EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2024, 25(5), 290–303
https://doi.org/10.12912/27197050/186181
ISSN 2719-7050, License CC-BY 4.0

Received: 2024.02.20
Accepted: 2024.03.21
Published: 2024.04.01

The Combined Effect of Pond Ash with Borrowed Soil Materials Along with Milling Waste for Flexible Pavement Sub-Grade Crater Foiling and Strength Characteristic Enhancement

Radhakrishnan Vijayakumar[1*], Kumar Govindhasamy[1], K. Sunil Kumar[2]

[1] Department of Civil Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Avadi 600 062, India

[2] Department of Mechanical Engineering, Faculty of Engineering, Mohamed Sathak A.J. College of Engineering, IT Park, Siruseri, Chennai 603103, India

* Corresponding author"s e-mail: vijayakumar.r@ashokabuildcon.in

ABSTRACT

Pond ash, which is the burnt by-product of fossil fuels such as coal and lignite, is increasing due to globalization, and the safe disposal of pond ash has become a challenging task for human society; the dumping of pond ash in a particular area makes the chosen area too vulnerable for any living kind. The retention of pond ash for a prolonged period leads to soil contamination and infertility of the soil. To overcome the issue, the accumulation of pond ash as a part of the road subgrade shall considerably reduce the dumping. The Pond ash contains both fly ash and bottom ash in a proportion that may vary as per age of dumping. Both fly ash and bottom ashes are rich in cementitious and silicious properties. When the pond ash is mixed with milling waste (reclaimed asphalt pavement) and flue-gas desulfurization material with a particular mix proportion, it leads to matrix material, which becomes a more idealized material for usage as road sub-grade stabilization. Pond ash and flue-gas desulfurization materials make up a key proportion of wet mix macadam material. The milling waste (reclaimed asphalt pavement), on the other hand, is the actual top layer of any road pavement in the form of rubbles and has the added advantage of a cohesive and additive nature. The selection of mix proportions for optimum content makes the matrix mix much espouse as a sub-base course that can readily disperse the tearing action of road surfaces due to differential loading of wheels, which leads to potholes over the lane over time. The California bearing ratio test is done to find the optimum mix.

Keywords: pond ash, reclaimed asphalt pavement, California bearing ratio, subgrade, stabilization, coupler effect of fly ash.

INTRODUCTION

With the rapid growth of industrialization, large quantities of industrial waste are produced. Due to this, health and the environment are getting polluted. The geotechnical characteristics of the waste and its interaction behavior with suitable admixtures like soil and cement are likely to give a viable, eco-friendly, and economically profitable utilization of the waste and solve the issues to a great extent. To reduce the impact of waste material, proper management. Waste materials are used as admixtures to increase the strength of the flexible pavement. The uses of waste help achieve low-cost material for construction and act as an environmentally friendly way of milling waste. To create a sustainable environment, the current study investigated waste and pond ash use in flexible pavements. Finally, briefly mention the main aim of the work and highlight the principal conclusions. As far as possible, please keep the introduction comprehensible to scientists outside your particular field of research.

References should be numbered in order of appearance and indicated by a numeral or numerals in square brackets (Barmade et al., 2022). The importance of the study of waste treatment plants concerned with soil pollution and the harmful effects on the environment effects is essentially monitored periodically to ensure the different types of soil characteristics and their strengths are studied thoroughly by qualified and essential team members during the experimentation process (Sharma and Sharma, 2021). The latest software was employed to get adequate results and past results of the soil permeability and its corrosion resistances throughout the concrete materials; flitched materials concerning the different densities ranging from 10 g/m^3 to 100 kg/m^3 are ensured with the help of OSTU technology followed by (Gupta et al., 2020), According to the (Arun et al., 2017), the gradual failures in the soil were found in the order of 5 to 10% compared to last two years; due to the lack of awareness of strengthen characteristics of the lake soil compared to the industry soil; the fragmented release of these minute diffractions defects the entire construction buildings resulting in the high maintenance costs compared to brick concentrates. Hence, it is required to study the properties of the soil, followed by erosion testing, corrosion testing, absorption tests, and diffraction stages. This research aims to investigate the possibility of utilizing the wastes in the form of subgrade without negotiating the strength and durability of flexible pavement in compliance with IS and IRC guidelines. A multiple mix proportion was prepared to form a soil matrix that shall be used as a subgrade to evaluate every mix as per the California bearing ratio (CBR), which is widely used as a standard evaluating practice. This paper concludes the optimum mix proportion. That will be suitable for constructing flexible road pavement for highways.

MATERIALS

Pond ash

Pond ash is the waste product of coal burning; coal is the central fuelling element in any red category major industries (Edeh et al., 2019). The pond ash is either called coal combustion products (CCPs) or called coal combustion wastes, or coal combustion residuals, which are classified into four groups, each based on physical and chemical forms derived from coal combustion methods and emission controls: bottom ash, fly ash, pond ash and flue-gas desulfurization (FGD). The combination of fly ash bottom ash and FGD will form the pond ash. The typical illustration of pond ash is shown in Figure 1.

Bottom ash

Bottom ash is the utmost part of combustible coal; beyond bottom ash, the substance becomes non-combustible when firing older anthracite and bituminous coal in a power plant boiler furnace or incinerator (Gupta and Kumar, 2016). In other words, it has traditionally been referred to as coal combustion. It covers traces of combustibles implanted in forming clinkers and sticking to hot side walls of a coal-burning furnace during its operation. The clinkers, formed as a cohesive of ashes, precipitate to the bottom and are collected as bottom ash. Figure 2 represents the reclaimed asphalt pavement materials.

