Investigation of Strength and Long-Term Durability Properties of stabilized Coal Mine Overburden Material for Base and Subbase Layer of Pavement

Subhash Chandra
Department of Civil Engineering, National Institute of Technology Patna, Bihar, India
subhashc.phd18.ce@nitp.ac.in (corresponding author)

Sanjeev Sinha
Department of Civil Engineering, National Institute of Technology Patna, Bihar, India
sanjeev@nitp.ac.in

Received: 17 May 2024 | Revised: 3 June 2024 | Accepted: 12 June 2024

 DOI: https://doi.org/10.48084/etasr.7861

ABSTRACT

The purpose of this study is to examine the possibility of using Coal Mine Overburden (CMOB) material as a secondary aggregate in low volume roadways' sub-base and/or base layer. Such roads usually experience less traffic, which means that weaker materials like CMOB could be used in various layers of the road after stabilization, either alone or in combination with cement or fly ash. After 7 and 28 days of curing, samples taken from Jharkhand mines were used to assess the strength characteristics of the stabilized samples, namely Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR). The findings demonstrate that the material, which has CBR of 80% or above and UCS of 3 MPa at 6% for Cement-Treated (CT-CMOB) and Cement-Fly Ash-Treated (CFA-CMOB) samples, may be utilized successfully as a secondary aggregate in low-volume road building. The results were then validated through standard acceptance as per IRC provisions and microstructural analysis. Additionally, correlations were established between the 7 and 28-day UCS properties of CT-CMOB and CFA-CMOB samples. This information can be beneficial for pavement engineers to estimate the strength properties associated with the base and subbase layer of pavement using CMOB as a suitable alternative to conventional aggregates.

Keywords-coal overburden material; cement stabilization; sustainable construction; long-term performance; unconfined compressive strength

I. INTRODUCTION

A. Background

The use of CMOB materials in road construction has become a subject of focus as a sustainable solution to address environmental challenges related to coal mining activities [1]. CMOB, a byproduct of coal extraction, provides an opportunity to reuse waste materials for infrastructure development, particularly in the construction of base and subbase layers of pavements [2]. The mining industry plays a critical role in meeting the increasing global energy demands, particularly in the coal sector [3]. An augmentation in coal consumption is followed by the generation of Overburden (OB) materials, which are often disposed of in mine OB dumps [4-5]. However, improper management of OB materials can lead to stability issues and pose significant risks to mining operations and the environment [5]. One challenge faced by coal mining operations is the instability of OB dumps, which can result in failures during adverse conditions such as heavy rainfall or seismic events [5]. These failures not only cause environmental damage, but also pose threats to human safety and mining equipment [5, 9]. For mining operations to be safe and sustainable, it is essential to comprehend the geotechnical characteristics and stability of OB dump materials [5-8]. Enhancing the geotechnical characteristics and stability of the latter with the inclusion of industrial by-products, such as fly ash from coal-based thermal power plants, is a viable approach [2, 7]. When added to an OB material, fly ash can change metrics related to shear strength, unconfined compressive strength, CBR, and compaction [9–11]. By studying the effects of fly ash on OB dump materials, researchers aim to identify safe and effective ways to utilize this industrial waste product [8-17]. These materials offer a potential alternative to natural aggregates, which are facing depletion due to the increasing demand and improper utilization [13-19].

B. Literature Review

Several studies have investigated the mechanical and durability properties of cement-treated and cement-fly ash treated CMOB materials. For example, authors in [1] explored the UCS, flexural strength, flexural modulus, and indirect tensile strength of CT from different mines in Jharkhand. The results showed significant improvement in strength characteristics, making them suitable for low-volume roads. Similarly, authors in [5] evaluated the geotechnical characteristics of cement-stabilized fly ash-CMOB mixes for subbase construction, demonstrating the potential for sustainable pavement applications. The incorporation of fly ash in CT-CMOB materials has been a topic of interest for researchers focusing on durability aspects. Authors in [20-21] assessed the performance of fly ash-cement stabilized CMOB material for haul road pavement, highlighting the role of fly ash in improving long-term durability and environmental sustainability. Furthermore, authors in [22] conducted an evaluation of fly ash-cement stabilized mine OB mix as a subbase construction material, emphasizing the positive impact of fly ash on the durability and stability of the materials. Researchers have emphasized the importance of utilizing alternative materials to reduce the depletion of natural aggregates and promote sustainable practices in the construction industry [23, 24]. Additionally, the environmental benefits of using stabilized OB materials have been stressed, showcasing the potential for reducing the reliance on virgin aggregates and promoting the circular economy concept in infrastructure development. At first, these substitute materials might not be able to match the specifications for subbase or base materials of pavement in terms of grading, Plasticity Index (PI), strength, stiffness, and durability. However, IRC: SP-20 (2002) and IRC: SP-89 (2010) advise that stabilizing with lime, lime-fly ash, or cement can improve the PI. For example, cementitious stabilization has demonstrated potential in lowering PI, particularly in situations where the availability of natural aggregates is restricted.

