Pavement Design and Cost Analysis of Mine Waste Stabilized Low Volume Roads

Shravan A. Kanalli, Sureka Naagesh, and K. Ganesh

Abstract The extraction of minerals from the earth through mining has been one of the human activities since prehistoric times. These mining activities conducted through surface or sub-surface method leads to the generation of mine waste during the processing and extraction of minerals. The lack of storage space for mine waste and the environmental impact caused due to its storage has also been a major issue for the mining agencies. Black cotton soil (BC soil), on the other hand, is considered problematic due to its swell–shrink behavior during seasonal changes. The subgrade constructed on Black Cotton soil undergoes settlement and causes the pavement structure to fail. In the current study, efforts were made to resolve the issue of storage space of Mine Waste generated from mining activity to strengthen the weak subgrade soil such as BC soil. The engineering properties of Mine Waste stabilized soil samples were carried out and the optimum BC soil–Mine Waste mix was determined. Further, Granulated Blast Furnace Slag (GBFS) was blended with optimum BC soil–Mine Waste to enhance the engineering property. Pavement design was carried out using IITPAVE software. Cost Analysis was performed for the pavement section using the latest schedule of rates of the Dharwad region. Results indicated that 60% BC soil: 40% Mine Waste mix improved CBR strength from 2.3% to 5.6% and hence was considered as an optimum mix. The addition of 30% of GBFS to the optimum BC soil–Mine Waste mix further improved CBR strength to 10%. The same mix resulted in total cost savings of 41%.

Keywords Mine waste · Black cotton soil · Granulated blast furnace slag · IITPAVE · Soil Stabilization

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1 Introduction

The subgrade is the bottom-most structure of the pavement which is constructed using natural or borrowed materials. This supports the granular layer, viz., subbase, base, and surface course. The performance, life span, and serviceability of the pavement primarily depend on the quality and strength of the subgrade layer. The northern part of Karnataka, India, is largely covered by Black Cotton soil. The presence of Kaolin and Montmorillonite particles leads to the exhibition of high plasticity, compressibility, high swelling, low durability, and reduction in strength. The expansive behavior is possessed by soil due to fluctuations in moisture and the clay minerals existing in the soil. It thus undergoes volume changes on seasonal moisture variation. The road constructed on this soil leads to pavement failure which necessitates frequent maintenance leading to an increase in maintenance cost.

Karnataka is one of the largest producers of Iron Ore mines in India. The mineral assessment done by the mining results in the formation of waste materials due to the removal of overburden. The waste produced is the largest waste generated in excess of the core minerals. The stripping ratio (waste to ore ratio) ranges from 2:1 to 6:1 which means for every one part of minerals produced, there is 2 to 6 times the waste generated [1]. The significant increase in open-cut mining has increased the production of Mine Waste at a higher rate than the minerals extracted. The wastes generated from mining activities in various forms have caused a serious impact on the lives of surrounding areas hampering the environment and resulting in deaths and serious injuries.

Past research has indicated that Iron Ore Mine Waste has found useful applications in the construction industries. As per research conducted by Mohan et al. [2], the use of Mine Waste in the form of coarse aggregate for manufacturing bricks improved the UCS results by 10% on 28 days of curing in comparison with natural aggregates. The studies in Western Australia [1] have found the utilization of Mining Waste for railway and road embankments as an ideal option. The engineering properties of Mine Waste were found to be similar to natural soil. The Mine Waste comprised 33% of clay particles, 17% of silt, and 50% of sand particles. The specific gravity was found to be 2.75. The use of wastes further reduced the need for large excavation of natural soil for the construction of embankments. The requirement of land for Mine Waste storage got reduced. Bastos et al. [3] evaluated the possibility of using Iron Ore Mine Waste in road construction. The microstructure of these wastes was tested by SEM. The compaction characteristics, CBR test, Unconfined Compression test, water absorption, and durability test were conducted to find the suitability of the materials for road construction. The samples were collected from the Iron Quadrangle region in Minas Gerais, Brazil. The results from chemical analysis concluded that the material is class II A, which states the material as nondangerous and noninert material; free from hazardous characteristics like toxicity, corrosivity, etc. It was proven that the Mine Waste was technically feasible when stabilized with 5% cement or 10% of lime.

