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Original Article

Strength Assessment of Cement Treated Coal Mine Overburden Material in Subbase and Base Layers

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Abstract *- This study investigates the possibility of using waste rocks from Coal Overburden Mining Operations (COMWR) as a substitute material for building roads. The objective is to protect natural resources and advance sustainable mining waste management. The objective of the research was to assess the fundamental compaction and physical properties of the material both prior to and following treatment with varying cement dosages ranging from 2% to 8% of its overall dry weight. The findings demonstrated the potential economic viability and utility of the strength gain and COMWR formulation for the subbase and base layers of pavement. With a 6% cement concentration, COMWR may be utilized as a sustainable substitute material for the pavement layer after stabilizing with cement. Moreover, low and high-volume road pavements can employ stabilizing agents in the ratio of 1:4 (COMWR: Cement), in accordance with the IRC SP 89 (Part I) 2010 standards for the use of COMWR in road sub-base and base layers. In conclusion, this research emphasizes how the integration of coal overburden material with cement in highway buildings may lead to both sustainable infrastructure development and efficient waste management in mining operations. When compared to traditional materials, coal overburden material may be recycled to help build safe, long-lasting, and ecologically responsible roadway projects by utilizing the geotechnical qualities and stability benefits it provides.*

Keywords *- Coal overburden material, Cement stabilization, Sustainable construction, Long-term performance, Unconfined compressive strength.*

1. Introduction

The rising demand for electricity and energy, along with the critical role of natural materials in road construction, has led to concerns about the depletion of aggregate resources due to overuse and improper extraction [1]. This situation necessitates the exploration of alternative materials that can substitute natural aggregates in different phases of road construction. Consequently, the use of waste materials, whether stabilized or not, as secondary aggregates in the structural layers of pavements has gained traction, particularly for low-volume roads. One such example is the utilization of coal overburden material [2]. Coal mine Overburden (OB) material is frequently regarded as trash. Presently, the construction sector encounters sustainability challenges arising from the depletion of natural reserves of minor minerals such as sand and aggregates. To address this issue, the industry must explore the extensive use of industrial waste materials such as fly ash, slag, and red mud in construction projects. The increasing demand for electricity and energy highlights the vital role of natural materials in road construction. However, the continuous exploitation of these resources has led to their depletion, raising concerns [1]. Therefore, it is essential to investigate alternative materials that can replace natural aggregates at various stages of road construction. Using waste materials, whether stabilized or not, as secondary aggregates in pavement structural layers, including coal Overburden (OB) material, has become increasingly popular, especially for low-volume roads [2]. Traditionally viewed as waste, OB material now presents an opportunity for addressing sustainability challenges in the construction industry, grappling with the dwindling supply of natural aggregates like sand and gravel. Therefore, exploring the extensive use of industrial waste materials, including fly ash, slag, red mud, and construction and demolition waste, emerges as a promising approach. Incorporating OB, which includes both coarse and fine aggregates, could help mitigate the shortage of construction materials affecting the industry. However, it is recognized that coal overburden material may not always meet the required standards for subbase and base materials in pavements, particularly concerning grading, Plasticity Index (PI), strength, stiffness, and durability [1]. In order to improve the characteristics of substandard materials like those derived from construction and demolition activities, mining activities, and industrial waste, researchers have investigated several stabilization methods utilizing lime, lime fly ash, or cement. These techniques are primarily selected based on their Plasticity Index (PI) [2]. Cementitious stabilisation, in particular, emerges as a promising method, especially in scenarios where natural aggregates are scarce. The key engineering attributes of cementitiously stabilised mixtures, crucial for subbase and base layers of roadways, are strength and durability. Numerous studies have investigated the mechanical properties of stabilised waste materials and their potential as pavement supplies. India's pursuit of transitioning to a net-zero emissions energy system is ambitious, especially given its vast population of 1.2 billion. However, this transition is anticipated to extend until 2050, with fossil fuels remaining a primary energy source for at least the next 30 years [3].

