



Preliminary Study On Suitable Technology Parameters For Manufacturing Non-fired Bricks From Products Of The Mineral Processing Industry (Red Mud, Phosphogypsum And Fly Ash)

Strengthening International Academic Cooperation: A Strategic Partnership between AGH University of Krakow and Leading Scientific Institutions in Vietnam

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SUSTAINABLE
SOLUTIONS



BETTER
ENVIRONMENT



STRONGER
FUTURE



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PHOSPHOGYPSUM, RED MUD, AND FLY ASH

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VIETNAM'S MINERAL RESOURCES AND SUSTAINABLE DEVELOPMENT STRATEGY

Compared with many countries worldwide and within the region, Vietnam possesses **significant advantages in mineral resources**, providing a solid foundation for sustainable industrial development.



RICH MINERAL RESOURCES

Currently, more than **1,000** mining operations are active across the country, extracting a wide range of minerals, including:



COAL



IRON ORE



TITANIUM



LIMESTONE



COPPER



LEAD



ZINC



TIN



APATITE



BAUXITE



Although the scale of extraction and processing varies among mineral types, most minerals undergo **beneficiation and processing** before being supplied to end users.



MINERAL PROCESSING VALUE CHAIN



EXPLORATION



MINING



BENEFICIATION



PROCESSING



INDUSTRIAL APPLICATIONS



Efficient and reasonable utilization of mineral resources is the key to sustainable development and national prosperity.



NATIONAL DEVELOPMENT STRATEGY

Decision No. 866/QĐ-TTg

Approving the Master Plan for Mineral Exploration, Mining, Processing, and Utilization for the period

2021 – 2030

Vision to 2050



Develop the field of exploration, mining, processing, and use of mineral resources in connection with the application of **advanced and modern science and technology**, aligned with the transformation of the national economy toward a **green economy** and a **circular economy**...; For minerals with large reserves and strategic importance, investment projects must apply **advanced technologies, modern equipment**, and ensure **sustainable environmental protection**.



STRATEGIC PRIORITIES FOR VIETNAM



SCIENTIFIC INNOVATION

Promote research, innovation, and application of advanced technologies in mineral processing and metallurgy.



SUSTAINABLE MINING

Optimize resource utilization, reduce waste generation, and minimize environmental impact.



CIRCULAR ECONOMY

Recycle and reuse by-products, transform industrial wastes into valuable materials.



ENVIRONMENTAL PROTECTION

Implement cleaner production, comply with environmental standards, and protect ecosystems.

VISION TO 2050

- ✓ Build a modern, competitive and environmentally friendly mineral industry
- ✓ Develop high-value products
- ✓ Promote digital transformation and smart mining
- ✓ Contribute to economic growth and national sustainable development



Vietnam's abundant mineral resources, combined with advanced technologies and circular economy principles, create strong opportunities for **sustainable growth** in mineral processing, metallurgy, and resource recycling industries.

TURNING INDUSTRIAL WASTE INTO VALUE

UNFIRED BRICKS FOR A GREEN AND SUSTAINABLE FUTURE



THE CHALLENGE

During the deep processing of mineral resources, a large quantity of industrial waste is generated and currently stored in waste disposal sites.



High risk of environmental pollution



Increased operational and production costs



Risk of production disruption when waste storage capacity is exceeded

TYPICAL INDUSTRIAL WASTES

PHOSPHOGYPSUM (PG)



By-product from DAP fertilizer production

RED MUD



By-product from alumina production

FLY ASH



By-product from coal-fired power plants

STONE DUST



By-product from aggregate and crushed stone production

THE SOLUTION

A promising solution aligned with the principles of green economy and circular economy is the production of **UNFIRED BRICKS** using the industrial waste materials listed above.



UNFIRED BRICKS

A sustainable and value-added use for industrial waste



THE KEY ISSUE:

Selecting an appropriate technology and optimizing mix proportions → to achieve the lowest production cost

FROM WASTE TO UNFIRED BRICKS



QUALITY PRODUCTS – MEET VIETNAMESE STANDARDS (TCVN)

- ✓ Good compressive strength
- ✓ Stable dimensions and durability
- ✓ Low water absorption
- ✓ Safe for use

TCVN
Comply with
Vietnamese Standards



Suitable for civil construction



Suitable for industrial applications



Wide range of applications

KEY BENEFITS



Reduces environmental pollution and conserves landfill space



Promotes resource recycling and circular economy



Lower production cost and improved economic efficiency



Produces quality bricks that meet TCVN requirements



Supports sustainable development and a green future



RED MUD: A CHALLENGING INDUSTRIAL WASTE FROM ALUMINA PRODUCTION

Red mud is an alkaline by-product of bauxite ore processing for alumina (Al_2O_3) production. Its large-scale disposal poses serious environmental, economic and social challenges.

1 WHAT IS RED MUD?

Red mud is the solid residue remaining after processing bauxite ore with NaOH to produce alumina (Al_2O_3).



Approximately 35–40% of the treated bauxite ore becomes red mud.



It contains 15–40% solids and 0.8–1.5 tons of red mud are generated per ton of alumina produced. [1]

2 ANNUAL GLOBAL GENERATION (ESTIMATED)



About 70 million tons of red mud are produced worldwide each year.



GREECE

0.7

million tons [2]



INDIA

2

million tons [3]



AUSTRALIA

30

million tons [4]



CHINA

~30

million tons



Red mud is a predominantly alkaline by-product (pH 10–12.5) containing fine particles and various trace metals.

3 ENVIRONMENTAL IMPACTS



Soil Pollution

High alkalinity and heavy metals degrade soil quality.



Groundwater Contamination

Leaching of alkalinity and metals affects groundwater.



Marine Pollution

Fine particles discharged to the sea cause turbidity and ecosystem damage.



Large Land Requirement

Storage in mud ponds requires vast land areas.



Airborne Dust Pollution

Dry disposal can generate dust, posing serious health risks to nearby communities.



High Disposal Cost

Red mud disposal cost is estimated to be around 2% of the alumina price. [5]

4 COMMON DISPOSAL METHODS

Mud Ponds



Discharged into tailings ponds near alumina refineries.

Dry Stacking



Stored in dry piles, causing dust emissions.

Pipeline Discharge to Sea



Pumped via pipelines and discharged offshore.



Large-scale disposal has led to severe environmental problems and high management costs.

5 RESEARCH AND UTILIZATION OF RED MUD



Researchers worldwide have conducted extensive studies to develop cost-effective and sustainable methods for utilizing red mud.



Utilization of red mud not only minimizes environmental impacts but also creates economic and material value.



6 POTENTIAL APPLICATIONS OF RED MUD

1. Road Base Stabilization Material [6]

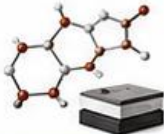


2. Adsorbent for Pollutant Removal [7]



- Heavy metals
- Dyes
- Phosphate
- Nitrate
- Fluoride

3. Catalyst Production



4. Recovery of Metals [8]

Fe Al Ti ...

- Iron
- Aluminum
- Titanium
- Other trace metals

5. Radiation Shielding Material [9]



6. Ceramics Production [10]



7. Construction Bricks [11]



8. Pigments and Paints [12]



9. Cement Production [13]



Sustainable management and valorization of red mud are essential to protect the environment, reduce costs, and promote a circular economy in the alumina industry.



Protects the environment



Reduces costs



Promotes circular economy



Creates economic and material value

FLY ASH: FROM INDUSTRIAL WASTE TO VALUABLE RESOURCE

Global Production, Environmental Challenges and Sustainable Applications

1 WHAT IS FLY ASH?

Fly ash is a fine powdery residue carried by flue gases during the combustion of coal for electricity generation, particularly in coal-fired thermal power plants.



Since large-scale coal combustion for power generation began in the **1920s**, millions of tons of ash and related by-products have been produced worldwide.



Current annual global production of coal ash is estimated at

600
million tons



Fly ash accounts for about

500
million tons

(75–80% of total ash generated) [14]

2 ENVIRONMENTAL CHALLENGES



Pollution Potential

Fly ash contains high concentrations of trace elements that may become toxic after condensation from flue gases.



Air Pollution

Fine particles can be released into the air during handling, transport and disposal, affecting air quality and health.



Landfill and Pond Disposal

A substantial amount of fly ash is still disposed of in landfills and/or ash ponds, requiring large land areas and causing long-term risks.



Low Utilization Rate

Global utilization rate ranges from 3% to 57%, but the global average is only about 16% of total ash generated. [14]

GLOBAL STATISTICS



Fly ash generated worldwide
~500
million tons / year
[14]



Utilization rate range
3% – 57%



Global average utilization rate
16%
of total ash
[14]

3 KEY APPLICATIONS OF FLY ASH



Cement & Concrete Production



Used as a supplementary cementitious material to produce concrete with improved strength, durability and reduced CO₂ emissions.



Road Construction



Used in embankments, base/sub-base layers and pavement to enhance performance and sustainability.



