



# Mechanical Characterization of Cement Stabilized Moorum-Steel Slag Systems for Sustainable Transportation Infrastructure

<sup>1</sup>Rameshwar Kumar Dewangan, <sup>2</sup>Akhand Pratap Singh, <sup>3</sup>Prof. R.R.L. Birali

<sup>1</sup>M.Tech. Scholar, <sup>2</sup>Assistant Professor, <sup>3</sup>Professor

Department of Civil Engineering

<sup>1,2</sup>Shri Rawatpura Sarkar University, Raipur Chhattisgarh

<sup>3</sup>MATS University, Aarang-493441, Raipur

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**Abstract:**-The rapid depletion of natural aggregate resources and the increasing generation of industrial waste materials have become major challenges in the road construction sector. Large quantities of aggregates are required for pavement construction, resulting in excessive quarrying, crushing, and transportation activities, which consume significant energy and harm the environment. At the same time, industrial by-products such as steel slag and locally available marginal materials like moorum create disposal and environmental problems. Therefore, the use of such alternative materials in pavement construction is an important step toward sustainable transportation infrastructure. This study focuses on the mechanical characterization of cement stabilized moorum-steel slag systems for use in pavement base and sub-base layers. Steel slag obtained from the steel industry and locally available hard moorum were used as alternative aggregate materials. The study evaluates their suitability through various laboratory investigations related to physical, mechanical, mineralogical, and environmental properties. Different tests were conducted to determine gradation, specific gravity, water absorption, compaction characteristics, California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS). Advanced analytical techniques such as X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Toxicity Characteristic Leaching Procedure (TCLP) were also performed to identify the chemical composition, mineral phases and environmental safety of steel slag. Conventional crushed

aggregates were blended with slag and moorum to satisfy the grading requirements specified by the Ministry of Road Transport and Highways (MoRTH). The experimental results indicated that steel slag possesses excellent engineering properties and can be effectively utilized up to 80% in pavement sub-base applications. Hard moorum was found suitable up to 50% when stabilized with cement. The cement stabilized moorum-steel slag mixtures showed satisfactory strength and durability characteristics for pavement construction. The toxicity analysis further confirmed that the concentration of heavy metals in slag and its leachate water remained within permissible environmental limits.

**Keywords:** Steel Slag, Hard Moorum, Cement Stabilization, Mechanical Characterization, Sustainable Transportation Infrastructure, XRD Analysis, Unconfined Compressive Strength.



## 1. Introduction

### 1.1 Background of the Study

Road transportation plays a vital role in the economic, industrial, social and cultural development of a country. In India, the road network is one of the largest transportation systems in the world and acts as the backbone of national connectivity and economic growth. As of 2025, India possesses more than 63 lakh km of road network, including about 1.46 lakh km of National Highways, making it one of the world's largest road infrastructure systems. Continuous development programs such as the National Highways Development Programme (NHDP), Bharatmala Pariyojana, and Pradhan Mantri Gram Sadak Yojana (PMGSY) have significantly improved urban and rural connectivity across the country.

Road pavements used in highway construction are generally classified into flexible pavements, rigid pavements and semi-rigid pavements. Flexible pavements are widely used in India because of their lower initial cost, ease of construction and better riding quality. A flexible pavement mainly consists of four layers: sub-grade, sub-base, base course and surface course. These layers collectively distribute traffic loads safely to the underlying soil. The sub-base and base layers are particularly important because they provide structural support, drainage, and load distribution. Granular Sub-Base (GSB) layers are commonly used to improve pavement stability and durability. Rigid pavements consist of cement concrete slabs supported by a base or sub-base layer. These pavements possess high flexural strength and durability but are generally associated with higher construction costs. Semi-rigid pavements, on the other hand, are formed by stabilizing aggregates or soils using binders such as cement, lime, fly ash, or other stabilizing agents. These pavements offer better strength and improved load carrying capacity compared to conventional flexible pavements. The rapid expansion of transportation infrastructure has resulted in a huge demand for natural aggregates used in pavement construction. Continuous quarrying, crushing and transportation of aggregates not only deplete natural resources but also consume large amounts of energy and create environmental problems such as dust pollution, land degradation and greenhouse gas emissions. Simultaneously, industrial wastes and by-products generated from steel plants and other industries are creating disposal and environmental management challenges. To address these issues, the utilization of alternative and sustainable materials in pavement construction has gained significant attention in recent years. Among these materials, steel slag, a by-product of the steel manufacturing industry and locally available hard moorum have shown considerable potential for use in pavement base and sub-base layers. Steel slag possesses high strength, hardness, and durability, while moorum is abundantly available in many regions of India and can be effectively stabilized using cement for engineering applications. In this study, an attempt has been made to evaluate the suitability of cement stabilized moorum-steel slag systems for sustainable transportation infrastructure. The research focuses on the mechanical characterization, mineralogical analysis and environmental assessment of steel slag and hard moorum for their application in pavement base and sub-base layers. Laboratory investigations such as gradation analysis, compaction tests, California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) tests were conducted to evaluate the engineering performance of the materials. Advanced analytical techniques including X-Ray Fluorescence (XRF), X-Ray Diffraction (XRD) and Toxicity Characteristic Leaching Procedure (TCLP) were also carried out to examine the chemical composition, mineral phases and environmental safety of steel slag. The study aims to promote the utilization of industrial by-products and locally available materials as sustainable alternatives to conventional aggregates in road construction. The effective use of steel slag and hard moorum can help conserve natural resources, reduce environmental pollution, minimize waste disposal problems, and support the development of sustainable transportation infrastructure.

