Grenze International Journal of Engineering and Technology, June Issue

Sustainable Concrete Development using Ternary Agro-Industrial Waste Blends as Cement Replacement

S.P. Raut[1], Uday Singh Patil[2], Amol Nagdeve[3], Ayush Bahadure[4], Paras Kangali[5] and Amit Patne[6]
[1]Professor, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India
[2]Assistant Professor, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India
Email: patil.udaysingh4@gmail.com
[3-6]B. Tech Undergraduate Students, Department of Civil Engineering, Yeshwantrao Chavan College of Engineering, Nagpur, India

***Abstract*— The construction sector is at a decisive juncture where decarbonization is necessary primarily due to the fact that the production of Ordinary Portland Cement (OPC) has an average contribution of approximately 8% of the total human-induced CO_2 on the planet. This paper addresses the following issues: how can cement be partially substituted with a blend of agro-industrial waste: Chana Husk Ash (CHA), Wheat Husk Ash (WHA), and Artificial Sand Waste (ASW) powder. The characterization of the materials reveals that, besides the agro-ashes being rather crystalline, they are also deficient in chemicals, i.e., low in SiO_2+and high in CaO in CHA. The ASW powder, though, meets the pozzolanic requirements with $SiO_2+Al_2O_3+Fe_2O_3$ ≈75.8%, which is the primary chemical participant in the mixture. The five mixes of concrete of M20 grade (M0-M4) with a maximum replacement of 80% were prepared and tested. An evaluation of 28-day mechanical strength and durability demonstrates that mix M4 - in which the overall replacement is 30 percent - provides the most desirable balance. M4 had a reduced embodied carbon emissions by 43% of that in normal concrete. These findings validate that massive waste valorisation can achieve both technical viability and which can be very beneficial to the environment, so as to make construction sustainable.**

***Keywords*— Chana Husk Ash (CHA), Wheat Husk Ash (WHA), Artificial Sand Waste (ASW).**

I. INTRODUCTION

The second material that is consumed more than water is concrete and that is a huge environmental nightmare. OPC is a massive carbon giver: It contributes 5-8 percent of the total CO_2 emissions produced by humans across the world [1]. The majority of these emissions are made during unavoidable calcination of limestone (most of which releases carbon) and the fuel required to heat the kilns; approximately half of it is due to the chemical decomposition, and approximately 40 percent of it is due to the fuel [2], [3]. Reducing the amount of clinker to Supplementary Cementitious Materials (SCMs) is one of the most popular and immediate measures to reduce carbon emissions to achieve climate goals [3], [4].
The two related issues addressed in this study include high carbon production and the accumulation of waste. We work on transforming big local waste streams into useful assets, in the style of the traditional circular economy [4], [5]. China Husk Ash (CHA) and Wheat Husk Ash (WHA) are considered the primary waste sources, as these are local agricultural wastes, and Artificial Sand Waste (ASW) powder is the industrial mineral waste.

Grenze ID: 01.GIJET.12.2.39_22

Agriculture, particularly in India, produces volumes of crop residues, and when this is processed properly, it would be a terrific SCM feedstock [6], [7]. Similarly, stone cutting industries emit fine mineral dusts (such as granite or basalt cutting dust) that can serve as mineral fillers, or even as pozzolans when appropriately defined [8], [9].

Past experience indicates that properly burned rice or wheat husk ash might be very well processed and of good pozzolanic activity, and it might be used at relatively small levels of replacement of 5-30 percent, increasing strength and making it satisfactory [10], [11]. Certain conditions may also cause mineral wastes such as granite or basalt dust to serve as micro-fillers or active pozzolans to enhance the particle packing and long-term performance [8], [9]. In this study the investigation of the synergy and performance of a ternary SCM blend of ASW, CHA and WHA in M20 concrete was carried out. The overall objective is to identify the optimal sustainable proportion of the mix that maximizes cement replacement (tested here between 30% and 80%) and still satisfies structural and durability criteria and measures the resulting decrease in embodied carbon [3], [4].