Brick Production



Improves brick strength, reduces energy consumption and conserves natural clay resources.
[16,17]

Other Valuable Applications



Low-cost Adsorbent for Flue Gas Treatment

Used to remove SO₂, NO_x, heavy metals and other pollutants from flue gases.
[18]



Agriculture & Engineering

Applied in soil improvement, land reclamation and various geotechnical engineering applications.
[19]



Zeolite Synthesis

Converted into zeolites for adsorption, ion exchange and catalyst applications.
[20]

4 FROM WASTE TO RESOURCE – TOWARDS A CIRCULAR ECONOMY



Coal Combustion
(Heat & Power)



Fly Ash
(Industrial Waste)



Resource Recovery
& Utilization



Building Materials &
Infrastructure



Sustainable Development
& Circular Economy

5 KEY MESSAGE



Transforming fly ash from an environmental liability into a valuable secondary resource is essential for sustainable construction and circular economy development.



PHOSPHOGYPSUM (PG)

Environmental Challenges and Circular Economy Opportunities

Phosphogypsum (PG) is a by-product of wet-process phosphoric acid production from apatite. Proper management and resource recovery are essential for environmental protection and sustainable development.



1 GLOBAL PG GENERATION

Generated during wet-process phosphoric acid production from apatite.



1 ton phosphoric acid produces
4 – 6 tons
of dry PG



Global PG generation
> 200 million
tons/year

15%

Recycled
(about 15%)

85%

Stockpiled in waste
disposal areas
(about 85%)



A huge amount of PG is still stockpiled, causing serious environmental and ecological impacts.

2 ENVIRONMENTAL RISKS



AIR POLLUTION

- Acidic dust and fine particles released during handling and weathering.
- Dispersion of hazardous substances into the air.



WATER POLLUTION

- Acidic leachates dissolve harmful compounds.
- Phosphate, fluoride and heavy metal ions migrate into surface water.



SOIL & GROUNDWATER IMPACTS

- Infiltration of fluoride and heavy metals.
- Contamination of soil and groundwater.
- Degradation of ecosystems and biodiversity.



Long-term accumulation of contaminants threatens environment, ecosystems and human health.

3 TYPICAL HAZARDOUS COMPONENTS



H_2SO_4

Sulfuric acid
Contributes to acidity and corrosion.



H_3PO_4

Phosphoric acid
Causes water pollution and eutrophication.



HF

Hydrofluoric acid
Highly toxic and corrosive.



Sulfates
(SO_4^{2-})

Increase salinity and can lead to soil degradation.



Phosphates
(PO_4^{3-})

Can cause eutrophication of water bodies.



Heavy metals
(e.g., Cd, Pb, Cr, As)

Toxic to living organisms; accumulate in food chain.



Radioactive elements
(e.g., U, Ra, Th)

Pose potential radiological risks.



The presence of multiple hazardous substances makes PG a potential environment threat.

4 SUSTAINABLE UTILIZATION OF PG



Construction Materials
Used in cement, concrete, mortar, road base and building materials.



Gypsum Products

Manufacture of gypsum boards, plaster, ceiling tiles.



Cement Additives

Used as setting regulator and gypsum binder in Portland cement.



Soil Amendments & Fertilizers

Improves soil properties and provides nutrients (Ca, S).



Chemical Feedstock

Raw material for H_3PO_4 and other chemicals.



Mine & Quarry Rehabilitation

Backfilling and land reclamation of abandoned mines/quarries.



Rare Earth Element Recovery

Recovery of valuable rare earth elements and by-products.



5 CIRCULAR ECONOMY PATHWAY



INDUSTRIAL PROCESS

Wet-process phosphoric acid production



PG WASTE GENERATION

Large amounts of phosphogypsum produced



RESOURCE RECOVERY

Collection, processing and quality control



VALUE-ADDED PRODUCTS

Construction, agriculture, chemical and other uses



SUSTAINABLE DEVELOPMENT

Reduced environmental impact and resource conservation

KEY MESSAGE



Transforming phosphogypsum from an environmental liability into a valuable resource is the key to achieving a circular economy and a sustainable future.



INDUSTRIAL WASTES FOR SUSTAINABLE UNFIRED BRICK PRODUCTION

Transforming Waste into Valuable Construction Materials

1. WHY UNFIRED BRICKS?

Traditional fired clay bricks cause serious environmental impacts



Large amounts of clay extraction



High energy consumption



Significant CO₂ emissions



Air pollution and environmental degradation



Unfired bricks provide a sustainable alternative



FIRED CLAY BRICKS



UNFIRED BRICKS

2. INDUSTRIAL WASTES AS RAW MATERIALS



FLY ASH

- By-product of coal-fired power plants
- Rich in SiO₂ and Al₂O₃
- Improves strength and durability



RED MUD

- Residue from alumina production
- Contains Fe₂O₃ and Al₂O₃
- Acts as filler and geopolymer precursor



PHOSPHOGYPSUM (PG)

- By-product of phosphoric acid production
- Improves setting and mechanical properties
- Enables recycling of phosphate industry waste



STONE DUST

- By-product of aggregate production
- Provides structural framework and density

3. TYPES OF UNFIRED BRICKS



CEMENT-AGGREGATE BRICKS

High strength and durability, suitable for structural applications.



LIGHTWEIGHT BRICKS (AAC & FOAMED CONCRETE)

Low density, good thermal insulation, and energy efficient.



WASTE-BASED BRICKS

Utilize construction and industrial wastes, reducing landfill and environmental burden.



GEOPOLYMER BRICKS

Alkali-activated materials with excellent chemical resistance and durability.

4. ENVIRONMENTAL BENEFITS



Reduction of industrial waste disposal



Conservation of natural clay resources



Lower carbon footprint



Reduced landfill requirements



Promotion of circular economy principles



Sustainable construction practices

5. CURRENT RESEARCH CHALLENGES



High or low pH values



Heavy metals and impurities



Variability in waste composition



Long-term durability assessment



Mix design optimization

6. FUTURE RESEARCH DIRECTION



Industrial Wastes



Optimized Mix Design



Unfired Brick Production



Standard Compliance



Sustainable Construction



Circular Economy

KEY MESSAGE



The combined utilization of fly ash, red mud, phosphogypsum, and other industrial by-products offers a promising pathway toward low-carbon, sustainable, and economically viable unfired brick production while reducing environmental burdens from industrial waste disposal.



UNFIRED BRICKS FROM INDUSTRIAL WASTES – A PATHWAY TO SUSTAINABLE CONSTRUCTION AND A GREENER FUTURE



Sustainable



Circular



Responsible



Resilient

Fly Ash-Based Bricks and Sustainable Construction Materials: Types and Compositions

Material Type	Main Components
Fiber-Reinforced Fly Ash Brick	Fly ash, cement, sand, stone dust, fibers
Non-Fired Fly Ash Brick	Fly ash, cement, lime, rice husk ash, PP fibers
Fly Ash Autoclaved Brick	Fly ash, lime, cement
Fly Ash Aggregate Brick	Fly ash, cement, sand, stone dust
Fly Ash Geopolymer Brick	Fly ash, alkaline activator
Fly Ash-Lime Brick	Fly ash, hydrated lime
Sustainable Roofing Tile	Fly ash, cement, recycled PE fibers
Fly Ash Coal Brick	Fly ash, cement, aggregates
Fly Ash Fired Clay Brick	Fly ash, clay, red mud
Fly Ash Geopolymer Foam Brick	Fly ash, metakaolin, silica fume

Fly ash can partially or completely replace natural raw materials.

✓ Various production routes include:

- Cement-based stabilization
- Autoclaving
- Geopolymerization
- Fired clay technology

✓ Fly ash utilization contributes to waste valorization and carbon emission reduction.

Mechanical Properties of Fly Ash-Based Construction Materials

Material Type	Compressive Strength (MPa)	Remarks
Fiber-Reinforced Fly Ash Brick	~10.3	Comparable to fired clay brick
Non-Fired Fly Ash Brick	High performance	Enhanced by PP fibers and SBR
Fly Ash Autoclaved Brick	14.3	Low density
Fly Ash Aggregate Brick	5.8–6.8	Improved by stone dust
Fly Ash Geopolymer Brick	20.3	Highest strength
Fly Ash-Lime Brick	7.5	Good thermal insulation
Roofing Tile	9.01	Similar to commercial clay tile
Reinforced Fired Clay Brick	8.3	Improved by fly ash and fibers
Geopolymer Foam Brick	~19	Lightweight and strong

⇒ Geopolymer technology provides the highest compressive strength and demonstrates strong potential for sustainable construction applications.

Advantages and Future Development of Fly Ash-Based Materials

• Advantages

- ♻️ Waste utilization and circular economy
- ♻️ Reduced consumption of clay and natural aggregates
- ♻️ Lower carbon footprint
- ♻️ Improved thermal insulation
- ♻️ Competitive mechanical performance

• Challenges

- ⚠️ Long-term durability data remain limited
- ⚠️ Variability in fly ash composition
- ⚠️ Water absorption issues in some formulations
- ⚠️ Scale-up and industrial implementation require optimization

• Future Research Directions

- ✓ Durability assessment under aggressive environments; Optimization of geopolymer formulations
- ✓ Incorporation of industrial by-products and recycled fibers; Life-cycle assessment (LCA) and carbon footprint analysis
- ✓ Industrial-scale production and commercialization

⇒ Fly ash-based bricks, particularly geopolymer bricks, exhibit excellent mechanical properties and significant environmental benefits, making them promising alternatives to conventional fired clay bricks for sustainable construction.

