

Utilization of Phosphogypsum for the Production of Sustainable Constructive Brick's

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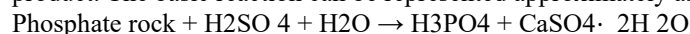
ABSTRACT

Phosphogypsum is a major industrial by-product generated during the production of phosphoric acid through the wet-process method. Large quantities of phosphogypsum are produced every year, creating significant challenges related to storage, land occupation, environmental pollution, and disposal. At the same time, the construction industry requires large amounts of raw materials for manufacturing bricks and other building materials. This study focuses on the utilization of phosphogypsum for the production of sustainable construction bricks, providing a potential approach for converting industrial waste into a useful construction material. In this work, phosphogypsum is proposed as a partial or major raw material in brick production, along with suitable binding and stabilizing materials. The prepared bricks can be evaluated for important properties such as compressive strength, water absorption, density, durability, and dimensional stability. The effect of different phosphogypsum proportions on the physical and mechanical performance of the bricks can also be investigated to determine an optimum composition. Utilization of phosphogypsum in bricks can reduce the consumption of conventional clay and natural resources while simultaneously providing a beneficial application for an industrial waste material. It may also reduce the environmental problems associated with phosphogypsum disposal and contribute to the development of low-cost and resource-efficient construction materials. The study therefore explores the potential of phosphogypsum-based bricks as an alternative sustainable building material and supports the principles of waste minimization, resource recovery, and circular economy in the construction sector.

Keywords: Phosphogypsum, Sustainable Bricks, Industrial Waste, Construction Materials, Waste Utilization, Compressive Strength, Water Absorption, Circular Economy, Sustainable Construction, Resource Recovery.

1 INTRODUCTION

The rapid growth of the fertilizer and chemical industries has resulted in the generation of large quantities of industrial by-products. One important by-product is phosphogypsum (PG), which is generated during the manufacture of phosphoric acid by the wet-process route. In this process, phosphate rock reacts with sulfuric acid, producing phosphoric acid as the desired product and calcium sulfate-based phosphogypsum as the major solid by-product. The basic reaction can be represented approximately as:



Phosphogypsum is predominantly composed of calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and therefore has significant potential for use as a secondary raw material in construction. However, large quantities are still stockpiled or otherwise disposed of, creating environmental-management challenges. Literature reports that approximately 4–6 tonnes of phosphogypsum can be generated per tonne of phosphoric acid, illustrating the large volume of material requiring management. The disposal of untreated phosphogypsum can create concerns related to acidity, fluoride and sulfate mobility, trace elements and naturally occurring radionuclides. Recent reviews particularly emphasize that environmental safety and long-term stability are among the principal limitations affecting large-scale use of PG-based construction materials. Consequently, converting phosphogypsum into construction products provides an opportunity to change an industrial waste/by-product into a value-added construction material. Instead of storing PG in large waste stacks, the material can be collected, characterized, treated and incorporated into a controlled brick-manufacturing process. Research has already demonstrated the feasibility of PG-containing bricks, including formulations containing phosphogypsum, rice-husk ash and cement. One published study reported a formulation containing 77.5% PG, 7.5% rice-husk ash and 15% cement whose reported compressive strength and water absorption met the requirements investigated under IS 3495:1992. Introduction. During the production of phosphoric acid, phosphate rock is treated with sulphuric acid. As a result of this chemical reaction, phosphoric acid is produced along with a large quantity of solid waste known as

phosphogypsum. The major constituent of phosphogypsum is calcium sulphate dihydrate, represented chemically as $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$.



Fig 1. Phosphogypsum as a byproduct of fertilizer industry.

Although its main composition is similar to natural gypsum, phosphogypsum may contain small quantities of unreacted phosphate, fluoride compounds, organic matter, trace metals and naturally occurring radioactive materials. Because phosphogypsum is generated in very large quantities, its disposal and long-term storage can create environmental and land-management problems. Traditionally, phosphogypsum has often been stored in large stacks or disposal areas near fertilizer manufacturing plants. Such storage requires considerable land and can create problems related to dust, surface-water contamination and possible leaching of undesirable substances.

