Process Parameter Optimization of CO_2 Moulding Process for Better Permeability

M.Venkata Ramana, Professor,
CVR college of Engineering/Mechanical Department,Hyderabad.
Email: ramlalith@rediffmail.com

Abstract—**Present investigation deals with optimization of process parameters of CO_2moulding process for better permeability. Percentage of sodium silicate, quantity of CO_2 gas, mixing time and percentage of coal dust are considered as factors. Each factor is considered at two levels. Taguchi method has been used for the purpose. It is observed that sodium silicate and coal dust addition are the significant factors affecting permeability. Optimum condition is verified through confirmation experiments.**

Keywords : **Permeability ,ANOVA ,Taguchi, Optimization**

I. Introduction

Metal casting is a basic primary manufacturing process and sand moulding is the extensively used moulding process for producing castings. Though several types of moulding processes are evolved, sand moulding has got its share in production of moulds for preparing castings. CO_2 moulding process is one of the sand moulding processes available. CO_2 moulding process was first conceptualized in 1898 and emerged as a popular process for core makingby1956.With the evolution of organically bonded sand system CO_2 process was pushed back and its application was limited to core making. Later the consequent environmental pollution problems of organic binders, brought CO_2 process again into lime light for the production of moulds.

A) CO_2Moulding Process

A mix of sodium silicate and silica sand is prepared in a mixer and this mix is poured around the pattern as loose ram. When carbon dioxide is sent in to mould, the following reaction takes place

Na2SiO3 +H2O +CO2 -→ Na_2CO3 +SIO2+H2O--(1)

Sodium silicate is a meta stable compound and can be easily decomposed into mono silisic acid Si(OH)4. Mono silisic acid further polymerizes into high polymers, namely ploy silisic acid, and a gel is formed. This gel gets the ability to adhere to clean surface of sand grains and in turn form a bridge between the sand grains. This silica gel bridge between sand grains provides the required strength to mould. Atterton [1], Warry [2], Srinagesh [3] explained the bond formation mechanism of CO_2 process in detail and quoted that silica binder bridge in CO_2moulding process is brittle and porous.

B) Permeability

General characteristics of sand mould are strength hardness permeability, collapsibility etc…. In present paper permeability is considered. Ability of sand mould to permit free escape of gases through its pores is known as permeability i.e. permeability reflects venting quality of mould. The time required to pass 2000cc of air through AFS standard cylindrical sand specimen is known as permeability

$$\text{Permeability} = \frac{vxh}{pxaxt} \quad \text{----------} \ (2)$$

Where v=volume of air in cc passing through AFS sand sample

h=height of specimen (5.08 cm)

p=Pressure of air in drum (10 gm/cm^2)

a=cross sectional area of specimen (20.268 cm^2)

t=time in seconds for passing 2000 cc of air to pass through sand specimen.

C) Importance Of Present Work

By varying different parameters of CO_2 moulding process, the properties of mould can be changed. Generally every foundry man concentrates on maximization of strength and hardness. If strength & hardness is maximized, its permeability may be low and at the same time if permeability is high, it tells upon strength and hardness of mould. Too high permeability of mould leads to weaker mould. At the same time mould with low permeability reflects on quality of casting with defects like internal porosity. Hence our attempt should not be towards either maximization of permeability or minimization of permeability but to attain a reasonably good value of permeability. This nominal value of permeability is chosen as 80(no units) permeability number [4]. There is a necessity to determine at what values of process parameters, the permeability of mould shall be nearer to 80 permeability number.

II. Purpose Of Investigation

Purpose of this investigation is to optimize the process parameters of CO_2 moulding process for a targeted value of permeability. Taguchi's orthogonal array is used as experimental plan for the purpose of optimization.

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A) Steps Involved

- Fixing number of levels and level values of each process parameter.
- Deciding suitable experimental plan based on number of factors and their levels.
- Experimental determination of permeability
- Analyzing the results to attain optimum condition and expected permeability, range of permeability at optimum condition.
- Validation of optimum condition through confirmation test.

B) Fixing Number Of Levels And Level Values Of Each Process Parameter

Permeability of mould varies according to the process parameters of the mould. Main parameters that affect permeability are percentage of sodium silicate, quantity of CO_2 gas, mixing time and type and amount of additives.

Percentage of Sodium Silicate:

Essential element that involves in bond formation of CO_2moulding process is sodium silicate. Hence percentage of sodium silicate is considered as factor. Usual percentage of silicate additions range from 3 to 6 percent. [5,6]. In present work two levels of sodium silicate i.e 4 percent and 6 percent are considered.

Quantity of CO2 gas:

Mixing of CO_2 gas with sodium silicate leads to formation of silica gel and this silica gel is prime responsible for bond formation in CO_2 moulding process. Supply of CO_2 gas to mould is to be properly controlled to maintain the permeability possibly nearer to target value.