### 1.2 Problem Statement

The rapid expansion of road infrastructure in India has created a huge demand for natural construction materials such as sand, gravel and crushed aggregates. These materials are widely used in highways, buildings, bridges and other construction projects. Continuous quarrying, crushing, and transportation of aggregates not only deplete natural resources but also cause environmental problems such as land degradation, dust, noise pollution and high energy consumption. By 2025, India's road network has expanded to more than 63 lakh km, significantly increasing the demand for pavement materials. At the same time, the steel industry generates large quantities of industrial waste such as steel slag, blast furnace slag, fly ash and



dolomite dust. Improper disposal of these wastes creates serious environmental and land management problems. Steel slag possesses good strength and durability properties, making it a potential alternative to natural aggregates in pavement construction. Similarly, locally available hard moorum can also be used effectively after cement stabilisation. The utilisation of these materials can reduce the consumption of natural aggregates and minimise industrial waste disposal problems. Therefore, there is a need to evaluate the suitability of cement stabilised moorum-steel slag systems for sustainable pavement base and sub-base applications. The present study focuses on the mechanical, mineralogical, and environmental assessment of these materials for sustainable transportation infrastructure development.

### 1.3 Objective

- ❖ The present study focuses on the mechanical characterization of cement stabilized moorum-steel slag systems for sustainable transportation infrastructure. Steel slag, locally available hard moorum, and conventional crushed aggregates were utilized for pavement base and sub-base applications. The main objectives of the study are:
- ❖ To determine the chemical composition, mineralogical characteristics, and presence of hazardous elements in steel slag and its leachate water.
- ❖ To evaluate the physical and mechanical properties of steel slag for its suitability in pavement sub-base applications.
- ❖ To examine the engineering properties of locally available hard moorum collected from Chhattisgarh and assess its suitability for pavement base and sub-base layers.
- ❖ To investigate the effect of cement stabilisation on moorum-steel slag mixtures through strength and compaction characteristics.
- ❖ To evaluate the performance of cement stabilised moorum-steel slag systems using laboratory tests such as CBR and UCS for sustainable pavement construction.
- ❖ To promote the utilization of industrial by-products and locally available materials as sustainable alternatives to natural aggregates in transportation infrastructure development.

## 2. Literature Review

Basic oxygen furnace (BOF) slag as well as electric arc furnace (EAF) slag is also used for road base as well as road base asphalt concrete. In a trial, the mix design and performance characterization of the bituminous mixes was done in Italy. Gyrotory compaction tests, indirect tensile strength tests, fatigue tests, permanent deformation tests and stiffness modulus tests (at various temperatures) of the mixtures of EAF slag and asphalt showed better mechanical characteristics than those of the conventional natural aggregate and asphalt mixture, satisfying the acceptable criteria for Italian road construction. [Pasetto and Baldo (2010)].

In a moisture damage investigation of the road, the BOF prepared asphalt mixtures were characterised by resilient modulus tests, indirect tensile strength tests. The freeze-thaw tests showed better moisture sensitivity of BOF slag mixture than that of the basalt mixture [Jun Xie., et al. (2012)].