II. Materials and Methodology

A. Materials

The five main constituent sustainable concrete mixes used were taken from three SCMs sourced from local waste streams. Ordinary Portland Cement: OPC 53 Grade was used as the main binder, conforming to BIS specification IS 12269 [12]. Fine and Coarse Aggregates: Standard River sand (fine aggregate) and crushed stone (coarse aggregate, nominal maximum size 20 mm) were used, conforming to IS 383 [13]. Industrial Waste (Artificial Sand Waste—ASW): The ASW powder was obtained from Sandtech Pvt. Ltd., Yavatmal, Maharashtra. The material was received as a fine powder/dust and needed only sieving and no thermal activation. Granite/basalt cutting dusts are known to primarily act as micro fillers and in many cases contribute chemically as pozzolans when silica/alumina contents are enough [8], [9]. Agro-Waste (Chana Husk Ash—CHA and Wheat Husk Ash—WHA): The raw husks were collected from nearby farmlands around Nagpur and brought to the laboratory for processing under controlled conditions. Raw husks were subjected to controlled combustion in a laboratory furnace at 600 °C to enhance conversion into reactive amorphous silica. This thermal treatment range is similar to the reported regimes for enhancing the pozzolanicity of biomass ashes [10], [11]. Physical and chemical characterization of the materials was done using established laboratory methods and Indian standards to determine the composition, fineness, morphology, and specific gravity.

B. Methodology

Figure 1 presents a step-by-step methodology adopted for the development of M20-grade sustainable concrete using ternary blends of various agro-industrial wastes, such as Chana Husk Ash (CHA), Wheat Husk Ash (WHA), and Artificial Sand Waste (ASW), as partial cement replacement. Each of these steps is discussed in detail below.

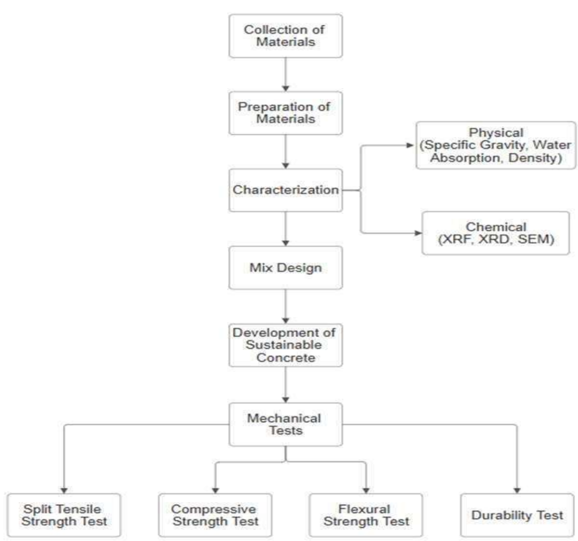


Figure 1. Flowchart for Methodology.

Collection of Materials: The primary materials used in this research include Ordinary Portland Cement of 43 grade, fine aggregates, coarse aggregates, and the selected agro-industrial wastes-CHA, WHA, and ASW. Locally available materials were used to ensure that the construction was economically viable and sustainable. The wastes collected in their raw state were stored in airtight containers to avoid contamination and moisture absorption.

Material Preparation: The collected waste was dried, ground, and sieved using a 90-micron sieve to obtain a uniform fineness. This also enhances the bonding with the cementitious materials and evenly distributes the particles in the mix. We used the aggregates, which had been cleaned and dried in the oven prior to use.

Material Characterization: Characterization was done to ascertain the physical and chemical characteristics of the materials used. The specific gravity, water absorption, and bulk density were measured according to the requirements of IS 2386 (Part III): 1963 and IS 383: 2016. These values have an influence on mix design and workability. X-ray fluorescence, X-ray diffraction and scanning electron microscopy were used to determine oxide composition and microstructure. The tests established the existence of silica, alumina, and calcium, which is a sign of pozzolanic potential.

