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Effect of Stabilization on Geomechanical Properties of Pond ash for Pavement Subbase Application

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Abstract. The shortage of traditional quality materials for road works, on the one hand, and the management of large -scale coal ash production from thermal plants on the other side, are the present significant challenges for the construction industry. Therefore, using pond ash as pavement material can provide a sustainable alternative to the problems mentioned above. Nonetheless, use ash alone cannot demonstrate desirable engineering behavior and requires proper modification with suitable additives to improve performance. In this regard, the engineering properties of pond ash mixed with lime (8%), fiber (1%), and their two combinations have been investigated for the strength (CBR) and stiffness (M_R) properties to be used as a subbase layer in flexible pavements. The individual and combined effects of additives on CBR and M_R of pond ash, as well as the impact of various stress levels on M_R have been observed. Based on results obtained, it was concluded that there was a significant improvement in CBR and M_R with the addition of additives. Furthermore, the experimental resilient modulus values were validated with four stress-dependent models available in the literature.

Keywords: Pond ash, Pavements, Lime, Fiber, Resilient modulus

1 Introduction

For the development of a country socially and economically, road infrastructure plays a vital role by connecting each part of the country through the road network. Therefore, the Government of India has initiated several road construction projects under various schemes, and thousands of kilometers have been constructed and also scheduled for the future. However, to construct these roads, many workplaces still rely on traditional paving materials include natural sand, crushed aggregates, and gravel [1-2]; a few worksites are being used alternative recycled materials but in a limited portion. One of such recycled materials is pond ash generated from thermal power plants (TPPs) as a waste by-product. The quantity of coal ash generation is about 200 MMTs [3]. Out of this vast quantity, only a small portion is being used in distinct applications, and the remaining is being disposed on valuable land, causing contamination problems in soil and water bodies, which further leads the problem to the public health and ecology system [4].

Apart from the above, pond ash is pozzolanic, slightly cementitious, and possess favourable engineering properties [5]. Because of these characteristics, pond ash could be converted into a viable wealthy resource for civil works and bring new possibilities for high volume usage for sustainable infrastructure growth. Previous researches [6-8] have reported enhanced strength characteristics, and its failure behaviour upon modification of soils with ashes in road construction works. Researchers like [9-12] have studied the geotechnical behaviour of coal fly ash modified with various cementitious binders like cement, lime, gypsum, GGBS, silica fume, etc., and found improvement in strength, stiffness as well as its durability nature under adverse conditions. Some researchers [13-18] have examined the effect of fiber inclusions of either natural or synthetic in discrete form as reinforcement in soil, coal ash and & or soil-coal ash mixtures. These studies have shown the beneficial effects in terms of increased strength properties (i.e., UCS, CBR, and shear strength) and the change of failure behaviour from brittle nature to ductile on the use of fly ash mixtures for road constructions.

Although most of the literature was focused on the beneficial effects of cementitious stabilization and fiber reinforcement in fly ashes individual basis, their combined effect on the performance of coal ashes was reported minimal. Furthermore, many research studies have been reported on stabilized/modified coal ash as pavement material on strength basis for road structures, their resilient behaviour in terms of stiffness (resilient modulus, M_R) is not well addressed under repeated loading conditions. Researchers [1, 19-21] have found that the strength-based parameters like CBR, could only use to guide the selection of material because the evaluation of these parameters cannot represent the actual mechanistic (traffic loading) behaviour. As a result, the design based on mechanistic-empirical (M-E) methods like AASHTO (2000) and NCHRP (2004) [22-23] have proposed resilient modulus (M_R) as a fundamental property in the characterization pavement analysis and design, particularly for coal ash-based pavements [24].

The aim of the paper is, therefore, to study strength (CBR) and stiffness (M_R) properties of pond ash modified with lime, fiber, and both, and investigate the feasibility for pavement subbase application.

