Technical Evaluation of Sustainable Cement Containing Fly Ash and Carbide Lime Sludge

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Abstract. Challenges faced by the consumption of cement in construction and loads build on natural raw materials mainly limestone, have necessitated need for other sustainable alternative cementations materials. Fly ash (FA) being waste product is used in manufacturing of Portland Pozzolana Cement (PPC), concrete and embankments. Still effective utilization of FA in terms of quantity is not achieved worldwide. Therefore, to increase the utilization of FA, Carbide Lime Sludge (CLS) an industrial waste, is used in the current study for the production of sustainable cement. The effective utilization of FA varying (5, 15, 25 and 35%) plus 10% CLS in terms of physical properties of cement with PPC containing FA varying (15, 25, 35 and 45%) have been evaluated. The outcome from this study would help to utilize up to 45% FA plus CLS with acceptable compressive strength vis a vis saving of limestone and reduction in carbon dioxide emissions.

1. Introduction
The manufacture of cement is energy-intensive and accounts for about 7% of the world's carbon dioxide (CO₂) emissions.[1][2]. It is well known that CO₂ contributes to the greenhouse effect and is responsible for the global warming of the earth as well. Therefore, research has increased on the usage of by-product cementing materials such as FA and granulated slag for more and more production and usage of blended cement instead of Ordinary Portland Cement (OPC).[3][4]. As far as cement consumption in India is concerned production of PPC is more than 70 percent during recent years[5]. On the other hand, increasing demand for electricity has also resulted in higher consumption of coal and more fly ash generation consequently. Millions of tons of fly ash is produced every year across the Globe and this industrial byproduct not only causes environmental problems but also occupies significant storage space on scarce land. Therefore, replacing cement with fly ash to the maximum possible extent is a feasible option for energy savings, cost savings and environmental protection[1]. Fly ash is one of the most popular and widely used pozzolanic material worldwide[1]. Disposal of tons of this waste without any treatment would cause soil contamination, water pollution, air pollution and the loss of flora and fauna. The use of fly ash in concrete has increased rapidly as it contains high silica and aluminum reactive forms[6][7]. Cement, fine aggregate and water are usually a mortar mixture in which coarse aggregate is avoided. Despite of the fact that there are advantages of using fly ash in mortar as in concrete, fly ash mortar research studies carried out so far are relatively less[1]. Depending on the available resources, Supplementary Cementing Materials (SCM) such as fly ash can
be used as a partial replacement for OPC[8][9]. While substituting materials can be used to replace natural aggregates in terms of resource use and energy usage greener concrete production can be achieved[8][10]. In some cases, with regard to its incorporation into concrete, the fact that the use of fly ash can enhance concrete durability without compromising strength has attracted a lot of attention[11][12]. Current global trends are focused on the recovery of waste from useable products, as well as the usage of waste as raw materials in construction wherever possible[6]. In the current research, it was found that FA was used without adding any admixture in the different studies, which could enhance its productive use in cement. In the form of calcium hydroxide, 10% CLS, obtained as a by-product from the acetylene industry, is used to increase the lime content and the lime-silica ratio to increase the effectiveness of FA.

2. Experimental investigations
This section describes the collection of materials, their preparation, and tests that are conducted for the analysis of samples.

2.1. Materials
The constituent components, such as clinker, gypsum, FA and CLS, used in current research work have been obtained from the following sources: Clinker has obtained from the Jaypee cement plant, Rewa (Madhya Pradesh), CLS and gypsum have obtained as acetylene industry from DCM Shri Ram Cement Works, Kota (Rajasthan) and fly ash has collected from Motipura Thermal Power Plant (Rajasthan), India is shown in Figure 1 (a-d).

![Figure 1](a-d). Collected raw materials

2.2. Preparation of materials
Clinker, FA and CLS have been grind in a laboratory ball mill and then sieving through a 90μm IS sieve. Sieved clinker has blended with 2.5% gypsum for the preparation of OPC.
2.3. Mix proportions

Eight mixes are used to examine the strength properties of different percentages of FA plus 10% CLS and FA mortar, as shown in Table 1. In the current research, FA plus CLS mixes are compared with FA mixes.

Table 1. Combinations of mixes

| Mixes (%) | Ordinary Portland Cement (OPC) | Fly Ash (FA) | Carbide Lime Sludge (CLS) |
|-----------|-------------------------------|--------------|---------------------------|
| OPC55FA35CLS10 | 85 | 5 | 10 |
| OPC55FA25CLS10 | 75 | 15 | 10 |
| OPC55FA15CLS10 | 65 | 25 | 10 |
| OPC55FA5CLS10 | 55 | 35 | 10 |

3. Test Program

The main objective of the present study is to study the performance of FA plus CLS and FA mixes according to the Indian Standard (IS) on the physical properties of cement. This list of tests is shown in Table 2.

