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A Research on the Feasibility of Using Landfill Fly Ash as A Portland Cement Substitute

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Abstract
When fly ash is disposed of without being used for any purpose, fly ash landfills are an issue for all power stations. This study investigates the possibility of substituting Portland cement type I with fly ashes that have a 6–24 month disposal period from power plant landfills in India. The fly ashes that were disposed of were pulverized to lower their median particle sizes from 55.4 to 99.3 µm to roughly 7.1 to 8.4 µm. The physical and chemical characteristics of both the original and ground-disposed fly ashes were examined. Compressive strengths of the resulting mortars were measured when Portland cement type I and discarded fly ash made up 10%, 20%, and 30% of the cementitious material, respectively. The results demonstrated that most of the initial fly ash particles were solid and spherical with some irregular shape, but the particles of fly ash that had been ground up were solid and irregularly shaped. There was significant fluctuation in the CaO and LOI concentrations of fly ashes that were disposed of at varying disposal times. Initial fly ash mortar compressive strengths were low; however, over seven days, the ground fly ash mortars' strengths exceeded 75% of the conventional mortar and reached 100% after sixty days. Despite being exposed to the elements for 24 months, based on the findings, ground-disposed fly ashes could be utilized as a partial cement substitute in concrete due to their high pozzolanic properties.

Introduction

A pozzolanic substance, fly ash is a waste product of power plants that burns pulverized coal. According to ASTM C 618 (1997), pozzolanic materials are those that contain siliceous or aluminous materials, have low cementitious value on their own, but when combined with moisture and finely powdered, they can chemically react with calcium hydroxide at room temperature to produce compounds with cementitious properties. Currently, fly ash is extensively utilized in concrete due to its abundance of siliceous and aluminous compounds, demonstrating significant potential as a raw material for the production of pozzolan cement or fine aggregate. It functions as a pozzolanic material to partially replace cement in concrete (Lamond, 1983; Bijen, 1983; Ravina, 1997; Sarkar et al., 1995).

The advantages of fly ash can be categorized into three primary benefits: first, it serves as a zero-cost raw material; second, It facilitates the conservation of natural resources and contributes to waste elimination (Ferreira et al., 2003).

Nonetheless, the production rate of fly ash exceeds its consumption. Unused fly ash was disposed of in ponds, lagoons, or landfills, contingent upon the specific location of each power plant (Iyer, 2002). Fly ash that originates from landfill is termed disposed fly ash.

A notable concern related to coal combustion power plants is the buildup of unutilized fly ash and bottom ash.
These byproducts contribute to environmental concerns, including air pollution and groundwater quality issues stemming from the leaching of metals, especially from the fine particles of unused fly ash (Iyer, 2002; Simsiman et al., 1987; Janos et al., 2002; Duchesne and Reardon, 1999).
The incorporation of fly ash as a substitute for cement in concrete mixtures can reduce the overall cement content, thereby leading to a decrease in both energy consumption and CO2 emissions associated with cement production. Carbon dioxide is a major contributor to the greenhouse effect and global warming (Ferreira et al., 2003; Tietenberg, 2003).
Limited use of fly ash in concrete has occurred due to uncertainties regarding its chemical and physical properties. Furthermore, it may contain an adulterant that influences the properties of concrete. Additionally, disposed fly ash, upon exposure to weather, formed large aggregates and demonstrated limited pozzolanic activity when used as a cementitious material.
Jaturapitakkul et al. (1992) and Ranganath et al. (1998) investigated the characteristics of disposed fly ash, revealing that it possesses pozzolanic properties. However, its larger particle size relative to conventional fly ash resulted in mortar mixtures exhibiting reduced compressive strength and limited enhancement of compressive strength through pozzolanic reactions. Singh et al. (1995) employed disposed fly ash from pond landfill as a reactive raw material in the black meal process of cement production. Studies demonstrate that the incorporation of disposed fly ash can improve cement quality, decrease fuel consumption, and aid in the grinding process relative to cement lacking disposed fly ash. The optimal incorporation of disposed fly ash was found to be restricted to 4%. Between 1970 and 2000, around 50 million tons of fly ash and bottom ash were disposed of in this open landfill.
This study seeks to examine and improve the quality of disposed fly ash for its application as a pozzolanic material, thus aiding in the reduction of landfill space.
The environmental issue associated with disposed fly ash, a significant concern for power plants, will also be addressed. The potential for mining disposed fly ash from landfills presents a significant opportunity for sourcing alternative materials for concrete production. Furthermore, the processes involved in the production of disposed fly ash could be developed for industrial application in the future.