2 Experimental Program

2.1 Materials

Pond ash was collected from Kakatiya thermal power plant, Telangana, India. The properties of pond ash are shown in Table 1. As per ASTM C 618-89 [25] specifications, the percentage of lime in pond ash is <15%; hence, it is categorized into Class F. Lime used in the study was quicklime (CaO) of purity 72.13%. The fiber used is polypropylene monofilament type having a length of 12 mm.

Table 1. Properties of Pond ash

Properties	Value
Specific Gravity	1.9
Plasticity Index	Non-Plastic
Grain Size Distribution	
i) % Gravel	0
ii) % Sand	69
iii) % Fines	31
Maximum Dry Density, MDD (kN/m^3)	11.21
Optimum Moisture Content, OMC (%)	34.01
Permeability, k (cm/sec)	6.7 x 10^{-4}
Angle of Internal Friction(φ^0)	32.1
Soaked CBR (%)	4.2

2.2 Mix proportions

In the study, pond ash was mixed both individually and in combination with 8% lime content and 1% fiber content. The proposed additive contents were chosen based on the previous experimental studies performed [12, 18] and the designation of mix proportions are shown in Table 2.

Table 2. Mix combinations and its designation

Mix combination	Designation
Pond ash	P
Pondash + 8% Lime	PL_8
Pond ash + 1% Fiber	PF_1
Pond ash + 8% Lime+ 1% Fiber	PL_8F_1

2.3 Test Conducted

CBR is a key parameter used to select materials, evaluate pavements, and design them (IRC 37-2012) [26]. Hence, CBR specimens of proposed mixtures were prepared in the standard mold and cured for 7 and 28 days in plastic bags at a room temperature of 27 ± 1°C. The specimens were subsequently immersed in water for 4-days and performed CBR tests as per IS 2720-16 (1987) [27].

M_R is a stress-based parameter used in mechanistic-empirical pavement design, which determine how the pavement system response to traffic load. Cyclic triaxial test is one of the effective experiment to compute the M_R. Specimens of size 75 mm X 150 mm (diameter to height) were prepared, cured for 7 and 28 days, and performed tests on repeated load triaxial (RLT) apparatus [22] (AASTHO T-307). During the test, cyclic loads were applied as a haversine function (0.1 sec load time and 1.0 Hz frequency), and the sample was subjected to repeated deviatoric (σ_d) and static confining stresses

(σ_c). The test procedure and load sequence applied during test was followed as per AASTHO T-307 (shown in Table 3). Eventually, the modulus at each stress level was determined by taking an average value of moduli of the last five-cycles for each sequence using equation (1).

$$M_R = \sigma_d / \varepsilon_r \tag{1}$$

M_R = resilient modulus
σ_d = cyclic deviatric stress
ε_r = resilient deformation at a given load pulse

Table 3. Cyclic load sequence

Sequence No.	Confining Stress, σ_c (kPa)	Deviatoric Stress, σ_d (kPa)	Total load cycles
0	103.4	103.4	500
1	20.6	20.6	100
2		41.3	100
3		62.1	100
4	34.4	34.4	100
5		68.9	100
6		103.4	100
7	68.9	68.9	100
8		137.9	100
9		206.8	100
10	103.4	68.9	100
11		103.4	100
12		206.8	100
13	137.9	103.4	100
14		137.9	100
15		275.8	100

3 Results and Discussions

3.1 California Bearing Ratio (CBR)

The CBR behaviour of both untreated and treated pond ash of various proportions cured for 7 and 28 days under the soaking condition are shown in Fig. 1. It can be seen that the CBR of untreated pond ash is 4.2. The addition of 8% lime caused to increase CBR of pond ash to 27.2 (548%) and 39.7 (845%) for both curing periods. This is because of the development of pozzolanic reactions that produce cementitious products (CSH, CASH) which bind the ash particles effectively and thus lead to an increase in bearing capacity [2]. Likewise, the Inclusion of fiber caused a considerable increase in CBR of pond ash up to 10.52 (150%) due to development resistance forces against applied loads that enhance frictional characteristics between fiber and ash particles [18]. After incorporating both additives in pond ash, CBR values increased furthermore to 32.1 (664%) and 45.6 (986%) at 7 and 28 days due to improvement in effective frictional surface area by bonding between ash particles and fiber [28]. Previous studies [15-17] also stated that the addition of fiber in cemented soil/ash compounds could change the failure behaviour from brittle to ductile by increased failure strain rate and reduced loss of post-peak stresses. Hence, the reinforcement inclusion would prevent the pavement structures from failing due to the impact of wheel loads.

