BONDING MECHANISM IN THE FLYASH CERAMIC SHELLS

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The characteristics dip-casting slurries judge the performance of investment casting process. The paper presents a hypothesis on the bonding mechanism in the ceramic 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.

INTRODUCTION

In the manufacture of ceramic shell 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 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/cc 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 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.

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EXPERIMENTAL PROCEDURE

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 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 30-35°C and 60-65.

The measuring of sedimentation was executed on the principle of of determination of the sediment height. This was performed in a glass tube of 25 mm 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].

Table- 1 : Colloidal Silica Binder

Particular	Quantity
Silica (SiO_2) weight %	30.0
PH (at 25°C)	10.0
Titrate Alkali (Na_2O) weight%	0.3 to 0.4
Chlorides / Sulphates	Traces
Specific Gravity	1.23
Specific Surface Area m^2/g	250 to 400

The ceramic shells for bending strength test were made by dipping wax patterns into the slurry and stuccoing with 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. 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 of 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.

RESULTS AND DISCUSSION

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 mullet, quartz, cristobalite and amorphous alumina-silicates. The scanning electron microscopy of flyash as represented in fig.1 shows glassy spheres. The particle size varies from sub-micrometers to 100 µm. upto 75 µm particle diameters sized fractions of flyash have surface areas ranging from 1.22 to o.45 m^2/g and densities ranging from 2.0 to 2.9 g/cm^3.

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.

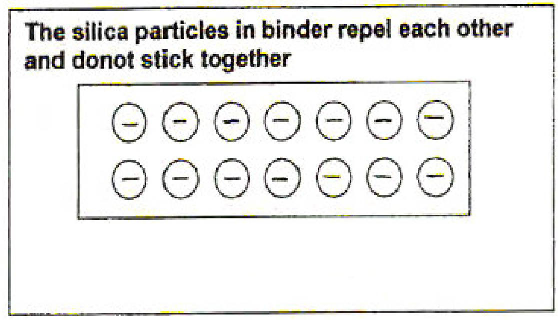

Fig. 1 : Silox binder

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_3	0.26
SO_3	0.05
Na_2O	0.50
K_2O	0.76
Loss on Ignition	0.63

Table 3 : Sedimentation of Refractory Fillers

Filler/Binder Ratio, cm^3/ml	Sediment Height, mm	
	Flyash	Alumina
0.45	17	28
0.55	20	33
0.65	28	38
0.75	35	53
0.85	44	73

Therefore, the particle retention along the slurry column is good in the flyash slurries. The slow sedimentation rate of flyash particles is also die to their hollow structure.

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 - 4 : Effect Filler Loading on Viscosity of Slurry

Filler/Binder Ratio, cm^3/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

Aging Time (m)	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-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 gellation 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 into the slurry (as the slurries continuously stirred to keep the filler from settling out of suspension). Thus the whole volume of the slurry gradually comes into the pre-gelled state.

BONDING MECHANISM V/S STRENGTH OF SHELLS

Silox binder consists of a colloidal dispersion of spherical silicon radicals in water. All the silicon radicals are negatively charged, they do not stick because of like charges repel as shown in fig.1. The pH of silox binder is 9.5 to 10.5. When the filler particles re added to the liquid binder, the pH of the binder falls due to the electrostatic bonds and subsequently the gels are formed in the slurries as shown in fig.2.

When the filler particles are added to the liquid binder, filler particles preferentially absorb hydroxyl (OH^-) ions from water present in the binder owing to the unsatisfied valence bonds at the surface of filler particle, and the filler-water particle becomes

