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Optimisation of Process Parameters of Co_2 Moulding Process For Better Tensile Strength-Taguchi Approach

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Abstract

Present investigation aims at optimizing the process parameters of CO_2 moulding process for better Tensile Strength. Taguchi method has been successfully applied for the purpose. It is observed that % of sodium silicate and coal dust are the significant factors affecting Tensile Strength and out of these two sodium silicate has got more predominant effect.

Key words: Tensile Strength, CO_2 moulding process, Taguchi approach.

Introduction

CO_2 Moulding process is one amongst the sand moulding processes that exhibit superior mould properties.

CO_2 Moulding process was first conceived in 1898 and it has become popular for mould and core making. At that moment it was the only alternative to conventional green sand and oil bond sand process.Co_2 process is suffering with inherent drawback of poor collapsibility [1].These drawbacks reduced usage of process by 1960.Development of organic binder systems addressed all negative points of CO_2 process. But the associated metallurgical and environmental problems with organic binder system drew the attention of foundries towards CO_2 Moulding process again. Tensile strength is important in sand Moulding to prevent defects like metal penetration and sand scabbing.

Bonding Mechanism In CO_2 Moulding Process

In the process of mould making the individual grains of sand are coated with a thin layer of sodium silicate and sand grains are made to tie with each other .The strength is a function of cohesion of bond medium to surface of sand grains and cohesion of material permits the bond. Adhesion is dependent as individual phenomena between bond medium and grain structure where as cohesion is governed by structural strength of medium. Sodium silicate is a very efficient wetting agent and hence used as detergent. Vali[2] quoted that sodium silicate is known to be more thorough wetting agent and detergent than powerful alkalis.

When surface of sand grains is covered with impurities like dirt and grease, the coating of sodium silicate on sand particles will be possibly dislodged from the surface and will be floated off. As a chemical sodium silicate is a meta stable compound which can be made to decompose by fairly easy means .One of the products of such decomposition is Mono silisic acid SI(OH)4 .Mono sililic acid is known to be unstable and polymerises in to Polysilisic acid. The newly formed gel, being in nascent state is able to adhere to cleaned surface of sand grains

Chemical Reaction involved in the process is

$Na_2Si0_3+H_2O+CO_2$-----→NA2CO3 - SIO_2+H_20

SIO_2 $2H_20$ is the silica gel and is prime responsible for forming bond between sand grains. This silica gel, after solidification is hard, permeable and brittle. Hence the mould made of CO2 moulding process is good in compression but may not be having adequately good Tensile strength. Hence Tensile strength is considered as response characteristic in the present investigation.

Taguchi method is an excellent technique of proven capability to determine the effect of all factors, discriminate significant and insignificant factors and further this method helps in drawing meaningful conclusions from smaller number of experimental trials. Hence Taguchi technique is used for process optimization.

Objective

Aim of the present investigation is to optimize the process parameters of CO_2 Moulding process for maximizing tensile strength. Taguchi technique is utilized for the purpose.

Steps

1. Fixing the process parameters and their levels
2. Deciding orthogonal array based on no of process parameters and their levels.
3. Determination of Tensile strength of samples as per experimental design matrix
4. Determination of the expected Tensile strength and range of Tensile strength at optimum condition.
5. Confirmation experiments to validate the obtained optimum value of Tensile strength.

Fixing Process Parameters And Their Levels

(a) Amount of sodium Silicate

Sodium silicate is the major binding element in CO_2 mouldness process. Usual % of sodium silicate addition is 3 to 6% (3, 4) .In this paper two levels 4% and 6% are considered.

(B)Mixing Time

Degree of mixing of Moulding sand and sodium silicate tells upon characteristics of mould. Too low mixing time leads to inferior moulds and too high mixing times make sand dry. Hence mixing time is considered as factor. Usually mixing time varies from 5 to 10 minutes. In the present work two levels of mixing time i.e. 5 minutes and 10 minutes are considered.

