Parametric Optimisation of Carbon - Dioxide Moulding Process for Maximum Mold Hardness

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***Abstract*—Mould hardness is the important property required for a mould while casting high density alloys. In the present study, it is attempted to optimize the process parameters of CO_2 moulding process for maximizing its mould hardness. Four process parameters i.e % of sodium silicate, quantity of CO_2 gas, mixing time and % of Coal dust are considered. Taguchi method is employed for the purpose .ANOVA & F-test are conducted to discriminate significant factors from the remaining factors. It is observed that all the considered process parameters are significant for maximizing mould hardness**

***Keywords*—Mould Hardness,Optimization,ANOVA**

I. INTRODUCTION

Sand molding is a conventional molding process to provide castings of various alloys in to different shapes as per the requirement .Variety of sand moulding process are available .But still carbon dioxide moulding process has its own merit in producing castings of sound quality.First sodium silicate process was conceived in 1898 and it has become a popular process for core making by 1956.

1.1Carbon Dioxide Moulding Process:-

In CO2 moulding process, moulding sand is mixed with sodium silicate .The mix is loosely rammed in the mould around the pattern. Carbon dioxide gas is sent into the mould .carbon dioxide is mixed with sodium silicate and hence silica gel is formed.

$Na_2SiO_3 + H_2O + CO_2$ -----→ $Na_2CO_3 + SiO_2 + H_2O$ ----- (1)

Attrton [1] expressed that there is considerable evidence to show that equation (1) is over simplified and in many ways always incorrect. Nevertheless, silica gel is a new product that is found most often in reactions caused by various hardeners.

Sol i.e colloid of solid in a liquid "formed when fine soild particles are dispersed in a liquid. In some cases it is possible to make the dispersed phase coagulate and enclose all the liquid within it. This new product is called gel and in the present case it is "silica gel" .In silica gel the dispersed phase is silica.

During CO_2 moulding process gel formation can be visualized as follows:

Water solution of sodium silicate reacting with CO_2 produces mono silisic acid and sodium carbonate.

$Na_2SiO_3 + SiO_2 + 2H_2O + CO_2$----→ $Si(OH)_4 + Na_2CO_3$-------------(2)

While giving a comprehensive description of strength development process in silicate bonded mould Sarkar[2] mentioned that silicic acid gel with condensed water precedes formation of silica gel and strength of silicic acid gel is achieved by removing the condensed water. Warry [3] described silicic acid gel as loose network of colloidal particles interconnected at only few points in which water and dissolved salts are immobilized .It is prevented from collapse by repulsive forces between other parts of particles. Sarkar [2] mentioned that over -gassing is a consequence of expelling water held in capillarity below a certain level causing gel to shrink and form cracks

Into to it can be concluded that the prime responsible for strength development in silicate bonded moulds is silica gel.

1.2. Importance of present investigation:-

Carbon dioxide moulds are useful for pouring alloys of high density like steel [4] .Hence the requirement of mould in high hardness and strength .High hardness of mould resist penetration of hot liquid metal, usually of high density, in to mould wall. So hardness of mould should be higher the better.

By varying different parameters of moulding process the properties of mould wall will alter. So it is necessary to find out a set of values of parameters of the process that maximizes mould hardness. Previously M.venkataRamana [5] optimized process parameters of CO_2 moulding process for better tensile strength.

1.3 Taguchi method: Conventional full factorial experimentation causes lot of time and money to arrive at optimum process parameter values [6]. It is very difficult to analyze the numerous data obtained and draw proper conclusions.

Design of experiments is highly useful in planning the experiments systematically and also helps in drawing a meaningful conclusion [7] Several stratified techniques are available to plan for engineering and scientific studies. One such technique is Taguchi method which prescribed a standard way to utilize design of experiment technique for improvement of quality of products and process [8] Several researcher [9,10] across the globe attempted optimization of process parameters of various manufacturing processes.

