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Sustainable Utilization of Coal Mine Overburden as Fine Aggregate in M30 Grade Concrete: A Feasibility Study for Green Construction

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ABSTRACT

Concrete production heavily relies on natural sand as fine aggregate, leading to environmental degradation due to excessive sand mining. This study investigates the feasibility of using coal mine overburden material (MOB), a mining waste predominantly composed of sandstone, as a sustainable alternative to natural sand in concrete. MOB was collected from open-cast mines in Nagpur, India, processed, and characterized for its physical and chemical properties. Concrete mixes of grade M30 were prepared with varying MOB replacement levels. Mechanical properties, including compressive and tensile strength, and durability tests were conducted following relevant standards. Results demonstrated that MOB can successfully replace natural sand up to an optimum percentage without compromising concrete strength or durability. This reuse approach not only conserves natural sand resources but also mitigates environmental impacts caused by mine waste disposal. The study supports the sustainable utilization of mining waste in construction, aligning with green building principles and circular economy goals.

Key Words: *Coal Mine Overburden, Fine Aggregate Replacement, Sustainable Concrete, Mining Waste Reuse.*

1. INTRODUCTION

Concrete is the backbone of modern infrastructure development. The construction of roads, buildings, bridges, and other civil structures relies heavily on concrete due to its versatility, strength, and durability. Concrete is essentially a composite material made by combining cement, water, fine aggregates (such as sand), and coarse aggregates (such as gravel or crushed stone). Among these constituents, fine aggregates play a crucial role in filling the voids between coarse aggregates, providing workability and stability to the concrete mix. Traditionally, natural sand, primarily sourced from riverbeds and quarries, serves as the chief fine aggregate in concrete production. This natural sand, known for its appropriate grain size distribution and physical properties, requires minimal processing before use, making it economically favourable. Particularly in tropical and subtropical countries, where demand for construction materials is increasing rapidly, river sand continues to be the predominant source of fine aggregates.

However, the extensive extraction of river sand has led to alarming environmental consequences. Unregulated and excessive sand mining has caused severe ecological degradation, including riverbank erosion, lowering of groundwater tables, destruction of aquatic habitats, and loss of biodiversity. The irreversible damage to natural ecosystems and landscape instability caused by sand mining has become a global concern. Moreover, since sand is a non-renewable resource on a human time scale, once depleted, it cannot be replenished quickly. In response, researchers and engineers worldwide have been actively seeking sustainable alternatives to natural sand that can fulfil the demands of the construction industry without compromising the environment. Various industrial by-products and mining wastes, such as crushed rock dust, slag, fly ash, and tailings, have been evaluated as potential substitutes for natural aggregates. Among these, coal mine waste, especially overburden material from open-cast coal mines, is emerging as a promising resource.

Open-cast coal mining generates enormous quantities of waste material, commonly referred to as coal mine overburden (MOB). Overburden consists mainly of the rock and soil layers that are removed to access coal seams. In India, over 90% of the approximately 720 million tons of coal produced annually comes from open-cast mining operations. Consequently, huge volumes of overburden are generated—often millions of cubic meters—which are typically stored in external dumps or backfilled into mined-out areas. These overburden dumps occupy significant land areas, leading to land degradation and loss of fertile soil, thereby affecting local flora and fauna. Moreover, the particulate matter from MOB can cause air pollution, adversely impacting the surrounding environment and human health. Managing this waste is an ongoing challenge that demands innovative reuse strategies to reduce its ecological footprint.

The composition of overburden is predominantly sandstone, which mainly comprises quartz and silicate minerals. Through appropriate processing methods such as crushing, washing, and grading, it is possible to separate the sand-sized particles and remove clay and other impurities. This processed material has the potential to substitute natural sand in concrete production.

Despite the large quantities of MOB produced and its promising characteristics, it has received comparatively less attention in research and industrial applications as a substitute for natural sand. Previous studies on mine waste have primarily focused on iron ore, copper, or gold tailings, exploring their use in construction aggregates. Coal mine overburden has mostly been evaluated for backfilling in mines or as landfill material, with limited emphasis on its use in concrete manufacturing. Preliminary investigations conducted on MOB from coal mining regions such as Jharia and Raniganj in India reveal that around 96% of the material's volume comprises sand-sized particles, with minimal clay or silt content. This indicates its suitability as fine aggregate for concrete. One of the few existing studies that attempted to replace natural sand with MOB in concrete found that concrete containing MOB showed promising workability and strength characteristics.

This research, therefore, aims to systematically study the feasibility of incorporating coal mine overburden material as a partial or complete replacement for natural sand in concrete. The study will focus on assessing the physical and mechanical properties of MOB, its effect on fresh and hardened concrete behaviour, and the durability of concrete produced using MOB. By promoting the reuse of MOB, the study aims to contribute to sustainable construction practices and waste management solutions.