Table 2. Indian Standards code for testing

| Property tested | IS code            | Reference |
|-----------------|--------------------|-----------|
| Chemical composition | IS 4032 – 2005     | [13]      |
| Insoluble residue | IS 4032 – 2005     | [13]      |
| Particle size distribution | IS 2720 (Part 4) - 2006 | [14]      |
| Setting time    | IS 4031 (Part 5) - 2005 | [15]      |
| Compressive strength | IS 4031 (Part 6) - 2005 | [16]      |
| Lime reactivity | IS 1721 - 2004     | [17]      |

4. Results and discussion

This section explains the analysis results of chemical composition, insoluble residue, particle size analysis, setting time, compressive strength and CO₂ emissions.

4.1. Chemical composition

Table 3 showed the major oxide compositions of collected materials such as clinker, carbide lime sludge and fly ash.
Table 3. Chemical composition of raw materials

| Oxide (%) | Clinker | Carbide lime sludge | Fly ash |
|-----------|---------|---------------------|---------|
| SiO₂      | 21.28   | 3.185               | 49.45   |
| Al₂O₃     | 5.21    | 0.19                | 26.61   |
| Fe₂O₃     | 4.13    | 0.14                | 10.72   |
| CaO       | 64.13   | 67.02               | 3.47    |
| MgO       | 3.54    | 0.38                | 1.3     |
| Cl        | 0.035   | 0.085               | 0.04    |
| SO₃       | 0.71    | 2.25                | 4.09    |
| Balance   | 0.965   | 26.75               | 4.32    |

4.2. Insoluble residue (IR)
The portion of material which is insoluble in acid as well as base is known as the insoluble residue. In the cement specifications, the limit for IR is defined therefore it is necessary to test this parameter in all the ingredients. IR for CLS, FA and OPC is evaluated and shown in Table 4.

Table 4. Insoluble residue of raw materials

| Raw materials                  | Insoluble residue (%) |
|--------------------------------|-----------------------|
| Carbide Lime Sludge (CLS)      | 23.61                 |
| Fly Ash (FA)                   | 24.52                 |
| Ordinary Portland Cement (OPC) | 1                     |

4.3. Morphology of carbide lime sludge
Back Scatter Electron (BSE) image with energy dispersive X-Ray analysis using scanning electron microscopy (SEM-EDAX) are shown in Figure 2 (a & b).

Figure 2. (a & b). Scanning electron micrographs and spectral image of raw material
The SEM image indicates that the material has porous characteristics and the presence of Ca, Mg, Fe and Si compounds in the material is confirmed by spectral image.
4.4. Particle size distribution
Hydrometer analysis is used to determine the particle size of powder materials is shown in Figure 3. Particle sizes of raw materials of less than 90μm were used in the current study.

![Particle size distribution](image)

**Figure 3.** Grain size compositions of materials

4.5. Setting time
The initial and final setting time of all mixes is shown in Figure 4 (a-d). These measurements were carried out using Vicat apparatus. Compared to the mix containing FA, the different percentages of FA plus CLS mixes resulted in a lower initial and final setting time. The possible explanation may be the smaller particle sizes of materials. The setting time of FA plus CLS mixes is within the acceptable limits as mentioned in Indian Standard[15].

![Setting time](image)

(a) Impact of 5% FA plus 10% CLS and 15% FA on cement paste

(b) Impact of 15% FA plus 10% CLS and 25% FA on cement paste
(c) Impact of 25% FA plus 10% CLS and 35% FA on cement paste

(d) Impact of 35% FA plus 10% CLS and 45% FA on cement paste

Figure 4(a-d). Effect of all mixes on setting time of cement

4.6. Compressive strength

In comparison to the FA mix, the mortar containing FA plus CLS mix contributes an earlier strength. At 45% FA plus CLS contribute greater compressive strength while 45% FA substitution decreases the compressive strength of mortar to a certain extent. This fact is corroborated by the lime reactivity test of this mixture (FA plus CLS), which is found to be 8 MPa as per Indian Standard[17]. The compressive strength of mortar for all mixes is shown in Figure 5 (a-d). The compressive strength of all the mixes of FA plus CLS is found to be within permissible limits as per IS 1489(Part 1)[18].
4.7. Carbon dioxide emissions

In the cement manufacturing process, clinker production is the most energy-intensive operation and generates high CO$_2$ emissions from the process[19]. Approximately 90% of the CO$_2$ emissions from the cement manufacturing process are direct emissions (calcination process), while the remaining 10% are from the transport of raw materials and other processes (Electricity consumption) of production[20][21]. Furthermore, the generation of fly ash from thermal power plants is also responsible for atmospheric CO$_2$ emissions. Approximately, combustion of 1 ton of coal (fossil fuel) emits three-quarters of CO$_2$[22].