However, there is a lacuna in the research on the usage of Mine Waste in Black Cotton soil stabilization for subgrade construction. The stress–strain analysis of the Mine Waste stabilized pavement structure is important to determine pavement performance. The cost analysis of roads constructed using Mine Waste needs to be carried out from economic considerations. The present study thus focuses on determining the optimum BC soil–Mine Waste mix for subgrade. Further using GBFS as additives if required to improve the properties and form a substantial mix for the subgrade construction.

2 Materials and Methodology

2.1 Black Cotton Soil (BC Soil)

The soil was collected from Yarikoppa village, Dharwad district, Karnataka, India. The particle size distribution, index properties, compaction characteristics, physio-chemical properties, and strength parameters of BC soil were determined as per Indian Standard (IS) codes. Table 2 represents the properties of BC soil. The soil consists of 14% sand, 42% silt, and 44% clay particles. It is classified as highly compressible clay CH as per IS classification. Liquid Limit and Plasticity Index were found to be 57 and 21.1%, respectively. The UCS and soaked CBR values were found to be 166 kPa and 2.3%, respectively. These results indicate the unsuitability of BC soil for subgrade layer as per MORT&H specification [4].

2.2 Mine Waste

The Iron ore waste in the form of overburden produced from mining was procured at Iron Ore Mining at Venkatagiri Iron Ore Mines, Bellary district, Karnataka, India. The particle size distribution, specific gravity and consistency limits, and mineralogical characteristics of the waste material were determined. The particle size analysis indicated that the Mine Waste consists of 37.72% of sand, 38.78% of silt, and 23.52% of clay particles as per IS classification of soil. The consistency limit of Mine Waste indicated that the material is non-plastic. The specific gravity of Mine Waste was 3.08 due to the higher Iron content in the material. Table 2 indicates the engineering properties of Mine Waste (Table 1).

Table 1 Mineralogical characteristics of materials

Oxides (%^)	BC soil	Mine waste	GBFS
SiO_2	65.54	33.23	13.28
Al_2O_3	20.44	19.67	5.37
Fe_2O_3	–	41.50	24.88
CaO	4.10	2.21	44.8
MgO	3.89	1.22	6.52
K_2O	0.78	0.55	1.63
Na_2O	0	0.19	0.79
TiO_2	0.39	0.19	2.30

Table 2 Engineering properties of materials

Sl. no	Property	BC soil	Mine waste	GBFS	Code
1	Grain size distribution % Gravel Sand Silt Clay	– 14 42 44	– 37.72 38.76 23.52	0.3 83.9 15.8 0	IS:2720-Part IV [5]
2	Soil classification	HRB: A-7-C IS: CH			IS:1498–1970 [6]
3	Specific gravity	2.62	3.08	2.82	IS:2720-Part III [7]
4	Consistency limits (^%) Liquid limit Plastic limit Plasticity index	57 35.9 21.1	NP*	NP*	IS:2720-Part V [8] IS:2720-Part VI
5	California bearing ratio (%)	2.3	–	–	IS:2720-Part XVI [9]
6	Unconfined compression strength (kPa)	166	–	–	IS:2720-Part X [10]
7	Free swell index (%)	55	0	0	IS:2720-Part XL [11]
8	Swell pressure (kPa)	268.70	‘122.58	27.45	IS 2720 Part XLI [12]

2.3 Granulated Blast Furnace Slag (GBFS)

The material was procured from Jindal Steel Work, Toranagallu, Bellary District, Karnataka, India. The specific gravity, particle size distribution, and mineralogical characteristics of the material were determined. The particle size distribution indicates that the GBFS consists of 0.3% of gravel, 83.8% sand, 15.8% silt, and no clay particles. The specific gravity of GBFS was found to be 2.82. The test was carried out as per Indian Standards. The engineering properties of Mine Waste have been shown in Table 2 (Fig. 1).

Fig. 1 Materials used for BC soil stabilization

3 Sample Preparations

Various tests such as Compaction characteristics, Consistency limits, CBR, and UCS were carried out as per standard procedures of IS 2720 and Durability tests as per ASTM D559.

