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Studies on Reactivity of Lime Pozzolona Mixture and their Influence on Mortar Specimens

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***Abstract*—Lime-pozzolana mortars and concretes were used by the Greeks and Romans to build walls, floors, baths, aqueducts, vaults and domes. Despite a long and rich history of lime in construction, Portland cements are now specified almost exclusively which is having high energy consuming and high carbon emission. Thus Lime pozzolana mortar are now regaining popularity as environmental sustainable alternatives to cements for masonry applications. This research is aimed to investigate the possibility of replacing cement with class F fly ash blended with hydrated Lime. The content of silicon oxide in Fly ash reacts with the lime to enhance the hydration process which contributes to the compressive strength, while on the other hand provides a better density by acting as filler. When fly ash is mixed with hydrated lime and Natural sand and the mass is compacted under pressure and subsequently treated under steam curing process, there is a noticeable improvement in the properties of mortar specimens. This paper outlines the composition of the material, method of preparation of mortar specimen, testing procedure, and the development of the compressive strength by varying the water–binder ratio, mix proportioning, and curing conditions. The lime–Pozzolanic mixture shows promising results as a binder which can be used as replacement to the Ordinary Portland cement.**

Index Terms—Compressive Strength, Fly Ash, Hydrated Lime, Natural Sand, Steam Curing

I. Introduction

Civil engineers constantly search for alternative sources of construction materials, for building more economical and durable structures. Since environmental destruction and Global warming have become the serious issue in recent years. Emission of greenhouse gases from industries and its unfavourable impact on climate has changed the way of thinking of people from the mass-production, mass-consumption, mass waste society of the past to a zero-emission society, utilization of industrial wastes and conservation of natural resources. Several studies have been conducted concerning the protection of natural resources, prevention of environmental pollution and contribution to the economy by using this waste material.

In recent years special attention has been given to the use of industrial by-products like fly ash, as alternative source for building materials for concrete construction. The fly ash, also known as pulverized fuel ash, Coal Fly ash (FA) is a by-product of the combustion of pulverized coal in thermal power plants. In India, the annual production of fly ash is about 170 million tons, but only about 35 percent of the total is being utilized, which is very low. Fly ash, being readily available and of lower cost than Portland cement has been increasingly used in the concrete construction industry.

Fly ash less than 5% CaO is Class F fly ash which has pozzolanic properties only whereas fly ash with CaO content in excess of 10% is Class C Fly Ash which possesses both pozzolanic and cementitious properties.

The American Society for Testing and Materials (ASTM) defines pozzolan as “a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically reacts with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.”

Lime has been one of the binding agents which man has used since ancient times as it can be obtained from carbonated stones, mainly limestone’s and dolomites, which are very common in the earth's crust (representing about 20%). Lime is produced through chemical reactions of calcination of limestone and slaking of quicklime. When limestone is heated, calcium carbonate is converted into calcium oxide known as quicklime. Then, the quicklime is slaked with water for the formation of lime

The Greeks and Romans were the first to use Pozzolanas in lime mortars. The Romans not only used crushed pottery bricks and tiles as artificial Pozzolanas but also found that some volcanic soils were excellent for producing hydraulic mortar when mixed with lime.

When Fly ash is mixed with right proportion of hydrated lime in presence of water, it develops pozzolanic characteristics and with the presence of sand when the mass is moulded, it forms different hydrated phases like calcium silicate hydrate, calcium aluminate hydrate etc. during hydration reaction.

Number of researches have already been done on fly ash-lime based compacts. Some of the important works have been mentioned here. [1] Studied that the relationship between the composition and physical characteristics of nine pozzolans and their corresponding reactivity, water demand, setting times and mechanical properties in lime/pozzolan pastes. Finally, it was also noted that the effect of the water content of the paste on the setting times surpasses the influence of the reactivity of the pozzolans and the pozzolanic reaction takes place at variable speed for different pozzolans. [2] studied the optimum lime content value for any combination of materials, may vary with the source of lime and pozzolana to be used. But, a rise in lime content higher than a specific optimum amount will increase the water requirement of the lime-pozzolana cement and lower the strength of the hardened paste. Curing studies by [3] revealed that mortar with higher curing days enhances the compressive strength of composites while lower curing reduces the performance of mortar due to lower carbonation rate.

