SSRG International Journal of Civil Engineering
ISSN: 2348-8352/ https://doi.org/10.14445/23488352/IJCE-V13I8P107

Volume 13 Issue 8, 111-136, August 2026

Original Article

Experimental Evaluation of Concrete Incorporating Processed Overburden Sand from Lignite Mines as Sustainable Fine Aggregate

Kolar Dinesh Singh[1], M. Purushothaman[2]

[1,2]*Department of Civil and Structural Engineering, Annamalai University, Tamil Nadu, India.*

[1]*Corresponding Author : kolardineshsingh@gmail.com*

Received: 16 April 2026 Revised: 10 June 2026 Accepted: 14 July 2026 Published: 31 August 2026

Abstract - *The high demand of natural river sand for concrete production has led to its rapid depletion and increased the necessity to explore sustainable alternatives to fine aggregates. The overburden materials generated during open cast mining have emerged as an abundant resource with significant potential for beneficial utilization. The current research aims at examining the suitability of processed overburden sand (POBS) derived from lignite mine overburden as a substitute for natural river sand in concrete at replacement levels of 20%, 40%, 60%, 80% and 100%. Fresh concrete characteristics were determined using slump test, Vee-Bee test, and flow table tests. Hardened concrete properties including compressive strength, flexural strength, stress-strain characteristics, modulus of elasticity, and durability parameters like water absorption, sorptivity, acid resistance, sulphate resistance, and salt resistance were studied. Workability decreased progressively with increasing POBS content, while all mixes maintained acceptable values for medium workability concrete production. Hardened properties showed a modest reduction up to 60% replacement, beyond which the rate of reduction became marginal. A similar trend was observed in durability performance. All mixes, including 100% POBS, satisfied the strength requirements of M20 grade concrete. The 60% replacement level was identified as optimal, providing a balanced performance in terms of strength, workability, and durability. The observed behavior is attributed to the gradation and morphology of POBS. Overall, the results demonstrate that POBS is a feasible and sustainable substitute to natural river sand in concrete.*

Keywords - *Concrete performance, Durability, Fine aggregate replacement, Lignite mines, Processed overburden sand.*

1. Introduction

Concrete continues to be the most widely employed building material in contemporary infrastructure owing to its flexibility, strength, and cost-effectiveness. Fine aggregate forms one of the largest portions of concrete and natural river sand has always been the primary source of fine aggregate. But the fast-paced development of infrastructure facilities has caused an exponential increase in the extraction of river sand, leading to environmental damage, water table imbalance, bank erosion of rivers, and depletion of natural resources. The building sector requires large amounts of fine aggregates each year, whereas the mining sector, especially mining of coal and lignite, produces a significant amount of overburden waste. Overburden material in the case of lignite mining involves the initial layers of soil, rocks, and sub-soils that have to be stripped away in order to mine the lignite beneath, with up to 7 tons of overburden produced for each ton of lignite mined [3, 4]. Studies show that the use of processed coal mine overburdens is feasible as fine aggregate replacement in mortars and concretes as long as proper control measures are taken [5, 6]. Sand extraction and processing from coal mine dumps have been recognized as a promising technique for efficient utilization of resources, especially in areas where the availability of river sand is becoming increasingly scarce [7]. The use of M-sand derived from overburden processing has demonstrated promising results when used in mortars, suggesting its applicability to concretes as well [8]. Reviews conducted on the topic of lignite overburden based construction materials have emphasized that the reuse of mine wastes would greatly diminish the demand for natural aggregates [9, 10]. Several studies have shown that the use of coal mine overburden materials will affect fresh concrete and hardened concrete properties according to the level of replacement and type of particles used. The use of overburden sand in cement mortars has been proven to exhibit adequate strength development [11], whereas concrete mixes using overburden waste rocks have proven to be resistant to corrosion and durable [12]. Likewise, the use of Coal Mine Overburden Material (CMOB) exhibited inadequate workability but had adequate compressive strength [13]. The investigations on compressive strength and chemical durability have shown that even high percentages of overburden dump materials as replacements can sustain structural quality concrete provided that suitable mix designs are employed [14]. Water absorption, sorptivity, and permeability parameters for self-consolidating concrete mixes containing CMOB were found to be satisfactory [15]. Moreover, microstructural analysis has indicated that decreased strengths in high replacement levels of CMOB are related to greater porosity and weakness in interfacial transition zones [16]. The effects of particle absorption and angularity of CMOB on mortar mix design were also investigated [17, 18].

Modern advances in sustainable concrete technology place greater emphasis on the utilization of waste products from industries and mining sectors as effective replacement options to traditional concrete aggregates with the intention of conserving resources and minimizing ecological impacts. Materials derived from overburden of mines and other mineral waste streams have been identified to have excellent engineering properties, especially when well-graded [19]. According to global sustainability investigations, there is an urgent need for alternatives to natural river sand due to their excessive mining [20]. Standardization of alternative aggregates has thus become essential, with their grading, density, and absorption characteristics being examined in accordance with established standards and tests on conventional aggregate material [21, 22].

For sustainable use in the manufacture of concrete, however, the integration of these materials should also conform to existing engineering guidelines for concrete production, which include proportioning, fresh concrete examination, strength determination, and concrete deformation properties [23-27]. Sustainable construction material technologies that have emerged recently reveal that mineral wastes, when processed effectively, can be integrated into conventional concrete technologies without deviating much from existing engineering practices. These technologies have been recognized as critical to the efficient manufacture of concrete in areas that lack sufficient sand but generate mining waste [28]. Though there have been many studies carried out in the area of using coal mine overburden, bottom ash, mine tailings, and other industrial waste products as sustainable alternatives to fine aggregates in cementitious materials, most of these studies have largely confined their scope to only partial replacement rates, mortar studies, or limited mechanical properties investigation.

Further, comprehensive research studies on the use of processed overburden sand (POBS) from lignite mines at higher replacement rates of up to 100% in conventional concrete are limited. Moreover, in previous research, there has been emphasis on the compressive strength property alone without much coverage of the fresh concrete performance, stress-strain relationship, modulus of elasticity, and durability under various environmental conditions.

The uniqueness of the present study is the overall evaluation of the processed overburden sand obtained from mining waste as an eco-friendly alternative to river sand in M20 grade concrete from the range of 0% to 100% replacement. While the earlier investigations focused mainly on mechanical properties alone or on limited replacement ratio, the current study evaluates fresh concrete performance, compressive strength, flexural strength, stress-strain behaviour, modulus of elasticity, water absorption, sorptivity, acid resistance, sulphate resistance, and salt resistance.

Moreover, this study presents a comparison of all the replacement ratios to establish the best possible use of the processed overburden sand for sustainable management of mining waste and natural river sand resources. As a result, the purpose of this research is to evaluate the performance and practicality of processed overburden sand from lignite mines as an environmentally sustainable replacement for fine aggregates in M20 concrete. The experiment's primary focus is on studying the performance characteristics of processed overburden sand, such as new concrete qualities, mechanical behavior, deformability, and durability.

2. Literature Review

The research towards exploring a sustainable alternative source of fine aggregates has been greatly amplified over the last few years because of the limitations placed on river sand extraction. Further the large quantities of mining waste generated provide an abundant resource for their gainful utilization. Research has been conducted using mining overburden, bottom ash, industrial wastes, and synthetic waste sources to replace fine aggregates in the concrete mix.

2.1. Coal Mine Overburden Waste as Fine Aggregate

There has been an increasing interest for sustainable sources of aggregates apart from the natural river sand due to restrictions imposed environmentally on the mining process and also the massive production of overburden waste as a result of mining activities. Some of the sources that have received significant consideration include mine overburden material which is abundant, needs minimal processing, and can act as fine aggregates in cementitious products provided adequate gradation is attained [1, 2]. It has been established environmentally that using mine waste as opposed to natural sand will minimize environmental degradation and also recover resources from the mine [3, 4].

Earlier research showed that processed mine overburden material can be used to produce construction aggregate through particle size classification with satisfactory mechanical properties in both mortar and concrete mixes [5, 6]. Sand recovered from mine dumping sites has also been found to be useful in reusing mining waste as a large-scale construction material [7]. Concrete mixes with processed mine overburden have been found to show adequate performance even when the replacement level was limited to a certain extent [8]. Lignite mine overburden sand was similarly found to yield fine aggregates derived from overburden, which provided stable mechanical behavior when used partially in concrete mixes [9]. Tests conducted with mortars made from processed mine overburden showed that these fine particles can perform satisfactorily when used as fillers in mortars [10].

Recent research studies reveal that processed coal mine overburden can be successfully employed as alternative fine aggregate after the process of crushing, washing, grading, and quality control. The use of processed overburden material is beneficial for sustainable mining operations due to the reduction of waste disposal and also reduces the use of natural river sand. Research work reveals that the processed overburden sand has adequate performance in engineering point of view, provided its physical properties fulfill the grading criteria required for concrete aggregates. Moreover, researches reveal that processing has notable effect on particle packing properties which lead to acceptable properties of fresh and hardened concrete.

2.2. Performance Features of Alternate Fine Aggregates in Concrete

Particle shape, surface roughness, and absorption properties of alternate fine aggregates play an important role in their performance as fresh concrete materials. Concrete mixes made from mine tailings fine aggregates tend to have lower workability than river sand mixes due to their angular shapes and higher water absorption during the mixing process [11, 12]. However, even high substitution rates can retain the required compressive strength as long as appropriate particle sizes and adequate moisture control are achieved [13]. Mineral composition of mine wastes may affect pore development, density of the material mixture, and thus early hydration and hardened structure [14, 15]. Accordingly, finely graded overburden wastes were found to be suitable materials for structural concretes at the right ratio [16]. The physical characteristics of alternative fine aggregates are mainly governed by the particle shape, mineralogy, water absorption, and texture. The processed overburden sand is more angular in shape and has a relatively rougher texture compared to natural river sand. This causes the processed overburden sand to have higher internal friction and results in poor workability of the fresh concrete. However, the rough texture ensures that there is good mechanical interlocking of particles and results in sufficient strength development provided proper mix design is used. There are recent findings that proper particle size distribution can adequately mitigate the higher water requirement of processed overburden aggregates [1, 7, 9, 11, 13].

2.3. Durability and Pore Structure Characteristics

Durability studies show that the porosity of particles and water absorption capacity of mined aggregates affect the penetration of water into the hardened concrete through capillary transport. However, fine particles obtained from overburden materials may result in increased internal pore connectivity, but optimized particle gradation will control the permeability of the material [17, 18]. Additionally, the optimization of aggregate handling and particle size improves interfacial bond strength between aggregates and the cement matrix, preventing the formation of cracks when exposed to service conditions [19].

In sustainable concrete construction using overburden, low levels of internal pore connectivity in combination with proper aggregate gradation that allows for denser matrix can be beneficial [20]. Structural stability is particularly important for the prevention of repeated cycles of wetting and drying processes or chemical attack on the material. The criterion of durability is one of the key requirements for the evaluation of the applicability of processed overburden sand in concrete on a long-term basis.

Previous research has shown that the higher water absorption and porous structure of sand might affect the permeability and resistance of aggressive chemicals. Nevertheless, the optimal grading of particles and mix proportions contribute greatly to increasing the density of cement matrix and decrease the connectivity of pores; therefore, the resistance of sand to sulfates, chlorides, and acids becomes better. It means that the evaluation of durability in aggressive environments becomes an indispensable stage in proving sustainability of processed overburden sand [1, 7, 11, 13].

2.4. Standardization and Current Sustainable Material Innovations

The suitability of fine aggregates for use in concrete manufacture should also be considered in terms of standardized gradation and material properties. The gradation requirements of aggregates under Indian Standard Codes IS 383: 2016 serve as the criteria in determining the possibility of using processed overburden as fine aggregates in concrete [21]. The physical characteristics of aggregates are determined in line with standardized methods for aggregate testing, which include specific gravity, density, water absorption, and void ratio [22].

Moreover, for the proper proportioning and strength determination of concrete with alternative aggregate materials, the criteria for designing and testing concretes in accordance with IS 456, IS 10262, and other relevant standards for concrete strength testing should also be adhered to [23-26]. The recent literature on sustainable construction has focused more on efficient building material systems in terms of resource use so as to reduce extraction impacts on the natural sand resources.

Various global studies have revealed serious environmental repercussions due to over-extraction of sand

and stressed on the need for alternative aggregate materials through industrial and mining waste products [20]. On the other hand, mineral resource analysis within sustainability suggests the need for alternative materials for the construction industries in developing countries [28]. The modern progress in the field of sustainable concrete has been more and more focused on the deployment of industrial and mining waste in the context of circular economy.

Overburden sand that has been processed can not only save natural aggregates, but also reduce negative impact on the environment related to mining waste disposal. Guidance from relevant standards that control grading of aggregates, density, water absorption, concrete mixture and concrete strength is vital for engineering application. The utilization of processed overburden material as a fine aggregate in concrete is both environmentally friendly and technically viable for sustainable infrastructure construction [20, 21, 28].