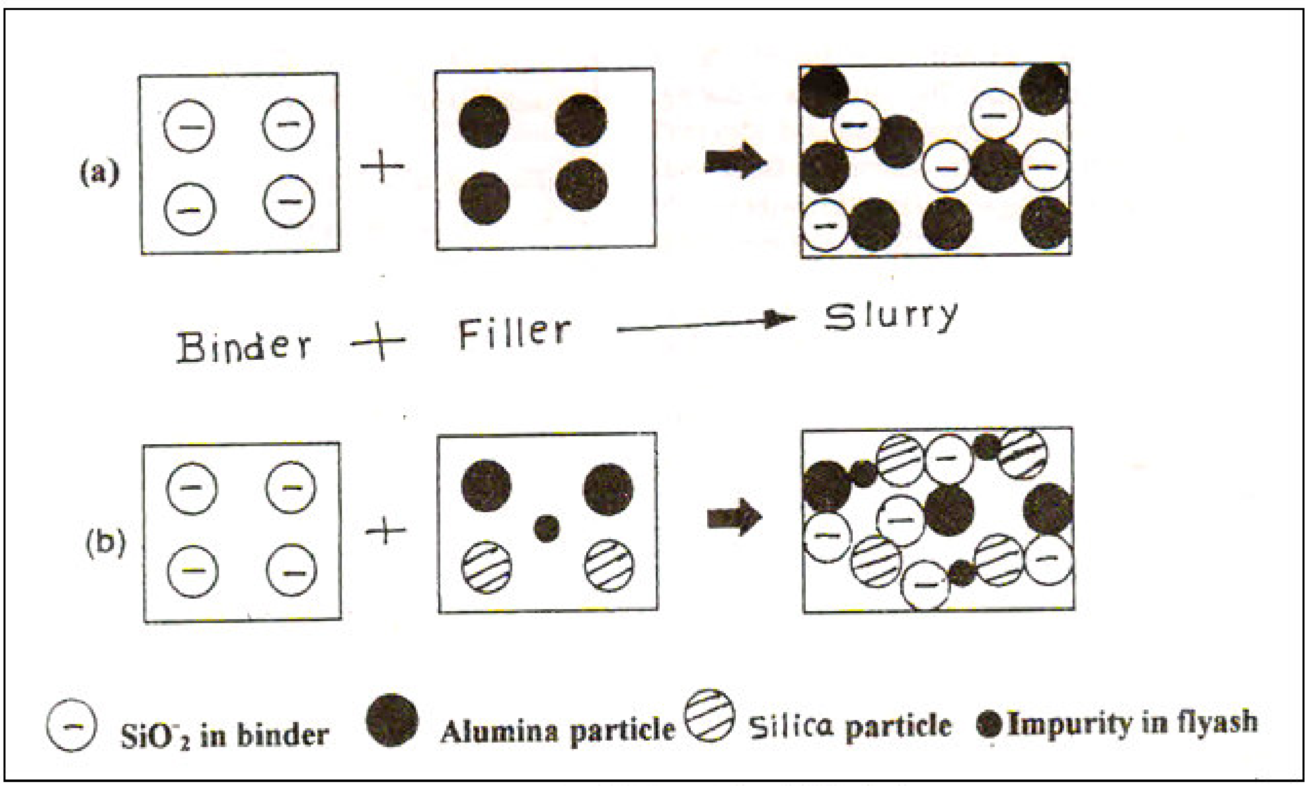

Fig. 2 : Dip-coating slurry (a) Alumina slurry (b) Flyash slurry.

negatively charged. As such, filler particle hull attracts positive (H^+) ions in the surrounding binder medium. The hydrogen counter ions and the absorbed hydroxyl ions about the filler particle comprise a double diffuse layer. The coal flyash consists of silica and alumina along with some impurities like Na, Ca and Mg. hydration of impurities may also occur in the coal flyash slurries. When the coarse sand grains are stuccoed onto the dip-coated wax patterns, particles of stucco sand grains also form micelles by the absorption of hydroxyl ions and hydrogen counter ions. The bonding mechanism developed between the dip-coat layer and stucco sand grains is as follows:

The negatively charged silica particles from the binder exhibit an attraction for positive filler particles; positive stucco sand grains and the counter ions contained in the filler and stucco sand micelles in case of alumina shells (fig.3); whereas in case of flyash shells there is also an attraction between negatively charged silica particles and positive impurity particles and counter ions contained in impurity micelles (fig.4). The final result is electrostatic bonds in the ceramic shells.

