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"Evaluation of Sustainable Green Concrete with Partial Replacement of Cement by Waste Supplementary Cementitious Materials"

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Abstract— Modern construction world focused on energy efficient and sustainable construction materials. Reducing cement consumption by partial replacement of cement with waste supplementary cementitious material (SCM) improves the sustainability of concrete and mortar used for construction works.

Partial replacement of cement with combination of two supplementary cementitious material's derived from waste materials yields a ternary blended green cement mortar which was more effective than conventional mortar in terms of both strength and performance. Waste banana leaves and cattle bones were collected, dried and powdered separately using miller machine.

SCM was made with different combination of banana leaf powder (BLP) and cattle bone powder (CBP). Experimental works were carried out on mortar and concrete with 20%, 30%, 40% partial replacement of cement with SCM. Optimum percentage of composite SCM for partial replacement of cement was identified as 30%, with 10% CBP and 20% BLP.

The concrete containing the composite SCM demonstrated higher strength and better economic viability than normal concrete. The findings indicated that the utilization of agricultural and animal waste materials as supplementary cementitious materials can contribute significantly to sustainable construction practices while reducing environmental impacts associated with cement production..

Keywords: Supplementary cementitious material, Waste banana leaves, cattle bones, Energy Dispersive, sustainability of concrete and mortar.

1. INTRODUCTION

The sustainable "green" concrete in this thesis was defined as the concrete created to develop the alternative material by utilizing waste materials to meet the environmental issues and without negotiating the performance and strength characteristics of concrete. Globally, cement functions as a major construction material and it was essential to increase the quality of cement. It was important to diminish the environmental issues, energy consumption and use of natural resources from cement production industry. One of the major causes for global warming was emission of CO2 from various sources. So it was important to focus on all sources of CO2 emissions in environment and one such source was from cement industry. Till date, suitable measures were not available to eliminate CO2 emission from cement industry. Hence, an attempt was made to reduce CO2 emission from cement industry through concrete.

Though focusing mainly on CO2 emission, it was equally important to focus on performance of concrete in order to increase its operational sustainability benefits.

SUPPLEMENTARY CEMENTITIOUS MATERIAL (SCM)

Supplementary cementitious material plays a vital role across the world. In ancient times, volcanic ash was used in lime mortar as supplementary cementitious material. Based on the type of reaction, SCM's were divided into two major categories: pozzolanic or hydraulic. In India, fly ash was used as foremost supplementary cementitious material. In modern era, the prominence and usage of supplementary cementitious materials in concrete improves the strength and performance and hence it becomes one of the common ingredients of modern concrete. Broad research all over the world yields the benefits that could be enlarged in the deployment of supplementary cementitiou

materials.

BANANA LEAF POWDER

Globally, banana leaves were available in large quantity. Though banana leaf was an organic decomposable material, its disposal was critical due to huge volume of waste from day-to-day activities and its bad odor at disposal yard. An attempt was made to utilize this huge volume of waste material in construction industry and thereby support the society in improving green environment. Million tons of waste banana leaves were disposed as landfills, which was unsustainable to the environment. Global cement demand was increasing significantly, leading to increase in CO_2 emission, which was harmful to the environment.

Dry Banana Leaves

BONE POWDER

Animal bones were also dumped in large quantities in disposal yards and creates bad odor thereby creates air pollution and diseases. Hence, it was necessary to dispose the above said waste in short span of time through an efficient way. Cattle bone was a hard substance containing calcium, phosphate, magnesium and hydroxyl ions. Also, carbonate was present as calcium carbonate crystals and carbonate apatite. Major minerals of the cattle bone were calcium and phosphate present in the form of rod-shaped crystals was responsible for rigidity, hardness and strength of bone. Powder form of these inorganic materials obtained by crushing cattle bone gives cattle bone powder, which has unique combination of elasticity and strength minerals**.**

Dry Cattle Bones

OBJECTIVES OF THE RESEARCH

1. To prepare powder form of supplementary cementitious material from waste banana leaves and cattle bones.

2. To determine the physical properties of banana leaf powder and cattle bone powder as supplementary cementitious material.

3. To conduct experimental investigation on mortar cubes 1:3 and 1:4 for 20%, 30%, and 40% percentage replacement of cement with SCM and compare the results with control specimens.

