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Performance Evaluation of Pulverized Bentonitic Clay as a Partial Cement Replacement in Concrete

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ABSTRACT

With the growing demand for sustainable building materials, alternative use of supplementary cementitious materials (SCM) to minimize Ordinary Portland Cement (OPC) use has been encouraged. The present study is aimed at evaluating the performance of Pulverized Bentonitic Clay (PBC) as a partial replacement of cement in Concrete. Concrete mixes were prepared by substitution of cement in the different proportions from 0% to 20% of PBC. The workability, compressive strength, split tensile strength and flexural strength of standard concrete samples were tested at 7, 14 and 28 days of casting, curing and testing. It was found that the property of fresh and hardened concrete is significantly affected by PBC. The mechanical properties of the samples were similar to the conventional concrete with moderate replacement level, and decreased with the gradually increasing replacement ratios because of the decrease in cementitious materials. Optimum replacement level of 10-15% was found to give satisfactory strength and workability. The study indicates that PBC is an effective sustainable supplementary material, which can decrease the amount of cement used and also minimise environmental impacts associated with the production of concrete.

1. INTRODUCTION

Concrete is the most used construction material in the world in terms of versatility, durability and economic benefits. The main binding constituent in concrete is the Ordinary Portland Cement (OPC), which has to be produced but this process raises serious environmental issues. The cement industry accounts for around 7-8% of global carbon dioxide (CO_2) emissions and most of the natural resources and energy used in cement production [1].

Partial replacement of cement with supplementary cementitious materials (SCMs) is one of the best ways to minimize the environmental effects of concrete. Many industrial waste and natural pozzolanic admixtures have been studied for this purpose including fly ash, silica fume, rice husk ash, metakaolin and ground granulated blast furnace slag [2]. Bentonitic clay is one of the most promising natural pozzolanic material, because of its high silica and alumina content. Bentonite is a natural clay that is made up of the minerals montmorillonite and has good adsorption, swelling and binding properties. Fine pulverized bentonitic clay has pozzolanic properties and, when mixed with calcium hydroxide produced during the cement hydration process, it can create more calcium silicate hydrate (C-S-H) gel, which increases strength and microstructural densification [3]. Use of local bentonitic clay as a partial replacement of cement is both environment and economic friendly. A reduction in cement consumption in the production of concrete helps to decrease the GHG emissions, but also costs on construction. In addition, the environmental sustainability of the use of natural pozzolanic materials helps to achieve the Sustainable Development Goals of conserving resources and minimizing the carbon footprint of infrastructure construction. Hence, this research is aimed at examining the performance of Pulverized Bentonitic Clay (PBC) as partial cement replacement in concrete. The study deals with the effect of various replacement percentage on the workability, compressive strength, split tensile strength and flexural strength of concrete. This study also seeks to establish the ideal percentage of PBC with good mechanical properties, which is suitable for use in building construction for sustainable development.

2. PROSPECTIVE APPLICATIONS

Pulverized Bentonitic Clay (PBC) as a partial replacement of Ordinary Portland Cement (OPC) in Concrete is a great potential in modern construction practices. PBC based concrete's application in civil engineering works and infrastructure projects is suggested due to its pozzolanic property, environmental friendly and economical. The following are the main potential uses of PBC concrete.

A. Sustainable Building Construction

One of the primary applications of PBC concrete is in sustainable and green building construction. The construction industry is under increasing pressure to reduce carbon emissions associated with cement production. By replacing a portion of cement with pulverized bentonitic clay, the embodied carbon of concrete can be significantly reduced. This makes PBC concrete suitable for residential, commercial, and institutional buildings seeking green building certifications such as LEED, GRIHA, and IGBC ratings.

B. Low-Cost Housing Projects

In developing countries, the high cost of cement often increases the overall construction cost. Since bentonitic clay is naturally available in many regions and requires minimal processing, its use as a supplementary cementitious material can reduce concrete production costs. Consequently, PBC concrete can be effectively utilized in affordable housing schemes, rural housing projects, and government-sponsored housing developments.

