A Systematic Review on Concrete Made with Processed Overburden Materials Replacement with Fine Aggregate for Sustainable Development

G. Sree Lakshmi Devi[1], *C. Venkata* Siva Rama Prasad[2*], *P.* Srinivasa Rao[3], *and Festus* Olutoge[4]

[1]Associate Professor, Department of Civil Engineering, Nalla Malla Reddy Engineering College (Autonomous), Divyanagar, Kachivanisingaram, Near Narapally, Ghatkesar Mandal, Medchal District-500088, Hyderabad, Telangana, India.
[2]Associate Professor, Department of Civil Engineering, Malla Reddy (MR) Deemed to be University, Hyderabad-500100, Telangana, India.
[3]Professor, Civil Engineering, JNTUH College of Engineering Hyderabad 500085, India.
[4]Professor, Department of Civil and Environmental Engineering, University of the West Indies, St. Augustine Campus, Trinidad and Tobago.

Abstract. Concrete is a widely used material in public works and structural engineering projects globally. River sand, a key ingredient in concrete, has become scarce due to river degradation and climate change. This shortage, along with rising construction costs, has driven the search for alternative materials to partially or fully replace natural sand in concrete mixes. Substituting sand with suitable materials has shown to improve the mechanical and physical properties of concrete while reducing environmental impact. Over recent decades, various replacements like marble powder have been studied to preserve natural resources and maintain ecological balance. In this study, processed overburden (OB) material from coal mines is investigated as a potential fine aggregate replacement. Overburden, a by-product of mining activities, is typically considered waste but can be reused after proper processing. This paper presents the results of experimental research on the characteristics of concrete incorporating processed OB material. The study aims to evaluate its impact on the physical properties, strength, and durability of concrete. The findings suggest that OB material may serve as an effective and sustainable alternative to river sand, promoting environmental conservation and cost-effective construction.

Keywords: Processed Overburden Material, Strength, Durability, Acid Resistance, Temperature Effects.

*Corresponding author: cvsrprasad90@gmail.com

1 Introduction

Concrete is a mixture of cement, water, and aggregates that sets to become an immensely durable material in construction [1]. Aggregates are significant elements in concrete that serve to minimize shrinking and increase the efficiency of concrete manufacturing [2]. Fine sand is obtained from riverbeds and is employed as fine aggregate in construction. In the past, river sand was perhaps the most suitable option for fine aggregates in concrete, but overuse of the resource has led to ecological concerns, degradation of natural sand supplies, and a surge in the material's price. Fine sand deposits are now being exhausted in the developing world, posing a significant danger to the environment and civilization [3–6].

High excavation of sand from streams and rivers generates challenges including the broadening of stream beds, deterioration of fauna on riverbeds, and damage to marine organisms, along with cultivation issues attributable to the depression of the aquifer from wells [7–9]. As a result, emerging infrastructure companies are under pressure to discover new substances to fulfill the need for natural sand.

Reusing construction and industrial waste materials—such as stone dust, overburden material from mining activities, crushed aggregates, foundry sand, and other mineral by-products—can significantly reduce costs, conserve natural resources, and minimize environmental pollution [10–12]. As a result, the need to identify suitable alternatives to river sand for use in concrete and mortar in infrastructure projects has become increasingly critical in recent years. Engineers and researchers have developed innovative strategies to reduce or entirely replace the use of natural river sand by adopting alternatives such as crushed stone aggregates, quarry dust, and processed industrial by-products [10–13].

2 Overburden Material

Overburden is the material overlying a mineral deposit that must be removed to access the ore and reserves. The soil profile consists of several layers, including the fertile topsoil and the underlying overburden. The surface layer (0–15 cm) holds a large reserve of nutrients and micronutrients that are vital to the long-term success of mine rehabilitation. Immediately above the rock matrix lies the overburden layer, comprising 30–100 cm of coarse subsoil. Once quarrying begins, topsoil and waste material are usually excavated separately. The topsoil is used immediately for rehabilitation, whereas when excavation is complete, the surplus material is collected and returned to the same mine pit. Because overburden contains no nutrients, storage has no effect on its quality.