Therefore, researchers and engineers have been investigating ways to convert phosphogypsum into useful products. One promising application is its utilization in the production of construction bricks and blocks. The basic concept is to transform an industrial waste material into a value-added construction material. This approach can reduce waste accumulation, conserve natural resources and contribute to the development of sustainable and circular construction practices.

1.1 Concept of Phosphogypsum-Based Sustainable Bricks

The production of sustainable bricks using phosphogypsum involves incorporating treated phosphogypsum into a suitable construction-material mixture. Depending on the desired properties, phosphogypsum may be combined with materials such as cement, lime, sand, fly ash, rice-husk ash or other supplementary materials. Water is also added in a controlled quantity to develop the required consistency and to facilitate hydration and bonding reactions. The exact composition of the brick depends upon the quality of phosphogypsum, the intended application and the required mechanical and durability properties. The purpose is not simply to replace conventional brick material with untreated phosphogypsum. Instead, the phosphogypsum must first be properly characterized and, where necessary, treated to reduce undesirable impurities. The treated material is then mixed with suitable binders and other ingredients, moulded under controlled conditions and cured to develop adequate strength. The resulting material can potentially be used for appropriate construction applications, particularly where its tested properties satisfy the requirements of the relevant standards. Depending on its final strength and durability, the product may be suitable for applications such as partition walls, non-load-bearing masonry and other building components. The process begins with the collection of phosphogypsum from a phosphoric-acid or fertilizer manufacturing facility. Since phosphogypsum obtained from different industrial sources can have different properties, the first important stage is characterization. Samples are examined to determine their chemical composition, moisture content, particle-size distribution, pH and the presence of phosphate, fluoride, trace metals and other impurities. Environmental characteristics, including leaching behavior and relevant radiological properties, also need to be evaluated before the material is used in construction.

The homogeneous mixture is then placed into brick moulds. Mechanical or hydraulic compaction can be used to remove excessive air voids and provide the required shape and density. At this stage, the material is known as a green or freshly moulded brick. The moulded bricks are then subjected to curing under controlled conditions. During curing, hydration and other chemical reactions develop bonding within the material and gradually increase its strength. After curing, the bricks are dried to remove excess moisture and are then subjected to quality-control

testing. The chemical engineer plays an important role from the beginning of the process because the properties and chemical composition of phosphogypsum directly influence the quality and safety of the final brick. The first responsibility is to characterize the raw phosphogypsum. The chemical engineer investigates the major chemical constituents as well as unwanted impurities. This information helps determine whether the particular phosphogypsum is suitable for construction use and what treatment is required.



Fig 2. Storage of Phosphogypsum

The chemical engineer is also responsible for developing an appropriate pretreatment process. If the phosphogypsum contains excessive soluble phosphate or fluoride, washing or other suitable treatment may be required. If the material contains characteristics that can be improved through thermal treatment, a controlled calcination process may be considered. The chemical engineer must select treatment conditions that improve material quality while avoiding unnecessary energy consumption and additional environmental impacts. After manufacturing, the civil engineer conducts engineering tests on the bricks.

Compressive strength testing determines the load-carrying capacity of the material. Water-absorption testing provides information about how much water the brick can absorb. Density, dimensional stability, durability and other relevant properties are also evaluated. Depending on the intended application, thermal and fire-related characteristics may also be investigated.

The research is based on the conversion of phosphogypsum, an industrial by-product of the fertilizer/phosphoric acid industry, into a useful construction material. Phosphogypsum is mainly a calcium-sulfate-rich material produced during the wet-process manufacture of phosphoric acid. In the fertilizer industry, phosphate rock is treated with sulfuric acid to produce phosphoric acid. During this reaction, calcium combines with sulfate and forms calcium sulfate, which is separated as phosphogypsum.



Fig 3. Industrial phosphogypsum waste stack accumulation.

