

# Evaluation of Indirect Tensile Strength and Unconfined Compressive Strength of Cement Treated Granular Subbase with Copper Slag

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## Abstract

*This study investigates the mechanical properties of Cement Treated Granular Subbase (CTGSB) with the inclusion of copper slag as a partial replacement material. The research focuses on evaluating the Indirect Tensile Strength (ITS) and Unconfined Compressive Strength (UCS) to assess the material's suitability for road construction. Various mix proportions of copper slag were analyzed to determine their effect on strength development. The results revealed that the ITS increased from 0.79 MPa in the control mix to 0.85 MPa with a 30% copper slag replacement. Similarly, the UCS improved from 3.31 to 4.33 N/mm<sup>2</sup> after 28 days of curing. The study confirms that incorporating copper slag enhances the structural integrity and load-bearing capacity of the subbase. These findings advocate the use of CTGSB with copper slag as a sustainable and cost-effective alternative in pavement construction.*

**Keywords:** Cement treated granular subbase, copper slag, indirect tensile strength, unconfined compressive strength, sustainable construction, pavement performance

## INTRODUCTION

The increasing concern over the environmental impact of industrial and construction waste has led to innovative approaches in civil engineering. In regions like Madhya Pradesh, where expansive soils are prevalent, infrastructure development often faces challenges due to the soil's shrink-swell behavior. Traditional soil stabilization methods rely heavily on natural aggregates and cement, contributing to resource depletion and carbon emissions. To address these issues, researchers have explored the use of industrial byproducts and waste materials for soil and pavement stabilization. Quarry Dust (QD), Copper Slag (CS), Fly Ash (FA), and plastic waste are gaining prominence due to their availability, cost-effectiveness, and beneficial engineering properties. Incorporating these materials into subgrade soil, sub-base, base layers, and bituminous pavement can enhance strength, durability, and load-bearing capacity, while reducing the reliance on conventional materials [1–4].

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This research investigates the utilization of these waste materials in expansive soil stabilization and pavement construction. By analyzing their physical and mechanical properties, the study aims to determine optimal mix proportions that ensure long-term performance and sustainability. The findings will contribute to the development of environmentally friendly and cost-effective construction practices, fostering sustainable infrastructure development in expansive soil regions [5–9].

## OBJECTIVES

The primary objective of this research is to evaluate the mechanical performance of Cement

Treated Granular Subbase (CTGSB) by analyzing its Indirect Tensile Strength (ITS) and Unconfined Compressive Strength (UCS). This study aims to investigate the effect of varying cement proportions on the tensile resistance and compressive strength of the subbase material. By conducting ITS tests, the research will determine the material's ability to withstand tensile stresses, which are critical for resisting cracking and deformation under traffic loads. Additionally, UCS tests will be performed at different curing periods to evaluate the load-bearing capacity and structural stability of the CTGSB. The findings from this study will contribute to identifying the optimal cement content for achieving enhanced mechanical properties, thereby supporting the design and construction of more durable and sustainable pavement layers [10–14].

## MATERIAL

In this study, various waste materials including Quarry Dust (QD), Copper Slag (CS), Fly Ash (FA), and plastic waste were utilized to assess their effectiveness in soil stabilization and pavement construction. The physical and chemical properties of these materials play a significant role in influencing the performance of stabilized soil and pavement layers [15–17].

1. *Quarry dust (QD)*: Quarry Dust is a byproduct generated during the crushing of rocks for aggregate production. It consists of fine particles that can enhance the density and strength of soil. Quarry Dust is commonly used in geotechnical applications due to its availability and cost-effectiveness.
2. *Copper slag (CS)*: Copper Slag, a waste material produced during the smelting of copper, is characterized by its angular and rough texture. It exhibits good abrasion resistance and is often used as a replacement for fine aggregates in various construction applications. The high specific gravity and pozzolanic properties of Copper Slag contribute to improved soil strength [18–20].
3. *Fly ash (FA)*: Fly Ash is a residue from coal combustion in thermal power plants. It is a pozzolanic material that reacts with lime in the presence of moisture to form cementitious compounds. Fly Ash enhances soil stability, reduces plasticity, and increases load-bearing capacity.
4. *Plastic waste*: Plastic waste, particularly in the form of Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE), is used as a bitumen modifier in flexible pavements. It improves the durability, fatigue resistance, and stability of asphalt mixtures. Recycling plastic waste in bituminous pavements addresses environmental concerns and reduces plastic pollution [20–24].
5. *Cement*: Ordinary Portland Cement (OPC) was used as a binding agent for soil and aggregate stabilization. Cement-treated granular sub-base layers provide enhanced compressive strength and resistance to environmental factors.
6. *Water*: Potable water conforming to the standards for concrete and soil stabilization was used for mixing and curing. Water quality directly impacts the hydration process of cement and the formation of cementitious compounds.

