ANALYSIS OF CORE CHARACTERISTICS IN VACM PROCESS USING RESPONSE SURFACE METHODOLOGY

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This paper comprehensively evaluates the influence of vacuum pressure, phenol formaldehyde resin and AFS fineness of sand grains on the core characteristics. Cores were produced using the principle of shell moulding by Vacuum Assisted Core Making (VACM) process. A complete 32 factorial matrix design was used to carry out experiments and the analysis of the results was based on the response surface methodology. The response surface and the corresponding functions were determined for major performance indices, such as tensile strength and density of core and surface of surface roughness of Al-12% Si alloy castings. With assistance of vacuum, the tensile strength and density of course and surface finish of castings were improved significantly. The improvement in surface finish was highly significant on Al-Si alloy castings. Small and complex shaped cores can be produced easily by VACM process.

INTRODUCTION

Most simply defined, cores are sand shapes which form the contour of casting that is not moulded with a pattern. Forming internal cavities depends mainly on cores which can be inserted into a mould of the casting exterior. Through their use in forming complex internal cavities, cores provide the casting process its ability to make the most intricate of shapes, eliminate much machining, and in fact produce shapes which would be impossible to machine. To achieve the utmost of intricacy in castings, cores must be collapsible after the metal is poured. Most cores are made of a core sand mixture of sand grains and binders which provide green strength, cured strength and collapsibility. The cores also should have stability of dimensions and shapes during handling, mould preparation and casting and should ensure low surface roughness of the casting. Constant research work in the field of core making process has been going on for process development to respond to the need of the present day quality consciousness. As a result, a large number of new processes have been developed. [1-8]

In the current research work, the cores were produced using the principle of shell moulding. The cores were compacted to the shape by the vacuum created in the core box. Response surface methodology was adopted for analyzing the characteristics of cores.

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EXPERIMENTAL PROCEDURE

Materials

Silica sand of grain fineness 40, 60 and 80 and phenol formaldegyde resin (thermosetting) were employed to make shell cores. Al-12% Si alloy was cast into hollow sand cores to produce cylindrical castings.

Process Modelling

A complete 3^2 factorial experimental model was formulated with full randomization with the aid of a random number table.[9] To simplify the analysis of the data, the levels were set at equal intervals and the resulting orthogonal contrasts facilitate easy computation of the regression coefficients. The variable factors selected are grain fineness (AFS number) of core sand, %weight of phenol formaldehyde resin and vacuum pressure (absolute). The control factors and their levels of variation including their coded values are shown in Table-1. Resin coated sands of different AFS grain fineness number and containing % resin as shown in Table-1 were procured from M/S Kashyap Coated Sands, Bangalore-58. The slected characteristics of core response are its tensile strength, density and the surface roughness projected on AL-Si castings. For increased precision, each experiment was replicated twice.

Mathematical Model of the Process

A general model of the process can be expressed as

$$Y = f(x_1, x_2, \ldots . x_3) \quad \ldots(1)$$

Y = response variable

f = response function
x_1, x_2, x_k = selected factors.

Table -1: The control factors and their levels

Factors	Code	Coded values		
		1	0	-1
% resin	x_1	2	3	4
Pressure, cm of Hg	x_2	20	35	50
AFS Grain Fineness No.	x_3	40	60	80

The total number of regression coefficients possible is given by the expression [10]:

$$N = \frac{n(n+3)}{2} + 1 \quad \ldots(2)$$

For a two factor experiment, therefore, only 6 regression coefficients are possible. Accordingly, it is assumed that a second order polynomial would be adequate to represent the response surface.

A second order polynomial representation of the surface is:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{11}{x_1}^2 + b_{22}{x_2}^2 + b_{12}x_1x_2 \quad \ldots (3)$$

where the coefficient b_0 represents the response of the centre of the experiment and the coefficients b_1, b_2, b_3, b_{11}, b_{22}, b_{12} represent the linear, quadratic and linear x linear interaction effects of the factors x_1 and x_2 respectively. The adequacy of fit was checked by the correlation coefficient.

