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Utilisation of Waste Materials in Concrete for Green Built Environment

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***Abstract*—This study investigates the use of red mud and stone dust as sustainable alternatives in concrete production. Red mud, a by-product of alumina production, and stone dust, a waste material from quarries, were examined as potential substitutes for cement and m-sand, respectively. Concrete mixtures for M25 grade were prepared by replacing cement by 20% with redmud and mssand by 50% with stonedust. The resulting concrete mixes were extensively tested for properties such as compressive strength, flexural strength, and split tensile strength. A comparative analysis was conducted to assess the performance and cost-effectiveness of the modified concrete compared to conventional concrete. The research findings demonstrate that incorporating red mud as a partial cement replacement improves the strength and durability of the concrete while reducing cement consumption and environmental impact. The study highlights the feasibility of using red mud and stone dust as sustainable alternatives in concrete production, offering a solution to decrease cement consumption and preserve natural resources. By promoting the utilization of industrial by-products in concrete production, this research contributes to environmentally friendly construction practices, minimizing waste generation and conserving natural resources.**

Keywords—concrete, red mud, stone dust, alumina waste, sustainable materials.

I. INTRODUCTION

Increasing population and industrial demand generate significant amounts of waste and by-products, posing disposal challenges for many countries. Safe disposal requires resources, time, and land. Research aims to find alternatives to utilize these materials, minimizing harm to the environment. Cement production releases CO_2, contributing to air pollution. Red mud, a by-product of aluminium manufacturing, poses disposal challenges. India's mineral industry plays a vital role in its economy, with a well-established aluminium sector. Managing solid waste in India is a major problem due to land scarcity and costly recycling. Utilizing industrial waste in concrete production offers cost-effectiveness and pollution mitigation. Red mud, highly alkaline, currently faces disposal issues, generating significant environmental concerns.

India's growing economy drives significant aluminium demand and bauxite waste production, causing environmental issues. Concrete consumption, the second largest globally, is expected to rise to 20 billion tons per year by 2050. Cement production emits CO2, while natural and artificial aggregates are limited. Red mud, an industrial waste, shows potential as a substitute in ceramics, cement, and bricks, reducing environmental impact. Disposing of industrial waste on land threatens the environment, and aluminium production generates 50 million tons annually. Red mud, a hazardous residue, can be used in cement-based materials, contributing to cleaner construction practices. Proper red mud disposal is crucial due to its high iron content and alkaline nature. About 35-40% of bauxite becomes alkaline red mud waste, with 0.8-1.5 tons generated per ton of alumina production.

In developing nations like India, the demand for natural sand (NS) in concrete construction is high, but its availability is limited. To address this issue, guidelines have been introduced to encourage the exploration of alternative aggregates. The disposal of granite and marble waste generated during their manufacturing process can be mitigated by incorporating these materials into concrete production, thereby turning waste into a valuable resource. Crushed rock dust can be used as a partial replacement for sand in concrete, up to 50 percent, while maintaining quality and standards of other ingredients. The use of manufactured sand (M-sand) has gained popularity, but it is not suitable for replacing cement in concrete due to its lower pozzolanic properties. Granite cutting waste (GCW) poses environmental challenges, requiring proper management and disposal methods. The excessive use of mortar in construction can hinder rainfall from replenishing groundwater levels. The use of alternative materials, such as stone waste, in concrete offers cost-effectiveness and environmental benefits, including the reduction of carbon emissions associated with cement production. Green concrete, focusing on environmental considerations throughout its lifecycle, provides a sustainable solution. These alternative solutions and practices contribute to the challenge of sustainable construction by reducing resource consumption and waste generation. The use of micron-sized fine granite powders in regions with abundant natural granite resources and related industries, like China, Brazil, and Turkey, may pose health risks due to potential inhalation disorders.

II. THEORY AND CONCEPTS

A. Mechanical strength of concrete:

Concrete's compression strength is a vital property that indicates its maximum resistance to pressure. It is measured in psi or MPa and depends on factors like cement type, water-cement ratio, aggregate properties, curing conditions, and age. Testing involves subjecting concrete specimens to increasing force until failure, recording the maximum stress. Generally, compressive strength improves with age due to cement hydration. Incorporating additives like red mud and stone dust can enhance concrete's compression strength. Red mud, a byproduct of alumina production, reacts with cement to form compounds that enhance strength and durability. Stone dust fills voids and improves packing density. Tensile strength, typically lower than compressive strength, can be improved by adding reinforcements like steel bars. Red mud densifies cement paste, while stone dust strengthens interlocking. However, their effects on tensile strength are less significant. Flexural strength, important for assessing bending resistance, can also be improved by using red mud and stone dust as partial replacements for cement and fine aggregate, respectively.

