"Fly Ash Reactivity with Lime: A Method of Durability Assessment for their Mix Mortar Cubes"

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1.0 Introduction

Durability of a fly ash – lime mortar is its ability to withstand exposure to weather and atmospheric conditions. It is deteriorated by the frost action on saturated mortar in case of humid atmosphere and due to application of excess water during curing and by effect of surrounding air . Though a mortar with good compressive strength is quite durable(6).

The fly ash lime mixture quality depends on the type of fly ash used and its degree of pozzolanicity which vary from source to source in India. The important is the presence of reactive components as well as fluxing agent in the used ash. Amongst all sources in India the fly ashes are having Alumina(21 to 27 percent), Silica (41 to 58 percent), Iron Oxide (4 to 17 percent) and Calcium Oxide (3 to 6 percent). Though the Indian code restricts the total content of Silica, Alumina and Iron Oxide to 70 percent (Class F) and maximum content of free Carbon to 12 percent for suitability of Indian fly ashes(4).

Pozzolanicity of fly ash is proved by sufficient reaction of Silica of fly ash with Calcium Oxide which is enhanced by adding proper quantity of Hydraulic Lime (Class A) in presence of water after hydration reactions under surrounding temperature and humidity conditions.

The affinity of fly ash towards such lime is the basis of its hardening which is measured as its lime reactivity which is observed to be maximum under ideal condition of temperature and humidity.

The hardness of the fly ash :lime : sand mortar is tremendously reduced under normal site condition due to less lime reactivity reactions and less formation of Calcium Silicate Hydrate. The reactivity of fly ash with residual free lime left unreacted after hydration process is controlled by crystalline mineral constituent like Alpha Quartz (SiO_2), Mullite($3Al_2O_3 . 2SiO_2$) , Magnetite (Fe_3O_4) and Haemetite(Fe_2O_3) and large proportion of glass(7). The spherical particle indicate glass content directly responsible for its fineness and pozzolanicity.

Indian fly ashes are collected after coarser coal grinding and hence undesirable from hardness and strength considerations which increase for finer particles less than 45 micron size. This affects its water requirement characteristic on hydration , lime reactivity and abrasion resistance and resistance to freezing and thawing (6). The need is to produce an optimum mix proportion which should have good workability(110$\pm$ 5 percent), water retentivity (minimum 70 percent) in plastic stage and consistent rate of hardening and low shrinkage in mortar cubes which may result into the best possible compressive strength ,hardness and hence durability.

2.0 Materials and Methods

The study was conducted with the type of fly ash shown in table (I) and collected from Faridabad, Bhatinda and Roper thermal power stations and lime from Vigyan chemicals of Dehradun in India according to Indian codes(1) for their lime reactivity in controlled conditions, water requirement , surface hardness observations compressive strengths and their test failure patterns and checked as per code guidelines (2).The hydraulic lime with specific gravity 2.06, fineness 2.16 and 28 days compressive strength 2.16 N/mm^2 were used with all sources of fly ash and tested as per codes (1). The fine aggregate as standard sand with fineness modulus 1.88, specific gravity 2.67, as per specifications of codes (10). The results of lime reactivity tests are shown in table (1) .

The mixtures of fly ash : lime were 90: 10, 80: 20, 70: 30, 67 : 33, 60: 40, and 50: 50 percent respectively by weight in definite proportions and uniform homogenous mixing. Each of the mixes were used to mould 50 mm size standard cubes of mortar types 1:2,1:3, 1:4 and 1:5 proportions of (fly ash : lime mix) : standard sand as fine aggregates respectively in normal temperatures and humidity in open site conditions. Their mortars were prepared by using potable water as percentage of total dry weight of materials of the mix. They were placed in ready moulds of cube size 50 mm in two layers of 25 mm thickness and compaction by 32 tonnes tapping for 10 seconds in four rounds and eight strokes on the surface of specimen in plastic stage as per code guidelines (2).

The cubes were removed from the moulds after 48 to 52 hours of rest under wet gunny bags , thereafter kept in conditions of moist and free air in surrounding for next seven days, thereafter direct application of fresh water on the surface for next seven days and thereafter kept immerged in fresh water till the age of the test. The behavior of the cubes were observed practically on direct application of water on cube surfaces when some showed minor cracks due to slow reactions and hardening. The cubes were tested in 10 tonne compressive testing machines at normal room temperature at the age of 7, 28, 56 and 91 days. The load was applied steadily and uniformly on the surfaces @ 3.5 N/mm^2 /min for at least four cubes cast with each type of fly ash : lime : sand mortars.

The lime reactivity results of each cube were indirectly analyzed in terms of their observed compressive strength from test results shown in tables (2,3,4) after different age and proper curing period.