The regression coefficients and the correlation coefficients were computed according to the standard statistical procedure[11]. A complete analysis of variance (ANOVA) was performed to test the significance of the coefficients obtained 1t 95% confidence level. The procedure is illustrated in Appendix-1.

Manufacturing of Cores and Castings

A schematic diagram of the vacuum Assisted Core making (VACM) machine is shown in Fig.1. The hopper stores the resin-coated sand. The nozzle of the VACM machine was connected to the vacuum pump by a hose pipe. The two halves of the core box were sprayed with silicon emulsion for easier removal of cores. The two halves of core box were clamped by using C-clamp. The core box was then placed in between lower and upper grip plates. The table was raised till there was no air leak into the core box. The regulating rod was rotated to allow the sand into the core box. The regulating rod was rotated by 90^o to align its orifice with the holes of main chamber, regulator and upper grip plate which allow the sand into the core box.

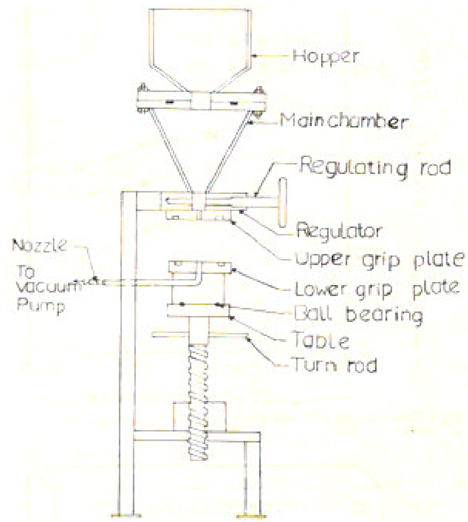

Fig. 1 Vacuum assisted core making machine

The vacuum pump was started to suck and compact shell core sand. The regulating rod was further turned 90^o, the hole of the regulator was closed and thus arrested the flow of sand into the core box. The core box heated to a curing temperature of 180^o for 10 minutes. The core box was cooled in the open air before opening and the solid core (Fig.2) was ejected out. The hollow cylindrical cores were also manufactured (a sectional view of core box and hollow core is shown in Fig.3) to obtain Al-12$Si alloy castings in the same manner as that of solid cores.

An AL-12%Si alloy was melted in a diesel fired furnace. The liquid melt was degasified with the hexacloroethane and the same was modified with coverall 35A (A Foseco Product). The liquid melt was then poured into the hollow cores to produce cylindrical castings.

Testing

The tensile strength of the shell cores was measured on the universal strength testing machine. The core density was calculated by its weight to volume ratio [i.e. core density (Bulk density of core) = weight of core/volume of core cavity in the core box].

The surface roughness was measured using pertho graph as shown in Fig.4. the cylindrical casting was placed in the V-block. The set up was then adjusted till the stylus probe touched the casting and a zero reading was obtained on the digital monitor. The stylus was moved parallel to the axis of casting for a sampling length of 10 mm. the readings were noted down to on the digital monitor. The same procedure was repeated at five locations on the surface of casting and the mean value was calculated[12].

RESULTS AND DISCUSSION

The experimental results used to arrive at equations 4 to 12 are given in table 2, 3 and 4. The final regression equations of the response surface for the selected characteristics of the core are:

$$\sigma_s = 16.99 + 1.88x_1 - 1.12x_2 - 1.81\,x_2^2 + 0.382x_1x_2 \quad ...(4)$$

$$\sigma_b = 13.37 - 2.13x_2 - 0.72x_3 - 2.20\,x_2^2 - 1.45x_3^2 \quad ...(5)$$

$$\sigma_v = 16.56 + 2.25x_3 - 2.67{x_1}^2 + 1.63x_3x_1 \quad ...(6)$$

$$\rho_s = 1.62 + 0.043x_1 - 0.123x_2 - 0.05\,x_2^2 \quad ...(7)$$

$$\rho_b = 1.57 - 0.09x_2 + 0.15x_3 - 0.02\,x_2^2 - 0.07\,x_3^2 + 0.03x_2x_3 \quad ...(8)$$