Red Mud as a Sustainable Raw Material for Brick Manufacturing

Background

- Red mud is a major by-product of the Bayer process for alumina production.
- Two main approaches have been investigated:
 - **Fired bricks**
 - **Unfired bricks**

Fired Brick Production

- Red mud can replace up to **80 wt.% of clay** in fired bricks.
- Mechanical strength increases with increasing firing temperature.
- Optimum conditions:
 - **40% red mud**
 - **1050°C sintering temperature**
 - **2 h holding time**
- Sintering significantly reduces the mobility of toxic metals.

Key Findings

- ✓ Higher compressive strength than conventional clay bricks.
- ✓ Lower water absorption.
- ✓ Up to **50% reduction in natural clay consumption.**
- ✓ Effective recycling route for industrial waste.

⇒ **Red mud is a promising substitute for clay in fired brick production, providing both environmental and technical benefits.**

Development of Unfired Bricks from Red Mud

Importance of Mix Design

- The performance of unfired bricks strongly depends on:
 - Raw material proportions
 - Preparation method
 - Curing conditions

Red Mud–CSA Bricks

- (CSA = Calcium Sulfoaluminate Cement)

Advantages

- Soluble Na accelerates CSA hydration.
- Efficient immobilization of:
 - Sodium (Na)
 - Fluoride (F)
 - Heavy metals

Performance

- Compressive strength satisfies engineering requirements.
- Meets national regulations regarding heavy metal leaching.

Economic and Environmental Benefits

- ♻️ Reduced disposal cost of red mud
- ♻️ Lower consumption of virgin raw materials
- ♻️ Reduced environmental pollution
- ♻️ Enhanced circular economy and resource recovery

⇒ **Unfired red mud bricks offer a low-energy and environmentally friendly alternative to conventional masonry materials.**

Phosphogypsum as a Secondary Raw Material for Brick Manufacturing

Background

- Phosphogypsum (PG), a by-product of phosphate fertilizer production, has attracted considerable attention as a sustainable construction material when combined with industrial wastes and conventional binders.

Applications in Brick Production

• Fired Bricks

- PG can partially replace clay in fired bricks.
- Incorporation of **30% PG** produces bricks meeting standard requirements.
- PG–fly ash–lime mixtures exhibit adequate strength and durability under sulfate conditions.

• Unfired Bricks

- PG-based compressed earth bricks satisfy construction standards.
- A novel **hydration–recrystallization process** produced high-performance unfired bricks.

• Optimum Mix for Unfired PG Bricks

- 75.0% PG
- 19.5% river sand
- 4.0% Portland cement
- 1.5% hydrated lime

• Key Benefits

- ✓ Improved compressive and flexural strength
- ✓ Reduced consumption of natural clay
- ✓ Effective recycling of industrial waste
- ✓ Lower environmental impact

⇒ Phosphogypsum can successfully replace conventional raw materials in both fired and unfired bricks while improving sustainability and resource efficiency.

Advanced Applications of Phosphogypsum in Construction

Cement and Concrete Applications

- Addition of **5–10% PG** improves:
 - Setting time
 - Mortar flowability
 - Compressive strength of mortar and concrete
- PG enhances bonding performance and reduces segregation in concrete mixtures.

Building Materials Developed from PG

• Floor Tiles

- Produced from calcined PG (anhydrite gypsum), fly ash, red mud, fiberglass, and additives.
- Flexural strength: **11–15 MPa**
- Compressive strength: **30–40 MPa**
- Water absorption: **2–3.5%**

• Gypsum Boards

- Manufactured using PG as the sole raw material.
- High density and mechanical strength.
- Fire-resistant, low-cost, and environmentally friendly.

• Self-Leveling Mortars

- Up to **55% PG incorporation**.
- Meets Chinese construction standards.
- Produces high-performance civil engineering materials.

Key Advantages

- ✓ Improved mechanical performance
- ✓ Good thermal and acoustic insulation
- ✓ Reduced use of natural resources
- ✓ Compliance with environmental and radiation safety requirements

⇒ **PG is a versatile raw material for producing cementitious materials, gypsum boards, floor tiles, and self-leveling mortars with excellent engineering performance**

Innovative Phosphogypsum-Based Construction Materials

Cold-Bonded Lightweight Aggregates (PCBA)

• Raw Materials

- Untreated phosphogypsum
- Ground granulated blast furnace slag (GGBS)
- Ordinary Portland cement (OPC)

• Key Findings

- PG content up to **80%** satisfies Chinese regulations.
- Suitable as lightweight aggregate for concrete.
- Reduces consumption of natural sand and gravel.

PG-Based Composite Cement Materials (PGCM)

• Characteristics

- Good thermal insulation
- Sound insulation
- High PG utilization rate

Lightweight Foamed Phosphogypsum Material (LFPM)

- **Optimum Composition:** 8% foam; 3.5% quicklime; 3% silica fume; 15% cement
- **Performance at 28 Days:** Compressive strength: **3.15 MPa**; Flexural strength: **0.97 MPa**

Advantages

- ✓ Lightweight
- ✓ Thermal insulation
- ✓ Acoustic insulation
- ✓ Fire resistance
- ✓ Cost-effective utilization of PG

Conclusions

- PG is a promising secondary resource for sustainable construction.
- It can be utilized in bricks, concrete, mortars, gypsum boards, lightweight aggregates, and foamed materials.
- High PG utilization rates significantly reduce waste disposal problems while promoting a circular economy.

⇒ **The development of PG-based construction materials provides an environmentally friendly and economically viable pathway for large-scale phosphogypsum recycling and sustainable infrastructure development.**



CURRENT STATUS AND POTENTIAL OF PG, FLY ASH, AND RED MUD RECYCLING

Transforming Industrial Wastes into Sustainable Construction Materials for a Greener Vietnam



1 PHOSPHOGYPSUM (PG)



Vietnam generates over 1 million tons of PG annually from fertilizer production in Dinh Vu Industrial Zone (Hai Phong).



By the end of 2022, approximately 12.7 million tons of PG had accumulated from three DAP fertilizer plants.



Utilization of PG in cement, gypsum boards, and construction materials remains limited due to impurities and contaminants.



Current research mainly focuses on low-grade PG as a cement additive, while applications in gypsum boards and unfired bricks remain largely unexplored.

2 FLY ASH AND BOTTOM ASH



Demand for construction materials is increasing rapidly.

Producing all bricks from fired clay would consume:



57–60 million m³ of clay



5.3–5.6 million tons of coal



Approximately 17 million tons of CO₂ emissions

Coal-fired power plants generate enormous quantities of ash:



61 million tons (2018)



109 million tons (2020)



248 million tons (2025 projected)

Only about 30% of ash and slag is currently recycled.

RESEARCH HIGHLIGHTS

- ✓ Unfired bricks produced from fly ash and bottom ash have demonstrated acceptable engineering performance.
- ✓ High-volume fly ash incorporation can improve durability and reduce water permeability.



3 RED MUD UTILIZATION



Red mud from Bayer alumina production is a major environmental concern.



Studies have demonstrated the feasibility of producing autoclaved geopolymer bricks using red mud.

PERFORMANCE OF RED MUD GEOPOLYMER BRICKS



Compressive strength
6.8–12.5 MPa



Softening coefficient
> 0.82



pH value
< 9.5



Environmentally friendly and suitable for masonry applications

- ✓ Comparable performance to fired clay bricks and concrete bricks



4 REMAINING CHALLENGES



Heavy metals and hazardous impurities remain a concern.



PG is highly acidic, while red mud is strongly alkaline.



Separate utilization often requires additional chemicals for neutralization and stabilization.



Additional aggregates are still required for brick production.



5 FUTURE RESEARCH DIRECTIONS



Develop integrated technologies combining:

- Phosphogypsum (PG)
- Fly ash
- Red mud



Optimize mix proportions and processing conditions.



Remove toxic metals and hazardous chemicals before utilization.



Develop sustainable, large-scale unfired brick manufacturing technologies.