B. Indian Scenario of Production/ Consumption of Cement:

India's cement industry has immense growth potential, fueled by its abundant limestone deposits. As the world's second-largest cement producer, India accounts for over 7% of global capacity. The top 20 companies contribute 70% of total production, which reached 329 MT in FY20 and is projected to reach 381 MT by FY22. Consumption stood at 327 MT in FY20 and is expected to reach 379 MT by FY22, with estimated demand touching 419.92 MT by FY27. Key players include ACC, Dalmia, and Ultratech Cement. With strong demand and increased infrastructure spending, cement production is forecasted to reach 550 MT by 2025 and 800 MT by 2030, surpassing the current installed capacity of 500 MTPA.

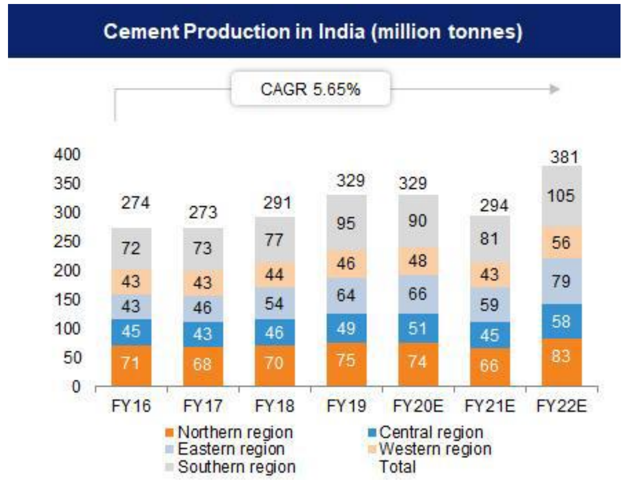

Fig 2.1 Cement Production in India

Source: Indian Brand Equity Foundation (website: ibef.org)

C. International Scenario of Production/ Consumption of Cement:

India ranks as the second-largest cement producer globally, with an annual production of approximately 330 million metric tonnes. The leading position is held by China, with a massive cement production of 2,500 million metric tonnes.

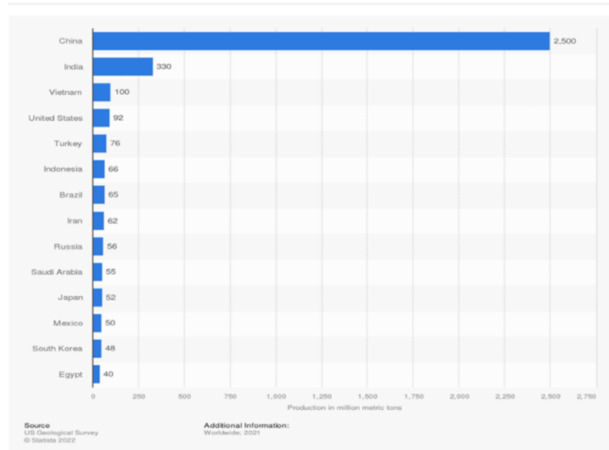

Fig 2.2 Top cement producing countries

D. Indian Scenario of Production / Consumption of sand:

The sand utilization factor, estimated to be around 2.5 for every unit of concrete consumed, implies that for a concrete utilization of 1 million tons in a district, the sand utilization would be approximately 2.5 million tons. This factor is determined based on per capita concrete utilization multiplied by 2.5, with sand utilization given a weightage of 50% and the remaining weightage allocated to other factors. Some states like J&K, Himachal Pradesh, Arunachal Pradesh, Manipur, Goa, Mizoram, Meghalaya, Nagaland, Sikkim, Andaman and Nicobar, and Chandigarh have a demand for sand under 8 million tons. West Bengal and Tripura are not included in the available data. Karnataka, Telangana, and Tamil Nadu are the leading states producing a significant amount of stone dust in India, driven by factors such as the high cost of river sand in Bangalore.

