Development of a ceramic shell moulding process from coal flyash for investment casting

A. Chennakesava Reddy[1], V.S.R. Murti[2] and S. Sundara Rajan[3]

'Department of Mechanical -Engineering, M.J. College of Engineering & Technology, Hyderabad-500 034, India

[2]Department of Mechanical Engineering, Osmania University, Hyderabad-500 007, India

[3]Production Division, Defence Research and[1] Development Laboratories, Hyderabad-500 058, India

---

Summary

Dip coating investment slurry composition is important parameter to judge the performance of ceramic shell moulding process. The paper presents the use of an industrial waste, namely coal flyash for the investment casting. Experiments have been conducted on the dip-coating slurry and shell moulds to examine their characteristics that enrich the ceramic shell moulding process from flyash. The results indicate substantial enhance in the quality of flyash shell moulds due to uniform slurry viscosity, low sedimentation rate, completion of electrostatic bonds and round particle shape.

Keywords : Flyash, Alumina, Viscosity, Sedimentation, Wettability, Bending Strength, Permeability

---

1. Introduction

The ceramic shell moulding process for investment casting consists of applying investment in layers by alternately dipping the wax pattern into a slurry containing liquid binder and refractory filler and sprinkling with refractory stuccoing material. These operations are repeated until the required shell thickness is built-up around the pattern. On achievement of the required thickness of the shell, the meltable pattern material is removed from the setup and the shell is fired, and the mould is poured [1-2].

The materials used to build the ceramic shell, specially refractory fillers used in the preparation of slurry, play a vital role in the production of quality castings.

In this investigation the conventional refractory filler was replaced by an industrial waste, namely coal-flyash from thermal power plants and the properties of slurry and shell were studied. The chemical analysis of coal-flyash is given in table-1. The micro analysis of coal-flyash shows that it consists of primarily of spherical particles of impure alumina silicate glass, The particle size varies from sub-micrometers to 100)A .m. Upto 75^L m particle diameter sized fractions of flyash had surface areas ranging from 1.27 to 0.45 m^2/g and densities ranging from 2: 0 to 2:8 g/cm ^{3}(3-4], Flyash can be separated into three major matrices, glass, mullite-quartz and magnetic spinal. The ,ratio of crystalline material to glassy, amorphous material increases with particle size.

Table 1 : Chemical analysis of flyash

Sl. NO.	Particular	% Weight
1.	$Si0_2$	60.43
2.	$A1_20_3$	33.02
3.	Fe_20_3	2.03
4.	$Ti0_2$	2.03
5.	MnO	0.03
6.	CaO	0.22
7.	MgO	0.43
8.	P_2O_5	0.26
9.	SO_3	0.05
10.	Na_20	0.50
11.	K_2O	0.76
12.	Loss on Ignition	0.63

2. Identification of Characteristics

Preliminary study was conducted on the process, with coal flyash to identify the important factors that influence the process. A regression modelling approach for the analysis of investment shell moulds was conducted by the authors for this purpose [5]. The following facts were obtained:

- With in the levels of variables chosen for the test, the grain size of refractory filler (coal flyash) added to the binder greatly affects the shell strength and the permeability.

- The highest degree of improvement in the permeability of shell mould is with coarse stuccoing sand.
- Filler to binder ratio influences the character of slurry and shell.

The last factor needs an in-depth study because in the ceramic shell moulding process, the slurry composition controls p^H level, viscosity, sedimentation and wettability of the slurry, which in turn influence the shell quality. Therefore, further experiments were carried out on the dip-coating slurry and shell moulds to examine their characteristics that enrich the ceramic shell moulding process from flyash. Alumina was used to compare the results of coal flyash.

3. Preparation of the slurry

Dip-coating slurries were prepared by adding the refractory filler to the liquid binder, using sufficient agitation to break-up agglomerates and thoroughly wet and disperse the filler. Colloidal silica binder was used for the preparation of both the slurries of coal-flyash and alumina. The colloidal concentration in the binder is 30%.

4. Manufacture of ceramic shells

Ceramic shells were made by applying a series of ceramic coatings to the 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 for 4 hours in the open air. The operations of coating, stuccoing, and drying were repeated six times. The seventh coat was left unstoccoed 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 stuccoed with a sand of AFS fineness number 50. After all coats, the shells were air dried for 24 hours.

5. Testing

The measuring of sedimentation was executed on the principle of determination of the sediment height in certain time intervals [6]. This was performed in a glass tube of 25 mm in diameter, 400mm high with 1-mm scaling. The viscosity of the slurry was measured by a Ford cup with an orifice of 5mm diameter [7]. The wettability was determined as the weight of filler coated on the wax pattern per unit area. The bending strength test of shells was conducted on an universal sand testing machine and permeability meter was used to test permeabilty of the shells [8].

