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Bearing ratio and leachate analysis of pond ash stabilized with lime and lime sludge

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ABSTRACT

Recycling of industrial waste is one of the effective ways to overcome their disposal problem. Ash produced by thermal power plants and lime sludge produced by paper mills require huge disposal land and may create environmental problems such as dusting and leaching of harmful heavy metals. Stabilization of the ash can improve its engineering properties and address the environmental problems. This paper reports the laboratory test results of a Class F pond ash stabilized with lime (2%, 4%, 6% and 8% by weight) alone and in combination with lime sludge (5%, 10% and 15% by weight). The X-ray diffraction (XRD) and scanning electron micrograph (SEM) tests were also performed to identify the possible formation of crystalline phases after stabilization. The effects of lime sludge on the unsoaked and soaked bearing ratios of pond ash with different lime contents, after 7 d, 28 d and 45 d of curing, were observed. Test results indicated that the bearing ratio increased considerably up to a 4% lime content which can be taken as the optimum lime content. Further increase in lime content increased bearing ratio gradually but at a slower rate. The effect of lime sludge was more pronounced at the optimum lime content, particularly at a low curing period. Lime sludge improved the bearing ratio in soaked condition significantly. Leachate analysis of stabilized ash was performed using toxicity characteristic leaching procedure (TCLP-1311) method. The concentrations of toxic elements Zn, Cu, Cd, Ni and Cr in the stabilized mixes were lower than those in the unstabilized waste. The results indicated that the pond ash-lime-lime sludge mixes have potential application as road subbase material.

1. Introduction

Coal ash is produced by coal-based thermal power plants (TPPs) for power generation in many countries. There are two types of ash produced by TPPs, i.e. fly ash (80%) and bottom ash (20%). The fly ash is collected by electrostatic precipitators from the flue gases of power plants, and the bottom ash is collected from the bottom of the boilers. The ash generated by TPPs is generally disposed by one of following two ways: (1) fly ash is transported in dry-form for advantageous recycle or disposal in on-site or off-site landfills, or (2) fly and bottom ashes are mixed with suitable proportion of water and pumped out from the TPPs as slurry in the ash pond. The second method is known as wet-disposal, which is most commonly used and an inexpensive management practice worldwide. The mix of fly and bottom ashes in ash pond is called pond ash.

The constant increasing need for wet-disposal storage capacity and concerns for fly ash leachate and dusting (Ghosh, 2010), groundwater contamination (Mehra et al., 1998) and impoundment failure (Ruhl et al., 2010) present environmental and logistical difficulties. As a result, the situation is expected to deteriorate further worldwide, with elapsed time. The favorable method to address these problems is to reuse the pond ash in construction, such as rail and road embankments, dykes and structural fill, after converting it into a nonhazardous, good-performance engineering material in a cost-effective means. Utilization of pond ash in construction is a solution to the disposal of pond ash and also to the scarcity of natural construction materials.

According to the ASTM classification (ASTM C618-08a, 2008), fly ash is classified as Classes C and F fly ash. Class C fly ash with high calcium content undergoes high reactivity with water even without addition of lime (Parsa et al., 1996). Class F fly ash contains lower percentages of lime. There are numerous studies (Ghosh, 1996;

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Table 1
Physical properties of pond ash sample (Suthar and Aggarwal, 2015).

Specific gravity	Color	Particle size distribution (%)				Particle size with 10% fines, D_{10} (mm)	Particle size with 30% fines, D_{30} (mm)	Particle size with 60% fines, D_{60} (mm)	Uniformity coefficient, C_u	Coefficient of curvature, C_c
		Coarse sand (4.75–2 mm)	Medium sand (2.0–0.425 mm)	Fine sand (0.425–0.075 mm)	Silt (0.075–0.002 mm)					
2.05	Gray	0.06	0.21	46.27	53.46	0.015	0.03	0.091	6.07	0.66

Table 2
Chemical composition of pond ash, lime and lime sludge (%).

Material type	SiO_2	Al_2O_3	Fe_2O_3	$CaO/CaCO_3$	TiO_2	P_2O_5	K_2O	MgO	MnO	Na_2O	SO_3	LOI	Others
Pond ash	62.45	27.77	4.45	0.66	1.78	0.5	1.43	0.45	0.05	0.08	0.09	2.39	–
Lime	0.43	0.07	0.06	65.21	–	–	–	12.34	0.01	–	0.08	21.76	0.04
Lime sludge	2.3	0.21	0.28	57.11	–	0.41	0.16	1.22	9.2×10^{-5}	0.84	0.64	36.67	0.15

Note: The data of pond ash are obtained from Suthar and Aggarwal (2015). LOI represents loss on ignition.

Pandian, 2004; Ghosh and Subbarao, 2007; Tastan et al., 2011) on Class F fly ash, stabilized with lime, cement, gypsum, or in combination, to improve the engineering properties of fly ash.

