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Laboratory Assessment of Cement-Stabilized Coal Mine Waste Rock as Pavement Foundation Materials

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Abstract. Coal Mine Waste Rock (CWR) has adverse impacts on the environment, including landslides caused by changes in the topography, hydrological systems, and air pollution from hazardous dust. Thus, it is crucial to conduct study on reusing the CWR as construction material. This study presents a laboratory analysis of the primary mechanical properties of CWR treated with cement incorporating coal ash of thermal power plant for use in mine haul road pavement structures. At 2% intervals, the cement content of, and the coal ash content of the mixtures, were varied from 6 to 8%, and 7 to 11%, respectively. According to laboratory test results, cement-stabilized CWR shows the potential to be utilized as substitute materials for pavement foundations due to their strength characteristics met all basic requirements.

1 Introduction

Coal Mine Waste Rock (CWR), coal slags are by-products of mining and of coal combustion process, respectively. Some of these two solid waste by-products are currently being put to some useful purpose such as a pozzolanic in cements industry, a raw material in alkali activation, construction materials [1–3]. Others are being disposed of elsewhere since they are not being used properly, which has a substantial impact on the environment [4–6]. Numerous attempts have been undertaken thus far to address the issues of disposal of waste in order to ensure environmental safety, for example: utilizing the CWR as underground mine filling materials, alternative construction materials [7,8]. According to current criteria, any waste disposal materials must be assessed for their short- and long-term hydro-physico-mechanical characteristics and environmental impact before being chosen as an alternative

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material for particular functions [9,10]. When it comes to materials for road foundations, the particular necessary material criteria frequently consist of specific gravity, absorption and gradation characteristics (AASHTO M 147:2017). The primary objective of this paper is to deliver the results obtained from laboratory experiments conducted on the CWR of the Cao Son Mine in Quang Ninh province of Vietnam to determine their feasibility for use in foundations of haul road embankments.

2 Materials and Methods

2.1 Material Selections

Materials used in the study included ordinary Portland cement, coal ash of thermal power plant, and CWR. The CWR material sample, a composite aggregate material consisting of soil-blasted waste rock, were collected nearby Cao Son Mine in Quang Ninh province of Vietnam, with a maximum grain size of 50 mm. Data regarding the gradation characteristics of the studied blasted waste material are given in Table 1. From the grain size distribution data, it can be seen that the CWR materials conform to the requirement for use in the construction of subbase, base course for gradings B to E specified in the AASHTO M 147:2017 as well as in TCVN 8857:2011 due to their mass fraction percent passing sieves 0.075, 0.425. The experimental results show that the CWR materials have a moisture content of 3.93%, a specific gravity of 2.7, a liquid limit of 22.18%, and plastic limit of 8.56%. The Atterberg limits test reveal that the plasticity of studied waste material was greater than required value, says 6.0% (AASHTO M 147:2017).

The Portland cement PCB 40 of Cam Pha cement factory was used in the study. The compressive strength of cement at the age of 28-day was of 40 MPa, the finesse examined by Blaine method was 2800 (cm^2/g), the initial and the last settling times were 120 min and 420 hrs.

Table 1. Grain size analysis of studied soil-aggregate mixture.

Sieve size, mm	Mass percent passing (by weight)
50	93.65
37.5	72.72
25	64.71
19	60.72
9.5	44.79
4.75	34.52
2.36	29.62
0.425	24.09
0.075	14.43

The coal ash used in this study was collected from Cam Pha thermal power plant (in Quang Ninh, Vietnam), their chemical composition is presented in Table 2.

Table 2. Chemical composition of Coal Ash.

Element	Value (%)
Al_2O_3	16.41
Fe_2O_3	2.892
CaO	1.7
SiO_2	41.61
MnO	0.046
TiO_2	0.077
V_2O_5	0.0174
ZnO	0.0115
CuO	0.0058
BaO	0.0421
Cr_2O_3	0.0048
K_2O	1.52

2.2 Laboratory Experiments

The required mechanical characteristics of the stabilized CWR materials was examined in laboratory experiments. For further study in the laboratory, CWR materials with a maximum size of 19.0 mm was selected for use in pavement foundation. Cement was added to the blasted waste materials at 2% intervals to determine its impact on strength development of stabilized CWR materials. The cement amount ranged from 6% to 8% by the weight of dry CWR. Table 3 shows the composition ratios, as well as the quantity of samples for every group test of this study. Standard compaction, CBR, Compressive strength tests were performed on cement-treated CWR materials.

2.2.1 Standard Proctor Compaction Test

Cement-treated CWR materials were subjected to standard Proctor compaction testing under optimum Proctor conditions. The compaction test was performed in accordance to standard test method AASHTO T180.