6. Results and Discussions

6.1 Dip - coating investment slurry

Fig. 1 shows the effect filler to binder ratio on the p^H of the dip - coating slurry. In the colloidal silica binder, the silica is present as small particles of colloidal dimensions suspended in water. The concentration of colloidal dispersion in the binder is 30 %. The colloidal silica particles in the binder are negatively charged and the binder is stabilised at 10 p^H. Once the filler is added to the binder, the negatively charged colloidal silica particles may link up with filler particles and thus form gel. The slurries of coal flyash show low p^H. This could be due to the composition and p^H level of flyash. P^H values of flyash and alumina are in the ranges of 6.0 - 7.0 and 8.5 to 8.9 respectively. During the conduction of experiments, it was experienced that the flyash slurries were gelled fast, This is mainly due to the presence of Na, Ca and Mg. These effectively introduce opposite charged particles which in turn link up the silica particles via a bridge. Thus the slurries of flyash exhibit lower p^H values due to partial neutralisation of negatively charged silicon (binder) particles by Na, Ca and Mg.

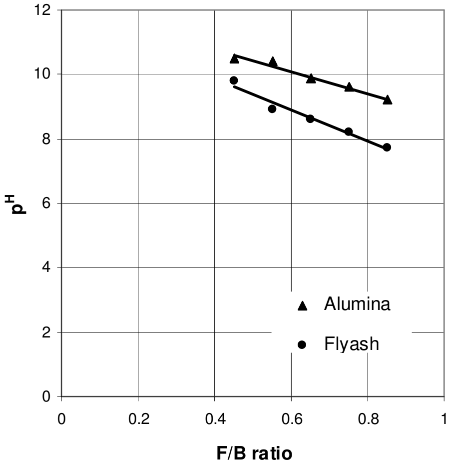

Fig.1. Effect of Filler / Binder ratio on the p^H of Slurry

The variation of viscosity with filler to binder ratio is shown in Fig. 2. The flow time (which is an index to viscosity) of slurry solution through Ford cup was directly proportional to the amount of filler added to the liquid binder. The increase in the slurry viscosity may be related to the presence of higher amount of filler particles and the formation of partially gelled solution. When the slurry stands on for a considerable period of time while dip coating the wax patterns, a gradual increase in the slurry viscosity may also be attributed to the evaporation of the water content.

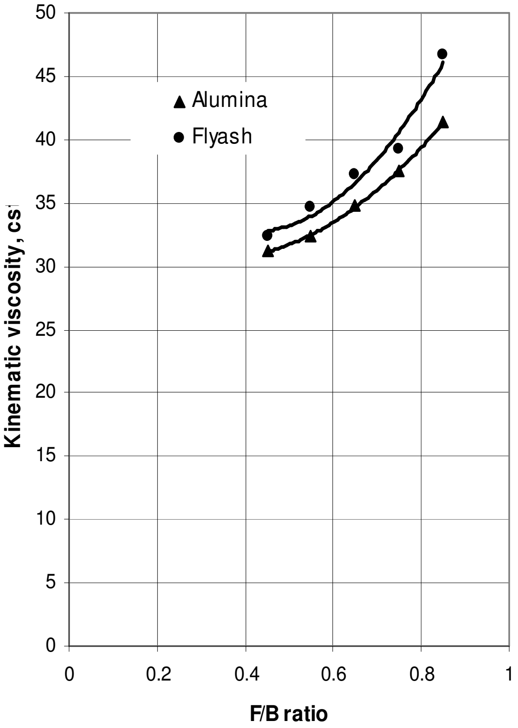

Fig.2. Effect of Filler / Binder ratio on the Slurry Viscosity.

The behaviour of slurry is also affected by the sedimentation of the refractory filler. The extent of refractory filler particles settling to the container bottom was determined in terms of sediment (hard pack) height. In fig. 3, the results of sediment height measured due to alumina and coal flyash sedimentation are shown. The sedimentation rate of alumina particles is greater than that of coal flyash particles in the slurry. But in both the slurries the trend is same. The formation of refractory particle hardpack is due to the density difference between the binder solution and the refractory filler. The densities of binder, alumina and flyash are respectively 1.23, 4,0 and 2.13 g/cm^3 The slow sedimentation rate of flyash particles is also due to the hollow structure of flyash particles.