(C) Quantity Of CO_2 Gas

Binder coat around the sand grains will be cured with CO_2 gas so that a bonding agglomerate of silica gel is formed. Flow rate of CO_2 gas and quantity of CO_2 gas controls gas distribution to all corners of mould. Lower amount of CO_2 gas will not cure sodium silicate sufficiently and hence bond strength between sand grains is inferior. Strength development reaction i.e silica gel formation reaction is exothermic [5].Higher quantities of CO_2 gas dehydrates silicate bond and hence strength of the mould will be decreased. Over gassing produces white patch on mould surface and makes surface friable. Both under gassing and over gassing diminishes bond strength, hence it is necessary to properly control quantity of CO2 gas. Chemical requirement of CO2 gas for reacting with Na2O is estimated to be 10 kg per 100 kg of sodium silicate [3].But in practical shop floor situation up to 40 kg of CO2 gas per 100 kg of sodium silicate are used [3].Hence in present investigation two levels of quantity of CO2 gas i.e 10 kg/100 kg of sodium silicate and 40 kg/100 kg of Sodium silicate are considered. For preparation of AFS standard sand sample of 2’’X2 these two levels are appropriately converted into gassing time by maintaining uniform flow rate of CO2 gas. The two levels of gassing time obtained are 13 seconds and 30 seconds.

(D) Quantity of Coal Dust

Basic drawback of CO_2 mould is poor collapsibility. To enhance ease of knocking either breakdown agents like coal dust, sugar based compounds are added or additives like Al_203 powder are added. In the present work coal dust is used as breakdown agent usually 1% to 2% of breakdown agent will be added to sand mix[3].Two levels of coal dust i.e. 0% and 2% are considered.

Factors considered in the present investigation and their levels are given in Table-1

Table 1: Description of factors and their levels

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)	5 minutes	10 minutes
4.	Quantity of CO_2 gas(gassing time)(GT)	13 seconds	30 seconds

Deciding Orthogonal Array

Inner array is based on “Theory of orthogonality” [6]. It states that each and every level of each and every parameter is in combination with each and every level of every other parameter at least once [7].

In the present study four factors are considered at two levels. Further two interactions are planned. Hence total degrees of freedom are ‘6’ [4(2-1) +2(1) =6]. L8 (2^7) orthogonal array that has seven columns is selected for the purpose. L_8 array is given in Table 5.4 and L_8 array with actual values of factor levels is given in Table 5.5

Table 2: L8 Orthogonal Array

Trail No.	**(1)**	**(2)**	(3)	**(4)**	**(5)**	**(6)**	**(7)**
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	2	2	2
4	1	2	2	2	1	1	1
5	2	1	2	1	1	2	2
6	2	1	2	2	2	1	1
7	2	2	1	1	2	1	1
8	2	2	1	2	1	2	2

Table 3: 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%
6	6%	13	2	10	2	-	0%
7	6%	30	1	5	2	-	0%
8	6%	30	1	10	1	-	2%

To ensure Taguchi’s robust design each experimental trial combination obtained through inner array should be replicated. Number of replications depend on number of noise factors and their levels, In literature [8] it is found that a general outer array can be considered and trial combination are repeated for three times with each experimental trial combination.

Grain fineness number of fresh silica sand used in the study is found to be 59.87 and screen distribute of sand is given in Table-4

Table 4: Screen distribution of fresh silica sand

Aperture Opening (microns)	Wt. of the sand retained in Each sieve(gm)	Percentage Retained	Multiplier	Product
1700	-	-	5	-
850	0.8	1.6	10	16
600	1.9	3.8	20	76
425	9.3	18.6	30	558
300	10.8	21.6	40	864
212	11.9	23.8	50	1190
150	5.8	11.6	70	812
106	4.6	9.2	100	920
75	2.1	4.2	140	588
53	1.6	3.2	200	640
Pan	0.4	0.8	300	240
Total	**49.3**	**98.6**		**5904**

Determination of Tensile Strength:

Response characteristic in the present study is Tensile Strength and its Quality characteristic is bigger the better. S/N analysis is made

S/N ratio = -10 log (MSD)

Where MSD=Mean Square Deviation

For bigger the better characteristic

$MSD=[(1/y1)^2+(1/y2)^2+(1/y3)^2+ \ldots\ldots]/n$

As per experimental trial combinations mentioned in Tab-(3) standard dog bone type of tensile specimens (shown in Fig-1) are prepared using tensile core box with provision for CO_2 gassing. Tensile strength of standard dog bone type specimen is determined using Universal Sand Strength machine as shown in fig-2