$$\rho_v = 1.59 + 0.06x_3 - 0.15x_1 - 0.08\,x_1^2 \quad ...(9)$$

$$R_s = 3.23 - 0.23x_1 + 0.4x_2 - 0.2\,x_2^2 \quad ...(10)$$

$$R_b = 3.33 + 0.55x_2 - 0.98x_3 \quad ...(11)$$

$$R_s = 3.22 - 0.67x_1 - 0.37\,x_1^2 - 0.42x_3x_1 \quad ...(12)$$

Tensile Strength

Response surface functions for tensile strength of the core are given in equations 4.5 and 6. It can be observed that the absolute pressure is highly significant on the tensile strength. The decrease in absolute (or increased vacuum) pressure causes increase in tensile strength of the core. This can be attributed to the closer compactness by the reduced absolute pressure and therefore a greater tensile force is required to break the core. It is also noticed that the increase in per cent resin causes increase in tensile strength of the core. This is owing to improved bonding between sand grains. The effect of grain fineness number of sans grains is not much significant, but the tensile strength of the core is high for the AFS number of 60. The interaction effects resin and vacuum pressure and AFS number of sand of sand and resin influence the tensile strength of core.

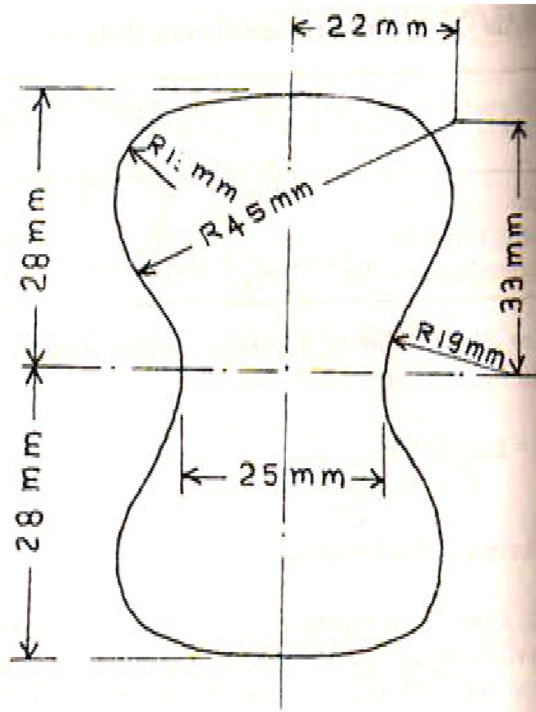

Fig. 2 Core

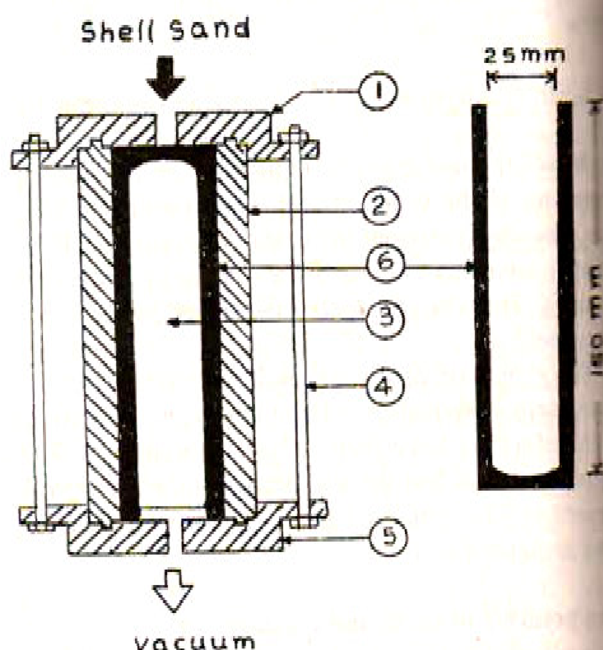

Fig. 3 Sectional view of core box and hollow cylindrical core.