2.2.2 CBR Test

The California Bearing Ratio, CBR, test as depicted in Figure 1, was conducted to assess the stability and bearing capacity of compacted specimens. The CBR test was executed in accordance to standard test for CBR, says AASHTO T193-90. First, all specimens compacted to their corresponding maximum dry density (MDD, according to standard proctor compaction test) in CBR test molds. The samples were then left to soak for 96 hours in the water containers. After soaking process, a cylindrical piston was driven into the soaked specimen at a speed of 1 mm per min to a maximum penetration of 12.5 mm, The CBR value (%) of each soil sample was calculated at penetrations of 2.54 mm and 5.08mm.

Table 3. Mix proportions of treated CWR materials

Mix type	**Mix Ratios**	**Number of samples for each group test**			**In total**	**Remarks**
		Compaction test	CBR test	Strength test		
CWR:C:CA*	100:6:7	3	3	3	9	M1
	100:6:9	3	3	3	9	M2
	100:6:11	3	3	3	9	M3
	100:8:7	3	3	3	9	M4
	100:8:9	3	3	3	9	M5
	100:8:11	3	3	3	9	M6

* CWR is Coal Mine Waste Rock, C is Portland Cement and CA is Coal Ash

Fig. 1. CBR test

2.2.3 Compressive Strength Test

The compressive strength test, as shown in Figure 2, was carried out in compliance with established test procedures, according to ASTM D1633. Cylindrical specimens measuring 101.6 mm in diameter and 116.4 mm in height were prepared at various mixtures of cement contents as well as their respective optimum moisture content and MDD. After compacted, all specimens were left to cure in an environment that was close to real conditions for 28 days at room temperature. Under a strain-controlled compression test regime, the cured specimens' compressive strength was determined at a strain rate of 3 mm/min.

Fig. 2. Compressive strength test

3 Results and Discussions

Table 4 presents the comprehensive experimental data assessing the mechanical properties of the mining waste rock mixture stabilized with cement and fly coal ash. A total of 56 experimental samples were conducted, with each experimental mixture comprising 3 samples for assessment.

Table 4. Test data

Mixtures	MDD, g/cm^3			OMC, %			CBR, %			UCS, MPa		
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3
M1	2.069	2.058	2.073	8.62	8.76	8.51	236.2	230.6	245.1	4.1	4.13	4.03
	Mean value: 2.067			Mean value: 8.63			Mean value: 237.3			Mean value: 4.1		
M2	2.026	2.033	2.021	9.63	9.47	9.78	232.8	240.3	230.3	3.49	3.53	3.42
	Mean value: 2.027			Mean value: 9.627			Mean value: 234.47			Mean value: 3.50		
M3	2.011	2.016	2007	10.38	10.23	10.55	229.5	230.3	222.6	3.04	3.09	3.01
	Mean value: 2.011			Mean value: 10.387			Mean value: 227.47			Mean value: 3.0		
M4	2.12	2.10	2.11	9.23	9.02	9.43	282.6	291.3	276.3	4.77	4.80	4.75
	Mean value: 2.11			Mean value: 9.227			Mean value: 283.40			Mean value: 4.8		
M5	2.094	2.094	2.096	9.36	9.48	9.39	277.8	286.7	282.7	4.31	4.35	4.29
	Mean value: 2.095			Mean value: 9.41			Mean value: 279.07			Mean value: 4.30		
M6	2.085	2.082	2.083	10.1	9.89	10.3	265.3	274.9	253.6	4.10	4.04	4.16
	Mean value: 2.083			Mean value: 10.097			Mean value: 264.60			Mean value: 4.10		

3.1 Compaction Characteristics

Figure 3 illustrates the compaction properties of treated CWR materials, the change in dry density, MDD, and moisture content, OMC, with varying cement and coal slag content.

According to the lab results, MDD increased with increasing cement content; however, an additional amount of coal slag content may reduce MDD at the same cement content. One possible explanation for the rise in MDD with increasing cement content is that cement particles have a higher specific gravity than CWR. When certain amounts of CWR particles are substituted with cement, the density of the entire treated CWR mass increases.