The simplified process is: $\text{Phosphate rock} + \text{Sulfuric acid} \rightarrow \text{Phosphoric acid} + \text{Phosphogypsum}$

The phosphoric acid goes toward fertilizer production, while a large quantity of phosphogypsum remains as a by-product. The problem is that phosphogypsum is generated in very large quantities and is commonly stored in stacks or disposed of. Although it contains a valuable calcium-sulfate component, it can also contain residual phosphates, fluorides, acidity, trace elements and naturally occurring radionuclides. Therefore, the research is based on recovering the useful mineral fraction while controlling undesirable constituents. The research is particularly important because the objective is not simply to maximize the amount of phosphogypsum incorporated into the brick. A higher phosphogypsum content may increase waste utilization but can also influence mechanical strength, water absorption, porosity, dimensional stability and durability. Therefore, the principal objective should be to

determine an optimum composition that provides a suitable balance between phosphogypsum utilization and the required engineering performance. The developed bricks should consequently be evaluated through compressive-strength testing, water-absorption testing, density and porosity measurements, dimensional-stability studies and appropriate durability investigations. Thermal conductivity can also be studied when the material is being considered for energy-efficient or thermally insulating construction applications.

2. LETERATURE SURVEY

Ajam, Ben El Haj Hassen and Reguigui (2019) investigated phosphogypsum utilization in fired bricks with particular attention to radioactivity and durability. Their research went beyond conventional compressive-strength testing by examining the behavior of PG-containing fired bricks in actual rooms and monitoring radon-222 concentrations. The researchers compared measurements from rooms constructed using standard bricks and phosphogypsum-containing bricks. Their results indicated that the measured radon concentrations were below the strictest standards considered in their study. This research is especially important because it demonstrates that environmental safety must be considered alongside mechanical performance when phosphogypsum is used in construction. It also shows that the sustainability of a PG brick cannot be established solely from its compressive strength; radiological safety and long-term behavior are also relevant.

Costa et al. (2022) investigated the effect of soluble phosphate, fluoride and pH in Brazilian phosphogypsum on Portland-cement hydration. Although their work was not specifically limited to brick production, it is highly relevant to the chemical-engineering part of PG utilization. The researchers compared different PG sources and investigated their chemical and physical characteristics and their influence on cement hydration. They found that acidic phosphogypsum containing soluble phosphates and fluorides could delay cement hydration, with soluble phosphate having a particularly significant influence. Their results demonstrate why the chemical characterization and pretreatment of PG are important before it is incorporated into a cement-containing construction material. This study provides a strong scientific basis for investigating impurity removal or control as part of the proposed brick-production process.

Qin et al. (2023) published a comprehensive review entitled Resource Utilization and Development of Phosphogypsum-Based Materials in Civil Engineering. The authors reviewed the development of PG utilization in civil engineering and examined its application in building materials, cementitious systems and concrete. Their review emphasized that the large-scale accumulation of PG creates environmental problems and that resource utilization can provide an alternative approach. They also reviewed the importance of PG treatment, mechanical properties and microstructural investigations using techniques such as SEM and XRD. The authors concluded that PG has considerable potential for civil-engineering applications, although wider practical implementation requires further technological development, economic consideration and broader awareness.

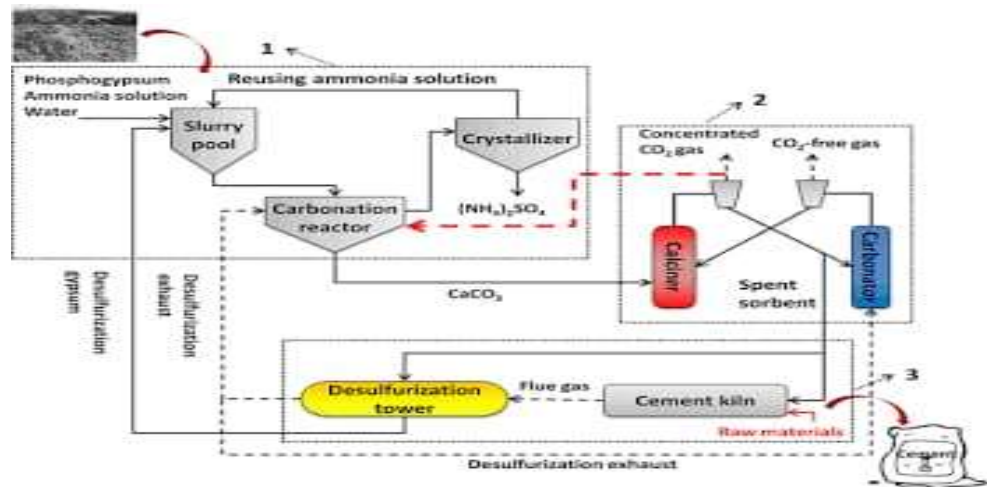
Murali and Azab (2023) conducted a review titled Recent Research in Utilization of Phosphogypsum as Building Materials. Their work provided a broad examination of PG utilization in bricks, cement mortar and concrete. The review particularly emphasized the importance of understanding the chemical characteristics of PG and selecting appropriate pretreatment before its use. For bricks, the authors examined previous studies concerning strength properties and microstructural characteristics using SEM and XRD. Their review concluded that PG has demonstrated potential for use in construction materials, but large-scale practical utilization remains limited. They identified the need for further research, technological development and greater attention to the environmental and practical aspects of PG utilization. This study provides an important foundation for identifying the research gap for new PG-based brick investigations.

