DAMPENING OF NOISE PARAMETERS FOR DEVELOPING CERAMIC SHELL PROCESS FROM COAL FLYASH BY TAGUCHI METHOD

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ABSTRACT

The present work highlights the optimization of process parameters to dampen the effects of noise (uncontrolled) factors. The dampening of noise factors and subsequent optimization have been carried out by Taguchi's method. The predicted optimum values of hot bending strength, hot permeability, and % thermal shock of shells are respectively 2.42 N/mm^2, 7.94 and 0.24.

NOMENCLATURE

α	risk
C.I	confidence interval
e	error
e_p	pooled error
F	ratio of variances
N	total number of observations
n_{eff}	effective' number of observations
p	percent contribution
SS	sum of squares
T	sum of square due to total variation
$\overline{T}$	Grand mean of ail observations
v	degrees of freedom
V	variance
V_e	degree of freedom for pooled error
V_{ep}	pooled error variance

INTRODUCTION

In the manufacture of ceramic shells by the investment casting process, a multi-layered ceramic shell is built-up by repeatedly dipping a wax pattern in a slurry, draining and sprinkling with a coarse sand. Each individual coat is air-dried prior to applying the next coat [1].

Dip-coating slurries for shell making are refractory filler materials dispersed in a liquid binder. Is it practically and economically feasible to control: i) equal size and same shape of filler and stucco particles; ii) constant temperature and humidity of air throughout the year; iii) settling down of filler due to standing of slurries (not stirred); iv) pre-gelling of slurries due to stirring; and v) increasing of slurry viscosity due to evaporation of liquid content ? These uncontrollable parameters are called noise parameters [2-4].

The present investigation was aimed at to design process parameters (control) of ceramic shell process from coal flyash damping the effects of noise parameters. This was carried out by Taguchi method.

EXPERIMENTAL PLANNING AND TESTING

RAW MATERIALS USED:

Binder - Colloidal Silica
Refractory filler - Coal flyash (4S and 74µm)
Coating powder - Zircon (45 µm)
Stucco sand - i) Primary stucco of AFS 120
ii) Back-up stucco of AFS 50.

PLANNING

The important process parameters by which the properties of the ceramic shell moulds could be affected are as follows:

- Concentration level SiO_2 in the binder.
- Particle size of filler.
- Filer to binder ratio in the dip-coating slurry.
- Standing time of dip-coating slurries.
- Type of coating.
- Air-drying time of coats.
- Sintering temperature of shells.

The individual and interaction contribution of the above-said process parameters were investigated by Taguchi method to dampen the noise factors.

The characteristics of shells optimized for the process are as follows:

- Hot bending strength
- Hot permeability
- %Thermal Shock

The effects of noise factors were dampened considering the signal - to - noise (S/N) ratios of shell characteristics. Hot bending strength, hot permeability and % thermal shock respectively were chosen as 'higher is better', 'nominal is best' and 'lower is better' type characteristics [3]. The selected levels for the chosen process parameters are summarized in Table - 1. Each of the seven process parameters was studied at two levels. There seems the possibility of 8 interactions among the process parameters. The assignment of process parameters and interactions along with the OA matrix is given in Appendix - A.

Table -1: Process Parameters and Levels

Factor	Symbol	Level-1	Level-2
%SiO_2 in Binder	A	25	30
Filler particle Size, µm	B	45	74
Filler/biner ratio, cc/ml	C	0.60	0.70
Standing time of slurry, hr	D	0	4
Drying time of shells, hr	E	2	4
Sintering temperature, ^{0}C	F	400	600
Coating on shells	G	No	Yes (Zircon)

Manufacturing of Shells and Testing.

Ceramic shells were made by applying a series of ceramic coatings to the wax patterns. The pattern was first dipped into the dip - coating slurry bath. The pattern was then withdrawn from the slurry and manipulated to drain off excess slurry and to produce a uniform layer. The wet layer was immediately stuccoed with coarse silica sand. Each coating was allowed to dry in the open air. The operations of coating, stuccoing, and drying were repeated six times. The seventh coat was left unstuccoed to avoid the occurrence of loose particles on the shell surface. The first two coats were stuccoed with a sand of AFS fineness number 120 and the next four coats were with a sand of AFS fineness number 50. As per the design of experiments, the first two coats on some of the patterns were also given by dipping them in the slurry prepared from zircon powder. The zircon coating was to improve the surface finish of castings and the refractoriness of shells. After all coats, the shells were air dried for 24 hours. Two shells for each treatment were on random basis distributing in one calendar year to involve the effects of noise factors.