Fly ash

Fly ash is a solidified micro fume that is suspended in the exhaust of a coal furnace and is collected by electrostatic precipitators or filter bags in any chimney; fly ash particles are most likely spherical in shape and range in size from 0.5 microns to 300 microns. Fly ash is heterogeneous because of the significant consequence of the

Figure 1. Pond ash

Figure 2. Reclaimed asphalt pavement material

rapid cooling; this quick cooling in a few minerals has time to crystallize, and mainly amorphous, quenched glass remains. The main chemical components present in pond ash are silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), ferric oxide (Fe_2O_3), and trivial calcium oxide (CaO); therefore, the composition of pond ash is assorted. The main constituents known are glass, quartz, mullite, and iron oxides such as hematite and magnetite.

FGD

FGD materials are the by-product materials derived from the process of removing the inorganic content within the coal before the utilization of coal as a fuel. The main desulfurization methods are chemical desulfurization, oxy-desulfurization, and bio-desulfurization. The alkaline desulfurization is effective in removing the pyritic sulfur from the coal, which is the less abundant form than the organic sulfur. FGD comprises 24% of all coal combustion waste. Residues vary but the most common are FGD is synthetic gypsum. Bottom ash and boiler slag can be used as raw feed for manufacturing Portland cement clinker, as well as for skid control on icy roads. These materials are also suitable for geotechnical applications such as structural fills and land reclamation (Bera and Kumar, 2010).

Asphalt

It is the matrix component that is formed by mixing the bitumen, fine aggregates, and coarse aggregate. The uppermost layer of asphalt road payment irrespective of road classifications either high-priority roads or low-priority roads. The quality of asphalt is determined by bitumen's engineering properties such as kinematic viscosity, absolute viscosity, consistency, ductility, The content of hydrocarbon, Solubility in trichloroethylene, and purity. At most, the asphalt is classified by its viscosity grades (VG) as Indian Road Congress. The grades are VG10, VG20, and VG30&VG40. These grades are categorized by their applications.

Aggregates

Aggregates, sometimes called mineral aggregates, are inert materials such as sand, gravel, mechanically crushed stones, slag, or quarry dust. Either fine or coarse aggregates, the aggregates should be complex (Sarkar and Dawson, 2017). Suitably selected and graded aggregates are mixed with the cementitious medium (bitumen) asphalt to form road pavements. Aggregates are the prime load-bearing components of an asphalt concrete pavement. The total constitute of the aggregates as a mixture in terms of weight shall be 90 to 95 percent and 75 to 85 percent by volume.

Treated reclaimed asphalt pavement or milling waste

Asphalt milling, also known as "cold milling" of asphalt pavement road, is the process of peeling off the topmost surface of the asphalt road with a predefined thickness; this includes surface dressing and surface course. Reclaimed asphalt pavement (RAP) is the term that signifies the material containing asphalt and aggregate in the form of removed and or processed milling waste (Mishra, 2015). RAP contains well-graded aggregate coated with bitumen concrete. Milling is done for various reasons, such as removing distressed material from the top surface to create a level and smooth surface and removing aggregate that has segregated from the binder course, also called "reveling".

EMULSIFYING AGENT

Emulsification is the vital process of extrication of asphalt components, leading to bitumen (binder) separation from the rest of the materials. The awareness of partially emulsifying milling waste will end up in a substance such as coarse aggregate coated with an adhesive layer, which is the critical factor of this work. The milling waste has to be worn out to a certain size and shape before emulsifying. Hence, the uppermost layer of asphalt pavement shall be made out of coarse aggregates sizing from 12 mm to 6 mm; the level of emulsifying should be done to segregate the boulder-sized milling waste to a size of cluster of aggregate, which makes double the size of coarse aggregate. The selection of emulsification is based on setting time and surface charges. Either chemical or thermal treatment shall be adopted as an emulsifier.

Hot mix recycling

It involves heating the RAP material from 45 °C to 55 °C to soften the asphalt aggregate coupled with pond ash and local earth materials to form novel materials readily available for backfill materials. Cold mix recycling involves crushing RAP materials into a subgrade, typically coarse silt to fine clay size. In cold mix recycling, the coupling effect can›t be achieved because of the absence of coherency.

Subgrade physical parameters and batching of materials

Sub-grade materials are classically categorized firstly by their resistance to deformation under load, in other words, their stiffness, and secondly by their bearing capacity, in other words, their strength. In general, resistance to deformation of the subgrade is directly proportional to load-bearing capacity earlier to reaching a critical deformation value. Other factors are involved when evaluating sub-grade materials, such as shrinking/swelling in the case of C-type soil. Stiffness is the most common characterization (Adhikari et al., 2018).

MATERIALS TESTING METHODS

The below-mentioned are basic subgrade stiffness/strength characterizations commonly adopted worldwide:

- California bearing ratio,
- modified proctor compaction,
- resistance value (R-value),
- resilient modulus (MR).

This paper is vital on the CBR, which is the ratio of the bearing load that penetrates a material to a specific depth compared with the load giving the same penetration into crushed aggregates. The test is performed as per IS: 2720-16: 1987. The specimens comply with clause 4.3 of IS: 2720-16 taken into consideration, i.e., Remoulded Specimens - The dry density for a remolding shall be either the field density or the value of the maximum dry density estimated by the compaction tests 1 see IS: 2720 (VII) – 1980 and IS: 2720 (VIII) – 1983. According to the situation, the water content used for compaction should be the optimum water content or the field moisture. IS:2720 (part 16) – 1987, Clause 4.3.3 is considered for compaction, i.e., dynamic compaction.

The California bearing ratio test is a penetration test intended to assess the subgrade strength of pavements and roads (Patil and Patil, 2013). The results obtained by these tests are used to frame the empirical curves to determine pavement thickness and its coherent courses. The CBR can be mathematically expressed as:

$$CBR = P/Ps \times 100 \tag{1}$$

where: P – measured pressure for site soil (MPa), Ps – pressure to achieve equal penetration on standard crushed aggregate (MPa).