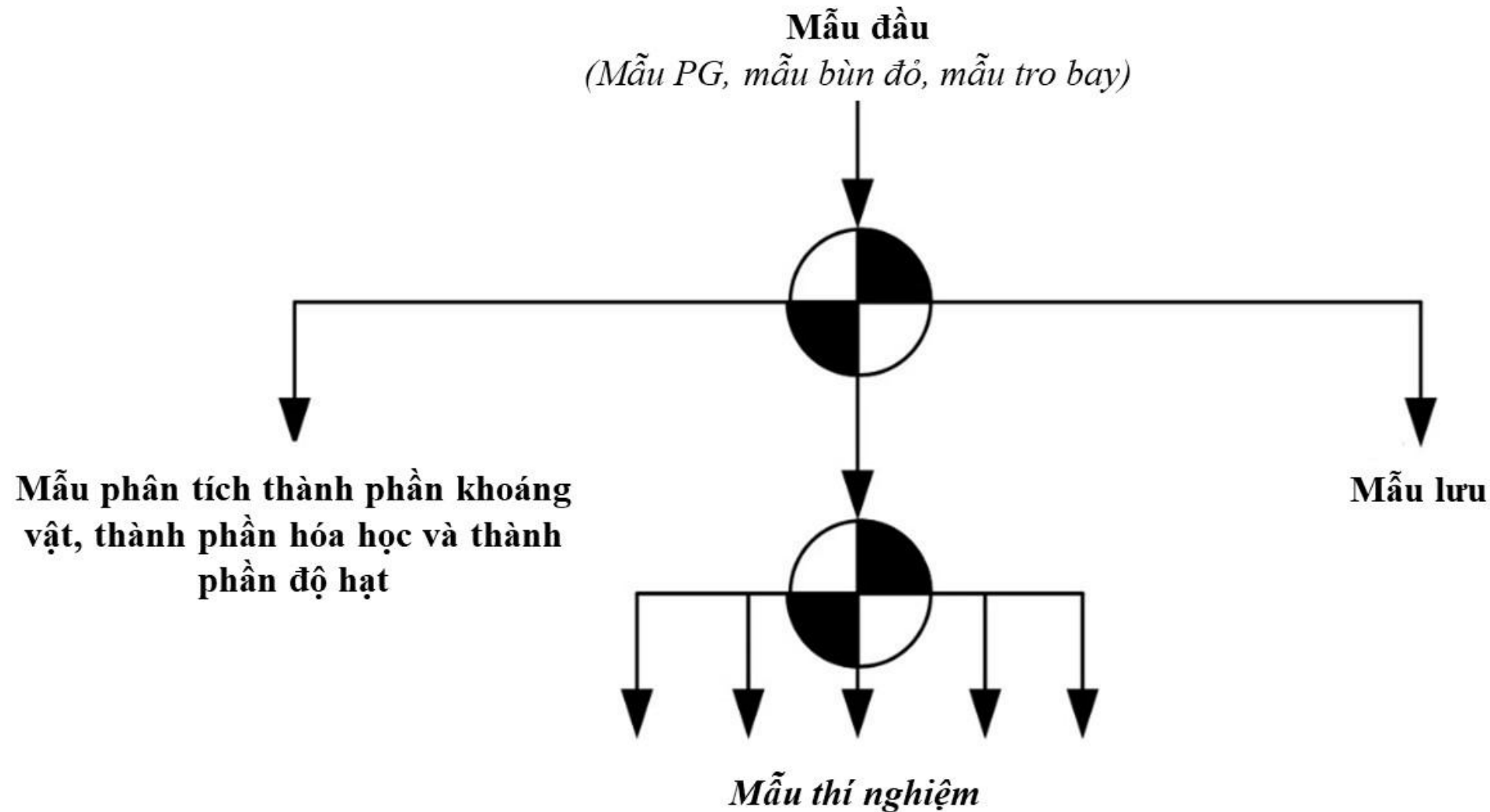
Vietnam possesses abundant industrial waste resources (PG, fly ash, and slag) that could significantly reduce environmental impacts and dependence on natural construction materials.



The combined utilization of phosphogypsum, fly ash, and red mud represents a promising pathway for sustainable construction materials in Vietnam, simultaneously addressing industrial waste management, environmental protection, and resource conservation.



PG samples were taken from the PG waste dump of DAP – Vinachem Joint Stock Company. Red mud samples were taken from the red mud pond, while fly ash samples were taken from the fly ash disposal area of the Dak Nong Aluminum Company's thermal power plant – Vinacomin.



Fraction, mm	Yield, %	P ₂ O ₅ content, %	SO ₃ content, %	SiO ₂ content, %	P ₂ O ₅ distribution, %	SO ₃ distribution, %	SiO ₂ distribution, %
+0.3	2,36	17,62	2,19	69,74	24,74	0,13	13,6
0,02-0,3	50,72	0,81	41,60	7,42	24,44	54,54	31,1
-0,02	46,92	1,82	37,38	14,26	5,82	45,33	55,3
Sum	100	1,68	38,69	12,1	100	100	100

Mineralogy	Content range,~%
CaSO ₄ (H ₂ O) ₂	1 – 2
CaSO ₄ (H ₂ O) _{0,5}	34 – 36
Thạch anh – SiO ₂	11 – 13
Felspat – K _{0,5} Na _{0,5} AlSi ₃ O ₈	1 – 3
Illit – KAl ₂ [AlSi ₃ O ₁₀](OH) ₂	10 – 12
Clorit – Mg ₂ Al ₃ [AlSi ₃ O ₁₀](OH) ₈	≤ 1
Gipxit – Al(OH) ₃	≤ 1