Material & Experiment

Materials

This research used cement (type I) and fine aggregate derived from graded river sand, which successfully passed through a 1.18 mm screen but was held on a 150 micron sieve, along with disposed fly ash from a power plant. Fly ashes were obtained from landfill sites at disposal intervals of 6, 12, and 24 months and Sun-dried for a duration of 1 to 2 days to lower the moisture content from approximately 10% to about 0.5%. The material was subsequently subjected to sieve No. 16, yielding two separate portions. The initial section was used as originally discarded fly ash. The second half was analyzed with a milling machine until the ash particles are maintained on a 45µm filter constituted under 5% by weight. The initially discarded fly ashes were classified according to disposal durations of 6, 12, and 24 months.

Material properties

The microstructure of Portland cement type I and both original and ground discarded fly ashes was examined using a scanning electron microscope (SEM). The crystalline composition, specific gravity, median particle size, and fineness of Portland cement type I and the discarded fly ashes were examined.

Using original or ground discarded fly ash at the rates of 10%, 20%, and 30%, by weight of cementitious material, normal consistency and setting times of cement paste and pastes with substitution of Portland cement type I were carried out.

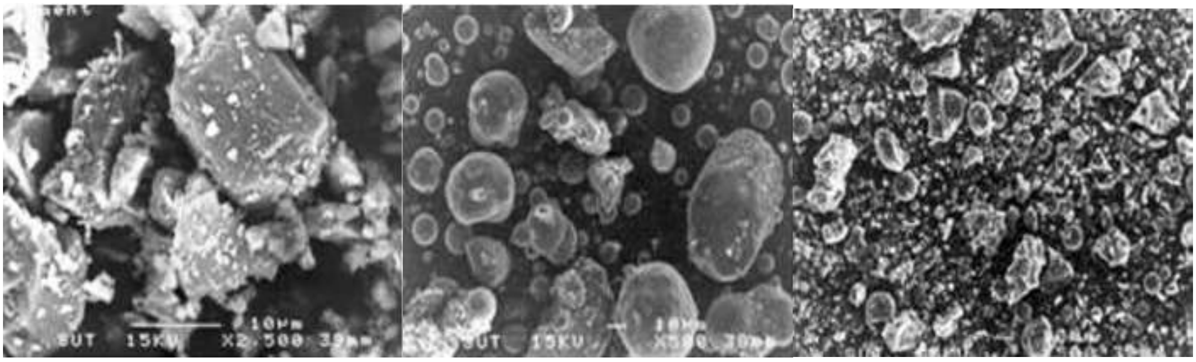
Details of mortar

For the purpose of testing the compressive strength, the usual 50 mm cube mortars were made. By weight of cementitious material, ten percent, twenty percent, and thirty percent of Portland cement type I were substituted with original or ground disposed flyash, respectively. The mortar's flow was kept between 105 percent and 115 percent while the cement-like component to sand ratio was kept constant at 1:2.75 by weight. After casting, each specimen was carefully removed from the mold and then cured in water. At3,7,14,28,60, and 90 days of age, the compressive strengths of all mortars were measured.