Mix Design: The concrete mix proportions that we developed based on the IS 10262:2019 and IS 456:2000 is M20 grade. The control mix (CM) involved 100 percent cement, and the rest of the mixes involved replacing cement with the ternary blend CHA + WHA + ASW in the proportions of 10 percent, 20 percent, and 30 percent. All other parameters, like the ratio of water to cement, grading of the aggregates, and admixtures, were maintained constant to enable us to examine the influence of SCM replacement rates on the mechanical properties.

Sustainable Concrete Development: In the laboratory, a pan mixer is used to mix the concrete. The first step was to combine the dry ingredients with water in order to obtain uniformity. The fresh concrete was placed into cube molds of 150mm x 150mm x 150mm and poured and compacted using a vibrating table, and the specimens were allowed to dry in water over a period of 28 days. These measures were taken to make sure that the concrete samples were reliable and consistent to test.

Mechanical Tests: After curing, the hardened concrete specimens were tested mechanically and for durability to assess their performance. The Split Tensile Strength Test was conducted on cylindrical specimens of 150 mm × 300 mm as per IS 5816:1999 to evaluate tensile strength. The Compressive Strength Test was carried out on 150mm cubes in a compression testing machine as per IS 516:1959 (Part 5). Strength results were compared between control and SCM-blended mixes. The flexural strength and cracking behavior of beam specimens having a size of 100 mm × 100 mm × 500 mm were tested according to IS 516:1959. The properties of durability were investigated in terms of water absorption, acid resistance, and sulphate attack to assess the long-term performance of SCM-based mixes.

C. Mix Design and Proportions

The nominal mix M20 of 1:1.5:3 was converted to mass proportions and kept constant at a constant W/B of 0.5 in experimental mixes. The control mix M0 had approximately 400 kg/m³ OPC. For experimental mixes M1 through M4, partial cement mass replacement (by weight) was carried out by the ternary SCM blend comprised of ASW, WHA, and CHA up to a maximum replacement of 80%. Simulated mix proportions per m³ of concrete are listed in Table I.

TABLE I. SIMULATED MIX PROPORTIONS

Mix ID	Cement (%)	ASW (%)	WHA (%)	CHA (%)	Total SCM Replacement (%)
M0 (Control)	100	0	0	0	0%
M1	20	65	10	5	80%
M2	40	45	10	5	60%
M3	60	25	10	5	40%
M4	70	15	10	5	30%

III. RESULTS AND DISCUSSIONS

A. Characterization of Raw Materials

XRD (X-ray Diffraction)

XRD analysis (Figures 2-4) was performed to find out the crystalline phases that are present in the materials and to approximately calculate their amorphous silica content. It determined that the patterns of CHA (Figure 2) and WHA (Figure 3) showed sharp crystalline peaks around 2θ≈27° and 35°. These peaks show comparatively high crystallinity, which could restrict early pozzolanic reactivity unless the percentage of amorphous silica is increased through proper burning and/or processing techniques. Whereas, the ASW XRD analysis (Figure 4), which showed strong crystalline peaks consistent with mineral dusts obtained from granite and basalt processing, confirmed its stable and mineral-rich origin.

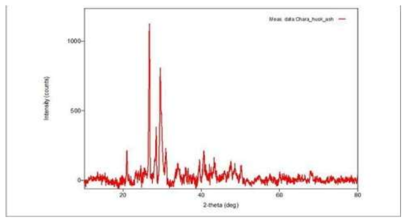


Figure 2. XRD Results for Chana Husk Ash

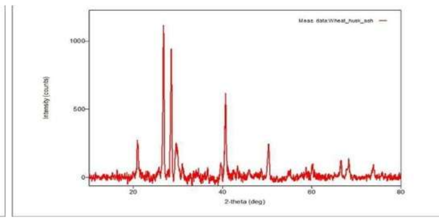


Figure 3. XRD Results for Wheat Husk Ash

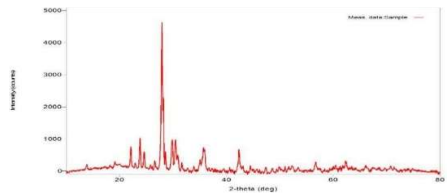


Figure 4. XRD Results for Artificial Sand Waste

XRF (X-ray Fluorescence):