The R-value test is a material stiffness test. The test procedure states the material's resistance against the deformation as a function of the ratio of diffused lateral pressure to applied Standard vertical pressure (Matos and Sousa-Coutinho 2022). It is a modified triaxial compression test. Materials tested are given an R-value. This study invokes multiple proportions, as in Table 1, which is a selection of individual materials based on different percentages based on volumetric change. As a trial proportion for the study, it has been batched like the following mix ratio(s). Emulsifying the RAP to the temperature of 50 °C just before the melting point of bitumen ensures the binding ability of the mixture with other materials, which forms the subgrade of pavement. Figure 3 represents the CBR test on samples.

RESULTS AND DISCUSSIONS

Mix 1 (100% pond ash)

This trial mix (mix 1) is entirely confined with pond ash as a trial to utilize the pond ash alone with no RAP and borrow soil and to check the CBR value for road pavement (Bishnoi 2023). The CBR test result is tabulated in Table 2 along with factored load as this may form the baseline for tracking end-to-end – results to define the optimum level of mix. Figure 4 represents the CBR curve for mix 1. For mix 1, The CBR value is 2.6% at 5 mm penetration which clearly emphasizes that under any circumstances the consolidated Pond ash alone cannot be used as subgrade even under unsaturated conditions clearly shows that Mix 1 is unsuitable for subgrade.

Figure 3. CBR test on samples

Table 1. Mix proportions (PA: RAP: BS) in terms of volume

No.	Specimens	Pond ash, %	Treated RAP, %	Borrow soil, %
1	Mix 1	100	0	0
2	Mix 2	80	10	10
3	Mix 3	60	20	20
4	Mix 4	40	30	30
5	Mix 5	20	50	30
6	Mix 6	10	70	20

Table 2. Test specimen of 100% pond ash as backfill for sub grade

Penetration of plunger (mm)	Load dial readings, divisions			Corresponding load with factor		
	Specimen 1 (Trial 1)	Specimen 2 (Trial 2)	Specimen 3 (Trial 3)	Specimen 1 load (kg)	Specimen 2 load (kg)	Specimen 3 load (kg)
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	4	03	7	5.68	4.26	9.94
1.0	7	05	12	9.94	7.1	17.04
1.5	15	09	18	21.3	12.78	25.56
2.0	19	12	24	26.98	17.04	34.08
2.5	24	16	32	34.08	22.72	45.44
4.0	30	22	38	42.6	31.24	53.96
5.0	36	26	43	51.12	36.92	61.06
7.5	45	34	51	63.9	48.28	72.42
10.0	55	44	59	78.1	62.48	83.78
12.5	62	51	66	88.04	72.42	93.72

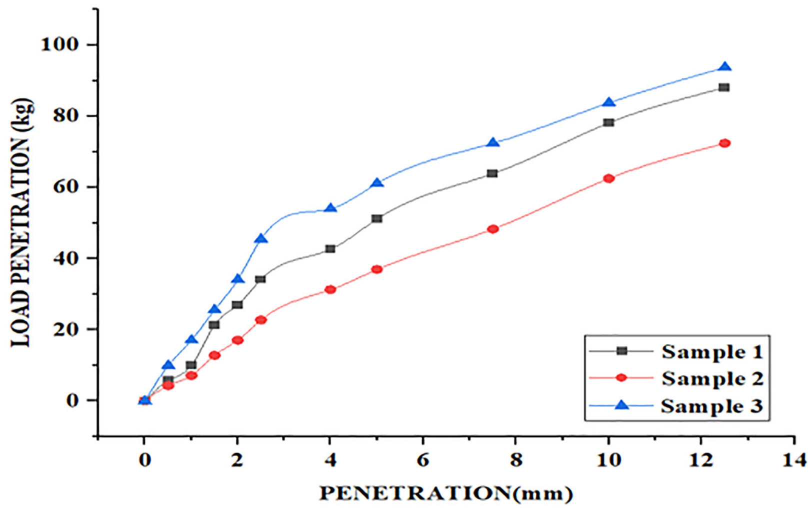

Figure 4. CBR curve for mix 1

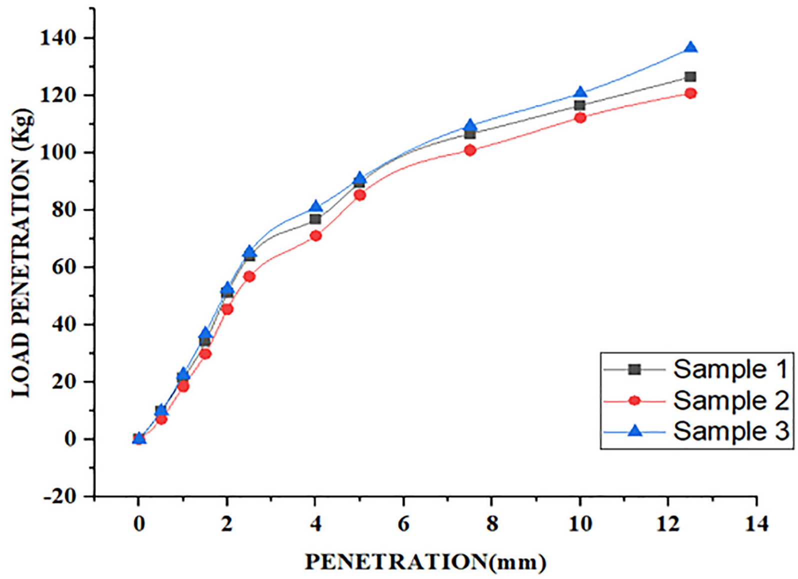

Figure 5. CBR curve for mix 2

Table 3. Test specimen of 80% pond ash, 10% treated RAP, and 10% of backfill

Penetration of plunger (mm)	Load dial readings, divisions			Corresponding load with factor		
	Specimen 1 (Trial 1)	Specimen 2 (Trial 2)	Specimen 3 (Trial 3)	Specimen 1 load (kg)	Specimen 2 load (kg)	Specimen 3 load (kg)
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	07	05	7	9.94	7.10	9.94
1.0	15	13	16	21.30	18.46	22.72
1.5	24	21	26	34.08	29.82	36.92
2.0	36	32	37	51.12	45.44	52.54
2.5	45	40	46	63.90	56.80	65.32
4.0	54	50	57	76.68	71.00	80.94
5.0	63	60	64	89.46	85.20	90.88
7.5	75	71	77	106.50	100.82	109.34
10.0	82	79	85	116.44	112.18	120.70
12.5	89	85	96	126.38	120.70	136.32