Samples were prepared by mixing BC soil with various Mine Waste content (replacing 10, 20, 30, and 40% of soil) and tested for various parameters. GBFS was further added to the optimum soil–Mine Waste mix that exhibited maximum dry density.

The BC soil–Mine Waste mixes and BC soil–Mine Waste-GBFS mixes were tested after a curing period of 1, 7, and 28 days in order to study the effect of curing. Samples were prepared and cured in a desiccator at 23 °C temperature and 100% relative humidity. The UCS and CBR test samples were prepared for MDD and OMC. CBR test was carried out on samples soaked for 4 days and one hour of drying before testing.

4 Design of Pavement

The analysis of pavement was done using IITPAVE software. The linear elastic multilayer analysis was performed through software to obtain stress, strain, and deflection. It can be applied to layered systems for different wheel load configurations (single, dual) with different layer behavior. The design life can be evaluated based on the fatigue crack and permanent deformation caused in each period over all load groups. The input parameters for the pavement analysis have been given in Table 3.

Table 3 Input parameters for IITPAVE analysis

Input Parameters	Value
The number of periods in a year	1
The number of load group Single Dual	1 2
No of layers	2–3
No of Z coordinates	Varies among no of interfaces and intermediate points
No of response	9
Unit	SI
Type of loading	Single Axle Single Wheel (SASW) Single Axle Dual Wheel (SADW)
Contact radius of circular loaded area	15.08 cm (SASW) 10.66 cm (SADW, Tandem, Tridem)
Contact pressure on circular loaded area	560 kPa
Radial distance	155 mm

4.1 *Input Parameters*

The elastic modulus and Poisson's ratio were the prime input embedded in the software. The Poisson's ratio for all the layers was considered as 0.35 as per IRC:37:2018 [13]. The elastic modulus of the material is dependent on the CBR value of the sample. The elastic modulus was determined from equations given in IRC: 37:2018. Equations 1 and 2 gives the elastic modulus value of subgrade. The elastic modulus for granular and surface layer is given in Eq. 3.

$$\mathrm{E} = 10 \times \mathrm{CBR}\ (\mathrm{CBR} < 5\%) \tag{1}$$

$$\mathrm{E} = 17.6 \times (\mathrm{CBR})^{0.64} (\mathrm{CBR} > 5\%) \tag{2}$$

$$\mathrm{E} = \mathrm{EB} \times 0.2 \times \mathrm{h}^{0.45} \tag{3}$$

where $\mathrm{E_B}$ = Modulus of elasticity of supporting layer (MPa); h = layer thickness (mm).

4.2 *Rutting Performance Model*

The standard rutting performance model, at different reliability levels, was used for the determination of critical strain at the top of the subgrade layer. The pavement layer system was considered efficient when the actual vertical strain is less than the critical strain obtained from the below equation. Equations 4 and 5 represent the rutting performance model at 80% and 90% reliability, respectively.

$$N_R = 4.1656 * 10^{-8} [1/€_v]^{4.5337} \tag{4}$$

$$N_R = 1.4100 * 10^{-8} [1/€_v]^{4.5337} \tag{5}$$

where N_R = Number of Cumulative ESAL to produce rutting up to 20 mm.

$€_v$ = vertical compressive strain at the top of the subgrade.

5 Results and Discussions

5.1 Effect of Mine Waste on Black Cotton Soil

The Mine Waste was stabilized with BC soil in the form of partial replacement at a rate of 10, 20, 30, 40, and 50% on a trial-and-error basis. The use of Mine Waste indicated a reduction in the Liquid Limit and Plasticity Index from 57 and 21.1%, respectively, to 42.5 and 8% for the partial replacement of 40% of Mine Waste. This was due to the reduction in the repulsive force that acts as particles come in contact with each other. The reduction in surface area and water affinity also contributed to the reduction of liquid limit and plastic limit values.