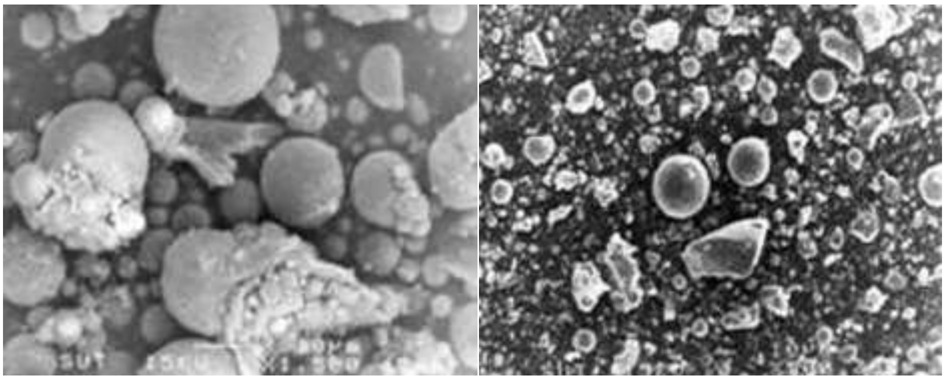
Results and discussion

Particle shape

Figure 1 shows the scanning electron microscopy (SEM) results for Portland cement type I, whereas distribution of particle sizes is seen in Figure 3 for both the original and disposed fly ashes. The powder materials' median particle sizes are shown in Table 1. C ement type I has a solid and irregular particle form with a median size of 13.0 µm, as seen in Figure 2a. No matter how old the fly ash is, the majority of its particles will always be round and solid spherical. On the other hand, as can be seen in Figures 2b, d, and f, weathering has made some of them uneven and porous. According to Kiattikomol et al. (2001), the median particle sizes of the initial fly ash from the same source range from 21 to 40 µm. After 6, 12, and 24 months, the median particle sizes are 56.3, 55.4, and 99.3 µm, respectively. As with Portland cement type I, the solid and irregularly shaped particles of ground dispersed fly ashes are seen in Figure 2c, e, and g. 7.6, 8.4, and 7.1 lm are the median particle sizes of the ground fly ash fractions (6GDF), and (12GDF), respectively. These fractions are about 7, 14 times smaller than the original fly ash fractions.



(a) Portland Cement type I (b) Original disposal fly ash (c) Ground disposal fly ash
6 Months (6ODF) 6 Months (6ODF)

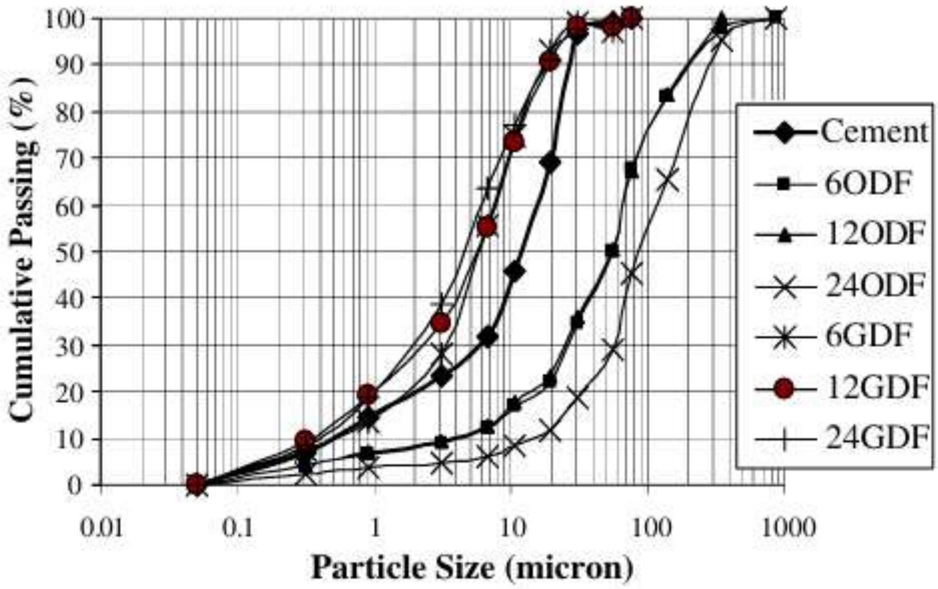


(d) original disposal fly ash 12 months (12ODF) (e) ground disposal fly ash 12 months (12GDF)