In the current study, the portion of fly ash is replaced with CLS with a view of maintaining compressive strength of cement vis–a-vis reduce the CO$_2$ emissions as compared to PPC. Figure 6 shows the CO$_2$ emission from the manufacturing of 1-ton sustainable cement (FA plus CLS) and PPC (only FA) by Yang Yan et al.[21].

![Figure 6. Carbon dioxide emissions](image)

(c) 35% of OPC substitution
(d) 45% of OPC substitution

**Figure 5(a-d).** Compressive strength of mortar in MPa at 3$^{rd}$, 7$^{th}$ and 28$^{th}$ day
5. Conclusions
The usage of fly ash provides advantages in terms of cost-effectiveness, ecological and technological aspects. Up to 45% FA plus CLS can be used without compromising the 28th day compressive strength (33 MPa) of PPC while 45% FA replacement decreases the compressive strength of PPC. The mix containing FA plus CLS is reducing the initial and final setting time of cement when compared with the FA mix. The usage of sustainable cement would reduce the cost of cement production and also reduce the emission of carbon dioxide.

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References
[1] Yerramala A and Desai B H A S K A R 2012 Influence of fly ash replacement on strength properties of cement mortar International Journal of Engineering Science and Technology4(8) 3657-3665.
[2] Björk F 1999 Concrete technology and sustainable developmentCANMET/ACI Int. Symp. Concr. Technol. Sustain. Dev1-9.
[3] Khatib J M and Wild S 1998 Sulphate resistance of metakaolin mortar Cement and concrete research28(1) 83-92.
[4] Chatveera B and Lertwattanaruk P 2009 Evaluation of sulfate resistance of cement mortars containing black rice husk ash. Journal of environmental management90(3) 1435-1441.
[5] Report of the working group on cement industry for XII five year plan 2012-2017.
[6] Ghazali N, Muthusamy K and Ahmad S W 2019 Utilization of Fly Ash in Construction. In IOP Conference Series: Materials Science and Engineering 601(1) 012023 IOP Publishing.
[7] Akmal A M N, Muthusamy K, Yahaya F M, Hanafi H M and Azzimah Z.N 2017 Utilization of fly ash as partial sand replacement in oil palm shell lightweight aggregate concrete In IOP Conference Series: Materials Science and Engineering 271(1) 012003 IOP Publishing.
[8] Attarde S, Marathe S and Sil A 2014 Utilization of fly ash in construction industries for environment management International Journal of Environmental, 3(2) 117-121.
[9] Poon C S, Kou S C and Lam L 2002 Use of recycled aggregates in molded concrete bricks and blocks Construction and building materials 16(5) 281-289.
[10] Zakaria M and Cabrera J G 1996 Performance and durability of concrete made with demolition waste and artificial fly ash-clay aggregates Waste Management 16(1-3) 151-158.
[11] Papadakis V G and Tsimas S 2005 Greek supplementary cementing materials and their incorporation in concrete Cement and Concrete Composites 27(2) 223-230.
[12] GoraI S 2018 Utilization of Fly ash for sustainable environment management J. Mater. Environ. Sci 9(2) 385–393.
[13] IS 4032 2005 Method of chemical analysis of hydraulic cement Bureau of Indian standards New Delhi.
[14] IS 2720(Part 4) 2006 Methods of test for soils Part 4 Grain size analysis Bureau of Indian standards New Delhi.
[15] IS 4031( Part 5) 2005 Methods of physical tests for hydraulic cement Part 5 Determination of initial and final setting times Bureau of Indian standards New Delhi.
[16] IS 4031( Part 6) 2005 Methods of physical tests for hydraulic cement Part 6 Determination of compressive strength of hydraulic cement other than masonry cement Bureau of Indian standards New Delhi.
[17] IS 1727 2004 Methods of tests for pozzolanic materials Bureau of Indian standards New Delhi.
[18] IS 1489 2005 Portland pozzolona cement specidication 1.
[19] ShenL, Gao T, ZhaoJ, Wang L, Wang L, Liu L, Chen F and Xue J 2014 Factory-level measurements on CO2 emission factors of cement production in China Renewable and
Sustainable Energy Reviews 34 337-349.

[20] Mikulčić H, Vujanović M and Duić N 2013 Reducing the CO2 emissions in Croatian cement industry Applied energy 101 41-48.

[21] Yang Y, Wang L, Cao Z, Mou C, Shen L, Zhao J and Fang Y 2017 CO2 emissions from cement industry in China: A bottom-up estimation from factory to regional and national levels Journal of Geographical Sciences 27(6) 711-730.

[22] Raghuvanshi S P, Chandra A and Raghav A K 2006 Carbon dioxide emissions from coal based power generation in India Energy Conversion and Management 47(4) 427-441.