In addition to electrostatic bonds, there may be surface tension bonds and frictional and/or mechanical interlocking bonds in ceramic shells. Each coating is allowed to set before the next one is applied. This is accomplished by air-drying. The operations of coating, stuccoing and drying are repeated a number of times until the required shell thickness is achieved. In the removal of water from each coating due to drying forces the particle together and thereby enhances the bonding mechanism in ceramic shells (table-6).

The effect of filler loading on the bending strength of shells is shown in table-7. The bonding mechanism in the shells is due to electrostatic bonds between colloidal silicon radicals in the finder, filler particles and stuccoing sand grains. Flyas shells exhibit high strength for filler to binder ratio of 0.65 whereas alumina shells high strength for filler to binder of 0.75. this is mainly due to the completion of electrostatic bond at these slurry compositions. Flyash shells have distinctly higher strength over alumina shells, as the number of positive charge 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,

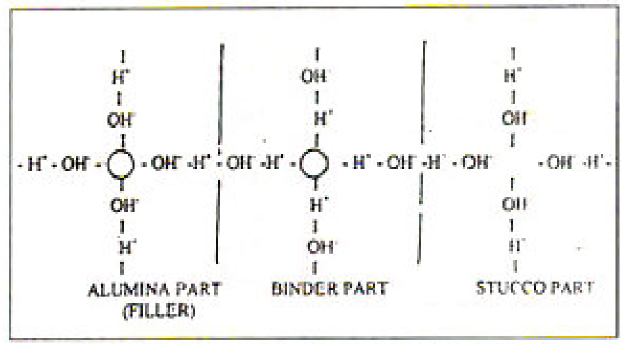

Fig. 3 : *Bonding Mechanism in the alumina shells.*

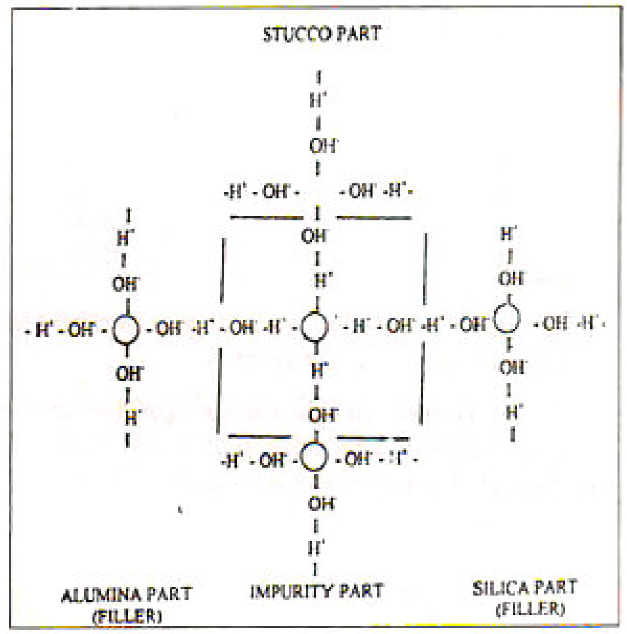

Fig. 4 : *Bonding Mechanism in the coal-flyash shells.*

Table 6 : 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

Table 7 : Effect of filler loading on bending strength

Filler /Binder Ratio, cm^3/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

which in turn linkup, the colloidal silica particles via a bridge and thereby complete gellation [complete neutralization of negatively charged silicon (binder particles].

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 filer particles in the slurry column. The slurries are coarsened by aging. The coarsening action is fast in flyash slurries; spontaneous gellation occurs at 8 hours of aging. Flyash slurries have distinctly higher strength over alumina shells, as the number positive charges carried by the cations are more in the flyash slurries. The removal of water from coats by air-drying enhances the boding mechanism in the shells.

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