

A Study on Utilization of Agricultural and Industrial Waste Materials as Partial Cement Replacements in High-Performance Concrete

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Abstract—This study investigates the viability of using agricultural cow dung ash and industrial waste phosphogypsum as partial replacements for cement in high-performance concrete, focusing on assessing the mechanical properties through compressive strength test. With the aim of promoting sustainable construction practices and mitigating environmental impacts, researchers are exploring alternative materials for concrete production. Agricultural waste, like cow dung, and industrial byproducts such as phosphogypsum, offer potential solutions for improving concrete performance while addressing waste disposal challenges. The pozzolanic reaction involves the interaction between pozzolanic materials and calcium hydroxide in the presence of water, leading to the development of supplementary cementitious compounds. Experimental concrete mix designs are developed by introducing varying proportions of cow dung ash and phosphogypsum as partial replacements for cement. These mix designs are meticulously formulated to identify optimal replacement levels that strike a balance between enhancing mechanical properties and potential material challenges. The subsequent compressive, flexural, and split tensile tests evaluate the performance of the concrete under different loading conditions. Cow Dung ash replacement was typically ranging from 0% to 15% of cement content, starting conservatively and gradually increasing based on testing. Phosphogypsum replacement is generally falls between 0% to 15% of cement content, considering its impact on concrete setting and properties.

Index Terms—Sustainable construction, High-performance concrete, Compressive Strength

I. INTRODUCTION

The rapid urbanization and industrialization of the modern world have led to unprecedented levels of

resource consumption, resulting in significant environmental challenges. One of the critical sectors contributing to these challenges is the construction industry, particularly the production of concrete, which is a fundamental building material. Cement, a primary component of concrete, is responsible for a substantial share of carbon dioxide emissions due to its manufacturing process. In response to the urgent need for sustainable construction practices, researchers and engineers have been exploring alternative materials to partially replace cement in concrete formulations. This study focuses on the utilization of agricultural and industrial waste materials as partial cement replacements in high-performance concrete, aiming to mitigate environmental impact while maintaining or even enhancing the concrete's mechanical properties.

The global construction industry has witnessed an unprecedented boom in recent decades, driven by urbanization and population growth. As a consequence, there has been an exponential increase in the demand for construction materials, particularly cement. However, the conventional production of cement involves energy-intensive processes, such as clinker production, contributing significantly to carbon dioxide emissions. The environmental implications of such production methods have spurred the search for sustainable alternatives to reduce the ecological footprint of the construction sector.

High-performance concrete (HPC) represents a promising avenue for sustainable construction, characterized by superior mechanical and durability properties. HPC is designed to achieve exceptional strength, durability, and workability, making it an ideal choice for critical infrastructure projects.

However, the production of HPC often involves higher cement content, exacerbating the environmental impact associated with traditional concrete mixes. This dilemma necessitates innovative approaches to enhance the sustainability of HPC, and one promising avenue is the incorporation of waste materials as partial cement replacements. Agricultural activities generate vast quantities of waste materials, such as rice husk ash, sugarcane bagasse ash, and coconut shell ash, which are currently underutilized and often disposed of in environmentally harmful ways. These agricultural by-products possess pozzolanic properties, making them suitable candidates for partial cement replacement in HPC. The incorporation of such waste materials not only mitigates the environmental impact of agricultural waste disposal but also contributes to the development of high-performance and sustainable concrete. In addition to agricultural waste, various industrial by-products have shown promise as partial replacements for cement in concrete formulations. Fly ash, a by-product of coal combustion, and ground granulated blast furnace slag (GGBFS), a by-product of iron production, are widely recognized for their pozzolanic and latent hydraulic properties. These materials not only provide an environmentally friendly solution to the disposal of industrial waste but also enhance the performance of concrete when properly incorporated. The use of these by-products in HPC not only reduces carbon emissions but also improves the long-term durability and strength of the resulting concrete.