Fig. 1. scanning electron microscopy (SEM) of Portland cement

Specific gravity and fineness

Figure 3 displays the physical parameters of discarded fly ashes and Portland cement type I before and after the process, as shown in Table 1. Distribution of particle sizes in type I Portland cement, original, and ground discarded fly ashes. The physical characteristics of discarded fly ashes and cement type I before and after grinding are shown in Table 1.



Type I Portland cement has a specific density is 3.14, while original fly ash has a specific density between 2.10–2.16, and ground disposed fly ash has a specific gravity of 2.52-2.59. Since the grinding process decreases the permeability and size of the particles of the ashes, the specific gravity of ground discharged fly ash is greater than that of original dumped fly ash. Studying the impact of grinding on fly ash particles, Payaet al. (1995, 1996, 1997) and Kiattikomol etal. (2001) also came to the same conclusion. The materials' fineness is shown in Table 1 using the Blaine air permeability technique and the % of particles retained on sieve No. 325 (45 µm opening). This piece of Portland cement has a Bleached fineness of 3,270 cm2/g and a retained particle size of 4.8%. Furthermore, the Sieve No. 325 retained 39.2%, 50.3%, and 63.1% of the particles for the original discarded flyashes from 6, 12, and 24 months, respectively. Seive No. 325 showed that the amount of discharged fly debris increased with disposal time.

Sample	Specific gravity	Retained on sieve No. 325 (%)	Blaine fineness (cm^2/g)	Median particle size (μm)
Cement	3.14	4.8	3270	13.0
6ODF	2.10	39.2	1820	56.3
6GDF	2.52	2.5	6325	7.6
12ODF	2.16	50.3	1790	55.4
12GDF	2.54	2.8	6535	8.4
24ODF	2.13	63.1	1760	99.3
24GDF	2.59	2.7	6210	7.1

ODF = Original disposed fly ash; GDF = Ground disposed fly ash; 6, 12, and 24 = Disposal time of fly ash (months).

Chemical Composition

Tabulated in Table 2 are the findings of determining the chemical composition of Portland cement type I and ground discharged flyashes using an X-ray fluorescence spectrometer. Based on the findings of previous studies (Jaturapitakkul et al., 1992; Paya et al., 1995; Songpir iyakij and Jaturapitakkul, 1995), this analysis only examined the chemical composition of ground fly ash that had been disposed of. The majority of ground disposed flyashes are composed of silica, aluminum oxide, ferric oxide, and calcium oxide, with a total percentage ranging from 81.93% to 93.17%. According to ASTMC618(1997), the minimum amount of SiO2+Al2O3 in fly ash Class F is 70% of the overall chemical composition, while in fly ash Class C, it ranges from 50% to 70%. After six, twelve, and twenty-four months, the total amounts of SiO2, Al2O3, and Fe2O3 in the discarded fly ash are 68.14%, 60.93%, and 76.30%, respectively, considering these oxides. Loss on ignition (LOI) percentages are 8.91%, 11.21%, and 6.81% for6,12, and 24 months of discarded fly ash, respectively, while CaOcontents are 16.70%, 21.0%, and 14.45%. On the other hand, CaO fly ash from the same disposal source had 9.39% and LOI fly ash from the same source had 1.22% (Kiattikomol et al., 2001). Class F flyash containing up to 12% LOI may be user-approved provided either acceptable performance records or laboratory tested findings are made available, according to ASTMC618(1997), which mandates that LOI offlyash be no more than 6%.