The 60% BC soil–40% Mine Waste mix also witnessed an improvement in the compaction characteristics due to the higher specific gravity of Mine Waste. MDD and OMC values were 18.96 kN/m^3 and 11.8%, respectively, and are higher than the minimum required MDD as per MORT&H. The compaction of soil at the lower water content is influenced by the flocculation of particles which ultimately reduces OMC values. The repulsion in the clay particles also leads to higher density [14]. The UCS value for untreated BC soil samples was found to be 166 kPa. The value increased gradually up to 197.1 kPa for 40% replacement of Mine Waste and got reduced to 187.58 kPa on further addition of Mine Waste. The UCS achieved after 7 days, and 28 days of curing was 350.15 and 475.52 kPa, respectively. There was also a significant increase in the CBR value on BC soil–Mine Waste samples. The optimum BC soil–Mine Waste mix achieved a CBR of 5.6% in comparison with the untreated BC soil sample of 2.3%.

5.2 Effect of GBFS on BC Soil–Mine Waste Mix

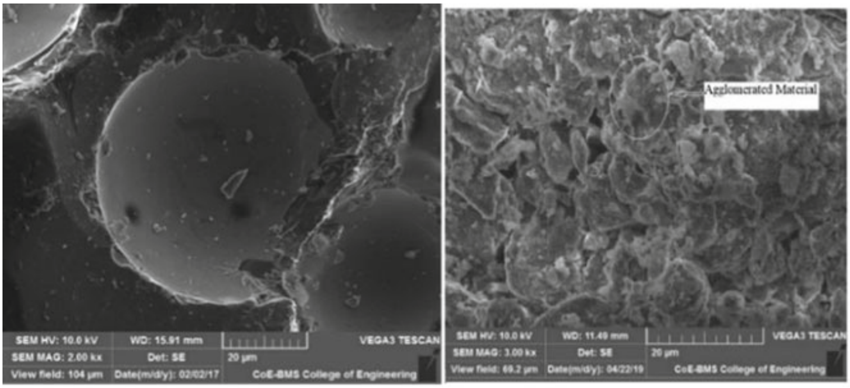
The GBFS was mixed with the soil–Mine Waste mix as an additive at various proportions of 10, 20, 30, and 40% to study its effect on CBR and UCS. It was observed that for mix 60:40:30, the soaked CBR value was 10% and UCS increased to 233.4 kPa from 197.1 kPa for 1 day curing. The UCS results achieved after 7 days and 28 days of curing was 414.82 and 677.93 kPa respectively. The 10% CBR is classified as the highest quality rating ‘S5’ as per IRC: SP: 72. GBFS being a cementitious binder material undergoes hydration to form new cementitious compounds like C–A–S–H and C–S–H which increases the strength of treated soil. However, beyond the optimum binder content, the material does not undergo a pozzolanic reaction and behaves like unbounded materials, thus decreasing the strength of the soil sample. The 60:40:30 (BC soil: Mine Waste: GBFS) was considered as the substantial mix.

5.3 Scanning Electron Microscopy (SEM)

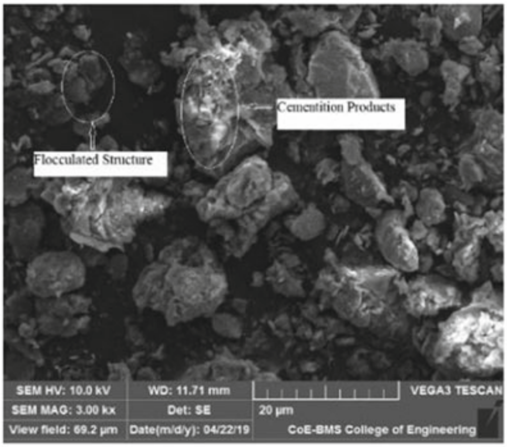
The microstructure and morphology of materials were studied using Scanning Electron Microscope. The image produces information on the composition of the sample and its surface topography due to the interaction of electrons with atoms present in the sample. Figure 2a shows untreated BC soil filled with large void spaces. The image indicates the sample as an amorphous material. It lacks the regularity in atomic structure and hence, does not possess a strong mechanical property. Figure 2b indicates the SEM of BC soil–Mine Waste mix. The mix is an amorphous material embedded with metals that gives the charging effect. The mix behaves like an agglomerated material. This was mainly due to the presence of Iron-oxide in Mine Waste. This leads to a slight enhancement in the engineering properties of BC soil. Figure 2c indicates substantial BC soil–Mine Waste-GBFS (60:40:30). It can be clearly seen that the fabric transforms from the particle-based form into a more integrated composition. Figure 2c clearly shows the flocculated material and patches of cementitious products. The soil mixes change from amorphous to crystalline with the addition of GBFS. This is primarily due to the presence of calcium and iron oxide that enhances the engineering properties of the mixes. This phenomenon is predominantly observed in substantial BC soil–Mine Waste-GBFS mix which certainly exhibits its greater effect on micro-structural effect on treated BC soil mix. The crystalline nature of the materials has certainly led to an increase in strength and durability and eventually lead to the reduction in pavement thickness requirement.