C. Research Gap and Problem

Previous studies have primarily focused on investigating the mechanical and durability properties of CT-CMOB and CFA-CMOB materials for pavement applications. These studies have explored the use of stabilization techniques to enhance the engineering properties of CMOB, with a particular emphasis on the strength and durability aspects of base and subbase layers in road pavements [1, 2]. Methodologies employed in these studies typically involved laboratory experiments to assess the performance of stabilized CMOB samples under various conditions, such as different curing durations, environmental exposures, and wet-dry weathering cycles. By determining the optimal cement content and evaluating the mechanical strength, durability characteristics, and moisture ingress resistance of the stabilized CMOB mixes, previous research has provided valuable insights into the feasibility of using CMOB as a secondary aggregate in low-volume road construction [1, 2, 6]. The findings from these studies have demonstrated that CT-CMOB and CFA-CMOB mixes exhibit improved strength properties, with UCS values reaching up to 3 MPa at 6% cement content. The research also highlighted the positive impact of environmental exposure on the mechanical strength of stabilized CMOB materials, emphasizing their resilience under weathering conditions [2]. Despite the advancements made in understanding the performance of stabilized CMOB in pavement construction, gaps still exist in the literature regarding the long-term durability and sustainability aspects of these materials. Further research is needed to explore innovative approaches and technologies for maximizing the utilization of CMOB in pavement design and construction, with a focus on enhancing the material's resistance to shrinkage cracks, capillary rise, and other durability challenges.

In this broader context of sustainable infrastructure development, the present research aims to build upon the existing knowledge by providing a comprehensive assessment of the impact of CFA-CMOB and CT-CMOB materials, both separately and in combination, on the geotechnical properties and durability of CMOB dump material. It also aims to provide insights into the potential benefits of incorporating fly ash in OB dump construction and to establish a better understanding of how fly ash and cement, both separately and in combination, can contribute to the stability and sustainability of coal mine operations. The primary objective of this study is to evaluate the strength and durability of CT-CMOB and CFA-CMOB materials for their efficient incorporation into the subbase and base layers of pavements. By assessing the long-term durability of the former, this research aims to provide valuable knowledge of their performance under adverse weathering conditions and environmental exposure. To achieve this objective, a laboratory study was conducted to assess the mechanical and durability characteristics of CT- CMOB materials.

II. MATERIALS AND METHODS

A. Materials

1) Coal Mine Overburden Materials (CMOB)

The properties of CMOB materials extracted from the Jharia Coal Field (JCF) in Dhanbad, Jharkhand, India are investigated in this paper. Table I summarizes the material characteristics. The CMOB dump materials were transported to the laboratory for examination using meticulous sampling and transportation protocols. A typical grain size distribution curve for the CMOB samples under investigation is presented in Figure 1, which reveals a significant sand content of more than 59%. Prior studies, such as [18-22], have all shown similar granulometric compositions in CMOB dump materials. Notably, every sample had a non-plastic behavior, which rendered the measurement of the plastic limit impractical. In accordance with the AASHTO recommendations, the samples are categorized as A-1-a and SP by the Indian Soil Classification System (ISCS) [27]. In addition, aggregate tests comprising specific gravity, water absorption, impact value, crushing value, abrasion, and shape analysis were performed on the coarser fractions of the CMOB materials.

2) Ordinary Portland Cement (OPC) 43 Grade

OPC 43-grade cement was used for the analysis of CT-CMOB in trial I, which is readily available at the road construction site. The former was employed as a stabilizer for CMOB. The initial setting time of the cement was 45 min, while the complete setting required 309 min. The fineness of the cement was determined to be 315 m^2/kg, and its compressive strength at 28 days was measured at 67.4 MPa, in accordance with ASTM C109 (ASTM 2011) standards. To assess the efficacy of granular materials for stabilization, authors in [25, 26] conducted experimental investigations utilizing cement as a binding agent for locally available materials in their study area. As previously indicated, to achieve a robust binding, cement was mixed with dumped overburden material at ratios ranging from 2% to 8%.

TABLE I. PHYSICAL PROPERTIES OF THE CMOB SAMPLE

Property	Standard code for reference	CMOB material specifications
Classification	AASTHO	A-1-a
	ISCS	SP
Gravel (%)	IS-2720-Part 4 (1985)	12.06
Sand (%)		56.50
Silt and clay (%)		31.44
Liquid limit (%)	IS-2720-Part 5 (1985)	21.14
Plastic limit (%)		Non-Plastic
PI (%)		-
Free swell ndex (%)	IS-2720-Part 40 (1977)	7
Optimum moisture content (%)	IS-2720-Part 8 (1983)	9.12
Maximum dry density (kN/m^3)		22.78
Un-soaked CBR (%)	IS-2720-Part 16 (1987)	7.98
Soaked CBR (%)		5.98
Swelling (mm)	IS-2720-Part 16 (1987)	0.31
UCS (kN/m^3)	IRC-SP-89 Part I (2010)	0.425

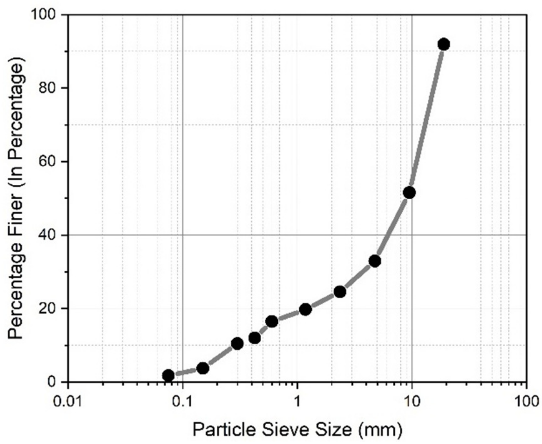

Fig. 1. Gradation curve of the CMOB sample.