These materials were sourced locally to ensure sustainability and cost-efficiency. Detailed analysis of their physical and chemical properties was conducted to determine their suitability for expansive soil stabilization and pavement applications [24–27].

## RESULTS

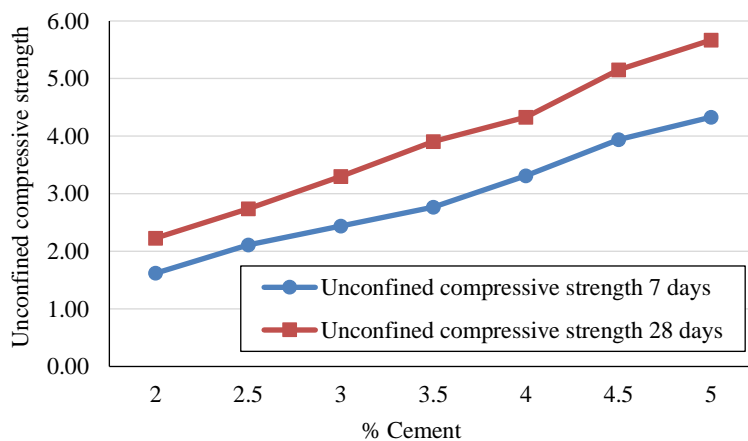
### Unconfined Compressive Strength of the Cement Treated Granular Subbase

Cementitious materials often develop cracks due to shrinkage and temperature fluctuations, even without the application of pavement loads. Slow-setting cementitious mixes with lower cement content are preferred over those with higher cement content, as they tend to form finer cracks instead of wider ones. When evaluating strength values for design purposes, it is essential to account for the reduction in strength caused by these cracks.

The granular sub-base materials were selected with an intermediate gradation to achieve optimal results. The incorporation of cement into the cement-treated granular sub-base enhances the compressive strength, reaching the required strength with the addition of 4% cement. The maximum compressive strength recorded was 3.31 N/mm<sup>2</sup> at 7 days and 4.33 N/mm<sup>2</sup> at 28 days, as illustrated in Table 1 and Figure 1.

**Table 1.** Unconfined compressive strength results.

% Cement	Unconfined compressive strength 7 days (N/mm <sup>2</sup> )	Unconfined compressive strength 28 days (N/mm <sup>2</sup> )
2	1.62	2.23
2.5	2.11	2.74
3	2.44	3.30
3.5	2.77	3.91
4	3.31	4.33
4.5	3.94	5.15
5	4.33	5.67



**Figure 1.** Cement Percentage vs. UCS for CTGSB.

Figure 1 presents the UCS values corresponding to different cement percentages for both 7 and 28-day curing periods. The graph demonstrates that an increase in cement content leads to a significant rise in strength, attributed to the hydration process. During hydration, cement particles fill the pores within the matrix, contributing to the enhanced rigidity of the structure. Additionally, strength gains are observed with longer curing times, as evidenced by the higher UCS values at 28 days compared to 7 days.

### Indirect Tensile Strength (ITS) Test for Bituminous Concrete (BC)

The Indirect Tensile Strength (ITS) test was conducted to evaluate the tensile properties and water sensitivity of various bituminous concrete (BC) mixtures. The results are presented in Table 2, showing the ITS values for both dry and wet conditions, along with the Tensile Strength Ratio (TSR).

The control mix exhibited an ITS value of 0.79 N/mm<sup>2</sup> in dry conditions and 0.73 N/mm<sup>2</sup> in wet conditions, with a TSR of 92.41%. Incorporating 20% Copper Slag (CS) resulted in a slight increase in both dry and wet ITS values to 0.83 and 0.78 N/mm<sup>2</sup> respectively, achieving a TSR of 93.98%. Further increasing the CS content to 30% demonstrated a marginally higher ITS value of 0.85 N/mm<sup>2</sup> in dry conditions and 0.80 N/mm<sup>2</sup> in wet conditions, with a TSR of 94.12%.