1. Top plate. 2. Circular box (2 halves). 3. Metallic insert with radial groove on bottom surface. 4. Bolts (2). 5. Bottom plate. 6. Hollow core.

Table-2: Experimental results (AFS number is constant)

Treatment No.	% resin x_1	Pressure cm of Hg x_2	AFS No. x_3	Tensile Strength Kg/cm^2		Core density g/cm^3		Surface roughness microns	
				Replica1	Replica2	Replica1	Replica2	Replica1	Replica2
1	-1	-1	0	15.6	16.7	1.65	1.68	3.42	3.15
2	0	-1	0	17.8	18.3	1.70	1.76	2.54	2.73
3	+1	-1	0	19.0	18.4	1.78	1.80	2.45	2.26
4	-1	0	0	16.8	17.0	1.54	1.59	3.81	3.52
5	0	0	0	18.3	17.9	1.60	1.66	3.20	3.54
6	+1	0	0	20.4	20.6	1.73	1.70	3.06	2.87
7	-1	+1	0	12.5	12.8	1.35	1.42	4.19	4.05
8	0	+1	0	15.2	14.5	1.47	1.51	3.70	3.49
9	+1	+1	0	16.9	17.6	1.60	1.54	3.32	3.24

Table -3 : Experimental results (Resin content is constant)

Treatment No.	% resin x_1	Pressure cm of Hg x_2	AFS No. x_3	Tensile Strength Kg/cm^2		Core density g/cm^3		Surface roughness microns	
				Replica1	Replica2	Replica1	Replica2	Replica1	Replica2
1	0	-1	-1	15.2	15.0	1.54	1.47	3.90	3.94
2	0	0	-1	16.7	15.6	1.37	1.38	4.02	4.00
3	0	+1	-1	9.60	9.40	1.28	1.30	4.74	4.96
4	0	-1	0	17.5	17.8	1.80	1.76	3.05	2.98
5	0	0	0	16.6	16.5	1.62	1.68	3.42	3.50
6	0	+1	0	14.6	14.2	1.48	1.45	3.76	3.74
7	0	-1	+1	14.3	14.0	1.76	1.81	1.46	1.52
8	0	0	+1	16.8	16.4	1.71	1.68	2.60	2.54
9	0	+1	+1	11.0	10.5	1.62	1.60	2.88	2.90

Table-4: Experimental results (Vacuum is constant)

Treatment No.	% resin x_1	Pressure cm of Hg x_2	AFS No. x_3	Tensile Strength Kg/cm^2		Core density g/cm^3		Surface roughness microns	
				Replica1	Replica2	Replica1	Replica2	Replica1	Replica2
1	-1	0	-1	14.6	14.8	1.40	1.36	3.42	3.50
2	-1	0	0	16.0	16.4	1.70	1.64	3.20	3.05
3	-1	0	+1	12.0	11.8	1.63	1.60	3.00	2.92
4	0	0	-1	16.0	15.8	1.30	1.34	3.68	3.70
5	0	0	0	17.6	18.0	1.56	1.60	3.52	3.45
6	0	0	+1	16.5	16.3	1.78	1.74	2.54	2.58
7	+1	0	-1	15.0	15.4	1.42	1.48	4.12	4.06
8	+1	0	0	21.2	21.0	1.70	1.72	3.64	3.84
9	+1	0	+1	19.8	20.0	1.90	1.85	1.90	1.82

Core Density

The core density improves significantly with resin content vacuum pressure and AFS fineness of sand grains (equations 7, 8 and 9) the influence of vacuum pressure on the core density is highly remarkable and clearly illustrates an increase in core density with decrease in absolute pressure. Under high vacuum more amount of sand can be packed closely in the fixed volume of the core box. The core density also increases considerably with the higher resin content and the increased fineness of core sand grains. The interaction effect of vacuum pressure and fineness of sand grains increases further the core density.