Studies by [4] have shown that the pozzolanic additives reduce porosity, increase density and as a consequence increase the chemical durability of concrete to sulphate ion containing solution. Studies by [5] showed that with the increasing amount of pozzolana in the mixture the open porosity goes down. This is accompanied by a liquid water absorption decrease. Also diffusion parameters are somehow worsened, as the water vapour diffusion resistance factor increases.

Lime-Pozzolana Mortars [LPM] and concretes were used by the Greeks and Romans to build walls, floors, baths, aqueducts, vaults and domes. Despite a long and rich history of lime in construction, Portland cements are now specified almost exclusively which has high energy consuming and high carbon emission. Thus new lime-pozzolana mortar and concrete is not a return to a former technology as it exploits carefully controlled pozzolanic materials, by-products of current industrial processes, and takes advantage of the significant advances in the development of concrete technology, specifically the performance of cutting edge water reducing admixtures. As a result the speed of set, workability and compressive strength of this lime-pozzolana mortar and concrete is unprecedented.

Considering the fundamental performance achieved by heritage structures with lime mortars in ancient times, it is important to study solutions that use materials which are available today in order to produce construction materials intended to repair and replace the old ones.

In the present investigation LPM have been hydrothermally cured and the effect of the variation in Binder/sand ratio on the properties of the mortar has been investigated.

II. MATERIALS

A) Fly Ash:

In the present study class F fly ash was collected from Raichur Thermal Power Station (Karnataka, India) and it has been used throughout the experiment. The physical, chemical and mineralogical properties were tested as per IS 1727 (1967): Methods of test for pozzolanic materials and results obtained were given in Table-I. The particle size distribution is as shown in Fig. 1.

TABLE I
PROPERTIES OF CLASS F FLY ASH

CHARACTERISTICS	VALUE
Specific gravity	1.96
Particle size distribution	
Sand fraction (4.75 mm to 0.075 mm)	29%
Silt fraction (0.075 mm to 0.002 mm)	69%
Clay fraction (< 0.002 mm)	4%
pH	11.58
Total Dissolved Solids	526.62mg/L
Loss on Ignition (LOI)	0.2%
Fineness modulus	2.62

B) Lime:

Hydrated Lime with high $Ca(OH)_2$ content (90%) which passes 250mesh has been used. Then Lime was stored in air tight container for subsequent use. The physical, and chemical properties were tested as per IS 1514 (1990): Methods of sampling and test for quick lime and hydrated lime and IS : 712 – 1984: Specification for Building Limes and results were as shown in Table-II.

XRD test result of hydrated lime sample showed that Portlandite [$Ca(OH)_2$] and Zinc Sulfide [ZnS] are predominantly present.

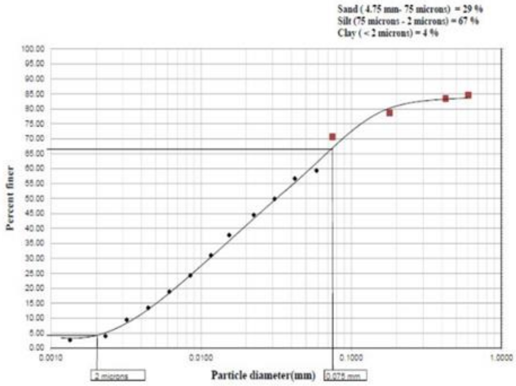

Fig. 1. Particle size distribution of class F fly ash

TABLE II
PROPERTIES OF HYDRATED LIME

CHARACTERISTICS	VALUE
Colour	White
Specific gravity	2.06
pH	12.6
Total Dissolved Solids	4512mg/L
Initial Consumption of Lime (ICL)	4.0%