A number of studies have been conducted on effective utilization of fly ash in bulk quantity in many civil engineering applications, such as using fly ash as fill material (DiGioa and Nuzzo, 1972; Faber and DiGioa, 1974; Joshi et al., 1975; Horiuchi et al., 2000), lightweight aggregate (Bin-Shafique et al., 2004), subbase material (Sherwood and Ryley, 1966; Leelavathamma et al., 2005; Ghosh and Subbarao, 2006), and volume replacement and self-compacting material for increasing the workability of concrete (Ganesh and Siva, 1993; Siddique, 2003; Jaturapitakkul et al., 2004; Yen et al., 2007; Mustafa et al., 2009), and also for soil stabilization (Tastan et al., 2011), replacement of cement (Xu and Sarkar, 1994), coastal land reclamation (Kim and Chun, 1994), and the manufacture of clay flooring and terracing tiles (Bou et al., 2009).

Lime sludge is another waste material, generated from paper, acetylene, sugar, fertilizer, sodium chromate, soda ash industries and water softening plants. Approximately 4.5 million tons of lime sludge is generated annually from these industries in India (Sahu and Gayathri, 2014), and disposal of the lime sludge is also a problem (Calacea et al., 2005; Mahmood and Elliot, 2006; Battaglia et al., 2007). As lime sludge contains calcium carbonate (Medhi et al., 2005), researchers proposed to utilize lime sludge in many civil engineering applications as building material (Singh and Garg, 2008), partial replacement material of cement in mortar (Sahu and Gayathri, 2014), subgrade material (Zhang and Yu, 2012) and even subbase material in village road (Talukdar, 2015).

Few studies are reported on the characteristics of pond ash-lime-lime sludge (PA-L-LS) mixes. The present study investigates the bearing ratio of Class F pond ash with lime (2%–8% by weight) alone and lime combined with lime sludge (5%–15% by weight), after different curing periods (7 d, 28 d and 45 d) under unsoaked and soaked conditions. The X-ray diffraction (XRD) and scanning electron micrograph (SEM) tests were also carried out on the stabilized pond ash samples. Further, to study the leaching behavior of selected harmful metals from lime sludge, unstabilized and stabilized pond ash samples, leaching tests was conducted using toxicity characteristic leaching procedure (TCLP-1311) method.

2. Materials and method

2.1. Experimental materials

2.1.1. Pond ash

Pond ash was collected from Deenbandhu Chhotu Ram Thermal Power Plant, Yamuna Nagar, India. According to ASTMC 618-08a (2008), the ash belongs to Class F. The physical properties and chemical composition (Suthar and Aggarwal, 2015) of the pond ash are presented in Tables 1 and 2, respectively.

2.1.2. Lime

Hydrated lime was used in the study. The chemical composition of the lime is presented in Table 2.

Table 3
Summary of mixes.

Sample No.	Mix combinations	Designation
1	Pond ash	PA
2	Pond ash + 2% lime	PA2L
3	Pond ash + 4% lime	PA4L
4	Pond ash + 6% lime	PA6L
5	Pond ash + 8% lime	PA8L
6	Pond ash + 2% lime + 5% lime sludge	PA2L5LS
7	Pond ash + 4% lime + 5% lime sludge	PA4L5LS
8	Pond ash + 6% lime + 5% lime sludge	PA6L5LS
9	Pond ash + 8% lime + 5% lime sludge	PA8L5LS
10	Pond ash + 2% lime + 10% lime sludge	PA2L10LS
11	Pond ash + 4% lime + 10% lime sludge	PA4L10LS
12	Pond ash + 6% lime + 10% lime sludge	PA6L10LS
13	Pond ash + 8% lime + 10% lime sludge	PA8L10LS
14	Pond ash + 2% lime + 15% lime sludge	PA2L15LS
15	Pond ash + 4% lime + 15% lime sludge	PA4L15LS
16	Pond ash + 6% lime + 15% lime sludge	PA6L15LS
17	Pond ash + 8% lime + 15% lime sludge	PA8L15LS

Table 4
MDD and OMC of various pond ash mixes.

Mix	Standard Proctor compaction	
	MDD (g/cm^3)	OMC (%)
PA	1.093	32.2
PA2L	1.094	31.3
PA4L	1.118	31
PA6L	1.127	28.7
PA8L	1.123	31.7
PA2L5LS	1.12	30.3
PA4L5LS	1.137	29.8
PA6L5LS	1.144	27.7
PA8L5LS	1.142	30.7
PA2L10LS	1.14	29
PA4L10LS	1.148	28.3
PA6L10LS	1.124	30.7
PA8L10LS	1.166	27.9
PA2L15LS	1.125	31.7
PA4L15LS	1.157	28
PA6L15LS	1.16	26.3
PA8L15LS	1.17	26.1

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