Technical and Environmental Assessment of Composite Cement Conataining Fly Ash and Mineral Additive

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Abstract — Fly ash (FA) utilization in concrete as partial replacement of cement is gaining importance day by day. Technological improvements in thermal power plant operations as well as collection systems of FA improved the quality of FA. FA is a waste product from the combustion of pulverized coal in electricity power plants and considered as a contributing factor for air, water and soil pollution that lead to human health problems and various geo-environmental issue. The use of FA in cement can reduce the consumption of natural resources and also diminishes the effect of pollutant in environment. In the current economic conditions, all construction works required cost efficient with good quality of work. Therefore, to increase the effective utilization of FA, Lime Sludge (LS) an industrial waste, is used in the current study for the production of green cement. The utilization of FA varying (5, 15, 25 and 35%) plus 15% LS in terms of physical properties of cement with Portland Pozzolana Cement (PPC) containing FA varying (20, 30, 40 and 50%) have been evaluated. The outcome from this study would help to utilize up to 50% FA plus LS with acceptable compressive strength vis a vis saving of limestone (CaCO3) and reduction in carbon dioxide (CO2) emissions.

Keywords: Fly Ash; Industrial Waste; Lime Sludge; Carbon Dioxide Emissions; Compressive Strength; Cement Industry

I. INTRODUCTION

In view of global warming, efforts are on to reduce the emission of CO_2 to the environment, cement industry is a major contributor in the emission of CO_2 as well as using up high levels of energy resources in the production of cement[1]. By replacing cement with a material of pozzolanic characteristics, such as FA, the cement and concrete industry together can meet the growing demand in the construction industry as well as help in reducing the environmental pollution[2][3].

FA can be defined as a waste residue that is released from coal combustion process in electric power stations. It is the unburned residue that is carried away from the burning zone in the boiler by the flue gases and then collected by either mechanical or electrostatic separators[4]. It contains silica, alumina, ferric oxide and other oxides material that might turn FA into hazardous material. These hazardous material is contributing factor in air, water and soil pollution that lead to human health problems and various geo-environmental issue. These bad situations will interrupt the entire ecological cycles if not properly disposed, therefore good waste management practice needed to sustain a healthy environment[5]. FA has been successfully used in concrete industry since over 50 years but its application is still limited due to lack of understanding of the characteristics of FA itself and the properties of cement containing FA[6][7].

Several researchers in the past investigated the effect of mineral and chemical admixtures on the properties of the cement adopting different theories[8][9]. Depending on the available resources, Supplementary Cementing Materials (SCM) such as FA can be used as a partial replacement for OPC[10]. While substituting materials can be used to replace natural aggregates in terms of resource use and energy usage greener concrete production can be achieved. In some cases, with regard to its incorporation into concrete, the fact that the use of FA can enhance concrete durability without compromising strength has attracted a lot of attention[11]. 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[12]. 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, 15% LS, 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.

II. MATERIAL USED

This section describes the collection of materials, their preparation and tests that are conducted for the analysis of samples. The constituent components, such as Ordinary Portland Cement (OPC), FA and LS, used in current research work have been obtained from the following sources:

A. *Fly Ash*

FA has collected from Motipura, Thermal Power Plant (Rajasthan). The FA was collected from the electrostatic precipitators and stored in air tight bags is shown in Figure 1.

Fig. 1: Collected fly ash

B. *Lime Sludge*

Lime sludge has obtained as acetylene industry from DCM Shri Ram Cement Works, Kota (Rajasthan). LS is that, in the acetylene production process, carbide is mixed with water to produce acetylene, carbide lime, heat, and the final products are suspended in water. Thus, LS is produced when calcium hydroxide reacts with water. The lime slurry produced is in solid form when the water has been evaporated or dried. The collected lime sludge shown in Figure 2.

Fig. 2: Collected lime sludge

C. Cement

An OPC 53 grade has been used in the current research study and PPC has also been used for the comparison purpose.

D. Preparation of FA and LS

FA has been grind in a laboratory ball mill and then sieving through a 90µm IS sieve. The collected lime sludge was sun dried for 48 hrs. to remove the initial moisture content. Subsequently, it was oven dried at 105˚C for 24 hrs. for removal of residual moisture content. Dried lime sludge is ground in a laboratory ball mill and subsequently sieved through a 90μm IS sieve. The process of lime sludge shown in Figure 3.