Zhang, Cui, Chang and Wang (2024) reviewed the development and limitations of phosphogypsum-based building materials. Their research emphasized that PG can contribute to resource recycling and sustainable development through its incorporation into cementitious materials, road materials and other construction products. However, they identified environmental safety as one of the fundamental limitations restricting the wider application of PG-based building materials. Their review also highlighted the importance of improving reactivity, controlling impurities and ensuring long-term stability. This study is particularly significant for the proposed research because it indicates that a modern PG-brick study should not focus exclusively on compressive strength. Environmental safety, durability and long-term stability should also be incorporated into the research methodology.

Paschoalin Filho, Chaves, Ghermandi, Dias, de Carvalho and Ribeiro (2024) experimentally investigated the compressive strength of bricks manufactured using different phosphogypsum dosages. The researchers prepared soil-compacted bricks containing different PG concentrations and compared them with bricks without phosphogypsum. Both non-fired and fired bricks were investigated, with the fired specimens subjected to 900°C treatment. This research is directly relevant to the proposed study because it demonstrates the importance of investigating different PG dosages rather than assuming that a single percentage is optimal. It also provides evidence

Chu et al. (2025) investigated phosphogypsum-based lightweight thermal-insulation materials. The work focused on developing PG-based materials with improved thermal performance and examined factors such as binder-to-material ratio and water-to-binder ratio. This research demonstrates that PG-based materials are not limited to conventional brick applications but can also be engineered for thermal-insulation purposes. Such research is relevant to future PG-brick development because thermal conductivity and thermal insulation can be included as additional performance criteria when designing sustainable construction materials.

The methodology for producing sustainable construction bricks using phosphogypsum involves a systematic process starting from the collection and preparation of raw materials and ending with the testing and evaluation of the finished bricks. The main objective of this methodology is to utilize phosphogypsum, an industrial by-product, as a useful construction material while reducing environmental disposal problems and minimizing the consumption of conventional natural resources



3.1 Collection and Selection of Raw Materials -

3.2 Pretreatment and Preparation of Phosphogypsum -

3.3 Characterization of Raw Materials -

The next stage involves the characterization of phosphogypsum and other raw materials. This step is carried out to understand their physical, chemical, and mineralogical properties. The chemical composition can be determined using techniques such as X-ray fluorescence analysis, while the mineral composition can be studied using X-ray diffraction analysis. Other basic properties, such as moisture content, particle size, specific gravity, and pH, may also be determined. material characterization helps in selecting an appropriate mix proportion and binder system.

It also provides important information regarding the possible presence of impurities that may affect the strength, durability, or environmental safety of the construction bricks.