Mix 2 (PA-80%, RAP-10%, BS-10%)

This trial mix (mix 2) is confined with 80% Pond ash, 10% treated RAP, and 10% backfill soil as a trial to utilize the pond ash along with RAP and borrow soil, and the CBR test conducted on the mix with three samples of the same mix. The CBR test result is tabulated along with a proven ring factor to acquire the factored load as the result falls in tracking end-to-end results to define the optimum mix level. Table 3 represents the test specimen with different properties. Figure 5 represents the CBR curve for mix 2. For mix 2, the CBR value is 4.53% at 2 mm penetration, which clearly emphasizes the poorly graded sub-grade strata but is an average CBR value for sub-grade. From mix 1 to mix 2, there is an increment of 42.6% in CBR value, which shows a significant growth impartially by 5% to that under any circumstances the consolidated Pond ash of 80% along 10% respectively of treated RAP and Borrow soil can't be used as subgrade (Muniamuthu et al. 2022). Here, it clearly shows that mix 2 is unsuitable for subgrade. Table 4 represents the CBR value for mixture 2

Mix 3 (PA-60%, RAP-20%, BS-20%)

This trial mix (mix 3) is confined with 60% pond ash, 20% treated RAP, and 20% backfill soil as a trial to utilize the pond ash along with RAP and Borrow soil, and the CBR test conducted on the mix with three samples of the same mix (Seferoğlu et al. 2018; Srimanickam and Kumar 2021). The CBR test result is tabulated along with a proven ring factor to acquire the factored load as the result falls in tracking end-to-end results to define the optimum mix level. Figure 6 represents the CBR curve for Mix 3. Table 5 describes the 60% pond ash penetrations. For mix 3, the CBR value is 8.05% at 2 mm penetration, which clearly emphasizes the moderate grade sub-grade strata but is a good enough CBR value for sub-grade (Karthikeyan et al. 2017). From mix 2 to mix 3, there is an increment of 43.73% in CBR value, which shows a significant growth impartially by

Table 4. The calculation for CBR value for mix 2

Description	Specimen 1		Specimen 2		Specimen 3	
	2.5 mm	5.0 mm	2.5 mm	5.0 mm	2.5 mm	5.0 mm
Proving ring reading	45	63	40	60	46	64
Factored load (kg) A	63.90	89.46	56.80	85.20	65.32	90.88
Std load (kg) B	1370	2055	1370	2055	1370	2055
CBR ratio A/B·100 (%)	4.66%	4.35%	4.15%	4.14%	4.77%	3.11%
Avg, CBR Ratio	2.5 mm penetration = 4.53%					
	5.0 mm penetration = 3.87%					

Table 5. Test specimen of 60% pond ash, 20% treated RAP, and 20% of backfill

Penetration of plunger (mm)	Load dial readings, divisions			Corresponding load with factor		
	Specimen 1 (Trial 1)	Specimen 2 (Trial 2)	Specimen 3 (Trial 3)	Specimen 1 load (kg)	Specimen 2 load (kg)	Specimen 3 load (kg)
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	15	15	13	21.30	21.30	18.46
1.0	31	32	30	44.02	45.44	42.60
1.5	45	47	43	63.90	66.74	61.06
2.0	63	65	61	89.46	92.30	86.62
2.5	78	80	75	110.76	113.60	106.50
4.0	90	94	88	127.80	133.48	124.96
5.0	103	109	100	146.26	154.78	142.00
7.5	114	116	111	161.88	164.72	157.62
10.0	129	132	125	183.18	187.44	177.50
12.5	140	143	137	198.80	203.06	194.54

10% to that under any circumstances the consolidated Pond ash of 60% along 10% incremental respectively of Treated RAP and Borrow soil can't be used as subgrade. Here, it clearly shows that mix 3 is suitable for subgrade pavement with moderate traffic flow. Table 6 represents CBR values for mix 3.

Mix 4 (PA-40%, RAP-30%, BS-30%)

This trial mix (mix 4) is confined with 40% Pond ash, 30% treated RAP, and 30% backfill soil as a trial to utilize the pond ash along with RAP and Borrow soil, and the CBR test conducted on the mix with three samples of the same mix. Figure 7 represents the CBR curve for mix 4. The CBR test result is tabulated along with a proven ring factor to acquire the factored load as the result falls in tracking end-to-end results to define the optimum mix level (Ghanizada et al., 2017; Rupesh et al., 2022). For mix 4, The CBR value is 8.98% at 2 mm penetration, which clearly emphasizes the poorly graded sub-grade strata but good CBR value for sub-grade. From mix 3 to mix four, there is an increment of 10.36% in CBR value. Here, the increment of CBR from the prior mix is low compared to earlier mixes, which shows a significant gain in strength and compatibility (Vivekananthan et al., 2022). The consolidated pond ash of 40% and 10% of treated RAP and borrow soil can be used as subgrade. Here, it clearly shows that Mix 4 suits sub-grade embankments for mild traffic. Table 7 represents the test specimens of 40% pond ash properties. Table 8 describes the calculation of CBR values for mix 4.