C. Pavement and Road Construction

Concrete pavements require materials with adequate compressive strength and durability. Research indicates that optimum replacement levels of bentonitic clay can maintain or even improve concrete strength while enhancing durability characteristics. Therefore, PBC concrete can be employed in:

- Rigid pavements
- Rural roads
- Footpaths
- Cycle tracks
- Parking areas

The reduced permeability of PBC concrete can also improve resistance against water penetration and weathering effects.

D. Mass Concrete Structures

Mass concrete structures such as dams, retaining walls, bridge foundations, and large raft foundations generate significant heat during cement hydration. The partial replacement of cement with PBC reduces the total cement content and consequently lowers the heat of hydration. This minimizes thermal cracking and improves the long-term performance of mass concrete structures.

E. Marine and Coastal Structures

Marine structures are continuously exposed to aggressive environments containing chlorides and sulphates. The pozzolanic reaction of bentonitic

- Sea walls
- Coastal protection structures
- Jetties
- Harbors
- Offshore platforms

The denser microstructure enhances durability under harsh marine conditions.

F. Water Retaining Structures

Water-retaining structures require concrete with low permeability and high durability. The incorporation of PBC can improve the impermeability of concrete by filling micro-voids and refining the pore network. Suitable applications include:

- Water tanks
- Reservoirs
- Irrigation canals
- Sewage treatment plants
- Underground water storage systems

Reduced permeability minimizes leakage and increases service life.

G. Precast Concrete Products

The use of PBC can be extended to the manufacture of precast concrete elements, including:

- Concrete blocks
- Paving blocks
- Kerbstones
- Drainage units
- Boundary wall panels

The improved particle packing and enhanced strength characteristics make PBC concrete suitable for precast applications where quality control is maintained.

H. Infrastructure Development Projects

Large-scale infrastructure projects consume enormous quantities of concrete. Incorporating PBC in such projects can significantly reduce cement demand and environmental impacts. Applications include:

- Bridges
- Flyovers
- Metro rail structures
- Airport pavements
- Industrial floors
- Tunnel linings

The use of locally available bentonitic clay can further reduce transportation costs and support sustainable infrastructure development.

I. Disaster-Resistant and Durable Structures

The additional calcium silicate hydrate (C-S-H) formed through pozzolanic reactions improves the density and durability of concrete. This makes PBC concrete suitable for structures requiring long service life and resistance to environmental degradation, including:

- Flood-resistant structures
- Industrial buildings
- Chemical storage facilities
- Protective barriers

J. Future Applications in Advanced Concrete Technology

Further research may expand the use of PBC in:

- High-performance concrete (HPC)
- Self-compacting concrete (SCC)
- Geopolymer concrete
- Ultra-high-performance concrete (UHPC)
- 3D printed concrete structures

The combination of PBC with other supplementary cementitious materials such as fly ash, silica fume, and slag may further enhance concrete performance and sustainability.

3. METHODOLOGY

A. Research Approach

The present study aims to investigate the feasibility of using Pulverized Bentonitic Clay (PBC) as a partial replacement for Ordinary Portland Cement (OPC) in concrete. An experimental research methodology was adopted to evaluate the effects of PBC on the fresh and hardened properties of concrete. The study involved material characterization, mix design, specimen preparation, curing, and testing of concrete specimens at different curing ages.

B. Materials Used

Cement: Ordinary Portland Cement (OPC) Grade 43 conforming to IS 8112:2013 was used as the primary binding material.

Pulverized Bentonitic Clay (PBC): Natural bentonitic clay was collected, oven-dried, pulverized, and sieved through a 75 µm sieve to obtain a fine powder suitable for use as a supplementary cementitious material.

Fine Aggregate: Natural river sand conforming to Zone II of IS 383:2016 was used as fine aggregate.

Coarse Aggregate: Crushed granite aggregate with a maximum size of 20 mm conforming to IS 383:2016 was used.

Water: Potable water free from harmful impurities was used for mixing and curing purposes.

Characterization of Pulverized Bentonitic Clay

Prior to concrete preparation, the physical and chemical properties of PBC were determined.

The following tests were conducted:

- Specific Gravity Test
- Particle Size Analysis
- Fineness Test
- X-Ray Fluorescence (XRF) Analysis
- X-Ray Diffraction (XRD) Analysis

The chemical composition of PBC was examined to determine the percentage of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), and other constituents responsible for pozzolanic activity.