5.4 Durability Test

The durability test proves to be a vital parameter in determining the ability of the material in attaining stability and retaining its bond with soil consistently over a long period under the application of destructive weathering agents. The durability studies were carried out on untreated BC soil and substantially treated soil mixes as per ASTM D559 [15]. The test samples were prepared in a similar line with UCS test samples for obtained MDD as per standard proctor test. The test samples of 38 mm



(a) BC soil (b) BC soil-Mine Waste (60:40)



(c) BC soil-Mine Waste-GBFS (60:40:30)

Fig. 2 SEM of untreated and stabilized BC soil

diameter and 76 mm height were prepared as per standard proctor condition. The samples were cured in a desiccator for 7 days. After curing, samples were soaked for a period of 5 h and oven dried for 42 h at a temperature of 71 °C. This 5 h of soaking and 42 h of oven drying constitute one cycle [15]. The results indicated that the untreated BC soil immediately collapsed during the first cycle. The BC soil–Mine Waste (60:40) too couldn't hold the stability and collapsed after two cycles. The soil mixes treated with GBFS withstood 12 cycles of wetting–drying cycles. The percentage loss in weight for substantial BC soil–Mine Waste: GBFS was 9.98%.

5.5 Pavement Design Using IITPAVE

The pavement structure is adopted from IRC SP:72–2015 [16]. The pavement structure consists of WMM granular surfacing laid on a granular base course resting on the subgrade. The input parameters are based on IRC: SP:72–2015 prepared by the Indian Road Congress for the pavement analysis of low volume roads. The pavement analysis for unpaved road is performed for cumulative ESAL of 10,000 to 30,000, 30,000 to 60,000, and 60,000 to 1,00,000. The CBR value of untreated BC soil was 2.3%. As per IRC: SP:72–2015, the subgrade falls in the S1 category which states that the subgrade strength is not suitable for ESAL greater than 30,000. The optimum combination of BC soil: Mine Waste (SM), optimum BC soil: Mine Waste: GBFS (SMG) in subgrade category S3 and S5 respectively. The modified subgrade was analyzed for cumulative ESAL application 10,000–30,000, 30,000–60,000, and 60,000–1,00,000. An unpaved road is not suitable for cumulative ESAL greater than 1,00,000. Table 4 indicates the subgrade and traffic category used in the design. The total pavement thickness of the respective subgrade category and cumulative ESAL applications as per IRC: SP:72–2015 are given in Table 5.

Excess vertical deflection is a major concern in pavement performance. Hence, this is one of the major criteria used for the design of pavement. The results indicate that the modification in the subgrade in the form of partial replacement of materials contributes to the reduction of deflection value. The stabilization also resulted in the reduction of vertical compressive strain at the top surface of the subgrade layer. Table 6 indicates the compressive strain for various cumulative ESAL. The actual strain values were compared with the allowable strain value to check the

Table 4 Category of traffic and subgrade

Materials	Category of subgrade	CBR (%)	Category of traffic	Cumulative ESAL applications
Untreated BC soil	S1	2.3	T1	10,000–30,000
BC soil: Mine Waste (60:40)	S3	5.6	T1	10,000–30,000
BC Soil: Mine Waste: GBFS (60:40:30)	S5	10	T2 T3	30,000–60,000 60,000–1,00,000