3) *Fly Ash*

Fly ash, a byproduct of burning pulverized coal in power plants, was collected from the National Thermal Power Plant (NTPC) and used in another trial. CFA-CMOB OPC 43- grade, which was accessible on the road construction site, was also utilized by the cement in Trial II to assess the completed job. The application of CFA on soil with optimal water content, as investigated in [28] according to IRC SP 89-Part-I (2010), states that Class F fly ash can be strengthened by adding a modest amount of cement. Cement and fly ash combined (CFA-CMOB) has been effectively applied to sub-base course stabilization.

B. *Methods*

1) *Experimental Setup*

Figure 2 depicts the experimental setup employed in the present study and the designed mixing combination noted in Table II. Crushed CMOB samples were categorized into groups based on particle size distribution using granulometric analysis. These samples were then precisely blended to meet the gradation criteria for sub-base and base materials specified by IRC: SP-89 part II (2018) for CT-CMOB and CFA-CMOB. To ensure uniformity, reconstituted samples of the same grade were utilized throughout the entire investigation. Table III provides a summary of the compaction properties of the CMOB dump materials, evaluated in accordance with IS 2720 Part 8 (1983).

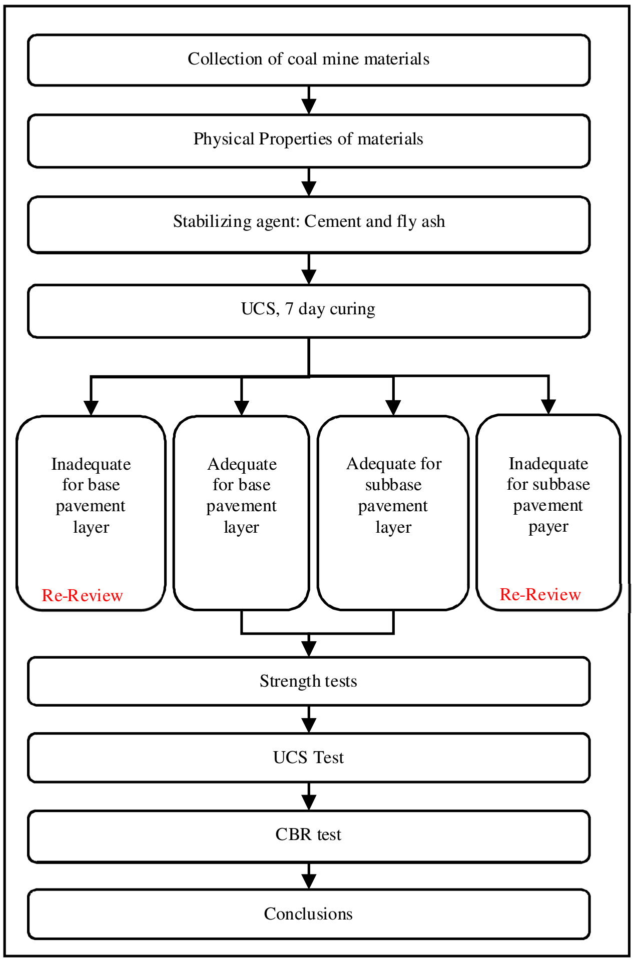

Fig. 2. Experimental program.

The inclusion of cement (2%, 4%, 6%, and 8%) led to an elevation in the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of CMOB blends, as illustrated in Figure 3. Notably, with each 2% increment in cement concentration, the OMC of the CT-CMOB and CFA-CMOB materials remained relatively consistent compared to the preceding composition. This finding implies that maintaining a balanced water-cement ratio is crucial for efficient hydration.

The variation in MDD of CMOB materials can be attributed to the higher specific gravity of cement (3.02 gm/cm^3).

TABLE II. DESIGNED MIXING COMBINATION

Sl. No.	Cement (%)	Fly Ash (%)	CMOB (%)	Notation
Trial I	0	-	100	CT-CMOB
	2	-	98	CT-CMOB I
	4	-	96	CT-CMOB II
	6	-	94	CT-CMOB III
	8	-	92	CT-CMOB IV
Trial II	2	8	90	CT-CMOB V
	4	16	80	CT-CMOB VI
	6	24	70	CT-CMOB VII
	8	32	60	CT-CMOB VIII

TABLE III. CHARACTERISTICS OF THE LARGER PARTICLES OF CMOB MATERIAL MEETING SUITABLE CRITERIA FOR PAVEMENT UTILIZATION

Properties	Standard	CMOB sample specifications	Criteria as IRC-SP 20
Dry impact value (%)	IS-2386-Part 4 (1963)	35.148	For subbase 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 subbase 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 subbase having less than 6% and base to be less than 3%

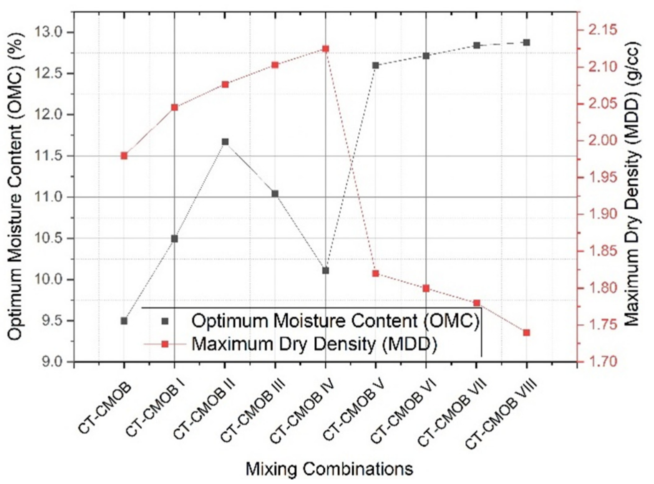

Fig. 3. Variation in OMC and MDD.