As per the IRC: 37 specifications, the minimum bearing ratio required for subbase material is 30%. Results of the present study show that the addition of both lime and fiber meets the required strength at seven days curing period.

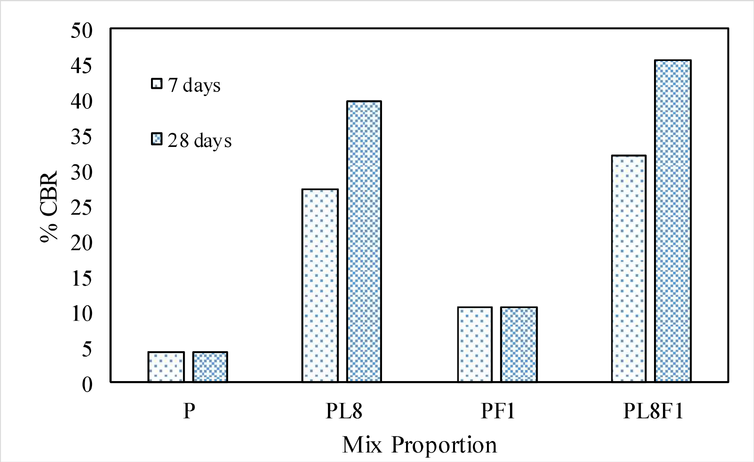

Fig. 1. CBR of untreated and treated pond ash under the soaked condition

3.3 Resilient Modulus (M_R)

Effect of additives on M_R of Pond ash

RLT tests were performed to evaluate the resilient modulus (M_R) behaviour of untreated and treated pond ash under various stress levels (σ_c and σ_d) for 28 days curing period (Fig. 2). The M_R values of untreated pond ash do not show considerable variation with increased stress levels (13 MPa to 25 MPa) (Fig. 2a). Whereas treated pond ash exhibits a significant change in M_R in an incremental way with increased stress levels, i.e., 59 MPa to 143 MPa for lime treated, and 28 MPa to 63 MPa fiber-reinforced pond ash (Fig. 2b). The cause of increment is due to the formation of cementitious bonds in lime treated pond ash, which exhibits strain hardening nature in the specimen and affects its behaviour for the stresses acting on it [21]. Similarly, fiber-reinforced pond ash showed an increased M_R values in a considerable manner due to mobilization of tensile strength in fibers, which allows a significant contribution to the rigidity of the composite (Fig. 2c) [16]. With the addition of both additives, M_R values of pond ash further increased (82 MPa to 196 MPa) with stress levels (Fig. 2d).