4. To conduct experimental investigation on M20 and M25 grade concrete cubes for 20%, 30%, and 40% percentage replacement of cement with SCM and compare the results with control specimens**.**

2. LITERATURE REVIEW

1. **Sharma and Gupta (2025)** presented a comprehensive review of waste-derived SCMs, including agricultural residues, bone ash, municipal solid waste ash, and industrial by-products. The review concluded that most waste-based SCMs can replace 10–30% of cement without compromising concrete performance. The authors emphasized the need for further research on durability, standardization, and large-scale implementation. From the reviewed literature, it is evident that significant research has been conducted on individual waste-derived SCMs such as rice husk ash, bagasse ash, fly ash, GGBS, and cattle bone ash. However, limited studies have explored the combined utilization of banana leaf powder (BLP) and cattle bone powder (CBP) as a ternary blended supplementary cementitious material.
2. **Kumar et al. (2024)** conducted a comprehensive study on the utilization of agricultural waste ashes, namely Rice Husk Ash (RHA), Sugarcane Bagasse Ash (SCBA), and Banana Leaf Ash (BLA), as supplementary cementitious materials (SCMs) in concrete production. The primary objective of the research was to investigate the feasibility of replacing a portion of Ordinary Portland Cement (OPC) with these waste-derived materials to enhance the sustainability of concrete while maintaining its engineering performance. The study was motivated by the growing environmental concerns associated with cement manufacturing, which contributes significantly to global carbon dioxide emissions. The researchers prepared concrete mixes with varying replacement levels of cement, ranging from 10% to 30%, using individual and blended agricultural waste ashes.
3. **Ahmed (2024)** presented a comprehensive review of supplementary cementitious materials (SCMs) and their influence on the fresh, mechanical, durability, and microstructural properties of concrete. The study was motivated by the increasing environmental concerns associated with cement production, which is one of the major contributors to global carbon dioxide emissions. The author emphasized that the incorporation of SCMs as partial replacements for Ordinary Portland Cement (OPC) offers a sustainable solution for reducing the environmental impact of concrete production while enhancing its performance characteristics.The review examined eleven widely used SCMs, including silica fume (SF), fly ash (FA), rice husk ash (RHA), ground granulated blast furnace slag (GGBFS), metakaolin (MK), palm oil fuel ash (POFA), sugarcane bagasse ash (SCBA), zeolite, eggshell powder (ESP), waste glass powder (WGP), and bentonite.
4. **Beka Benti Teshome (2019)** hydration products of Portland cement ASTM C618 requires that the pozzolanic activity index of Portland cement should be minimum of 75 percent of the average 28 days compressive strength of control mixes made with Portland cement. Chemical process, that occurs between pozzolan and calcium hydroxide with the presence of water leads to the formation of cementitious compounds Normally, the amorphous

content of a pozzolan was much more vulnerable to the attack of calcium hydroxide than the crystalline content. With respect to chemical compositions, pozzolans were usually abundant in silica, alumina or both.

5. **Shailza Singh Sapal (2018)** A suitable material as a partial substitution for cement to be identified as an alternative material to inhibit the cementitious properties. It also has to reduce CO2 emission in the environment. Literature review shows that a single alternative waste material cannot achieve maximum efficiency to concrete especially when it was partially replaced for cement. But combination of different waste material will be able to achieve the target strength and performance, when they were used at proper proportion in replacement for cement in concrete. Combination of waste materials can even serve better than Portland cement in cement concrete mixes.
6. **Ondrej Jankovsky et al. (2017).** The waste materials with pozzolanic properties were more important in developing countries to enhance the shortage of construction materials as well as in the development of low-cost construction materials. Some agricultural waste materials such as wheat straw ash (WSA), corncob ash (CCA), pawpaw leaf ash, Neem Seed Husk Ash (NSHA), sugar cane bagasse ash (SCBA), bamboo leaf ash (BLA), banana leaves ashes (BLA) have been used as partial replacement for cement in concrete.