2.5. Identified Gap in Research and Scope of the Current Research Work

Numerous experimental investigators have studied the utilization of overburden material of various coal mines across India as alternative fine aggregates in concrete. These investigations have primarily emphasized on coal mines from Jharkhand [2, 6, 7, 11, 15], Chhattisgarh [3], Telangana [8], [16], Odisha [1, 5, 13, 18] and Maharashtra regions [4, 17]. The above studies have covered properties of the fine aggregates processed from the overburden materials of these coal mines including the detailed investigations on fresh concrete properties, mechanical and durability properties at various levels of replacement. Although the existing studies have established the potential of coal mine overburden derived sand as a fine aggregate in concrete, these studies differ in terms of source of parent overburden material, its processing, replacement level and grade of concrete.

Based on literature reviewed in this study, relatively few investigations have examined the processed overburden sand of lignite mines in Tamil Nadu region as a fine aggregate in mortar and concrete [9, 10]. These studies have covered the properties of overburden material and characterization of processed overburden sand. However, they primarily focused on complete replacement of material in mortar and concrete with emphasis on compressive strength testing.

The fresh properties of concrete for evaluating the workability and detailed assessment of other mechanical properties such as flexural strength and elastic modulus were not sufficiently addressed in the existing studies. These studies have also identified the need for further investigation of long term durability of lignite overburden sand as a fine aggregate in concrete. The study on variation of durability properties at different replacement levels and comparison with a control mix using river sand remains limited in the available literature.

Table 1 provides an overview of past research into coal and lignite mine overburden which have been considered as alternatives to fine aggregate either in raw or processed form for utilization in mortar and concrete. The details of overburden material, fine aggregate, replacement level and the parameters that were mainly considered along with the identified gap of the respective study are presented. From the comparison, it can be seen that a considerable number of studies have focused on material characterization, mortar testing, individual aspects of mechanical and durability properties separately.

However, a clear gap identified in these studies is the systematic and integrated assessment of fresh, mechanical and durability properties of concrete utilizing processed overburden sand from lignite mines at various levels of replacement. This study is thus aimed at addressing these issues following a holistic approach by evaluation of fresh, mechanical and durability properties in a combined experimental programme covering various levels of fine aggregate replacement in M20 grade concrete.

The scope of the present study takes into account the combination of slump properties, Vee-Bee, flow, compressive strength, flexure, elasticity, sorptivity, water absorption, acid resistance, sulphate resistance, and salt resistance all together for a systematic performance evaluation of processed overburden sand from lignite mines as a fine aggregate in concrete.

Thus, the novelty of the present study is integrated assessment of all the above properties by using processed overburden sand in concrete at different replacement levels. Further, a comparison of these properties with reference to the control mix incorporating 100 % river sand provides a comprehensive understanding of the overall effect of fine aggregate replacement. This helps in identifying an appropriate extent of replacement of processed overburden sand from lignite mines for a balanced performance in concrete supporting its practical engineering application as an alternative fine aggregate.

3. Materials and Methods

The experimental study sought to investigate the viability of processed overburden sand sourced from lignite mines as a fine aggregate in concrete. This was carried out through physical characterization of processed overburden sand (POBS) followed by verifying its compliance with respective Indian standards for assessing the suitability of fine aggregates in concrete.

Further, this section covers the physical properties of natural river sand for providing a comparison with respect to the proposed alternative fine aggregate. This section also covers the mix design methodology followed for the concrete mixes.

Table 1. Summary of previous studies and identification of research gap

Material	Fine aggregate used	Replacement level	Main parameters studied	Research gap identified from the reported study	Reference
Coal mine overburden, Jharsuguda region, Odisha	CMOB (Coal Mine Overburden)	Varying levels up to 100%	Strength, durability properties of mortar and concrete	Focus on coal mine overburden of Odisha	[1, 5, 13]
Coal mine overburden, Dhanbad region, Jharkhand	CMOB	100% only	Material characterization, Mortar properties	Intermediate replacement levels not investigated within the reported scope	[2]
Coal mine overburden, Surguja region, Chhattisgarh	CMOB sand	Not investigated	Material characterization	Mechanical and Durability properties of concrete were outside the reported scope	[3]
Coal mine overburden, Chandrapur region, Maharashtra	Extracted sand from CMOB	100% only	Material characterization and concrete compressive strength	Durability properties of concrete were outside the reported scope	[4]
Coal mine overburden material, Jharkhand	CMOB sand	Varying levels up to 100%	Fine aggregate properties and concrete mechanical properties	Durability properties of concrete were not evaluated within the reported scope	[6]
Coal mine overburden waste rock, Dhanbad region, Jharkhand	CMOB	100% only	Corrosion resistance	Focus on coal mine overburden of Jharkhand	[7]
Lignite mines overburden, Neyveli, Tamil Nadu	Sand extracted from lignite mine overburden	100% only	Material characterization	Intermediate replacement levels not investigated within the reported scope	[9]
Lignite mines overburden, Tamil Nadu	Sand extracted from lignite mine overburden	Masonry mortar	Masonry mortar performance	Mechanical and Durability properties of concrete were outside the reported scope	[10]
Mine overburden sand, Warangal region, Telangana	Processed CMOB sand	100% only	Material characterization and concrete compressive strength	Durability properties of concrete were outside the reported scope	[16]

The procedures followed for assessing the fresh concrete properties, mechanical strength testing and durability aspects of concrete mixes at various POBS replacement levels are included.

3.1. Materials Used

The major binder material used in this experiment was Ordinary Portland Cement 43 grade, which meets the requirements of Indian Standard (IS) 269: 2015 - Ordinary Portland Cement—Specification. The physical properties of the cement are shown in Table 2. The fine aggregate used in this study was derived from overburden materials obtained from lignite mines in Tamil Nadu's Neyveli region. The processing included crushing, washing, sieving, drying and grading operations to separate the sand fraction and achieve a gradation comparable to natural fine aggregates. This fine aggregate thus obtained will be henceforth called Processed Overburden Sand (POBS). Readily applicable River Sand (RS) was utilized as a natural fine aggregate.

Table 2. Physical characteristics of Ordinary Portland Cement (OPC 43 Grade)

Property	Value
Consistency (in %)	28.5
Setting time (in minutes)	
Initial	125
Final	205
Specific gravity	3.12
Compressive strength (in MPa) with Tamil Nadu Minerals Limited (TAMIN) Sand	
3 days	26.5
7 days	38.5
28 days	50.5
Fineness in Air Permeability (m^2/Kg)	324.7

The physical characteristics of fine aggregates utilized in the experimentation were determined as per relevant Indian Standards. The particle size distribution and the percentage of material finer than 75 µm for both Processed Overburden Sand (POBS) and River Sand (RS) were determined in accordance with IS 2386 (Part 1) [29]. The fineness modulus was computed based on the cumulative retained mass values of sieve analysis using IS sieves between 10 mm to 0.150 mm. The specific gravity, water absorption, and bulk density of the fine aggregates were measured following the procedures outlined in IS 2386 (Part 3) [22]. These tests are very important to understand their effect on performance of POBS as fine aggregate at various replacement levels on concrete properties. From previous literature, it has been observed that controlled grading of overburden materials mined from the earth is necessary for ensuring proper packing, minimizing generation of fines, and suitability with the cementitious medium. It has been seen that proper processing of overburden materials increases their suitability as a substitute of fine aggregates through obtaining better grading. In the current research work, processing was performed with an objective to achieve a fine aggregate fraction that can be used in concrete mix design and hence evaluate the suitability of POBS as a substitute source of natural river sand in M20 concrete mixes at various substitution levels. RS was used as a reference fine aggregate for control concrete mixes in this study. The use of processed overburden sand from lignite mines as an alternative fine aggregate in concrete overcomes the shortage of river sand and promotes sustainable mining operations. Tables 3 and 4 display the particle size distribution and other physical properties of POBS. Tables 5 and 6 exhibit the gradation and physical properties of RS, respectively. The gradation curves of POBS and RS as exhibited in Figure 1 and Figure 2 correspondingly, satisfy Zone II grading requirements of IS 383:2016 specifications indicating their suitability as fine aggregates for concrete.

Table 3. Particle size distribution of Processed Overburden Sand (POBS) and compliance with IS 383:2016 Zone II grading requirements

Sieve Size (mm)	Passed %	Zone-II recommendations as per IS 383: 2016
10	100	100
4.75	99	90-100
2.36	92	75-100
1.18	81	55-90
0.6	53	35-59
0.3	24	8 to 30
0.15	2	0-20

Table 4. Physical characteristics of Processed Overburden Sand (POBS)

Characteristics		Value
Specific gravity		2.48
Fineness modulus		2.49
Grading zone		II
Water absorption	%	2.82
Bulk density (loose)	kg/l	1.49
Bulk density (After void removal)	kg/l	1.64
Materials finer than 75 microns	%	3.5

The appropriate usage of processed overburden sand as fine aggregate does not depend only on the grading features but also on the mineralogy, particle shape, density, and water absorption property of processed overburden sand. The processed overburden sand utilized in the current study met the grading criteria of Zone II of IS 383:2016, thereby proving its suitability in concrete fabrication. The higher value of water absorption related to that of natural river sand can be attributed to the presence of rough surface and porous bond of particles due to the effect of geological weathering and mining activities. This experimental outcome explains the increase in amount of water required by the fresh concrete and better mechanical interlocking of aggregate and cement paste [13-15, 18, 21]. Crushing, washing, sieving, and grading procedures followed in material processing helped in getting homogenous particle size distribution and elimination of any kind of impurities from the raw overburden material. Proper processing of overburden material is necessary to get consistent engineering properties and improve the performance of concrete containing overburden sand [4, 5, 16].

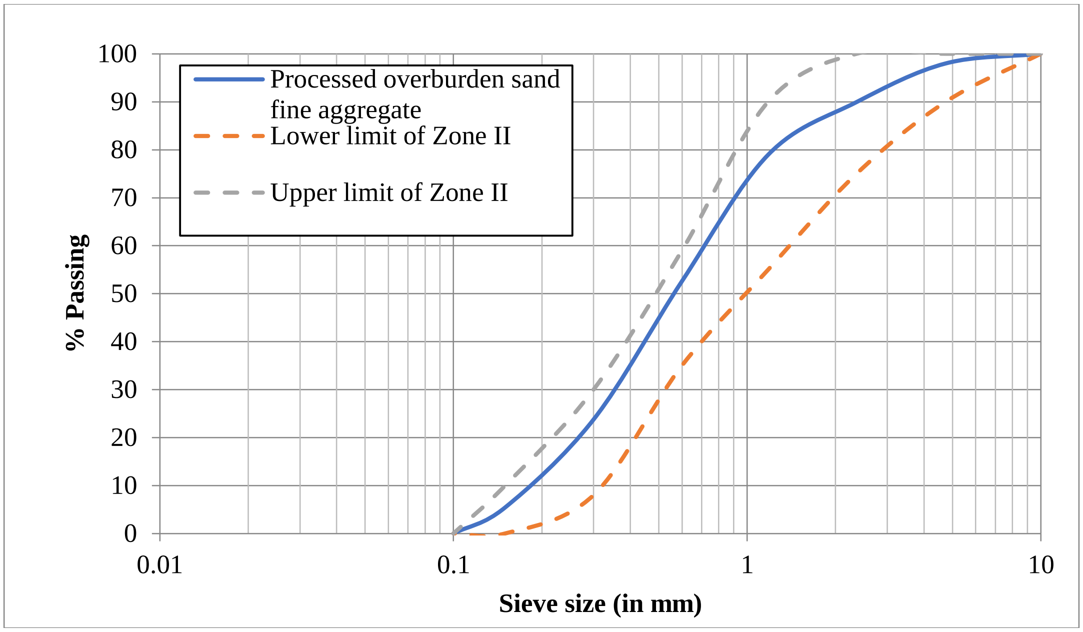

Fig. 1 Gradation curve of Processed Overburden Sand (POBS)

Table 5. Natural River Sand (RS) particle size distribution and compliance with IS 383:2016 Zone II grading requirements

Sieve Size (mm)	Passed %	Zone-II recommendations as per IS 383: 2016
10	100	100
4.75	98	90-100
2.36	89	75-100
1.18	72	55-90
0.6	38	35-59
0.3	15	8 to 30
0.15	3	0-20

Table 6. Physical characteristics of Natural River Sand (RS)

Characteristics		Value
Specific gravity		2.66
Fineness modulus		2.85
Grading zone		II
Water absorption	%	0.68
Bulk density (loose)	kg/l	1.66
Bulk density (After void removal)	kg/l	1.8
Materials finer than 75 microns	%	1.9

