Characterization of Dip-Coating Slurries from Coal Flyash for Investment Casting Process

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Abstract

The characteristics dip-coating slurries judge the performance of investment casting process. The paper presents a hypothesis on the bonding mechanism in the shells developed from coal flyash. Experiments have been carried out to study the effects of filler loading, aging and air-drying on the strength of shells. The results indicate substantial reduction in the sedimentation under operating conditions and enhancement in the shells strength.

1. INTRODUCTION

In the manufacture of shells moulds by the investment casting process, a multi-layered shell is built up by repeatedly dipping a wax pattern cluster into a slurry containing liquid binder and refractory filler and stuccoing with a coarse sand. Each individual coat is air-dried prior to applying the next coat. On achievement of the required thickness of the shell, the meltable pattern material is removed from the setup and the shell is fired[1-2].

The dip-coating slurries are more effective in controlling the quality of shell because of characteristic problems associated with the method of handling of these slurries and the nature of bonding mechanism in the shells[3-4]. Sedimentation, viscosity and strength are important characteristics by which the performance of shell for investment casting can be evaluated. The most commonly used refractory fillers are **silica, alumina** and **zircon** powders. Especially the latter two fillers have high densities (4.0 and 4.6 g/cm^3 respectively) and if the slurries are not maintained properly, the fillers settle down and subsequently result non-uniform viscosity to the slurry. For practical use, slurries with the lowest sedimentation are most advantageous. They also insure a more constant strength of coats and shell[5].

The objective of the present investigation is to study the physico-chemical properties of **coal flyash** as a refractory filler and its slurry and to compare the results with those of alumina under the same moulding conditions. The bending strength of shells is also investigated with respect to the bonding mechanism developed in the shells.

Here is an interesting paper on **Investment casting** from the work being done at the Inversities/ Laboratories in Andhra Pradesh. It focuses on the difference between **coal flyash** and **alumina**, suspended in colloidal silica binder. Foundrymen dealing with investment castig process will find the content informative and useful. - **Editor**

2. EXPERIMENTAL PROCEDURE

Dip-coating slurries were prepared by adding the refractory filler to the liquid binder using sufficient agitation to breakup 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 chemical composition of the binder is shown in *Table 1*. The particle size of fillers was 45 μm. The ambient temperature and relative humidity were respectively 35-35°C and 60-65 %.

The measuring of sedimentation was executed on the principle of determination of the sediment height. This was performed in a glass tube of 25mm in diameter, 400 mm high with 1 mm scaling[6]. The viscosity of the slurry was measured by a Ford Cup with an orifice of 5 mm diameter[7].

The investment shells for bending strength test were made by dipping wax patterns into the slurry and stuccoing with a coarse sand. Each coating was allowed to dry for 4 hours in the open air. The operations of dipping, stuccoing and drying were repeated six times. The seventh coat was left unstuccoed to avoid the occurrence of loose particles on the shell surface.

Table 1
Colloidal Silica Binder

Particular	Quantity
Silica (SiO_2)(weight %)	30.0
PH (at 25 °C)	10.0
Titrate Alkali (Na_2°) (weight %)	0.3 to 0.4
Chlorides / Sulphates	Traces
Specific Gravity (m^3/g)	1.23
Specific Surface Area (m^2/g)	250 to 400

Table 2
Chemical Analysis of Coal Flyash

Particular	% Weight
SiO_2	60.43
Al_2O_3	33.02
Fe_2O_3	2.03
TiO_2	1.64
MnO	0.03
CaO	0.22
MgO	0.43
P_2O_5	0.26
SO_3	0.05
Na_2O	0.50
K_2O	0.76
Loss on Ignition	0.63

The first two coats were stuccoed with a sand of AFS fineness number 120 and the next four coats with sand of AFS fineness number 50. After all coats, the shells were air-dried for 24 hours. The bending strength test of shells was conducted on a universal sand testing (hydraulic type) machine.

3. RESULTS AND DISCUSSION

3.1 Physico-Chemical Properties of Coal Flyash

Coal flyash was the residue of coal combustion in coal fired power generations. When coal was totally burnt, the constituents of coal viz., principally the oxides of silica and alumina converted into flyash. The chemical composition of coal flyash is given in Table 2. The data indicate that the bulk of flyash is composed of mullite, quartz, cristobalite and amorphous alumina-silicates.

Figure 1 Scanning Electron Microstructural view of coal-flyash (2000X, 20μm, 10 kV). Dark areas are organic matter. Light areas are mineral matter. Round particles are SiO_2.

The scanning electron microscopy of flyash as represented in Figure 1 shows glassy spheres. The particle size varies from sub-micrometers to 100μm. Upto 75 μm particle diameters sized fractions of flyash have surface areas ranging from 1.22 to 0.45 m^3/g and densities ranging from 2.0 to 2.8 g/cm^3.