3.0 Results and Discussions

The test results have been shown in tables 1 to 4 which represent the performance of lime fly ash reactions on hydration and curing up to the age of test. There are wide differences in results if compared with conventional cement mortar cubes in various aspects taken as:

3.1 Water Requirement

It increases with the increase in the percentage of lime as shown in table 2 . The ratio of W/(L + FA) also increases with the lime percent in the mix and with the leanness of the mixes. Its minimum value is 0.74 in 1 : 2 mortar with minimum 10 percent lime content and maximum of 1.47 in leanest mortar 1 : 5 with maximum 50 percent lime content(8). It also increases with content of fine aggregate in the mix mortar. Though the percentage of water requirement decreases with the leanness of the mix mortar for the same flowability to develop the same workability. This indicates that the affinity for water is enhanced for more volume of the lime in the mix mortars to wet their particle surfaces and to overcome the inter particle adhesion among ingredients of the mix(5).

3.2 Surface Hardness

The lime reactivity test conducted in controlled condition of temperature and humidity in isolation from the normal atmospheric surrounding revealed that specimen stored in hot and humid condition undergo faster hydration reactions by fusing glass(SiO_2) content to react with lime and harden. The hardening in such surrounding started from the external surfaces and developed sufficient surface abrasion resistance against external disturbances and those during handling and successful testing of the cubes. The cubes moulded, stored and cured successively in air, spraying water and immersed in fresh water tank in normal room temperature condition showed very slow hydration reactions due to delay in fusing of glass content with the lime as well as less content of dissolvable calcium in the used lime to produce binding composite compounds and hardness on surfaces and within the cubes (10). It was very critical during early days when the surfaces were very soft having enough dampness in the material of the cube due to retained water used in mixing the mortars. This property was gradually improved as the age increased with sufficient reaction up to 91 days as shown in table 4.

3.3 Compressive Strength

A good compressive strength of the mix mortar is also an indication of its good tensile, bond and shear strength which appear as major lateral stresses. As shown in table 4 it is observed that the early age strength up to 28 days strength increases with the increase in the lime content in the mix which is maximum of 36.9 percent of reference cement mortar. It increases further with age up to 91 days and reaches a maximum of 54.3 percent with 30 percent of lime in the mix and 1:2 mix mortar. The value of strength decreases with the leanness of the mortar and the peak strength has been observed with lime percentage of 30 to 40 percent range varying non uniformly(9). The variation in the strength may be because of the fact that at lesser percentage of lime ,all particles of fly ash could not be available for hydration with lime particles and hence slow rate of strength development some fly ash remained unreacted. This problem of the mix got reduced on increasing the lime content by establishing more homogenous mixture under hydration reactions developed more strength . Though larger percentage as 30 to 33 and 33 to 50 lime of the mix it was observed that increase in the strength might be due to availability of both unreacted fly ash and lime both which could not harden.Though the variation in strength got relatively stabilized after 56 and better after 91 days as shown in fig.1.The compressive strength and hence durability has been affected due to colour of fly ash too. The Ropar fly ash used had whitish grey particles which indicated less presence of unburnt carbon. This affected the surface characteristic and hardness. It was surprisingly noted that the lime reactivity test result after 10 days of storage in controlled condition of surrounding produced about four to five times better strength than those in the normal condition.

4.0 Conclusion

The following conclusions are arrived after the above investigation

* As water requirement increases with increase in lime content in the mix a portion of water absorbed by lime particles could not dissolve calcium to participate in the hydration reaction and in tern increased the surface dampness causing surface efflorescence and decrease in durability in the early age up to 28 days . More water used caused more pores in the cube cores and reduction in the direct compressive strength as well as reduction in lateral strength and shear stresses also. There was an exception for 1:2 mortars with 10% lime which showed an abrupt increased strength and decrease in strength for the next percent of lime.
* During curing curing of such mix mortar specimen application of water spray after 7 days up to 28 days increase the hardness gradually and add to the compressive strength .
* Water immersion curing of such cubes are safe only after 28 days of age by the time they develop sufficient hardness of the cube body and seal many pores otherwise penetration of surrounding water in to the pores of specimen and lead to hydrostatic pressure failure of the samples.
*The surface hardness and compressive strength improves very slowly in early age and gain in major portion of strength is gained after 56 days and upto 91 days even when the full extent of lime reactivity hydration reaction are not completed and only 50 to 54 percent strength and hardness are achieved in normal condition of temperature and humidity.
* lime of better quality with sufficient dissolvable calcium to undergo hydration reaction will increase the hardness of the exposed surface and the compressive strength by faster and full reaction between the ingredient of the mix.

Reference

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Table 1
Test results for different sources

Physical properties of Fly ash	Test results for different sources			Specifications as per IS-3812-1966
	Ropar	Faridabad	Bhatinda	
Fineness(cm/gm^2)	3516	1800	3050	3200 (Minimum)
Specific gravity	2.04	1.96	2.1	1.97 – 3.02
Lime reactivity after 10 days as compressive strength in N/mm^2 of 1: 3 mortar using mix as per IS-1727 - 1967	9.6	*	3.53**	4.0 (Minimum)

* The test specimen collapsed in the controlled test conditions of temperature and humidity and lime reactivity reactions could not start to give hardening and hence rejected.