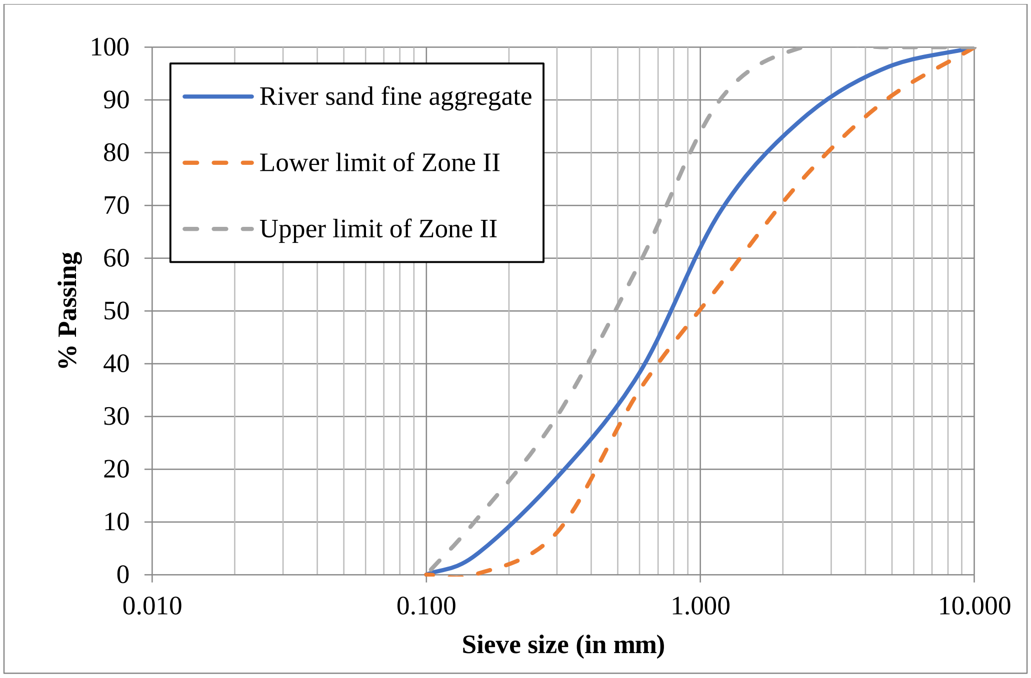

Fig. 2 Gradation curve of Natural River Sand (RS)

Fig. 3 Processed Overburden Sand (POBS) and Natural River Sand (RS)

Table 7. Physical characteristics of coarse aggregate used in concrete mixes

Characteristics	Value
Specific gravity	2.70
Fineness modulus	6.63
Water absorption	0.2 %

All concrete mixes contained coarse aggregate with a maximum of 20 mm nominal particle size and the properties are shown in Table 7. During concrete mixing and curing operations, clean water was utilized.

3.2. Rationale behind the Selection of Processed Overburden Sand Replacement Levels

Processed overburden sand replacement levels were selected in 20% increments (0%, 20%, 40%, 60%, 80%, and 100%) to analyze the experimental outcome of incremental addition of processed overburden sand on the characteristics of fresh concrete. The selected replacement levels would give an exhaustive insight into the process of moving from regular concrete to concrete with complete replacement of processed overburden sand. This method has already been widely employed in many past studies for finding out the optimum level of replacement [1, 2, 5, 7, 9, 13]. Incremental replacement is useful in evaluating changes in workability, strength gain, deformation behavior, and durability of concretes with varying content of processed overburden sand. The use of a complete replacement level in the design of the experimental study provides useful insight into the maximum extent that lignite mine overburden can be utilized as an auxiliary fine aggregate. Incremental replacement method plays an important role in conserving natural resources by reducing reliance on natural river sand, while at the same time using mining waste for producing concrete.

3.3. Concrete Mix Proportioning

Concrete mixes for grade M20 concrete mix proportion were designed in accordance with IS 10262: 2019 and IS 456: 2000 requirements. A water-to-cement ratio of 0.50 was used, with cement, fine aggregate, and coarse aggregate in the proportions of 1:2.16:3.53. The river sand fine aggregate based concrete mix was considered as control mix CC-R100. The river sand (RS) was substituted by Processed Overburden Sand (POBS) at six levels: 0%, 20%, 40%, 60%, 80%, and 100% for studying the effect of POBS fine aggregate on concrete properties. The modified mixes based on their replacement levels were designated as C1-R80-O20, C2-R60-O40, C3-R40-O60, C4-R20-O80 and C5-O100 as shown in Table 8. It was envisaged that the inclusion of several replacement ratios would provide a clear picture of the progressive effect of POBS on the characteristics of fresh and hardened concrete. The proportion of the concrete mixes was set in line with the requirements of the standards IS 10262:2019 and IS 456:2000 for M20 grade of concrete targeting medium workability and strength properties. In all the experiments, the w/c ratio of 0.50 was constantly maintained to make sure that the effect of processed overburden sand used as partial replacement was assessed independently from the change in water. All concrete mixes were made by adding the same amounts of cement, coarse aggregates, and water but varying fine aggregates based on the different replacement ratios.

Table 8. Details of concrete mix proportions for control and POBS incorporated mixes

Mix ID	River Sand	Processed Overburden Sand	Cement (kg/m³)	RS F.A (kg/m³)	POBS F.A (kg/m³)	C.A (kg/m³)	Water (kg/m³)
CC-R100	100%	0%	340	733	0	1201	170
C1-R80-O20	80%	20%	340	586	147	1201	170
C2-R60-O40	60%	40%	340	440	293	1201	170
C3-R40-O60	40%	60%	340	293	440	1201	170
C4-R20-O80	20%	80%	340	147	586	1201	170
C5-O100	0%	100%	340	0	733	1201	170

3.4. Workability Test

The slump test, Vee-Bee test, and flow table test were used to investigate the behavior of fresh concrete shortly after it was mixed. The slump test was performed to determine the consistency and workability of the concrete mixtures. The Vee-Bee test was used to assess compactness and consistency when mixed under vibration, particularly for low workability mixes. The flow table test was used to measure the mobility and flow qualities of fresh concrete when repeatedly vibrated. The choice of these tests is justified by the high absorption rate of POBS and rough surface texture compared to river sand. Workability tests were done immediately after mixing to avoid the effect that might result from loss of workability as a function of time. Tests of slump, Vee-Bee consistency, and flow table test were chosen due to the fact that together they give enough information about the workability, compaction, and mobility of the fresh concrete. The combination of these tests makes it feasible to evaluate the performance of the fresh concrete better than by employing any one of the tests [21, 25].

3.5. Mechanical Properties Assessment

The mechanical parameters were assessed using compressive strength, flexural strength, and modulus of elasticity. Compressive strength was measured using test cubes at 7, 14, and 28 days ages of curing. The flexural strength of prism specimens was measured under two-point loading for similar curing times. The modulus of elasticity was determined using cylindrical specimens.

3.6. Program for Testing Durability

Tests for determining durability characteristics include water absorption test, sorptivity test, acid attack test, sulphate attack test, and salt attack test. Acid attack test covers hydrochloric acid attack and sulphuric acid attack, while sulphate attack test is carried out by soaking the specimens in sodium sulphate. Salt attack test is performed using sodium chloride solution. To determine the long-term behavior of the concrete incorporating processed overburden sand, the durability performance was tested using water absorption, sorptivity, acid resistance, sulphate resistance, and salt resistance. Water absorption and sorptivity tests were performed to determine the characteristics of permeability and water transportation via capillarity in the concrete matrix. Chemical durability was investigated by exposing the concrete samples to hydrochloric acid solution, sulphuric acid solution, sodium sulphate solution, and sodium chloride solution for designated time periods. After that, the change in compressive strength and the degree of deterioration were carefully analyzed to evaluate the resistance of each concrete mixture against the aggressive environment. The chosen durability tests, on the whole, cover all the major deteriorations mechanisms encountered by concrete building in their service life.

4. Experimental Outcomes

The experimental outcomes of the fresh concrete, mechanical strength, and durability tests provide insight into the consequences of using POBS as a fine aggregate replacement for river sand in concrete. This section presents the results of workability, compressive, flexural strength, stress-strain characteristics. It also covers the durability aspects such as water absorption and resistance to different chemical exposures. Further, the variations of the measured properties are compared with the reference control mix.

4.1. Workability

The fresh concrete workability was found using a slump cone test, Vee-Bee test, and flow table test to evaluate the effect of the processed overburden sand on the consistency, compactability, and mobility of the material. The slump test determines the fresh concrete workability, while the Vee-Bee test evaluates its stiffness when vibrated.

4.1.1. Slump Test Results

As shown in Table 9, the slump values in the slump test reflect a steady decline in workability as the proportion of processed overburden sand in place of river sand increases. The reason behind this trend lies in the physical characteristics of POBS such as higher angularity, surface roughness, and increased fines content, which elevate inter-particle friction and water demand compared to RS.

Fig. 4 Slump test appearance of concrete mixes at different replacement levels of Processed Overburden Sand (POBS)

Table 9. Slump test results of concrete mixes incorporating Processed Overburden Sand (POBS)

Mix ID	Slump Value (mm)
CC-R100	95
C1-R80-O20	85
C2-R60-O40	75
C3-R40-O60	70
C4-R20-O80	65
C5-O100	60

4.1.2. Vee-Bee Consistency Test Results

In Table 10, the Vee-Bee consistency values demonstrate a gradual rise in vibration time from 3 seconds for the control concrete to 12 seconds when river sand is fully replaced by overburden sand. It clearly implies that the workability of the fresh concrete becomes poor and it exhibits greater stiffness. The angular shape and high-water absorption of overburden sand cause increased internal friction due to which more vibration time is needed to make the mix remouldable dynamically.

Table 10. Vee-Bee Consistency Test Results of Concrete Mixes Incorporating Processed Overburden Sand

Mix ID	Vee-Bee Time (seconds)
CC-R100	3
C1-R80-O20	5
C2-R60-O40	7
C3-R40-O60	8
C4-R20-O80	10
C5-O100	12

4.1.3. Flow Table Test Results

The results obtained from the flow test table are summarized in Table 11. There is an observed decrease in flow values from 118% for the control mix to 94% when the river sand is replaced with processed overburden sand in full measure. The trend observed clearly indicates that the increase in percentage of processed overburden sand in fresh concrete decreases its mobility due to dynamic loading. The major reason for such decreased flow values could be linked to the high-water absorption capability of the processed overburden sand. It is evident from the progressively decreasing slump, increasing Vee-Bee and decreasing flow values that there is an impact of using processed overburden sand on the rheological behavior of fresh concrete. Increased ability to absorb water and irregular particle shape of processed overburden sand results in increased internal friction among the particles of aggregates and led to decreased mobility of the fresh concrete mixture. Although workability of concrete has been decreased due to these reasons, all the concrete mixtures were still within acceptable medium workability range for M20 conventional concrete. It is clear from the above discussion that processed overburden sand can be utilized as a fine aggregate in sustainable way.

Table 11. Flow table test results of concrete mixes incorporating Processed Overburden Sand (POBS)

Mix ID	Flow Value (%)
CC-R100	118
C1-R80-O20	112
C2-R60-O40	106
C3-R40-O60	102
C4-R20-O80	98
C5-O100	94

4.2. Compressive Strength Test Results

Results of compressive strengths at ages 7, 14, and 28 days show that the compressive strength reduces progressively with an increase in POBS content (replacing natural river sand) from zero to 60%. This can be largely because of the increased surface roughness and angularity, as well as high water absorption rate, exhibited by POBS particles and resulting in poor compactability of fresh concrete and packing efficiency of the cement matrix. Also, the high porosity of POBS particles is likely to result in the creation of more voids. Above the 60% replacement ratio, the decline in strength becomes marginal, and the compressive strength results of 80% and 100% replacement ratios do not differ substantially at any curing age. This observation implies that beyond a certain point, the concrete mass achieves an internal structure that is relatively stable, and additional incorporation of POBS would not lead to a corresponding decrease in strength. This may be attributed to progressive adaptation of the cement matrix to the modified aggregate network, enabling efficient stress distribution through the new interfacial transition zone. The consistency in strength at high replacement ratios also implies that POBS has enough mineral stability to act as a fine aggregate structure without disturbing hydration processes severely. This clearly signifies that grading the overburden material is essential for mechanical behavior even at high replacement ratios.

It is apparent from the above findings of the compressive strength tests that there is a gradual reduction with the increase in the quantity of processed overburden sand used in the concrete mixture; but the decrease in compressive strength is quite lower beyond the 60 percent replacement ratio. In other words, it can be said that as the concrete matrix gradually starts adjusting itself with the change in the aggregate system, the strength of the mixture also remains quite consistent after reaching beyond a particular limit of replacement of aggregates.

Another critical conclusion from the findings is that the compressive strength criteria for M20 grade concrete is fulfilled by all concrete mixtures. This means that processed overburden sand is capable of replacing natural river sand in concrete without affecting its structural integrity. From the engineering application aspects, the 60 percent replacement ratio appears to be the most desirable replacement ratio.