Mix 5 (PA-20%, RAP-50%, BS-30%)

This trial mix (mix 5) is confined with 20% pond ash, 50% treated RAP, and 30% backfill soil as a trial to utilize the pond ash along with RAP and Borrow soil and the CBR test conducted on the mix with three samples of the same mix. The CBR test result is tabulated along with a proven ring factor to acquire the factored load as the result falls in tracking end-to-end results to define

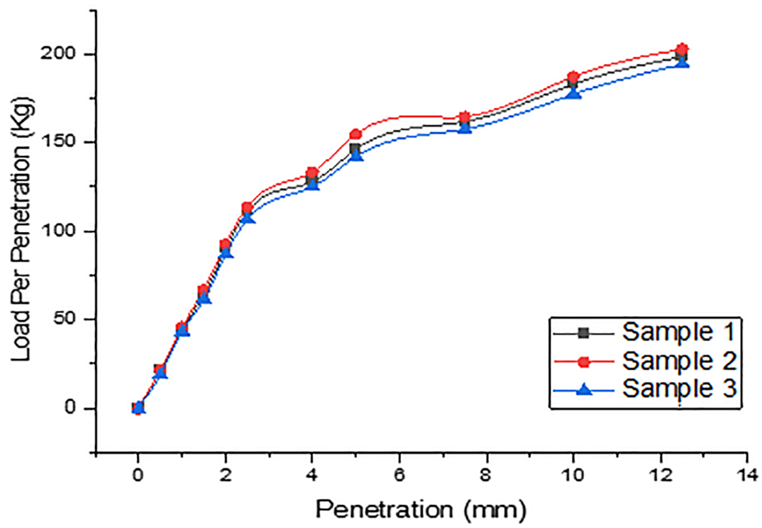

Figure 6. CBR curve for mix 3

Table 6. The calculation for CBR value for mix 3

Description	Specimen 1		Specimen 2		Specimen 3	
	2.5 mm	5.0 mm	2.5 mm	5.0 mm	2.5 mm	5.0 mm
Proving ring reading	78	103	80	109	75	100
Factored load (kg) A	110.76	146.26	113.60	154.78	106.50	142
Std load (kg) B	1370	2055	1370	2055	1370	2055
CBR ratio A/B·100 (%)	8.08%	7.11%	8.29%	7.53%	7.77%	6.9%
Avg, CBR ratio	2.5 mm penetration = 8.05%					
	5.0 mm penetration = 7.18%					

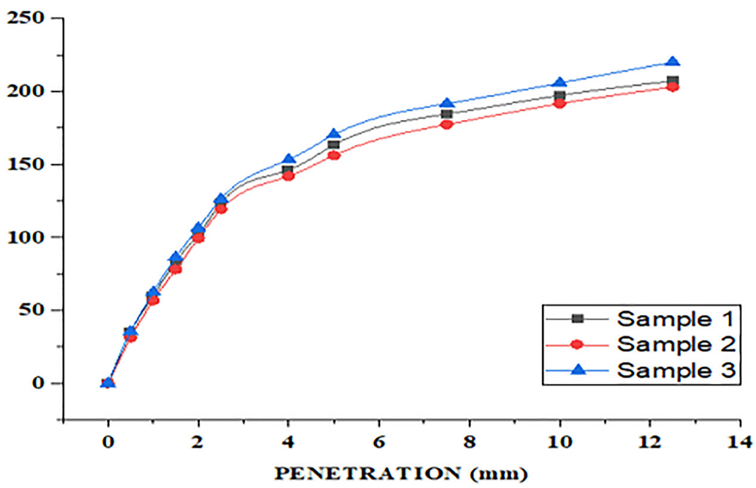

Figure 7. CBR curve for mix 4

Table 7. Test specimen of 40% pond ash, 30% treated RAP, and 30% of backfill

Penetration of plunger (mm)	Load dial readings, divisions			Corresponding load with factor		
	Specimen 1 (Trial 1)	Specimen 2 (Trial 2)	Specimen 3 (Trial 3)	Specimen 1 load (kg)	Specimen 2 load (kg)	Specimen 3 load (kg)
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	25	22	25	35.5	31.2	35.5
1.0	42	40	44	59.6	56.8	62.5
1.5	59	55	61	83.8	78.1	86.6
2.0	72	70	75	102.2	99.4	106.5
2.5	87	84	89	123.5	119.3	126.4
4.0	103	100	108	146.3	142.0	153.4
5.0	115	110	120	163.3	156.2	170.4
7.5	130	125	135	184.6	177.5	191.7
10.0	139	135	145	197.4	191.7	205.9
12.5	146	143	155	207.3	203.1	220.1

Table 8. The calculation for CBR value for Mix 4

Description	Specimen 1		Specimen 2		Specimen 3	
	2.5 mm	5.0 mm	2.5 mm	5.0 mm	2.5 mm	5.0 mm
Proving ring reading	87	115	84	110	89	120
Factored load (kg) A	123.54	163.30	119.28	156.20	126.38	170.4
Std Load (kg) B	1370	2055	1370	2055	1370	2055
CBR ratio A/B·100 (%)	9.02%	7.95%	8.71%	7.60%	9.22%	8.29%
Avg, CBR Ratio	2.5 mm penetration = 8.98%					
	5.0 mm penetration = 7.95%					

the optimum level of mix. Table 9 represents the 20% pond ash properties. Table 10 represents CBR values for mix 5. Figure 8 represents the CBR curve for Mix 5.