The hot bending strength and hot permeability of shells were conducted on an universal sand strength machine and standard permeability meter with an attached electrical oven respectively. The length, width and thickness of shells were measured using vernier calipers before and after sintering in the electrical oven. The % thermal shock was computed using the following formula:

% thermal shock =

$$\left[\frac{\begin{pmatrix}\text{Volume of shell}\\ \text{after sintering}\end{pmatrix} - \begin{pmatrix}\text{Volume of shell}\\ \text{before sintering}\end{pmatrix}}{\text{Volume of shell before sintering}}\right]\times 100$$

The S/N ratios of hot bending strength, hot permeability and % thermal shock were calculated. The equations for calculating S/N ratios are as follows:

S/N ratio of hot bending strength,

$$Y_b = -10\log\left[\frac{1}{r}\sum_{i=1}^{r}\frac{1}{y_i^2}\right] \quad [1]$$

S/N ratio of hot permeability, $Y_p = -10\log v_e$ [2]

S/N ratio of % thermal shock,

$$Y_b = -10\log\left[\frac{1}{r}\sum_{i=1}^{r} y_i^2\right] \quad [3]$$

where,
r = number of tests in a trial

$$V_e = \frac{SS_e}{v_e} = \frac{SS_T - SS_m}{r-1} \quad [4]$$

$$SS_T = \sum_{i=1}^{r} y_i^2 \quad [5]$$

$$SS_m = r(y)^2 \quad [6]$$

ANALYSIS AND DISCUSSION

The S/N ratios of hot bending strength, hot permeability and % thermal shock of shells are given in Appendix - B.

HOT BENDING STRENGTH OF SHELLS

Table - 2 gives the pooled ANOVA summary of S/N ratios. The percent contribution indicates that parameter F (sintering temperature) contributes 45% to reduce variation; parameter B aids $^{1}/4$th of total reduction in variation and the interaction subscribes a contribution of 11.26 %, Even though the parameters A {concentration of SiO_2 in the binder), C (filler/binder ratio) and D (standing time of slurry) are significant their contribution to reduce variation in hot strength of shells is less, The particle size and shape of filler are uncontrollable. Fine particles of coal flyash exhibit greater strength of shells. Lots of smaller particles will produce more individual links than fewer large particles. The rate of sintering the ceramic shells is greatly affected by the thermal conductivity of shells and heat dissipation to the surroundings. The sintering causes the crystallographic change of silica content in the coal flyash. Coal flyash consists of 62 % of SiO_2.

Table-2 : Pooled ANOVA Summary - Bending Strength

Source	SS	V	V	F	P
A	1.155	1	1.155	$8.59^{\#}$	1.33
B	19.228	1	19.228	143.01^{+}	25.01
C	1.79S	1	1.795	13.35+	2.17
BxC	8.732	1	8.732	64.94^{+}	11.26
D	4.972	1	4.972	36.98^{+}	6.33
F	36.360	1	36.360	270.44^{+}	47.46
e_P	1.210	9	0.134	-	6.44
T	76.319	15	-	-	100.00

+ at least 99% confidence
 # at least 95% confidence

HOT PERMEABILITY OF SHELLS

The pooled ANOVA summary is given in Table - 3. The only one controllable parameter to reduce variation in the hot permeability of shell is E, drying time. The others are found to be less significant in controlling the noise effects in the permeability of shells. If drying is too long, the evaporation of liquid content in the slurry forces the filler and stucco particles together. This results the reduction in size of voids in a layer of shell. On subsequent dip - coatings, these voids are also further filled up by the slurry. This can actually reduces the permeability in the ceramic shells. Therefore, a relative humidity of 50% is recommended for normal conditions.

Table -3: Pooled ANOVA Summary – Permeability

Source	SS	v	V	F	P
A	69.472	1	69.472	$5.86^{\#}$	21.39
e_p	165.858	14	17.847	-	78.61
T	269.371	15	-	-	100.00

 # at least 95% confidence

THERMAL SHOCK OF SHELLS

The pooled ANOVA analysis of S/N ratios is shown in Table - 4. The analysis indicates that parameter F, sintering temperature is very important to reducing variation of thermal shocks of shells. This variation is in two forms: variation due to phase changes of filler and stucco particles and variations due to thermal expansion / contraction of shells. Parameters A, B, C and interaction CxF are relatively weak.

Table - 4 : Pooled ANOVA Summary - % Thermal Shock

Source	SS	V	V	F	P
A	1.416	1	1.416	11.93+	0.30
B	9.796	1	9.796	82.55+	2.26
C	1.392	1	1.392	11.73^{+}	0.29
F	412.09	1	412.09	3472.66^{+}	96.53
CxF	0.624	1	0.624	$5.25^{\#}$	0.11
e_p	426.761	15	-	-	100.00

+ at least 99 % confidence
 # at least 95 % confidence

OPTIMUM LEVELS OF PROCESS PARAMETERS :

The confirmation tests were carried out (Appendix - C) to validate the conclusions drawn during the analysis phase. The predicted values of hot bending strength, hot permeability and % thermal shock are respectively 2.42 N/mm^2, 7.94 and 0.24 which are approximately equal to the average values (converted from dB values) of treatment No. 10. Hence, all the process parameters with the levels of treatment No. 10 are chosen for the manufacturing of ceramic shells from coal flyash.