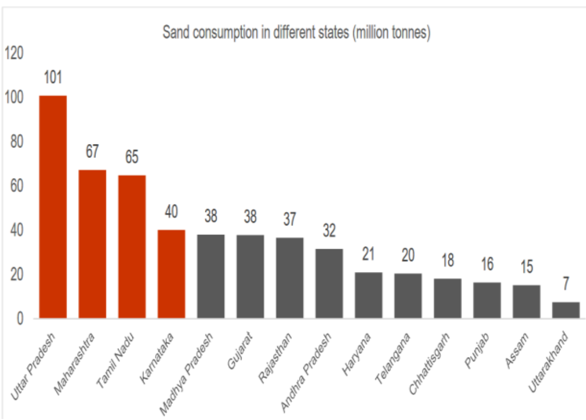

Fig 2.3 Estimation of State-wise Sand consumption in FY17

Source: RBI, Analysis

E. International Scenario of Production / Consumption of Sand:

Globally, the consumption of sand and rock amounts to approximately 50 billion metric tons annually, equivalent to 18 kilograms per person per day. However, the growing demand for sand poses a significant sustainability challenge in the 21st century, requiring improved management of global sand resources, according to the United Nations. The report highlights the need for policies that reduce the demand for new sand and promote solutions to mitigate the adverse environmental impacts of sand mining. It also emphasizes the importance of establishing a more transparent sand supply chain through enhanced monitoring and global information sharing. The accompanying figure provides data on cement production in different countries, including statistics on the top sand-producing nations.

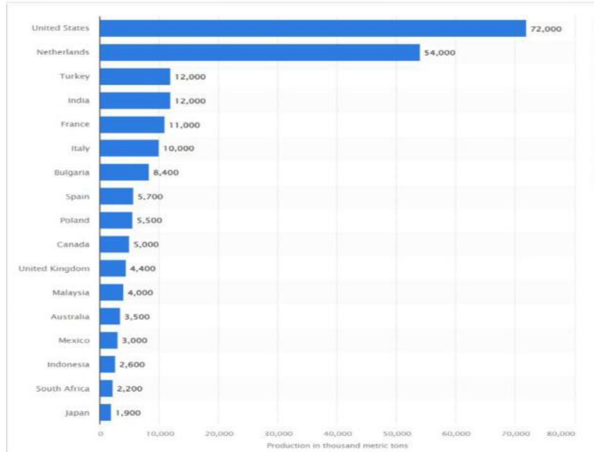

Fig 3.4 International Scenario of Cement Production

Source: US Geological Survey (website: statista.com)

F. Bauxite Residue (Red Mud)

Red mud is a waste product produced during the aluminium production process known as the Bayer's process. It is highly alkaline and presents difficulties in disposal. When disposed on agricultural lands, it renders the soil infertile for an extended period. Comprised of solid and metallic oxide-bearing impurities such as iron, silica, residual aluminium, and titanium oxide, red mud's red color is attributed to its oxidized iron content, which can make up to 60% of its mass. Globally, around 70 million tons of red mud is generated annually, with India alone contributing over 4 million tons each year. The high alkalinity of red mud poses significant environmental hazards to water, land, and air, and its storage and disposal entail substantial costs due to the large area required for containment.

G. Stone dust

Stone dust, a byproduct generated from crusher plants, has the potential to be a suitable alternative to natural river sand in concrete production. Its utilization not only improves the quality of concrete but also helps conserve natural river sand reserves for future use. Stone dust possesses several desirable properties, such as being flat and smooth, making it ideal for creating level surfaces during paving projects. Additionally, it is cost-effective compared to other options like sand, making it a preferred choice for many. It also helps prevent weed growth between paving stones and acts as a non-porous material, preventing water seepage and reducing the risk of damage to the paving stones. Local sourcing of stone quarry dust is common, and its proportions in concrete mixes are kept consistent based on ongoing research on mortar cubes.

III. MATERIALS AND METHODOLOGY

A. List Of Materials:

1. Cement OPC-53
2. Bauxite residue (red mud)
3. Stone dust
4. Aggregates
   a) Coarse aggregate: 20 mm downsize
   b) Fine aggregate: M-Sand
5. Water: Potable

B. Conduction of basic tests on materials

All the materials used are subjected to basic tests like, specific gravity, setting time, standard consistency, fineness modulus and hydrometer analysis. Based on the test results their suitability for use is decided.