10 kg of CO_2 gas per 100 kg of sodium silicate satisfies chemical equation involved in bonding process. [7]. But usually on shop floor 40kg of CO_2 gas is used per 100 kg of sodium silicate [8]. To exercise control over CO_2 gas supply an experimental setup with a rotameter is built up that maintains constant flow rate of CO_2 gas. Hence the above two quantities of 10 kg and 40 kg of CO_2 gas per 100 kg of sodium silicate are appropriately converted into gassing time i.e 13 seconds and 30 seconds respectively

So the two levels of quantity of CO_2 gas are 13 seconds and 30 seconds and in future section of this paper the factor quantity of CO_2 gas is termed as gassing time

Mixing time

Proper mixing is to be ensured to maintain desired level of permeability. Usually 5 to 10 minutes of mixing time are employed [8].In present work, two levels of mixing time i.e 5 minutes and 10 minutes are considered.

Coal dust Addition:

Common problem with CO_2 mould is poor collapsibility. To circumvent this problem coal dust additions are made to the mix. But this coal dust addition may influence permeability of mould. Generally coal dust up to 2 percent is added [8]. Hence in the present study, two levels i.e. 0 percent and 2 percent coal dust additions are considered.

C)Deciding Suitable Experimental Plan Based On Number Of Factors And Their Levels

Four factors and two interactions are proposed to be studied. An L8 orthogonal array with 7 degree of freedom is the suitable experimental plan for current work because it has got seven columns that can accommodate seven two level factors. Factors considered and their level values are shown in Table-1. Experimental plan with actual level values are shown in Table-2

TABLE-1

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)	5minutes	10minutes
4.	Gassing time	13seconds	30seconds

TABLE- 2

L8 ORTHOGONAL ARRAY WITH ACTUAL VALUES OF FACTOR LEVELS

Trail No.	SS (1)	GT (2) (Sec)	SSXGT (1X2)	MT (4) (Mins)	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%

D) Experimental Determination Of Permeability

Sand mixes are prepared as per the experimental plan given in Table-2 Standard AFS sand specimens are prepared with the help of a gassing arrangement. Schematic of gassing arrangement is given in fig-1. Gassing arrangement ensures supply of exact quantity of CO_2 gas to mould or AFS sand specimen

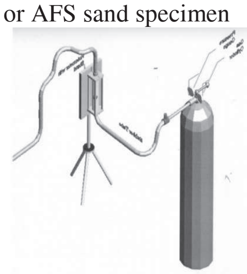

Fig-1 Schematic Of Gassing Arrangement Setup

Permeabilities of all the samples are determined with the help of a permeability meter (shown in Fig-2), and all tests are conducted according to AFS testing procedures 318-87-5….[8]. To reduce the effect of noise on result, each experiment is replicated thrice and experimental observations are tabulated in Table-3. Average value and S/N ratio are also given in same table.
S/N ratio can be calculated using the formula

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

Where MSD=Mean Square Deviation
In this paper, it is attempted to optimize the process parameters CO_2 moulding process for a targeted value of permeability number i.e ‘80’. Hence the quality characteristic of permeability is “Nominal the better type”
For Nominal the better type quality characteristic”

$MSD=[(y_1-y_0)2+(y_2-y_0)^2+(y_3-y_0)^2+\ldots..]/n$ -------(3)

Where n=number of replications and
y_0=Targeted value of permeability

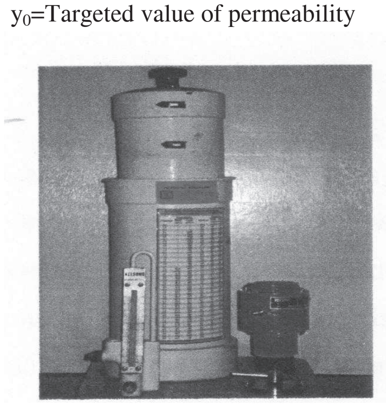

Fig:2 Permeability meter

TABLE-3

EXPERIMENTAL OBSERVATIONS

Expt no	Permeability No (large orifice)			Average Value	S/N ratio
1	550	492	525	442.333	-52.928
2	525	398	467	383.333	-51.751
3	492	550	550	450.666	-53.094
4	650	650	950	670	-56.711
5	99	90	99	16	-24.594
6	235	264	326	195	-45.963
7	275	226	226	162.33	-44.296
8	185	226	226	132.33	-42.526
				306.5	-46.456

E) Analysis of Results

S/N ratio of each experimental trial combination are computed and are given in Table-3. To determine the effect of variation of value of each factor on permeability, response graphs are drawn and is given in Fig-3. From Response graphs one can obtain the optimum condition by considering the level value of each of process parameter that maximizes S/N value as optimum condition. But exact optimum condition is to be decided after discriminating significant and insignificant factors. For identifying significant factors, we have to perform Analysis of Variance (ANOVA) and then F-test. ANOVA table of experimental observations are given in Table-4