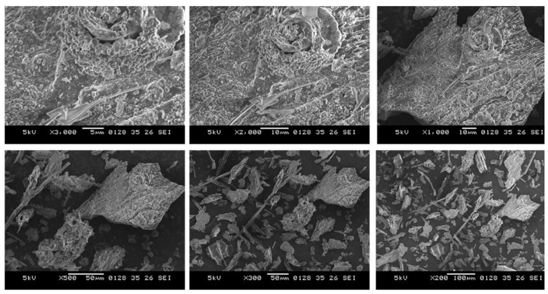
The XRF analysis was performed to find out the elemental composition of ther materials and to estimate their pozzolanic potential using the traditional criterion of $SiO_2 + Al_2O_3 + Fe_2O_3$. The oxide composition of materials as mass percentage is listed in Table II. The XRF test determine that ASW is the chemically active pozzolan with S+A+F≈75.8%, which exceeded the 70% criterion. Therefore, we can say that unless the silica availability of CHA and WHA are increased, they are expected to play a major role in physical/micro filling and nucleation in the ternary blend.

TABLE II. COMBINED OXIDE COMPOSITION

Formula	Chana Husk Ash (CHA)	Wheat Husk Ash (WHA)	Artificial Sand Waste (ASW)
Na_2O	0.415	226.7	5.99
MgO	3.53	1.389	5.38
SiO_2	6.768	45.013	46.3
P_2O_5	1.042	0.843	0.306
SO_3	4.001	2.029	0.114
Cl	2.659	5.885	—
K_2O	32.301	25.787	0.324
CaO	39.069	12.167	9.29
O_2	1.07	0.742	2.35
V_2O_5	342.8	115.4	0.114
Cr_2O_3	—	95	—
MnO	0.169	852.5	0.205
Fe_2O_3	8.421	5.657	12.9
CuO	333	160	0.027
ZnO	698.8	531.5	0.011
As_2O_3	17.4	—	—
Br	96.9	61.3	—
Rb_2O	586.4	384.6	—
SrO	0.191	549.6	0.026
Y_2O_3	—	47.9	—
ZrO_2	413.8	367.2	0.019
SnO_2	498.5	298.1	—
TeO_2	558.4	324.4	—
PbO	53.1	—	—
BaO	—	849.8	—
Al_2O_3	—	—	16.6
NiO	—	—	0.018
Re	16.9	17.5	—

SEM (Scanning Electron Microscopy)

SEM is used to examine a sample's surface, providing its detailed information about its morphology, composition and microstructure. The SEM results (Figure 5-7) showed that CHA and WHA particles are irregular, porous and fibrous type (which is typical of biomass ash morphology). These particles can promote micro-filling and nucleation activity in the paste. Whereas, ASW particles showed dense, angular and blocky morphologies having rough surfaces, which is suitable for packing and interparticle friction, thereby keeping with their role as a densifier and physical filler in the composite.



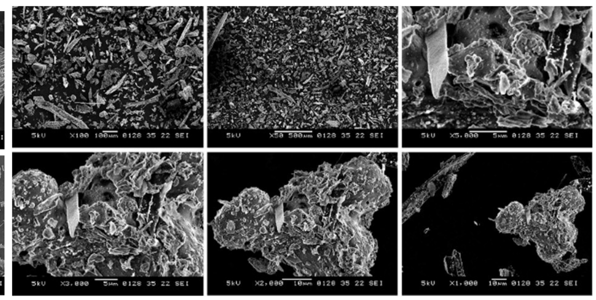


Figure 5. SEM Results for Chana Husk Ash Figure 6. SEM Results for Wheat Husk Ash