Casting Surface Roughness

The response surface functions (equations 10, 11 and 12) for the surface roughness (Ra value) indicate improvement of surface finish with vacuum assisted core making (VACM) process. It is attributed to the vacuum pressure (suction) which ensures close packing of the sand grains resulting in a smooth surface of the cores made. Another contributing factor is the fineness of sand grains, where generally improved surface finish is obtained. When high per cent resin was used in the preparation of core sand mix, pin hole porosity was resulted on the surface of casting due to gas generation at the core and metal interface. A response surface for surface roughness of the castings as dispersed in Fig.5 confirms the argument. The similar response surfaces for other core characteristics can be constructed to validate the discussion.

As the strength and density values of the core are more approvable, the VACM process can be used for small and complex shaped cores as the shape of core does not affect the suction of sand mixture into the core box under vacuum. The resin content of the sand can be maintained at low level not only to avoid pin hole porosity but also to reduce the cost of production.

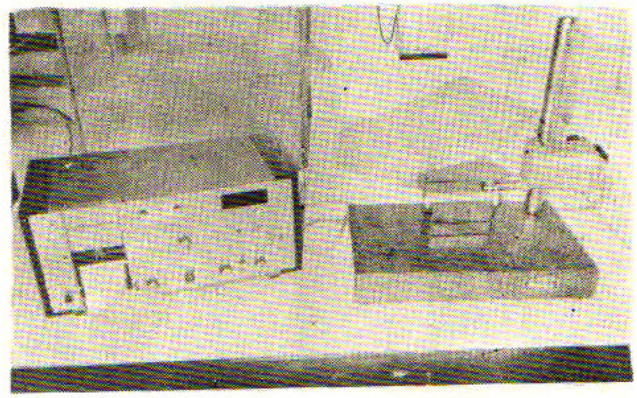

Fig. 4 Measurement of surface roughness

CONCLUSIONS

A second order polynomial proved to have an excellent fir in the case of each of the response surfaces. The influence of vacuum on core making may be summarized as follows:

1. The tensile strength of the core increases due to very close packing of the sand grains bonded by phenolic resin.
2. The core density also increases.
3. Surface finish of casting is also improved significantly owing to better packing efficiency.
4. Small and complex shaped core can be produced efficiently by VACM process.

Appendix - 1

Regression Coefficient	Estimate bij	d.o.f.	S.S.	M.S.	F_{cal}	H_o
b_1	1.80	1	38.88	38.88	194.4+	Reject
b_2	- 1.12	1	15.05	15.05	75.3 +	Reject
b_{11}	- 0.067	1	0.02.	0.02	0.1 *	Accept
b_{22}	- 1.817	1	13.21	13.21	66.1 +	Reject
b_{12}	- 0.383	1	1.17	1.17	5.85 +	Reject
SSR		5	68.33	13.67		
SSE		12	2.37	0.20		
SST		17	70.70			

+ Significant

* Not Significant

Coefficient of correlation, $r = \frac{68.33}{70.70} = 0.966$

Table:5 – The estimates of the Regression coefficients and the test of their significance are presented in an ANOVA table. Hypothesis tested are: H_0: $b_{ij} = 0$. $F1_{, 12(\alpha=0.05)} = 4.75$.

Nomenclature:

σ_s, σ_b and σ_v = Tensile strengths of cores with constant AFS number of sand, binder content and vacuum pressure respectively.

ρ_s, ρ_b and ρ_v = Core densities with constant AFS number of sand, binder content and vacuum pressure respectively.

R_s, R_b and R_v = Average surface roughness of the castings of cores with constant AFS number of sand, binder content and vacuum pressure respectively.

d.o.f = degree of freedom
SX = Sum of squares
MS = Mean sum of squares
SSR = Sum of squares due to regression
SSE = Error sum of squares
SSt = Total sum of squares
Fcal = Calculated Fisher's ratio
Ho = Hypothesis

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