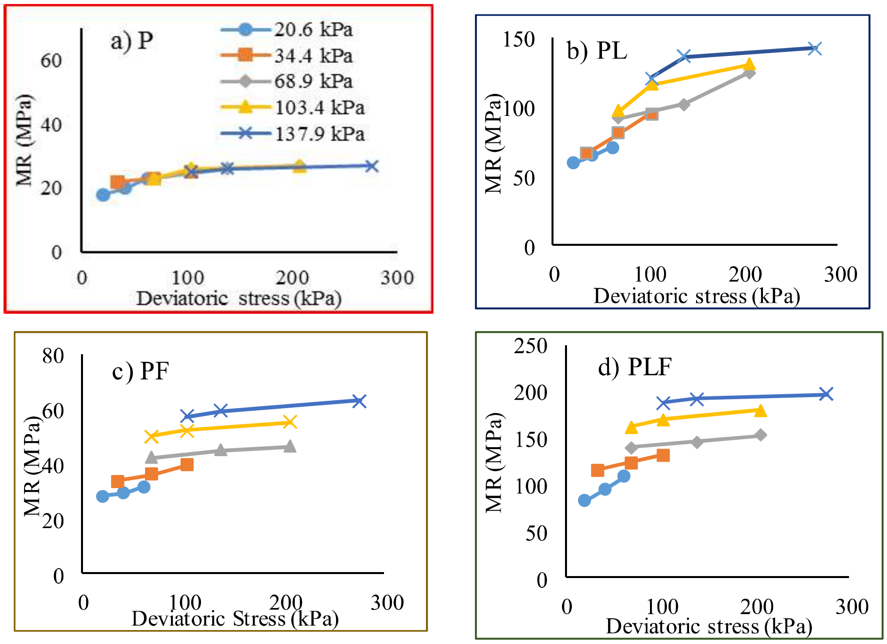

Fig. 2. M_R of a) untreated and b) 8% lime c) 1% fiber d) lime-fiber treated pond ash at various σ_c and σ_d stress levels (28 days)

Effect of confining and deviatoric stress on M_R

Fig 3 and 4 show the effect of σ_c and σ_d stresses acting on the pond ash specimens. For a typical flexible pavement, the base/subbase layers in general experience confining and deviatoric stresses of 34.5 kPa and 103.4 kPa, respectively [23] (NCHRP 2004). Therefore, these stresses were considered as a reference for comparing M_R in the following section.

From Fig 3, it can be observed that with an increase of confining stresses, M_R values were increased. This is due to an increase of confinement around the specimen, resulting in the reduction of lateral strain deformation and which leads to improving bearing capacity under given deviatoric stress level. The same can be observed for all specimen combinations. For instance, at a constant σ_d of 103.4 kPa, M_R values of PL_8 specimen increased by 42% with an increase of σ_c from 34.4 kPa to 137.9 kPa. In a similar way, except for untreated pond ash, M_R values were observed to be increased with the increase of deviatoric stresses (Fig 4). For instance, at σ_c of 34.4 kPa, with an increase of σ_d from 34.4 kPa to103.4 kPa, M_R values of PL_8 specimen increased by 30% due to strain hardening nature of the sample. Whereas for reinforced pond ash 14% increase in M_R was observed due to enhanced pond ash-fiber interface mechanism [29]. Nevertheless, the increment rate of M_R with σ_d is lower at high σ_c conditions compared to lower σ_c stresses.

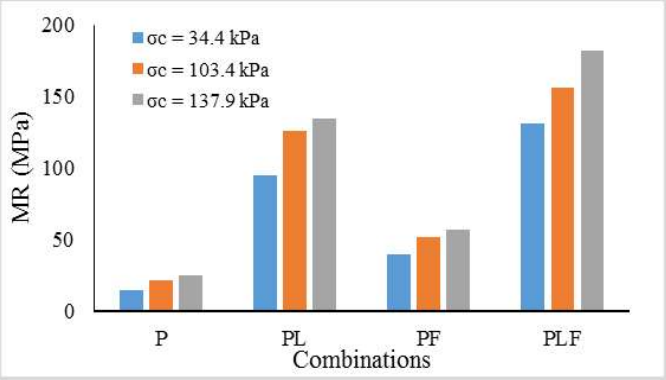

Fig. 3. M_R of a) untreated and b) 8% lime c) 1% fiber d) lime-fiber treated pond ash at constant σd = 103.4 kPa (28 days)