The addition of Fly Ash (FA) to the CS mixtures exhibited a minor reduction in ITS values. The mix with 20% CS+FA showed a dry ITS value of 0.75 N/mm<sup>2</sup> and a wet ITS value of 0.70 N/mm<sup>2</sup>, with a TSR of 93.33%. Similarly, the mix with 30% CS+FA had slightly improved ITS values of 0.77 (dry) and 0.72 N/mm<sup>2</sup> (wet), resulting in a TSR of 93.51%.

The inclusion of Waste Shredded Plastic (WSP) in the CS and FA mixes provided enhanced results. The mix with 20% CS+FA+WSP achieved ITS values of 0.80 (dry) and 0.75 N/mm<sup>2</sup> (wet), with a TSR of 93.75%. The combination of 30% CS+FA+WSP displayed slightly increased dry ITS values of 0.81 N/mm<sup>2</sup> and wet ITS values of 0.75 N/mm<sup>2</sup>, with a TSR of 92.59%.

**Table 2.** ITS and TSR Values for BC Mix with different proportions of CS, FA, and WSP.

Mix designation	ITS (Dry) (N/mm <sup>2</sup> )	ITS (Wet) (N/mm <sup>2</sup> )	TSR (%)
Control mix	0.79	0.73	92.41
CS 20	0.83	0.78	93.98
CS 30	0.85	0.8	94.12
CS 20+FA	0.75	0.7	93.33
CS 30+FA	0.77	0.72	93.51
CS 20+FA+WSP	0.8	0.75	93.75
CS 30+FA+WSP	0.81	0.75	92.59

Overall, the test results indicate that the addition of CS, FA, and WSP in various proportions generally enhances the tensile strength of bituminous concrete. The TSR values for all modified mixes remained above 92%, demonstrating good resistance to moisture damage and improved performance compared to the control mix.

## CONCLUSION

- The addition of cement in Cement Treated Granular Subbase (CTGSB) significantly improved its mechanical properties.
- Indirect Tensile Strength (ITS) increased from 0.79 MPa in the control mix to 0.85 MPa for the mix containing 30% copper slag, indicating enhanced tensile resistance.
- Unconfined Compressive Strength (UCS) showed a substantial rise from 3.31 to 4.33 N/mm<sup>2</sup> over a 28-day curing period, reflecting greater load-bearing capacity.
- The optimized cement content ensured improved durability, contributing to the long-term structural performance of the pavement.

The findings support the suitability of Cement Treated Granular Subbase as a sustainable and resilient subbase material for road construction.

## REFERENCES

1. Afroz Sultana SK, Prasad KSB. Utilization of Waste Plastic as a Strength Modifier in Surface Course of Flexible and Rigid Pavements. *Int J Eng Res Appl.* 2012; 2(4): 1185–1191.
2. Agarwal N. Effect of stone dust on some geotechnical properties of soil. *Journal of Mechanical and Civil Engineering.* 2015; 12(01): 61–64.
3. Akshaya Kumar Sabat, Bidula Bose. Improvement in Geotechnical Properties of an Expansive Soil using Flyash - Quarry Dust Mixes. *Electron J Geotech Eng.* 2013; 18: 3487–3500.
4. Ali Behnood, Mahsa Modiri Gharehveran, Farhad Gozali Asl, Mahmoud Ameri. Effects of copper slag and recycled concrete aggregate on the properties of CIR mixes with bitumen emulsion, rice husk ash, Portland cement and flyash. *Constr Build Mater.* 2015; 96: 172–180.
5. Amir Modarres, Hamidreza Hamedi. Effect of waste plastic bottles on the stiffness and fatigue properties of modified asphalt mixes. *Mater Des.* 2014; 61: 8–15.
6. Amiruddin Ismail, Mojtaba Shojaei Baghini, Mohamed Rehan Bin Karim, Foad Shokri, Al-Mansoba Ramez A, Ali Asghar Firoozi, Ali Akbar Firoozi. Laboratory investigation on the strength characteristics of Cement- Treated Base. *Applied Mechanics and Materials (AMM).* 2014; 507: 353–360.
7. Amit Gawande, Zamarea G, Rengea VC, Saurabh Taydea, Bharsakale G. An Overview on Waste Plastic utilization in Asphaltting of Roads. *Journal of Engineering Research and Studies.* 2012; 3(2): 01–05.
8. Anjan Kumar M, Prasada Raju GVR. Use of Lime Cement Stabilized Pavement Construction. *Indian J Eng Mater Sci.* 2009; 16: 269–276.
9. Arun Kumar U, Biradar Kiran B. Soft subgrade stabilization with quarry dust – An industrial waste. *Int J Res Eng Technol.* 2014; 03(08): 409–412.