For mix 5, The CBR value is 10.05% at 2.5 mm penetration, which clearly emphasizes the grade subgrade strata with good CBR value for subgrade. From mix 4 to mix five, there is an increment of 10.64% in CBR value. Here, the increment of CBR from mix 4 to mix five turns into a consistency compared to earlier mixes, which shows a significant improvement

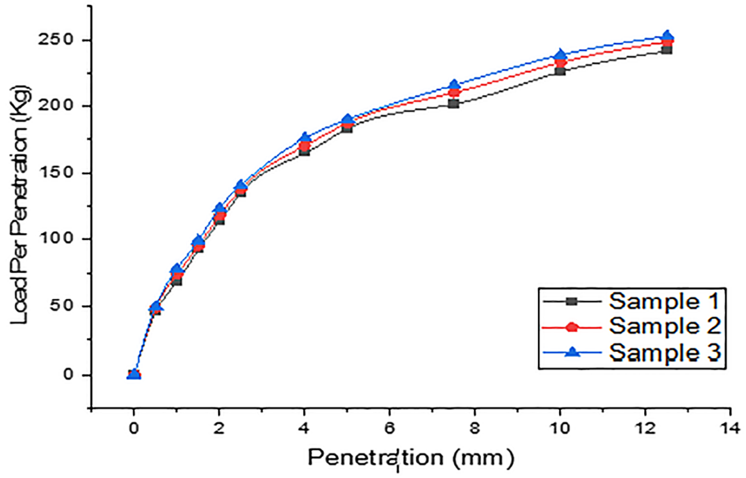

Figure 8. CBR curve for Mix 5

Table 9. Test specimen of 20% pond ash, 50% treated RAP, and 30% of backfill

Penetration of plunger (mm)	Load dial readings, divisions			Corresponding load with factor		
	Specimen 1 (Trial 1)	Specimen 2 (Trial 2)	Specimen 3 (Trial 3)	Specimen 1 load (kg)	Specimen 2 load (kg)	Specimen 3 load (kg)
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	32	34	35	45.44	48.28	49.70
1.0	48	52	55	68.16	73.84	78.10
1.5	65	67	70	92.30	95.14	99.40
2.0	80	83	87	113.60	117.86	123.54
2.5	95	97	99	134.90	137.74	140.58
4.0	116	120	124	164.72	170.40	176.08
5.0	129	132	134	183.18	187.44	190.28
7.5	142	148	152	201.64	210.16	215.84
10.0	159	164	168	225.78	232.88	238.56
12.5	170	175	178	241.40	248.50	252.76

Table 10. The calculation for CBR value for mix 5

Description	Specimen 1		Specimen 2		Specimen 3	
	2.5 mm	5.0 mm	2.5 mm	5.0 mm	2.5 mm	5.0 mm
Proving ring reading	95	129	97	132	99	134
Factored load (kg) A	134.90	183.18	137.74	187.44	140.58	190.28
Std load (kg) B	1370	2055	1370	2055	1370	2055
CBR ratio A/B·100 (%)	9.85%	8.91%	10.05%	9.12%	10.26%	9.26%
Avg, CBR Ratio	2.5 mm penetration = 10.05%					
	5.0 mm penetration = 9.09%					

in load-carrying capacity with minimum plunging and good compatibility. The consolidated Pond ash of 60% and 10%, respectively, of treated RAP and borrow soil can be used as a base course. Since this mix can be used as a sub-base, it is also suitable for subgrade and clearly shows that Mix 5 is ideal for subgrade embankment for moderate traffic.

For mix 6, The CBR value is 12.33% at 2 mm penetration, which shows a decremental phase from mix 5 to mix 6; as there is a drop in CBR value, it marks the optimum mixture of treated

RAP, pond ash, and borrow soil. From mix 5 to mix 6, there is a decrement of 3.82% in CBR value, which is a gentle dip states that almost Mix five and mix 6 set a scale to optimize our work of determining the mixture content. The optimum mix proportion is finalized as the current result shows a decremental phase.

Mix 6 (PA-10%, RAP-70%, BS-20%)

This trial mix (mix 6) is confined with 10% pond ash, 70% treated RAP, and 20% backfill soil as a trial to utilize the pond ash along with RAP and borrow soil, and the CBR test conducted on the mix with three samples of the same mix. The

Table 11. Test specimen of 10% pond ash, 70% treated RAP, and 20% of backfill

Penetration of plunger, mm	Load dial readings, divisions			Corresponding **load with f**actor		
	Specimen 1 (Trial 1)	Specimen 2 (Trial 2)	Specimen 3 (Trial 3)	Specimen 1 load (kg)	Specimen 2 load (kg)	Specimen 3 load (kg)
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	40	43	40	56.8	61.06	56.80
1.0	55	57	54	78.1	80.94	76.68
1.5	70	75	68	99.4	106.50	96.56
2.0	95	97	94	134.9	137.74	133.48
2.5	112	116	115	159.0	164.72	163.30
4.0	135	140	133	191.7	198.80	188.86
5.0	145	150	140	205.9	213.00	198.80
7.5	160	170	155	227.2	241.40	220.10
10.0	172	182	164	244.2	258.44	232.88
12.5	182	189	179	258.4	268.38	254.18

Table 12. The calculation for CBR value for mix 6

Description	Specimen 1		Specimen 2		Specimen 3	
	2.5 mm	5.0 mm	2.5 mm	5.0 mm	2.5 mm	5.0 mm
Proving ring reading	112	145	116	150	115	140
Factored load (kg) A	159.04	205.9	164.72	213	163.3	198.8
Std load (kg) B	1370	2055	1370	2055	1370	2055
CBR ratio A/B·100 (%)	11.61%	10.02%	12.02%	10.36%	11.92%	9.67%
Avg, CBR ratio	2.5 mm penetration = 11.85%					
	5.0 mm penetration = 10.01%					

Table 13. Average of load per penetration individual mixes

Penetration of plunger (mm)	Average corresponding load with factor (kg)									
	Mix 0	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7	Mix 8	Mix 9
0.0	0	0	0	0	0	0	0	0	0	0
0.5	6.6	9.0	20.4	34.1	47.8	66.3	58.2	62.0	54.0	40.7
1.0	11.4	20.8	44.0	59.6	73.4	89.0	78.6	82.4	69.1	65.3
1.5	19.9	33.6	63.9	82.8	95.6	118.3	100.8	110.3	94.2	85.2
2.0	26.0	49.7	89.5	102.7	118.3	153.4	135.4	145.3	129.2	98.0
2.5	34.1	62.0	110.3	123.1	137.7	175.6	162.4	169.0	152.4	113.6
4.0	42.6	76.2	128.7	147.2	170.4	201.6	193.1	192.2	176.6	125.9
5.0	49.7	88.5	147.7	163.3	187.0	222.9	205.9	205.9	192.6	139.2
7.5	61.5	105.6	161.4	184.6	209.2	241.9	229.6	226.7	208.3	161.4
10.0	74.8	116.4	182.7	198.3	232.4	251.8	245.2	240.5	216.3	174.2
12.5	84.7	127.8	198.8	210.2	247.6	264.1	260.3	248.0	223.4	188.9

CBR test result is tabulated along with the proven ring factor to acquire the factored load; as a result, it falls in tracking end to result to define the optimum level of the mix. Table 11 represents the 10% pond ash properties.