Table 12. Compressive strength of concrete mixes incorporating Processed Overburden Sand (POBS)

Mix ID	7 days (MPa)	14 days (MPa)	28 days (MPa)
CC-R100	21.33	26.4	30.29
C1-R80-O20	20.80	25.68	29.12
C2-R60-O40	19.87	24.85	28.10
C3-R40-O60	19.44	24.46	27.83
C4-R20-O80	19.26	24.28	27.65
C5-O100	19.22	24.2	27.57

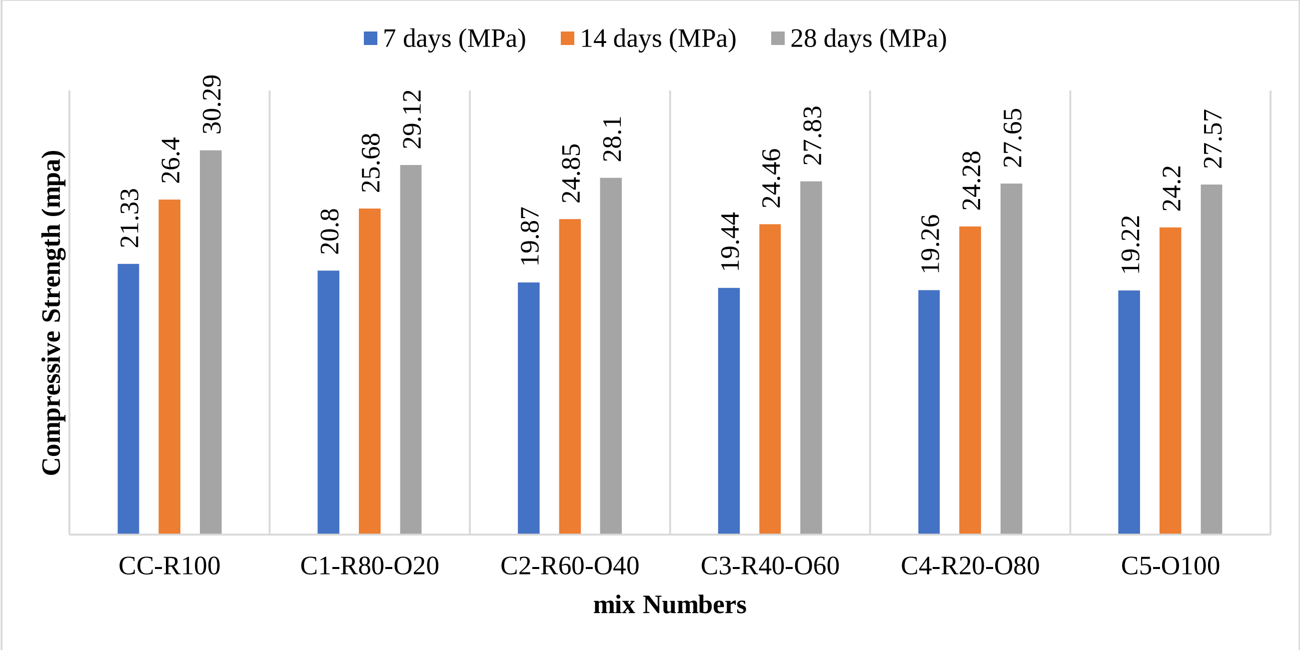

Fig. 5 Compressive strength development of concrete mixes incorporating Processed Overburden Sand (POBS) at different curing ages

Fig. 6 Preparation, casting, curing, specimen arrangement for mechanical and durability testing of concrete mixes

4.3. Flexural Strength Outcomes

Flexural strength test results in Table 13 depict a declining trend from zero percent substitution to 60% substitution of river sand with overburden sand, after which a negligible decline is depicted in the value of flexural strength of concrete. The above trend implies that more than 60% substitution had a limited additional influence on the flexural response owing to the characteristics of processed overburden sand.

Table 13. Flexural strength of concrete mixes incorporating Processed Overburden Sand (POBS)

Mix ID	7 days (MPa)	14 days (MPa)	28 days (MPa)
CC-R100	3.23	3.72	4.19
C1-R80-O20	3.12	3.63	4.08
C2-R60-O40	3.05	3.54	3.97
C3-R40-O60	3.02	3.46	3.88
C4-R20-O80	2.98	3.41	3.83
C5-O100	2.95	3.39	3.81

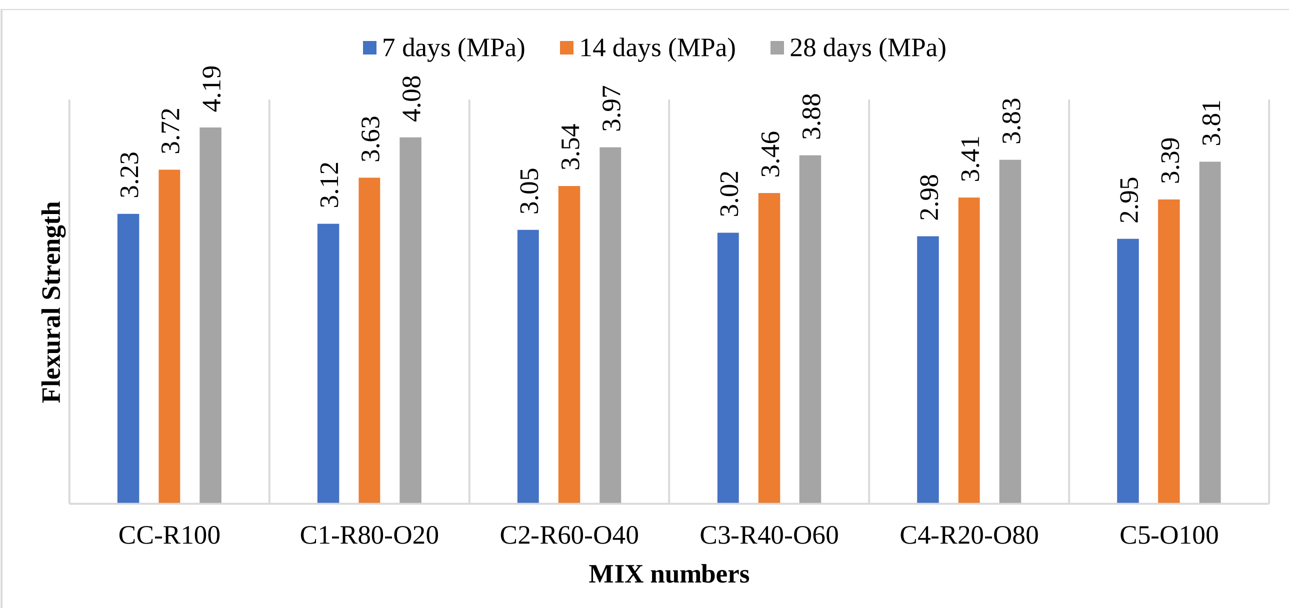

Fig. 7 Flexural strength development of concrete mixes incorporating Processed Overburden Sand (POBS) at different curing ages

Flexural strength varies in the same pattern as that seen for compressive strength. Even though there is a slight reduction seen with an increase in the amount of processed overburden sand used, the reduction is quite small after 60% of the replacement. This suggests that the bond between the cement paste and processed overburden sand is strong enough to resist tension during the bending process. The rough surface of the processed overburden sand facilitates mechanical interlock of the processed overburden sand and makes up for its high porosity.

Fig. 8 Flexural strength testing of concrete prism specimen using universal testing machine

4.4. Stress Strain Curve Analysis and Elastic Modulus of Concrete

According to the stress-strain relationship depicted in Table 14, all mixes of concrete show similar nonlinear compressive behaviour whereby stress increases steadily with an increase in strain over the measured range. Control mix was found to exhibit the highest levels of stress compared to mixes that contained processed overburden sand. At higher replacement levels, the differences in stress-strain responses were minimal indicating comparable deformation properties under compression loads.

Table 14. Stress-Strain response of concrete mixes obtained from longitudinal compressometer analysis

Strain	Stress for CC-R100 (MPa)	Stress for C1-R80-O20 (MPa)	Stress for C2-R60-O40 (MPa)	Stress for C3-R40-O60 (MPa)	Stress for C4-R20-O80 (MPa)	Stress for C5-O100 (MPa)
0.00010	2.73	2.64	2.59	2.57	2.56	2.56
0.00021	5.74	5.55	5.43	5.40	5.39	5.38
0.00031	7.68	7.44	7.23	7.17	7.12	7.10
0.00038	9.05	8.90	8.60	8.30	8.25	8.20
0.00043	9.80	9.70	9.40	9.10	9.00	8.90
0.00050	11.00	10.70	10.40	10.20	10.05	10.01
0.00100	17.30	17.00	16.70	16.40	16.30	16.20
0.00150	21.20	20.90	20.60	20.30	20.20	20.10
0.00200	23.50	23.20	22.90	22.60	22.50	22.40
0.00243	24.20	24.10	23.80	23.50	23.40	23.30

The stress-strain behavior found in all samples of concrete mixes confirms the non-linear nature of behavior that is usually found in traditional cement concrete. The control sample exhibits the maximum stress values, which may be attributed to the favourable packing characteristics of the natural river sand. Yet, the stress-strain behavior found in the concrete mix using processed overburden sand revealed similar nature of deformability which implies that the use of processed overburden sand does not appreciably change the deformability nature of concrete. The relatively small difference found beyond 60% replacement suggests that processed overburden sand does not substantially affect the deformation characteristics of concrete under compression.

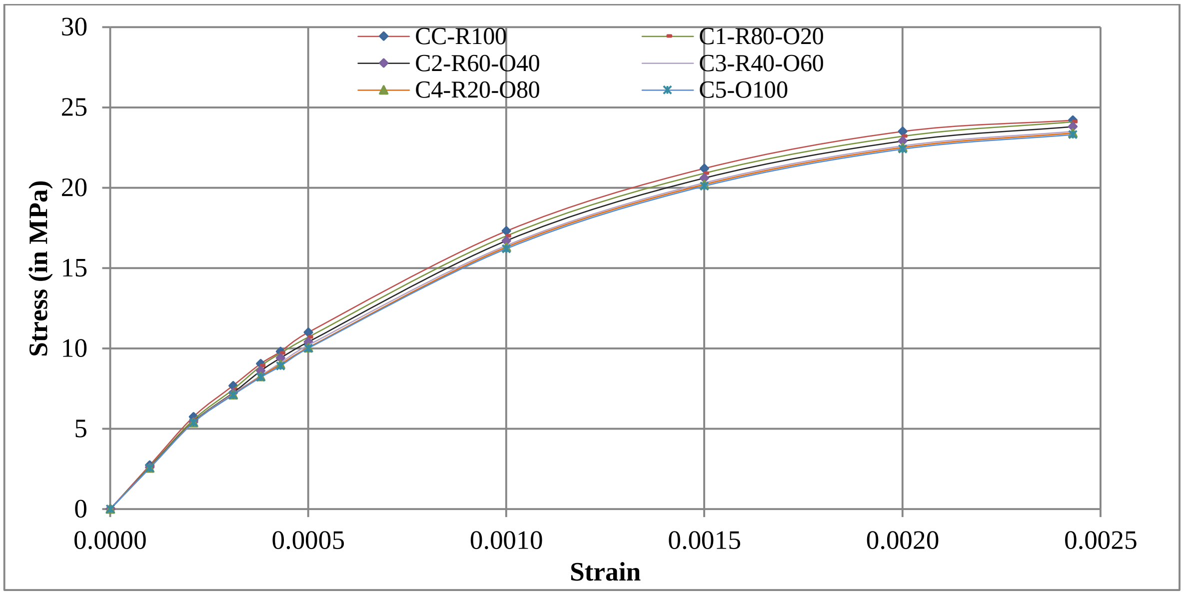

Fig. 9 Stress–Strain curves of concrete mixes obtained from longitudinal compressometer analysis

Table 15. Elastic modulus results of concrete mixes from longitudinal compressometer analysis

Mix ID	Elastic Modulus (MPa)
CC-R100	27330
C1-R80-O20	26440
C2-R60-O40	25880
C3-R40-O60	25710
C4-R20-O80	25640
C5-O100	25620

The modulus of elasticity in this study was determined from the slope of the initial portion of the stress–strain curve passing through the origin. The findings in Table 15 show a gradual decrease in the modulus of elasticity as the level of river sand replacement with processed overburden sand increases. The control sample had an elastic modulus value of 27330 MPa while the sample with complete replacement showed a relatively lower elastic modulus of 25620 MPa. These values show that, at higher replacement levels, the difference in elastic modulus becomes relatively small indicating comparable stiffness among the mixes.

4.5. Durability Test Results

To examine the durability performance of concrete that uses processed overburden sand, the durability tests were performed on concrete samples. This involved testing of water absorption and water permeable voids test, sorptivity test, acid resistance test using sulphuric acid (H_2SO_4) and hydrochloric acid (HCl), sulphate resistance test using sodium sulphate (Na_2SO_4), and salt attack resistance test. This was done to determine whether the concrete sample would resist moisture penetration, chemical degradation, capillary action, and aggressiveness of the environment.

4.5.1. Test for Water Absorption and Volume of Permeable Voids

From Table 16, it is evident that water uptake and permeable pore volume progressively rose with the rise in the proportion of processed overburden sand used as a substitute for river sand. This suggests that there was an increase in the internal porosity of the concrete matrix. The bulk density, on the other hand, declined slightly due to the reduced specific gravity of processed overburden sand. The trend stabilizes beyond 60% replacement.