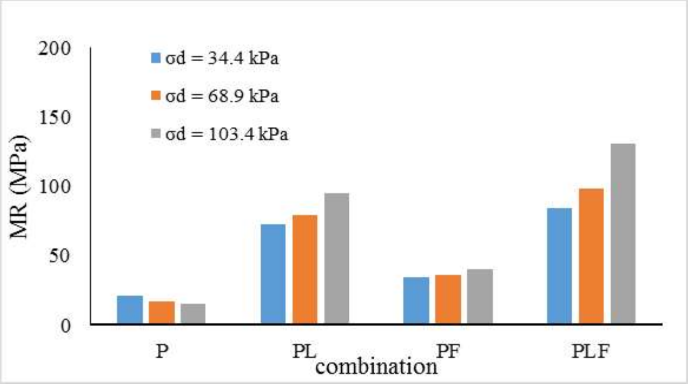

Fig. 4. M_R of a) untreated and b) lime treated c) fiber-reinforced d) lime-fiber treated pond ash at constant σ_c = 34.4 kPa (28 days)

3.4 Modelling studies of M_R

To validate the experimental M_R values, several stress-dependent models are available in the literature for the pavement materials. From which four stress-dependent models have been chosen.

Model 1: Bulk stress model, Uzan (1985)

$$M_R = k_1 * \theta^{k_2} \tag{2}$$

Model 2: Power model, Witczak & Uzan (1988)

$$M_R = k_3 * {\sigma_d}^{k_4} \tag{3}$$

Model 3: NCHRP model, suggested by Patel and Shahu 2016.

$$M_R = k_5 * \left(\frac{\sigma_c}{P_a}\right)^{k_6} * \left(\frac{\sigma_d}{P_a}\right)^{k_7} \tag{4}$$

Model 4: Octahedral shear stress model, AASTHO (2008)-MEPDG.

$$M_R = k_8 * \left(\frac{\theta}{P_a}\right)^{k_9} * \left(\frac{\tau_{oct}}{P_a} + 1\right)^{k_{10}} \tag{5}$$

Where,

Model 1, 2, and Model 3, 4 are referred to as Two-parameter and Three-parameter based models.

σ_3 = confining stress; σ_d = deviator stress (cyclic); P_a = atmospheric pressure (101.4 kPa); θ= bulk stress ($\sigma_d + 3\sigma_3$); τ_{oct} = octahedral shear stress 1/3 $\{(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2\}^{1/2}$; k_1–k_{10} = model constants.

Table 4. Regression analysis constants of resilient modulus

		P	PL_8	PF_1	PL_8F_1
Model 1	k_1	15.824	9.1682	4.946	16.154
	k_2	0.001	0.4195	0.387	0.386
	R^2	0.415	0.893	0.781	0.88
Model 2	k_3	14.728	17.559	10.808	34.269
	k_4	0.065	0.38	0.309	0.315
	R^2	0.056	0.864	0.693	0.713
Model 3	k_5	0.528	1.039	0.743	1.237
	k_6	0.371	0.199	0.291	0.273
	k_7	-0.213	0.231	0.091	0.11
	R^2	0.928	0.977	0.986	0.968
Model 4	k_8	0.488	0.795	0.591	0.989
	k_9	0.448	0.323	0.424	0.431
	k_{10}	-0.724	0.267	-0.104	-0.125
	R^2	0.769	0.975	0.985	0.975

The regression constants k_1 to k_{10}, and corresponding correlation coefficient (R^2) of models obtained from the statistical analysis are presented in Table 4. It can be seen that the R^2 values for two-parameter models (Model 1 and Model 2) are less than 0.9

compared to three-parameter models (Model 3 and Model 4). This is due to consideration of the effect of only confining stress (in Model 1) and deviatoric stress (in Model 2), and ignoring the combined effect all stresses acting on the specimen during loading. Whereas, the three-parameter models (Model 3 and 4) considered the combined stress effects acting on the specimen and showed good correlation values ($R^2 > 0.9$), indicate the better fitting with experimental results. Besides, the advantage of these three-parameter models is lies in the separation of individual stress effect on M_R values.

4 Conclusions

Based on the present investigation on the strength and resilient properties of modified pond ash for pavement application, the following conclusions can be drawn.