Normal consistency and setting time of paste

Cement paste, paste containing original fly ash, and paste with ground discharged fly ash typically have the consistency shown in Table 3. Cement paste typically has a consistency of 26.8%, but original fly ash cement pastes often have a consistency ranging from 27.8% to 29.0%. The typical consistency of cement pastes made from originally disposed of fly ash improved as the amount of fly ash in the combination rose. This is because fly ash has a high porosity, meaning it absorbs water and causes increased water usage. Furthermore, the there was a general trend toward a deterioration in consistency as the percentage of ground-disposed fly ash in cement pastes including this ingredient rose, with most recipes calling for 26.6% to 27.3% of the ash. The porosity of discarded fly ash may be reduced during the grinding process, which in turn reduces the paste's typical consistency.

Chemical composition (%)	Disposed fly ash		
	6GDF	12GDF	24GDF
SiO_2	40.97	38.29	43.47
Al_2O_3	19.73	16.89	22.73
Fe_2O_3	7.44	5.75	10.1
CaO	16.7	21.00	14.45
MgO	2.16	1.88	2.61
K_2O	2.15	1.70	2.39
Na_2O	0.06	0.05	0.06
Mn_2O_3	0.05	0.05	0.07
SO_3	0.83	0.71	1.03
LOI	8.91	11.21	6.81

Cement pastes made from originally discarded fly ash have setting durations ranging from 180 to 210 minutes and 87 to 165 minutes, respectively. According to the findings of setting times obtained by utilizing fly ash, employing original discarded fly ash in the combination instead of Portland cement type I enhances the setting times (Songpiri yakij and Jaturapitakkul, 1995). Both the initial and final setting periods for ground-disposed flyash cement pastes are between 93 and 113 and 165 and 195 minutes, respectively. Due to a decrease in the amount of tricalcium silicate (C3S), which is responsible for the hardening and compressive strength of the paste at an early age, in blended pastes, the pastes that include discarded fly ash take longer to set than cement paste.

Type of pastes	Normal consistency (%)	Initial setting time (min)	Final setting time (min)
Cement	26.8	87	165
6ODF10	27.8	104	180
6ODF20	27.8	116	195
6ODF30	28.1	127	210
12ODF10	28.5	105	180
12ODF20	28.4	113	195
12ODF30	28.9	124	195
24ODF10	28.8	111	180
24ODF20	28.5	119	195
24ODF30	29.0	128	210
6GDF10	26.9	94	165
6GDF20	27.0	102	180
6GDF30	26.6	113	195
12GDF10	27.3	97	165
12GDF20	27.3	107	180
12GDF30	27.0	112	180
24GDF10	26.8	93	165
24GDF20	26.8	99	180
24GDF30	26.9	107	180

10, 20, and 30 = Percent replacement of disposed fly ash by weight of cementitious material.