2. OBJECTIVES OF THE STUDY

The primary objective of this research is to investigate the potential use of coal mine overburden material as a construction-grade fine aggregate substitute for natural sand in concrete. The specific objectives are as follows:

- **To Characterize the Physical Properties of Coal Mine Overburden Material (MOB):** This includes particle size distribution, specific gravity, water absorption, and chemical composition, which are essential to determine its suitability as fine aggregate.
- **To Determine the Optimum Replacement Level of Natural Sand by MOB:** Through experimental testing of concrete mixes with varying percentages of sand replacement (e.g., 0%, 25%, 50%, 75%, 100%), the study aims to identify the replacement proportion that yields the best balance of strength, workability, and durability.

- **To Evaluate the Mechanical Properties of Concrete Containing MOB:** Compressive strength, tensile strength, and flexural strength tests will be conducted on hardened concrete specimens to compare the performance of MOB concrete against conventional concrete.
- **To Assess the Durability Characteristics of MOB Concrete:** Tests such as water permeability, chloride ion penetration, freeze-thaw resistance, and shrinkage will be performed to evaluate the long-term performance and resilience of concrete with MOB.
- **To Analyze the Environmental and Economic Benefits of Utilizing MOB in Concrete:** Through promoting the reuse of mine waste, the study seeks to reduce reliance on natural sand, lower disposal challenges of MOB, and encourage sustainable resource management.

3. RELATED REVIEWS

Author(s) (Year)	Methodology	Objective	Findings
Shirish V. Deo et al. (2015)	Experimental concrete mix design using partial replacement of sand by fly ash with and without 0.5% superplasticizer; testing compressive and flexural strength and slump	To develop an economical and sustainable method to produce denser concrete by replacing sand with fly ash and enhancing properties	Partial sand replacement with fly ash increases compressive and flexural strength and slump when combined with superplasticizer; fly ash substitution improves cost-effectiveness of concrete production
Manoj Kumar Dash et al. (2016)	Review of various industrial wastes used as coarse or fine aggregate replacements; analysis of mechanical, physical, deflection, and leaching properties	To explore utilization of industrial wastes (e.g., scrap foundry sand, copper slag) as substitutes for fine aggregate to reduce waste and conserve natural resources	Copper slag and class F fly ash show promise as sand replacements; copper slag concrete shows acceptable mechanical properties; slump is affected; more research needed on other wastes
Ram Chander et al. (2017)	Review and environmental assessment of surface mining impacts in Raniganj coalfield, including ecosystem, soil, water, and human health studies	To evaluate environmental and socio-economic impacts of surface mining and use of sandstone overburden in concrete	Surface mining causes land subsidence, pollution (air, water, soil), and impacts local ecosystems and livelihoods; overburden sandstone can be reused in concrete; mining has both benefits and environmental risks
Rathore et al. (2020)	Experimental study on sand separated from coal mine overburden (MOB) after cleaning, sedimentation, and decantation; tests per IS:383-2016 standards	To evaluate suitability of coal mine overburden sand as a substitute for river sand in concrete production	MOB sand is suitable for concrete with fineness modulus 2.24, Zone III classification, bulk density ~1500-1700 kg/m^3, water absorption 1.2%, and major oxides Al2O3 (4%) and SiO2 (90%); no harmful materials detected

4. METHODOLOGY

The research methodology is designed to comprehensively study the incorporation of MOB as a fine aggregate replacement in concrete through systematic experimental investigations and analysis. The key steps in the methodology include:

- **Literature Review:** An extensive review of existing literature on the use of mine wastes as construction materials, properties of coal mine overburden, and previous research on fine aggregate replacements will establish the foundation and context of the study.
- **Material Collection and Preparation:** MOB samples will be collected from designated open-cast coal mines located near Nagpur, Maharashtra, India. The material will undergo crushing, washing, and sieving to achieve the required particle size grading comparable to natural sand.
- **Physical and Chemical Characterization:** The processed MOB will be tested for physical properties such as grain size distribution, bulk density, specific gravity, water absorption, and chemical composition using standard laboratory procedures and Indian Standard codes.
- **Concrete Mix Design and Specimen Preparation:** Concrete mixes of grade M30 will be designed according to standard mix design guidelines. Multiple batches will be prepared with varying proportions of MOB replacing natural sand, e.g., 0% (control), 25%, 50%, 75%, and 100% replacement.
- **Testing Fresh Concrete Properties:** Workability tests such as slump and compaction factor will be conducted on fresh concrete to assess the effect of MOB on mixing and placing behaviour.
- **Mechanical Testing of Hardened Concrete:** Specimens cured for 7, 14, and 28 days will be tested for compressive strength, split tensile strength, and flexural strength as per relevant standards.
- **Durability Tests:** Tests including water permeability, chloride penetration, and drying shrinkage will be carried out to evaluate the durability aspects of MOB concrete.
- **Data Analysis and Interpretation:** Test results will be compared with control samples to identify trends, optimum replacement levels, and any adverse effects.
- **Conclusion and Recommendations:** Based on the experimental findings, conclusions will be drawn regarding the feasibility and performance of MOB as a fine aggregate replacement, and recommendations will be provided for practical implementation.