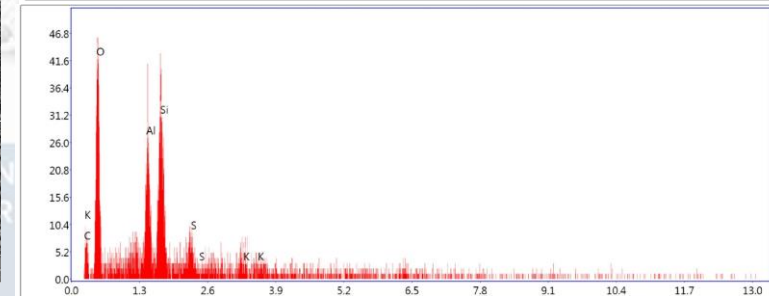
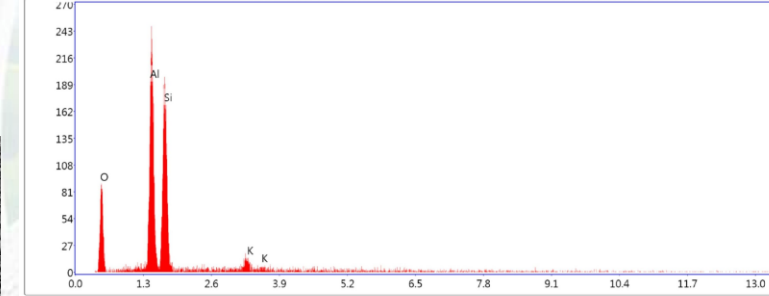
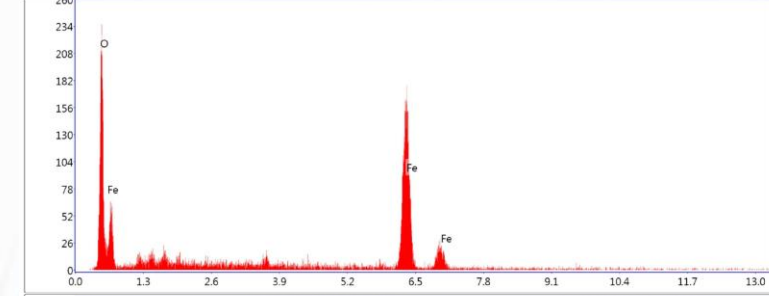
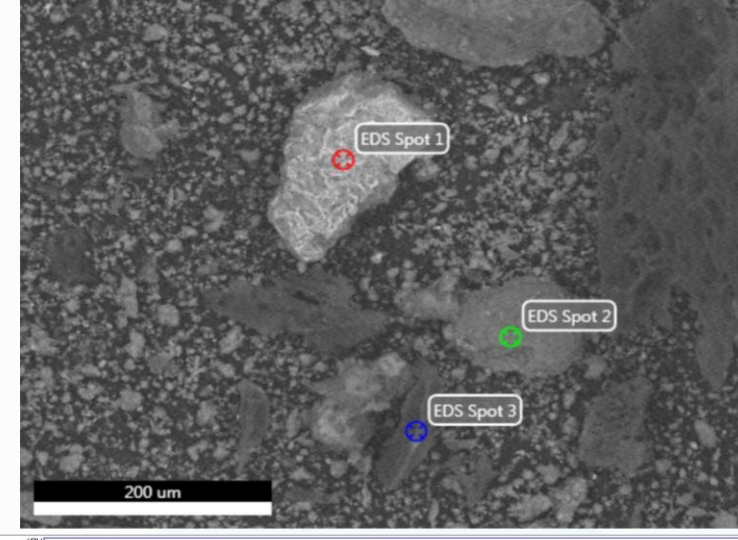
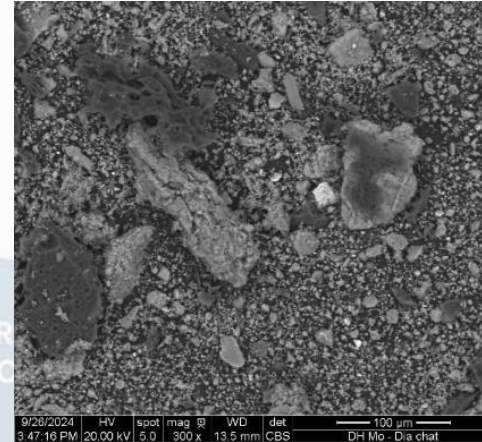
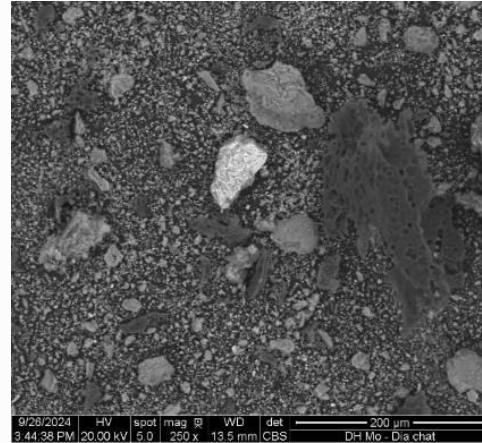
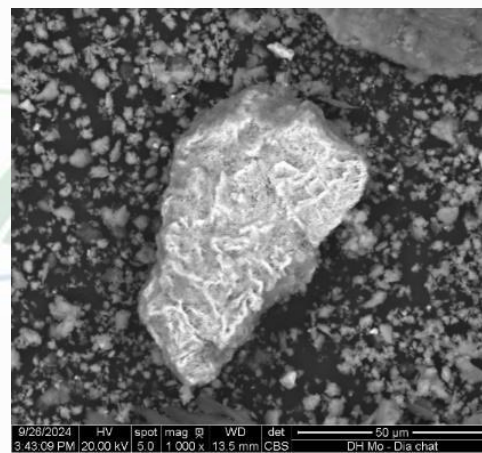
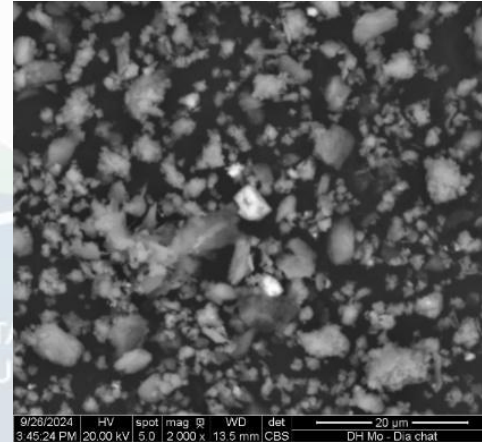
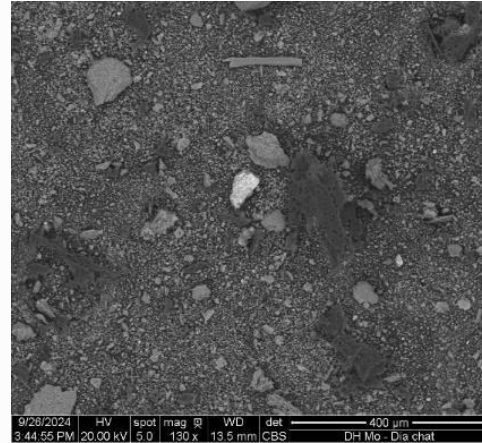
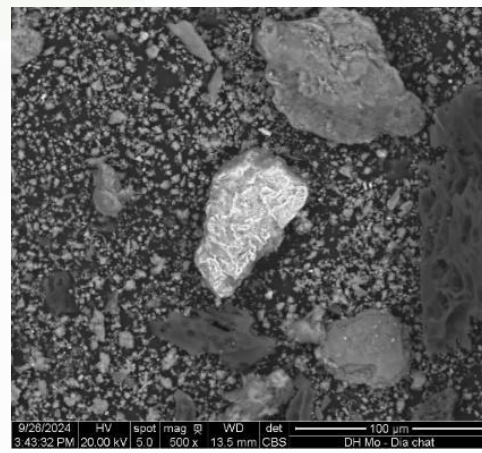
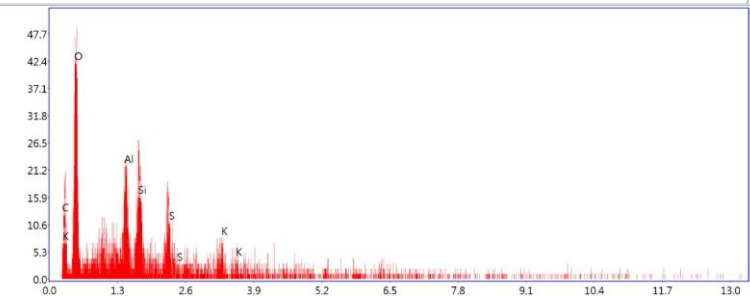
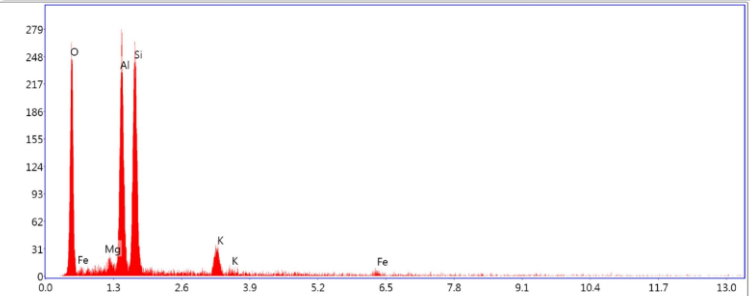
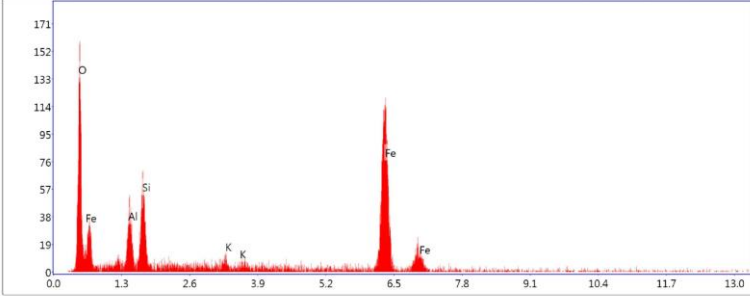
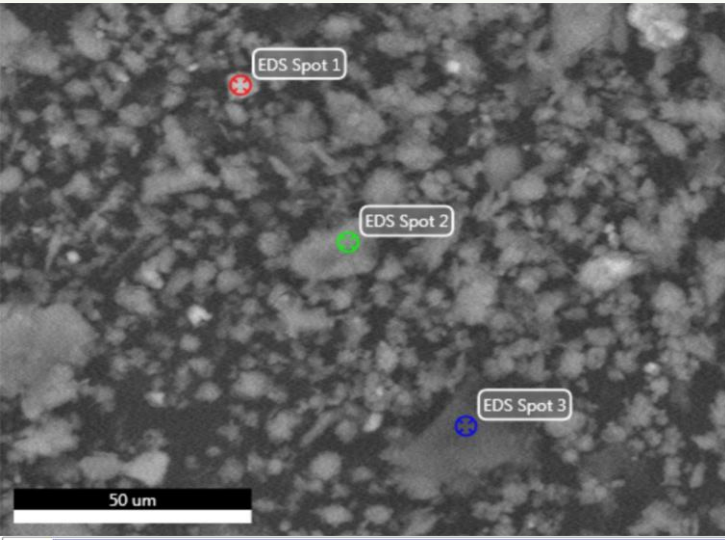
TT	Thông số	ICP- M1	ICP-M2
1	SO ₃ (%)	38,69	
2	P ₂ O ₅ (%)	1,68	
3	SiO ₂ (%)	12,10	
4	Fe ₂ O ₃ (%)	0,32	0,26
5	Al ₂ O ₃ (%)	0,099	0,101
6	MgO(%)	0,052	0,048
7	K ₂ O(%)	0,03	0,024
8	TiO ₂ (%)	0,044	0,052
9	BaO(%)	0,0216	0,0219
10	NiO(%)	0,0029	-
11	CuO(%)	0,0017	0,0003
12	La ₂ O ₃ (%)	0,0045	0,0045
13	CeO ₂ (%)	0,003	0,003
14	Nd ₂ O ₃ (%)	0,0036	0,0036



SUSTAINABLE
SOLUTIONS



BETTER
ENVIRONMENT



			No.	Criteria	Unit	Value	No.	Criteria	Unit	Value
Fraction, mm	Yield,%	Ash, %	1	Al ₂ O ₃	(%)	25,25	9	Ag	< 2	
0,5-1	0,25	71,76	2	CaO		1,56	10	As	< 20	
0,2-0,5	0,42	71,97	3	TFe ₂ O ₃		6,25	11	B	< 10	
0,1-0,2	7,74	65,25	4	K ₂ O		4,35	12	Ba	863,6	
0,074-0,1	7,21	61,37	5	MgO		1,43	13	Be	< 5	
0,04-0,074	18,38	50,11	6	MnO		0,05	14	Bi	< 10	
0,02-0,04	14,13	49,12	7	P ₂ O ₅		0,12	15	Cd	< 2	
-0,02	51,87	80,83	8	TiO ₂		1,06	16	Ce	< 5	
Sum	100	68,03					17	Co	56,7	
							18	Cr	150,6	
							19	Cu	101,6	
							20	Ga	< 10	
							21	Ge	< 20	
							22	La	54,6	
							23	Li	74,4	
							24	Mo	5,0	
							25	Nb	46,3	
							26	Ni	197,1	
							27	Pb	120,8	
							28	Sb	< 10	
							29	Sc	24,9	
							30	Sn	88,1	
							31	Sr	121,3	
							32	Ta	< 10	
							33	V	257,4	
							34	W	131,9	
							35	Y	56,0	
							36	Zn	308,6	
								(ppm)		

No.	Sample	Contents (%)							
		SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	K ₂ O	Na ₂ O	SO ₃	Cl-	LOI
1	Fly ash	44,88	25,55	6.34	4,45	0,34	0,37	0,14	12,31

