# The Use of Fly Ash and Lime Sludge as Partial Replacement of Cement in Mortar

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## Abstract

The increased demand of drinking water and power has led huge generation of water treatment plant residue i.e. sludge and the thermal power plant by-product such as fly ash. Large quantities of sludge and fly ash are produced in India and disposed off by landfilling or dumping in and around sites. In this study fly ash and water softening sludge (lime sludge) has been utilized in mortar. Two types of mortar (type I and II) with four binder combinations have been tried. Binder I consists of 70% fly ash (FA) and 30% lime sludge (LS) , 0 % gypsum (G), binder II is 70% FA, 30% LS and 1% G, binder III is 50% FA, 30% LS and 20% cement and the binder IV is 40% FA, 40% LS with 20% cement. The effect of various combinations on strength has been discussed here. This paper outlines the composition of the composite material, method of preparation of mortar specimen, testing procedure and salient results thereof.

**Keywords:** Fly ash, lime sludge, mortar

## 1. Introduction

The creation of non-decaying waste materials, combined with a growing consumer population has resulted in a waste disposal crisis leading to an economic and environmental problem. These wastes that produced today will remain in the environment for hundreds, perhaps thousands of years. The magnitude of environmental problems like air, surface and ground water pollution and economic problem like landfilling maintenance cost, etc., is very high for both wastes. This rapidly increasing waste stream remains a significant environmental issue and needs to manage in an economic and environmentally sustainable manner. India also faces this crisis to a large extent. One solution to this crisis lies in recycling waste into useful products to replace the natural/commercial products wherever possible which will reduce the economic and environmental problem of waste disposal and also reduce the depletion of natural resources. Large quantities of drinking water treatment plant sludge are produced in India and across globe and disposed off by landfilling. Space limitations on existing landfill sites and problem of waste stabilization have prompted investigations into alternative reuse techniques and disposal routes for sludge. The best practical way of recycling these wastes is to use in civil engineering constructions since bulk quantities of materials are used in a short time in civil engineering constructions.

The demand for electric power and drinking water had risen tremendously in India because of the industrialization and rapid economic growth. This has resulted in setting up of large number of thermal power plants for the generation of electricity

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and water purification plants for supplying drinking water. In India, the thermal power generation constitutes 73% of the total power generation installed capacity. Out of which nearly 90% is coal based power generation. The high ash content (30-50%) of Indian coal is a contributing factor for the huge production of fly ash. Fly ash (FA) generation in India was 112 Mt during 2005 and it is expected to hike between 150 and 170 Mt per year by the end of 2012 [25]. Formation of FA depends on the ash content of coal and Indian coal used in power plants generally has very high ash content (35–45%) and is of lower quality [24]. As a consequence, a large amount of FA is generated in thermal power plants, and is disposed off in unmanaged landfills, lagoons and ponds. FA disposal in an unscientific way affects the local ecosystems due to the heavy metal pollution through erosion and leachate generation. The scenario with respect to fly ash management has undergone considerable improvement over the past few years. Due to increasing dependence on coal as a major resource for energy production and growing environmental concern due to the haphazard of FA disposal, it has become imperative exploring viable avenues for FA management. Hence, the thrust of this discussion was to review the existing FA management options in India and recommend strategies for minimizing the problems related to FA disposal and encouraging its effective utilization.

Lime sludge is generated 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. The study has 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 [9].

While considerable development has been made in utilization of fly ash which was just 3% in 1994, increased to 13% in 2002, and reached almost 50% in 2011, the water treatment plant sludge need more attention for their reuse. Continuous efforts are under way to find applications where fly ash can be used effectively in bulk quantities in several civil engineering applications for example using as a fill material [4, 14, 15], as a lightweight aggregate [3, 6, 17, 29, 30], as a subbase material [5, 12, 23, 33, 21] for the manufacture of clay flooring and terracing tiles [7, 35] as an absorbent material [13, 16], as a binder material in concrete technology [2, 11, 27], and as a volume replacement and self-compacting material for increasing the workability of concrete [19, 20, 26, 34, 36, 38]. Strength development in fly ash is critical in most applications, but it varies considerably depending on several parameters.