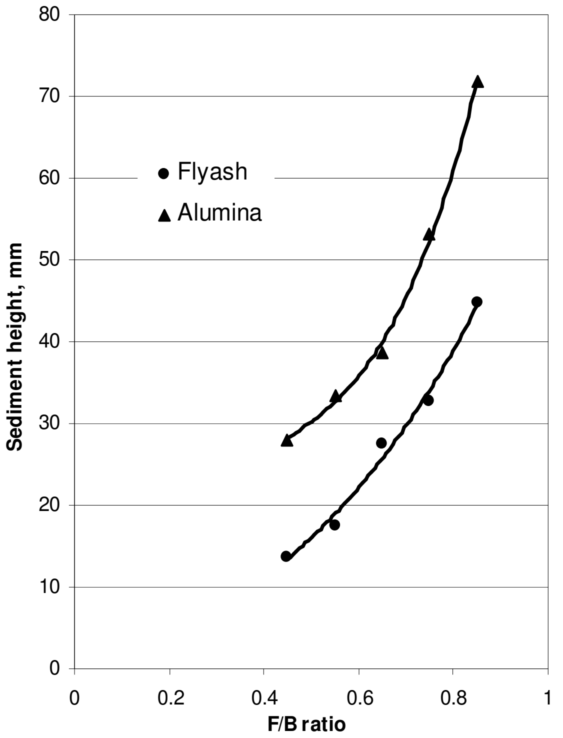

Fig.3. Effect of Filler / Binder ratio on the Sediment Height

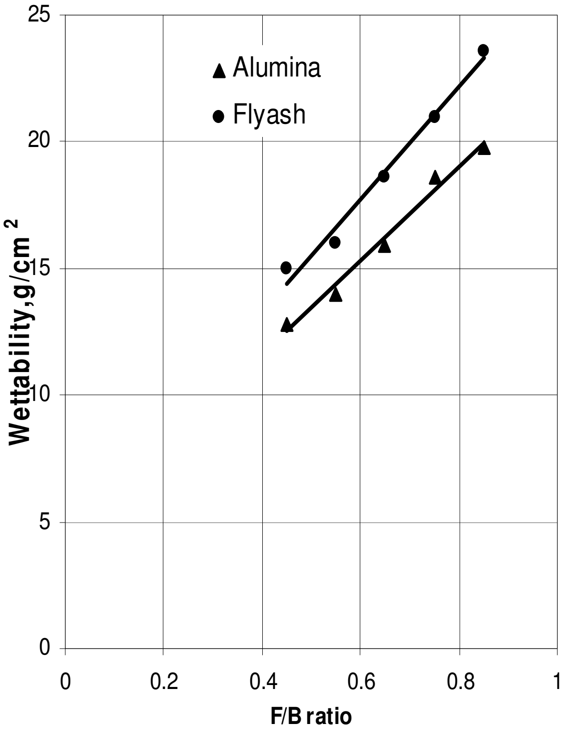

Fig.4. Effect of Filler / Binder ratio on the Wettability

The wettability of slurry to the wax pattern is influenced by the degree of suspension (filler to binder ratio) in the slurry, dipping time of the pattern tin the slurry and also the viscosity of slurry. The wettability of slurry to the wax pattern increases with increase in amount of •filler to binder ratio (fig.4) and with increase in dipping time of pattern in the slurry (fig.5). Flyash has better wettability than alumina containing slurries.

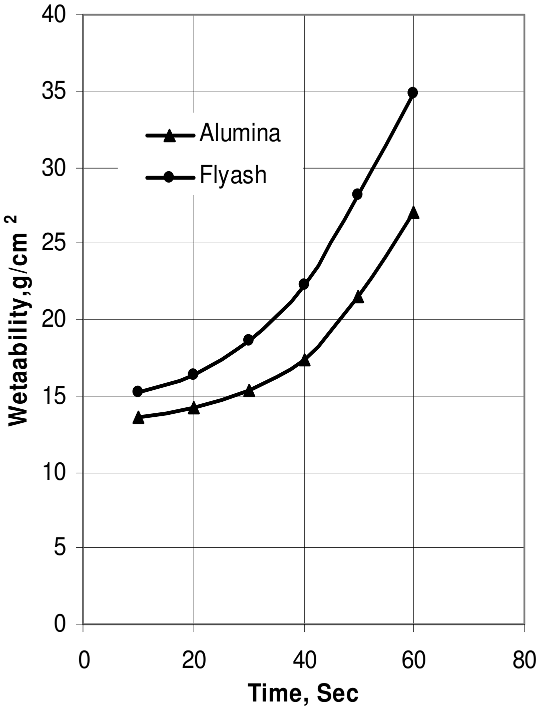

Fig.5. Effect of Dipping Time on the Wettability

6.2 Ceramic shell moulds

Bending strength of ceramic shells is affected by filler to binder ratio in the slurry as shown in Fig.6. Flyash shells exhibit high strength for filler to binder ratio of 0.65 whereas alumina shells show high strength for filler to binder ratio of 0.75, This is mainly due to completion of electrostatic bonds between silicon radicals in the binder, filler particles and stuccoing sand grains at these slurry compositions. Flyash shells have distinctly high strength over alumina shells as the number positive charges carried by the cations are more in the flyash slurries. Excess filler material multiplies thick (muddy) and completely gelled (impotent) slurry which inactively link stucco sand grains and subsequently result weak shells. The permeability of shells is decreased with increasing filler to binder ratio as displayed in fig.7. This is owing to the reduction of voids in the dip - coated layers of ceramic shell moulds. Thin slurries develop greater permeability than thick slurries. The flyash shells have greater permeability owing to its round particle shape.