Table 5 Total pavement thickness as per IRC SP:72–2015

Subgrade category	Cumulative ESAL applications		
	10,000–30,000	30,000–60,000	60,000–1,00,000
S1 (2%)	300 mm	–	–
S3 (5–8%)	175 mm	250 mm	275 mm
S5 (10–15%)	125 mm	150 mm	175 mm

Table 6 Actual vertical compressive strain of untreated and treated bc soil layer for different axle wheel configurations and various Cumulative ESAL

Materials	Wheel configuration	Vertical compressive strain (Micro strain) Cumulative ESAL		
		10,000–30,000	30,000–60,000	60,000–1,00,000
Untreated BC soil	SASW	4460		
	SADW	3130		
SM mix	SASW	3630	2430	2010
	SADW	2440	2310	1400
SMG mix	SASW	3430	2930	1840
	SADW	2390	1990	1250

Table 7 Critical vertical compressive strain for various cumulative ESAL

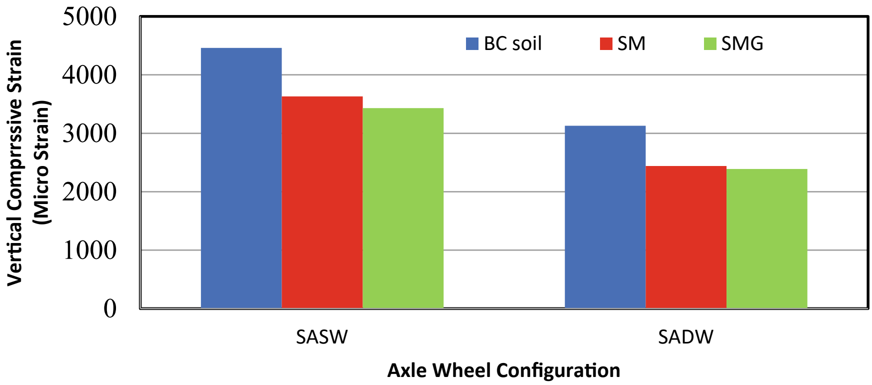
Cumulative ESAL	Allowable vertical strain (Micro strain)
10,000–30,000	2420
30,000–60,000	2080
60,000–1,00,000	1850

efficiency of the design. The allowable strain on top of the subgrade layer was determined using the Rutting performance equation (Eq. 4). The actual strain values for different axle wheel configurations were observed. The vertical strain was found to be higher on the Single Axle Single Wheel (SASW) configuration for all the material combinations. Table 7 shows the critical strain for various cumulative strains (Fig. 3).

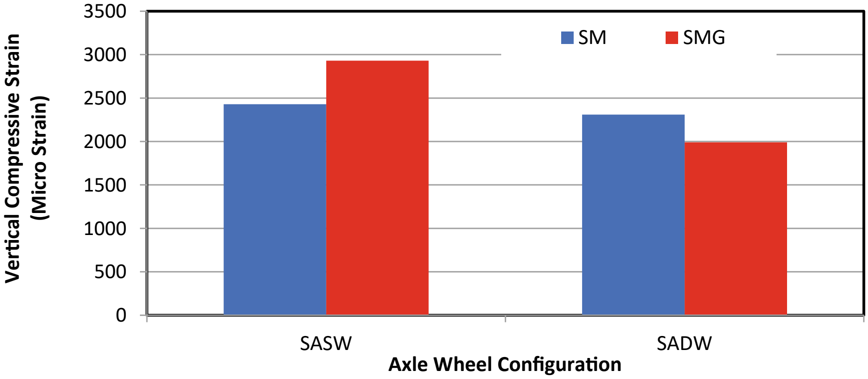
5.6 Pavement Structure

The ideal pavement structure was determined in consideration with displacement, vertical stresses, and vertical compressive strain on the top of the subgrade layer. The actual vertical strain on the BC soil subgrade layer was higher than the critical strain for all the axle wheel configurations. The actual vertical strain on the pavement structure supported by the modified subgrade provided better results. The compressive strain on the top surface of the subgrade made of modified BC soil was less than the allowable vertical strain for gravel base thickness of 325 mm constructed on optimum BC soil–Mine Waste mix and 225 mm for substantial BC soil–Mine Waste-GBFS mix.

