant flow rate of CO_2 gas .To maintain constants flow rate of CO_2 gas, a gassing arrangement setup is made. Gassing arrangement setup consisting of CO2 gas cylinder. Rotameter and nozzle. Schematic of gassing arrangement setup is shown in Fig-1

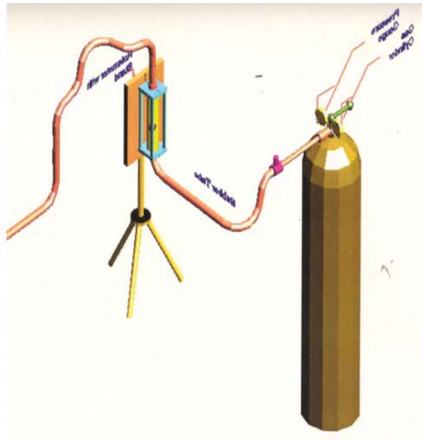

Fig-1 Schematic of gassing arrangement setup

II. EXPERIMENT AND RESULT

2.4 Experimental determination of compression strength:

Fresh silica sand having a grain fineness number of 59.87 is considered in present investigation. AFS standard sand samples of 2'X2' cylindrical shape are prepared as per experimental plan and compression strength values are determined by using a universal sand strength machine. Universal sand strength machine and standard sand sample are given in Fig-2& Fig-3 respectively

Tests are conducted according to standard AFS testing procedure 318-87—5,302-87-S [11]

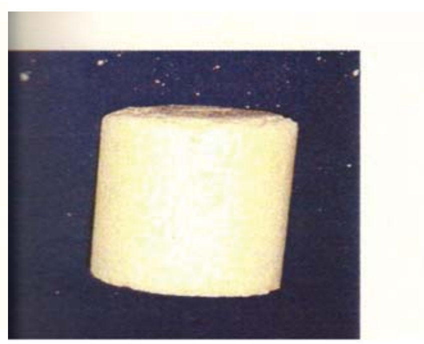

Fig: 2 Universal sand strength machine   Fig:3 AFS Standard sand specimen

Compression strength values that are experimentally determined as per experimental plan are shown in Table-3. Each experiment is replicated thrice. It is desirable to have maximum possible compression strength of mould, hence for the response characteristic" Compression strength", the quality characteristic is "Bigger the better type"

S/N ratio = -10 log (MSD)------------------(2)

Where MSD=Mean Square Deviation

For bigger the better type quality characteristic

$MSD=[1/ y_1^2+1/ y_2^2+1/ y_3^2]/n$ -------------------------(3)

Table-3: Experimental values of compression strength

Expt Trial No	Compression Strength(Kg/sq.cm)			Average Value	S/N ratio
1	4.46	4.72	4.26	4.48	13.002
2	4.08	4.18	4.3	4.186	12.132
3	4.62	4.51	4.48	43536	13.132
4	2.7	3.87	3.87	3.479	10.446
5	5.62	5.59	5.41	5.539	14.866
6	5.14	5.02	5.21	5.123	14.187
7	5.96	5.3	5.2	5.4866	14.739
8	5.22	5.28	5.19	5.23	14.369

2.5 Analysis of experimentally obtained compression strength & Optimization

S/N analysis of compression strength values are made and effect of each factor and interaction on compression strength is presented in the form of response graph in fig.4

2.5.1 Response graph: Based on response graph shown in fig-4, the level of value of each factor that maximizes S/N ratio can be considered as optimum level. But appropriate judgement can be made only after ascertaining significance of each factor and interaction after performing ANOVA & F-test

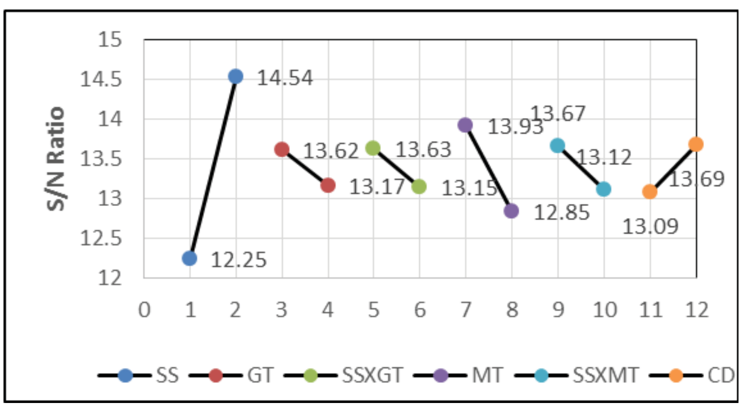

Fig4.Response graph

2.5.2ANOVA: **ANOVA** is performed on compression strength values and it is tabulated in Table-4