The moorum collected from Sukrut (Uttar Pradesh) was mixed with Ganga sand and cement stabilised for use in Wet Mix Macadam (WMM) [Ransinchung., et al. (2014)]. The physical properties of moorum, Ganga sand, crushed aggregate and stone dust were found out. The proportions of individual aggregates were determined so that the mixture would satisfy the desired gradation of MoRTH specifications. Ordinary Portland cement was used as a stabiliser and varying the cement content the CBR tests and the unconfined compressive strength tests were conducted. The results showed highest CBR value (423%) and unconfined compressive strength (18.55 kg/cm<sup>2</sup>) at 9 percent cement content.

### 2.1 Critical Review

Various research studies have shown that steel slag can be effectively utilised in road construction because of its high strength, hardness, and durability. Its engineering properties are often found to be comparable or superior to conventional natural aggregates. Chemical characterisation and leachate studies have also confirmed that properly processed steel slag has minimal environmental impact and can be safely used in pavement base and sub-base layers when it satisfies the required specifications and toxicity limits. Compared to steel slag, the use of hard moorum in pavement construction has received less research attention. However, available studies indicate that hard moorum possesses good potential for use in road base and sub-base



applications after suitable stabilisation. Since the engineering properties of moorum vary depending on geographical location, detailed investigation is necessary before its large-scale application in pavement construction. In the present study, steel slag collected from Bhilai and locally available hard moorum from different regions of Chhattisgarh were evaluated for sustainable pavement applications. The study mainly focuses on the mechanical characterisation, mineralogical analysis, and environmental assessment of cement stabilised moorum-steel slag systems to determine their suitability for pavement base and sub-base layers and to promote sustainable transportation infrastructure development.

### 3. Experimental Methodology

Whether using natural aggregates, industrial wastes/by-products, or locally available materials, it is essential that these materials satisfy the desired physical properties and strength parameters for application in the base or sub-base layer of road pavement. Additionally, materials with the potential to affect the environment are subjected to chemical tests and characterization to ensure they are environmentally acceptable.

In this work, the chemical composition and characterization of slag were undertaken. The physical properties of slag, natural crushed aggregates, and moorum were determined according to relevant codes, specifications, and literature. The following test methods were carried out in this study:

- Chemical composition analysis to determine the elements present in slag and their concentrations.
- Phase composition analysis to identify the mineral phases in the slag.
- Hazardous materials assessment in slag and its leachate water to ensure environmental safety.
- Physical property tests for slag, natural crushed aggregates, and moorum, including:
  - ✓ Gradation and particle size distribution
  - ✓ Specific gravity and bulk density
  - ✓ Moisture content and absorption
  - ✓ Compaction characteristics (Proctor test)
  - ✓ California Bearing Ratio (CBR) test for strength evaluation
- Cement stabilization effects on the mixture of natural aggregates and moorum to assess improvements in strength and durability.

These comprehensive tests ensure that the materials meet the necessary standards for use in road construction while promoting sustainable practices by utilizing locally available and industrial by-product materials.

#### 3.1 Materials Used

The following materials were used in the present study for the preparation and evaluation of pavement base and sub-base mixtures:

- ❖ **Steel Slag:** Steel slag was collected from the steel plant area of Bhilai. It was used as an alternative aggregate material in pavement applications.
- ❖ **Hard Moorum:** Locally available hard moorum was collected from different regions around Raipur for use in pavement base and sub-base layers.
- ❖ **Crushed Aggregates:** Conventional crushed stone aggregates of different sizes were used for blending with steel slag and moorum to satisfy the grading requirements specified by MoRTH.
- ❖ **Cement:** Ordinary Portland Cement (OPC) was used as a stabilising binder to improve the strength and durability of moorum-steel slag mixtures.
- ❖ **Chemicals:** Different laboratory chemicals and reagents were used for XRF, XRD, TCLP, and other chemical analyses to study the composition and environmental safety of steel slag.

These materials were selected to investigate the mechanical performance, durability, and environmental suitability of cement stabilised moorum-steel slag systems for sustainable pavement construction.