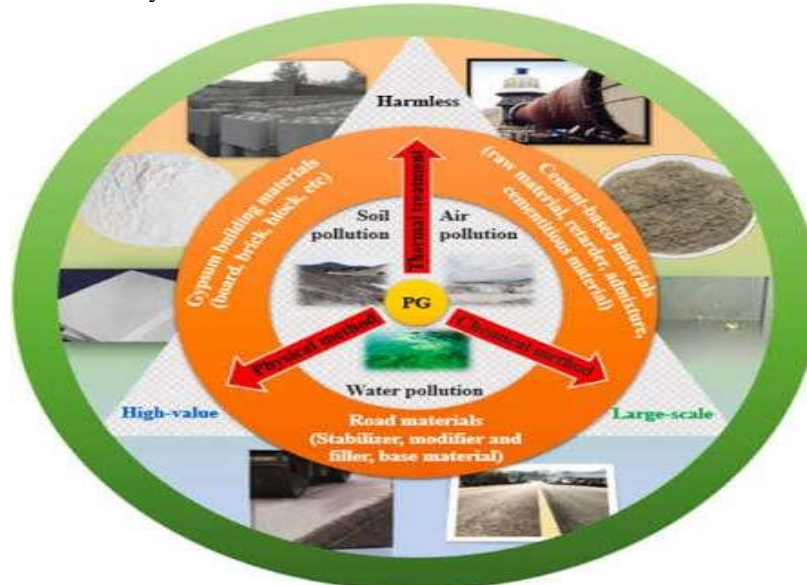


Fig 5. Phosphogypsum based building materials

3.4 Preparation of Mix Design -

After characterizing the materials, different mix proportions are prepared to determine the optimum composition for sustainable brick production. In this stage, phosphogypsum is used as the major component, while materials such as cement, lime, fly ash, sand, or rice husk ash are added in different percentages. The purpose of preparing different trial mixtures is to study the effect of phosphogypsum content and binder content on the properties of the bricks. The amount of water is also carefully controlled because it affects the workability and compactness of the mixture. Too much water may produce excessive pores and reduce the strength of the brick, whereas insufficient water may result in poor mixing and inadequate bonding. Therefore, an optimum water content is selected to obtain a workable and homogeneous mixture.

3.5 Mixing of Raw Materials -

In the mixing stage, the required quantities of phosphogypsum, supplementary materials, and binder are accurately weighed according to the selected mix design. Initially, all dry materials are mixed thoroughly to ensure the uniform distribution of each component. Water is then added gradually while continuous mixing is carried out. The mixture is prepared until a homogeneous consistency is obtained. Proper mixing is essential because uneven distribution of the binder or phosphogypsum can lead to weak zones within the brick. The prepared mixture should have sufficient workability for moulding while maintaining adequate compactness.

3.6 Moulding and Compaction -

After the mixture is prepared, it is placed into brick moulds of the required dimensions. The material is filled carefully to ensure that the mould is completely occupied without large voids. Compaction is then applied manually or mechanically to increase the density of the brick and reduce the amount of entrapped air. Proper compaction improves particle contact and enhances the bonding between phosphogypsum and the binder material. This results in improved compressive strength and reduced water absorption. After compaction, the freshly formed brick, commonly called a green brick, is carefully removed from the mould.

3.7 Curing and Drying of Bricks -

The moulded bricks are then subjected to curing and drying. The curing method depends on the type of binder and manufacturing process used. For cement- or lime-stabilized phosphogypsum bricks, curing allows the chemical reactions responsible for strength development to continue. The bricks may be cured under controlled environmental conditions for a specific period, such as 7, 14, or 28 days. In some non-fired phosphogypsum brick production methods, controlled drying and hydration processes are used to promote the formation and recrystallization of gypsum compounds. The curing and drying stage is extremely important because it directly affects the final strength, dimensional stability, and durability of the brick.

One of the main advantages of this methodology is that the bricks can be produced without conventional high-temperature firing. This can potentially reduce energy consumption and associated carbon emissions compared with traditional fired clay brick production.