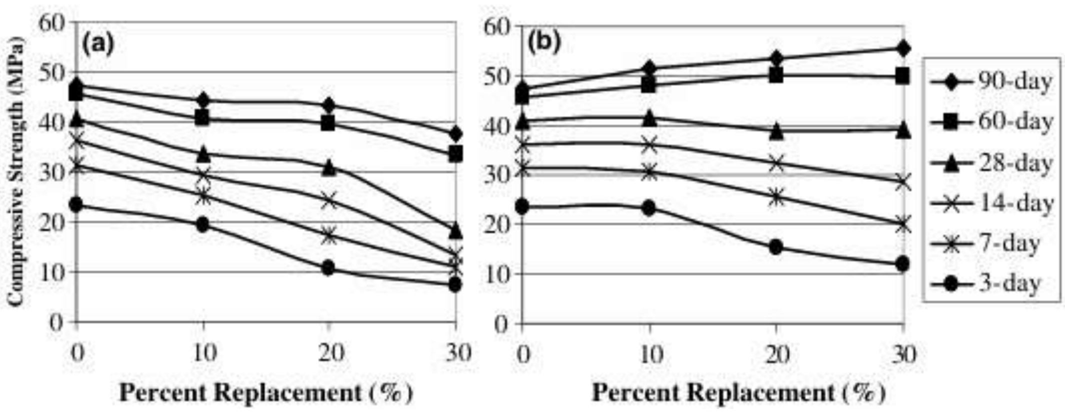
Water requirement of mortar

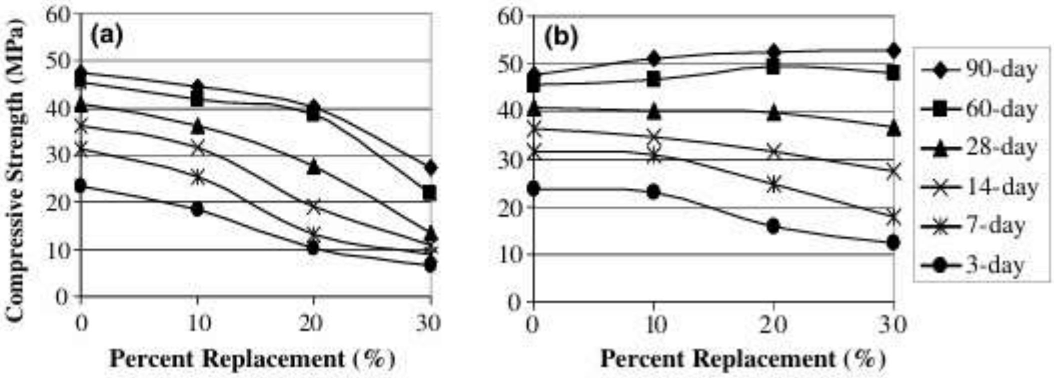
The water demand of mortar, expressed as a percentage, is determined by dividing the water used in the standard mortar by the water used in the disposal of flyash mortar. The water needs of all mortars are shown in Table 4. Water needs for original disposal flyash mortars ranged from 100% to 103%, making them somewhat more water-intensive than regular mortar. On the other hand, needed water at a rate of 97-100%. This is due to the fact that, compared to Portland cement type I, ground disposed fly ash has smaller particles, smoother surfaces, and less porosity as a result of the grinding process. Additionally, since some of the ground-dispersed fly ash particles are solid and spherical in form, they lubricate and aid the movement of the other components in the mortar. The outcome is comparable to what happens when ground fly ash is used.