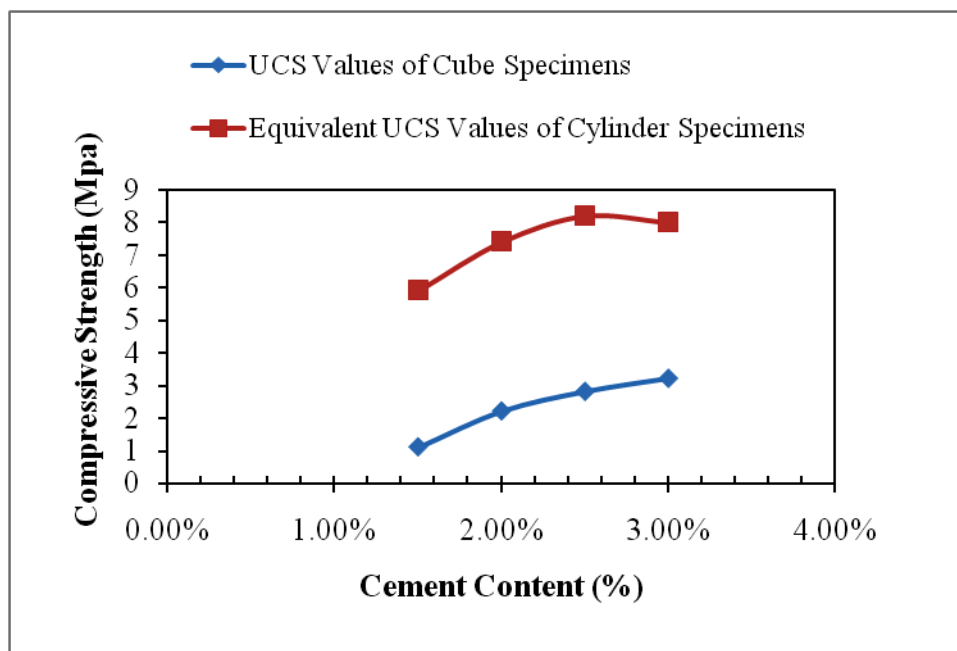
#### 4. Results and Discussion

##### 4.1 Characterization of Slag

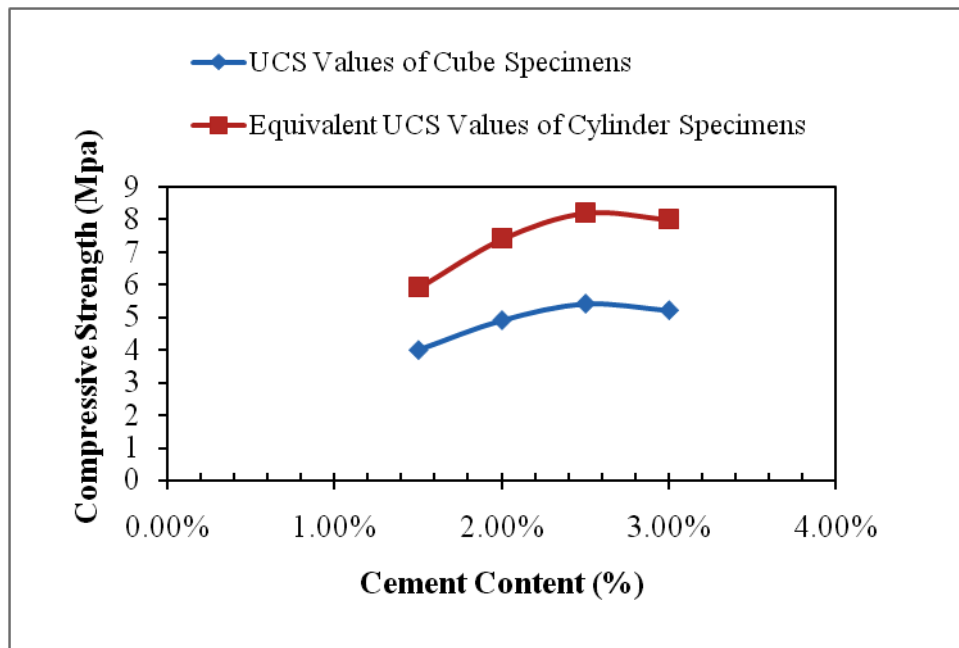
##### 4.1.1 Chemical Composition

The chemical composition of the slag samples was determined by the XRF technique and is presented in table *Table 4.1. Chemical Composition of the Slag Samples Determined By XRF Technique*

Chemical Composition	Percentage
SiO <sub>2</sub>	27.33
FeO	20.91
Al <sub>2</sub> O <sub>3</sub>	6.03
CaO	31.03
MgO	9.24
MnO	4.50
S	0.10
TiO <sub>2</sub>	0.66
K <sub>2</sub> O	0.14