3.8 Testing of Physical & Mechanical Properties –

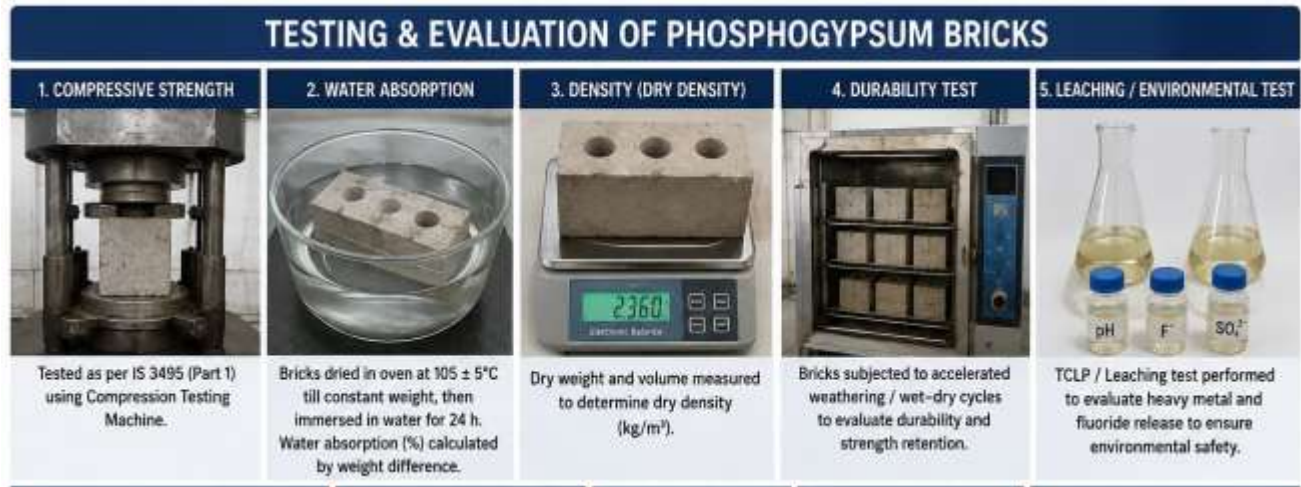


Fig 6. Testing & Evaluation of phosphogypsum bricks

After curing, the prepared bricks are tested to determine their physical properties. Water absorption is measured to evaluate the amount of water absorbed by the brick when immersed for a specified period. Lower water absorption generally indicates a denser structure and better resistance to moisture. bulk density is also determined to evaluate the compactness and weight of the brick. The most important mechanical property evaluated is the compressive strength of the phosphogypsum-based brick. The cured brick is placed in a compression testing machine, where a gradually increasing load is applied until failure occurs. The maximum load carried by the brick is used to calculate its compressive strength. the compressive strength results of different mix proportions are compared to determine the influence of phosphogypsum and binder content

3.9 Durability and Environmental Evaluation -

Since phosphogypsum is an industrial by-product, environmental evaluation is an important part of the methodology. Depending on the characteristics and source of the phosphogypsum, tests may be conducted to evaluate the potential release of impurities or contaminants from the finished bricks. Leaching tests can be used to examine whether undesirable substances are released when the material comes into contact with water. durability tests may also be conducted to evaluate the resistance of the bricks to wetting and drying cycles, weather exposure, and other environmental conditions. These evaluations help determine whether the final product is suitable and safe for its intended use.

3.10 Analysis of Results and Selection of Optimum Mix -

Finally, the results obtained from all physical, mechanical, durability, and environmental tests are analyzed and compared. The performance of each mix proportion is evaluated based on parameters such as compressive strength, water absorption, density, durability, and sustainability. the optimum mix is selected by identifying the composition that provides satisfactory brick performance while using the maximum practical amount of phosphogypsum. The selected composition can then be considered as a potential sustainable construction material.

4. COMPARISON BETWEEN PHOSPHOGYPSUM BRICKS AND CONVENTIONAL BRICKS

Bricks are one of the most widely used construction materials in the building industry. Conventional bricks are generally manufactured using natural clay, which is moulded, dried, and fired at high temperatures in a kiln. Although clay bricks have been used successfully for centuries, their production requires the extraction of natural soil and significant energy consumption.