TABLE-4

ANOVA TABLE

Factor	Dof	SS	Variance	F-ratio	Percentage Contr -ibution
SS	1	410.725	410.725	9.539	56.5
GT	1	58.356	58.356	1.355	8.02
SSxGT	1	16.114	16.114	0.374	2.2
MT	1	61.913	61.913	1.437	8.5
SSXMT	1	37.731	37.731	0.87	5.19
CD	1	99.05	99.05	2.3	13.62
Error	1	43.056	43.056		5.97
Total	7	726.94			100

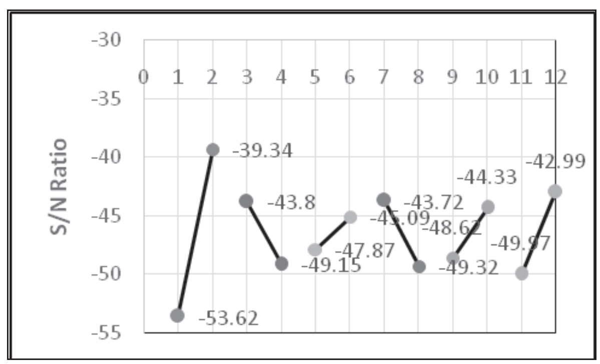

Fig-3 Response graph

F-Test:

By comparing computed F-ratio values from ANOVA table and F-ratio values obtained from statistical table corresponding to degrees of freedom of factor and error degrees of freedom, it is found that only sodium silicate (SS) and coal dust addition (CD) are the significant factors. Percentage contribution of each factor and interaction on permeability is shown in Fig-4. Optimum condition for “Nominal the better type” quality characteristic of permeability is given in Table-7.

TABLE 7

OPTIMUM CONDITION

Factor name	Level Description
SS	6% [2]
GT	13 Sec [1]
SSxGT	[2]
MT	5 Min [1]
SSxMT	[2]
CD	2% [2]

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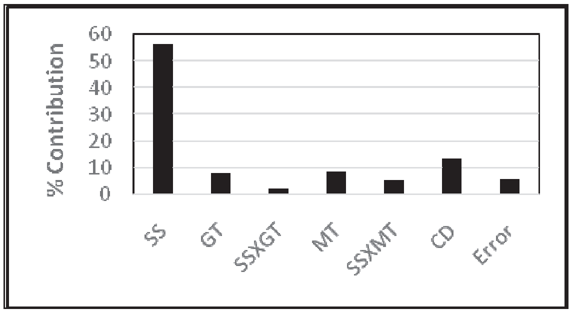

Fig4: Percentage Contribution Of Each Factor And Interactions On Permeability

Expected permeability at optimum condition

$$Yopt=\overline{T}+[\overline{SS2}-\overline{T}]+[\overline{CD2}-\overline{T}]$$

= -46.45+10.138+6.491

=-29.82(S/N values)

=110.9

Range of expected permeability at optimum condition

$$\text{Confidence interval [C.I]}=\sqrt{\frac{F(1,n2)*Ve}{N2}} \quad \text{---(4)}$$

Ve=error variance

$$Ne=\frac{\text{Total number of S/N values}}{\text{DOF of mean + Dof of factors}}$$

$$=\frac{8}{1+4}=1.6$$

F(1,n2) = F-values from statistical table corresponding to error degree of freedom and factor degree of freedom

C.I = +- 5.079

Range of expected permeability at optimum condition

=-27.48 to -34.9 (S/N values)

=90.2 to 135.5 (Actual values)

It can be observed that sodium silicate is the most significant factor affecting permeability relative to other factors and interactions. However the percentage contribution of sodium silicate towards permeability is less compared to mould hardness and compression strength. As percentage of sodium silicate increases permeability decreases and hence optimum level of sodium silicate for the target value of permeability is 6 percent. Next best significant factor is coal dust. Coal dust, being very fine, compared to fresh silica sand, may clog the pores between sand grains and hence permeability decreases with increase in percentage of coal dust. Hence optimum level of coal dust for targeted value of permeability is 2 percent.

F) Validation of Optimum Condition Through Confirmation Test

Optimum condition obtained through Taguchi analysis is ascertained through validation experiments conducted at optimum condition. Average of permeability of three experimental trials conducted at optimum condition is observed to be 99, which is well within the range of expected permeability at optimum condition.

III. Conclusion

Process parameters of CO_2moulding process are optimized, using Taguchi technique. For better permeability. it is observed that percentage of sodium silicate and percentage of coal dust are the significant factors.

Optimum condition: Percentage of sodium silicate -6 percent; Mixing time- 5 minutes; Gassing time -13 seconds and coal dust -2percent

The optimum condition obtained is confirmed through validation experiments.

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