3. METHODOLOGY

MATERIAL SELECTION AND CHARACTERISTICS

The supplementary cementitious materials, banana leaves and cattle bones were obtained from waste and available in plenty of quantity. The material dumped in large volume of waste from day to day activities and its disposal was critical and creates air pollution and diseases. Hence, it was necessary to dispose the above said solid waste in short span of time through an efficient way. Hence, banana leaf wastes and cattle bone wastes were selected as supplementary cementitious material.

EXPERIMENTAL INVESTIGATION ON MORTAR CUBES

As lean mortar and very lean mortar has low cement content, addition of supplementary cementitious materials will drastically reduce cement content, which may not yield satisfactory result. Hence it was recommended to use supplementary cementitious materials in rich mortar mixes only. So, mix proportions of 1:3 and 1:4 were selected for current experimental investigation work on mortar. Among one part of cement in selected mortar mixes, it was proposed to partially replace cement by various percentage of supplementary cementitious material. In this experimental work it was proposed to replace a combination of banana leaf powder and cattle bone powder by 20% (10 % BLP + 10 % CBP), 30% (20 % BLP + 10 % CBP) and 40% (30 % BLP + 10 % BP) of overall cement content by volume in rich mortar mixes.

Properties of Supplementary Cementitious Material (SCM)

SCM Material	BLP	CBP
Specific Gravity	1.8	2.3
Bulk Density (kg/m^3)	710	1020

COMPRESSIVE STRENGTH

The compressive strength was the utmost important of all the properties. The compressive strength of supplementary cementitious material cement mortar cubes for 1:3 and 1:4 after 3 days, 7 days, 14 days, and 28 days were tested using 150x150x150 mm cubes as per IS 4031 (Part 6): 1988 at various mix proportions. The compressive strengths were taken on the three samples and the average was reported as a result. The development in the compressive strength at later ages was primarily due to the pozzolanic reaction and the admixture dosages provided for concrete.

RESULTS AND DISCUSSIONS

COMPRESSIVE STRENGTH OF SCM MORTAR

Average compressive strength values for each category of 1:3 mortar mix and 1:4 mortar mix were calculated and tabulated in Table below:

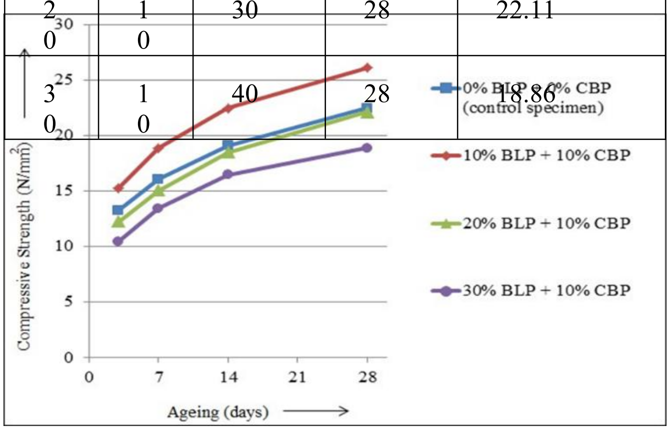
Compressive Strength of SCM mortar cubes

BLP %	CPB %	Total SCM %	Average Compressive Strength of 1:3 cubes (N/mm^2)	verage ompressive trength of 1:4 ubes (N/mm^2)
0	0	0	13.24	16
0	0	0	16.05	.31
0	0	0	19.06	.65
0	0	0	22.47	.73
10	10	20	15.25	36
10	10	20	18.86	.18
10	10	20	22.47	.52

10	10	20	26.08	).40
20	10	30	12.24	42
20	10	30	15.05	l.77
20	10	30	18.46	5.05
20	10	30	22.11	3.06
30	10	40	10.43	29
30	10	40	13.44	90
30	10	40	16.45	l.50
30	10	40	18.86	3.98

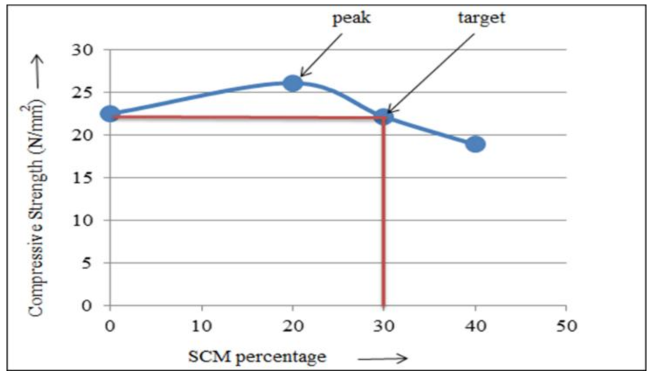
Compressive Strength of SCM mortar cubes (1:3) at 28 days