Overburden material used in construction must be free from contaminants and debris. A double-refining process using sieves was implemented to remove unwanted materials such as clay, silt, and vegetative matter. In this study, the overburden (OB) material was treated in this way and is referred to as processed overburden material, as shown in Fig. 1.

Fig. 1. Processed Overburden Material.

The Building Control Authority of Singapore has been seriously engaged with the industries of the country to change over to the sustainable construction from the present traditional method of construction [13]. By appropriate changes in design and regulatory controls concerning sustainable construction coupled with the adoption of recycled materials, the industry has tuned to benefits of switching over to alternate construction materials and methods. This approach not only helps in preventing overexploitation of natural resources and their consequential depletion but also promotion of the principle of sustainable development which means preserving the natural resources for use by future generation.

3 Experimental Programme

3.1 Materials

Ordinary Portland Cement (OPC) of 53 grade was used in this study. The fine aggregate was fully replaced (100%) with processed overburden material, while river sand was used in the control mixture, along with 20 mm coarse aggregate. The chemical and physical properties of the processed overburden material were analysed, and the results are tabulated in Tables 1, 2, and 3.

Table 1. Properties of River Sand.

Property	Test Data
Fineness Modulus	2.71
Specific Gravity	2.53
Bulk Density (kg/m³) a) Loose b) Compacted	1600 1720
Silt Content	1%

Table 2. Properties of Processed Overburden Material.

Property	Test Data
Fineness Modulus	2.88
Specific Gravity	2.60
Bulk Density (kg/m³) a) Loose b) Compacted	1450 1610
Silt Content	1.4%

Table 3. Properties of Processed Overburden Material (Chemical).

S.No	Test	Result
1	Deleterious Material a) Materials <75 μ b) Clay Lumps c) Coal & lignite	5.0% 4.8% Nil
2	Chemical analysis i) Loss on Ignition ii) Silica (SiO_2) iii) Ferric oxides (Fe_2O_3) iv) Alumina (Al_2O_3) v) Calcium Oxide (CaO)	% by weight 1.27 88.67 1.82 4.49 0.45 0.08

3.2 Mix Proportions

In the present work, M20 grade concrete is casted, tested and the physical properties with concrete making materials are shown in Table 4 and 5.

Table 4. Quantity of Material required for 1m^3 M-20 Grade Concrete with Processed Overburden Material.

Grade	W/C Ratio	Water	Cement	Fine aggregate	Coarse aggregate	Super Plasticizer (ml)
M-20	0.55	184	335	734	1118	0

Table 5. Concrete Mix Design.

Grade	M-20
Cement	1
Fine aggregate	2.20
Coarse aggregate	3.34
W/C	0.55

3.3 Specimen Preparation and Testing

Specimens were cast in accordance with the relevant test standards. Table 6 presents the specimen sizes used for each test. The strength and durability of the concrete were evaluated, with durability assessed through resistance to H_2SO_4, Na_2SO_4, and HCl solutions. The durability tests involved long-term immersion in these chemical solutions, each at a concentration of 5%. Weight loss was measured at 28 and 90 days. Permeability was evaluated using the rapid chloride penetration test (RCPT) and a water permeability test. The specimen testing is shown in Figs. 2 and 3.

Table 6. Size of Specimens.

S.No	Test – Size of Specimen
1	Compression Test – 150×150×150 mm
2	Flexural Test – 500×150×150 mm
3	Split Tensile Strength – 150×300 mm
4	Durability – 100×100×100 mm

4 Results and Discussions

4.1 Mechanical Properties

Tables 7 and 8 present the strength results of the processed OB concrete and the conventional concrete. For M20 processed overburden concrete, the compressive, split tensile, and flexural strengths increased by 5.21%, 6.75%, and 7.28%, respectively, from 28 to 90 days of curing.

Table 7. Strength Properties of Processed OB Concrete.

Test Description	28 Days	90 Days
Compressive Strength (MPa)	48.55	51.08
Split Tensile Strength (MPa)	3.26	3.48
Flexural Strength (MPa)	4.81	5.16

Table 8. Mechanical Properties of Traditional Concrete.