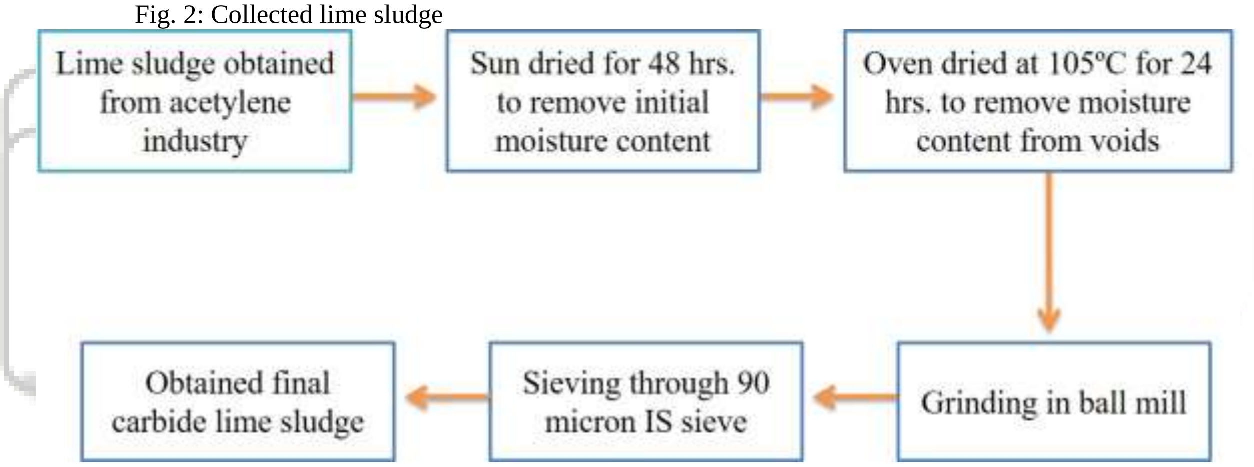


Figure 3. Preparation of lime sludge in final form

III. EXPERIMENTAL PROGRAM

All the mortar mix samples were prepared as per IS-4031: Part 6 (1998), using following building materials and tested under controlled laboratory conditions, i.e., temperature 28˚C (recommended 27±2˚C) and relative humidity 62% (recommended 67±5%).

A. Mix Preparation

Eight mixes are used to examine the strength properties of different percentages of FA plus 15% LS and FA mortar, as shown in Table 1. In the current research, FA plus LS mixes are compared with FA mixes.

Mixes (%)	Ordinary Portland Cement	Fly Ash	Lime Sludge
	Composite Cement Mixes using FA with LS		
$OPC_{80}FA_{5}LS_{15}$	80	5	15
$OPC_{70}FA_{15}LS_{15}$	70	15	15
$OPC_{60}FA_{25}LS_{15}$	60	25	15
$OPC_{50}FA_{35}LS_{15}$	50	35	15
	PPC Mixes using FA		
$OPC_{80}FA_{20}$	80	20	-
$OPC_{70}FA_{30}$	70	30	-
$OPC_{60}FA_{40}$	60	40	-
$OPC_{50}FA_{50}$	50	50	-

Table 1: Combinations of mixes

B. Test Program

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

Property Tested	IS Code	Reference
Chemical composition	IS 4032 – 2005	13
Insoluble residue	IS 4032 – 2005	13
Setting time	IS 4031 (Part 5) - 2005	14
Compressive strength	IS 4031 (Part 6) - 2005	15

Lime reactivity	IS 1721 - 2004	16
Particle size distribution	IS 2720 (Part 4) - 2006	17

Table 2. Indian Standards code for Testing

IV. RESULT AND DISCUSSIONS

This section explains the analysis results of chemical composition, insoluble residue, particle size analysis, setting time, compressive strength and CO_2 emissions.

A. *Chemical Composition*

For the current study, the aforementioned materials are collected in sufficient quantity to maintain identical chemical compositions throughout the study. Table 3 showed the major oxide compositions of collected materials such as OPC, LS and FA[13].