2) Sample Preparation

The coal OB and cement were first mixed in the necessary amounts when they were dry, prior to carrying out particular tests. After that, the mixes were given a certain amount of water, and specimens were created in special molds. By using the proper hammer weight and drop height, proper compaction was accomplished and the density, as determined by the modified Proctor effort, was equal to the MDD. The specimens were then sealed and left in their molds for two days in order to keep moisture from evaporating. Following this initial period, they were removed from the molds and covered with plastic wraps for the remaining specified curing period.

In compliance with IS 2720 Part 10, five cylindrical specimens measuring 100 mm in diameter and 50 mm in height were made for every mix combination for the UCS testing after seven and 28 days. Likewise, four cylindrical specimens of 100 mm in diameter and 50 mm in height were created for each mix combination and subjected to the soaking and drying technique of durability testing as per IS 4332 Part IV (1968). Furthermore, the CBR test was performed on several mix combinations and an untreated sample in accordance with Indian Standard 2720 (Part 16).

III. RESULTS AND DISCUSSION

A. Effect on Unconfined Compressive Strength

The untreated sample of coal OB exhibited a UCS value of less than 0.5 MPa. However, upon the addition of cement, there was a significant enhancement in UCS values, which was further improved with longer curing durations. Figure 4 shows the differences in UCS of CMOB mixes with respect to cement content and curing time. Interestingly, after 28 days of curing and 4 hours of soaking, samples treated with 4% cement fulfilled the minimal UCS limits stipulated by Austroads (2012) for the subbase layer of low-volume roads. The rate of strength improvement increased noticeably with cement additions of up to 6%, was increased at a slower rate beyond that.

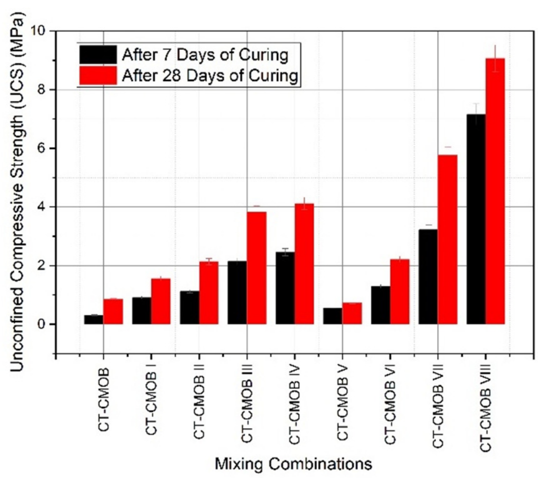

Fig. 4. Variation in UCS value at each cement percentage.

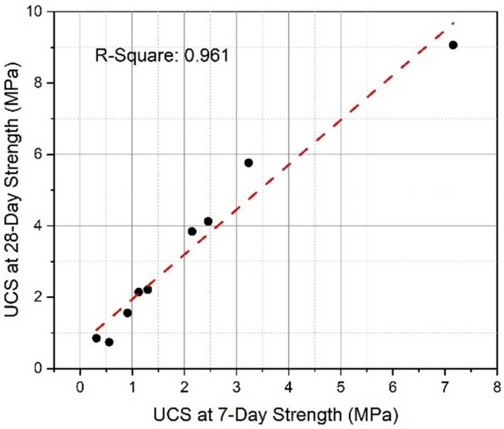

Fig. 5. Relation between 7 and 28 days of UCS strength value.

Figure 5 displays a strong correlation ($R^2 = 0.961$) between UCS values at 7 and 28 days for various cement percentages. Remarkably, after 7 and 28 days of curing, the UCS values of CT-CMOB and CFA-CMOB samples that were molded at OMC were considerably impacted by a four-hour soaking period. Notably, due to the potential impact of water on lower pavement layers, IRC: SP 72 (2015) and NCHRP (2004) recommend considering minimum UCS values of 1.094 MPa and 1.122 MPa, respectively, for coal OB samples in the sub-base of low-volume roads after 7 days of curing and 4 hours soaking. Figure 4 depicts the notable increase in the UCS ratio for CT-CMOB with cement addition up to 6%, beyond which the growth rate declines sharply, indicating stability samples treated with cement even in the presence of water. Similarly, at 6% cement and 24% fly ash combination (CFA-CMOB VII) a similar trend is observed.