Consequently, coal extraction is expected to persist, further contributing to the accumulation of coal mine Overburden (OB). To address this challenge, research efforts have focused on valorizing, reusing, disposing of, and recycling solid wastes, including OB, in various industries, such as construction and building materials [3–9]. For instance, studies by Behera et al. [6] and Gupta et al. [9] demonstrated the potential of utilizing coal mine wastes, fly ash, and other industrial by-products in construction applications, including road embankments and earthworks. Furthermore, investigations conducted by Mishra et al. [13, 14] delved into the transformation of OB into usable materials such as sand and gravel, underscoring its potential as an alternative to natural aggregates in cement mortar and concrete applications.

The present study is centred on assessing the strength characteristics of Coal Mine Overburden (COMWR) materials treated with cement and fly ash for the construction of subbase and base layers in pavements. Given the substantial quantities of OB generated by coal mining operations and the associated disposal challenges, exploring the suitability of COMWR materials emerges as a sustainable solution. By reducing the environmental footprint of coal mining operations, this research aims to contribute to a more sustainable approach to utilizing OB in construction projects.

1.1. Research Gap and Problem

This research examines into use of waste rocks from coal mining to build roads, focusing on how strong cement-treated coal mine overburden material is when used in road layers. It aims to bridge the research gap by exploring the potential of coal mine overburden material as a sustainable alternative for pavement construction, particularly in low-volume road projects. The challenges faced by the construction industry due to the depletion of natural reserves of minor minerals like sand and aggregates. This depletion has led to concerns regarding the sustainability of traditional construction materials. This research examines how industrial waste materials, like coal mine overburden, can be used as secondary aggregates in pavement layers. The study shows that even though coal overburden is usually seen as waste, it can help address sustainability issues in construction by being a viable substitute for natural aggregates.

2. Materials and Methods

2.1. Materials

2.1.1. Coal Mine Overburden Material

The properties of Coal Mine Overburden (COMWR) materials from the Jharia Coal Field (JCF) in Dhanbad, Jharkhand, India, are detailed in this study. Table 1 summarizes the characteristics of these materials. For the analysis, OPC 43-grade cement, readily available at the construction site, was used. Strict sampling and transportation procedures were followed to transfer COMWR dump materials to the laboratory for testing. Table 1 includes data on the granulometric composition, consistency limits, classification, compaction behavior, California Bearing Ratio (CBR), swelling after 96 hours of soaking, and Unconfined Compressive Strength (UCS) of untreated crushed COMWR dump materials. Figure 1 shows a typical grain size distribution curve for the COMWR samples, revealing a sand content of over 55%. Similar granulometric compositions in COMWR dump materials have been reported in previous studies by Rai et al. [15], Yaseen et al. [16], Mallick et al. [17], Rajak et al. [18], and Mallick and Verma [19]. Notably, all samples were non-plastic, making determining the plastic limit impossible. According to the Indian Soil Classification System (ISCS), the samples are categorized as A-1-a and SP, aligning with AASHTO guidelines [20]. Additionally, the coarser fractions of the coal mine OB materials were subjected to aggregate tests, including specific gravity, water absorption, impact value, crushing value, abrasion, and shape analysis.

Table 1. Physical properties of the coal mine overburden material sample

Property	Specification	COMWR Material
Classification	AASTHO	A-1-a
	ISCS	SP
Gravel (%)	IS-2720-Part 4 (1985)	11.06
Sand (%)		55.96
Silt and Clay (%)		32.98
Liquid Limit (%)	IS-2720-Part 5 (1985)	22.34
Plastic Limit (%)		Non-Plastic
Plasticity Index (%)		-
Free Swell Index (%)	IS-2720-Part 40 (1977)	8
Optimum Moisture Content (%)	IS-2720-Part 8 (1983)	9.82
Maximum Dry Density (KN/m^3)		21.37
Un-soaked CBR (%)	IS-2720-Part 16 (1987)	8.17
Soaked CBR (%)		6.02
Swelling (mm)	IS-2720-Part 16 (1987)	0.21
Unconfined Compressive Strength (MPa)	IRC-SP-89 Part I (2010)	0.350