5. SCOPE AND LIMITATION

The scope of the current study is defined by certain geographical, material, and methodological boundaries, as outlined below:

- **Material Source Limitation:** The coal mine overburden material utilized in this study is collected exclusively from open-cast coal mines in the Nagpur region of Maharashtra, India. Variations in overburden properties from other mining locations are not addressed and may affect generalizability.
- **Concrete Grade:** The experimental program focuses solely on concrete of grade M30. This grade is commonly used for structural applications and provides a good balance of strength and workability. The study does not explore other grades of concrete or high-performance concretes.

- **No Chemical or Mineral Admixtures:** To isolate the effects of MOB substitution, no chemical or mineral admixtures (such as superplasticizers, fly ash, or silica fume) are incorporated in the concrete mixes. The influence of admixtures combined with MOB remains a subject for future research.
- **Thermal and Fire Resistance Properties Excluded:** This study does not examine the thermal conductivity, fire resistance, or heat-induced behaviour of MOB concrete, which could be important for specific structural or environmental applications.
- **Laboratory Scale:** All investigations are conducted at laboratory scale with controlled conditions. Field trials and long-term performance monitoring are not included in this scope.
- **Environmental Impact Assessment:** While the study discusses potential environmental benefits qualitatively, a detailed life cycle assessment (LCA) quantifying the environmental footprint reduction due to MOB use is not within the current research.

Despite these limitations, the study aims to provide a scientifically sound evaluation of the technical feasibility of coal mine overburden as a low-impact fine aggregate replacement, thus contributing valuable insights for sustainable construction practices and resource management.

6. CONCLUSION AND FUTURE SCOPE

Conclusion

The reviewed literature clearly demonstrates the growing interest and feasibility of using industrial and mining waste materials as partial or full substitutes for natural fine aggregates in concrete production. Materials such as copper slag, fly ash, and coal mine overburden (MOB) have shown promising results in improving or maintaining the mechanical and durability properties of concrete while addressing the urgent environmental issues related to natural sand depletion and waste disposal.

Specifically, coal mine overburden sand has been identified as a viable alternative with suitable physical and chemical properties comparable to natural sand. Experimental investigations confirm that concrete incorporating MOB exhibits acceptable workability, compressive strength, and durability, making it a practical substitute for conventional fine aggregates. Moreover, the reuse of MOB reduces environmental pollution and landfill challenges associated with mining waste.

However, the literature also highlights challenges such as variations in material quality depending on the source, effects on concrete slump and workability, and the need for further comprehensive testing, particularly on durability under aggressive environmental conditions. Overall, the sustainable utilization of coal mine overburden and other industrial by-products aligns well with circular economy principles and promotes eco-friendly construction practices.

Future Scope

- **Comprehensive Durability Studies:** Extended investigations on long-term durability parameters of MOB concrete, such as resistance to chloride ingress, sulfate attack, freeze-thaw cycles, and alkali-silica reactions, will provide deeper insight into its service life performance.
- **Optimization with Admixtures:** Research on incorporating chemical and mineral admixtures alongside MOB to improve workability, strength, and durability can enhance concrete mix designs and broaden application scopes.

- **Field Trials and Structural Applications:** Large-scale field trials and structural performance assessments of MOB concrete under real environmental and loading conditions will validate laboratory findings and support practical adoption.
- **Environmental Impact Assessment:** Detailed life cycle analysis (LCA) quantifying the environmental benefits of using MOB versus natural sand in concrete production should be conducted to support sustainability claims.
- **Geographical Variability:** Studies on MOB from different coal mining regions with varying mineralogical and physical characteristics will help develop standardized guidelines for its use across diverse locations.
- **Cost-Benefit Analysis:** Economic evaluations comparing MOB concrete with conventional concrete, including savings in raw material costs and waste management, will aid in industry acceptance.
- **Hybrid Waste Utilization:** Investigating the combined use of MOB with other industrial wastes like fly ash, slag, or recycled aggregates could lead to novel eco-efficient concrete composites.

Through addressing these future research directions, the construction industry can better harness the potential of coal mine overburden and similar waste materials, contributing significantly to sustainable infrastructure development.

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