Table 16. Water absorption, density characteristics and volume of permeable voids of concrete mixes incorporating Processed Overburden Sand (POBS)

Description	Mix ID					
	CC-R100	C1-R80-O20	C2-R60-O40	C3-R40-O60	C4-R20-O80	C5-O100
Water absorption after immersion %	4.05	4.18	4.29	4.35	4.41	4.43
Water absorption after immersion and	4.18	4.3	4.39	4.47	4.54	4.58
Bulk density, dry, Mg/m3	2.36	2.35	2.34	2.32	2.30	2.29
Bulk density after immersion Mg/m3	2.46	2.45	2.44	2.44	2.42	2.41
Bulk density after immersion and boiling	2.47	2.46	2.46	2.45	2.43	2.42
Apparent density, Mg/m3	2.63	2.63	2.62	2.62	2.61	2.6
Volume of permeable pore space %	10.2	10.58	10.72	10.95	11.09	11.14

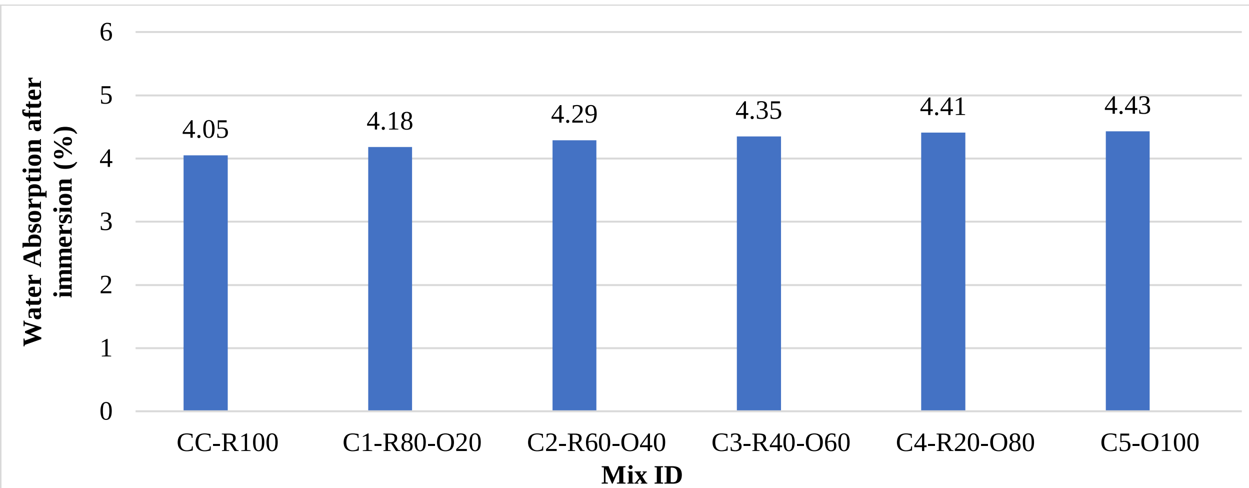

Fig. 10 Variation of water absorption after immersion of concrete mixes incorporating Processed Overburden Sand (POBS)

As illustrated in Figure 10 below, there is an increment in water absorption as the level of processed overburden sand substitution increases. The control specimen gave the least water absorption, whereas maximum substitution gave relatively higher value. However, the increment is still within reasonable limits, implying that the increase in POBS content had modest effect on the absorption characteristics of concrete.

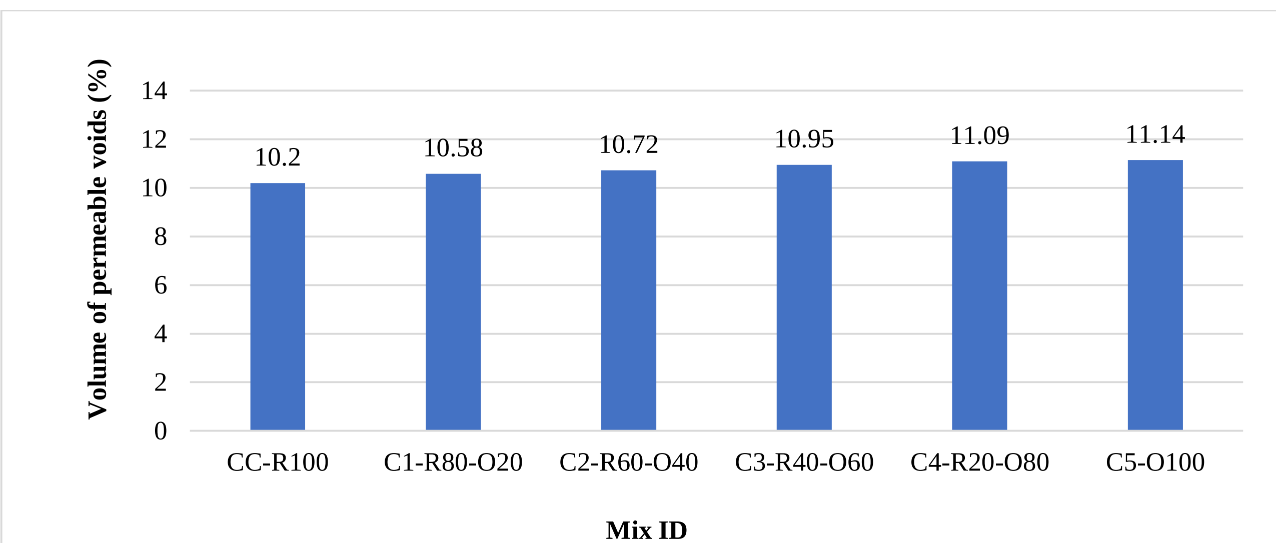

Fig. 11 Change in void volume in concrete mixes containing Processed Overburden Sand (POBS)

From Figure 11, there is an evident increase in the proportion of permeable void volume with a raise in the quantity of processed overburden sand substitution.

This is because the proportion of voids increases slightly owing to increased water absorption capacity of the processed overburden sand

Fig. 12 Laboratory test procedure on absorption of water and density of concrete specimen

The above Figure 12 shows the procedure employed in the laboratory in carrying out water absorption tests such as weighing specimens after oven drying, submerging of the specimens into water, and weighing using electronic balance.

4.5.2. Test for Sorptivity

Results from Table 17 illustrate the capillary absorption characteristics of concrete mixes tested using varying square roots of time. All concrete mixes exhibited an increasing trend of absorption with time, signifying normal capillary action in hardened concrete. The concrete mix with higher percentage of processed overburden sand showed higher absorption values at all measured time periods compared to other mixes. However, the differences in absorption among the mixes remained gradual during the test period. This indicates that the incorporation of processed overburden sand resulted in consistent trend of capillary absorption among the concrete mixes.

Table 17. Capillary absorption characteristics of concrete mixes with Processed Overburden Sand (POBS)

Mix ID	Square root of time ($min^{1/2}$)											
	0	1	2	3	4	5	8	11	13	15	17	19
	Absorption (mm)											
CC-R100	0	0.25	0.29	0.56	0.68	1.03	1.48	2.15	3.26	3.61	4.11	4.34
C1-R80-O20	0	0.46	0.75	1.07	1.24	1.43	1.8	2.27	3.34	3.62	4.12	4.37
C2-R60-O40	0	0.47	0.87	1.22	1.58	1.75	2.01	2.76	3.83	4.1	4.61	4.88
C3-R40-O60	0	0.55	0.99	1.32	1.59	1.76	2.19	2.97	4.32	4.55	5.03	5.22
C4-R20-O80	0	0.6	1.01	1.34	1.6	1.81	2.27	3.02	4.35	4.68	5.16	5.38
C5-O100	0	0.65	1.02	1.39	1.61	1.85	2.38	3.26	4.39	4.76	5.45	5.77

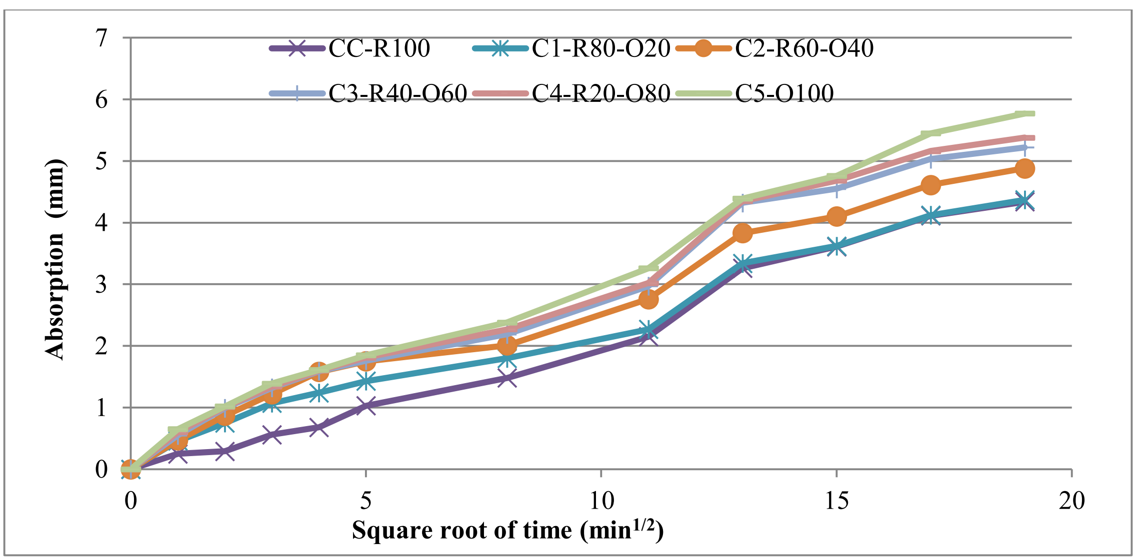

Fig. 13 Sorptivity curves of concrete mixes incorporating Processed Overburden Sand (POBS)

As can be seen from Figure 13, an increase in capillary absorption was recorded continuously with time for all the concrete mixes. It was observed that mixes with higher proportions of processed overburden sand exhibited higher capillary absorption. A progressive increase in the values was observed at the intermediate levels of replacement.

Fig. 14 Preparation of discs specimen for sorptivity tests on concrete mixes

Figure 14 shows the preparation method used during the sorptivity test, including the method of sectioning concrete cylinders into discs. Consistent specimen thickness was ensured in order to achieve uniform capillary absorption in all mixes of concrete using the overburden sand sample.

4.5.3. Test for Acid Resistance in Sulphuric Acid (H_2SO_4)

Table 18 reveals the resistance capacity of the concrete mix to sulphuric acid (H_2SO_4) in terms of weight and strength loss percentage. Weight and strength losses increase progressively with increasing amounts of processed overburden sand content. Nevertheless, variations among all mixes are marginal, implying that concrete made with processed overburden sand performs similar to control mix with respect to sulphuric acid attack.

As depicted in Figure 15, the trend is an increasing weight loss when the amount of processed overburden sand replacement increases after sulphuric acid attack. The lowest was observed in the control mix, whereas the maximum was noted in the case of 100% replacement.

Table 18. Effect of resistance of concrete mix to sulphuric acid (H_2SO_4)

Mix ID	Weight Loss (%)	Strength Loss (%)
CC-R100	6.58	14.9
C1-R80-O20	6.75	15.83
C2-R60-O40	6.87	16.44
C3-R40-O60	7.03	16.97
C4-R20-O80	7.13	17.08
C5-O100	7.17	17.13

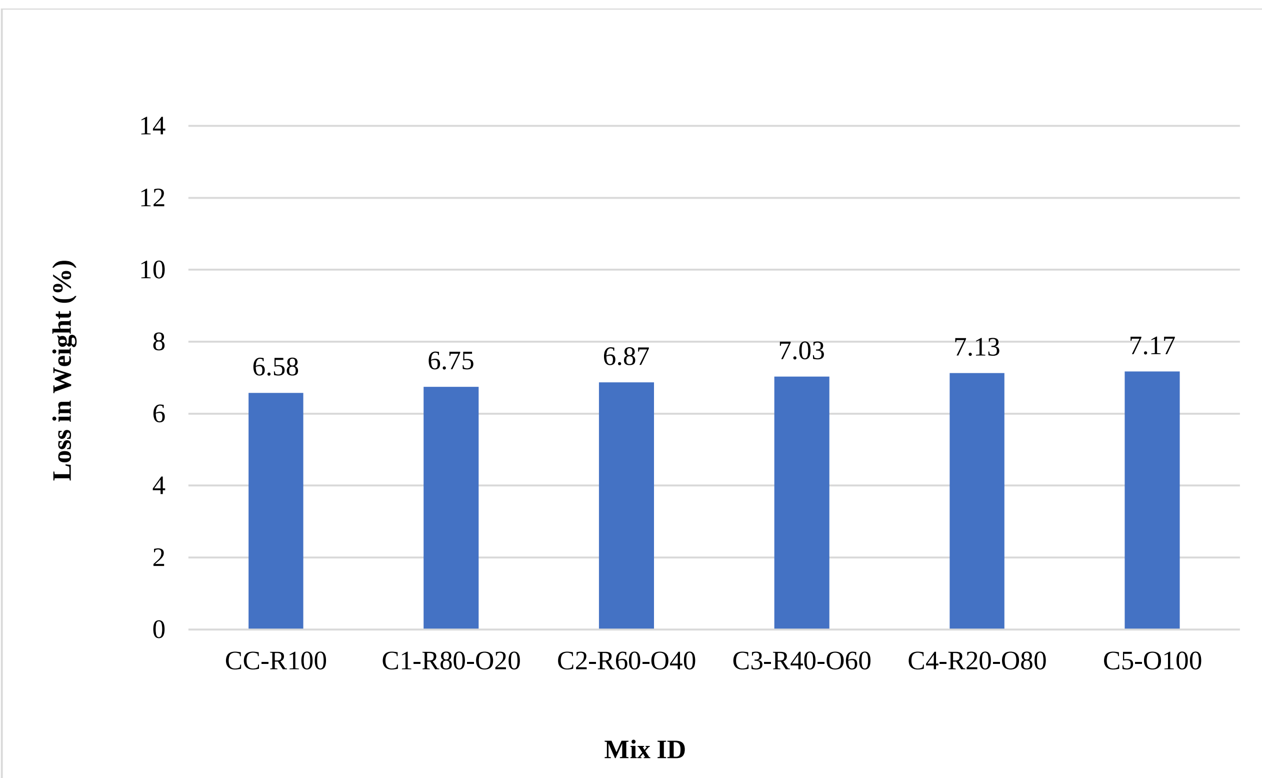

Fig. 15 Weight Loss variation of concrete mix under sulphuric acid (H_2SO_4)

