REDUCTION OF CASTING POROSITY IN THE LOST WAX PROCESS CHOOSING RIGHT COATING MATERIALS BY RESPONSE SURFACE CRITERIA

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ABSTRACT

The paper presents the reduction ofAl-12% Si alloy casting porosity in the lost wax process choosing right coating materials. The variable factors were type of flour, flour particle size, viscosity of slurry and grain fineness of stucco sand. The results were compared in respect of hot bending strength and hot permeability of ceramic shells and % volume porosity of castings. The analysis of the results was based on the response surface criteria. The response functions were determined for the indices. The casting porosity was not resulted due to the use of aluminium silicate as a flour material.

NOMENCLATURE

Y_1	- Hot bending strength N/mm^2
Y_2	- Hot Permeability
Y_3	- % Volume Porosity
Dof	- Degrees of freedom
SS	- Sum of squares
MS	- Mean sum of Squares
F_{cal}	- Calculated Fisher's ratio
H_0	- Hypothesis
SSR	- Sum of squares due to regression
SSE	- Sum of squares due to error
SST	- Total sum of squares.
R	-Coefficient of correlation

INTRODUCTION

In the manufacture of ceramic shell moulds by the lost-wax process, a multi layered ceramic shell is built up repeatedly dipping a wax pattern cluster in a slurry, draining and sprinkling with a coarse stucco grit. Each individual coat is hardened prior to applying the next coat [1].

The shell making process is shown in fig-1.

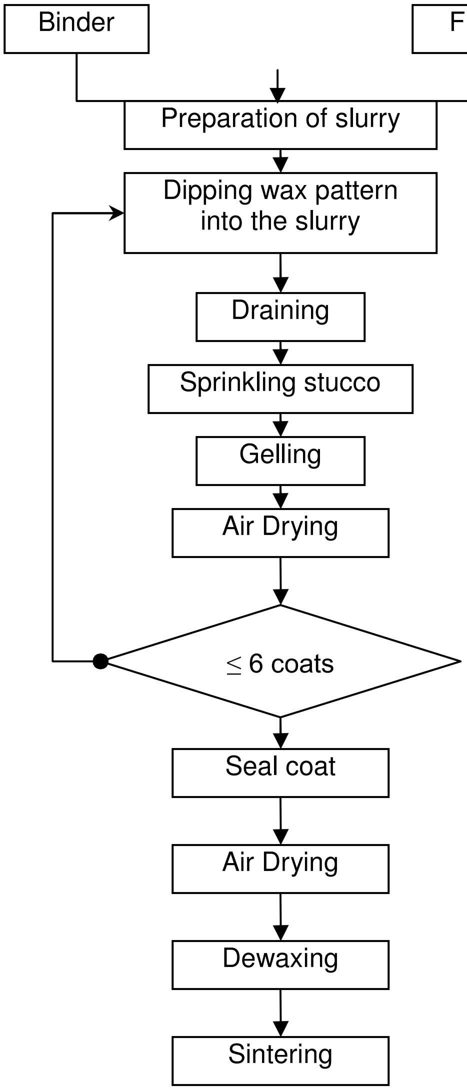

Fig. 1 : Shell making process

The refractory coating materials used to develop the shells in the lost wax process play a vital role in the production of quality castings. There are two grades of refractories used: flours for use in the slurries and grains for stuccoing the shell. Dip-coating slurries for shell making are refractory flour dispensed in liquid binder. The first two coats are made from a thin slurry and a fine sprinkling sand to obtain a thoroughly fine surface of the shell and a fine copying of smallest details of the pattern [2] Backup coats are formulated to coat readily over the prime coats to provide permeability and to build up the required thickness with a minimum of coats [3].

The A!-alloys used for aerospace applications should return intricate and dimensionally controlled shapes and sizes. If the shells have low permeability a back pressure will develop owing to sudden expansion of gas/air in the shells when liquid metal is poured. This back pressure may crack the shell, if not, may increase porosity in the castings or may result in complete filling or may affect dimensions of shell [4]. If the shell is too permeable, strength and dimensional stability may be sacrificed. The most common refractories used for ceramic shells are fused silica, zircon and alumina. Alumina is generally considered too expensive and unnecessary for commercial hardware casting. The present work was concerned about the reduction of gas porosity in the castings choosing right coating materials to develop ceramic shells in the lost-wax process, as well as the replacement of alumina by aluminum silicate (78%Al_20_3+22% $Si0_2$), The response characteristics of ceramic shells and the investment castings were analysed by the response surface criteria.