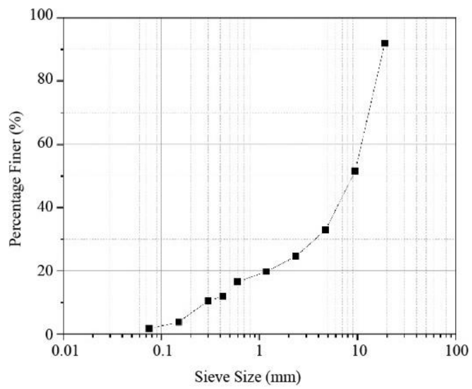

Fig. 1 Gradation curve of coal mine overburden material sample

2.1.2. Cement

To assess the efficacy of granular materials for stabilization, Saurav et al. conducted experimental investigations utilizing cement as a binding agent for locally available materials in their study area. Ordinary Portland Cement (OPC) grade 43 was employed as a stabilizer for coal overburden material in their study. As previously indicated, to achieve a robust binding, cement was mixed with dumped overburden material at ratios ranging from 2% to 8%. In this study, OPC-43 Grade cement was chosen for this study, obviating the need for additional specific qualities. The cement exhibited an initial setting time of 45 minutes and a final setting time of 309 minutes. Its fineness was measured at 315 m²/kg, and its compressive strength at 28 days reached 67.4 MPa, following ASTM C109 (ASTM 2011) standards.

2.2. Method

Figure 2 illustrates the experimental setup used in this study. Crushed Coal Mine Overburden (COMWR) samples were grouped based on particle size distribution through granulometric analysis. These samples were then carefully blended to meet the gradation standards for sub-base and base materials as specified by IRC: SP-89 part II (2018) for cement stabilization. To maintain consistency, reconstituted samples of the same grade were used throughout the investigation. Table 2 summarizes the compaction properties of the COMWR dump materials, evaluated according to IS 2720 Part 8 (1983). The addition of cement in varying percentages (2%, 4%, 6%, and 8%) resulted in an increase in the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of Coal Mine Overburden (COMWR) blends, as shown in Figure 3. Interestingly, each 2% increment in cement concentration kept the OMC of the COMWR materials relatively stable compared to the previous composition, indicating the importance of maintaining a balanced water-cement ratio for effective hydration. The changes in MDD of COMWR materials are due to the higher specific gravity of cement (3.02 gm/cm³). Before starting particular tests, the coal Overburden (OB) and cement were mixed together in the correct amounts. Then, water was added to the mixtures, and moulds were made.

The right hammer weight and drop height were used to compact the mixture to achieve the density needed for the modified Proctor effort. The moulds were sealed for two days to keep the moisture in, and then the specimens were taken out and wrapped in plastic for the rest of the curing time. For the Unconfined Compressive Strength (UCS) testing, five cylindrical specimens (100 mm in diameter and 50 mm in height) were prepared for each mix combination according to IS 2720 Part 10 and tested after 7 and 28 days. Additionally, the California Bearing Ratio (CBR) test was performed following Indian Standard 2720 (Part 16) on various mix combinations and an untreated sample.