Oxide (%)	Ordinary Portland Cement	Lime Sludge	Fly Ash
SiO_2	21.28	3.185	49.45
Al_2O_3	5.21	0.19	26.61
Fe_2O_3	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
SO_3	0.71	2.25	4.09
Balance	0.965	26.75	4.32

Table 3: Chemical composition of raw materials

B. *Insoluble Residue (IR)*

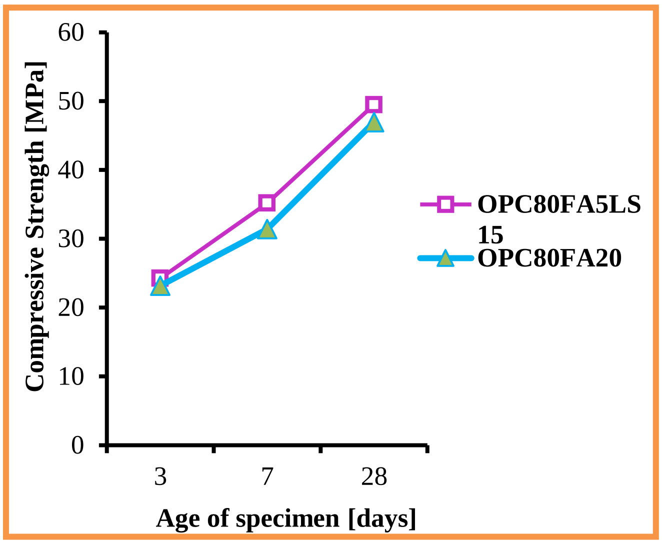
The portion of material which is insoluble in acid as well as base is known as the insoluble residue. In the cement specifications, the limit for IR is defined therefore it is necessary to test this parameter in all the ingredients[13]. IR for LS, FA and OPC is evaluated and shown in Table 4.

Raw Materials	Insoluble Residue (%)
Lime Sludge	23.61
Fly Ash	24.52
Ordinary Portland Cement	1

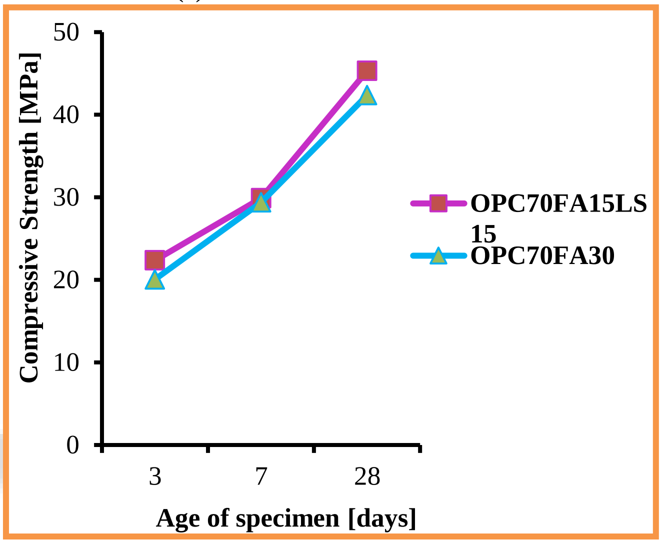
Table 4: Insoluble residue of raw materials

C. *Compressive Strength of Mixes*

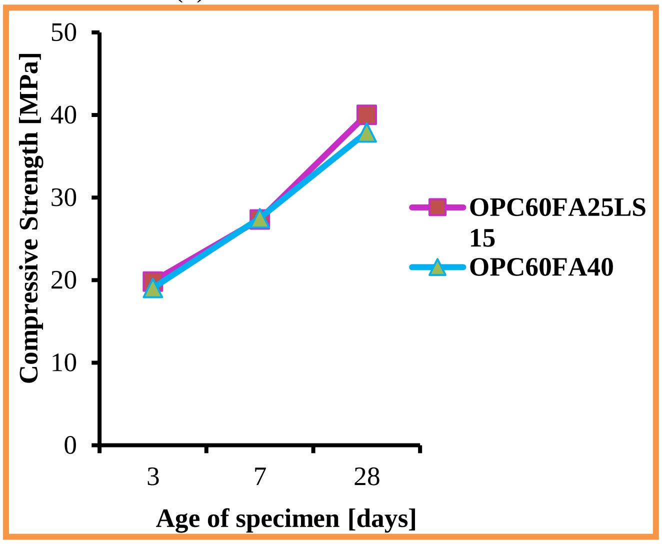
In comparison to the FA mix, the mortar containing FA plus LS mix contributes an earlier strength. At 50% FA plus LS contribute greater compressive strength while 50% FA substitution decreases the compressive strength of mortar to a certain extent[15]. This fact is corroborated by the lime reactivity test of this mixture (FA plus LS), which is found to be 8 MPa as per Indian Standard[16]. The compressive strength of mortar for all mixes is shown in Figure 4 (a-d). The compressive strength of all the mixes of FA plus LS is found to be within permissible limits as per IS 1489(Part 1)[18].