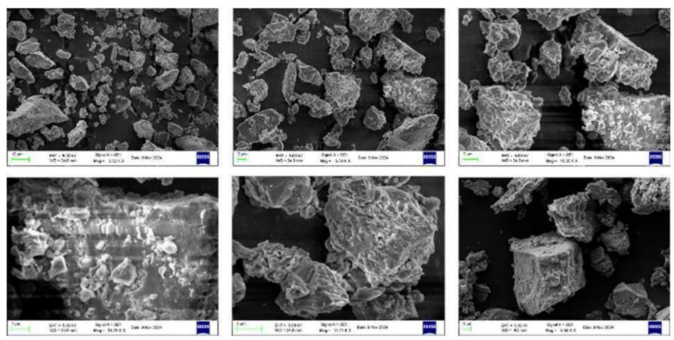


Figure 7. SEM Results for Artificial Sand Waste

B. Physical Test Results on Raw Materials

Specific Gravity Test

The specific gravity test was performed as per IS 2386 [14] and IS 4031 [15] to find the relative density for the mix proportioning. The specific gravity test results are shown in Table III. The test determined that CHA and WHA have lower specific gravity, about 1.4 and 2.3 respectively, which characterizes the porous biomass ash. Whereas, ASW had specific gravity of about 2.9, which is near mineral aggregates. All these outcomes are in line with the expectations for mineral dust and agro-ashes.

Bulk Density Test

The bulk density test was performed as per IS 2386 and used to showcase packing. The bulk density results are shown in Table III. WHA and CHA, with the bulk density of 0.44 g/cm³ and 0.63 g/cm³, showed very low bulk density and high porosity. Whereas, ASW showed a comparatively high bulk density of 1.74 g/cm³, which is to be expected from crushed mineral dust.

Water Absorption Test

Water Absorption test was performed as per the Modified ASTM C642 to determine the water holding capacity of the materials. The results for water absorption test are shown in Table III. As the results indicate, WHA and CHA had very high water absorption value (35.44% and 32.82%), which indicate serious internal void volume of both the agro-ashes and requires adjustments in the mix design to maintain workability of concrete. Meanwhile, ASW showed low water absorption, which indicate its dense mineral origin.

Particle Size Distribution: Particle Size Distribution was performed as per IS 2386 [14] to identify the distribution of various particle sizes in a sample. The PSD showcased that the SCM powders are finer in comparison with OPC. The ultra fineness of the SCM helps in the micro-filling and densification of the matrix.

TABLE III. SPECIFIC GRAVITY TEST RESULTS

Material	Specific Gravity	Bulk Density (g/cm³)	Water Absorption (%)
ASW	2.9	1.74	13.31
CHA	1.4	0.63	32.82
WHA	2.3	0.44	35.44

C. Mechanical Test Results on Developed Concrete

Compression Strength Test

The compression strength test was performed as per IS 516 [16] and the result for the test is shown in Figure 8. The result of the test show that the increase in SCM content decreases the concrete strength. It shows that if more cement is replaced with SCM, the concrete becomes weaker as the quantity of cement is less in the concrete, and therefore, the pozzolanic reaction happens very slowly. The control mix with 0% SCM had the strongest concrete. Whereas when too much SCM was used instead of cement (80%) the strength of the concrete was reduced to some extent. However, mixes with SCM replacement levels between 30% and 40% demonstrated compressive strengths comparable to the control mix. This suggests that this range provides an optimal balance, where agro-industrial waste materials contribute to strength development through the formation of secondary calcium silicate hydrate (C–S–H). Therefore, replacing up to 30–40% of cement with SCMs can produce structurally adequate and environmentally sustainable concrete with only a minimal reduction in strength.