B. Effect on CBR Strength

Granular materials with CBR values more than 15% and 100% are required to be used in the sub-base and base courses of low-volume roads, respectively, under IRC: SP 20 (2002). It is essential to evaluate CBR in wet situations due to these layers' vulnerability to water effect. Authors in [28] pointed out that a decrease in soaking CBR values is caused by saturation, a decrease in effective stresses, and the loss of surface tension. Samples of cementitiously stabilized CT-CMOB and CFA-CMOB under soaking circumstances fulfill the requirements for the granular subbase of low-volume roads in accordance with IRC: SP 20 (2002). It has been noted that CMOB mixtures with higher cement contents have higher soaking CBR values. The increase in soaking CBR values with higher cement content can be attributed to several key mechanisms:

- Cementitious Stabilization: The addition of cement to CMOB mixtures initiates a process of cementitious stabilization, wherein the cement particles react with water to form hydration products. This chemical reaction leads to the development of a cementitious matrix that binds the CMOB particles together, enhancing the overall cohesion and strength of the mixture.
- Increased Density and Compaction: Higher cement contents promote better compaction of the CMOB mixtures, resulting in increased density and reduced void spaces within the material. This densification improves load-bearing capacity and resistance to deformation, contributing to higher CBR values in soaked conditions.
- Formation of Cementitious Bonds: The hydration of cement creates strong bonds between the CMOB particles and the cement matrix. These interparticle bonds enhance the interlocking of particles and provide resistance against moisture-induced softening, maintaining the structural integrity of the stabilized mixtures under wet conditions.
- Reduction of Permeability: The cementitious matrix formed within the CMOB mixtures acts as a barrier to water infiltration, reducing the permeability of the material. Lower permeability limits the ingress of water into the stabilized layers, preventing excessive softening and maintaining the CBR values even in saturated conditions.

The increase in CBR gain, indicative of the strength enhancement resulting from cement addition to coal OB 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 in [1-4, 29, 30]. Figure 6 demonstrates that specimens treated with 8% cement exhibited a maximum gain of more than 110% in the wet state, while those treated with 2% cement showed a minimum gain of 23.11%. Furthermore, Figure 6 manifests the influence of cement content on the CBR improvement of stabilized samples.

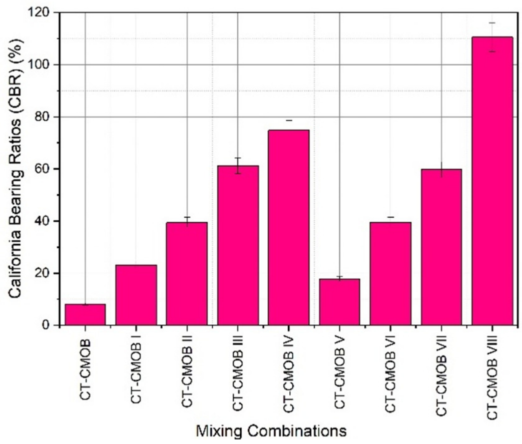

Fig. 6. CBR value.

C. Effect on Durability Properties

In this study, stabilized soil sample soaking and drying procedures for durability analysis were uniform at every mix configuration and satisfied IRC SP 89 Parts I and II (2010) standards. This demonstrates that, despite having been molded at OMC as opposed to cement concrete, the strength is less susceptible to moisture levels even after 12 curing cycles [26–30]. Because of the substantial drop in strength throughout inquiry, the applicability of a stabilized soil sample based on the wetting-drying cycle should be planned cautiously. According to IRC 37 (2018) and IRC SP 89 (2010), the volume change requirements are limited to 20% for base layer materials and 30% for subbase layer materials. The stability of the strength values throughout the course of the full 12 cycles is supported by the findings evidenced in Figures 7 and 8 for each mix combination of treated soil specimens. The strength after 12 cycles was also calculated in Figure 8. Confirming the findings of [1, 25, 26], the UCS improved in value, indicating that the stabilized specimens continue to perform on the upper side for strength with long-term durability.

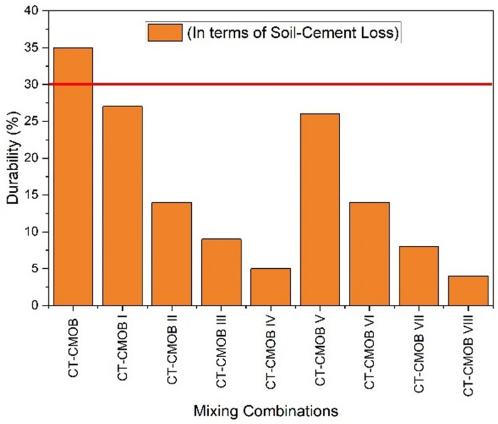

Fig. 7. Durability test results.

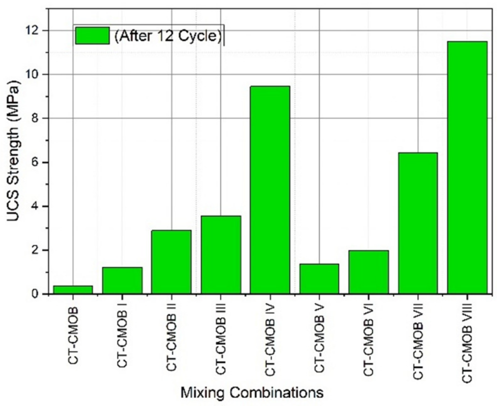

Fig. 8. Strength value after 12 durability cycles.