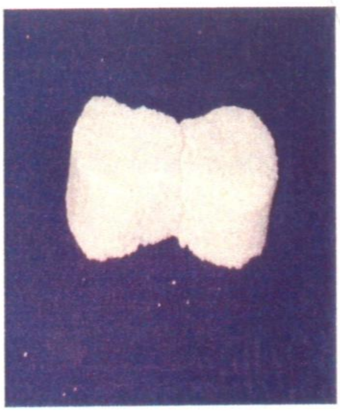

Figure 1: AFS standard dog bone

Figure 2: Universal sand strength Tensile test specimen machine along with tensile test attachment

Experimentally determined tensile strength values of fresh silica sand specimens are given in Table-5. Average values and S/N values of tensile strength are computed and also shown in Table-5. Effect of each factor and interaction on tensile strength is given in Table-7 and is represented in the form of response graph in Fig-3. ANOVA for S/N data of tensile strength is performed and is given in Table-6.

Table 5: Experimental values of Tensile Strength

Expt. No	**Tensile Strength (kg/cm2)**			**Average value**	**S/N Ratio**
1	0.8	1	1	0.9	-1.024
2	1.1	1	1	1.066	0.534
3	1	1.2	1.2	1.066	0.466
4	1	0.8	0.8	0.93	-0.747
5	1.4	1.3	1.3	1.433	3.031
6	1.2	1.2	1.2	1.166	1.316
7	1.3	1.3	1.3	1.333	2.483
8	1.8	2.02	2.02	2	5.933

Table 6: ANOVA Table

Factor Name	DOF	SS	Variance	F- Ratio	Percentage of contribution of factor
SS	1	22.956	22.896	31.929	63.04
GT	1	2.286	2.286	3.188	6.3
SS x GT	1	1.8	1.86	2.594	4.9
MT	1	0.54	0.54	0.753	1.5
SS x MT	1	0.241	0.241	0.337	0.66
CD	1	7.871	7.871	10.976	21.6
Error	1	0.716	0.716		2.0
Total	**7**	**36.413**			**100**

Table 7: Effect of each factor and interaction on Tensile Strength

Factor Name	L1	L2	L2-L1
SS	-.193	3.191	3.888
GT	.964	2.034	1.069
SSXGT	1.981	1.017	-.965
MT	1.239	1.759	.519
SSXMT	1.673	1.325	-.349
CD	.507	2.491	1.984