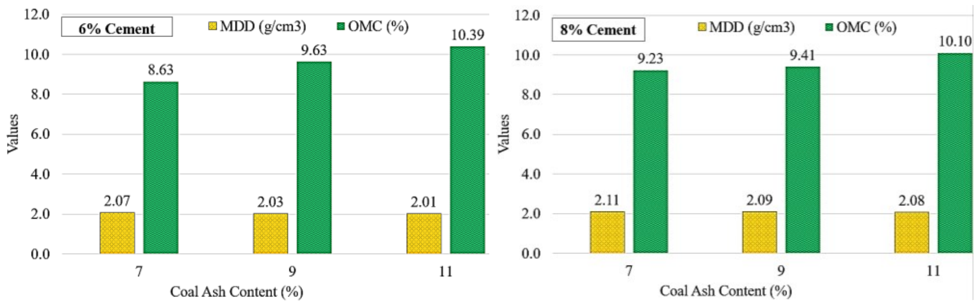

Fig. 3. Compaction behavior of treated CWR materials

3.2 CBR

The CBR values for treated CWR materials with different cement and coal slag concentrations after four days of water curing are displayed in Figure 4. At the same coal ash value, it is clear that the CBR values of all specimens increase as the cement content increases. The CBR test conducted in the lab suggests that adding cement to the treated CWR materials may increase their bearing capacity. According to current requirements, treated CWR materials has a high enough CBR value to be utilized in pavement foundations [9,10].

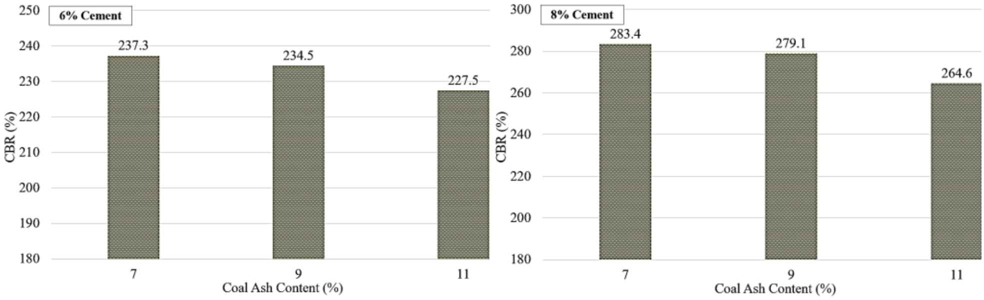

Fig. 4. CBR behavior of treated waste materials

Since the CWR materials are primarily composed of granular particles with negligible cohesiveness, the mobilization of particle surface friction may be the cause of the increase in CBR (or bearing capacity) of treated CWR materials. A higher cement content in the mixture may result in a larger volume of hydrated cement-gel, which would cause the particles to bind more effectively and enhance the CBR values.

3.3 Compressive strength

After 28 days of curing, the samples of treated CWR materials were examined for compressive strength as shown in Figure 5. The laboratory observed that while the magnitude of compressive strength increased with an increase in cement content, the specimens' strength decreased with an increase in coal ash. A possible cause for the reduction in strength of treated CWR materials is that coal slag has a lower density than cement. The mass of all treated specimens increases as the cement content reduces which causes more C-H-S gel formations to form. The results of the experiment revealed that the sample's strength exceeded the minimal 3.0 MPa criterion that shows in some of current standards, for example TCVN 8858:2023 [8].

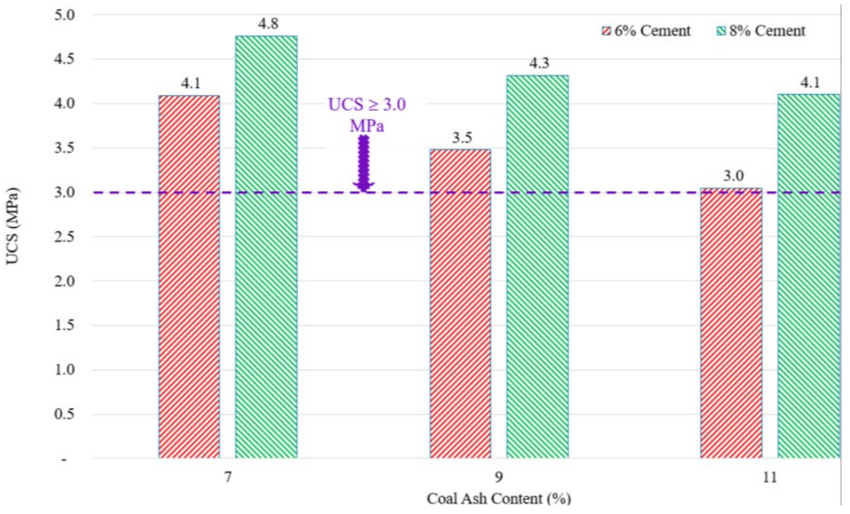

Fig. 5. Compressive strength of treated waste materials

4 Conclusions

The findings of experimental experiments assessing a few critical mechanical properties of waste rock reclamation as an embankment material are presented in this paper. According to the experimental findings, cement-coal ash treated CWR materials 's mechanical qualities satisfy the existing standards needed for usage as an embankment material. To provide a foundation for a thorough evaluation of the appropriateness of employing CWR materials, more laboratory testing is recommended.

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