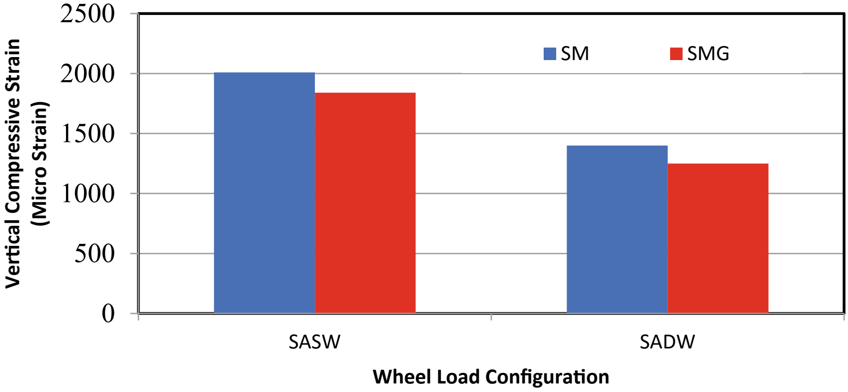
The gravel surfacing of 50 mm supported by a gravel base of 225 mm and resting on the subgrade was considered an ideal pavement structure (Fig. 4).



(a) ESAL 10,000-30,000



(b) ESAL 30,000-60,000



(c) ESAL 60,000-1,00,000

Fig. 3 Compressive strain values of untreated and modified BC soil at various cumulative ESAL

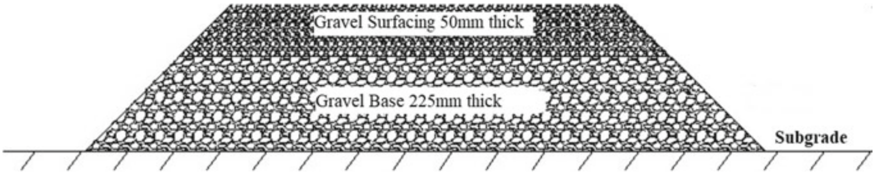


Fig. 4 Pavement structure on SMG mix

Table 8 Cost comparison for low volume roads on untreated and stabilized BC soil subgrade

Material	h (mm)	Total cost/cum (Rs)	Material	h (mm)	Total cost/cum	Savings in cost (%)
Untreated BC soil	500	809.89	SM	325	578.6	28.55
Untreated BC soil	500	809.89	SMG	275	469.98	41

h = Total thickness of pavement

5.7 *Cost Evaluation*

The alternate design has been developed as per IRC: SP:72–2015 for the BC soil subgrade layer, subgrade layer with modified BC soil, and substantial BC soil–Mine Waste-GBFS mix. The cost analysis was carried out as per the Schedule of Rates 2019, Public Works Department (PWD), Dharwad. Cost analysis consists of construction cost, cost of materials, labor, and transportation cost. All the subgrade materials were obtained free of cost. The transportation cost depended on the location of the material site from Dharwad, Karnataka.

The gravel base layer thickness for untreated BC soil and unsubstantial stabilized BC soil layer has been increased to achieve the actual vertical strain less than the allowable vertical strain. The theoretical pavement structure of untreated BC soil and unsubstantial modified BC soil subgrade layer was compared with the pavement structure of the substantial BC soil–Mine Waste-GBFS mix for cost analysis. A pavement section of 1 m × 1 m was considered for the analysis. The percentage of cost savings was determined for a different combination of materials in comparison with the pavement structure laid on an untreated BC soil layer. Table 8 illustrates the cost comparison for unpaved roads constructed on various types of subgrade layers.

6 Conclusions

1. The soil sample considered for testing is classified as CH Inorganic high compressible clay having a plasticity index of 26%, Unconfined Compressive Strength (UCS) of 166 kPa, and CBR of 2.3%. The laboratory results of various

properties of the soil confirmed that it is highly plastic in nature. Mine waste with a specific gravity of 3.08 was non-plastic with an iron oxide content of 42%. The soil and mine waste mixed in a 60:40 proportion exhibited maximum soaked CBR strength of 5.6% and was considered an optimum Mix. The UCS of 28 days cured optimum mix was found to be 475 kPa.