1. Specific Gravity of Cement: The test is conducted as per the IS 2720- Part-3. The cement's specific gravity is determined by dividing its mass or density by that of a standard substance. Conducted using kerosene as the liquid medium of reference, which does not react with cement. Also, a standard specific gravity bottle is employed.
2. Standard Consistency of Cement: The test conducted according to IS Code 4031 determines the standard consistency of a cement paste. The standard consistency refers to the level of consistency at which the Vicat plunger penetrates the cement paste to a depth of 5 mm to 7 mm from the bottom of the Vicat mold. The test involves preparing cement paste samples and assessing the penetration depth of the plunger to determine the standard consistency.
3. Initial Setting Time of Cement: The test is conducted as per the IS1489-Part 1. The time elapsed between the moments when water is added to the cement to the time when the square needle penetrates a depth of 33 to 35 mm from the top of the mould is known as the Initial Setting Time of that cement.
4. Final Setting Time of Cement: The test is conducted as per the IS 4031-Part-5. The period elapsing between the time when water is added to the cement and the time at which the needle makes an impression on the surface of the text block while the attachment fails to do so shall be the final setting time.
5. Fineness Modulus: The test is conducted as per the IS 383:(1970). The Fineness Modulus (FM) is an empirical figure obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves and dividing the sum by 100.

C. Mix Design

I. Conventional concrete M25 grade mix proportion

- Cement = 410.77 kg/m³
- Water = 197.17 l/m³
- Fine aggregate = 752.212 kg/m³
- Coarse aggregate 20 mm = 954.073 * 60 % = 572.44 kg/m³
- Coarse aggregate 10 mm = 954.073 * 40 % = 381.63 kg/m³
- Water-cement ratio = 0.48

II. Mix proportion for replaced concrete

- Cement = 410.77 kg/m³
- Red mud = 82.155 kg/m3
- Water = 197.17 l/m³
- Fine aggregate = 376.106 kg/m³
- Stone dust = 380.430 kg/m3
- Coarse aggregate 20 mm = 954.073 * 60 % = 572.44 kg/m³
- Coarse aggregate 10 mm = 954.073 * 40 % = 381.63 kg/m³
- Water-cement ratio = 0.48

D. Methodology:

1. Collection of red mud and stone dust material.
2. Tests on materials are conducted according to IS code arrangements and water cement ratio (proportion) are fixed. (Specific gravity, fineness modulus, etc.)
3. Tests on cement and fine aggregate is conducted according to IS code provisions.
4. Calculation of quantity of materials for the cube, cylinder and beam.
5. Casting of cube, cylinder and beam.
6. Determination of strength of casted cube, cylinder, beam for 7, 14, and 28 days.
7. Cost correlation of the structure blocks/cubes with ordinary blocks/cubes (conventional blocks) in light of standard market cost.

IV. RESULTS AND ANALYSIS

A. Basic tests

Table 4.1 Basic Materials Tests

Sl No	Test	Marerial	Result
1	Specific Gravity	Cement	3.05 g/cc
2	Specific Gravity	Red Mud	2.68 g/cc
3	Specific Gravity	M-Sand	2.61 g/cc
4	Specific Gravity	Stone Dust	2.64 g/cc
5	Specific Gravity	Coarse Aggregates	2.58 g/cc
6	Fineness Modulus	M-Sand	2.6 g/cc
7	Fineness Modulus	Stone Dust	3.26 g/cc
8	Fineness Modulus	Coarse Aggregates	3.92 g/cc
9	Normal Consistency	Cement	30%
10	Normal Consistency	Red Mud	30%
11	Initial Setting Time	Cement	105 min
12	Initial Setting Time	Red Mud	50 min
13	Final Setting Time	Cement	256 min
14	Final Setting Time	Red Mud	300 min

B. Compressive Strength

Cubes are tested after 7, 14 and 28 days of curing and strength obtained are listed in the table and graphs are generated for the same. By replacing cement by 20% with redmud and msand by 50% with stonedust.

Table 4.2: Compressive strength of mix combinations

Combinations	Result (Strength in MPa)		
	7 Days	14 days	28 Days
Conventional Mix	2.45	3.48	3.96
Replaced Mix	2.32	3.57	4.32

Fig 4.1: Compressive strength of mix combinations

C. Flexural Strength

Beams are tested after 7, 14 and 28 days of curing and strength obtained are listed in the table and graphs are generated for the same. By replacing cement by 20% with redmud and msand by 50% with stonedust.