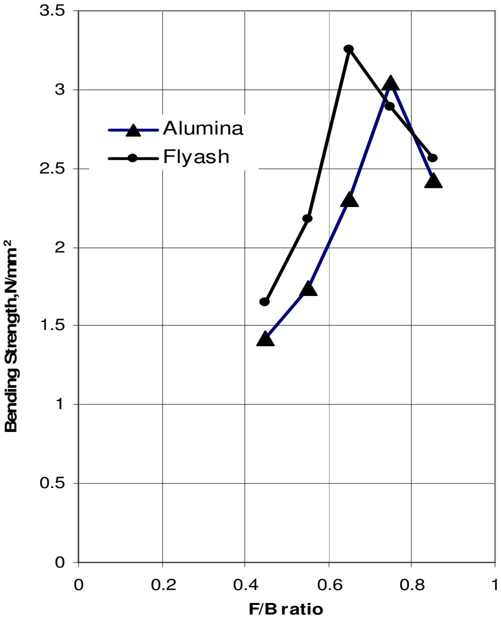

Fig.6. Effect of Filler / Binder ratio on the Bending Strength of Shells

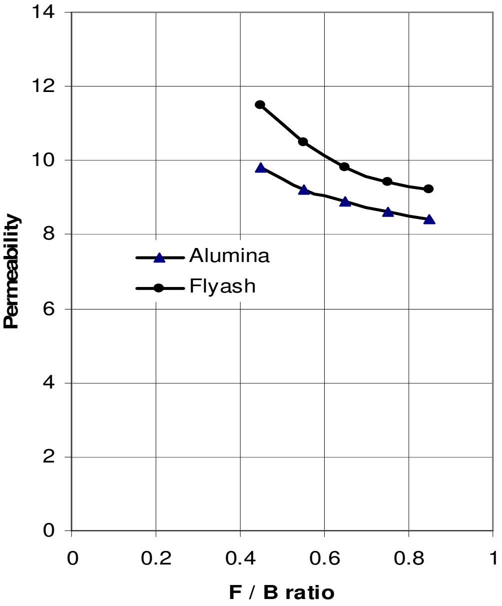

Fig.7. Effect of Filler / Binder ratio on the Permeability of Shells

Conclusion

Flyash provides high viscosity to the dip- coating slurries on account of partial gelation caused by Na, Ca and Mg. The sedimentation rale of alumina in the slurry is more due to its high density; whereas flyash slurry has better retention of particles in the entire slurry column. Flyash slurries promote greater strength and permeability to the ceramic shells owing to partial gelation and completion of electrostatic bonds at low levels of filler to binder ratio and round particle shape.

References

[1] R.A. Horten, Investment Casting, Metals Hand book, 8th Edition, Vol.5, (1975), pp. 253-267.

[2] A. Chennakesava Reddy and V.S.R. Murti, Studies on Lost - Wax Process using Silox Binder, Proceedings of Xth ISME conference on Mechanical Engineering, (1996), pp II82-86

[3] V. Sundara, Characterization of Flyash and Utilization, Ph.D Thesis, Indian School of Mines, Dhanbad, India, (1985).

[4] A. Chennakesava Reddy, Coal Flyash Environmental Impact and Utilization, Engineering Advances, Vol. 9/2. (1997) pp 48-49.

[5] A. Chennakesava Reddy, V.S.R. Murti and S. Sundara Rajan, Regression Modelling Approach for the Analysis of Investment Shell Moulds from Coal Flyash, Foundry, Vol. 15, (1997), pp 36-40,

[6] A. Chennakesava Reddy, K.M. Babu, P.M. Jebaraj and M.P. Chowdaiah, Accelerator for Faster Shell Making and its Effect on the properties of Investment Moulds, Indian Foundry Journal, Vol. 41/10, (1995), pp 3-8.

[7] A. Chennakesava Reddy, H.B. Niranjan and A.R.V. Murti, Optimization of Investment Shell Mould using Colloidal Silica Binder, Indian Journal of Engineering and Materials Sciences, Vol. 3/2 , (1996), pp 180-184.

[8] J. Doelman, Standardization of Methods of Determining Permeability and Strength of ceramic shells, Foundry Trade journal. Vol. 121, (1996), pp 724 - 727.