Flexural Strength Test

The test was performed as per IS 516 [16]. (Table IV) All mixes made from SCM demonstrated decreases in 28-day compressive strength compared to the control, while M4, with 30% total replacement, developed 26.1 MPa, about 5.1% less than the control. This is indicative of dilution effects due to the reduced OPC content and the limited chemical reactivity observed for the agro- ashes at early ages. Similar patterns have been reported for high replacement mixes in which strength drops unless reactive SCMs or additional curing/activation are used.

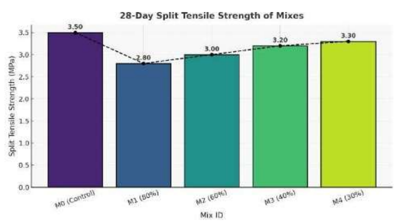


Figure 8. Compressive Strength Test Results

TABLE IV. FLEXURAL STRENGTH TEST RESULTS

Mix ID	28-Day Flexural Strength (MPa)
M0 (Control)	4.5
M1 (80%)	3
M2 (60%)	3.8
M3 (40%)	4.1
M4 (30%)	4.2

Split Tensile Strength Test

The test was performed as per IS 516 [16]. Figure 9 shows that the tensile strength of SCM mixes was lower than the control, with M4 about 5.7% lower, consistent with the trends shown in compressive and flexural strength.

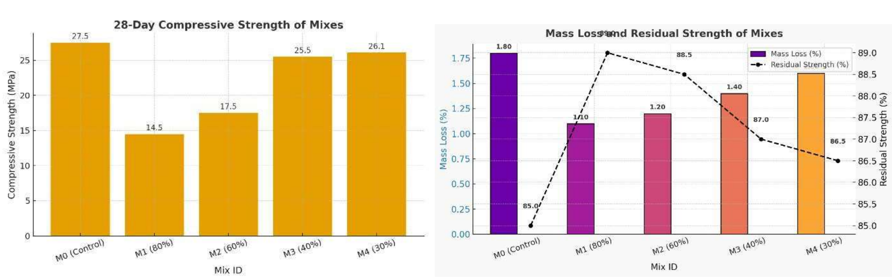


Figure 9. Split Tensile Strength Test Results

D. Durability Tests

Acid Attack Test (Dilute H_2SO_4)
For acid attack resistance, the testing included immersion in 5% H_2SO_4 solution for 28 days; residual mass and strength are presented in Figure 10. Acid resistance of SCM mixes was better compared to the control showing that pozzolanic consumption of CH by SCMs reduced acid-sensitive phases and refined the pore structure.

Carbonation Test
(Table V) Accelerated carbonation test results, as per IS 516 Part 2 (accelerated method) [17], showed that ternary SCM additions reduced the carbonation depth compared with the control, indicating improved permeability by the pore refinement effect of ultra-fine SCM particles.

TABLE V. CARBONATION TEST RESULTS

Mix ID	28-Day Carbonation Depth (mm)
M0 (Control)	2.5
M1 (80%)	1.5
M2 (60%)	1.8
M3 (40%)	2
M4 (30%)	2.2

IV. CONCLUSION

This study demonstrate that a truly innovative M20 grade concrete can be developed by partially replacing cement and incorporating a triple supplementary cementitious material (SCM) system comprising CHA, WHA and ASW. After a bit of experimenting with strength, durability and overall carbon impact, we found out that the best overall balance is obtained by a 30% sum total cement replacement mix. Mix M4 provided with the best results. In terms of structural strength, Mix M4 obtained 26.1 MPa strength at a period of 28 days, which is approximately around 5.1% lower that
the OPC control mix, which is also acceptable. The latter drop shows the advantages provided by CHA and WHA for micro-filling and nucleation, as well as the particle packing and the pozzolanic properties of ASW. The numbers obtained from the results are in support with the information found in the literature: moderate replacement of cement with SCM (10-30%) maintains the mechanical performance of concrete at a healthy level, whereas the excess replacement may damage and harm the early strength, unless the methods of activation are used. By using the Mix M4, the overall carbon footprint can be lowered by about 108.0 kg CO_2e of concrete per cubic metre. This result supports the idea that by substitution of cement with mineral dust and agro-industrial leftovers can drastically lower the embodied carbon. This means the utilization of what would've been wasted into something useful, thereby reducing waste.
The results obtained from the durability test were also likewise positive. Mix M4 had less deep carbonation and was also more resistant to acid attack that in the control mix. Overall, the test results show that the M4 blend achieves the balance between mechanical efficiency and greenery. Additionally, elimination of CHA, WHA and ASW from the waste streams results in measurable carbon reductions. In order to truly identify the environmental benefits obtained, the future study needs to scale this up to the operational levels, evaluate the long-term durability and field performance, and the life cycle analysis use. Increasing the CHA processing should also raise the concrete's amorphous silica concentration of the concrete, thereby making it even more reactive.