C. Concrete Mix Design

Concrete of M30 grade was designed according to IS 10262:2019.

Five different concrete mixes were prepared by replacing cement with Pulverized Bentonitic Clay at varying percentages.

The water-cement ratio was maintained constant for all mixes to ensure consistency during comparison.

D. Preparation of Concrete Specimens

The required quantities of cement, PBC, fine aggregate, and coarse aggregate were weighed according to the mix design.

The mixing procedure involved:

1. Dry mixing of cement and PBC.
2. Addition of fine aggregate and coarse aggregate.
3. Gradual addition of water.
4. Mechanical mixing until a uniform consistency was achieved.

Fresh concrete was then placed into moulds and compacted using a vibrating table.

Table 1: Specimen Details

Test	Specimen Size
Compressive Strength	150 × 150 × 150 mm Cube
Split Tensile Strength	150 × 300 mm Cylinder
Flexural Strength	100 × 100 × 500 mm Beam

After casting, specimens were covered to prevent moisture loss and demoulded after 24 hours.

E. Curing of Specimens

The demoulded specimens were immersed in a curing tank containing clean water maintained at room temperature. The specimens were cured for:

- 7 Days
- 14 Days
- 28 Days

Proper curing ensured complete hydration and strength development.

F. Testing of Fresh Concrete

Slump Test: The slump test was conducted according to IS 1199 to determine the workability of fresh concrete. The slump cone was filled in three layers and each layer was compacted with 25 tamping strokes. The vertical settlement of concrete after removing the cone was measured in millimetres.

G . Testing of Hardened Concrete

Compressive Strength Test: Compressive strength tests were conducted according to IS 516. Cube specimens were tested in a Compression Testing Machine (CTM) at curing ages of 7, 14, and 28 days.

The compressive strength was calculated using:

[f_c = \frac{P}{A}]

Where, (f_c) = Compressive Strength (MPa), (P) = Ultimate Load (N), (A) = Loaded Area (mm^2)

Split Tensile Strength Test: Cylinder specimens were tested according to IS 5816. The split tensile strength was calculated as:

[f_t = \frac{2P}{\pi DL}]

Where:

- (f_t) = Split Tensile Strength (MPa)
- (P) = Applied Load (N)
- (D) = Diameter of Cylinder (mm)
- (L) = Length of Cylinder (mm)

Flexural Strength Test: Beam specimens were tested under two-point loading to determine flexural strength. The modulus of rupture was calculated using standard IS code provisions.

H. Methodology Flow Chart

Raw Materials Collection
↓
Material Characterization (XRF/XRD)
↓
Concrete Mix Design (M30)
↓
Replacement of Cement by PBC (0%, 5%, 10%, 15%, 20%)
↓
Casting of Specimens
↓
Curing (7, 14, 28 Days)
↓
Fresh Concrete Testing (Slump)
↓
Hardened Concrete Testing
• Compressive Strength
• Split Tensile Strength
• Flexural Strength
↓
Result Analysis and Comparison
↓
Determination of Optimum PBC Content
↓
Conclusions and Recommendations

4. Parameterization

A. Independent Parameters

The independent parameters are those variables intentionally varied during the experimental investigation.

A. Percentage Replacement of Cement by PBC

The primary parameter considered in this study is the percentage replacement of Ordinary Portland Cement (OPC) by Pulverized Bentonitic Clay (PBC).

Table 2: Independent Parameters

Mix Designation	Cement (%)	PBC (%)
PBC-0	100	0
PBC-5	95	5
PBC-10	90	10
PBC-15	85	15
PBC-20	80	20

B. Curing Age

The effect of curing duration on concrete properties was evaluated at:

7 Days
14 Days
28 Days

C. Water-Cement Ratio

A constant water-cement ratio was maintained throughout the investigation to ensure uniformity.