BLP %	CPB %	Total SCM %	Age (days)	Compressive Strength of 1:3 cubes (N/mm²)
0	0	0	28	22.47
10	10	20	28	26.08
20	10	30	28	22.11
30	10	40	28	18.86



Compressive Strength of SCM mortar cubes (1:3)

0% BLP + 0% CBP indicates compressive strength of control specimen without SCM. Compressive strength of 20% SCM mortar with 10% BLP and 10% CBP was higher than that of control specimen. Compressive strength of 40% SCM mortar with 30% BLP and 10% CBP was lower than control specimen and also not attained target strength at 28 days. Compressive strength of 30% SCM mortar with 20% BLP and 10% CBP has attained target strength at 28 days and also very close to control specimen values. Hence 30% SCM mortar performed well in 1:3 ratio mortar mixes.



Compressive Strength of SCM mortar cubes (1:3) at 28 days

28 days compressive strength variation with respect to different SCM percentages was plotted. Both peak value and target values were mentioned in the graph. Peak value was attained for 20% SCM mortar whereas target strength was achieved by 30% SCM mortar at 28 days ageing. Intersection point of target mean strength and 28 days ageing indicates that 30% SCM mortar performed well in 1:3 ratio mortars.

COMPRESSIVE STRENGTH OF SCM MORTAR (1:4 RATIO

Compressive strength of control specimen having 0% BLP and 0% CBP at the age of 3, 7, 14, 28 days yielded strength of 8.16 N/mm2, 12.31 N/mm2, 15.65 N/mm2 and 18.73 N/mm2.

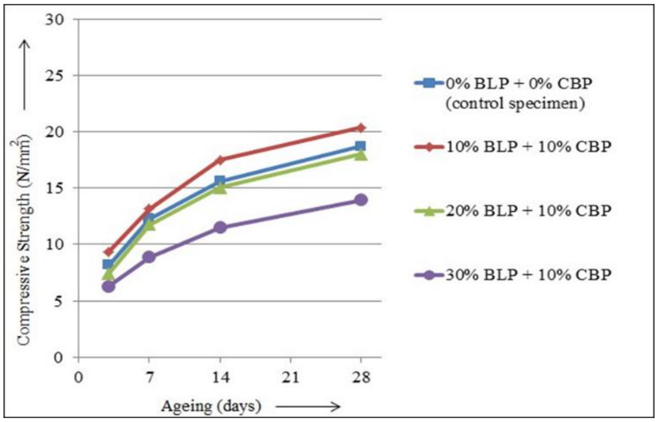
Compressive strength was also tested on mortar cubes with replacement of 20% (10% BLP +10% CPB), 30% (20% BLP +10% CPB) and 40% (30% BLP +10% CPB) of cement for 1:4 mix ratio.

Compressive strength of 20 % SCM having mortar 10% BLP and 10% CBP at the age of 3, 7, 14, 28 days yielded strength of 9.36 N/mm2, 13.18 N/mm2, 17.52 N/mm2 and 20.40 N/mm2.

Compressive strength of 30 % SCM having mortar 20% BLP and 10% CBP at the age of 3, 7, 14, 28 days yielded strength of 7.42 N/mm2, 11.77 N/mm2, 15.05 N/mm2 and 18.06 N/mm2.