For mix 6, The CBR value is 11.85% at 2 mm penetration which primes the well-grade subgrade strata with good CBR value for subgrade. From mix 5 to mix 6 there is a decrement of 7.57% in CBR value. Here the decrement of CBR from mix 5 to mix 6 attains almost a flat curve which in turn means the load-carrying capacity becomes almost firm and with the same plunging it turns are monotonous curve (Lu et al., 2020). Table 12 represents the CBR values for mix 6 and Table 13 represents the average of load. Figure 9 represents CBR curve for mix 6. Table 13 cumulates every mix trail as a single entity to better understand the performances of every proportion. All the data complied with the guidelines of IS: 2720 – 16: 1987 and IRC 37 – 2012. Figure 10 represents the CBR average curve.

CONCLUSIONS

This Investigation was carried out to look for the possibility of utilizing the wastes as subgrade without negotiating the strength and durability of flexible pavement in competence with IS and

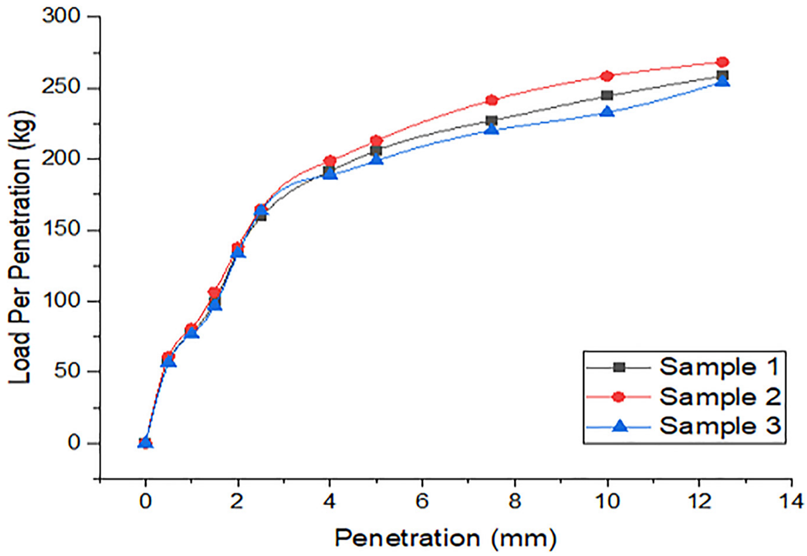

Figure 9. CBR curve for mix 6

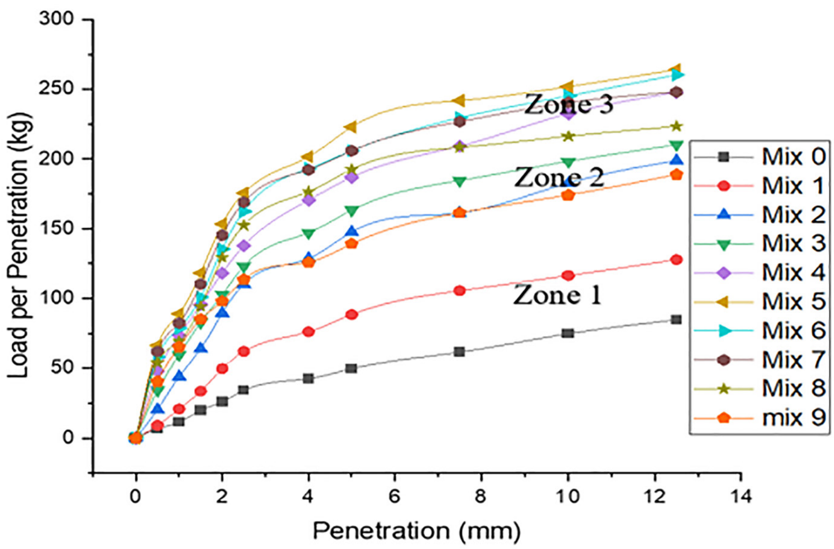

Figure 10. The master graph shows every mix CBR average curve

IRC guidelines. A multiple mix proportion was prepared to form a soil matrix that shall be used as a subgrade on the evaluation of every mix as per the California bearing ratio, which is widely used as a standard evaluation practice. This paper concludes the optimum mix proportion. That will practically be suitable for constructing flexible road pavement for highways.

The CBR curve is plotted for every mix; as a result of observation, the curves are batched into three zones: Zone I covers the range of 50 to 200 kg load per penetration, Zone II encloses the range of 201 to 250 kg load per penetration, Zone III encloses the range from 251 to 300 kg load per penetration. This zoning is done based on the distinct formation of the CBR curve.