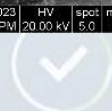
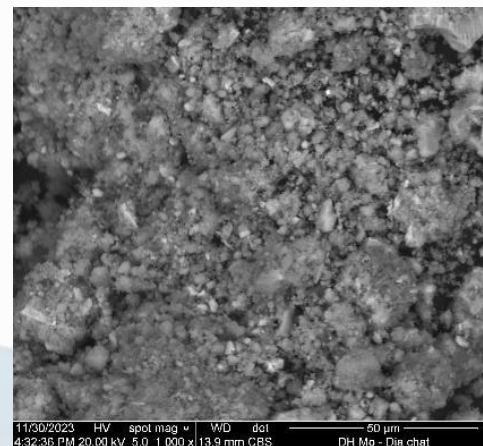
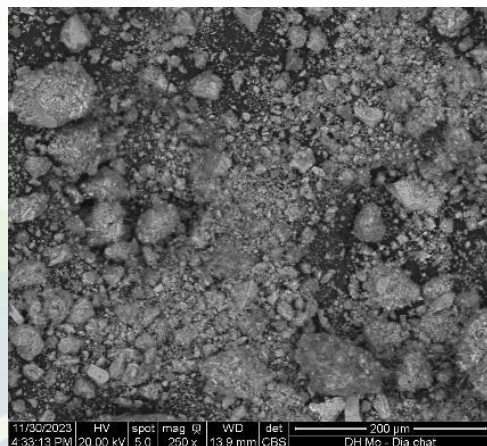
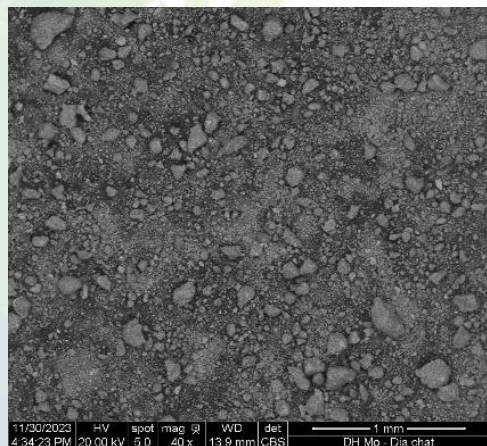
SUSTAINABLE SOLUTIONS

BETTER ENVIRONMENT

STRONGER FUTURE

Fraction, mm	Yield, %
+ 2	0
1 - 2	0
0,5 - 1	0
0,2 - 0,5	1,15
0,1 - 0,2	1,24
0,074 - 0,1	1,39
0,045 - 0,074	5,11
0,02 - 0,045	1,36
- 0,02	89,75
Sum	100

Elements	Contents,%	Elements	Contents,%	Elements	Contents,%
Al	14,28	Na	0,43	Ca	0,76
Fe	37,8	Si	8,2	Ag	0,0001
Cr	0,14	Pb	0,0028	Zn	0,01
Cd	0,0002	Bi	0,0001	Mn	0,08
Ni	0,0061	As	0,0007	Sb	0,004
Cu	0,013	P	0,29	Sn	0,0024
Te	0,0046	Co	0,0005	Se	0,0001
TiO ₂	0,01				



SUSTAINABLE
SOLUTIONS



BETTER
ENVIRONMENT



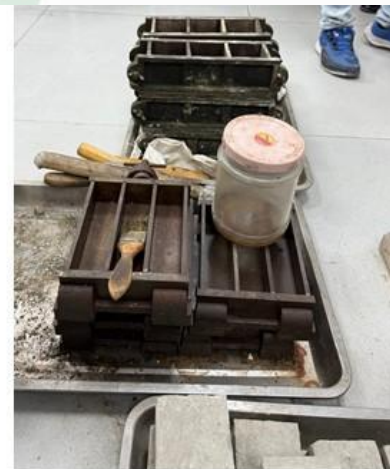
STRONGER
FUTURE



Đá mặt



Máy trộn vữa xi măng tiêu chuẩn



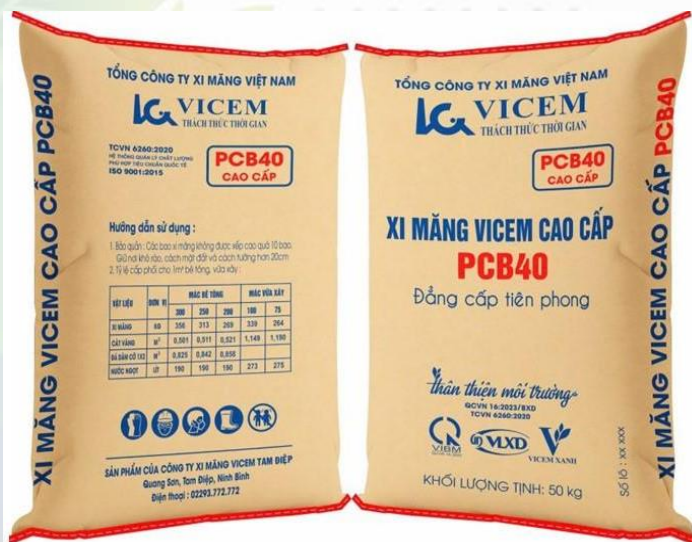
Khuôn đóng gạch



Máy test cường độ nén



Máy rải vữa xi măng



Xi măng

SUSTAINABLE
SOLUTIONS



BETTER
ENVIRONMENT



STRONGER
FUTURE

EXPERIMENTAL PROCEDURE FOR MANUFACTURING AND TESTING UNFIRED BRICKS

Mixing → Molding → Compaction → Curing → Testing

1 MIXING OF MATERIALS



Red Mud



Fly Ash



TAHP Gypsum



Stone Dust



Cement



Mix red mud and fly ash for 1–2 min



Add TAHP gypsum and stone dust, mix for 1–2 min



Add cement, mix for 1–2 min



Add water (10 wt.% of total mixture) and mix until homogeneous

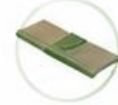
2 SPECIMEN PREPARATION



Fill the mold in 2 layers



Compact each layer approximately 10 times with a tamping rod



Remove excess mortar and smooth the surface

3 COMPACTION



Jolting machine



60 jolts / 60 s (± 2 s)



Drop height: 15 ± 0.3 mm

4 CURING



Water curing



28 days

- Cover with plastic film
- Water 3–4 times per day

5 TESTING

COMPRESSIVE STRENGTH TEST

According to TCVN 6477:2016



Testing Ages

- 1 day
- 3 days
- 28 days

KEY PARAMETERS



Water Content
10 wt.%



Mold Size
 $40 \times 40 \times 160$ mm



Jolting Cycles
60 jolts / 60 s (± 2 s)



Drop Height
 15 ± 0.3 mm



Curing Period
28 days



Test Standard
TCVN 6477:2016



Utilizing industrial by-products (red mud, fly ash, TAHP gypsum, stone dust) to produce sustainable and environmentally friendly unfired bricks.

MIX DESIGN OPTIONS AND MIX PAIRS FOR INVESTIGATION

Unfired bricks are produced from: PCB40 Cement, Stone Dust, Phosphogypsum, Red Mud and Fly Ash



ROLE OF RAW MATERIALS IN UNFIRED BRICKS

1. PCB40 CEMENT



Binder that connects aggregates: PCB40 combines with water, stone dust, sand, or fly ash to form a strong matrix that binds and connects all components.



Determines compressive strength: With high strength (>40 MPa), PCB40 helps the bricks meet the standard for hardness and load bearing even with low cement content, optimizing cost.



Provides durability & water resistance: Additives in PCB40 (such as pozzolan) improve impermeability, resistance to erosion, and extend service life in tropical conditions.

2. FLY ASH



Replaces part of cement, reducing production cost.



Enhances strength and bonding: Rich in SiO_2 and Al_2O_3 , fly ash reacts pozzolanically, providing high strength and increasing long-term stability.



Improves product quality: Produces finer bricks with better surface finish.



Reduces weight and drying shrinkage: Lowers density and dead load; reduces drying shrinkage and improves crack resistance.



Environmental benefit: Utilizes coal fly ash, reducing industrial waste and CO_2 emissions.

Widely used in AAC blocks, concrete blocks, and geopolymer bricks.

3. RED MUD



Ultra-fine filler: Very fine and porous particles increase density and compactness of bricks.



Binder-forming component: Rich in Fe_2O_3 and Al_2O_3 , which participate in chemical reactions to form strong bonds.



Natural coloring agent: Iron oxides give bricks a natural red color pigments.



Environmental solution: Helps reduce the huge amount of industrial waste.

4. STONE DUST



Framework aggregate: Main component that provides strength and durability to the brick.



Fills voids and improves bonding: Fine particles fill gaps and, with cement and water, form a dense, low-porosity structure.



Optimizes hydraulic pressing: Moisture and small particle size facilitate pressing and molding better than ordinary sand.



Cost-effective: By-product of the stone crushing process, reducing raw material cost.

5. PHOSPHOGYPSUM



Controls setting time: PG (with low impurity content) retards cement setting, ensuring stable molding.



Improves strength and durability: PG powder significantly improves compressive strength and overall durability.



Improves surface quality: Increases fineness, reduces cracking and warping.



Enhances thermal & acoustic insulation: Contributes to air-void structure in lightweight bricks.