1. Untreated pond ash does not show desirable CBR-strength for road subbase applications. The addition of additives (lime, fiber, and lime-fiber) improved the CBR of pond ash significantly. As per IRC: 37, the subbase material should have a minimum CBR value of 30%. The CBR value of PL_8F_1 specimen was found up to 32.1 even after seven days and satisfied the criteria compared to PL_8 and PF_1 combinations.
2. Compared to treated pond ash, the variation in M_R values of untreated pond ash show less significant with increased stress levels. M_R values vary from 59 MPa-143 MPa for lime treated, 28 MPa -63 MPa for fiber-reinforced, and 82 MPa-196 MPa for lime-fiber treated pond ash compared to compacted pond ash of 13 MPa-25 MPa at 28 days curing period, respectively.
3. With increased deviatoric stress, the rate improvement in M_R values is higher at lower confining stresses than at higher confining stresses.
4. Based on model studies, three-parameter models (M3 and M4) provide a good correlation coefficient ($R^2 > 0.9$) for the experimental results of resilient modulus.

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References

1. Sarkar, R., & Dawson, A. R. (2015). Economic assessment of use of pond ash in pavements. International Journal of Pavement Engineering, 18(7), 578-594. https://doi.org/10.1080/10298436.2015.1095915

2. Suthar, M., & Aggarwal, P. (2018). Bearing ratio and leachate analysis of pond ash treated with lime and lime sludge. Journal of Rock Mechanics and Geotechnical Engineering, 10(4), 769-777. https://doi.org/10.1016/j.jrmge.2017.12.008
3. Patel, D., Kumar, R., Chauhan, K. A., & Patel, S. (2019). Experimental and Modeling Studies of Resilient Modulus and Permanent Strain of Stabilized Fly Ash. Journal of Materials in Civil Engineering, 31(8), 06019005. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002798
4. CEA “Fly ash generation at coal/lignite based thermal power stations and its utilization in the country for the year 2016-2017”, New Delhi: Central Electricity Authority, 2017 http://www.cea.nic.in/tcd.html
5. Sivapullaiah, P. V., Prashanth, J. P., & Sridharan, A. (2000). Optimum lime content for fly ashes and the role of the curing period. Journal of testing and evaluation, 28(6), 499-506. https://doi.org/10.1520/JTE12141J
6. Consoli, N. C., Prietto, P. D. M., Carraro, J. A. H., & Heineck, K. S. (2001). Behavior of compacted soil-fly ash-carbide lime mixtures. Journal of Geotechnical and Geoenvironmental Engineering, 127(9), 774-782. https://doi.org/10.1061/(ASCE)1090-0241(2001)127:9(774)
7. Arora, S., & Aydilek, A. H. (2005). Class F fly-ash-amended soils as highway base materials. Journal of Materials in Civil Engineering, 17(6), 640-649. https://doi.org/10.1061/(ASCE)0899-1561(2005)17:6(640)
8. Gupta, D., & Kumar, A. (2017). Performance evaluation of cement-treated pond ash-rice husk ash-clay mixture as a highway construction material. Journal of Rock Mechanics and Geotechnical Engineering, 9(1), 159-169. https://doi.org/10.1016/j.jrmge.2016.05.010
9. Chand, S. K., & Subbarao, C. (2007). Strength and slake durability of lime treated pond ash. Journal of materials in civil engineering, 19(7), 601-608. https://doi.org/10.1061/(ASCE)0899-1561(2007)19:7(601)
10. Ghosh, A. (2009). Compaction characteristics and bearing ratio of pond ash treated with lime and phosphogypsum. Journal of materials in civil engineering, 22(4), 343-351. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000028
11. Sivapullaiah, P., & Moghal, A. (2011). CBR and strength behavior of class F fly ashes treated with lime and gypsum. International Journal of Geotechnical Engineering, 5(2), 121-130. https://doi.org/10.3328/IJGE.2011.05.02.121-130
12. Mogili, S., Mudavath, H., Gonavaram, K. K., & Paluri, Y. (2020). Strength and resilient behavior of lime modified pond ash as pavement layer. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2020.02.168
13. Kaniraj SR, Gayatri V (2003) Geotechnical behavior of fly ash mixed with randomly oriented fiber inclusions. Geotext Geomembr 21(3):123–149 https://doi.org/10.1016/S0266-1144(03)00005-0
14. Kumar P, Mehndiratta HC, Chandranarayana Singh SP (2005) Effect of randomly distributed fibers on flyash embankment. J Inst Eng (India) 86(5):113–118
15. Tang C, Shi B, Gao W, Chen F, Cai Y (2007) Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil. Geotext Geomembr 25(3):194–202. https://doi.org/10.1016/j.geotexmem.2006.11.002
16. Kumar P, Singh SP (2008) Fiber reinforced fly ash sub-bases in rural roads. ASCE J Transp Eng 134(4):171–180. https://doi.org/10.1061/(ASCE)0733-947X(2008)134:4(171)