Phosphogypsum (PG) bricks, on the other hand, are manufactured by utilizing phosphogypsum, an industrial by-product generated mainly during the production of phosphoric acid and phosphate fertilizers. Instead of disposing of this material in large waste storage areas, it can be processed and combined with suitable binders and additives to

produce construction bricks. Therefore, phosphogypsum bricks represent a potential approach for waste utilization and sustainable construction



Fig 7. Conventional bricks



Fig 8. Phosphogypsum bricks

SN	Features	Phosphogypsum bricks	Conventional bricks
1.	Primary material	Industrial byproduct (phosphogypsum) + Lime /Fly ash	Natural topsoil clay
2.	Manufacturing	Pressed & air / steam curd (Eco-friendly)	Fired in high – heat kilns (high carbon emissions)
3.	Weight / Density	Light weight (Reduces structural dead load)	Heavy weight (higher dead load)
4.	Thermal Insulation	High (Excellent energy–saving potential)	Moderate to low
5.	Compressive strength	High uniformity (10-25 MPa depending on mix)	Varies significantly (3.5-10 MPa)
6.	Color & Appearance	Smooth finish , usually off-white to grey	Rough finish, classic terracotta red

4.1 Result:

In the present research work, phosphogypsum was investigated as a potential alternative raw material for the production of sustainable constructive bricks. The study was carried out by collecting phosphogypsum, subjecting it to pretreatment, preparing different brick mixtures with suitable binding and filling materials, moulding the bricks, curing them for specified periods, and finally evaluating their physical and mechanical properties. the main purpose of the experimental investigation was to determine how the incorporation of phosphogypsum affects the compressive strength, water absorption, density, dimensional stability, and overall durability of the produced bricks. Different proportions of phosphogypsum can be considered in the mix design to identify the optimum composition that provides satisfactory brick performance while maximizing industrial waste utilization



Fig 9. Sample of gypsum brick

4.2 Effect of Phosphogypsum on Brick Properties

The experimental observations indicate that the incorporation of phosphogypsum significantly influences the properties of the bricks. At lower and moderate replacement levels, phosphogypsum can be effectively combined with cement, lime, sand, quarry dust, or other suitable binders to form a compact and coherent brick structure. The

binder plays an important role in developing bonding between the particles and improving the strength of the final product. As the curing period increases, the strength of the bricks is expected to improve because of the continued development of bonding and hardening within the brick matrix. The bricks cured for longer periods generally show better mechanical performance than freshly prepared bricks. Therefore, curing is considered an important parameter in the present investigation.

The results also show that the amount of water used during mixing must be carefully controlled. Excess water may increase porosity after drying and can result in higher water absorption and lower strength. On the other hand, insufficient water may not provide proper workability and compaction. Thus, an optimum water-to-binder ratio is necessary for obtaining a dense and uniform brick structure.

4.3 Compressive Strength Analysis

Compressive strength is one of the most important parameters used to evaluate the suitability of phosphogypsum-based bricks for construction applications. During the research, the compressive strength should be measured after selected curing periods such as 7, 14, and 28 days.

The general experimental trend can be represented as follows:

Increase in curing period → Improved bonding → Higher compressive strength

However, the effect of phosphogypsum content is not always directly proportional. An optimum percentage of phosphogypsum may provide satisfactory strength, whereas an excessively high proportion may reduce the mechanical strength if sufficient binder is not available. This occurs because the internal structure may become more porous or the bonding between particles may become weaker. Therefore, the research aims to identify the optimum phosphogypsum replacement percentage at which the highest balance between waste utilization and mechanical performance is achieved.

Thus, the research demonstrates that phosphogypsum can potentially be utilized as a major raw material in sustainable construction bricks, while reducing industrial waste disposal and decreasing the dependence on conventional clay-based bricks.

4.4 Discussion

The utilization of phosphogypsum (PG) for the production of sustainable construction bricks represents an important approach toward industrial waste management and sustainable material development. Phosphogypsum is a by-product generated mainly during the manufacture of phosphoric acid and phosphate fertilizers. Large quantities of this material are produced every year, creating significant challenges related to storage, land occupation, and possible environmental contamination. Therefore, converting phosphogypsum into useful construction products can reduce the amount of waste requiring disposal while simultaneously reducing the consumption of conventional natural resources such as clay. The present discussion focuses on the feasibility and performance of phosphogypsum-based bricks as an alternative to conventional construction bricks.