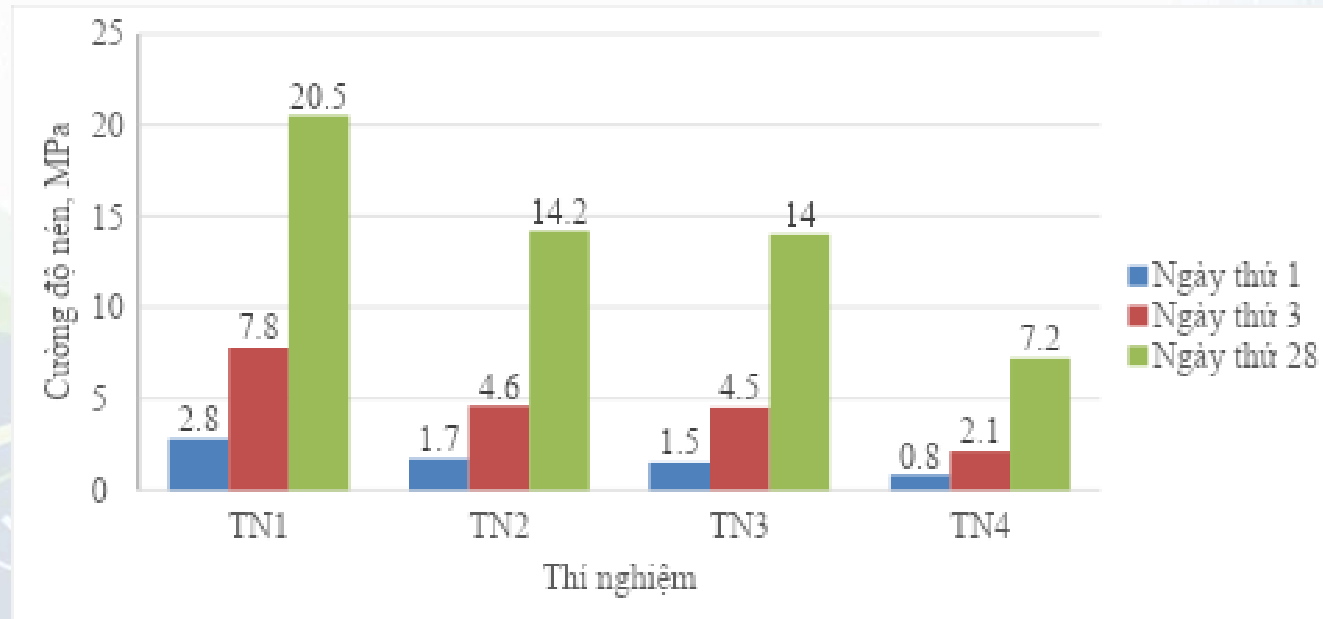
Waste utilization: Utilizing PG helps treat industrial waste and protect the environment.

Utilizing industrial by-products (fly ash, red mud, phosphogypsum, stone dust) in unfired bricks helps reduce cost, save natural resources and protect the environment.

Test for the change of dust stone and PG

Test	Cement	Dust stone	PG	Red mud + Fly ash (ratio 1:1)
TN1	10%	50%	20%	20%
TN2		40%	30%	
TN3		30%	40%	
TN4		20%	50%	

Test	Compressive (MPa)		
	1 st day	3 rd day	28 th day
TN1	2,8	7,8	20,5
TN2	1,7	4,6	14,2
TN3	1,5	4,5	14
TN4	0,8	2,1	7,2



EFFECT OF STONE DUST AND PHOSPHOGYPSUM CONTENT ON COMPRESSIVE STRENGTH OF UNFIRED BRICKS

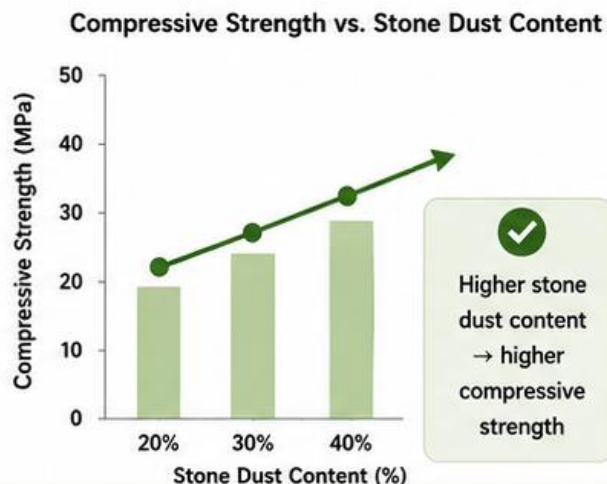


With constant cement content and red mud-fly ash mixture, the compressive strength of unfired bricks is influenced by the amount of stone dust and phosphogypsum (PG).

1. EFFECT OF STONE DUST CONTENT



When the content of stone dust increases while other components remain constant, the compressive strength of bricks tends to **increase**.



2. EFFECT OF PHOSPHOGYPSUM (PG) CONTENT



When PG content changes from 30% to 50%, corresponding to a reduction of stone dust from 40% to 20%, the differences in compressive strength at all test ages are **not significant**.



The compressive strength tends to **increase slightly** as the PG content increases.

Compressive Strength (MPa)

PG Content (%)	Stone Dust Content (%)	Test Age (Days)		
		1 Day	3 Days	28 Days
30	40	14.2	19.8	25.6
35	35	14.6	20.3	26.4
40	30	15.0	20.9	26.9
45	25	15.3	21.3	27.6
50	20	15.6	21.7	28.2



Differences in compressive strength are **not large**, but the strength tends to **increase** as PG content increases.

3. OPTIMUM STONE DUST CONTENT



When stone dust content reaches **50%**, corresponding to a reduction of PG to 20%, the compressive strength reaches the highest level at 28 days with **more than 30 MPa**.



4. RECOMMENDED MIX PROPORTION (EXPERIMENT NO. 4)

Based on the above results, the optimal mix proportion is recommended as follows:



This mix achieves the highest compressive strength at 28 days (> 30 MPa) and is recommended for further experimental study.



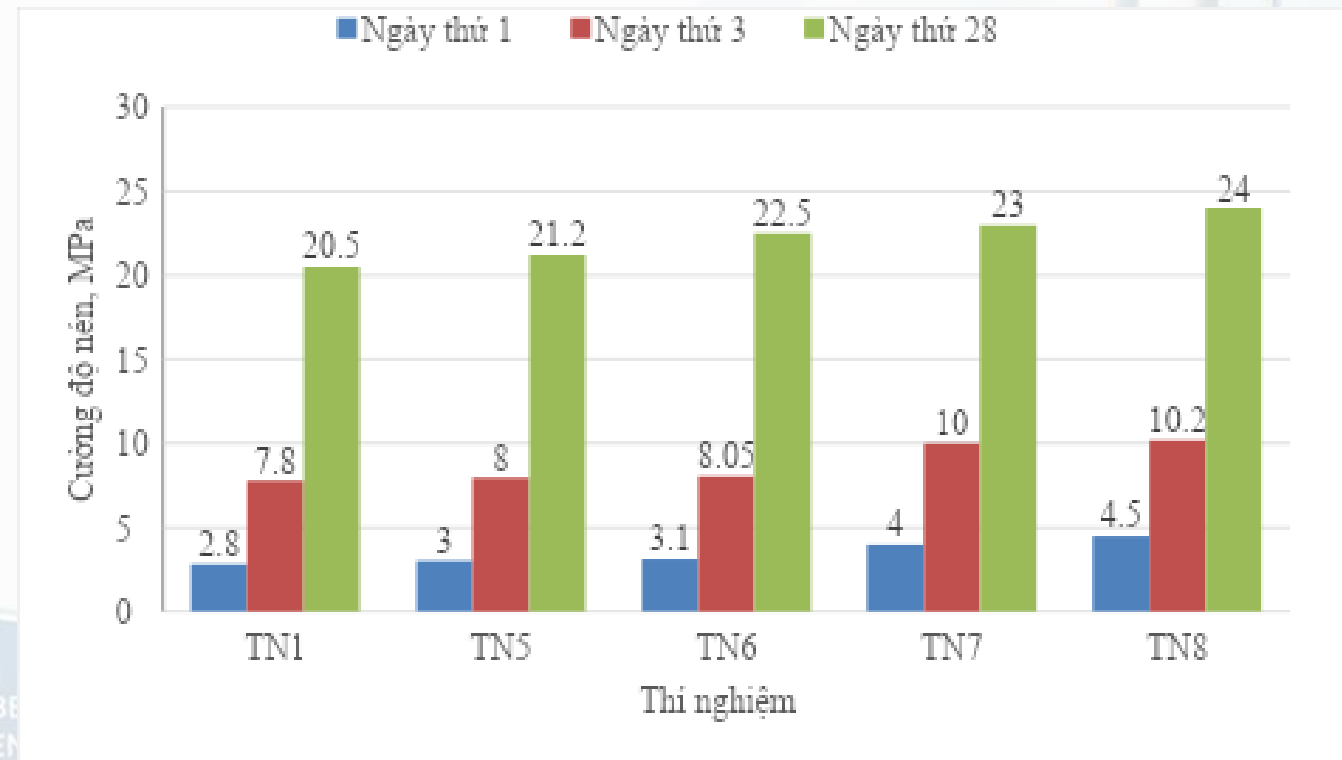
This optimal mix not only improves the performance of unfired bricks, but also helps **reduce production cost** and **effectively utilizes industrial waste materials**, contributing to **sustainable construction** and **environmental protection**.