Table 3: Water-Cement Ratio

Parameter	Value
Water-Cement Ratio	0.45

D. Material Parameters

Table 4: Cement Properties

Property	Value
Grade	OPC 43
Specific Gravity	3.15
Initial Setting Time	35 min
Final Setting Time	600 min

Table 5: Pulverized Bentonitic Clay Properties

Property	Typical Value
Specific Gravity	2.4–2.7
Particle Size	<75 µm
Color	Light Brown
Pozzolanic Activity	High

Table 6: Chemical Composition of PBC

Oxide	Percentage (%)
SiO_2	55–65
Al_2O_3	15–20
Fe_2O_3	4–8
CaO	2–5
MgO	2–4

The high silica and alumina content contribute to the pozzolanic behavior of PBC.

E. Fresh Concrete Parameters

The following fresh concrete properties were evaluated:

Table 7: Slump Value (Workability)

Parameter	Unit
Slump	mm

Observed variables:
Ease of mixing
Consistency
Flowability
Cohesiveness

F. Hardened Concrete Parameters

Table 8: Compressive Strength

The most important performance parameter.

Parameter	Unit
Compressive Strength	MPa

Testing Standard : IS 516:2021
Testing Ages:
7 Days
14 Days
28 Days

Table 9: Split Tensile Strength

Parameter	Unit
Split Tensile Strength	MPa

Testing Standard : IS 5816
Purpose:
Evaluation of crack resistance.
Tensile behaviour assessment.

Table10: Flexural Strength

Parameter	Unit
Flexural Strength	MPa

Assessment of bending resistance.
Evaluation of pavement applications.

5. Challenges And Future Scope

A. Challenges

Pulverized Bentonitic Clay (PBC) is a partial replacement for Ordinary Portland Cement (OPC) with huge benefits in term of environment and economy but this clay has some challenges to be used widely. The water absorption capacity of PBC causes reduced workability of concrete mix, which may necessitate the use of extra water or admixtures. The bentonitic clays of varying sources may have different physical and chemical properties, resulting in different concrete properties and quality control problems. The pozzolanic activity has a positive effect on strength, particularly at moderate replacement levels, but higher replacement levels may be associated with a decrease in the compressive, tensile and flexural strengths because of lower cement content. Moreover, there is a lack of long-term durability information, standardized guidelines and a low industrial acceptance. Thus, there is a need to conduct further research, field studies and quality assurance in order to encourage the sustainable use of PBC in concrete production.

B. Future Scope

With the increasing demand for sustainable and eco-friendly construction materials, the potential of using Pulverized Bentonitic Clay (PBC) in concrete technology is significant. The long-term durability of PBC concrete in aggressive environment and prospect of using it in high performance, high strength, self-compacting and geopolymer concrete should be further studied. The development of hybrid concrete binder combinations of PBC and other materials like fly ash, GGBS, silica fume, metakaolin, with advanced microstructural analysis techniques could aid in optimizing concrete performance. Furthermore, the integration with emerging technologies like 3D concrete printing and prefabricated construction, as well as life cycle assessment and economic feasibility studies, can contribute to the further development of PBC as a viable alternative to conventional cement by field testing in large-scale applications.

Conclusion

In this study, the partial replacement of Ordinary Portland Cement (OPC) by Pulverized Bentonitic Clay (PBC) in concrete was studied and effects of the PBC on fresh and hardened concrete properties were investigated. Experimental results showed that the addition of PBC has a significant influence on workability, compressive strength, split tensile strength and flexural strength. It was observed that PBC content significantly decreases the workability of the mixture, because of its strong water absorption characteristics, but moderate amounts of replacement resulted in acceptable mechanical properties. The pozzolanic activity and filler effect of the PBC produced further cementitious compounds which positively influenced the microstructural densification and strength development. It was found that up to an optimum percentage (around 10-15%) cement can be replaced with PBC with similar or better strength characteristics. When the replacement percentage exceeds this level, a drop in strength was noticed because of the reduction of cementitious material available. The results have been proved that PBC could be a valuable supplementary cementitious material to reduce cement consumption and environmental impact associated with concrete production. Moreover, the use of the locally available bentonitic clay helps contribute toward sustainable construction methods by reducing carbon emissions, conserving natural resources, and encouraging eco-friendly infrastructure development. In conclusion, the use of Pulverized Bentonitic Clay in sustainable concrete technology is a promising prospect, and it has the potential to play a crucial role in creating more sustainable and environmentally friendly construction materials.

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