The study on the long-term strength and durability of CT-CMOB materials in the subbase and base layers of low-volume roads made significant advancements in assessing durability properties. By determining the optimum cement content of 6% for achieving desired mechanical strength and durability characteristics of CT-CMOB and CFA-CMOB mixes, the research provided crucial insights for road construction applications. Through wet-dry weathering cycle tests, the study revealed the positive impact of environmental exposure on mechanical strength up to 12 cycles, highlighting the material's resilience under weathering conditions. Additionally, the investigation into capillary rise resistance demonstrated the excellent moisture ingress resistance of CMOB mixes with 6% or higher cement content. By recommending a minimum curing period of 7 days to control shrinkage cracks, the importance of proper curing practices in enhancing the long-term durability of CMOB materials is emphasized. Overall, these achievements contribute valuable knowledge to optimize CT-CMOB for sustainable infrastructure development.

These findings provide valuable insights for engineers, designers, and decision-makers involved in infrastructure projects. The successful performance of these materials under weathering conditions underscores their potential to contribute to sustainable and resilient road infrastructure development. The main advantages of utilizing CT-CMOB materials are:

- Long-Term Durability: The consistent stability of strength values of CT-CMOB materials over 12 wet-dry weathering cycles indicates their ability to withstand environmental challenges and maintain structural integrity over extended periods. This long-term durability is essential for ensuring the longevity and performance of subbase and base layers in road construction, where materials are exposed to varying weather conditions and traffic loads.
- Resilience to Weathering: The observed improvement in unconfined compressive strength of the stabilized CMOB materials over time demonstrates their resilience to weathering effects, such as moisture ingress, freeze-thaw cycles, and mechanical stresses. This resilience is critical for ensuring that the materials can withstand the detrimental effects of environmental exposure without compromising their structural properties.
- Practical Implications for Road Construction: The findings from the durability tests highlight the suitability of CT-CMOB materials for practical applications in road construction, particularly in subbase and base layers of low-volume roads. By demonstrating long-term durability and resilience under weathering conditions, these materials offer a sustainable and cost-effective alternative for road infrastructure projects.
- Enhanced Performance: The consistent improvement in UCS of the stabilized CMOB materials signifies their enhanced performance characteristics, including increased load-bearing capacity, reduced deformation, and improved resistance to environmental factors. This enhanced performance can contribute to the overall stability and longevity of road pavements constructed using CT-CMOB materials.
- Sustainable Infrastructure Development: Incorporating CT-CMOB materials in road construction projects aligns with the principles of sustainable infrastructure development by utilizing alternative materials, reducing waste, and enhancing the durability of pavement layers. The long-term performance of these materials can lead to cost savings, reduced maintenance needs, and improved overall sustainability of road networks.

IV. CONCLUSION, LIMITATIONS AND FUTURE WORK

Coal Mine Overburden (CMOB) refers to the material that lies above a coal seam and is typically removed during mining operations. In this paper, CMOB is being studied for its potential use as a secondary aggregate in road construction. Unconfined Compressive Strength (UCS) is a measure of the maximum compressive stress a material can withstand before failure. It is an important parameter for assessing the strength and stability of construction materials like Cement-Treated CMOB (CT-CMOB). California Bearing Ratio (CBR) is a penetration test used to evaluate the strength of road subgrade, subbase, and base materials. It provides an indication of the material's load-bearing capacity and suitability for pavement construction.

Based on the results and discussion presented in the provided information, the following conclusions can be drawn regarding the use of CMOB materials stabilized with CT-CMOB and cement-fly ash (CFA-CMOB) for road construction applications:

- The untreated CMOB sample exhibited a UCS value less than 0.5 MPa, which significantly increased upon the addition of cement, with further improvements observed at longer curing durations.
- Samples treated with 4% cement met the minimum UCS standards specified by Austroads (2012) for the sub-base layer of low-volume roads after 28 days of curing and four hours of soaking.
- A strong correlation ($R^2 = 0.961$) was found between UCS values at 7 and 28 days for various cement percentages.
- The UCS ratio for CT-CMOB was notably increased with cement addition up to 6%, beyond which the growth rate declined sharply, indicating the stability of samples treated with cement even in the presence of water.
- CT-CMOB and CFA-CMOB samples under soaking conditions met the specifications for the granular sub-base of low-volume roads as per IRC: SP 20 (2002) guidelines.
- An increase in cement content in CMOB mixes enhanced the soaked CBR values, with a noticeable 4% improvement upon cement addition, followed by a plateauing effect with 6% and 8% cement content.
- Specimens treated with 8% cement exhibited a maximum gain of more than 110% in the wet state, while those treated with 2% cement showed a minimum gain of 23.11%.
- The wetting and drying of stabilized soil samples for durability analysis were consistent at each mix combination, meeting the criteria outlined in IRC SP 89 Parts I and II (2010).
- The strength after 12 cycles was determined, and the UCS resulted in increased values, showing that the performance of the stabilized specimens remains on the higher side for strength with long-term durability.

Hence, CMOB materials stabilized with cement and cement-fly ash have the potential to be used in sub-base and base layers of low-volume roads, meeting the required strength and durability criteria. The optimum cement content for achieving desired mechanical strength and durability characteristics was found to be 6% for both CT-CMOB and CFA-CMOB mixes.