Thí nghiệm thăm dò ảnh hưởng sự thay đổi của tỷ lệ xi măng và hỗn hợp bùn đỏ + tro bay đến cường độ nén của gạch không nung

Test	Cement	Dust stone	PG	Red mud/ Fly ash (ratio 1:1)
TN1	10%	50%	20%	20%
TN5	15%			15%
TN6	20%			10%
TN7	25%			5%
TN8	30%			0%

Test	Compressive (MPa)		
	1 st day	3 rd day	28 th day
TN1	2,8	7,8	20,5
TN5	3	8	21,2
TN6	3,1	8,05	22,5
TN7	4	10	23
TN8	4,5	10,2	24



SUMMARY OF EXPERIMENTAL FINDINGS AND RECOMMENDATIONS

Optimizing the use of red mud and fly ash in unfired bricks for cost reduction, resource efficiency and environmental protection

1. EFFECT OF CEMENT CONTENT ON COMPRESSIVE STRENGTH



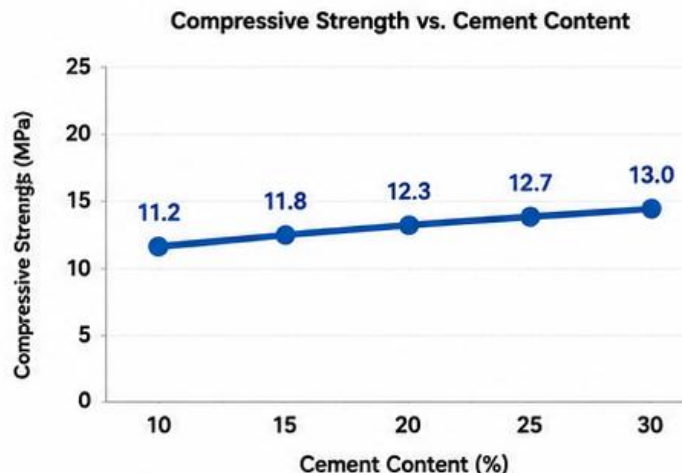
When increasing cement content from 10% to 30%, the compressive strength of unfired bricks tends to increase slightly.



The increase is not significant.



This shows that although the binding and compressive performance of red mud + fly ash are lower than cement, the mixture still contributes to the stability of the unfired brick structure.



↑ Cement content
10% → 30%

↓ Red mud + fly ash
content decreases

ROLE OF RED MUD + FLY ASH



RED MUD



FLY ASH



Contributes to the stability and integrity of unfired bricks



Improves particle packing and density



Provides partial binding through pozzolanic and geopolymeric reactions



Enhances structural stability and reduces porosity



Utilizes industrial waste and supports environmental protection

2. FUTURE RESEARCH DIRECTIONS

Further experiments are needed to investigate:



Optimal ratio of red mud and fly ash



Presence of activators:
 NaOH , Na_2CO_3 , Ca(OH)_2



Formation of geopolymer structure



Partial or total replacement of cement

3. APPLICATION AND PERFORMANCE

The unfired bricks in these experiments meet the requirements of different strength grades:

M3,5

M5,0

M7,5

M10

M12,5

M15

M20

Suitable for:



Partition walls



Auxiliary structures



High-rise buildings



Retaining walls

4. PRELIMINARY RECOMMENDATION



In this preliminary study, it is recommended to use **10% cement content** and optimize the red mud + fly ash mixture to:



Reduce production costs



Maximize the utilization of industrial waste from the mineral processing industry



Contribute to environmental protection



Maintain the required strength and durability of unfired bricks



The optimal ratio of red mud and fly ash, the use of activators (NaOH , Na_2CO_3 , Ca(OH)_2) to form geopolymer, and the potential replacement of cement should be further investigated in the next phase of research.





CONCLUSION



1. RAW MATERIALS FOR UNFIRED BRICK PRODUCTION



The study identified suitable raw materials for the production of unfired bricks. These materials are industrial by-products and cement.



RED MUD

(a waste by-product from alumina production)



FLY ASH

(a waste by-product from coal-fired power plants)



STONE DUST

(a by-product of crushed stone production)



PHOSPHOGYPSUM (PG)

(a waste by-product from DAP fertilizer production)



PCB40 PORTLAND CEMENT

(PCB40 Portland cement)

2. UNFIRED BRICK MANUFACTURING PROCESS

1



Red mud + Fly ash mixing
(1 – 2 min)

2



Stone dust + Phosphogypsum mixing
(1 – 2 min)

3



Cement mixing
(1 – 2 min)

4



Addition of water
(10 wt.% of total mixture)

5



Molding

6



Compaction

7



Curing

8



Compressive strength testing at 1, 3, and 28 days

3. OPTIMUM MIX PROPORTION AND PERFORMANCE



A preliminary optimum mix design was identified that satisfies the requirements for both civil and industrial applications.

PCB40 CEMENT



10%

STONE DUST



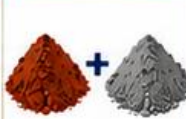
50%

PHOSPHOGYPSUM (PG)



20%

RED MUD + FLY ASH (MIXTURE 1:1)



20%

TOTAL: 100%



Compressive strength reached **20.5 MPa** after 28 days of curing.



Meets the requirements of Vietnamese standards (TCVN) for unfired bricks.

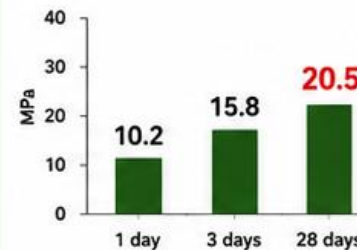


Suitable for use in civil and industrial construction.



Promotes the utilization of industrial waste materials and supports environmental sustainability.

COMPRESSIVE STRENGTH (MPa)



UNFIRED BRICK

Strong – Durable – Environmentally friendly



Utilizes industrial waste materials



Reduces production costs



Meets Vietnamese standards (TCVN) for unfired bricks



Contributes to environmental protection



Supports sustainable construction and development



RECOMMENDATIONS

FOR FUTURE RESEARCH

Proposed research directions to improve the performance and sustainability of unfired bricks produced from industrial by-products.



1

CHEMICAL COMPOSITION ASSESSMENT

Evaluate the effects of chemical compositions of raw materials on the properties of unfired bricks, particularly the major components and associated impurities.

- Al_2O_3 (Alumina)
- Fe_2O_3 (Iron Oxide)
- SiO_2 (Silica)
- CaSO_4 (Calcium Sulfate)
- Na_2O (Sodium Oxide)
- Impurities and trace elements



→ Understand their impact on brick performance and environmental safety.

2

OPTIMIZATION OF MIX PROPORTIONS

Conduct detailed investigations on the variation of mix proportions and the interactive effects among raw materials on the compressive strength and overall performance of unfired bricks.



→ Determine optimum proportions for maximum compressive strength and durability.

3

GEOPOLYMER DEVELOPMENT

Perform in-depth studies on red mud-fly ash ratios, activators and additives, and processing conditions to promote geopolymer formation and replace conventional Portland cement binders.

- Optimize the ratio of Red Mud + Fly Ash
- Evaluate activators and additives such as NaOH , Na_2CO_3 , $\text{Ca}(\text{OH})_2$
- Enhance geopolymer formation and binding mechanism
- Reduce cement consumption and carbon emissions

→ Develop sustainable and eco-friendly geopolymer-based binder systems.

4

AUTOClave CURING INVESTIGATION

Evaluate the influence of autoclave curing conditions on the mechanical and physical properties of unfired bricks to further enhance material performance.



- Temperature
- Holding Time
- Pressure

→ Improve strength, durability, dimensional stability, and resistance to harsh environments.

5

PROCESS OPTIMIZATION AND SCALE-UP

Investigate the effects of key technological parameters to establish an optimal production process at laboratory scale and facilitate future pilot-scale and semi-industrial production.

- Mix Proportions**
(Components and ratios)
- Water-to-Solid Ratio**
(Workability and strength)
- Additive Selection**
(Workability, strength, and durability)

→ Establish the optimal process and transfer to pilot-scale and semi-industrial production.

EXPECTED OUTCOMES



Higher utilization of industrial wastes

Efficient recycling of red mud, fly ash, phosphogypsum, and other by-products.



Reduced environmental impact

Lower carbon emissions and less landfill disposal.



Sustainable construction materials

Production of high-performance and durable unfired bricks.



Lower production costs

Utilization of low-cost industrial by-products and optimized processes.



Improved mechanical performance

Higher compressive strength, durability, and service life.



Data-driven technology development

Scientific understanding to support standards, quality control, and industrial adoption.



These research directions will contribute to the development of sustainable, cost-effective, and high-performance unfired bricks, supporting green construction and circular economy.



Green Construction



Industrial Waste Valorization



Quality and Durability



Socio-economic Benefits



Acknowledgement

This work was carried out as a part of the project "Strengthening International Academic Cooperation: A Strategic Partnership between the AGH University of Krakow and Leading Scientific Institutions in Vietnam", implemented within the framework of the NAWA Strategic Partnerships Programme – call 2024 – contract number BPI/PST/2024/1/00122/U/00001, financed from the national funds.



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