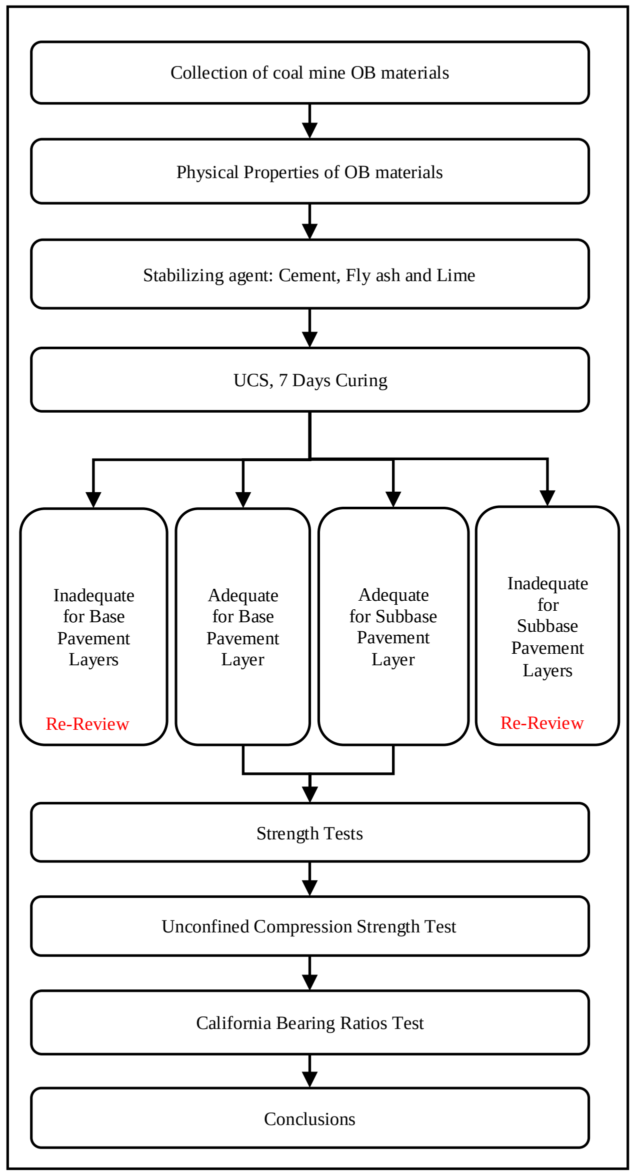

Fig. 2 Experimental programme

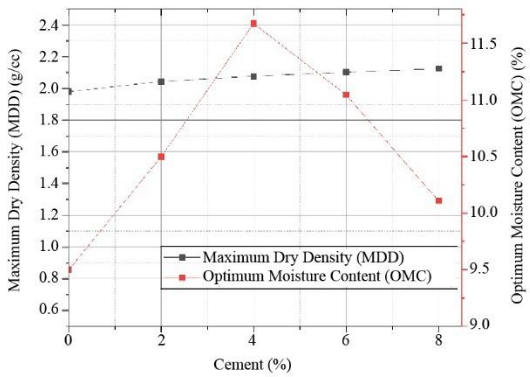

Fig. 3 Variation in OMC and MDD at each cement percentage

Table 2. Characteristics of the larger particles of coal mine overburden material meeting suitable criteria for pavement utilization

Properties	Specifications	COMWR Sample	Criteria as IRC-SP 20
Dry impact value (%)	IS-2386-Part 4 (1963)	35.148	For Sub-base having less than 50% and Base to be less than 40%
Wet impact value (%)	IS-5640 (1970)	39.954	-
Crushing value (%)	IS-2386-Part 4 (1963)	42.265	-
Abrasion value (%)	IS-2386- Part 4 (1963)	38.971	-
Flakiness index (%)	IS-2386-Part 1 (1963)	12.450	For Sub-base having less than 40% and Base to be less than 30%.
Elongation index (%)	IS-2386-Part 1 (1963)	15.040	-
Specific gravity	IS-2386-Part 3 (1963)	2.843	-
Water absorption (%)	IS-2386-Part 3 (1963)	7.541	For Sub-base having less than 6% and Base to be less than 3%.

3. Result and Discussion

3.1. Effect on Unconfined Compressive Strength

The untreated coal overburden sample had a UCS value of less than 0.5 MPa. However, the addition of cement significantly increased the UCS values, which further improved with longer curing times. Figure 4 illustrates the variations in UCS of COMWR mixes concerning cement content and curing duration. Notably, samples treated with 4% cement met the minimum UCS standards specified by Austroads (2012) for the subbase layer of low-volume roads after 28 days of curing and four hours of soaking. When cement content was increased to 6%, the strength gain rate accelerated noticeably, although it plateaued after that.