Table 4.2: Flexural strength of mix combinations

Combinations	Result (Strength in MPa)		
	7 Days	14 Days	28 Days
Conventional Mix	21.75	26.30	32.10
Replaced Mix	22.07	27.25	32.63

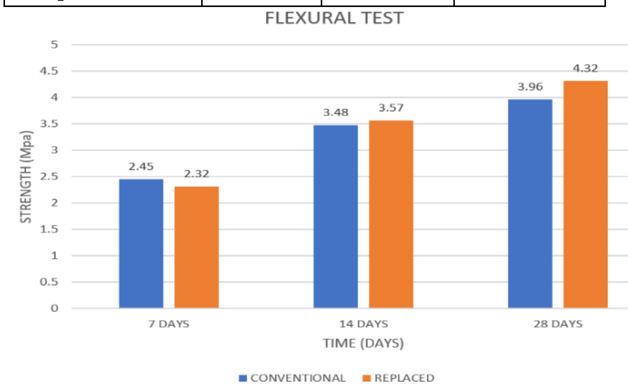

Fig 4.2: Flexural strength of mix combinations

D. Tensile Strength

Cylinders are tested after 7, 14 and 28 days of curing and strength obtained are listed in the table and graphs are generated for the same. By replacing cement by 20% with redmud and msand by 50% with stonedust.

Table 4.3: Tensile strength of mix combinations

Combinations	Result (Strength in MPa)		
	7 Days	14 Days	28 Days
Conventional Mix	1.80	2.10	3.05
Replaced Mix	1.95	2.50	3.15

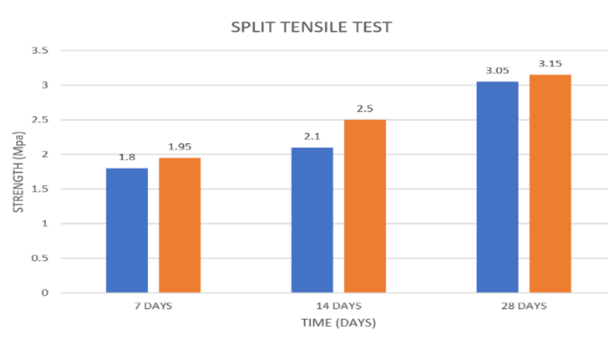

Fig 4.3: Tensile strength of mix combinations

V. CONCLUSIONS

This chapter provides the conclusions based on the results obtained the impact of incorporating red mud as a partial substitute for cement, as well as stone dust and stone fines as partial replacements for fine aggregates

Based on the results and analysis the following conclusions were drawn

- The experimental findings suggest that replacing 50% sand with stone dust and substituting 20% cement with bauxite can yield positive results.
- The use of stone dust and bauxite ore in construction has been identified as a viable alternative for addressing the challenges in industrial waste disposal.
- Concrete specimens with stone dust and bauxite ore additives exhibited increased flexural strength, tensile strength and compressive strength.
- In cylinders 9% increase in flexural strength found by replaced concrete than the conventional concrete.
- The study revealed that the price of traditional concrete per cubic meter. was 4220.18 INR, while the cost of replaced concrete was 3580.25 INR, resulting in a cost reduction of 17.88%.

A. Scope for Future Study

- The outcome of the study should be validated by a wider testing scope, different dosage of materials and long-term testing procedures.
- It is recommended to conduct further research to explore the long-term performance, durability, and structural behavior of concrete with red mud and stone dust. This will provide a more comprehensive understanding of the material's behavior and ensure its suitability for various construction applications.
- The study which encompasses laboratory experiments, testing different proportions and combinations of red mud and stone dust in concrete, and evaluating their effects on properties such as compressive strength, workability, and resistance to various forms of deterioration.
- The research will explore the ecological benefits of utilizing these waste materials as alternative resources in concrete production, aiming to reduce the environmental impact associated with traditional concrete manufacturing processes. It will investigate the potential reduction in carbon emissions and energy consumption, as well as the overall ecological footprint of using red mud and stone dust in concrete.
- The study will also consider economic factors, assessing the cost-effectiveness and feasibility of implementing such sustainable practices in the construction industry.

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