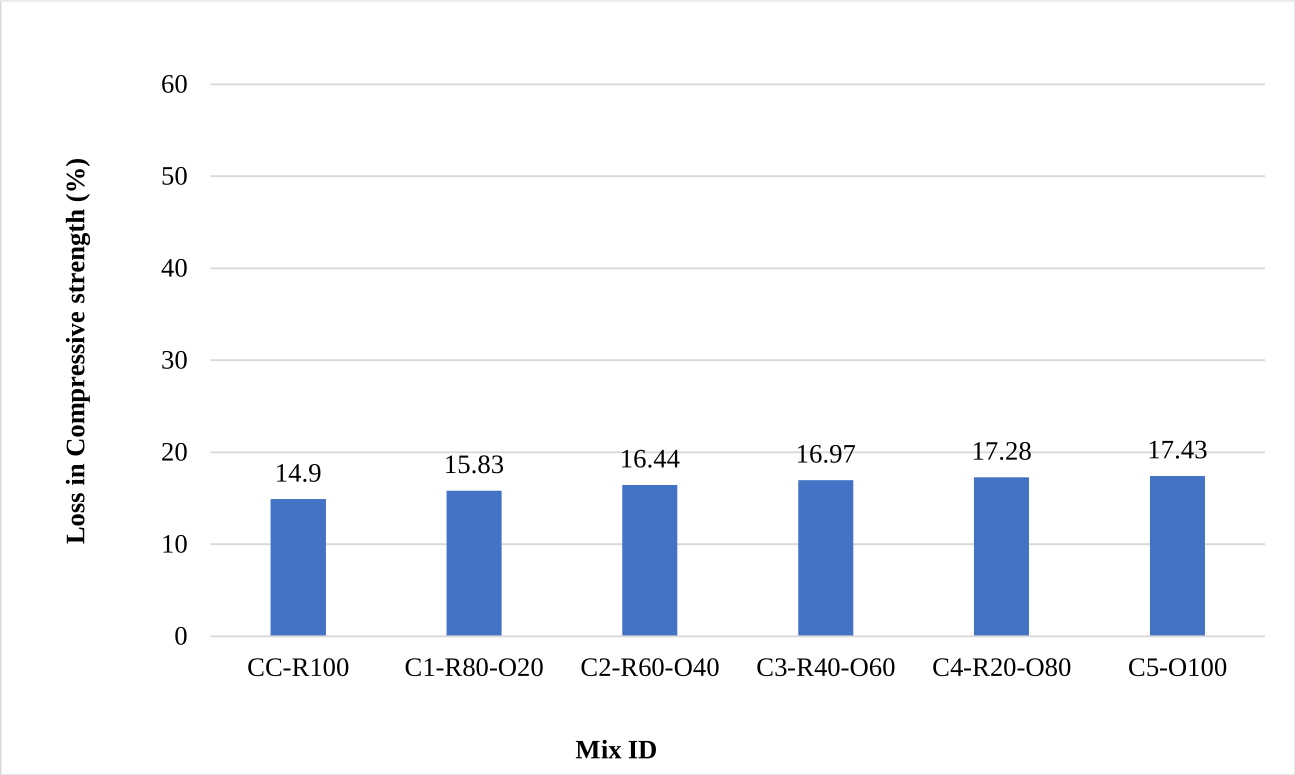

Fig. 16 Residual compressive strength of the concrete mix after sulphuric acid (H_2SO_4) Exposure

In Figure 16, the trend displays that there was a slight reduction in residual strength by increasing the amount of processed overburden sand added to the concrete mix with reference to control mix.

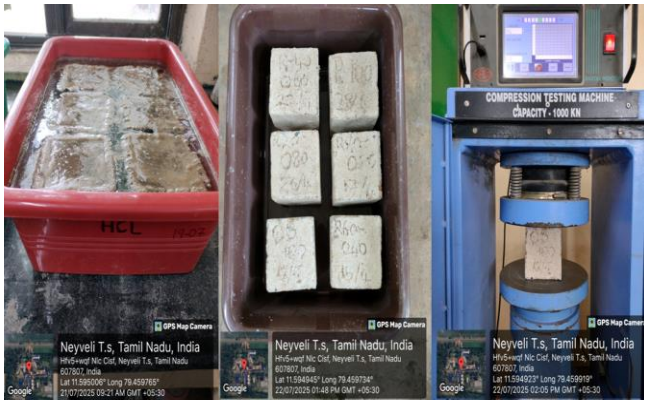

Fig. 17 Procedure for HCl resistance test on concrete samples

Figure 17 is a diagram indicating the steps of conducting the resistance of concrete to Hydrochloric Acid (HCl). This procedure was adopted to determine the chemical resistance of concrete samples prepared using processed overburden sand exposed to acidic environments.

4.5.4. Test for Acid Resistance in Hydrochloric Acid (HCl)

The performance of concrete mixes under hydrochloric acid attack was evaluated using Table 19, which records weight loss and strength loss due to exposure. These two parameters steadily increased with an increase in processed overburden sand substitution, showing that there was only a minor increase in the degree of acid attack.

However, the level of damage was considerably lower compared to that seen in sulphuric acid attack indicating the relatively lower aggressive chemical action of HCl.

Table 19. Resistance to acid attack in concrete mixes when exposed to hydrochloric acid (HCl)

Mix ID	Weight Loss (%)	Strength Loss (%)
CC-R100	1.13	4.97
C1-R80-O20	1.17	5.14
C2-R60-O40	1.19	5.25
C3-R40-O60	1.21	5.32
C4-R20-O80	1.22	5.40
C5-O100	1.23	5.45

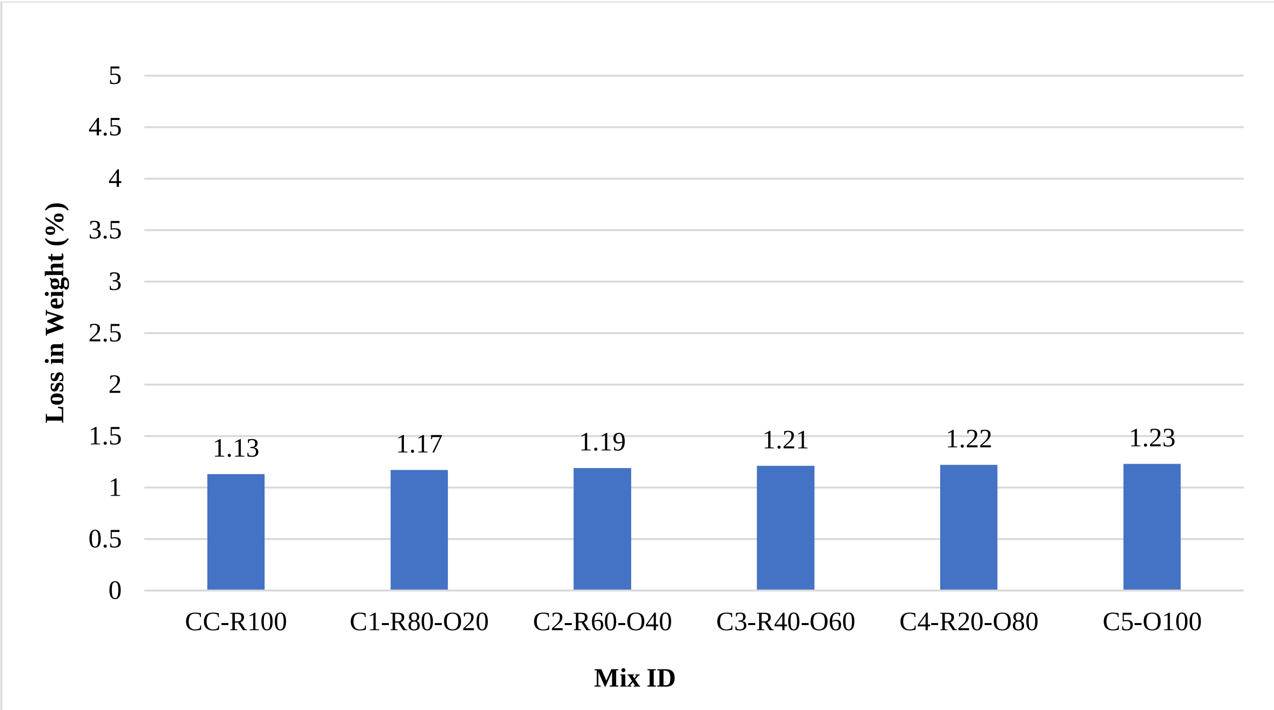

Fig. 18 Weight loss variation of concrete mixes subjected to hydrochloric acid (HCl)

The data provided in Figure 18 show that the weight loss marginally raises with increase in replacement proportion of processed overburden sand in hydrochloric acid environment. The control mix displayed the lowest weight loss, whereas the fully-replaced mix had exhibited relatively higher loss. In general, the weight loss was very low as compared to sulphuric acid environment; hence, it may be deduced that there is lower deterioration caused by hydrochloric acid on concrete samples.

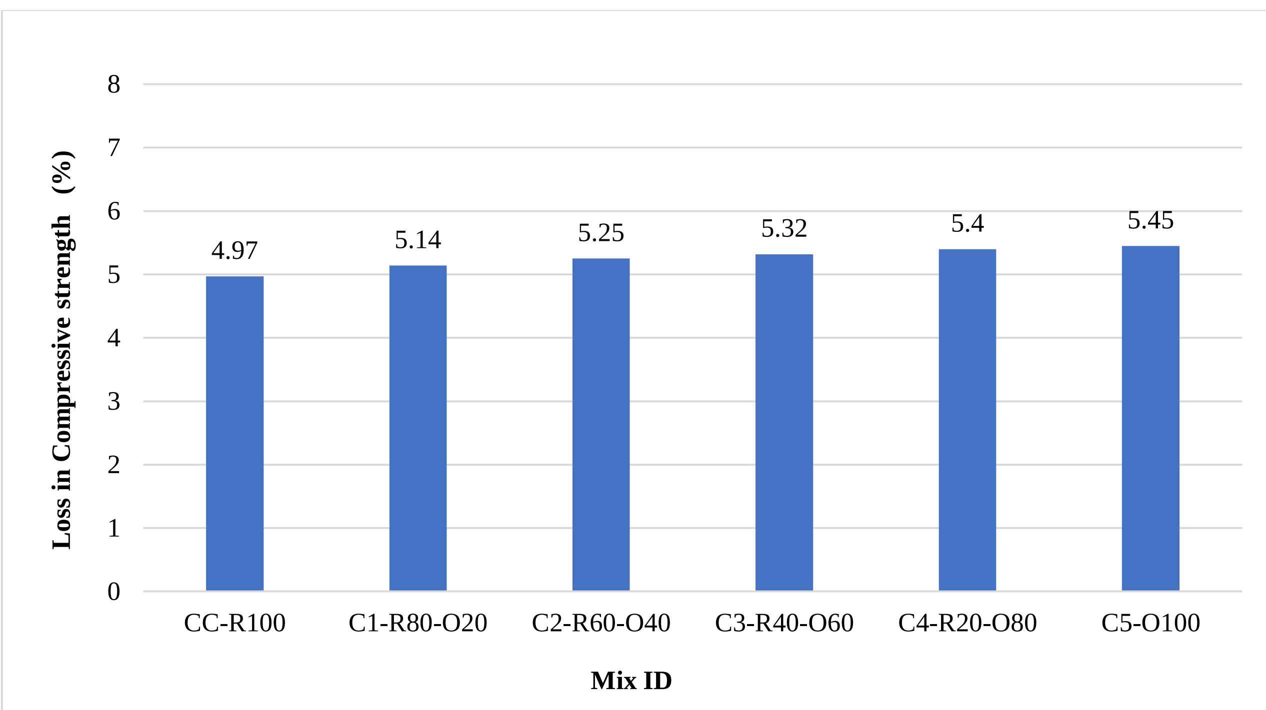

Fig. 19 Compressive strength loss of concrete mixes exposed to hydrochloric acid (HCl) attack

In Figure 19, it is evident that there was an increase in compressive strength loss in the concrete mixes exposed to hydrochloric acid attacks with the increase in the level of processed overburden sand substitution. The concrete mix without processed overburden sand had the least amount of strength loss while the concrete mix with complete substitution had the greatest loss. Notably, the differences between all the mixes were not high, hence the effect of the hydrochloric acid attack on the concrete was moderate.