EXPERIMENTAL DETAILS

Materials used:

Refractory flours: Alumina and

alumina si!icate(78%Al_2 O_3+22% Si O_2)
Binder : Collidal Silica(30% Si O_2)
Flour particle size:
for prime coats : 45microns
for Backup coats: 45microns and 74 microns
Stucco grit for first two coats : AFS 100
Stucco grit for back up coats: AFS 30 and 50
Pattern : Bees wax
Alloy to be cast : Al 12%Si

PROCESS MODELLING

The variable factors selected are type of refractory flour, particle size of flour, grain fineness of back up stucco sand and viscosity of slurry. A fractional factorial experimental model was formulated with full randomization with the aid of a random numbers table [5].Three 2-level important interactions were considered in the design of experiments. The other 2^{j} level and high level interactions were found to be insignificant for the present work. For increased precision each experiment was replicated twice.

Mathematical model of the process:
A general model of the process can be expressed as: $Y = f(x_1, x_2 \ldots\ldots\ldots x_n)$ (1)

Y = response variable
F = response function
$X_1 \ldots x_2$ = Selected factors

A second order polynomial representation of the response surface is

$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_{13}x_1x_3 + b_{23}x_2x_3 + b_{34}x_3x_4$
where the coefficient b_o represent the response at the centre of experiment, the coefficients $b_1, b_2, b_3, b_4, b_{13}, b_{23}, b_{34}$ represent linear and linear x linear interaction effects of the factors x_1, x_2, x_3 and x_4 respectively.

The regression coefficients were computed by the least-square method [6]. A complete analysis of variance (ANOVA) was performed to test the significance of the obtained coefficients at 5% level of significance. The procedure is illustrated in Table –A.

PREPARATION AND TESTING OF SHELLS AND CASTINGS

The dip coating slurry was prepared by adding the refractory flour to the binder liquid using sufficient agitation to break up agglomerates and thoroughly wet and disperse the powder. The viscosity of the slurry was tested using the ford cup. Six layered specimens for bending and permeability tests were made by repeatedly dipping the slurry draining stuccoing and drying. First two coats were stuccoed with a fine sand of AFS 100 to facilitate fine copying of the wax pattern details, fine surface of the casting and low metal penetration into shell. Next four coats were stuccoed with coarse sand. Each coat was air dried for 2 hours. The specimens were fired at 400° for one hour and cooled to room temperature, and the same were tested for hot bending strength and hot permeability. An Al-12%si alloy was melted in a diesel furnace and the liquid melt was degasified with hexachlorine tablets and modified with cover all (a Fosceco company product). The liquid melt was then poured into the preheated (300°C) ceramic shell moulds. The solidified castings were tested for porosity. The volume porosity was calculated by using the relation:

$$\% \text{ Volume Porosity} = \frac{P_t - P_a}{P_t} \qquad (2)$$

Table -A : ANOVA analysis

S.No	Factor	Estimate-b	SS	DOF	MS	F	H₀
1.	b1	-0.22	0.801	1	0.801	356.00	Reject
?.	b2	-0.16	0.416	1	0.416	184.88	Reject
3.	b3	-0.33	1.729	1	1.729	786.44	Reject
4.	b4	-0.09	0.141	1	0.141	62.66	Reject
5.	b13	0.21	0.706	1	0.706	313.77	Reject
6.	b23	0.08	0.109	1 '	0.109	48.44	Reject
7.	b34	0.04	0.026	1	0.026	11.55	Reject
8.	SS12		3.928	7			
9.	SSE		0.018	8	0.002		
10.	SST		3.946	15			

Coefficient of Correlation = Square root of (SSR/SST) = 0.998
Hypothesis tested are : $H_0 = b = 0$; $f_{t,\,8\,(=0.05)} = 5.32$

The theoretical density (P_t) was calculated by using the theoretical densities of various ingredients of the Al-2% si alloy. The theoretical density of this alloy is 2.684. Actual density (P_a) was calculated by using the weight lost method.