REFERENCES

[1] R. M. Andrew, “Global CO_2 emissions from cement production, 1928– 2018,” Earth Syst. Sci. Data, vol.10, pp. 195–217, 2018. DOI: 10.5194/essd-10-195-2018.

[2] D. Cheng et al., “Projecting future carbon emissions from cement production,” Nat. Commun., 2023.DOI: 10.1038/s41467-023-43660- x.

[3] International Energy Agency (IEA), Technology Roadmap — Low- Carbon Transition in the Cement Industry, 2018. (IEA report summarizing process and fuel emission breakdowns and mitigation pathways).

[4] M. Z. Khaiyum, “Evaluation of Carbon Emission Factors in the Cement Industry,” Sustainability, vol.15, no. 21, 2023. DOI: 10.3390/su15215407.

[5] L. Prasiţsopin and D. Trejo, “Evaluation of RHA Properties and Their Effects on Fresh, Mechanical, and Durability Properties of Concrete,” Sustainability, vol. 15, no. 1, p. 137, 2023. (Review of rice/wheat husk ash behavior in concrete).

[6] H. Biricik, "Study of pozzolanic properties of wheat straw ash," Fuel, 1999. (Classic study exploring combustion temperature effect on pozzolanicity).
[7] A. C. D. R. (et al.), "The utilization of waste from the natural stone cutiţng and polishing industry for roof tile production," Materials, vol. 16, no. 1, p. 64, 2024. (Example of stone cuţng waste applications).
[8] S. Çelikten, "A comprehensive assessment of mechanical and environmental properties of waste basalt/granite powder modified mortars," (2024). (Recent study showing beneficial effects of basalt/granite waste powders).
[9] "Quarrying and processing of granite produce large amounts of waste residues," Zealpress, 2013. (Background on stone industry waste volumes).
[10] S. A. Endale, "Rice Husk Ash in Concrete — Review," Sustainability (MDPI), 2022. (Review of RHA effects on concrete strength and durability).
[11] P. Naskar et al., "Durability of Concrete with Agro Waste: A Local Approach to Sustainability," International Journal of Civil Engineering, 2018. (Local studies on agro-waste in concrete).
[12] IS 12269: 1987 — Specification for 53-grade ordinary Portland cement. Bureau of Indian Standards (BIS). (Available PDF: law.resource.org).
[13] IS 383: 2016 — Coarse and Fine Aggregate for Concrete — Specification. Bureau of Indian Standards (BIS).
[14] IS 2386 (Part 1): 1963 — Methods of Test for Aggregates for Concrete Part I: Particle Size and Shape. (BIS).
[15] IS 4031 (Parts) — Methods of Physical Tests for Hydraulic Cement (various parts addressing fineness, density, compressive strength). Bureau of Indian Standards (BIS).
[16] IS 516: Part 1 (2021) — Hardened concrete — Methods of test — Part 1: Testing of strength of hardened concrete (compressive, flexural and split tensile). Bureau of Indian Standards (BIS).
[17] IS 516: Part 2: Sec. 4: 2021 — Determination of carbonation resistance by accelerated carbonation method. Bureau of Indian Standards (BIS).