Experimental Investigation on Fly Ash and Lime Sludge in Cement Mortar

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Abstract: - **An experimental investigation has been carried out to study the effect of Lime sludge and Fly ash in cement mortar. Recycling is a key concept of modern waste management and is the third component of waste hierarchy. Disposal of lime sludge remains a major challenge. Disposal of lime sludge from water softening adds about 7-10% to the cost of water treatment. Having effective and safe options is essential for future compliance. Lime sludge production is a by-product of water treatment plant and Fly ash is by-product of coal thermal power plants. To date, these by-products are being used in other industrial branches and in the field of civil constructions. Considering the specificity of physical and chemical properties of fly ash and lime sludge and a series of possibilities for their use in concrete, this research work demonstrates the possibilities of using fly ash and Lime sludge together as partial replacements of cement in cement mortar.**

This research work presents an investigation of compressive strength of cement mortar by adding Lime sludge and Fly ash as partial replacement of cement in various percentages. In this work cement has been replaced by four proportions of Fly ash & Lime sludge. The four proportions are (100 % cement +0 % Fly ash + 0% Lime sludge), (75 % cement + 12.5 % Fly ash + 12. 5% Lime sludge), (50 % cement + 25 % Fly ash + 25% Lime sludge) &(25 % cement + 37.5 % Fly ash + 37.5 % Lime sludge).

It has been observed from the 7, 14 and 28 days tests of compressive strength of cement mortar that compressive strength decreases as the percentage of Lime sludge increases in the mix when compared with controlled concrete. Results indicated that the decrease in compressive strength with the increase in Lime sludge replacement.

Key words: **Lime Sludge, Fly ash, replacement in cement mortar, compressive strength.**

I. INTRODUCTION

The disposal of industrial wastes is a problem of increasing importance throughout the world [1]. Sludge from water treatment plant and fly ash from the combustion of coal in thermal power plants are produced in large quantities in most industrial nations of the world today due to the large usage drinking water and electrical energy requirements constitute one of our most serious environmental problems. When lime sludge is dewatered and dried, it is mostly calcium carbonate, or the same substance chemically as limestone. Dried lime sludge is fine grained and was classified as a silt size material with a large available surface area. Whereas fly ash has been found a numerous use in cement and building material as in bricks, light weight aggregates embankments filling and in soil stabilization.

Lime sludge could be disposed of in municipal solid waste (MSW) landfills. However, it is safe to assume that MSW landfills would not accept stockpiled lime sludge unless it was dried, because landfills need to minimize the amount of leach ate they generate. Furthermore, if lime sludge were sent to a MSW landfill, the water treatment plant disposing of the sludge would need to pay for the costs of drying, loading, and transporting the sludge, plus tipping fees. It makes more sense to find alternative uses for lime sludge in which the consumer pays for the material. Part of solving this problem is blending in concrete making purpose to meet the demand of disposal of waste in concrete [1].

Fly ash is a byproduct from coal based thermal power plants. The thermal power plants ash generation in India has increased day to day , At the time of independence in 1947, the installed capacity was 1,361 MW, which has increased to 1, 87, 732 MW on 31 March, 2012. Out of it, 1, 10, 232 MW is thermal (Coal/Lignite) based and is responsible to co-generate nearly 200 million tons of fly ash per year [2]. Now days, fly ash is commonly used in concrete in replacements, ranging from 0 % to 30 % by weight of the total cementitious material. The rising of cement demand can be further resolved by utilizing high volume (more than 50 %) of fly ash in concrete. And this process obviously will be economical as well as reduces green house gas emission, minimize waste disposal and health hazards. Thus the use of high volume fly ash in concrete has recently gained popularly as a resource – efficient, durable cost-effective, sustainable option for ordinary Portland cement (OPC) concrete applications [3].

The purpose of this research was to study the application and utility of these industrial wastes as a cementitious/pozzolanic material in construction Industry.

II. LIME SLUDGE

Lime sludge, an inert material mostly composed of calcium carbonate, is the result of softening hard water for distribution as drinking water [2]. It is generated in from paper, acetylene, sugar, fertilizer, sodium chromate, soda ash industries, and water softening plants. Approximately 4.5 million tons of sludge in total is generated annually from these industries [4].