2. OBJECTIVE OF PRESENT INVESTIGATION:

In the present investigation it is attempted to optimize the process parameters of CO_2 molding process for maximizing the mould hardness of mould. Taguchi method is employed for the purpose of optimization

3. SEQUENTIAL STEPS OF INVESTIGATION:

Sequential steps of the present investigation are

- **i)** Identification of process parameters that affect mould hardness and fixing their level values.
- **ii)** Deciding suitable experimental plan using Taguchi orthogonal arrays
- **iii)** Arrangement of setup for supplying desired quantity of CO_2 gas
- **iv)** Experimental Determination of mould hardness as per the plan.
- **v)** Analysis of results

3.i .Identification of process parameters that affect mould hardness and fixing their level values:-

Process parameters that affect mould hardness of CO_2 moulding process are:

a) Percentage of sodium silicate
b) Quantity of CO_2 gas
c) Mixing time of sodium silicate and sand mix
d) Percentage of coal dust.

3.i.a)percentage of sodium silicate : Sodium silicate is prime responsible for strength and hardness of mould made of CO_2moulding process .Usually 3% to6% sodium silicate is used in the process [11].Hence in present investigation % of sodium silicate is considered at two levels i.e 4% and 6%.

*3. i.b) Quantity of CO_2**gas(** CO_2 gassing time):* Carbon dioxide gas , when passed through the mould, mixes with sodium silicate and silica gel is formed. This silica gel is the main bonding agent between the sand grains .If sufficient quantity of CO_2 gas is not supplied it may hamper the bonding process. At the same time if more amount of CO_2gas is supplied, it may result in to formation of white patches indicating the formation of sodium bicarbonate .This sodium bicarbonate formation reduces the strength of the bond. Hence adequate supply of CO_2gas is essential for maximizing mould hardness. As per the Chemical balance between CO_2 and Na_2 O of Sodium silicate, it is estimated that 10kg of CO_2gas is required for 100kg of silicate used. However in shop floor conditions, quantity up to 40kg of CO_2 per 100kg of sodium silicate is used

The two levels of CO_2gas supply are appropriately converted into gassing time and hence in this paper the parameter, quantity of CO_2 gas is termed as gassing time. First level of quantity of CO_2gas i.e 10kg per100kg of sodium silicate yield to 13 seconds gassing time and second level i: e 40kg per100kg of sodium silicate yields to 30 seconds.

3. i.c)Mixing time: Mixing of sand and sodium silicate ensures uniform coating of silicate on sand grains which will further ensure proper formation of silica gel on the entire sand grain surface. Generally a mixing time of 5 minutes to 10minutes is employed .In present study two levels i.e. 5 minutes and 10minutes are considered.

3.i.d) Coal dust: **C**oal dust addition enhances collapsibility of CO_2 mould after pouring .Usually 2% of coal dust addition are made [12] .The two levels of coal dust considered are 0% and2%.

Process parameters and their level values are given in Table-1

Table-1 Description of 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)	5 minutes	10 minutes
4	Quantity of CO2 gas(gassing time(GT)	13 seconds	30 seconds

3. ii)Deciding suitable experiment plan using Taguchi orthogonal array.

Four factors at two levels lead to 4 degrees of freedom and the two interactions between sodium silicate & gassing time and sodium silicate & mixing time lead to two more degrees of freedom and total degrees of freedom account to 6' .So a L_8 orthogonal array with seven degrees of freedom suffices the requirement.

L_8 orthogonal array with actual level values of factors is presented in Table2

Table -2 Experimental plan

Trail No	GS(1)	GT(2) (Seconds)	SSX GT(1 X2)	MT(4) (Minutes)	SSXMT (1X4)	Unused colum n	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%

3. Iii) Arrangement of setup for supplying desired quantity of CO_2 gas:

To ensure adequate supply of CO_2 gas a gassing arrangement setup with Pressure gauge and Rota meter is made.

3. iv)Experimental Determination of mould hardness as per the plan.

Fresh silica sand with a grain Fineness number of 59.87 is considered in present work. Screen distribution of the used sand is given Table-3

Table-3 Screen distribution of fresh silica sand

Aperture Opening	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

AFS standard specimen of 2'' X2" cylindrical shape are prepared as per experiment plan mentioned in Table-2.Mould hardness values are determined using scratch hardness tester. Standard AFS specimen and scratch hardness tester are shown in Fig-1 and Fig-2 respectively.