However, unlike the case of fly ash which has several papers and reviews on its beneficial reuse already published, it appears beneficial reuses of lime sludge is lacking for now. Few constructive attempts and research works have been made particularly in recent years to reuse waterworks sludge in many beneficial ways. Utilization of lime sludge in India is very limited, the incorporation of lime sludge for productivity enhancement of lime kilns was tried and found feasible [28] and incorporation of lime sludge in cement manufacturing was discussed in CPCB report [9].

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 effect of admixture namely gypsum on the strength of the mix is also discussed. The results obtained from the tests are presented, compared and discussed in this paper.

## 2. Material Used

### *2.1. Fly ash*

Fly ash used is collected from Badarpur thermal power plant, Delhi. The fly ash was collected from the electrostatic precipitators and stored in air tight bins. Morphological characteristics were determined for the fly ash. The chemical composition for the fly ash has been referred from literature.

### *2.2. Lime sludge*

Sludge used in this study is collected from water treatment plant, Delhi, India with installed capacity of 4.5 million liters per day (MLD) and producing about 4-5 ton of sludge daily. 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.

### *2.3. Cement and sand*

An ordinary Portland cement of 43 grades has been used in the present work. The river bed sand passing through sieve size 4.75 mm has been used in the study.

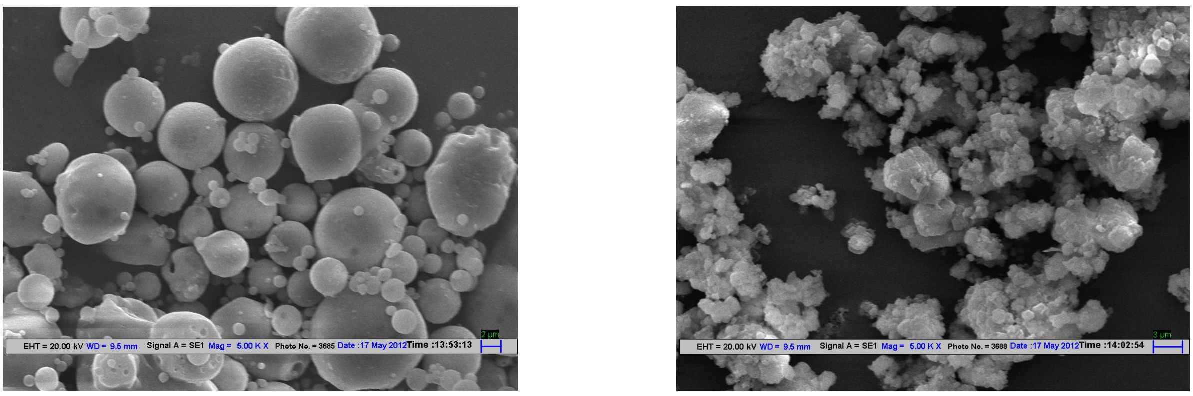
### *2.4. Gypsum*

Analytical grade calcium sulphate dihydrate (gypsum) $CaSO_4.2H_2O$ has been used.

## 3. Characteristics of Fly Ash and Lime Sludge

### *3.1. Morphological characteristics*

The morphological characteristics of fly ash and lime sludge were studied by scanning electron microscopic technique. Zeiss EVO series scanning electron microscope model EVO 50 was used to examine the morphology of the materials. Figure 1 (a) and (b) show the scanning electron micrographs of fly ash and sludge respectively at 5000 times magnification. The fly ash particles are spherical in shape and have a wide range of particle size or diameter while the sludge particles are irregular in shape and show the agglomerated structure.



(a) (b)

Fig. 1 Scanning electron micrographs for (a) fly ash and (b) sludge

### 3.2. Chemical composition

The chemical composition of Indian lime sludge and fly ash referred from literature is presented in table 1. It shows that generally the fly ash is rich in silica (SiO2) and alumina (Al2O3), the lime sludge contains a good amount of calcium oxide (CaO). Hence this combination can replace cement which generally contains large amount of CaO and less concentration of silica and alumina.