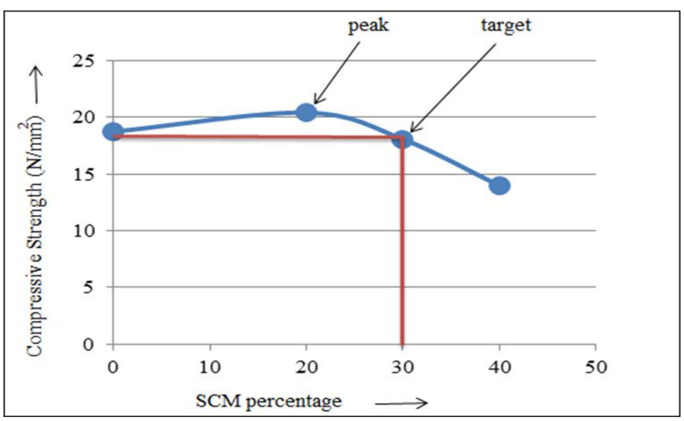
Compressive Strength of SCM mortar cubes (1:4) at 28 days

A Graph was plotted for compressive strength values of 1:4 mortar mixes as shown in Figure 6.3. Average compressive strength values of control specimen and various percentages of SCM cement mortar cubes were plotted in the graph. Ageing was plotted in X-axis and average compressive strength was plotted in Y-axis. Plotted points were joined using lines for each variant to highlight the variation in average compressive strength for SCM mortar**.**



Compressive Strength of SCM mortar cubes (1:4)

0% BLP + 0% CBP indicates compressive strength of control specimen without SCM. Compressive strength of 20% SCM mortar with 10% BLP and 10% CBP was higher than that of control specimen. Compressive strength of 40% SCM mortar with 30% BLP and 10% CBP was lower than control specimen and also not attained target strength at 28 days. Compressive strength of 30% SCM mortar with 20% BLP and 10% CBP has attained target strength at 28 days and also very close to control specimen values. Hence 30% SCM mortar performed well in 1:4 ratio mortar mixes.



Compressive Strength of SCM mortar cubes (1:4) at 28 days

BLP %	CPB %	Total SCM %	Age (days)	Compressive Strength of 1:4 cubes (N/mm^2)
0	0	0	28	18.73
10	10	20	28	20.40
20	10	30	28	18.06
30	10	40	28	13.98

28 days compressive strength variation with respect to different SCM percentages was plotted. Both peak value and target values were mentioned in the graph. Peak value was attained for 20% SCM mortar whereas target strength was achieved by 30% SCM mortar at 28 days ageing. Intersection point of target mean strength and 28 days ageing indicates that 30% SCM mortar performed well in 1:4 ratio mortars.

20% SCM usage yield peak value of compressive strength at 28 days. Although 20% SCM mortar cubes yields the maximum strength of 20.40 N/mm2, 30% SCM mortar cubes attain the target mean strength at 28 days of ageing Hence 30% replacement of cement with SCM was recommended for 1:4 ratio mortar mixes

CONCLUSIONS

COMPRESSIVE STRENGTH OF SCM CONCRETE AND MORTAR

Experimental investigation proved that 30% SCM used 1:3 and 1:4 ratio mortar cube yields target compressive strength at 28 days of ageing although 20% SCM mortar cubes yields the maximum strength.

Hence it was concluded that the combination of banana leaf powder (20%) and cattle bone powder (10%) can partially replace cement up to 30% in 1:3 and 1:4 mortar mixes.

Similarly for M20 and M25 grade concrete cubes experimental investigation predicted that 30% SCM used cube yields target compressive strength at 28 days of ageing although 20% SCM concrete cubes yields the maximum strength.

Hence it was concluded that the combination of banana leaf powder (20%) and cattle bone powder (10%) can partially replace cement up to 30% in M20 and M25 grade concrete mixes.

MICROSTRUCTURE MODEL

Virtual microstructure image of prepared dry cement Mix “SCM MIX 30” with 30% replacement of cement by way of supplementary cementitious material shows that mineral structure of image was analogous to that of conventional theoretical model. Microstructure image of hydrated Mix with 30% replacement of cement with supplementary cementitious material shows that SCM induces no change in C-S-H gel product morphology.

The distribution of SCM particles in cement matrix was satisfactory. SCM distribution reduces pore volume when compared to theoretical model image. SCM exhibits surface modification and passive binding with CSH gel, thus indirectly participating in binding of cement phase with aggregate phase.

Dried and powdered BLP with specific gravity of 1.8 and bulk density of 710 kg/m3 and CBP with specific gravity of 2.3 and bulk density of 1020 kg/m3 was used for concrete.

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