Some limitations of the current study are:

- Limited Field Validation: The study primarily focuses on laboratory testing of CT-CMOB materials. Field validation studies on actual road construction sites could provide further insights into the real-world performance of these materials.
- Short-Term Testing: The durability tests conducted over 12 cycles provide valuable information on the material's resilience. However, longer-term studies spanning multiple years could offer a more robust assessment of the material's durability under varying environmental conditions.

Future research could include:

- Field Performance Studies: Conducting field trials to assess the performance of CT-CMOB materials in actual road construction projects would validate the laboratory findings and provide practical insights for engineers and practitioners.
- Environmental Impact Assessment: Investigating the environmental implications of using CMOB materials in road construction, involving factors, such as carbon footprint, energy consumption, and sustainability metrics, could enhance the understanding of the material's overall impact.
- Optimization of Mix Design: Exploring different mix proportions, additives, and curing methods to optimize the performance of CT-CMOB materials for specific road construction applications could lead to further improvements in strength, durability, and cost-effectiveness.

ACKNOWLEDGMENT

The authors would like to thank Mr. Samir Saurav, Research Scholar at the Civil Engineering Department and technical staff of the transportation laboratory at the National Institute of Technology Patna for helping with the experimental setup, formulations and performing and utilizing the lab facility.

REFERENCES

[1] M. Mohanty and S. S. Mohapatra, "Long-Term Strength and Durability of Cement-Treated Coal Mine Overburden Materials in Subbase and Base Layers of Low-Volume Roads," *Journal of Materials in Civil Engineering*, vol. 36, no. 4, Apr. 2024, Art. no. 04024035, https://doi.org/10.1061/JMCEE7.MTENG-16621.

[2] T. K. Rajak, L. Yadu, and S. K. Chouksey, "Effect of fly ash on geotechnical properties and stability of coal mine overburden dump: an overview," *SN Applied Sciences*, vol. 2, no. 5, Apr. 2020, Art. no. 973, https://doi.org/10.1007/s42452-020-2803-3.

[3] M. Mohanty, S. S. Mohapatra, and A. Padhi, "Exploring mechanical and microstructural properties of cement-stabilized coal mine overburden materials," *Road Materials and Pavement Design*, pp. 1–33, 2023, https://doi.org/10.1080/14680629.2023.2287219.

[4] N. Mondem and U. Balunaini, "Manufacturing Artificial Aggregates from Overburden Coal Mine Waste and Their Properties for Pavement Applications," *Journal of Materials in Civil Engineering*, vol. 36, no. 7,

Jul. 2024, Art. no. 04024147, https://doi.org/10.1061/JMCEE7.MTENG-17138.

[5] A. Mishra, S. K. Das, and K. R. Reddy, "Potential Use of Coal Mine Overburden Waste Rock as Sustainable Geomaterial: Review of Properties and Research Challenges," *Journal of Hazardous, Toxic, and Radioactive Waste*, vol. 28, no. 1, Jan. 2024, Art. no. 04023039, https://doi.org/10.1061/JHTRBP.HZENG-1258.

[6] M. Amrani, Y. Taha, Y. El Haloui, M. Benzaazoua, and R. Hakkou, "Sustainable Reuse of Coal Mine Waste: Experimental and Economic Assessments for Embankments and Pavement Layer Applications in Morocco," *Minerals*, vol. 10, no. 10, Oct. 2020, Art. no. 851, https://doi.org/10.3390/min10100851.

[7] M. Mahamaya and S. K. Das, "Characterization of mine overburden and fly ash as a stabilized pavement material," *Particulate Science and Technology*, vol. 35, no. 6, pp. 660–666, Nov. 2017, https://doi.org/10.1080/02726351.2016.1194344.

[8] S. K. Das, M. Mahamaya, and K. R. Reddy, "Coal mine overburden soft shale as a controlled low strength material," *International Journal of Mining, Reclamation and Environment*, vol. 34, no. 10, pp. 725–747, Nov. 2020, https://doi.org/10.1080/17480930.2020.1721043.

[9] B. Behera, "Geotechnical properties of lime stabilized fly ash - mine overburden for haul road," *International Journal of Advances in Mechanical and Civil Engineering*, vol. 3, no. 6, pp. 7–12, Sep. 2016.

[10] B. Behera and M. K. Mishra, "California Bearing Ratio and Brazilian Tensile Strength of Mine Overburden–Fly Ash–Lime Mixtures for Mine Haul Road Construction," *Geotechnical and Geological Engineering*, vol. 30, no. 2, pp. 449–459, Apr. 2012, https://doi.org/10.1007/s10706-011-9479-9.

[11] B. Behera and M. K. Mishra, "Strength behaviour of surface coal mine overburden–fly ash mixes stabilised with quick lime," *International Journal of Mining, Reclamation and Environment*, vol. 26, no. 1, pp. 38–54, Mar. 2012, https://doi.org/10.1080/17480930.2011.552285.

[12] Gupta A. K. Gupta and B. Paul, "A review on utilisation of coal mine overburden dump waste as underground mine filling material: a sustainable approach of mining," *International Journal of Mining and Mineral Engineering*, vol. 6, no. 2, pp. 172–186, Jan. 2015, https://doi.org/10.1504/IJMME.2015.070380.

[13] C. E. Carr and N. J. Withers, "The Wetting Expansion of Cement-Stabilised Minestone — an Investigation of the Causes and Ways Of Reducing the Problem," in *Advances in Mining Science and Technology*, vol. 2, A. K. M. Rainbow, Ed. Amsterdam, Netherlands: Elsevier, 1987, pp. 545–559.