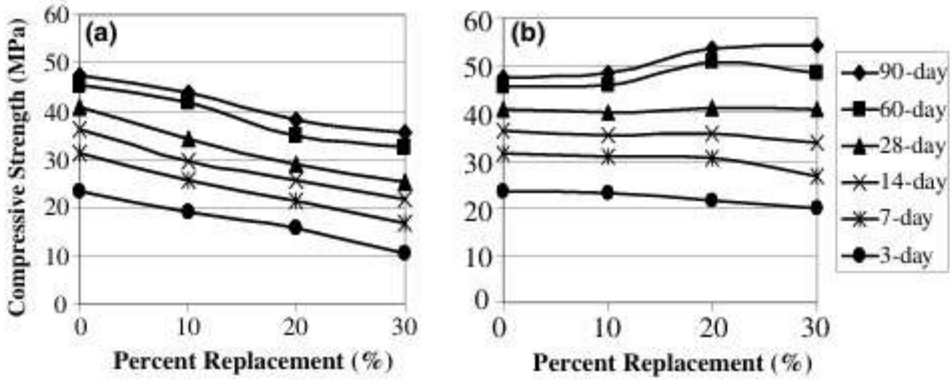
Compressive strength of mortar

Type of mortars	W/(C+F)	Compressive strength (MPa) – *percentage compressive strength* (%)						Flow (%)	Water requirement (%)
		3-day	7-day	14-day	28-day	60-day	90-day		
STD	0.70	23.5-*100*	31.4-*100*	36.3-*100*	40.8-*100*	45.6-*100*	47.5-*100*	114	100
6ODF10	0.71	19.4-*83*	25.2-*80*	29.5-*81*	33.8-*83*	40.7-*89*	44.3-*93*	107	101
6ODF20	0.71	10.7-*46*	17.5-*56*	24.2-*67*	30.0-*74*	39.7-*87*	43.4-*91*	112	101
6ODF30	0.71	7.2-*31*	10.9-*35*	13.2-*36*	18.4-*45*	33.4-*73*	37.8-*80*	115	101
12ODF10	0.71	18.6-*79*	25.5-*81*	31.7-*87*	36.3-*89*	41.8-*92*	44.6-*94*	115	101
12ODF20	0.70	10.2-*43*	13.3-*42*	19.1-*53*	27.7-*68*	38.7-*85*	40.3-*85*	114	100
12ODF30	0.71	6.6-*28*	9.0-*29*	11.0-*30*	13.6-*33*	21.6-*47*	27.3-*57*	115	101
24ODF10	0.70	19.2-*82*	25.8-*82*	29.8-*82*	34.2-*84*	41.9-*92*	43.7-*92*	111	100
24ODF20	0.71	15.7-*67*	21.4-*68*	25.7-*71*	29.0-*71*	34.8-*76*	38.1-*80*	108	101
24ODF30	0.72	10.5-*45*	16.8-*54*	21.7-*60*	25.4-*62*	32.8-*72*	35.5-*75*	112	103
6GDF10	0.69	23.2-*99*	30.6-*97*	36.1-*99*	41.7-*102*	48.2-*106*	51.6-*109*	108	99
6GDF20	0.69	15.5-*66*	25.4-*81*	32.5-*90*	38.9-*95*	50.1-*110*	53.3-*112*	114	99
6GDF30	0.68	11.8-*50*	20.1-*64*	28.7-*79*	39.3-*96*	49.9-*109*	55.5-*117*	110	97
12GDF10	0.69	23.1-*98*	30.7-*98*	34.6-*95*	40.1-*98*	46.7-*102*	51.2-*108*	111	99
12GDF20	0.69	15.8-*67*	24.8-*79*	31.5-*87*	39.7-*97*	49.4-*108*	52.3-*110*	108	99
12GDF30	0.70	12.3-*52*	17.8-*57*	27.3-*75*	36.7-*90*	47.9-*105*	52.8-*111*	105	100
24GDF10	0.69	23.1-*98*	30.7-*98*	35.2-*97*	40.0-*98*	46.0-*101*	48.5-*102*	115	99
24GDF20	0.68	21.6-*92*	30.5-*97*	35.6-*98*	41.0-*100*	50.7-*111*	53.5-*113*	109	97
24GDF30	0.68	19.9-*85*	26.7-*85*	33.6-*93*	40.8-*100*	48.5-*106*	54.2-*114*	114	97

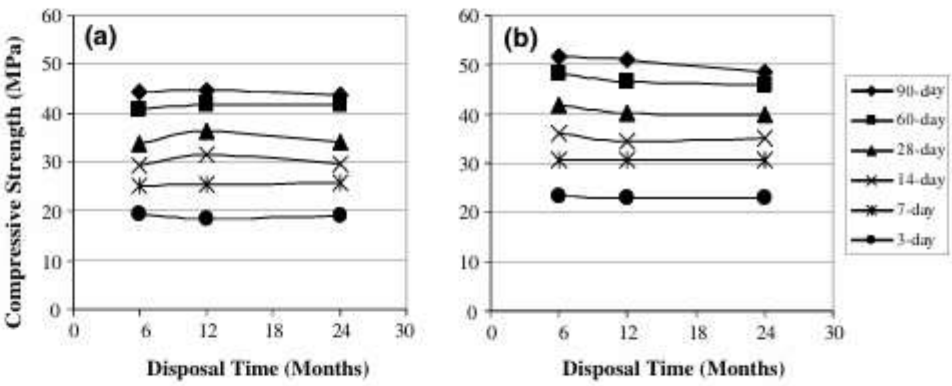
Effect of replacement of disposed fly ash