2.1 Characteristics of Lime sludge/mud

Lime sludge is a very fine precipitated CaC03 particles along with unsettled dregs carried over from green liquor clarifier. Major impurities associated with lime mud (sludge) are Silica and Magnesium. Silica enters mainly via raw materials or through purchased lime and goes to chemical recovery loop. During the caustic zing operation $Si0_2$ forms Ca $Si0_3$ which is gelatinous in nature. This gelatinous nature hinders the setting property of lime mud (sludge). It has been observed that high percentage of silica in lime mud entraps higher moisture content. The average Chemical properties of Lime Sludge waste are given in Table 1.1

Ca (OH)2 + Si02 + Na2 C03 = NaOH + CaC03 + Ca Si03
(Green liquor) (Slow setting lime mud)

Table1.1: Chemical properties of Lime sludge (*CRI-ENG-SP 965March 2000*)[5]

MC %	SiO2 %	Al2 O3%	Fe2 O3%	CaO %	MgO %	LOI %	SO3	Na2 O %
40-60	2-8	0.8-1.2	0.8-1.2	48-53	0.2-3.0	37-42	0.1-0.3	0.8-2.0

2.2 Utilization of Lime sludge in Construction Industry

Detailed investigations were carried out on the utilization of lime sludge from various industries. Most of the Literature revealed that sludge from paper industry can be utilized up to 74 percent (dry basis) as a component of raw mix for the manufacture of cement clinker. In addition to it around 30 percent (dry basis) lime sludge can also be utilized for the manufacture of masonry cement. Due to the presence of higher quantities of deleterious constituents in carbide sludge, it can be used up to 30 percent whereas level of utilization for other sludge could reach to only 10 percent in the manufacture of cement clinker [4]

The lime sludge from paper industry has been found suitable as blending material for manufacture of masonry cement in the proportion of up to 30 percent con-forming the Indian Standard specification of IS: 3466-1988. Some of the Major industrial applications are mentioned below

- ✓ Lime Sludge in Dry Scrubbing Power Plants
- ✓ Replacing Limestone with Lime Sludge in Cement Kilns
- ✓ Re-Use of Lime Sludge for Wastewater Neutralization
- ✓ Use of Lime Sludge for Dust Control on Gravel Roads
- ✓ Lime Sludge Use for Construction Fill Applications

III. FLY ASH

Fly ash is a naturally-cementitious coal combustion by-product. About 120 coals based thermal power stations in India are producing about 112 million tone fly ash per year. According to ASTM C-618 fly ash is broadly classified into two major categories: Class F and Class C fly ash. The chief difference between these two classes is the amount of calcium, silica, alumina, and iron content. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite). However, unlike the case of fly ash which has several papers and reviews on its beneficial reuse already published, some of them are

- ✓ Cellular Light Weight Concrete (CLC) Blocks:
- ✓ Development of fly ash Based Polymer Composites as Wood Substitute:
- ✓ Portland Pozzolana Cement
- ✓ Ready mixed fly ash concrete:
- ✓ Fly Ash- Sand-Lime-(Gypsum /Cement) Bricks /Blocks:
- ✓ Fly Ash in Road Construction
- ✓ Asphalt concrete

An attempt has been made in this study to utilize two potential industrial by-product i.e. fly ash and lime sludge in mortar mix. The compatibility of the fly ash and lime sludge is assessed by the compressive strength of the cement-mortar mix. A series of laboratory compression strength tests were carried out with varying content of fly ash, lime sludge and cement as binder The results obtained from the tests are presented, compared and discussed in this paper.

IV. MATERIALS USED

A. Cement and Sand

Ordinary Portland Cement (OPC) having 28 day compressive strength 0f 54 Mpa was used throughout the course of investigation, which conforms to IS 12269 – 1987. All the tests for the physical properties of the cement were conducted in accordance with the IS: 4031-1968. Local river sand passing through sieve size 4.75 mm having specific gravity of 2.56 and fines modules of 2.65.

B. Fly Ash

The fly ash of Class F collected from Rayalaseema Thermal power plant (RTPP) , Muddhanur , Kadapa , and a single lot is used entire investigation .It was dry without lumps and gray in color and stored in air tight tins. The physical are in Table 1.2 and chemical composition of both cement and fly ash mentioned in Table 1.2 & Table 1.3 from literature.