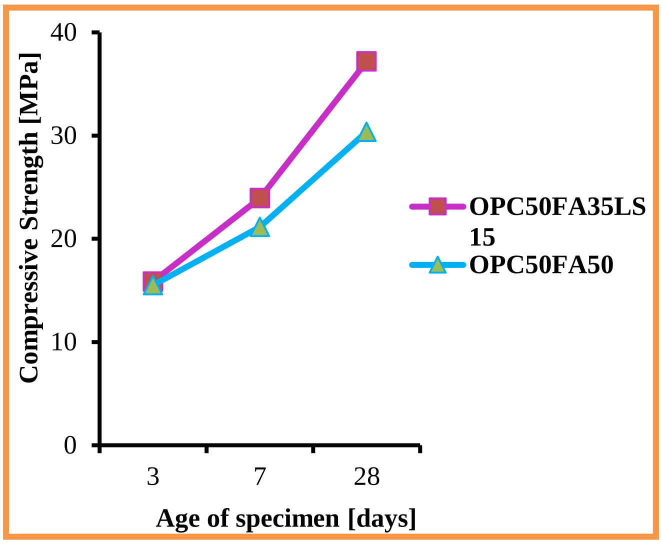
(a) 20% of OPC substitution



(b) 30% of OPC substitution



(c) 40% of OPC substitution

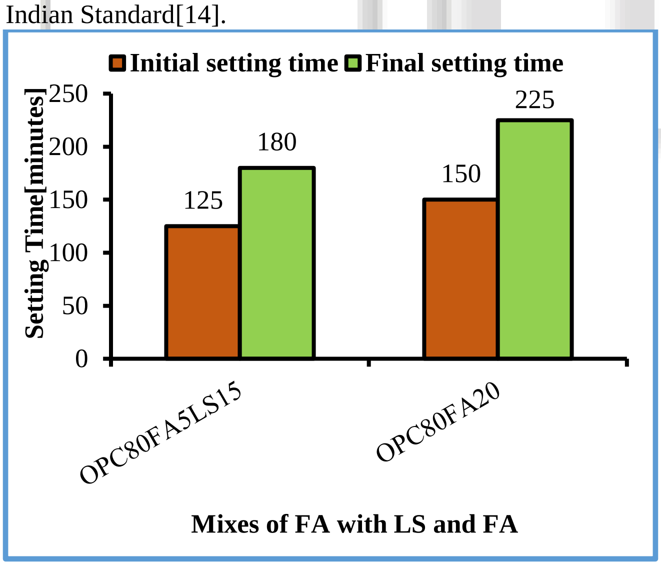


(d) 50% of OPC substitution

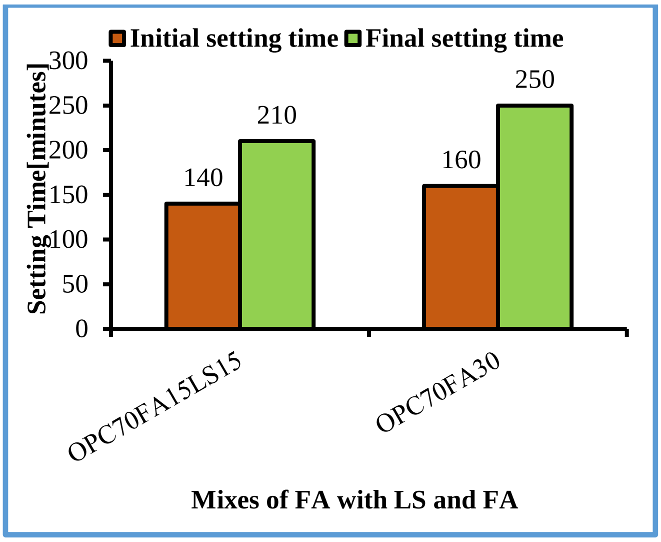
Fig. 4: (a-d) Compressive strength of mortar in MPa at 3rd, 7th and 28th days