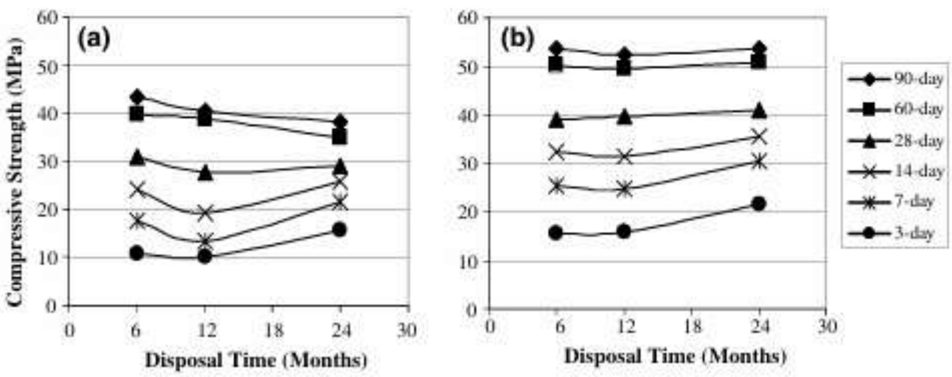


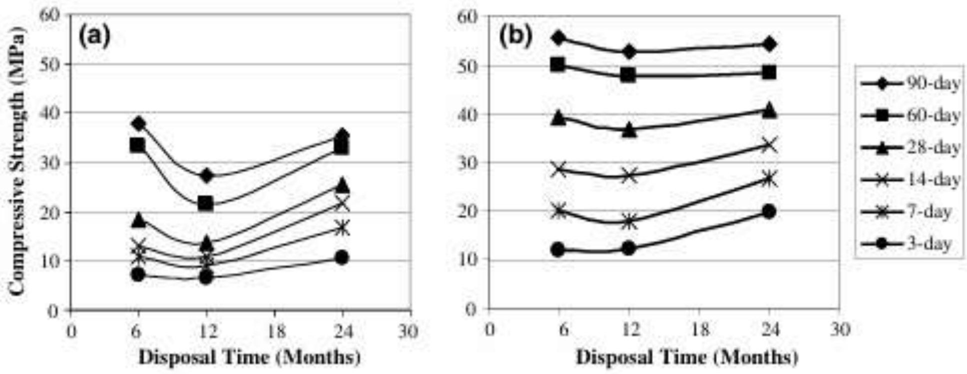




Effect of disposal time of fly ash







Conclusion

The study on the disposal of fly ash from the power plant landfill in India as a replacement for Portland cement type I yields the following conclusions:

1. The fly ashes that are disposed of after six to twenty-four months vary in terms of their chemical makeup and particle sizes. In comparison to the fly ash that comes from the same source, the median particle sizes are much bigger. Additionally, there is a substantial amount of fluctuation in the amount of CaO and Loss of Ignition present.
2. The poor compressive strength of mortar is caused by using original, discarded fly ash that is between six and twenty-four months old as pozzolanic ingredient. But the ground-disposal fly ashes are excellent pozzolanic material as their particle sizes retained on filter 45µm sieve are less than 5five percent by weight.
3. When determining the compressive strength of mortar, the fineness of the ground fly ash is a crucial aspect. Compressive strengths in excess of 75 percent of the normal mortar at between seven and eighteen days are achieved by using ground discharged fly ash mortar at a rate of twenty per cent replenishment. After sixty days, their compressive strength may surpass that of regular mortar by more than one hundred percent.
4. The fly ash that was disposed of has the pozzolanic composition. It indicates that fly ash that has been disposed of from the open landfill of the power station has the potential to be utilized as a partial replacement of Portland cement or as pozzolanic material in concrete, provided that the quality of the fly ash is enhanced by grinding it to a high fineness.

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