In Zone I, mix 0, mix 1, and mix 9 curves show the spongy material's behavior as the constituent is filled with pond ash as a significant portion; pond ash being porous, compressible, and absorbent, the CBR curve validates the mix proportion. 40% of the established mix falls in this zone. In zone II, mix 3, mix 4, mix 7 and mix eight fall in this zone; 40% of the established mix falls in Zone II, which states that the mix is classified as a suitable composite for sub-grade materials for different types of traffic flows especially low traffic (up to 400 vehicles per day) to medium traffic (up to 400 to 1000 vehicles) or class III type roads. The optimum mix proportion obtained was mix 5 with a mix proportion of PA:RAP:BS as a 50:25:25 ratio regarding specimen volume. Mix 5 and mix 6 are categorized as Zone III, which shows a well-defined CBR curve that replicates a well-graded granular soil sample, which will be considerable as appropriate material for sub-grade, and surprisingly, the same constituent can also be used as a sub-base course as it satisfies the required CBR value for sub base.

As a final prospect, the pond ash of any class shall be utilized along with treated reclaimed asphalt pavement and any locally available soil as backfill fill, which in turn is known as borrow soil as per the concluded proportion. The CBR curve of mix 5 shows that the specimen's load-carrying capacity is exponential from initial penetration, i.e., 0.5 mm to 5 mm, which clarifies that with minimum stain in volume, the resilience was equal to confined, well-graded granulated soil. Beyond 5 mm penetration to 12.5 mm, the load-carrying capacity shows a gentle slope, which emphasizes that the strength of the soil doesn't deteriorate as a sudden failure; this ensures the durability of the mixed specimen.

Acknowledgment

The authors would like to acknowledge the IIT Madras for helping successfully to complete the project.

REFERENCES

1. Adhikari, S., Khattak, M.J., Adhikari, B. 2020. Mechanical characteristics of Soil-RAP-Geopolymer mixtures for road base and subbase layers. International Journal of Pavement Engineering, 21(4), 483–496.
2. Barmade, S., Patel, S., Dhamaniya, A. 2022. Performance evaluation of stabilized reclaimed asphalt pavement as base layer in flexible pavement. Journal of Hazardous, Toxic, and Radioactive Waste, 26(1), 04021051.
3. Bera, A.K. and Kumar, A. 2010. December. Effect of pond ash content on engineering properties of fine-grained soil. In: Indian Geotechnical Conference, 16–18.
4. Edeh, J.E., Joel, M., Abubakar, A. 2019. Sugarcane bagasse ash stabilization of reclaimed asphalt pavement as highway material. International Journal of Pavement Engineering, 20(12), 1385–1391.
5. Gupta, D. and Kumar, A. 2016. Strength characterization of cement stabilized and fiber reinforced clay–pond ash mixes. International Journal of Geosynthetics and Ground Engineering, 2, 1–11.
6. Gupta, G., Sood, H., Gupta, P. 2020. Performance evaluation of pavement geomaterials stabilized with pond ash and brick kiln dust using advanced cyclic triaxial testing. Materials, 13(3), 553
7. Mishra, B. 2015. A study on use of reclaimed asphalt pavement (RAP) materials in flexible pavements. International Journal of Innovative Research in Science, Engineering and Technology, 4(12), 12170–12177.
8. Patil, B.M. and Patil, K.A. 2013. Effect of pond ash and RBI grade 81 on properties of subgrade soil and base course of flexible pavement. International Journal of Civil and Environmental Engineering, 7(12), 966–971.
9. Karthikeyan, N.K., Arun, S., Mohan, G.S., Kumar, S. 2017. Structural analysis of exhaust manifold for 1500 Hp engine. International Journal of Mechanical Engineering and Technology, 8(3), 379–387.
10. Sarkar, R. and Dawson, A.R. 2017. Economic assessment of use of pond ash in pavements. International Journal of Pavement Engineering, 18(7), 578–594.

11. Seferoğlu, A.G., Seferoğlu, M.T., Akpınar, M.V. 2018. Investigation of the effect of recycled asphalt pavement material on permeability and bearing capacity in the base layer. Advances in Civil Engineering, 1–6.
12. Sharma, A. and Sharma, R.K., 2021. Sub-grade characteristics of soil stabilized with agricultural waste, constructional waste, and lime. Bulletin of Engineering Geology and the Environment, 80(3), 2473–2484.
13. Vivekananthan, V., Vignesh, R., Vasanthaseelan, S., Joel, E., Kumar, K.S. 2023. Concrete bridge crack detection by image processing technique by using the improved OTSU method. Materials Today: Proceedings, 74, 1002–1007.
14. Rupesh, P.L., Raja, K., Kumar, K.S., Vijaydharan, S., Reddy, A.M.M., Kumar, P.D. 2022. Experimental evaluation of thermal stress on the surface of butterfly specimen through irreversible colour change of thermal paint. Materials Today: Proceedings, 59, 1768–1775.
15. Srimanickam, B., Kumar, S. 2021. Drying investigation of coriander seeds in a photovoltaic thermal collector with solar dryer.
16. Muniamuthu, S., Kumar, K.S., Raja, K., Rupesh, P.L. 2022. Dynamic characterization of hybrid composite based on flax/E-glass epoxy composite plates. Materials Today: Proceedings, 59, 1786–1791.
17. Bishnoi, D. 2023. Pressure exertion and heat dissipation analysis on uncoated and ceramic (Al_2O_3, TiO_2 and ZrO_2) coated braking pads. Materials Today: Proceedings, 74, 774–787.
18. Lu, Y., Tian, A., Zhang, J., Ang, Y., Shi, P., Tang, Q., Huang, Y. 2020. Physical and chemical properties, pretreatment, and recycling of municipal solid waste incineration fly ash and bottom ash for highway engineering: A literature review. Advances in Civil Engineering, 2020, 1–17.
19. Matos, A.M. and Sousa-Coutinho, J. 2022. Municipal solid waste incineration bottom ash recycling in concrete: Preliminary approach with Oporto wastes. Construction and Building Materials, 323, 126548.
20. Arun, S., Nagoorvali, S.K., Kumar, K.S., Mohan, G.S. 2017. Automation of main bearing bolt and cap loosening machine for automobile crankshaft. International Journal of Mechanical Engineering and Technology, 8(2).