RESULTS AND DISCUSSION

The experimental results were tabulated in Table -B. The response functions obtained for hot bending strength, hot permeability and % volume porosity are:

$$Y_1=1.21–0.22x_1-0.16x_2+0.33x_3+0.09x_4+0.21x_1x_3 + 0.08x_2x_3 + 0.04\, x_3x_4 \quad (3)$$

$$Y_2=16.38+4.5x_1+1.25x_2-2.63x_4 \quad (4)$$

$$Y_3=1.32–0.45x_1+0.23x_3+0.17x_4+0.25x_1x_3 + 0.14x_2x_3 + 0.06\, x_3x_4 \quad (5)$$

Table -B. Experimental **Results**

Treatment No	Hot Bending Strength N/mm^2		Hot Permeability		% Volume Porosity	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
1	1.05	1.00	16	15	0.92	0.90
2	2.06	2.10	5	7	2.64	2.38
3	0.78	0.74	10	12	1.63	1.70
4	1.92	1.80	16	14	1.94	2.10
5	0.93	0.85	18	18	0.91	1.02
6	1.50	1.46	22	20	0.85	0.89
7	0.80	0.88	24	25	0.82	0.80
8	0.70	0.75	19	21	0.85	0.80

The coefficients of correlation for hot bending strength hot permeability and %Volume porosity respectively were 0.998, 0.997 and 0.995. The near unity correlation Coefficients obtained indicate- excellent fit of the response surfaces.

Hot Bending strength

The response function for shell bending strength is represented by equation (3). All four individual variable factors and three interaction were found to be insignificant. The influence of slurry viscosity (b_3=0.33) and flour particle size (b_1=-0.22) on hot bending strength of shells is highly remarkable. The increase in slurry viscosity causes increase in bending strength of shells; where as increase in flour particle size results in decrease in the strength of shells. Smaller the flour particle size, greater the surface area for bonding action. The interaction of flour particle size and slurry viscosity (b_{13}=0.21) also influences the strength of shells. The negative sign on coefficient {b_2= - 0.16} indicates that aluminium silicate provides higher strength to the ceramic shells.

HOT PERMEABILITY

Equation (4) illustrates the response for hot permeability of shells. Flour particle size, type of flour and fineness of stucco sand are powerful in controlling the permeability of shells. No interactions is found effective on the shell permeability. The effect of flour particle size is very strong (b =4.5) with the use of coarse particles to the back up coats large voids are generated in the shells and consequently promoted high permeability to the shells. The second strong variable (b_4--2.63) factor is fineness of stucco sand. Finer the stucco sand lowers the shell permeability. Aluminium silicate imposes low permeability to the shells. This is attributed to round particle shape of aluminium silicate flour particles. Some hair cracks were observed on the aluminium shells due to thermal shocks. The hair cracks might be responsible for higher permeability in alumina shells. The viscosity of the slurry is not significant on the permeability of shells.

PERCENT VOLUME POROSITY:

In equation (5) % Volume porosity indicates that the reduction of gas porosity in the Al-12% si alloy castings is with the use of thin slurry (kinematic viscosity 25 cst) and coarse refractory flour and stucco sand. The replacement of alumina by alumina silicate did not induce (as b is insignificant) any gas porosity in the castings. Even though the aluminium silicate shells had low permeability the back pressure due to expansion of gas in the shell was considerably relieved. This was confirmed as no shells were cracked down due to back pressure porosity. Free Al si alloy castings can be produced by employing coarse refractory materials and thin slurry for the back up coats and using fine refectory materials and thick slurry for the prime coats of ceramic shells. The use of aluminium silicate flour can reduce the cost of manufacturing as it is cheaper than alumina.

CONCLUSIONS

I. The hot bending strength of shells was greatly influenced by viscosity of slurry flour particle size and their interaction. The bonding action was high between thick slurry and fine flour particles.

2. Coarse flour particles and stucco sand grains resulted very high permeability in the ceramic shells.

3. The soundness of AM2%Si alloy casting was not effected due to the use of aluminium silicate in the place of alumina as a flour material.

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