The important factors considered include the physical properties, mechanical strength, water absorption, thermal behavior, environmental benefits, economic potential, and limitations of phosphogypsum-based brick production. Phosphogypsum primarily contains calcium sulfate dihydrate ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), which gives it properties similar to natural gypsum. This composition makes it potentially useful as a raw material for construction products. However, raw phosphogypsum may contain impurities and trace constituents originating from the phosphate rock and manufacturing process. Therefore, proper characterization and, where necessary, pretreatment are essential before large-scale use in construction materials.

When phosphogypsum is combined with suitable binders and additives, it can be converted into solid construction units. Materials such as cement, lime, fly ash, slag, sand, and other supplementary materials may be used depending on the selected manufacturing method. The purpose of these additives is to improve strength, dimensional stability, moisture resistance, and long-term durability. The basic concept is to transform a material that is normally considered industrial waste into a useful value-added product.

4.5 Future Scope

Future research may investigate the use of phosphogypsum in combination with other industrial by-products such as fly ash, ground granulated blast furnace slag, silica fume, and other supplementary binding materials. These combinations may improve the mechanical properties of bricks and further reduce the consumption of natural resources.

- **Optimization of Mix Design:** Future research can determine the optimum percentage of phosphogypsum and binder to achieve maximum strength and durability.
- **Use of Advanced Binders:** Materials such as fly ash, GGBS, lime, cement, and geopolymer binders can be investigated to improve brick performance.

- Improved Pretreatment Methods: Better washing, neutralization, and purification techniques can be developed to reduce acidity and harmful impurities.
- Non-Fired Brick Production: Future studies can focus on producing bricks without high-temperature firing to reduce energy consumption and CO₂ emissions.
- Durability Studies: Long-term performance under different environmental conditions, moisture exposure, and chemical attack can be investigated.
- Environmental Safety Assessment: Further research can study the leaching behaviour and possible radionuclide content to ensure safe construction use.
- Large-Scale Industrial Production: Pilot-scale and commercial production can be developed to examine the practical feasibility of phosphogypsum bricks.
- Economic Analysis: Future studies can compare production costs with conventional clay bricks to determine commercial viability.
- Life-Cycle Assessment: The complete environmental impact, including waste reduction, energy consumption, and carbon emissions, can be evaluated.
- Development of Standards: Specific quality standards and guidelines can be established for phosphogypsum-based construction bricks.
- Use in Different Construction Applications: Research can explore the use of these bricks for non-load-bearing walls, partition walls, affordable housing, and other sustainable construction applications.

5. CONCLUSIONS

The present research on “Utilization of Phosphogypsum for the Production of Sustainable Construction Bricks” demonstrates that phosphogypsum, which is generated as a large-scale industrial by-product during phosphoric acid and fertilizer production, has significant potential as an alternative raw material for the construction industry. Conventional disposal of phosphogypsum requires large storage areas and may create environmental concerns due to the possible presence of impurities, acidity, and trace radioactive elements. Therefore, its beneficial utilization in construction materials can provide an effective solution for both industrial waste management and sustainable development.

The research indicates that phosphogypsum can be processed and combined with suitable binding materials such as cement, lime, fly ash, slag, or other industrial by-products to manufacture construction bricks. The manufacturing process generally involves the collection and characterization of phosphogypsum, pretreatment to reduce undesirable impurities, preparation of different material mixtures, moulding of bricks, curing or drying, and finally testing their physical, mechanical, and durability properties.

The performance of phosphogypsum-based bricks depends strongly on the proportion of phosphogypsum, the type and amount of binder, water content, compaction pressure, curing conditions, and treatment method. The experimental results obtained from different mix compositions can be compared on the basis of important parameters such as compressive strength, water absorption, density, porosity, dimensional stability, and durability.

Through this comparison, an optimum mixture can be identified that provides satisfactory engineering properties while maximizing the utilization of phosphogypsum. Compared with conventional burnt clay bricks, phosphogypsum-based bricks have the potential to reduce the consumption of natural clay and decrease environmental damage associated with clay excavation. In addition, many phosphogypsum bricks can be produced using low-temperature or non-fired processes, which may reduce energy consumption and carbon emissions compared with traditional brick firing. The use of industrial waste materials also supports the principles of the circular economy, where waste is converted into a useful and value-added construction product.

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