4.5.5. Test for Sulphate Resistance test

As shown in Table 20, there is evidence regarding the sulphate resistance test results of the concrete mixes. It can be observed from the data presented that the weight loss as well as strength loss is modest with increasing the replacement of processed overburden sand. In fact, the control mix exhibited the least deterioration, whereas there was a slight increase in deterioration in the fully replaced mix. The extent of change was minor for all mixes, thus indicating the high resistance to sulphate attacks.

Table 20. Sulphate Resistance Test Results of Concrete Mixes with Sodium Sulphate (Na_2SO_4) Attack

Mix ID	Weight Loss (%)	Strength Loss (%)
CC-R100	0.05	0.78
C1-R80-O20	0.051	0.80
C2-R60-O40	0.0518	0.82
C3-R40-O60	0.0523	0.84
C4-R20-O80	0.0534	0.85
C5-O100	0.0542	0.86

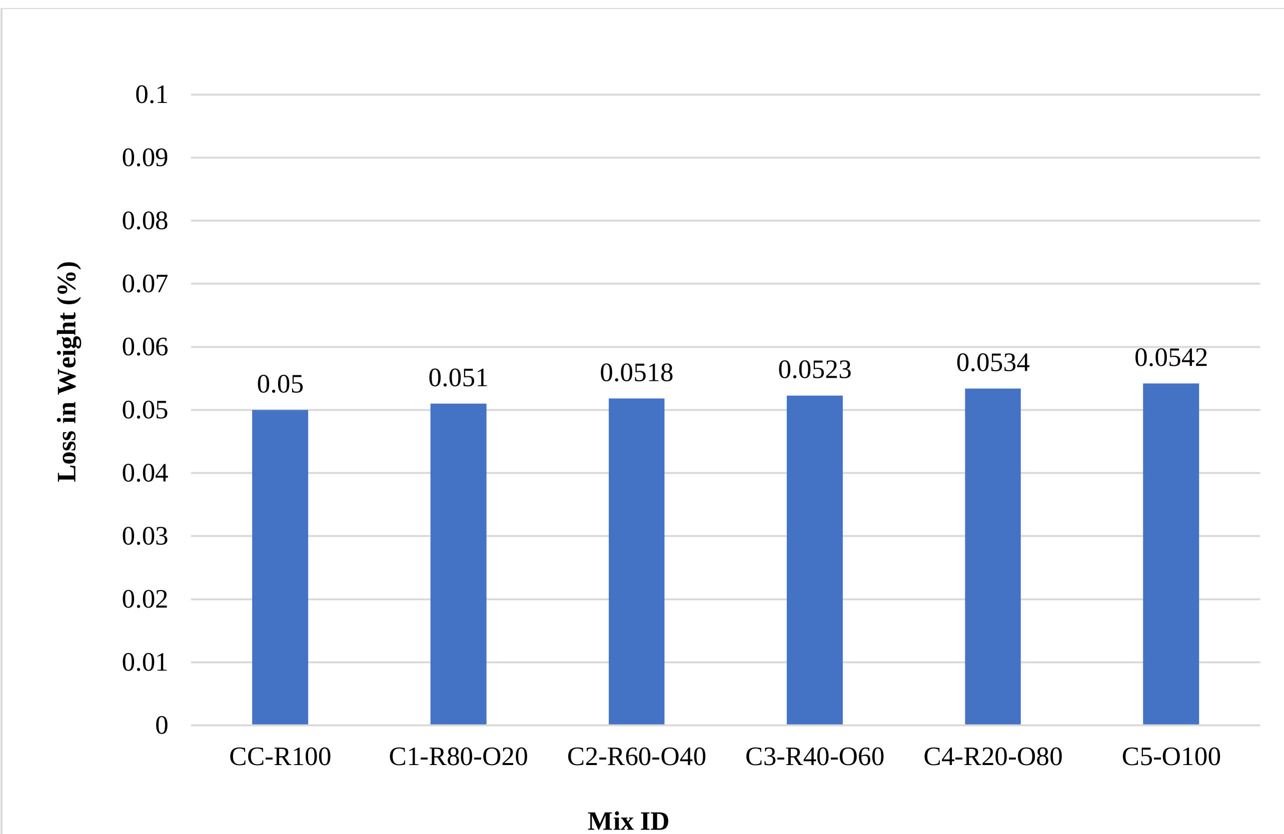

Fig. 20 Variance of weight loss for concrete mix with sodium sulphate (Na_2SO_4) resistance

As depicted in Figure 20, the variance in weight loss in concrete mixes when subjected to sodium sulphate was small, with no significant changes seen even when the amount of processed overburden sand in replacement was gradually increased. The difference between the control group and full replacement groups was quite negligible. Hence, it is evident that processed overburden sand-containing concrete is resistant to sulphate damage.

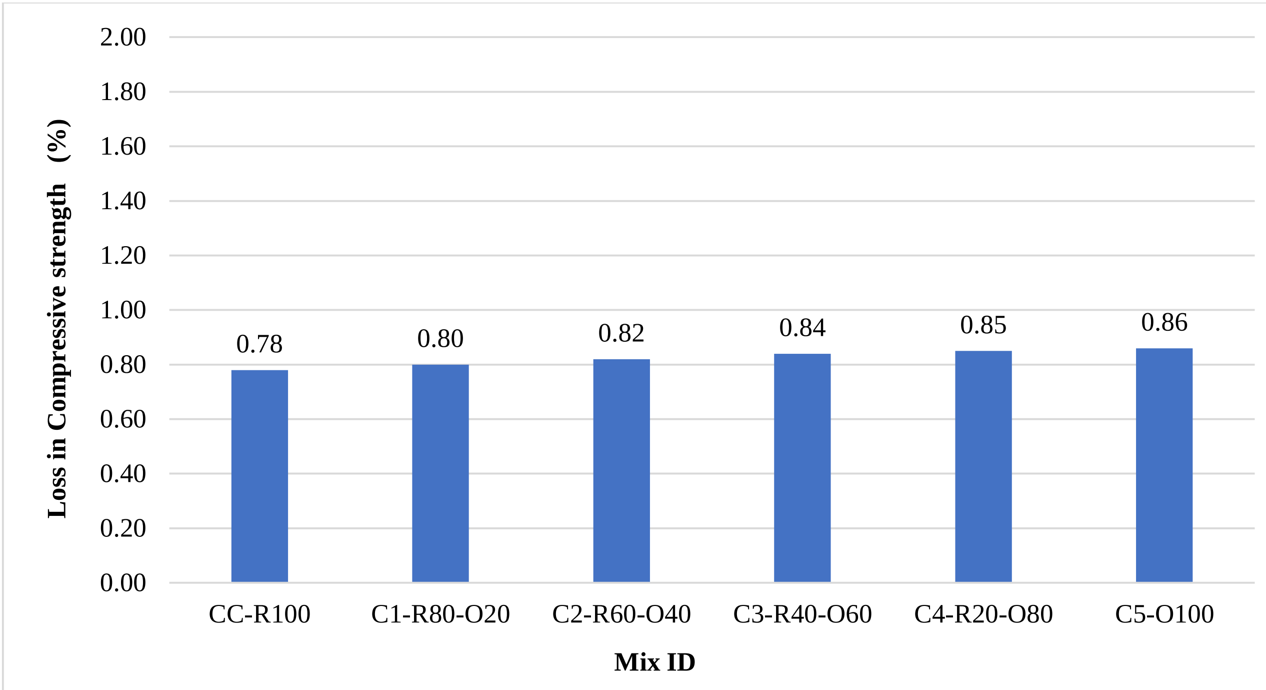

Fig. 21 Compressive Strength reduction of concrete mixes subjected to sodium sulphate (Na_2SO_4)

As shown in Figure 21, the compressive strength reduction caused by sodium sulphate exposure was small in all concrete mixes. There is marginal compressive strength reduction when the percentage of processed overburden sand is increased. This is an indication that sodium sulphate did not cause notable internal degradation on processed overburden sand based concrete.

Fig. 22 Setup used for measuring sulphate resistance of concrete specimen in sodium sulphate (Na_2SO_4) Solution

Figure 22 presents the setup that was used for measuring the sulphate resistance of the concrete specimen using sodium sulphate solution. It was carried out to establish the weight reduction and strength reduction as a result of the chemical attack.

4.5.6. Resistance to Salt Attack

The data provided in Table 21 indicate that the resistance to salt attack in concrete mixes is good, since there was no serious deterioration in any of the mixes. This is seen from the lower values of both the weight reduction and loss in compressive strength.

The control mix had the smallest loss in weight and strength, whereas the totally modified concrete mix had a slightly higher value. The readings remained fairly close, indicating that salt exposure did not cause significant damage to the concrete matrix.

Table 21 Resistance to salt attack of concrete mixes containing Processed Overburden Sand (POBS)

Mix ID	Weight Loss (%)	Strength Loss (%)
CC-R100	0.041	0.48
C1-R80-O20	0.042	0.5
C2-R60-O40	0.042	0.52
C3-R40-O60	0.043	0.54
C4-R20-O80	0.043	0.55
C5-O100	0.043	0.56

Fig. 23 Experimental setup for salt attack resistance test on concrete cubes

Figure 23 shows the experimental setup for testing salt attack resistance on concrete cubes, whereby concrete cubes were submerged into saline water in a laboratory setting. The objective was to determine weight and strength loss after salt exposure for various types of concrete. From the analysis conducted on the durability of the processed overburden sand concrete, it is evident that the concrete shows good durability properties when subjected to environmental effects such as moisture content and chemical attack. Though there was an increment in water absorption and sorptivity as the percentage replacement increased, the changes were within acceptable limits. The effect of acidic, sulphate, and chloride environments on the compressive strength was not too great as well. This suggests that the processed overburden sand is a durable fine aggregate material for normal-strength concrete.

4.6. Statistical Analysis of Experimental Data

The experimental results generated by the experiment showed consistent and systematic trends for all percentages of processed overburden sand (POBS) replacements. This consistency and systematic trend in workability, compressive strength, flexural strength, stress-strain relation, modulus of elasticity, and durability of the mixtures indicated an identifiable relationship between the percentage of POBS replacements and concrete properties. There were no unexpected irregularities and inconsistencies in the experimentally derived results, showing that the material processing technique and the mix design adopted were effective. The gradual decrease in the properties of workability and mechanical strength was observed to be consistent to the increase in the percentage of processed overburden sand due to its properties. Nevertheless, this decrease was observed to be minor after the 60% replacement due to the fact that the matrix of the concrete had attained stability to maintain satisfactory engineering performance. In the same way, there were predicted changes in the durability properties depending on the type of aggressiveness of the environment. The results from the tests indicate significant consistency in the obtained properties and confirm the efficiency of the employed testing methods. The analysis of the fresh concrete properties, mechanical performance, and durability properties helps to identify the 60% processed overburden sand replacement as the optimal ratio in order to achieve the highest degree of balance between all the properties of M20 concrete.

4.7. Practical Engineering Implications

The results obtained during the current study show that there is considerable scope for the practical use of processed overburden sand in the construction industry. The POBS can be offered as an alternative fine aggregate in concrete structures, roads, masonry blocks and other applications where M20 grade concrete is suitable. The use of processed overburden sand helps in saving the natural resources of river sand and also in lowering the environmental impact of mining waste management. From the sustainability point of view, using processed overburden sand ensures resource efficiency by making productive use of those materials which need to be disposed of for a long time. Thus, the use of processed overburden sand in concrete helps in adopting environmentally sound construction practices.

5. Discussion

Discussion of experimental outcomes from the study of concrete mixes using Processed Overburden Sand (POBS) as a substitute for conventional river sand will be presented in this section with regard to properties associated with freshly mixed concrete, strength evolution, deformations, and durability. Special emphasis is placed on the effects of aggregate gradation, particle surface roughness, absorptive ability, and matrix alteration due to higher proportions of POBS usage. Understanding the effect of POBS in interaction with cementitious matrix in fresh and hardened states requires careful interpretation of observed tendencies. The following experimental data will be analyzed in order to determine the extent of substitution at which technical feasibility can be achieved.

5.1. Fresh Concrete Behavior

The rheological behavior of fresh concrete is impacted by processed overburden sand, as demonstrated by the decrease in workability evaluated by slump, Vee-Bee, and flow methods. As replacement increased, the slump value steadily decreased from 95 mm to 60 mm, and the Vee-Bee time increased from 3 to 12 seconds, indicating increased stiffness. The drop in flow values from 118% to 94% is indicative of this. The main causes of this behavior are the angularity, roughness, and higher water absorption of processed overburden sand compared to river sand. As a result, there is higher water demand and elevated inter particle friction in the concrete mix.

5.2. Discussion of Mechanical Strength Development

It is evident from the mechanical strength results that processed overburden sand causes marginal reductions in compressive and flexural strengths of concrete. At complete replacement of RS by POBS in concrete, the 28-day compressive strength dropped by 2.72 MPa and the flexural strength dropped by 0.38 MPa, which corresponds to a decrease of around 10 % with reference to control mix. The main conclusion of these trials is that the drop in mechanical strength becomes marginal above 60% replacement level, which may be associated with improved internal packing and homogeneity achieved in the concrete matrix. At this replacement level, the concrete matrix has optimum level of POBS to govern the resulting behaviour which may be attributed to properties of POBS.