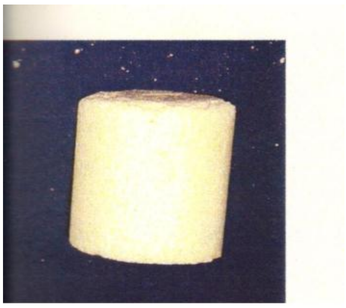

Fig.1 AFS standard sand specimen

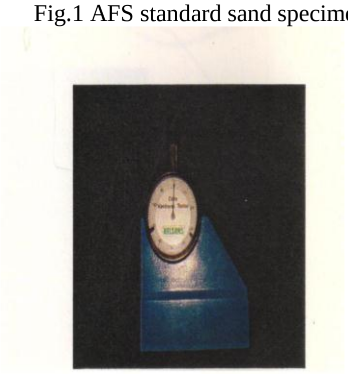

Fig.2 Scratch hardness tester

Experimentally determined mould hardness values of fresh silica sand mould are tabulated in Tab-4

Table-4 : Experimental values of mould hardness

Expt Trail No	Mould hardness (Scratch Hardness No)			Average Value	S/N ratio
1	72	72	71	71.67	37.105
2	63	64	67	64.67	36.204
3	75	71	70	72	37.135
4	71	75	72	72.67	37.219
5	81	79	81	80.33	38.096
6	75	78	80	77.67	37.795
7	81	82	82	81.67	33.24
8	78	78	76	77.33	37.765

Quality characteristic for mould hardness is "Bigger the better type"

S/N ratio = -10 log(MSD) -------(3)

Where MSD=mean square deviation

For "Bigger the better type"quality characteristic

MSD = $[(1/y_1^2+1/y_2^2+1/y_3^2+\ldots.)/n$----------------(4)

3.v Analysis of Results

S/N analysis of experimentally obtained mould hardness values are made and response graphs are shown Fig-3

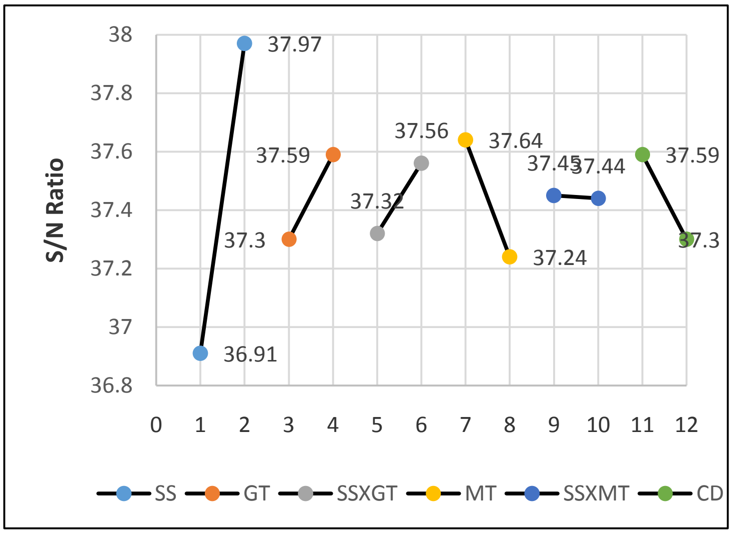

Fig.3:Response graph

Optimum condition for maximizing mould hardness can be determined based on response graphs, but prior to that significant and insignificant factors are to be discriminated. This can be done by performing Analysis of Variance (ANOVA) on obtained mould hardness data and performing

F-Test

. Analysis of Variance for Mould hardness is given in Table-5.