Table 1.2 Physical Properties of Fly ash

Characteristics	Value
Specific gravity	1.86
Bulk density(kg/m3)	400
Colour	Gray

Table 1.3 Chemical Properties OPC and Fly ash

Chemical Composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_4	Loss on Ignition
OPC	18.62%	4.75 %	3.02%	61.42%	3.21%	1.51 %	1.42 %	2.29%	3.55 %
Fly Ash	64.58%	25.89%	5.27%	0.59 %	0.26%	0.027%	0.041%	0.31%	2.40 %

C. *Lime Sludge*

In this work Lime Sludge is taken from water treatment plant Good Care Enviro system Pvt Ltd, Chennai, India. It is White in colour and look like as slaked lime. During the process of producing potable water, some commercial products are added to raw water in order to assure its quality for human consumption. In the present study calcium hydroxide, poly aluminum chloride (PAC) and a flocculating agent were added to treat the water. The flocs produced during coagulation and flocculation treatment is settled in the clarifier. The sludge is collected from the bottom of the clarifier and stored in the sump tank. A centrifuge thicker is used to remove the water content of the sludge and make it dry. The sludge collected after centrifuge thickening process was in dry state and stored properly in air tight containers.

V. METHODS EMPLOYED

5.1 Mix preparation

The fly ash and ordinary Portland cement was sieved and portion retained on 90 micron was used. The sludge was oven dried for about 16-18 hours at 60^{o}C and the lumps were broken gently using the pestel. It was sieved through 150 micron sieve and portion retained on 90 micron sieve was used. Four different proportions of binders were prepared. The four proportions are (100 % cement +0 % Fly ash + 0% Lime sludge), (75 % cement + 12.5 % Fly ash + 12. 5% Lime sludge), (50 % cement + 25 % Fly ash + 25% Lime sludge) &(25 % cement + 37.5 % Fly ash + 37.5 % Lime sludge) In this paper, the mixes are designated by a common coding system consisting of three alphabets, namely ‘FA’ for fly ash, ‘LS’ for lime sludge, ‘C’ for cement The variables used are presented in table 1.4

Table 1.4 Chemical Properties OPC and Fly ash

Binder name	C (%)	FA (%)	LS(%)
Binder I	100	0	0
Binder II	75	12.5	12.5
Binder III	50	25	25
Binder IV	25	37.5	37.5

5.2. Consistency test

To determine the water content for the mortar mix, consistency test for all the four binder combination was performed. The consistency was determined as per IS: 4031 (Part 4)-1988. 400 g of binder materials were weighed and mix with 26, 28, 29 % and 30 % of water and check for penetration of plunger from bottom. At 29% of water content, the penetration was within the range of 5-7 mm. Hence optimum water content was 29 % and standard consistency (P) was determined as 10.25 %.

5.3. Specimen preparation

For compression tests of mortar, cubes of size 70.6 x 70.6 x 70.6 mm were prepared for all the four types of binder. In the cement mortar mixes cement was replaced with fixed proportions for all mixes and 0%, 25 %, 50 %, 75 % of fly ash and lime sludge. Cubes were casted for subsequent testing at 7, 14, and 28 days strength. To prepare mortar mixture, first the required amounts of binder and sand were weighed and mixed together in the dry state. The dry mixture was then mixed with the required amount of water and again mixed properly in wet state. All mixing was done manually, and proper care was taken to prepare homogeneous mixtures at each stage of mixing. The entire required quantity of the moist binder-sand mixture was placed in three equal layers, each followed by tampering and scratching the top surface before placing the other layer inside the assembly.

5.4. Method of curing

It was observed that certain specimens could not be taken out from the mould after 24 h indicating that the rate of strength gain was slower in first 2 days. To make the curing uniform, all the specimens were demolded after about 48 hours and were kept in humidity chamber for moist curing. The humidity chamber was maintained at 95% relative humidity and 25oC temperature. The curing was continued till the respective specimens were tested after 7, 14 and 28 days for compressive strength.

5.5. Compressive strength test

For each binder combination three identical specimens were tested. The samples were tested on a universal testing machine. As an acceptance criterion, the specimen, whose individual strength deviated by more than 10% from an average strength of the three identical specimens, was rejected. The tests were conducted on all combinations of fly ash – lime sludge – and Cement.