II. LITERATURE SURVEY

A. Ibrahim Y Hakeem, Mohamed Amin et al (2023) studies that the construction industry heavily relies on concrete, with ultra-high performance concrete (UHPC) gaining popularity due to its exceptional mechanical properties. However, the extensive use of Ordinary Portland cement (OPC) in UHPC raises cost, environmental concerns due to CO₂ emissions, and depletes natural resources. To address this, the study proposes substituting OPC with alternative additives and utilizing recycled aggregates in UHPC production. By combining industrial and agricultural waste, this research aims to create a cost-effective and sustainable UHPC. For instance, glass particles from glass waste replace fine aggregate ("sand") at ratios of 0%, 50%, and 100%, while wheat straw ash substitutes OPC at

0%, 10%, 20%, and 30% ratios. Twelve different mixtures were experimented with and divided into three groups, analyzing factors like flow, mechanical properties, shrinkage, high temperatures, and microstructure. Results indicate that higher ratios of glass particles replacing sand improved workability. Optimal mechanical characteristics were achieved by replacing 20% of OPC with wheat straw ash and keeping sand substitution with glass particles at 0%. Increasing wheat straw ash while maintaining the glass particle substitution level significantly reduced drying shrinkage. Notably, using glass particles instead of sand enhanced the compressive strength of UHPC components exposed to temperatures up to 200°C. Overall, this experimental study highlights the positive impact of employing glass particles and wheat straw ash in producing sustainable ultra-high-performance concrete.

B. Hasan ,Sahan Arel and Ertug Aydin (2018) examined how Class F fly ash (FA), coconut husk ash (CHA), and rice husk ash (RHA) impact the workability, setting time, compressive strength, and pullout strength of concrete when used as replacements for cement at different proportions. The investigation involved replacing 20% and 40% of cement with FA, and 10%, 15%, and 20% with CHA and RHA. The findings demonstrated the viability of using FA, CHA, and RHA as cement alternatives in concrete production, fostering sustainability and ecological benefits. Specifically, a combination of 20% FA and 20% RHA exhibited a 15.3% higher compressive strength compared to the standard mix after 180 days. However, there was a slight decline in this aspect with FA-CHA blends. Notably, combinations of FA and RHA consistently displayed superior compressive and pullout strengths across all tested aging periods.

C. Mohammad I. AlBiajawi, Rahimah Embong (2022) studied that over time, supplementary cementitious materials (SCMs) have found success in concrete construction but have seen limited use in concrete pavements. Recently, with the increasing significance of concrete pavements, researchers have started investigating the performance of different SCMs specifically tailored for this purpose. This overview evaluates existing research focusing on utilizing various silica-rich waste materials as SCMs. Five

agricultural wastes—rice husk ash (RHA), rice straw ash (RSA), corn cob ash (CCA), palm oil fuel ash (POFA), sugarcane bagasse ash (SBA)—and three industrial by-products—fly ash (FA), ground granulated blast furnace slag (GGBFS), and microsilica (MS)—were chosen for analysis. Their impacts on concrete properties were extensively reviewed in this study. Additionally, the paper provides insights into why there's limited literature on using SCMs in concrete pavements.

III. RESEARCH SIGNIFICANCE

The demand for sustainable development has risen, presenting a significant challenge for the construction industry to maximize benefits while minimizing the use of fine and coarse aggregates. This can be achieved by incorporating blended fine and coarse aggregates along with recycled materials in concrete, which not only lowers construction costs but also mitigates environmental pollution.

Recent studies have delved into the potential of improving concrete properties through the incorporation of alternative materials such as stone dust and over-burnt brick. However, the majority of current research predominantly examines the effects of these materials individually. To address this gap, the present study seeks to explore the combined impact of both stone dust and over-burnt brick aggregate on the mechanical properties of concrete. Specifically, it will focus on evaluating the compressive strength characteristics of concrete mixtures that contain varying proportions of these two materials. By investigating their synergistic effects, this research aims to provide valuable insights into enhancing the performance and sustainability of concrete.

IV. METHODOLOGY FOR EXPERIMENTS

A. Concrete Mix Design

Introduction:

The process of selecting suitable ingredients of concrete and determining their relative amount with the objective of producing a concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2 states,

namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance.

The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking.

The actual cost of concrete is related to the cost of materials required for producing a minimum mean strength called characteristic strength that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the quality control adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

Requirements of concrete mix design:

The requirements which form the basis of selection and proportioning of mix ingredients are:

- a) The minimum compressive strength required from structural consideration
- b) The adequate workability necessary for full compaction with the compacting equipment available.
- c) Maximum water-cement ratio and/or maximum cement content to give adequate durability for the particular site conditions
- d) Maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete.

V. TYPES OF MIXES

A. Nominal Mixes

In the past the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed cement-aggregate ratio which

ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

B. Standard mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under- or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes.

IS 456-2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28 day cube strength of mix in N/mm². The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

C. Designed Mixes

In these mixes the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance.

For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 N/mm². No control testing is necessary reliance being placed on the masses of the ingredients.