Table-4: ANOVA Table

Factor Name	DOF	SS	Variance	F-ratio	Percentage of contribution of factor
SS	1	10.466	10.466	25.648	67.96
GT	1	0.405	0.405	0.993	2.63
SSXGT	1	0.455	0.455	1.117	2.95
MT	1	2.318	2.318	5.68	15.05
SSXMT	1	0.609	0.609	1.494	3.95
CD	1	0.734	0.734	1.798	4.76
Error	1	0.407	0.407		2.7
Total	**7**	**15.398**			**100**

2.5.3 F-Test: By comparing F-ratio values obtained from statistical table, corresponding to degrees of freedom of factor and error degrees of freedom with computed F-ration from ANOVA ,it is observed that SS MT are significant factors and all other factors including interactions are insignificant. Hence from response graph (fig-4) SS at 2nd level i.e 6% MT at 1st level i.e 5 minutes that maximize S/N ratio are considered as optimum combination. Remaining factors, as they are not significant, can be maintained either at first level or second level. So GT& CD can be maintained either at 1 st level or at second level,however for safety purpose GT at first level i.e 13 seconds and CD at 2 nd level i.e 2%can be taken as optimum condition.Optimum condition for maximum compression strength is given is Table-6. Percentage contribution of each factor and interactions towards compression strength is given in Fig-5 As sodium silicate is mainly responsible for bond formation% of q sodium silicate is the most significant factor that affects compression strength .Next important factor is mixing time .probably the fact that too low mixing time leads to non-uniform mixing and too high mixing time makes the mix dry could be the reason for obtaining mixing time as the next best significant factor.

Table-6 Optimum condition

Factor Name	Level Description	Level Contribution
SS	6% [2]	1.143
GT	13 Sec [1]	0.225
SSXGT	[1]	0.238
MT	5Min[1]	0.538
SSXMT	[1]	0.276
CD	2% [2]	0.302
		2.721

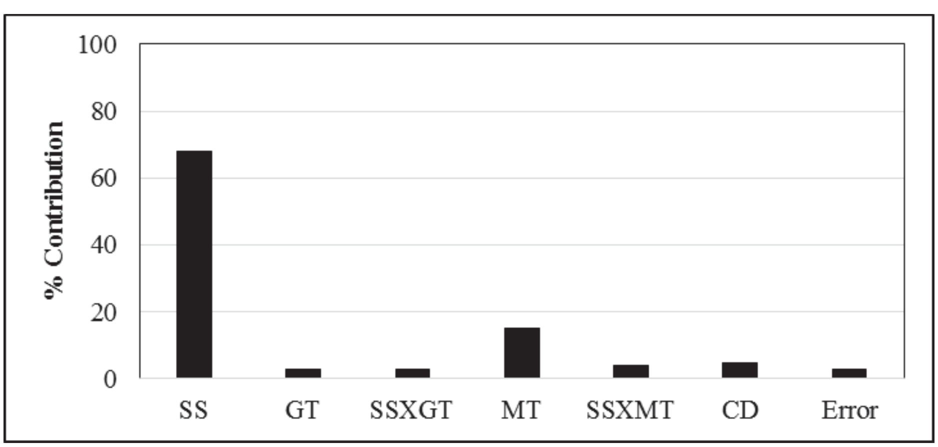

Fig 5: Percentage contribution of each factor & interaction

2.5.4 Expected compression strength & Range of expected compression strength at optimum condition

Expected compression strength at optimum condition

Y optimum = $\overline{T} + [\overline{SS2} - \overline{T}] + [\overline{MT2} - \overline{T}]$

=13.396+1.43+0.538

=15.364(S/N value)

=5.86 Kg/cm^2 (Actual value) (Based on the significance of factors and their percentage contribution towards result)

Range of expected compression strength at optimum condition

The Confidence interval is calculated by using the equation 5.5

Confidence interval = CI=+/- 0.49

Range of expected Compression Strength= (15.364-0.49) to (15.364+0.49)

=14.874 to 15.854(A/N value)

= (5.409) to (6.204) Kg/cm^2

(Actual value)

2.5.5: Confirmation Test: To validate the optimum condition, confirmation experiments are conducted optimum condition and compression strength is found to be 5.47 kg/cm^2 (Average of three trials) ,which is Will within the range of expected compression strength at optimum condition.

III. CONCLUSION

Parametric optimization ofCO_2moulding process has been successfully made, using Taguchi technique, percentage of sodium silicate and mixing time are observed to be the significant factors that affect mould hardness. Optimum condition is percentage of sodium silicate: 6 mixing time : 5 minutes ;Gassing time:13 sec and coal dust2percent. Optimum condition is validated through conformation test.

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