2. The optimum mix of soil and mine waste was further strengthened by the addition of Granulated Blast Furnace Slag independently in various proportions. The calcium oxide in GBFS was 23%. The maximum soaked CBR was 10% for the optimum mix with 30% GBFS. The improvement in strength upon curing is due to the pozzolanic reaction between soil particles and calcium-rich additives. The formation of CAH and CASH, CSH cementitious compounds is seen in SEM. The crystallization and hardening of these compounds eventually led to the development of strength.
3. The compressive strain was reduced due to the modification of the subgrade layer in comparison with the untreated BC soil subgrade. The requirement of the thickness of the gravel base layer got reduced from 350 to 300 mm for optimum SM mix and 225 mm for optimum SMG mix for cumulative ESAL of 60,000–1,00,000.
4. The reduction in compressive strain for a reduced thickness of gravel base layer of treated soil mixes was mainly due to the higher resilient modulus and CBR values. The vertical compressive strain achieved for all the treated soil mixes was lower than the allowable strain as per the rutting equation.
5. The cost analysis indicated a percentage savings in the cost of 27.33% for the SM mix. However, the maximum percentage cost savings achieved was 41% for the SMG mix. Hence, SMG mix was considered as the substantial mix for unpaved roads. The reduction in cost was mainly due to higher CBR and resilient modulus value that eventually led to the reduction in gravel base thickness for stabilized mixes. The Mine Waste and GBFS were available free of cost from the source.

References

1. Francis Atta Kuranchie et al (2013) Mine Wastes in Western Australia and Their suitability for embankment construction. In: Geo-Congress, pp 1450–1459
2. Yellishetty M et al (2008) Reuse of iron ore mineral wastes in civil engineering constructions: A case study. Resour Conserv Recycl 52:1283–1289. https://doi.org/10.1016/j.resconrec.2008.07.007
3. Bastos LADC et al (2016) Using iron ore tailings from tailing dams as road material. J Mater Civil Eng 28. https://doi.org/10.1061/%28ASCE%29MT.1943-5533.0001613
4. Ministry of Road Transport and Highways, Specifications for Roads, and Bridges, 5th edn. Indian Roads Congress, New Delhi (2013)
5. IS: 2720 PART IV (1986) Methods of Test for Soil, Bureau of Indian Standard, New Delhi
6. IS: 1498 (1970) Indian Standard Code of Practice for Soil Classification, 3rd edn. Bureau of Indian Standards, New Delhi
7. IS: 2720 PART III (2002) Determination of Specific Gravity, Indian Standard Institute, New Delhi

8. IS: 2720 PART V (1985) Determination of liquid Limit and Plastic Limit, Indian Standard Institute, New Delhi
9. IS: 2720 PART XVI (1987). Laboratory Determination of CBR, Indian Standard Institute, New Delhi
10. IS: 2720 PART X (1991) Determination of Unconfined Compressive Strength, Indian Standard Institute, New Delhi
11. IS: 2720 PART XL (1977) Determination of Free Swell Index, Indian Standard Institute, New Delhi
12. IS: 2720 PART Xl (1977) Determination of Swell Pressure, Indian Standard Institute, New Delhi
13. IRC: 37–2018 (2018) Guidelines for the design of Flexible Pavements, Indian Roads Congress, New Delhi, India
14. Lekha BM, Goutham S, Shankar AUR (2014) Evaluation of lateritic soil stabilized with arecanut coir for low volume pavements. Transp GeoTech 2:20–29. https://doi.org/10.1016/j.trgeo.2014.09.00
15. ASTM D 559–03 (2003) Standard test methods for wetting and drying compacted soil-cement mixtures. https://doi.org/10.1520/D0559-03
16. IRC: SP:72 (2015) Guidelines for the Design of Flexible Pavements for Low Volume Rural Roads, The Indian Roads Congress, New Delhi