VI. RESULTS AND DISCUSSIONS

A. COMPRESSIVE STRENGTH TEST

The compressive strength test is a common method used to determine the ability of a material to withstand

axial loads pushing it together. This test is crucial in assessing the suitability of materials for construction and engineering applications, particularly for structures like buildings, bridges, and dams.

Here's a general overview of how the compressive strength test is conducted:

B. Equipment and Materials

1. Specimen:

The material being tested, often in the form of cylinders, cubes, or prisms, depending on the standard or application.

2. Compression Testing Machine:

A specialized apparatus designed to apply compressive loads gradually until failure.

3. Loading Frame:

The part of the compression testing machine that holds and applies the force to the specimen.

4. Load Cell

A device that measures the applied force.

5. Compression Plates:

Flat, parallel plates that distribute the load uniformly on the specimen.

6. Testing Procedure:

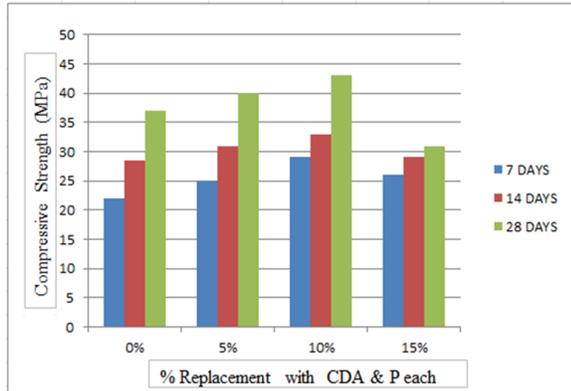
The test typically follows these steps:

C. Testing Procedure

Common shapes for concrete specimens. Standard sizes are specified by testing standards. Material Condition Specimens are usually cast from the same batch of material as the structure they represent. Concrete specimens are often cured in a water bath or covered with wet burlap to prevent moisture loss during the initial curing period. Place the specimen between the compression plates and ensure it is aligned properly. Adjust the machine to ensure that the load cell reads zero with no load applied. The load is applied at a specified rate, usually in Newtons per second or Pounds per square inch per second. The machine continuously records the applied load and the corresponding deformation. The test continues until the specimen fails, which is typically marked by a sudden drop in load or a noticeable deformation. The maximum load applied before failure is recorded.

Compressive Strength is calculated by dividing the failure load by the cross-sectional area of the specimen. The compressive strength is reported in units such as megapascals (MPa) or pounds per square

inch (psi). Any unusual behavior or characteristics observed during the test are also reported.



1. Standard M30 Concrete Mix

The standard M30 concrete mix exhibits a compressive strength of 22 MPa after 7 days of curing. The strength increases to 28.5 MPa at 14 days. The compressive strength further improves to 37 MPa after

2. Compressive Strength at 7 days curing

Introducing 5% agricultural cow dung ash (CDA) and 5% industrial waste phosphogypsum (P) results in a higher compressive strength of 25 MPa after 7 days. Further increasing the proportions to 10% CDA and 10% P results in a higher compressive strength of 29 MPa at 7 days. Surprisingly, the mix with 15% CDA and 15% P shows a lower compressive strength of 26 MPa at 7 days.

3. Compressive Strength at 14 days curing

The strength continues to increase to 31 MPa at 14 days. Further increasing the proportions to 10% CDA and 10% P results in a higher compressive strength of 33 MPa strength at 14 days. The strength slightly decreases to 29 MPa at 14 days for the mix with 15% CDA and 15% P.

4. Compressive Strength at 28 days curing

Finally, at 28 days, the compressive strength reaches 40 MPa. The addition of CDA and P seems to enhance the early and later strength development. At 28 days, the compressive strength further increases to 43 MPa. The higher percentages of CDA and P appear to contribute to improved strength. At 28 days, the compressive strength further decreases to 31 MPa. This unexpected trend might indicate an adverse effect

of higher proportions of CDA and P in this specific mix.

VII. OBSERVATIONS

Influence of Additives: The data suggests that the addition of 5% and 10% CDA and P generally improves compressive strength.

•**Optimization Needed:** The results for the mix with 15% CDA and 15% P indicate that there might be an optimal range for the additive percentages, and exceeding this range could have a negative impact on strength.

VIII. CONCLUSIONS

A. Balanced Enhancement

The mix with 10% CDA and 10% P demonstrates balanced enhancement across key strength properties: Compressive Strength: 5.0 MPa (7 days), 6.0 MPa (14 days), 6.5 MPa (28 days).

B. Optimal Proportion

The 10% CDA and 10% P proportion shows optimal utilization, contributing positively to all strength aspects without excessive use of additives

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