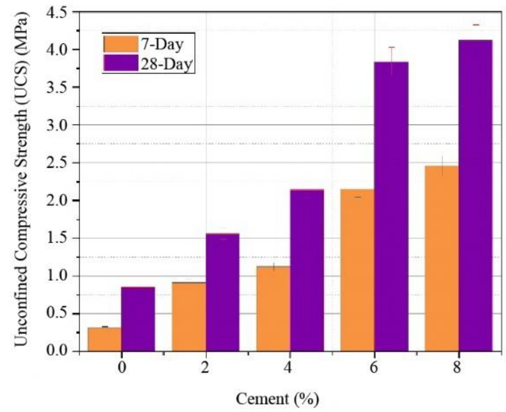

Fig. 4 Variation in UCS value at each cement percentage

Figure 5 demonstrates a robust correlation (R^2 = 0.97) between UCS values at seven and 28 days across various cement percentages. Interestingly, the UCS values of COMWR samples, compacted at Optimum Moisture Content (OMC), were notably affected after undergoing four hours of soaking following seven and 28 days of curing.

It is noteworthy that IRC: SP 72 (2015) and NCHRP (2004) recommend considering minimum UCS values of 1.094 MPa and 1.122 MPa, respectively, after seven days of soaking (seven days cured + four hours soaked) for coal overburden samples in the sub-base of low-volume roads due to the potential impact of water on lower pavement layers.

Figure 4 further demonstrates the significant rise in the UCS ratio with cement incorporation, reaching up to 6%. However, beyond this threshold, the growth rate experiences a sharp decline, suggesting the stability of COMWR samples treated with cement, even when exposed to water.

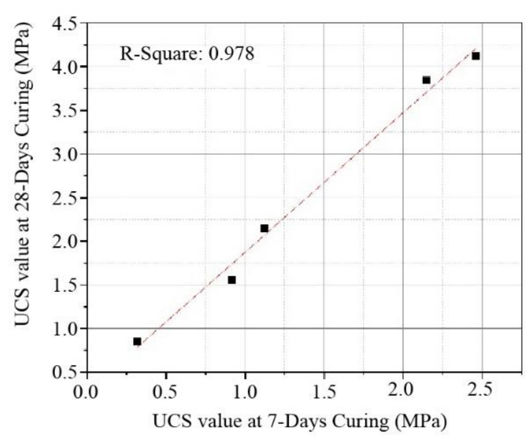

Fig. 5 Relation between 7 and 28 days of UCS strength value

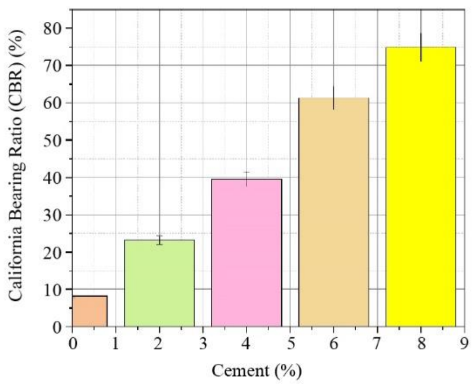

Fig. 6 CBR strength value

3.2. Effect on CBR Strength

As per IRC: SP 20 (2002), it is specified that granular materials should have California Bearing Ratio (CBR) values exceeding 15% and 100% for sub-base and base courses of low-volume roads, respectively. Given the vulnerability of these layers to water, estimating CBR under wet conditions becomes crucial. Toth et al. [21] emphasized that saturation, reduction in effective stresses, and loss of surface tension contribute to a decline in soaked CBR values. In line with IRC: SP 20 (2002) guidelines, samples of cementitious stabilized COMWR under soaking conditions meet the specifications for the granular subbase of low-volume roads. It has been noted that an increase in cement content in COMWR mixes enhances the soaked CBR values. The increase in CBR gain, indicative of the strength enhancement resulting from cement addition to coal overburden material mixtures compared to untreated specimens, has been computed over a four-day soaking period. A noticeable 4% improvement in CBR gain is evident upon cement addition, followed by a plateauing effect with 6% and 8% cement content. This phenomenon could be attributed to the optimal levels of CaO, Al_2O_3, and SiO_3 achieved with 6% cement addition, as discussed by Sivapullaiah and Jha [22]. Figure 5 demonstrates that specimens treated with 8% cement experienced a maximum increase of 74.85% in the wet state, whereas those treated with 2% cement exhibited a minimum gain of 23.11%. Additionally, Figure 6 showcases the impact of cement content on the CBR enhancement of COMWR samples.