** The specimen showed insufficient reactivity with mixed lime and hence rejected.

Table 2

Percentage water requirement (by weight of dry mortar mix materials) For used lime- fly ash proportions as percentages of the mixes for same flowability for different lime percents in the mix.

Type of (Fly Ash – Lime) : sand mortars	Type of source	water requirement for different mix					
		10: 90	20: 80	30 : 70	33 : 67	40 : 60	50 : 50
1 : 2	Ropar	24.3	24.8	25.1	25.5	25.9	26.4
1 : 3	Ropar	20.6	21.0	21.5	22.0	22.6	23.1
1 : 4	Ropar	19.2	19.5	20.7	20.5	21.1	21.5
1 : 5	Ropar	18.9	19.2	19.6	20.2	20.8	21.1

Table 3

Mortar mix proportions (by mass in grams) of lime(L), Fly ash (FA), Sand (S), Quantity of water (W) for constant flow (110$\pm$ 5) percent for 0.001 m^3 of mortars for different lime percents with the suitable source of fly ash

Type of mix mortars	Ingre -dients of mortars	Ropar fly ash with different lime percents					
		10	20	30	33	40	50
1 : 2	L	68	138	206	226	276	344
	FA	610	542	474	454	406	338
	S	1786	1786	1786	1786	1786	1786
	W	500	510	520	536	548	560
	*W/(L + FA)	**0.74**	**0.75**	**0.76**	**0.79**	**0.80**	**0.82**
	28days compressive strength in N/mm^2	**2.85**	**2.70**	**3.25**	**3.25**	**3.35**	**3.5**
1 : 3	L	52	104	154	170	206	258
	FA	458	406	356	340	304	254
	S	2010	2010	2010	2010	2010	2010
	W	584	482	490	496	504	512
	W/(L + FA)	**0.94**	**0.96**	**0.97**	**0.99**	**1.00**	**1.02**

	28days compre-ssive strength in N/mm^2	**2.60**	**2.85**	**3.40**	**3.15**	**3.25**	**3.05**
1 : 4	L	42	84	124	136	164	206
	FA	366	326	284	272	244	204
	S	2144	2144	2144	2144	2144	2144
	W	460	470	478	492	498	510
	W/(L + FA)	**1.13**	**1.15**	**1.17**	**1.2**	**1.22**	**1.24**
	28days compr-essive strength in N/mm^2	**2.10**	**2.75**	**3.35**	**3.10**	**3.00**	**2.80**
1 : 5	L	34	70	104	114	138	172
	FA	304	272	236	226	204	170
	S	2234	2234	2234	2234	2234	2234
	W	456	466	476	488	498	504
	W/(L + FA)	**1.35**	**1.36**	**1.4**	**1.43**	**1.46**	**1.47**
	28days compre-ssive strength in N/mm^2	**2.00**	**2.55**	**2.30**	**2.65**	**3.00**	**2.85**

*W/(L + FA) - This ratio here were treated as water cement ratio in case of a cement mortar

Table 4

Compressive strength of each mix mortar 50 mm cube size after different age of test in days expressed as percents of 28 days compressive strength (9.48 N/mm^2**)** of reference cement : sand Mortar (1 : 5**)** and the same cube size

Type of (Fly Ash – Lime) : sand mortars	Lime : fly ash Proportions as percentages of the mix	Ropar fly ash for different age of test			
		7 days	28 days	56 days	91 days
1 : 2	10: 90	19.0	30.1	38.5	41.1
	20: 80	20.0	28.5	40.1	45.4
	30: 70	21.1	34.3	43.2	54.3
	33: 67	17.9	34.3	46.4	50.6
	40: 60	21.6	35.3	41.1	49.0
	50: 50	26.4	36.9	42.2	45.9
1 : 3	10: 90	17.9	27.4	37.4	40.1
	20: 80	19.5	30.1	40.1	43.8

	30: 70	20.0	35.9	41.7	51.2
	33: 67	18.5	33.2	42.2	49.0
	40: 60	19.5	34.3	40.6	48.0
	50: 50	21.1	33.2	39.6	44.3
1 : 4	10: 90	17.4	22.1	28.5	38.0
	20: 80	19.0	29.0	32.2	41.1
	30: 70	23.7	35.3	40.6	46.9
	33: 67	25.3	32.7	44.3	48.5
	40: 60	24.3	31.6	38.5	46.4
	50: 50	23.7	29.5	36.9	42.7
1 : 5	10: 90	15.3	21.1	31.6	38.0
	20: 80	15.8	26.9	35.3	40.1
	30: 70	13.7	24.3	33.7	42.2
	33: 67	13.2	28.0	36.9	45.9
	40: 60	14.8	31.6	38.5	43.8
	50: 50	21.1	30.1	37.4	41.1