D. *Setting Time*

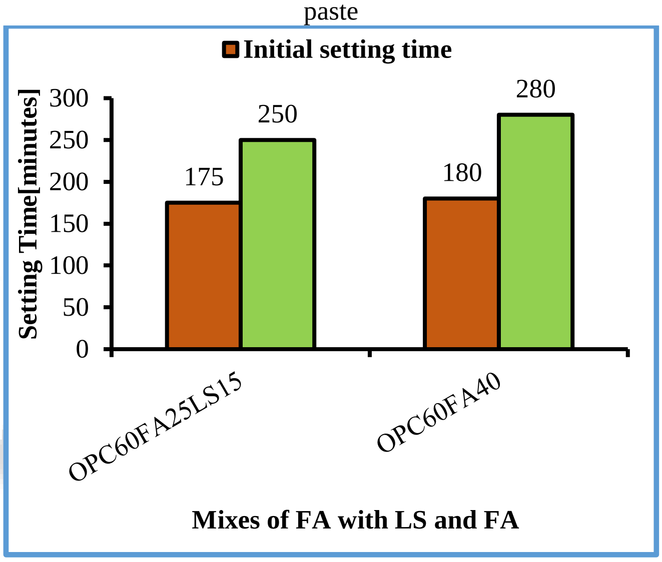
The initial and final setting time of all mixes is shown in Figure 5 (a-d). These measurements were carried out using Vicat apparatus. Compared to the mix containing FA, the different percentages of FA plus LS mixes resulted in a lower initial and final setting time. The possible explanation may be the smaller particle sizes of materials. The setting time of FA plus LS mixes is within the acceptable limits as mentioned in Indian Standard[14].



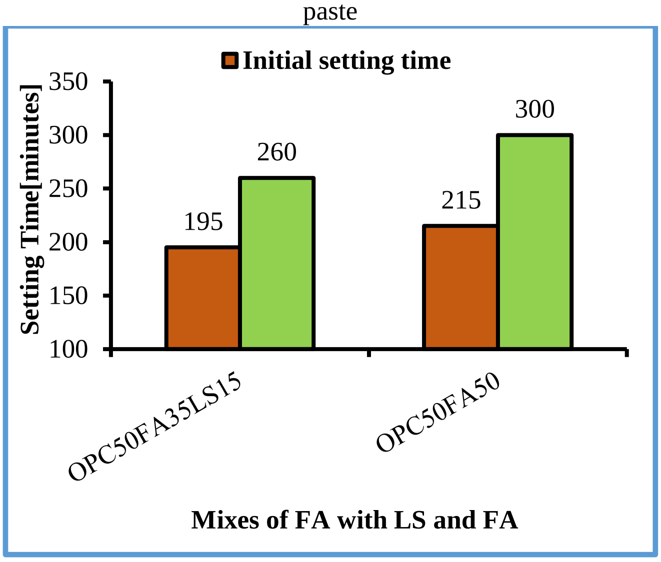
(a) Impact of 5% FA plus 15% LS and 20% FA on cement paste



(b) Impact of 15% FA plus 15% LS and 30% FA on cement paste



(c) Impact of 25% FA plus 15% LS and 40% FA on cement paste



(d) Impact of 35% FA plus 15% LS and 50% FA on cement paste

Fig. 5: (a-d). Effect of all mixes on setting time of cement

E. Particle Size Distribution

Hydrometer analysis is used to determine the particle size of powder materials is shown in Figure 6. Particle sizes of raw materials of less than 90µm were used in the current study[17].