17. Chore HS, Dhole SS, Abnave SB, Shinde SS, Kumthe AA, Kamerkar SG (2011) Performance evaluation of polypropylene fibers on sand-fly ash mixtures in highways. J Civ Eng (IEB) 39(1):91–102 https://doi.org/10.1007/s40891-015-0032-4
18. Mogili, S., Mohammed, A.G., Mudavath, H., & Gonavaram, K. K. (2020). "Mechanical strength characteristics of fiber-reinforced pond ash for pavement application". Innovative Infrastructure Solutions, 5(3), 1-12. https://doi.org/10.1007/s41062-020-00313-y
19. Puppala, A. J., Hoyos, L. R., and Potturi, A. K. (2011). "Resilient moduli response of moderately cement-treated reclaimed asphalt pavement aggregates." J. Mater. Civ. Eng., 10.1061/(ASCE)MT.1943-5533.0000268, 990–998
20. Arulrajah, A., Piratheepan, J., Disfani, M. M., and Bo, M. W. (2013). "Resilient moduli response of recycled construction and demolition materials in pavement subbase applications." J. Mater. Civ. Eng., 10.1061/(ASCE)MT.1943-5533.0000766, 1920–1928
21. Dev, K. L., & Robinson, R. G. (2015). Pond ash based controlled low strength flowable fills for geotechnical engineering applications. International Journal of Geosynthetics and Ground Engineering, 1(4), 32. https://doi.org/10.1007/s40891-015-0035-1
22. American Association of State Highway and Transportation Officials AASHTO, 1993. AASHTO guide for design of pavement structures, AASHTO, Washington, D.C. https://habib00ugm.files.wordpress.com/2010/05/aashto1993.pdf
23. National Cooperative Highway Research Program (NCHRP). (2004). Guide for mechanistic-empirical design of new and rehabilitated pavement structures. National Cooperative Highway Research Program 1-37 A. http://onlinepubs.trb.org/onlinepubs/archive/mepdg/2appendices_RR.pdf
24. Lav, M. A., & Lav, A. H. (2014). Effects of stabilization on resilient characteristics of fly ash as pavement material. Construction and Building Materials, 54, 10-16. https://doi.org/10.1016/j.conbuildmat.2013.12.029
25. ASTM C618-89 "Standard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete." West Conshohocken, PA.
26. IRC 37-2012. "Tentative guidelines for the design of flexible pavements.", New Delhi, India.
27. IS: 2720 (Part 16), Laboratory Determination of CBR, Bureau of Indian Standards, New Delhi, India, 1987.
28. Dhar, S., & Hussain, M. (2019). The strength behaviour of lime-stabilised plastic fibre-reinforced clayey soil. Road Materials and Pavement Design, 20(8), 1757-1778. https://doi.org/10.1080/14680629.2018.1468803
29. Consoli, N. C., Heineck, K. S., Casagrande, M. D. T. & Coop, M. R. (2007b). Shear strength behavior of fiber-reinforced sand considering triaxial tests under distinct stress paths. Journal of Geotechnical and Geoenvironmental Engineering, 133, No. 11, 1466–1469. https://doi.org/10.1061/(ASCE)1090-0241(2007)133:11(1466)