Table 1 Chemical composition of fly ash and lime sludge in India

| Mineral | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | LOI | $SO_3$ | $Na_2O$ |
|---|---|---|---|---|---|---|---|---|
| Fly ash[1] | 38-63 | 27-44 | 3.3-6.4 | 0.2-8 | 0.01-0.5 | 0.2-3.4 | ------- | ------ |
| Lime sludge[2] | 2-8 | 0.8-5 | 0.8-2.5 | 35-70 | 0.2-10 | 20-50 | 0.2-9 | 0.8-2.0 |

Source: [1]Pandian, 2004 [2]CPCB, 2007

## 4. Experimental program

### 4.1. 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 60oC 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. Two sets of mortar mix (type I and type II) were prepared, each set with two different types of binders. Type I mortar is cement less mortar, where 100% cement is replaced with a combination of fly ash and lime sludge with 0 & 1% of gypsum. Type II mortar consists of 20% cement content, fly ash and lime sludge. All the sets of mortar were prepared with 1:3 binder-to-sand ratio. 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 and 'G' for gypsum. The variables used are presented in table 2.



Table 2 Variables used in the study

| Binder name | FA (%) | LS (%) | C (%) | G (%) |
|---|---|---|---|---|
| Type I - without cement | | | | |
| Binder I | 70 | 30 | 0 | 0 |
| Binder II | 70 | 30 | 0 | 1 |
| Type II - with cement content | | | | |
| Binder III | 50 | 30 | 20 | 0 |
| Binder IV | 40 | 40 | 20 | 0 |

### 4.2. Consistency test

To determine the water content for the mortar mix, consistency test for all the three binder combination was performed. The consistency was determined as per IS: 4031 (Part 4)-1988. 200 g of binder materials were weighed and mix with 35, 38 and 40 % of water and check for penetration of plunger from bottom. At 40% of water content, the penetration was within the range of 5-7 mm. Hence optimum water content was 40% and standard consistency (P) was determined as 13%.

### 4.3. Specimen preparation

For compression tests of mortar, cubes of size 60x60x60 mm were prepared for all the four types of binder, sand and 13% of water content as specified by standard consistency test. 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.

### 4.4. 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 demoulded after about 48 hours and were kept in humidity chamber for moist curing. The humidity chamber was maintained at 95% relative humidity and 25°C temperature. The curing was continued till the respective specimens were tested after 3, 7 and 28 days for compressive strength.