[14] M. D. A. Thomas, R. J. Kettle, and J. A. Morton, "Short-Term Durability of Cement Stabilised Minestone," in *Advances in Mining Science and Technology*, vol. 2, A. K. M. Rainbow, Ed. Amsterdam, Netherlands: Elsevier, 1987, pp. 533–544.

[15] A. Jamal and S. Sidharth, "Value added constructional bricks from overburden of opencast coalmines," *Journal of Scientific and Industrial Research*, vol. 67, pp. 445–450, Jun. 2008.

[16] A. Mishra, S. K. Das, and K. R. Reddy, "Processing Coalmine Overburden Waste Rock as Replacement to Natural Sand: Environmental Sustainability Assessment," *Sustainability*, vol. 14, no. 22, Jan. 2022, Art. no. 14853, https://doi.org/10.3390/su142214853.

[17] A. Mishra, S. K. Das, and K. R. Reddy, "Use of Coal Mine Overburden as Sustainable Fine Aggregate in Cement Mortar," *Journal of Materials in Civil Engineering*, vol. 35, no. 9, Sep. 2023, Art. no. 04023272, https://doi.org/10.1061/JMCEE7.MTENG-15424.

[18] A. K. Rai, B. Paul, and G. Singh, "A study on physico-chemical properties of overburden dump materials from selected coal mining areas of Jharia coalfields, Jharkhand, India," *International Journal of Environmental Sciences*, vol. 1, no. 6, pp. 1350–1360, 2011.

[19] S. Yaseen, A. Pal, S. Singh, and I. Y. Dar, "A Study of Physico-Chemical Characteristics of Overburden Dump Materials from Selected Coal Mining Areas of Raniganj Coal Fields, Jharkhand, India," *Global Journal of Science Frontier Research Enviornment & Earth Sciences*, vol. 12, no. 1, pp. 7–13, 2012.

[20] S. R. Mallick, A. K. Verma, and K. U. Rao, "Characterization of Coal Mine Overburden and Assessment as Mine Haul Road Construction Material," *Journal of The Institution of Engineers (India): Series D*, vol. 98, no. 2, pp. 167–176, Oct. 2017, https://doi.org/10.1007/s40033-016-0126-8.

[21] T. K. Rajak, L. Yadu, S. K. Chouksey, and P. K. Dewangan, "Stability analysis of mine overburden dump stabilized with fly ash," *International Journal of Geotechnical Engineering*, vol. 15, no. 5, pp. 587–597, May 2021, https://doi.org/10.1080/19386362.2018.1503780.

[22] S. R. Mallick and A. K. Verma, "Performance of RBI"" stabilized coal mine overburden material for haul road pavement," *Arabian Journal of Geosciences*, vol. 13, no. 14, Jul. 2020, Art. no. 684, https://doi.org/10.1007/s12517-020-05649-4.

[23] I. M. K. Artoshi, L. A. Abdulateef, I. H. Farman, and A. M. Ahmed, "Efficiency and Durability Assessment of Soil Stabilization using Waste Tire Shreds," *Engineering, Technology & Applied Science Research*, vol. 14, no. 1, pp. 13012–13016, Feb. 2024, https://doi.org/10.48084/etasr.6740.

[24] I. Y. Amir, A. M. Yusuf, and I. D. Uwanuakwa, "A Metaheuristic Approach of predicting the Dynamic Modulus in Asphalt Concrete," *Engineering, Technology & Applied Science Research*, vol. 14, no. 2, pp. 13106–13111, Apr. 2024, https://doi.org/10.48084/etasr.6808.

[25] S. Saurav and S. Sinha, "Evaluation of Cementitiously Stabilized Granular Materials for Low Volume Roads in India," *International Journal of Pavement Research and Technology*, Dec. 2023, https://doi.org/10.1007/s42947-023-00399-4.

[26] S. Saurav and S. Sinha, "Mechanical characterisation of cementitiously stabilised moorum for use as structural layers in paving road construction," *Road Materials and Pavement Design*, vol. 25, no. 7, pp. 1551–1574, Jul. 2024, https://doi.org/10.1080/14680629.2023.2268742.

[27] AASHTO, *Standard specifications for transportation materials and methods of sampling and testing*. Washington, DC, USA: American Association for State Highway and Transport Officials, 2011.

[28] P. S. Toth, H. T. Chan, and C. B. Cragg, "Coal ash as structural fill, with special reference to Ontario experience," *Canadian Geotechnical Journal*, vol. 25, no. 4, pp. 694–704, Nov. 1988, https://doi.org/10.1139/t88-080.

[29] P. V. Sivapullaiah and A. K. Jha, "Gypsum Induced Strength Behaviour of Fly Ash-Lime Stabilized Expansive Soil," *Geotechnical and Geological Engineering*, vol. 32, no. 5, pp. 1261–1273, Oct. 2014, https://doi.org/10.1007/s10706-014-9799-7.

[30] S. Saurav and S. Sinha, "Strength and Durability Characteristics of Stabilised Clayey Soil for Low Volume Roads," in *International Conference on Transportation Planning and Implementation Methodologies for Developing Countries*, Mumbai, India, Dec. 2022, pp. 323–338, https://doi.org/10.1007/978-981-99-6090-3_26.