Test Description	28 Days	90 Days
Compressive Strength (MPa)	50.17	53.87
Split Tensile Strength (MPa)	3.41	3.65
Flexural Strength (MPa)	4.35	4.59

Fig. 2. Compressive strength of Processed Overburden Concrete specimen under testing.

Fig. 3. Split Tensile strength of Processed Overburden Material Concrete specimen under testing.

4.2 Durability Properties

Percentage Weight losses of M-20 Grade Concrete with and without Processed Overburden Material in 5% H_2SO_4 Solution at 28 days immersion is 8.23 and at 90 days is 9.34. Percentage Weight loss of Ordinary Concrete at 28 days immersion is 4.97, at 90 days is 5.60. In 5% HCL Solution, weight loss at 28 days immersion is 1.59, at 90 days is 2.80. Percentage Weight loss of Ordinary Concrete at 28 days immersion is 4.23, at 90 days is 4.89. In 5% Na_2SO_4 Solution, weight loss at 28 days immersion is 0.1 and at 90 days is 0.81. Percentage Weight loss of Ordinary Concrete at 28 days immersion is 0.4, at 90 days is 0.80. The preparation and testing of the samples is shown in Fig. 4, 5 and 6.

Fig. 4. Specimens under immersion for Durability test of Processed Overburden Material in H_2SO_4, HCL & Na_2SO_4 Solutions.

Fig. 5. Specimens of Processed Overburden Material Concrete after 28 days immersion in H_2SO_4, HCL and Na_2SO_4 Solutions.

Fig. 6. Testing arrangements of water permeability test.

Permeability of M20 grade concrete made with river sand and processed OB material results using water permeability test and RCPT method are represented in Table 9.

Table 9. Permeability Results of Concrete with Processed Overburden Material and Concrete with River Sand (Rapid Chloride Permeability Test).

Sample Type	28 Days (Coulombs)	Remark	90 Days (Coulombs)	Remark
River Sand – Sample 1	2200	Moderate	2150	Moderate
River Sand – Sample 2	2300	Moderate	2180	Moderate
Overburden – Sample 1	2250	Moderate	2160	Moderate
Overburden – Sample 2	2350	Moderate	2190	Moderate

The permeability values for Ordinary concrete of M20 grade with River sand from 28 days are 2200 and 2300 coulombs; 90 days are 2150 and 2180 coulombs. Similarly, the permeability values for Concrete of M20 Grade with Processed Overburden Material from 28 days are 2250 and 2350 Coulombs; 90 days are 2160 and 2190 coulombs.

5 Conclusions

- Processed Overburden Material can be economically used in the manufacturing of Cement blocks and other Plain Cement Concrete works and other R.C.C Works of M20 Grade Concrete.
- Based on the results, it is concluded that Processed Overburden Material can be used in Concrete for M20 Concrete.

- The percentage increase in compressive strength of M20 grade ordinary concrete at 90 days when compared to 28 days is observed to be 7.37%, Split tensile strength is 7.35%, and Flexural strength is 5.52%.
- The percentage increase in compressive strength of M20 grade over burden concrete at 90 days when compared with 28 days is observed to be 5.21%, Split tensile strength is 6.75%, and Flexural strength is 7.28%.
- Higher exposure times resulted in a greater percentage drop in weight loss for Ordinary Concrete with River Sand and Concrete with Processed Overburden Material. Permeability results of concrete by RCPT showed that the concrete is having moderate chloride ion penetration due to good packing density between the particles.
- From the results, Rapid Chloride Permeability Test shows that the reduction in pores in concrete improves the surface integrity of concrete, improves its homogeneity, good bonding and reduces the probability of cracks.
- The River Sand may be contaminated with Clay, silt and other organic matter. The potential existences of above impurities in Processed Overburden Material are almost ruled out. Processed Overburden Material is used as a safe supplement for river sand in concrete.
- From various tests conducted on overburden concrete as per the test procedures prescribed by the codes for traditional fine aggregate it was determined that the qualities of Refined overburden soil seems to be as effective as traditional river sand, and research has shown that it could be utilised as fine aggregate in concrete manufacturing instead of river sand. As Sand is becoming increasingly rare and pricey these days, overburden soil will be an alternative option.

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