Table 3
Sedimentation of Refractory Fillers

Filler / Binder Ratio (cm^3 per Volume of binder in ml)	Sediment Height (mm) Flyash	Sediment Height (mm) Alumina
0.45	17	28
0.55	20	33
0.65	28	38
0.75	35	53
0.85	44	73

3.2 Sedimentation of Slurry

The behavior of dip-coating slurry was 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. The results of sediment height measured (after one hour) due to alumina and coal flyash sedimentation are shown in table-3. The sedimentation rate of alumina particles was greater than that of coal flyash particles in the slurry. The formation of refractory particle hard pack was due to the density difference between the binder solution and the refractory filler. The densities of binder, alumina and flyash are respectively 1.23, 4.00 and 2.13 g/m^3. The difference between the downward gravity force of filler and the upward buoyancy force of colloidal silica binder is comparatively low in flyash slurries. Therefore, the particle retention along the slurry column is good in the flyash slurries. The slow sedimentation rate of flyash particles is also due to their hollow structure.

3.3 Viscosity Of Slurry

Table-4 shows the effect of filler to binder ratio on the viscosity of slurry. The viscosity of the slurry is directly proportional to the amount of filler added to the binder. Viscosity initially tests excessively high because of air entertainment and lack of particle wetting; therefore, mixing is continued until the viscosity falls to its final level before the slurry is put into use. The flyash slurries exhibit higher viscosity due to partial gelation caused by the impurities present in the flyash.

Table-5 demonstrates the effect of aging time on the viscosity of slurries. With aging, the viscosity increases. The aging of slurry is coarsening of colloidal particles in the binder and filler particles by mutual bonding. The coarsening action is fast in flyash slurries; a spontaneous gelation occurs at 8 hours of aging. The evaporation of water content of the binder from the surface of the slurry produces a pre-gelling condition of the upper layer, which then is mixed continuously into the slurry (as the slurries continuously stirred to keep the filler from settling out of suspension). Thus the whole volume the slurry gradually comes into the pre-gelated state.

Table 4
Effect Filler Loading on Viscosity of Slurry

Filler / Binder Ratio (cm^3 per Volume of binder in ml)	Kinematic Viscosity (CST)	
	Flyash	Alumina
0.45	31.13	30.57
0.55	33.93	33.09
0.65	35.05	34.49
0.75	37.05	36.17
0.85	42.85	41.21

Table 5
Effect of Aging on Slurry viscosity (CST)

Aging Time (hr)	Kinematic Viscosity (CST)	
	Flyash	Alumina
0	35.05	34.49
1	44.56	36.17
2	56.55	40.87
4	69.32	47.14
6	82.65	55.77
8	180.65	69.09
12	-	154.49

Table 6
Effect of filler loading on bending strength

Filler / Binder Ratio (cm^3 per Volume of binder in ml)	Bending Strength (N/mm^2)	
	Flyash	Alumina
0.45	1.68	1.45
0.55	2.20	1.82
0.65	3.23	2.25
0.75	2.72	2.96
0.85	2.42	2.34

Table 7
Effect of Aging on Bending Strength of Shells

Aging Time (hr)	Bending Strength (N/mm^2)	
	Flyash	Alumina
0	3.23	2.25
1	3.30	2.30
2	3.52	2.56
4	3.86	2.90
6	3.60	3.50

3.4 Strength of Shells

The effect of filler loading on the bending strength of shells is shown in Table-6. The bonding mechanism in the shells is due to electrostatic bonds between colloidal silicon radicals in the binder, filler particles and stuccoing sand grains. Flyash shells exhibit high strength for filler to binder ratio of 0.65 whereas alumina shells show high strength for filler to binder ration of 0.75. This is mainly due to the completion of electrostatic bonds at these slurry compositions. Flyash shells have distinctly higher strength over alumina shells as the number of positive charges carried by the cations are more in the flyash slurries. This is mainly due to the presence of Na, Ca and Mg. These effectively introduce opposite charged particles, which in turn linkup, the colloidal silica particles via a bridge and thereby complete gelation [complete neutralisation of negatively charged silicon (binder) particles].

The effect of aging time of slurries on the strength of shells is shown in Table-7. Aging time is the time between the preparation and the use of slurries. The fresh slurries develop lower strength than the aged slurries. In the course of aging the slurries, a certain time is needed for a thorough soaking of surfaces refractory filler particles by the liquid binder. The flyash slurries give greater strength at low aging times due to good wettability of flyash particles. Excess filler material results thick and completely gelled (impotent) slurry, which inactively link stucco, sand grains and subsequently produce weak shells.

Table-8 shows the effect of air-drying time on the strength of shells. As drying time increases the bending strength of shells also increases. The removal of water from coats forces the particles together and accelerates the bonding mechanism in the shells.

4. CONCLUSION

The bulk of coal flyash is composed of mullite, quartz, cristobalite, and amorphous alumino-silicates. The scanning electron microscopy of flyash shows glassy spheres. Flyash results slow sedimentation and uniform slurry viscosity due to better retention of filler particles in the slurry column. The slurries are coarsened by aging. The coarsening action is fast in flyash slurries; spontaneous gelation occurs at 8 hours of aging. Flyash slurries have distinctly higher strength over alumina shells as the number of positive charges carried by the cations are more in the flyash slurries. The removal of water from coats by air-drying enhances the bonding mechanism in the shells.

Table 8
Effect of drying time on bending strength of shells

Drying time, hr	Bending Strength (N/mm^2)	
	Flyash	Alumina
1	2.50	1.96
2	3.03	2.25
4	3.42	2.76
8	4.21	3.72
12	4.30	4.06

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