### 4.5. 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 – cement and gypsum.

## 5. Results and Discussion

### 5.1. Type I mortar with 0% cement (cement less)

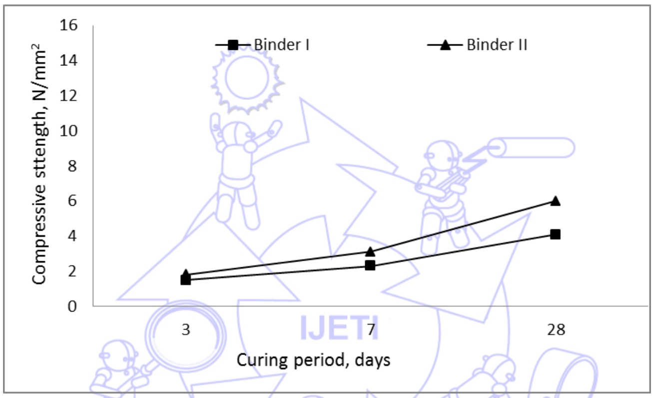



Fig. 2 Compressive strength versus curing period for type I mortar

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 I & II, which consists of fly ash and lime sludge (with 0 and 1% gypsum). The mortar specimen with binder I (70FA:30LS:0C:0G) and binder II (70FA:30LS:0C:1G) were tested after curing them as per standards method. Fig. 2 shows the compressive strength achieved at 3, 7 and 28 days curing for specimen prepared with binder I & II. It shows that the strength of both the mortar mix increases with curing period. 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 strength with curing is given in table 3. 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 aluminate hydrates and calcium sulfoaluminate hydrates ($C_4AH_{13}$, $C_3A.3CaSO_4.32H_2O$ and $C_3A.CaSO_4.12H_2O$). The addition of small amount of gypsum (1%) enhances the strength of the mix. The percentage increase in strength on gypsum addition is given in table. The addition of gypsum accelerates strength by altering the course of hydration of calcium silicate which is predominantly formed in the early hydration stage. Here the calcium ions are supplied from lime sludge and fly ash is rich in silica and alumina. Fly ash is nonplastic in nature, addition of gypsum and lime sludge imparts plasticity to the mix. Gypsum also renders workability to the binder at early age of hydration. Nevertheless, gypsum also contributes for strength acceleration in the early stages of hydration. This binder shows the compatibility of lime sludge with fly ash in mortar mix without adding any cement to it. After extensive studies the binder II (with gypsum) can be successfully used in various applications.

Table 3 Percent increase in strength with curing period

| Curing period | Percent increase |
|---|---|
| Binder I (0% gypsum) | |
| 7 | 53 |
| 28 | 78 |
| Binder II (1% gypsum) | |
| 7 | 72 |
| 28 | 93 |

Table 4 Percent increase in strength on gypsum addition

| Curing period | Percent increase |
|---|---|
| 3 | 20 |
| 7 | 26 |
| 28 | 46 |

*5.2. Type II mortar with 20% cement*

Under this section, 20% of cement was added along with fly ash and lime sludge. Binders III & IV, namely 50FA:30LS:20C and 40FA:40LS:20C were prepared. In binder III, FA content is more (50%) and LS is less (30%) whereas in binder IV, the FA content was decreased from 50 to 40% and LS content increased from 30 to 40%, the cement content is kept constant in both the binders. Figure 3 shows the strength of both the binders. It is observed that the strength gain is more in binder IV (40FA:40LS:20C) than binder III (50FA:30LS:20C). The strength increases with increase in lime sludge content (from 30 to 40%) and subsequent reduction in fly ash content (from 50 to 40%). 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 14 $N/mm^2$ was observed for binder IV. The percent increase in strength for binder IV as compared to binder III is given in table 5.

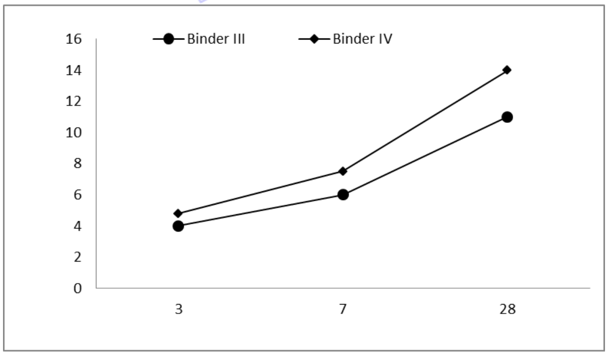



Fig. 3 Compressive strength versus curing period for type II mortar

Table 5 Percent increase in strength for binder IV as compared to binder III

| Curing period | Percent increase |
|---|---|
| 3 | 20 |
| 7 | 25 |
| 28 | 27 |

## 6. Conclusions

Beneficial 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. Continue refinement of optimum content, long term strength, durability studies, and leachate analysis of the composite could provide a way to effectively utilize these waste materials as an economic and sustainable development strategy.

The study brings forth the following conclusions:

(1) This work brings forth the compatibility of two potential industrial by-products namely fly ash and lime sludge in mortar mix.

(2) 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.

(3) The strength was increased continuously with curing period.

(4) The addition of gypsum showed positive effect on strength due to accelerated pozzolanic reaction. For type I mortar, the highest strength of 6 N/mm$^2$ was observed for binder II (1% gypsum) after 28 days curing period.

(5) By increasing the content of LS and subsequent decrease of FA content under type II mortar showed increased strength of binder IV as compared to binder III. The maximum strength achieved after 28 days curing for type II mortar was 14 N/mm$^2$ (binder IV).

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