5.3. Discussion on the Stress-Strain Relationship and Elastic Modulus

Results from the stress-strain relationship indicate that all concrete samples exhibited conventional non-linear behavior. The stress–strain curves showed a progressive increase in stress values with compressive strain, followed by a gradual reduction in the rate of stress increase at higher strain levels. The control concrete mix recorded maximum stress compared to specimens incorporated with processed overburden sand. The elastic modulus decreased from 27.33 GPa for control mix to 25.62 GPa with POBS total replacement, a modest stiffness reduction. However, this decrease became relatively small beyond 60% replacement, as seen from the stabilizing trend of the elastic modulus values.

5.4. Discussion of Durability Performance

The durability test results suggest that incorporating POBS as fine aggregate leads to a slight increase in permeability properties without deteriorating the specimen critically. The water absorption level was observed to increase from 4.05% to 4.43%, while the permeable void volume level was recorded to be 11.14% at full replacement. There was also an observed increase in the capillary absorption value with increasing POBS content, signifying higher capillary water uptake in the POBS based mixes. The chemical resistance analysis showed that sulphuric acid had a more pronounced effect than hydrochloric acid. The loss of strength under sulphate and salt attacks remained below 1% for all the concrete mixes. Further, strength did not diminish significantly at higher replacement levels indicating that the increase in POBS content has not aggressively affected the resistance of the concrete mixes to the tested chemical exposure conditions.

5.5. Optimum Level of Replacement and Its Engineering Implications

In terms of workability, strength, and durability, replacement at 60% of processed overburden sand (POBS) shows optimal performance from both engineering and practical perspectives. In this case, there are no major drawbacks in workability, and the decrease in strength and durability are acceptable. Complete substitution is possible in technical terms, although there would be a slight reduction in strength and resistance to water penetration. Therefore, processed overburden sand has excellent prospects as a viable alternative for fine aggregates in concrete.

6. Conclusion

In this study, Processed Overburden Sand (POBS) from lignite mines is chosen as a possible replacement for river sand in concrete manufacturing. The physical characterization of POBS demonstrated that it is suitable for usage as fine aggregate in concrete mixes since its gradation (Zone II) and other physical characteristics meet the IS 383:2016 requirements. It has been observed that increasing the POBS content from control (RS) to full replacement reduced the fresh concrete workability, as evidenced by the values of slump decreasing from 95 mm to 60 mm, Vee-Bee time increasing from 3 to 12 seconds, and flow decreasing from 118% to 94%.

The hardened mechanical properties trended downward as the proportion of POBS replacement increased, but the compressive strength, flexural strength, and elastic modulus remained within the permissible range for M20 grade concrete. At 28 days, the compressive strength of conventional mix was 30.29 MPa, which decreased to 27.57 MPa after total replacement with POBS. The control mix achieved a flexural strength of 4.19 MPa, which reduced to 3.81 MPa after total replacement. Nearly comparable stress-strain parameters were observed in all concrete mixes. The stress-strain response exhibited nonlinear behaviour among the measured strain range. A decrease in elastic modulus from 27.33 GPa for control mix to 25.62 GPa at full POBS replacement was noted.

The durability tests of POBS based concrete mixes revealed that water absorption, permeable pore volume, and capillary absorption gradually increased with addition of POBS. The value of water absorption after immersion increased from 4.05% to 4.43%, while the value of porosity increased from 10.2% to 11.14%. The values of capillary absorption also depicted a marginal increasing trend, suggesting that there is relatively lower effect due to capillarity. The chemical durability findings revealed that the sulphuric acid attack had a relatively pronounced effect, with a strength reduction of 14.9% to 17.13%, while hydrochloric acid exposure resulted in the comparatively lower strength reductions ranging from 4.97% to 5.45%. The sulphate and salt attacks had negligible levels of deterioration, where the strength loss was less than 1% across all concrete mixes. This suggests that POBS concrete has good resistance to both chloride and sulphate environments but moderate sensitivity to highly acidic conditions. Hardened and durability properties showed a modest reduction up to 60% replacement, beyond which the rate of reduction became marginal. All mixes, including 100% POBS, satisfied the strength requirements of M20 grade concrete, with 60% identified as optimum replacement level for a balanced strength, workability, and durability. This study with its experimental outcomes shows that POBS is an acceptable substitute for river sand in concrete, while also allowing for the sustainable use of lignite mine overburden.

Conflict of Interest

The authors state that there are no conflicts of interest in the publishing of this research.

Funding Statement

This study received no particular grants from public, commercial, or non-profit funding entities.

Acknowledgements

The authors are grateful to Annamalai University's Department of Civil Structural Engineering for providing laboratory facilities and technical support for this research project. The authors also express their heartfelt appreciation to the workers and research scholars who provided invaluable assistance during the experimental studies.

Author Contributions

Kolar Dinesh Singh: Conceptualization, Methodology, Experimental Investigation, Data Analysis, and Original Draft Preparation.

M. Purushothaman provided experimental support, supervision, guidance, results interpretation, and final manuscript validation, review, and editing. All authors read and approved the final version of the manuscript.

Ethics Approval

There were no human or animal experiments in this study. Thus, ethical approval was not necessary. The research followed institutional rules for academic research.

Data Availability

The datasets generated and/or analysed during the current investigation are accessible from the corresponding author on reasonable request.

Abbreviations

- POBS: Processed Overburden Sand
- RS: River Sand
- OPC: Ordinary Portland Cement
- C.A: Coarse Aggregate
- F.A: Fine Aggregate
- CMOB: Coal Mine Overburden
- IS: Indian Standard
- HCl: Hydrochloric Acid
- H_2SO_4: Sulphuric Acid
- Na_2SO_4: Sodium Sulphate
- NaCl: Sodium Chloride
- MPa: Megapascal

References

[1] Biswajit Jena et al., “Experimental Studies on Coal Mine Over-Burden Incorporated Concrete as a Sustainable Substitute for Fine Aggregate in Concrete Construction,” *International Journal of Materials Research*, vol. 115, no. 11-12, pp. 867-880, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[2] Anshumali Mishra, Sarat Kumar Das, and Krishna R. Reddy, “Use of Coal Mine Overburden as Sustainable Fine Aggregate in Cement Mortar,” *Journal of Materials in Civil Engineering*, vol. 35, no. 9, pp. 1-13, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] A. S. Rathore, Manoj Pradhan, and S. V. Deo, “Assessment of Coal Mine Overburden Sand for Use in Concrete Making as Fine Aggregate,” *International Journal of Advanced Research in Engineering and Technology*, vol. 11, no. 9, pp. 368-379, 2020. [Google Scholar] [Publisher Link]

[4] Ramesh D. Dod et al., "Extraction of Sand from the Complex Matrix of Coal Mining Dump Waste: A Sustainable Approach in Indian Context," *Cleaner Materials*, vol. 12, pp. 1-10, 2024. [CrossRef] [Google Scholar] [Publisher Link]
[5] Biswajit Jena, Pradip Sarkar, and Pradip Sarkar, "Feasibility of Incorporating Coal Mine Overburden Material as Construction-Grade Fine Aggregate," *Particulate Science and Technology*, vol. 42, no. 8, pp. 1333-1342, 2024. [CrossRef] [Google Scholar] [Publisher Link]
[6] Murlidhar Sharma, and Prakash Kumar Orang, "Coal Mine Overburden Waste as a Sustainable Substitute for Fine Aggregates in Concrete," International Journal of Research and Analytical Reviews, vol. 10, no. 4, pp. 99-106, 2023. [Publisher Link]
[7] Anshumali Mishra, Sarat Kumar Das, and Krishna R. Reddy, "Valorization of Coalmine Overburden Waste Rock as Fine and Coarse Aggregate of Mortar and Concrete: Corrosion Resistance Evaluation," *Waste and Biomass Valorization*, vol. 14, pp. 3881-3892, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[8] O. Venkateswarlu, and M. Nageswararao, "The Experimental Investigation on the Use of Coal Mine as Replacement of Fine Aggregates in Concrete," *International Journal of Engineering Research-Online*, vol. 5, no. 3, pp. 17-4, 2017. [Publisher Link]
[9] B. Balakrishna Prasanna et al., "Mining Overburden Sand from Lignite Mines as a Partial Replacement for Fine Aggregates in Concrete," *Physics and Chemistry of the Earth, Parts A/B/C*, vol. 141, 2025. [CrossRef] [Google Scholar] [Publisher Link]
[10] A. S. Menaka, R. G. Robinson, and K. Ramamurthy, "Performance of Cement–Fly Ash Masonry Mortar with Sand from Mine Overburden as an Environment-Friendly Alternative to Conventional Fine Aggregate," *Advances in Civil Engineering Materials*, vol. 12, no. 1, pp. 99-113, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[11] Van Minh Nguyen et al., "Mechanical Properties and Durability of Concrete Containing Coal Mine Waste Rock, F-Class Fly Ash, and Nano-Silica for Sustainable Development," *Journal of Engineering Research*, vol. 11, no. 3, pp. 75-86, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[12] Biswajit Jena, Nikhil P. Zade, and Pradip Sarkar, "Variability of Coal Mine Overburden Incorporated Concrete and its Effect on the Seismic Safety of Reinforced Concrete Building," *Structural Concrete*, vol. 25, no. 3, pp. 2122-2140, 2024. [CrossRef] [Google Scholar] [Publisher Link]
[13] Biswajit Jena et al., "Sustainable Integration of Coal Mine Overburden as a Substitute for Natural Sand in Concrete to Enhance its Mechanical and Durability Properties," *Construction and Building Materials*, vol. 411, 2024. [CrossRef] [Google Scholar] [Publisher Link]
[14] Arvind Kumar Rai, Biswajit Paul, and Gurdeep 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. [Google Scholar] [Publisher Link]
[15] Sayar Yaseen et al., "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: Environment & Earth Sciences*, vol. 12, no. 1, pp. 1-7, 2012. [Google Scholar]
[16] A. Guru Brahmam, and D. Sisindree, "Experimental Examination on Utilization of Processed Mine Overburden Sand by Substituted to River Sand in Construction," *International Journal of Innovative Technology and Exploring Engineering*, vol. 9, no. 5, pp. 1858-1865, 2020. [CrossRef] [Google Scholar] [Publisher Link]
[17] B.V. Bahoria, and Ashwini Badhiye, "Study of Mechanical Properties of Sand extracted from Overburden of WCL Mines –The Effective Sustainable Sand Solution," *Turkish Journal of Computer and Mathematics Education*, vol. 12, no. 10, pp. 6152-6159, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[18] Jitesh Kumar Maharana, and Amiya Kumar Patel, "Physico-Chemical Characterization and Mine Soil Genesis in Age Series Coal Mine Overburden Spoil," *Journal of Phylogenetics & Evolutionary Biology*, vol. 1, no. 1, pp. 1-7, 2013. [CrossRef] [Google Scholar] [Publisher Link]
[19] Sarat Kumar Das, Mahasakti Mahamaya, and Krishna 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, 2020. [CrossRef] [Google Scholar] [Publisher Link]
[20] Aurora Torres et al., "A Looming Tragedy of the Sand Commons," *Science*, vol. 357, no. 6355, pp. 970-971, 2017. [CrossRef] [Google Scholar] [Publisher Link]
[21] "*IS 383: Coarse and Fine Aggregate for Concrete — Specification*," Bureau of Indian Standards, pp. 1-22, 2016. [Google Scholar] [Publisher Link]
[22] "*IS 2386-3 (1963): Methods of Test for Aggregates for Concrete, Part 3: Specific Gravity, Density, Voids, Absorption and Bulking*," Bureau of Indian Standards, pp. 1-22, 1963. [Google Scholar] [Publisher Link]
[23] "*IS 456: Plain and Reinforced Concrete — Code of Practice*," Bureau of Indian Standards, pp. 1-114, 2000. [Google Scholar] [Publisher Link]
[24] "*IS 10262: 2019 Concrete Mix Proportioning — Guidelines*," Bureau of Indian Standards, pp. 1-44, 2019. [Google Scholar] [Publisher Link]
[25] "*IS 1199: Methods of Sampling and Analysis of Concrete*," Bureau of Indian Standards, 1959. [Google Scholar]

[26] "IS 516 (Part 1/Sec 1): Methods of Tests for Strength of Concrete," Bureau of Indian Standards, 2021. [Publisher Link]

[27] "*IS 516 (Part 8/Sec 1): 2020 Hardened Concrete — Methods of Test Part 8 Determination of Modulus of Elasticity Section 1 Static Modulus of Elasticity and Poisson's Ratio in Compression*," Bureau of Indian Standards, pp. 1-14, 2020. [Publisher Link]

[28] Arpita Bisht, "Sand Futures: Post-Growth Alternatives for Mineral Aggregate Consumption and Distribution in the Global South," *Ecological Economics*, vol. 191, pp. 1-8, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[29] "*IS 2386-1 (1963): Methods of Test for Aggregates for Concrete, Part I: Particle Size and Shape*," Bureau of Indian Standards, pp. 1-26, 1963. [Google Scholar] [Publisher Link]