Tables-5 : Analysis of Variance

Factor Name	DOF	SS	Variance	F-ratio	Percentage of contribution of factor
SS	1	2.239	2.239	27.816	72.6
GT	1	0.167	0.167	2.08	5.418
SSXGT	1	0.108	0.108	1.353	3.504
MT	1	0.317	0.317	3.946	10.28
SSXMT	1	0	0	0	0
CD	1	0.167	0.167	1.98	5.418
Error	1	0.084	0.084		2.78
Total	7	3.082			100

3.v.a)F-Test : From F-test it can be observed that except interactions all the factors are significant. Hence from response graph and F-Test optimum condition can be obtained and the obtained condition is given inTable-6 Percentage contribution of each factor and interaction towards mould hardness is given in Fig-4

Table-6: Optimum condition

Factor Name	Level Description	Level Contribution
SS	6%(2)	0.529
GT	30 sec(2)	0.144
SSXGT	(2)	0.116
MT	5 min (1)	0.199
SSXMT	(1)	0.005
CD	0% (1)	0.144

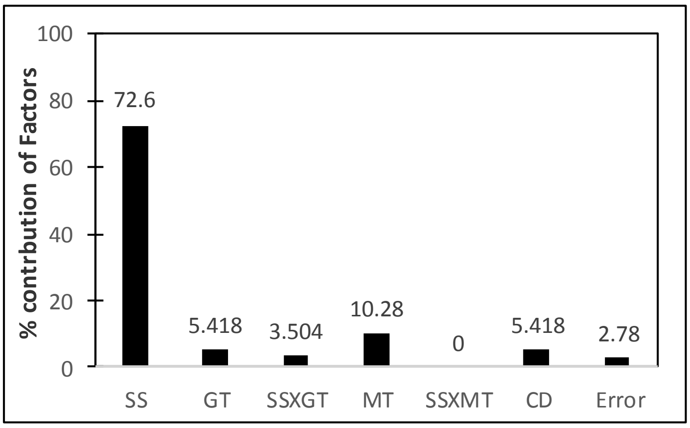

Fig-4Percentage contribution of each factor and interaction on mould hardness

Grand average of S/N values of mould hardness ($\bar{T}$)=37.445

3.v.b)Expected mould hardness at optimum condition:

Expected mould hardness at optimum condition

Y optimum = $\bar{T} + [\bar{SS}_1 - \bar{T}] + [\bar{GT}_2 - \bar{T}] + [\bar{MT}_1 - \bar{T}] + [CD_1 - \bar{T}]$

= 37.445+0.529+0.144+0.199+0.144

=38.461 (S/N value) (based on the significance of factors and their percentage contribution towards result)

After obtaining optimum value of S/N ratio MSD can be calculated using equation 3 and by using equation 4, MSD value can be converted in to actual value of mould hardness and the value is 83.76

3.v.c)Range of Expected mould hardness at optimum condition

Range of expected mould hardness at the obtained optimum condition of process parameters with specified confidence level is determined as follows

Confidence level(CL)=95%

F(n1,n2)=F(1,1)=1.6

Confidence interval (CI)

$$CI = \sqrt{F(1,n2)*Ve/NE} \quad \text{----------- (5)}$$

Ve =Error variance=0.084

Ne=Effective number of replications

=Total number of S/N values

DOF of mean (always=1)+DOF of factors

=8/(1+4)=1.6

Confidence interval (C.I)=+/- 0.2828

Range of Mould hardness at optimum condition = (38.461-0.2828) to (38.461+0.2828)=38.1782 to 38.743(S/N value)

Using equation 3 and4 S/N values are converted in to actual values of mould hardness and it is found that the range of mould hardness value at optimum condition is from 81 to 86.5

Conformation test is conducted at obtained optimum condition and average of three mould hardness values at this optimum condition is observed to be 82. This mould hardness value is well within the range of expected mould hardness value at optimum condition

4.CONCLUSIONS:

Using Taguchi Technique Process parameters of CO_2 moulding process are successfully optimized for maximum mould hardness. All the process parameters considered i.e % of sodium silicate, quantity of CO_2 gas mixing time and % of coal dust are observed to be significantly affecting mould hardness Optimum value of process parameters are

% of Sodium Silicate: 6% ; Quantity of CO2 gas (gassing time):30secnds

Mixing time: 5 minutes; % of Coal dust:0%

None of the considered interactions are found to be significant. Mould hardness obtained through validation experiment conducted at optimum condition is well within the expected range of mould hardness at optimum condition.

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