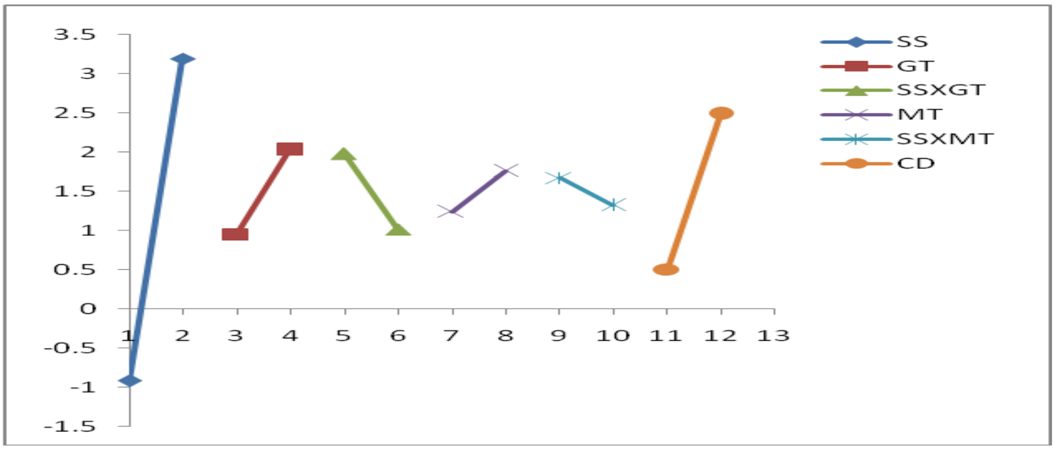

Figure 3: Response Graph

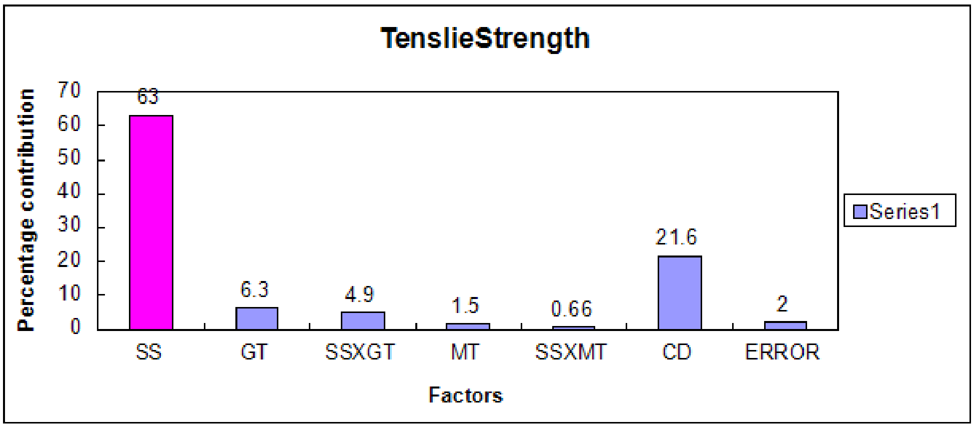

Figure 4: Percentage of contribution of each factor and interaction on Tensile Strength

F-Test

By comparing F ratio values obtained from statistical tables corresponding to degrees of freedom of factor and error degrees of freedom with computed F-ratio from ANOVA it is observed that SS,CD,GT and (SSXGT) are the significant factors but the contribution of (SSXGT) is very small. Percentage contribution of each factor and interaction on tensile strength are shown in Fig 4.Optimum condition for "bigger the better type quality characteristic" of tensile strength is given in Table 7

Table 7: Optimum condition for Tensile Strength

Factor Name	**Level Description**	**Level Contribution**
SS	6 % [2]	2.691
GT	30 sec[2]	0.534
SSXGT	[1]	0.432
MT	10 min [2]	0.259
SS X MT	[1]	1.73
CD	2% [2]	0.991
		5.129

$\overline{T}$ = Grand average of S/N values of tensile strength = 1.499

Expected tensile strength at optimum condition

Y optimum = $\overline{T} + [\overline{SS1} - \overline{T}] + [\overline{CD2} - \overline{T}] + [\overline{GT2} - \overline{T}]$ T_2

= 1.499+2.691+0.991+0.534=5.715 (S/N value)

= 1.93 Kg/cm^2 (Actual value)

Range of expected tensile strength at optimum condition

Confidence interval (C.I)=+/- 0.75

Range of expected tensile strength at optimum condition

=4.965 to 6.465 (S/N value)

=1.77to2.1Kg/ Kg/cm^2 - (Actual value)

Discussion of Results

Tensile strength value of Specimen made of fresh silica sand is considerably low. At lower percentage Sodium silicate tensile strength values are almost zero. Response graphs for Tensile Strength indicates optimum condition (Ref Fig3).But significance of factors and their relative percentage contribution can be ascertained through ANOVA and F-Test. Sodium silicate is the most significant factor .Coal dust and gassing time are the next best significant factors affecting Tensile Strength.

Generally higher percentage of coal dust should diminish strength values but in present case optimum level of coal dust is at higher level i.e 2% .Probably the coal dust entrapped within the binder bridge may be resisting the applied tensile force during tensile test and hence the optimum level of coal dust is at higher level i.e 2%

Conformation Experiments

To ensure validity of the optimum conditions obtained through Taguchi technique confirmation experiments are conducted. To determine tensile strength and average value of Tensile strength is observed to be 1.8 kg/sqcm while the range of expected tensile strength of mould at optimum condition is 1.77 to 2.1 kg/sqcm

Conclusion

Taguchi method has been successfully employed to optimize process parameters of CO_2 moulding process for better Tensile strength. It is observed that Sodium silicate, Amount of Coal dust, quantity of CO_2 gas is the significant factors. But percentage contribution of Sodium silicate on variation of Tensile strength is very high.

Result of conformation test is within the range of expected Tensile strength at optimum condition with a confidence level of 95%.

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