10. Bhageerathy KP, Alex Anu P, Manju VS, Raji AK. Use of Biomedical Plastic Waste in Bituminous Road Construction. *Int J Eng Adv Technol*. 2014; 3(6): 89–92.
11. Bidula Bose. Geo-Engineering Properties of Expansive Soil Stabilized with Flyash. *Electron J Geotech Eng*. 2012; 17: 1339–1353.
12. Chayan Gupta, Ravi Kumar Sharma. Black cotton soil modification by the application of waste materials. *Period Polytech Civ Eng*. 2016; 60(4): 479–490.
13. Javiya Darshit H. Performance of Bituminous Mix using E- waste and Fly-ash for the Flexible pavement. *Int J Res Appl Sci Eng Technol*. 2018; 06(01): 1138–1146.
14. Gupta RC, Blessen Skariah Thomas, Prachi Gupta, Lintu Rajan, Dayan Thagriya. An experimental study of clayey soil stabilized by copper slag. *Int J Struct Civ Eng Res*. 2012; 01(01): 110–119.
15. Abdelfattah Hossam FH, Khalid Al-Shamsi, Khalifa Al-Jabri. Evaluation of rutting potential for asphalt concrete mixes containing copper slag. *Int J Pavement Eng*. 2018; 19(7): 630–640.
16. Costa Liliana MB, Silva Hugo MRD, Oliveira Joel RM, Fernande Sara RM. Incorporation of Waste Plastic in Asphalt Binders to Improve their Performance in the Pavement. *Int J Pavement Res Technol*. 2013; 6(4): 457–465.
17. Mohammed A, Mistry Hevin M, Patel Vikas D. Improvement in Soil properties of Expansive Soil by using Copper Slag. *International Journal of Advance Research in Engineering, Science & Technology (IJAREST)*. 2015; 02(07): 125–30.
18. Mohan Chand A, Ramesh Babu V, Ramesh Babu B, Niveditha K. Behavior of black cotton soil with addition of copper slag and steel slag. *Int Res J Eng Technol*. 2017; 04(01): 752–758.
19. Murat Aziz Ozdemir. Improvement in Bearing Capacity of a Soft Soil by Addition of Flyash. *Procedia Eng*. 2016; 143: 498–505.
20. Patil PS, Damgir RM, Hake SL. Strengthening of Soil by Using Flyash. *Int J Emerg Technol Adv Eng*. 2014; 04(05): 201–205.
21. Raposeiras AC, Vargas-Cerón A, Movilla-Quesada D, Castro-Fresno D. Effect of copper slag addition on mechanical behaviour of asphalt mixes containing reclaimed asphalt pavement. *Constr Build Mater*. 2016; 119: 268–276.
22. Samidurai V, Gokulan Y, Krishnan N. Influence of Flyash on expansive Soils. *Int J Emerg Trends Sci Technol*. 2017; 04(02): 4998–5003.
23. Shukla MK, Gupta N. Evaluation of Flexible pavement with stabilized granular and bituminous base. *Journal of the Indian Road Congress*. 2017 Jul–Sep; 78(2): 109–120.
24. Siyyagalla Subbarayudu, Rozwana S, Susmitha Y, Mallesh M, Chandrasekhar T. Study of Soil Stabilization by using Recron-3S, Flyash & Lime. *Int J Technol Res Eng*. 2017; 04(09): 1568–571.
25. Srinivas A, Prasad DSV, Anjan Kumar M, Prasada Raju G. Utilisation of waste materials in the construction of roads. *International Journal of Engineering Research and Development (IJERD)*. 2015; 11(1): 55–62.
26. Venkateswarlu H, Prasad ACSV, Prasad DSV, Prasada Raju GVR. Study on Behavior of Expansive Soil Treated With Quarry Dust. *International Journal of Engineering and Innovative Technology (IJEIT)*. 2015; 4(10): 193–196.
27. Xuan DX, Houben LJM, Molenaar AAA, Shui ZH. Mechanical properties of cement-treated aggregate material – A review. *Mater Des*. 2012; 33: 496–502.