VI. RESULTS AND DISCUSSION

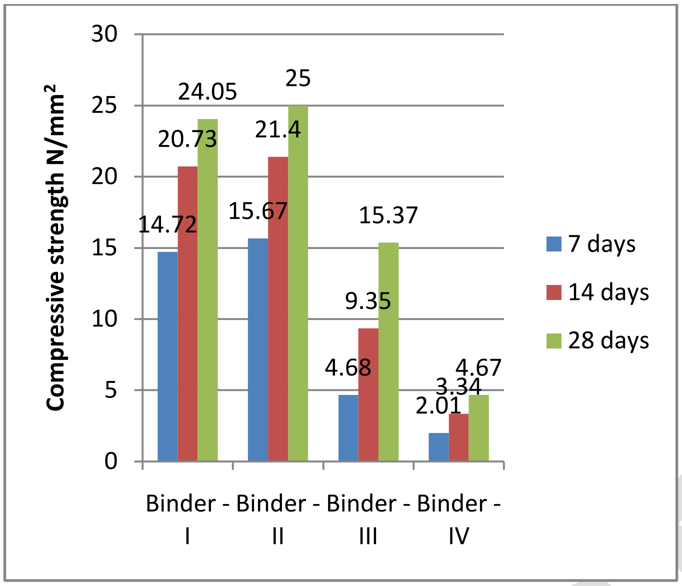

Fig 1: Compressive strength versus curing period for Four Binders.

The chemical composition of FA and LS shows that the high amount of silica and alumina of FA and rich content of calcium oxide of LS make them compatible and they can replace cement when used in a proper composition. Based on this fact, mortar specimens were prepared using binder III & IV, which consists of fly ash and lime, sludge more than 50 % & 75 % respectively. The mortar specimen with binder III (25 %FA: 25% LS: 50%C) and binder IV (37.5%FA: 37.5%LS: 25%C) were tested after curing them as per standards method. Fig. 1 shows the compressive strength achieved at 7, 14 and 28 days curing for specimen prepared with binder III & IV. It shows that the strength of both the mortar mix increases with curing period (Binder IV to Binder III. The rate of gain in compressive strength is found to be slow in initial days and it increases with the age. The percent increase in 28 days strength is 30%. This increase may be due to the nature of the hydrate phases formed during the hydration process. The formation of hydration products decreases the total porosity and increases the compressive strengths. The gain in compressive strength at early ages of hydration is generally attributed to the formation of calcium silicate hydrate (CSH) gel, together with crystalline products, which include calcium aluminates hydrates and calcium sulfo aluminates hydrates (C4AH13, C3A.3CaSO4.32H2O and C3A.CaSO4.12H2O). This binder shows the non compatibility of lime sludge with fly ash in mortar mix decreeing cement to it.

Whereas more than 50% of cement was added along with fly ash and lime sludge. Binders I & II, namely 0%FA: 0%LS: 100C and 12.5% FA: 12.5 % LS: 75 % C were prepared. Figure 1 shows the strength of both the binders. It is observed that the strength gain is more in binder II than binder I. The strength increases with increase in lime sludge content and subsequent increase in fly ash content. The reason may be due to the presence of calcium oxide (CaO) in lime sludge which is responsible for strength gain.. Hence sludge addition shows strength gain. The highest strength of 25 N/mm2 was observed for binder II. The percent increase in strength for binder II as compared to binder I is 10% for 28 days strength. After extensive studies the binder II can be successfully used in various applications.

VII. CONCLUSIONS

Based on the experimental investigations, it may be concluded that Utilization of fly ash and lime sludge in mortar mix presents an opportunity to achieve sustainable utilization of natural and/or conventional resources. The four binders discussed here can be gainfully exploited as the building materials in construction. The large amount of silica and alumina available in fly ash and rich content of calcium oxide in lime sludge, make them compatible with each other and can replace cement also. Upto the 25% of replacement of LS and FA in cement mortar it gives higher 28 days strength and it is comparatively developing decrease in strength compared to control mortar. However percentage strength gain with respect to ages is higher compared to lower percentages of replacements of LS and FA.

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