CONCLUSION

The sintering temperature and filler particle size are very important to reducing variation of shell bending strength. The amounts of percent contributions for sintering temperature and filler particle size are respectively 45 and 25. The only one controllable parameter to dampen the effects of noise parameter in hot permeability of shells is the drying time. The variation in the thermal shock of shells is caused due to phase changes of filler and expansion/contraction of shell. The predicted values of hot bending strength, hot permeability and % thermal shock are respectively 2.42 N/mm^2, 7.94 and 0.24.

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[1]. Chennakesava Reddy. A and Murti VSR,| Studies on Lost - Wax Process using Siloxj binder, Proceeding at Xth ISME Conference on Mechanical Engineering, New Delhi , 1996, pp 82-86.

[2]. Doskar J and Gabriel J, How Dip coat materials affect ceramic investment shells, Part - II, Foundry, V 95, 1967, pp 146 -151.

[3]. Luneav N.A, Coefficient of Thermal Expansion of Investment Moulds, SOV cast technol, V1, 1987, pp 36 - 40.

[4]. Chennakesava Reddy A, Murti VSR and Sundara Rajan S, Some aspects of Reducing Sedimentation of Refractory Fillers in the Investment Casting Process, Engineering Advances V10, N8, 1998, pp 61-63.

[5]. Ross P.J, Taguchi Techniques for Quality Engineering, McGraw Hill, New York, 1988.

Appendix – A: Orthogonal Array (OA16) – Process Parameters and Interactions Assignment

Treat NX	A	B	CD	C	BD	BC	D	E	BF	CG	F	CD / BG	e	G	CF
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
I	1	1	1	1	1	1	1	I	1	1	1	I	1	1	1
2	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2
3	1	1	1	2	2	2	2	1	1	1	1	2	2	2	2
4	1	1	1	2	2	2	2	2	2	2	2	1	1	1	1
5	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2
6	1	2	2	J	1	2	2	2	2	1	1	2	2	1	1
7	1	2	2	2	2	1	I	1	1	2	2	2	2	1	1
8	1	2	2	2	2	I	I	2	2	1	1	1	1	2	2
9	2	I	2	1	2	1	2	1	2	1	2	I	2	1	2
10	2	I	.2	1	2	1	2	2	1	2	1	2	1	2	1
11	2	1	2	2	1	2	1	1	2	1	2	1	2	1	2
12	2	1	2	2	1	2	1	2	1	2	1	1	2	1	2
13	2	2	1	1	2	2	I	I	2	2	1	1	2	2	1
14	2	2	I	I	2	2	I	2	1	1	2	2	1	1	2
15	2	2	1	2	1	1	2	1	2	2	2	2	1	1	2
16	2	2	1	2	1	1	2	2	1	1	J	1	2	2	1

Appendix – B: S/N ratios of Shell Characteristics

Treatment No.	Hot Bending Strength Y_b, dB	Hot Permeability Y_p, dB	% Thermal Shock Y_t, dB
1	6.30	24.95	13.14
2	3.34	21.43	2.04
3	5.79	21.43	11.52
4	2.21	27.45	1.77
5	0.29	27.45	0.72
6	4.13	23.93	11.52
7	0.62	20.09	0.81
8	3.61	29.03	10.16
9	5.36	15.41	1.72
10	7.90	27.45	12.38
11	2.07	26.11	1.30
12	4.24	33.47	11.69
13	3.52	23.93	9.88
14	0.28	23.93	0.26
15	5.01	21.43	9.61
16	2.21	27.45	0.08

Appendix – C:

The optimum value of hot bending strength of shells was predicted at the selected levels of significant factors. The significant factors are % SIO_2 in the binder at level 2 (A_2), Standing time of slurry at level 2 (D_2), the sintering temperature at level 1 (F1) and the interaction B_1 x C_1.

The estimated mean of hot bending strength = $\overline{A_2} + \overline{B_1 \times C_1} + \overline{D_2} + \overline{F_1} - 3\overline{T}$

= 1.61 + 1.97 + 1.67 +1.82 – 3 X 1.55

Where grand mean, $\overline{T}$ = 1.55

$$N_{eff} = \frac{\text{N}}{1+(\text{Total degrees of freedom associated in the estimate of mean})}$$

$$\frac{32}{1+4} = 6.4$$

$$F_{\alpha:1:v_e} = F_{5:1:25} = 4.24$$

Confidence Interval, CI = $\sqrt{\frac{F_{\alpha:1:v_e} V_{ep}}{\ }} = \sqrt{\frac{4.25 \times 0.006}{\ }} = 0.063$

The predicted range of hot bending strength is 2.375 < 2.42 < 2.438