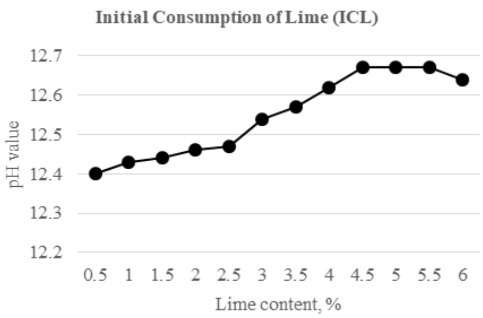

Fig. 2. Initial consumption of lime (ICL)

C) Sand:

Locally available Natural sand passing through 4.75mm sieve was used for the experiments. The physical properties were specific gravity and gradation of sand as per IS: 383-1970 tested. The sand belongs to zone -II as per IS: 383-1970. The specific gravity of sand = 2.64. Particle Size Distribution of Sand is given in Table-III and Fig. 3.

TABLE III
PARTICLE SIZE DISTRIBUTION OF FINE AGGREGATE

PARTICLE SIZE	CUMULATIVE % FINER
4.75mm	94.8
2.36mm	78.0
1.18mm	58.5
600micron	18.2
300microns	8.7
150microns	3.8

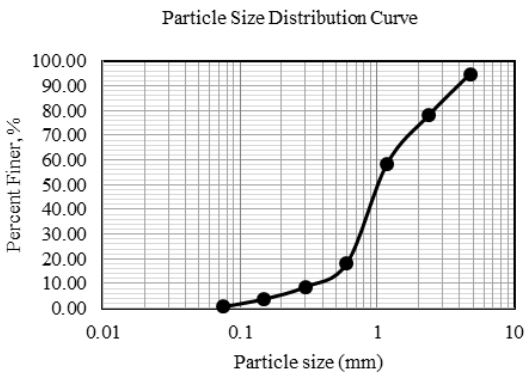

Fig. 3. Particle size distribution of fine aggregate

The particle size distribution graph indicates that the sand contains more percentage of finer particles and less coarser particles. This shows that the greater percentage of finer particle of sand has the ability to improve the mortar properties.

III. Experiment

To synthesize appropriate lime Pozzolona paste with varying proportions so as to achieve adequate setting time similar to that of cement and sand paste.

The procedure for selection of mix proportions used for Portland cement mortar is also applicable to mortar incorporating fly ash and lime with some modifications. The main steps of procedure are as follows.

- Selection of water to Binder materials ratio to meet durability and strength parameters.
- Calculation of Binder content i.e. Lime + fly ash.
- Calculation of fine aggregate content.
- Trial batch adjustments.

Simple Replacement method consists of direct replacement portion of Portland cement by fly ash and lime by volume or by mass, which mainly consists of modifying an existing Portland cement mix to include fly ash or lime without other adjustments. The mortar designed with this method usually has performance compared to that of mortar made with Portland cement.

A) Variables Studied:

In this investigation different binder aggregate (B/Ag) ratios were selected varied around 1:3 as the most cited ratio in the literature. The Binder and Fine aggregate ratio used in preparation of mortar were 1:2, 1:3, and 2:1 by weight and different types of specimen were prepared by varying the lime content. The 3 composite mortars tried were 50:50, 70:30 and 80:20. Using 70.6mm mortar moulds the different mix ratios were casted to check compressive strength.

B) Sample Preparation:

Test specimens of size 70.6mm x 70.6mm x 70.6mm were prepared for testing the compressive strength. In this study, the mix was done manually. The Binder and fine aggregate were first mixed dry to uniform colour. Water was then added and the whole mass mixed. The interior surface of the moulds and the base plate were greased before mortar is placed as shown in Fig. 4. After 48hours the specimens were removed from the moulds and placed for curing in both ambient air and steam curing.

Fig. 4. Lime Pozzolana mortar specimens for different ratios

C) Curing:

- **Ambient Air curing**: After demoulding, one set of specimens were kept under curing using gunny bags, at room temperature for a period of 7, 14 and 28 days.
- **Steam Curing**: To explore the effect of curing at high temperature, another set of Specimens were placed in water bath maintained at a temperature of 80ºC for a period of 16 hours.

Fig. 5. Specimens under steam curing

Properties of the different test samples after complete curing have been detailed below.