*Figure 4.8 (b) Comparison of the UCS values of cube specimens with the equivalent UCS values of cylinder specimens for use in the cement treated base [Moorum=50%+ A10=15%+A6=35%]*



**Figure 4.8 (C) Comparison Of UCS Values Of Cube Specimens With Equivalent UCS Values Of Cylinder Specimens For Use In The Filter Layer Of Cement Treated Sub-Base [Moorum=50%+ A10=15% +A6=35%]**

The UCS value of the combination of moorum and crushed aggregates was found to be more as compared to that of the combination of crushed aggregates only for particular cement content. The equivalent UCS values of the cylinder specimens were found to be more as compared to those of the cube specimens. The 7 days UCS values for cement bound materials should be between 4.5 to 7 MPa for use in the base and between 1.5 to 3 MPa for use in sub-base (drainage or filter layer) as per IRC SP: 89(2010). So depending on the required UCS value for construction of a particular layer the corresponding cement content can be taken to satisfy the requirements.

## 5. Conclusion and Future Scope

### 5.1 General

The present study investigated the suitability of steel slag and locally available hard moorum for use in pavement base and sub-base layers. Based on the laboratory investigations and analysis of results, the following conclusions are drawn.

#### 5.1.1 Characterization of Steel Slag

- ❖ The steel slag collected from Bhilai mainly contains CaO, SiO<sub>2</sub>, FeO, along with smaller amounts of Al<sub>2</sub>O<sub>3</sub> and MgO, confirming its suitability as a steel industry by-product for pavement applications.
- ❖ XRD and chemical analysis showed that the major phases present in the slag are mainly in silicate, carbonate, and hydroxide forms, which are suitable for construction purposes.
- ❖ Toxicity and leachate studies indicated that the concentration of hazardous and heavy metals in steel slag and its leachate water is either negligible or within permissible environmental limits. Hence, the environmental risk associated with the use of steel slag is very low.

#### 5.1.2 Physical and Mechanical Properties

- ❖ The steel slag was found to be well graded and required only a small quantity of conventional crushed aggregates to satisfy MoRTH grading requirements for pavement sub-base applications.
- ❖ Steel slag can be effectively utilised up to 80% in granular sub-base layers while maintaining the required grading and strength properties.
- ❖ The locally available hard moorum collected from regions around Raipur contains comparatively higher fine content, which limits its usage to about 50% in the total aggregate blend.



- ❖ Due to the higher plasticity of moorum, cement stabilisation was necessary to improve its engineering performance.
- ❖ The impact value, specific gravity, compaction characteristics, and CBR values of steel slag and moorum blends were found suitable for pavement base and sub-base applications.
- ❖ The impact value, specific gravity, compaction characteristics, and CBR values of steel slag and moorum blends were found suitable for pavement base and sub-base applications.
- ❖ The cement stabilised moorum–steel slag mixtures showed satisfactory Unconfined Compressive Strength (UCS) values and met the required strength criteria for cement treated pavement layers.
- ❖ The UCS values of cement stabilised moorum blends were found to be higher than conventional crushed aggregate blends for similar cement content.

## 5.2 Conclusion

The study demonstrates that steel slag and locally available hard moorum can be effectively utilised as alternative pavement materials for sustainable transportation infrastructure. Steel slag exhibited excellent physical, mechanical, and environmental properties and can replace a significant portion of conventional aggregates in pavement sub-base layers. Similarly, hard moorum, after cement stabilisation, showed satisfactory strength and durability characteristics for pavement applications. The utilisation of cement stabilised moorum-steel slag systems can reduce the consumption of natural aggregates, minimise industrial waste disposal problems, lower construction costs, and support environmentally sustainable road construction practices.

## 5.3 Future Scope of Work

Although the present study has established the suitability of steel slag and hard moorum for pavement applications, further research can be carried out in the following areas:

- ❖ Evaluation of resilient modulus and fatigue behaviour under repeated traffic loading conditions.
- ❖ Study of long-term durability and field performance of cement stabilised moorum-steel slag pavement layers.
- ❖ Investigation of permeability and drainage characteristics of slag based granular sub-base mixtures.
- ❖ Microstructural analysis using advanced techniques such as SEM and EDX for better understanding of bonding behaviour in stabilised mixtures.

Development of sustainable pavement design guidelines using industrial by-products and locally available marginal materials.

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