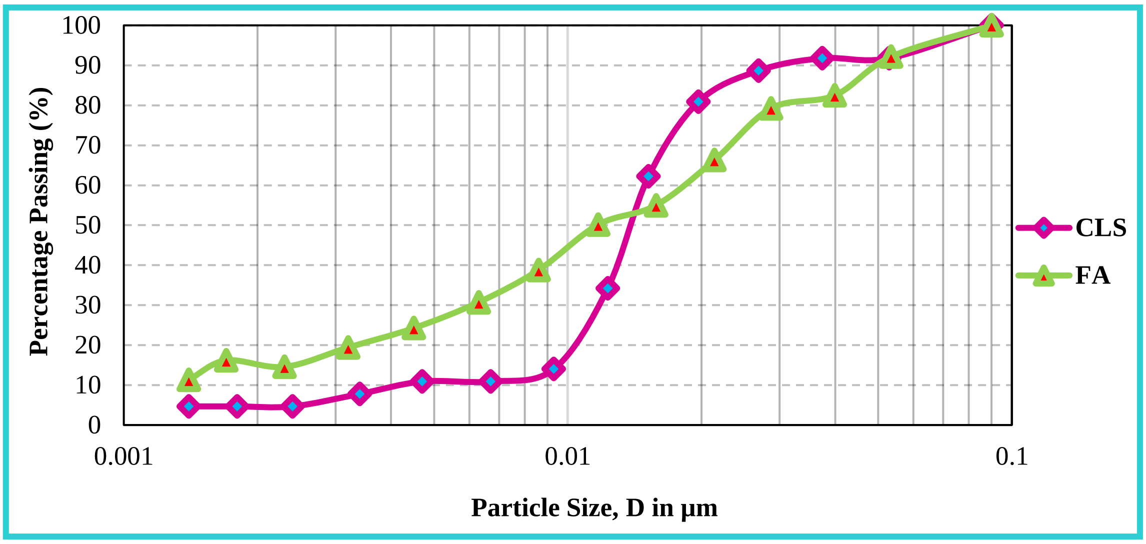


Fig. 6: Grain size compositions of materials

F. Carbon Dioxide Emissions

In the cement manufacturing process, clinker production is the most energy-intensive operation and generates high CO2 emissions from the process[19].

Approximately 90% of the CO2 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 CO2 emissions. Approximately, combustion of 1 ton of coal (fossil fuel) emits three-quarters of CO2[22].

In the current study, the portion of FA is replaced with LS with a view of maintaining compressive strength of cement vis – a - vis reduce the CO2 emissions as compared to PPC. Figure 7 shows the CO2 emission from the manufacturing of 1-ton sustainable cement (FA plus LS) and PPC (only FA) by Yang Yan et al.[21].

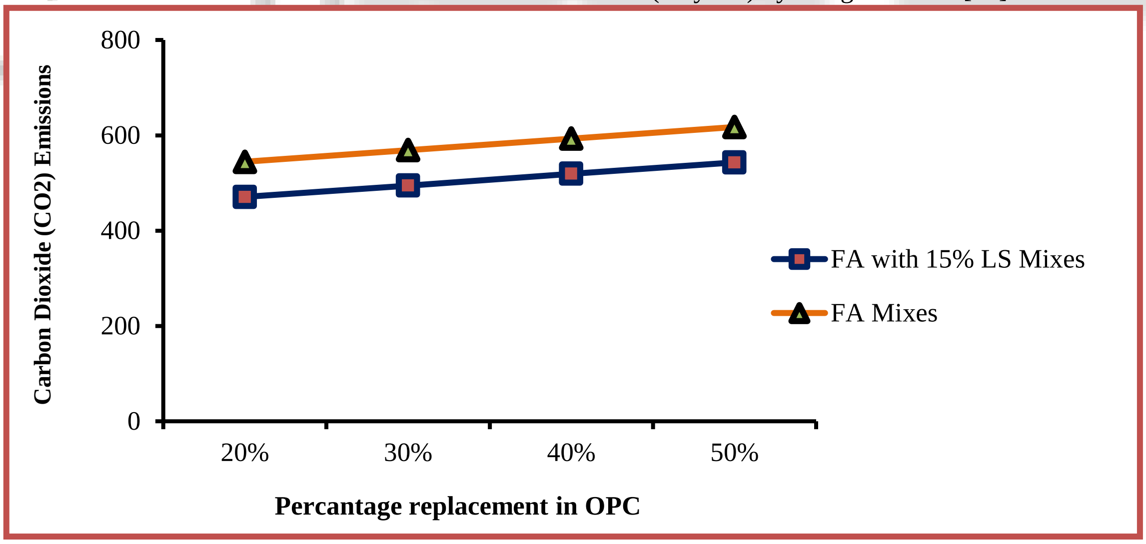


Fig. 7: Carbon dioxide emissions

V. Conclusion

The usage of fly ash provides advantages in terms of cost-effectiveness, ecological and technological aspects. Up to 50% FA plus LS can be used without compromising the 28 days compressive strength (33 MPa) of PPC while 50% FA replacement decreases the compressive strength of PPC. The mix containing FA plus LS 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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