D) Tests for Compressive strength:

Fig. 6. Test setup for compressive strength in universal testing machine

Cured specimens were surface dried and the specimens were tested in the dry state. The specimens were weighed to the nearest 0.1 g and loaded with a hydraulic compression testing machine at a constant rate until failure as shown in Fig. 6. Each record was an average of three tests.

IV. Test Result and Discussion

A) Compressive strength:

The purpose of the test was to determine the strength development as the powder proportions and W/B were varied. Specimens were tested for compressive strengths at 7, 14, and 28 days. A strength increase with increased Fly Ash content and reduced Lime content is observed.

Among the 3 Binder-Sand ratios i.e., 1:3, 1:2 and 2:1 with varying Fly Ash-Lime content from 50-50, 70-30 and 80-20, 1:3 ratio with 80% Fly Ash and 20% Lime with suitable W/B ratio gave a maximum Compressive strength of 3.97MPa and 4.4Mpa under ambient curing for 28days and steam curing for 16hrs respectively.

TABLE IV
Compressive strength result

S.No.	Binder: Sand	Fly Ash (%)	Hydrated Lime (%)	Compressive Strength (MPa)	
				Ambient Curing for 28days	Steam curing for 16hrs
1	1:3	50	50	2.68	3.05
2	1:3	70	30	3.17	3.69
3	1:3	80	20	3.97	4.41
4	1:2	50	50	2.56	2.72
5	1:2	70	30	2.64	3.08
6	1:2	80	20	2.92	3.41
7	2:1	50	50	2.60	3.21
8	2:1	70	30	2.96	3.61
9	2:1	80	20	3.20	3.69

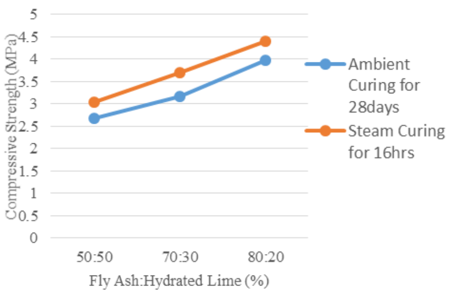

Fig. 7. Compressive strength result for 1:3 ratio

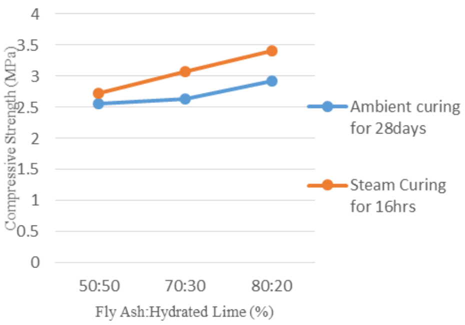

Fig. 8. Compressive strength result for 1:2 ratio

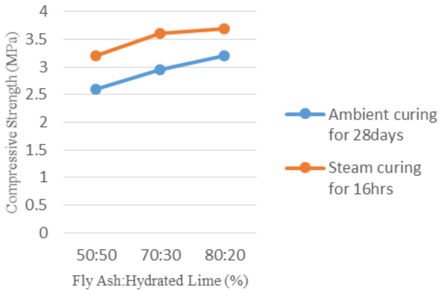

Fig. 9. Compressive strength result for 2:1 ratio

V. Conclusion

Based on the test results and analysis, the following conclusions can be drawn:

- LPM with Binder Aggregate ratio 1:3 composed of 80% Fly Ash, 20% hydrated lime shows good compressive strength compared to other ratios.
- This study has also shown that the 28-day strength of the paste can be greatly achieved by steam curing at 80°C for 16hrs.
- On the other hand, it can also be observed that the LPM strength continues to rise with curing period.

Increasing fly ash content provided more silica and alumina, which could react with calcium hydroxide to form binding C–S–H and C–A–H phases, resulting in high strength.

A high W/B results in less binding powder in a given volume of paste, and excess water which did not participate in the chemical reactions of the binding powders occupied space and contributed to porosity. However, less water in the paste can lead to incomplete reaction of the powders and strength reduction. It is thus important to determine the minimum w/b that gives the best results.

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