3.3. Discussion

When assessing how strong cement-treated coal mine overburden material is for building roads, several factors help achieve better outcomes than methods found in existing studies:

(a) Optimized Cement Dosage: The study explores the impact of varying cement dosages ranging from 2% to 8% on the strength characteristics of coal mine overburden material. By systematically testing different cement concentrations, the researchers can identify the optimal dosage that enhances the strength properties of the material. This approach allows for more precise control over the cement stabilization process, leading to improved results compared to studies that use fixed or arbitrary cement dosages.

(b) Thorough Material Characterization: The research provides a detailed analysis of the properties of coal mine overburden material, including granulometric composition, consistency limits, compaction behaviour, California Bearing Ratio (CBR), swelling, and Unconfined Compressive Strength (UCS). By thoroughly characterizing the material, the researchers gain a comprehensive understanding of its geotechnical properties, which is essential for evaluating the effectiveness of cement treatment. This detailed material characterization contributes to achieving better results by ensuring a more informed and targeted approach to material treatment.

(c) Focus on Sustainable Construction: The study emphasizes the sustainability aspect of utilizing coal mine overburden material in pavement construction. By highlighting the potential economic viability and utility of the material as a substitute for traditional aggregates, the research addresses the growing need for sustainable construction practices. This focus on sustainability aligns with current trends in the construction industry and adds value to the study by offering a practical and environmentally friendly solution to construction material shortages.

(d) Compliance with Standards: This research adheres to the standards outlined in IRC SP 89 (Part I) 2010 regarding the utilization of coal mine overburden material in road sub-base and base layers. By ensuring compliance with established standards, the study provides a benchmark for evaluating the effectiveness of the material in practical applications. This adherence to standards enhances the credibility and applicability of the research findings, setting it apart from studies that do not consider industry guidelines.

(e) In-depth Analysis of Strength Properties: The study evaluates the Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) properties of the treated coal mine overburden material. By conducting a detailed analysis of these strength characteristics, the researchers can assess the performance of the material under different loading conditions. This in-depth analysis allows for a comprehensive evaluation of the material's suitability for pavement construction, leading to better results compared to studies that focus on a limited set of strength properties.

In summary, this study achieves better results compared to state-of-the-art techniques by optimizing cement dosage, conducting thorough material characterization, focusing on sustainability, complying with standards, and performing an in-depth analysis of strength properties. These factors contribute to the effectiveness and relevance of the study in addressing the challenges of utilizing coal mine overburden material in pavement construction.

4. Conclusion

The investigation aimed to evaluate how the inclusion of cement affects the strength and California Bearing Ratio (CBR) properties of coal overburden material. The results unveiled a remarkable enhancement in both Unconfined Compressive Strength (UCS) and CBR values upon cement addition. Initially, untreated coal overburden samples exhibited UCS values below 0.5 MPa. However, with the introduction of cement, these values experienced a significant surge, meeting the necessary standards for the subbase layer of low-volume roads after a 28-day curing period. Similarly, CBR values displayed improvement as the cement content increased, fulfilling the requirements for the granular subbase of low-volume roads. Furthermore, the research found that adding cement caused the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the coal overburden material to increase. Interestingly, the OMC stayed the same with each 2% rise in cement content, showing the lowest water-cement ratio required for effective hydration. The greater density of cement, compared to the coal overburden material, probably helped raise the MDD. The study found that when the ground is wet, the CBR values go down because of saturation, less effective stresses, and surface tension loss. However, even in wet conditions, the coal overburden material mixed with cement still met the requirements for the subbase of small roads.

In conclusion, the study underscores that the addition of cement to coal overburden material substantially enhances its strength gain and CBR characteristics, rendering it suitable for low-volume road applications. Optimal results were achieved with a 4% cement content, providing maximum strength gain while meeting subbase layer criteria. These findings highlight the potential of coal overburden material as a sustainable and cost-effective alternative for road construction, particularly in regions where natural aggregates are scarce or expensive. The significance of the study lies in its contribution to reimagining the utilization of coal overburden material in road construction. By promoting the development of sustainable and cost-effective road construction materials, the study aims to mitigate the environmental impact of coal mining while advocating for the utilization of waste materials in construction practices.

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