Researching materials to create insulating and decorating wall and floor tiles from concrete light decorated on foam glass bubble

Ngoc Minh Nguyen¹, Ngoc Gia Nguyen² and Ky Khae Nguyen³
¹ Department of Construction, Hanoi Architectural University, Viet Nam
² Department of Construction, Construction College No. 1, Ministry of Construction, Viet Nam
³ Department of Construction, Hanoi Architectural University, Viet Nam

E-mail: ¹ b1quannhan@gmail.com ² ngocbxd37ldl@gmail.com ³ kynk@hau.edu.vn

Abstract. Due to tropical climate, in Vietnam, the summer outdoor temperature is above 40°C, amplified by the high UV content sun rays (8-10) and thus, heated the atmosphere. A combination of high temperatures, sun-proofing roof, thin walls intertwined with glass wall panels has formed giant greenhouses and has caused the temperature inside the building to rise as if it is roasting the living residence. Clay tiles on the floor was deformed, causing surface cracking and leakage from rainwater. In order to reduce the heat transfer, the use of insulation materials, decorative for facade walls and roof floors is deemed a necessary solution, and the study of the application of decorative colored concrete proved to be the ultimate solution. The study of factors affecting the quality of wall cladding, heat-insulating and decorative products for walls and roof floors from lightweight concrete decorative blends insulating on porous glass aggregates will solve the problem that the Ministry of Construction Vietnam No. RD 44-19 project set out.

1. Introduction
Currently the population situation in Vietnam as well as in the world is constantly increasing, resulting in a great demand for housing needs. A series of constructions and buildings are being built with high density, especially concentrated in urban areas and big cities. When constructing buildings, there are many issues to be concerned such as: reducing construction load; insulation, heat resistance and saving energy used to cooldown buildings. There are problems when handling construction waste, especially glass and construction glass ... The research to find a light, heat-insulating, decorative, resistant to the hot and humid climate of Vietnam, has the right intensity and environment-friendly or being a green architectural material to be used as cladding, paving for exterior walls and roofs, is essential today [1,5]. Materials and decorative materials are the parts that make up the structure, complete the appearance of the structure; the good or bad materials also directly affect the quality and aesthetics of the building, moreover, they occupy a very large percentage in total construction cost (up to 85%) [3,5].

Therefore, the selection and use of construction materials and appropriate architectural decoration materials are very necessary. Since 1969, the Soviet Union has set out a plan to produce and use architectural decorative materials to increase the durability and charm of the building with materials and materials such as colored bricks. non-plaster, ceramic, decorative ceramic, colored concrete, aluminum
and non-ferrous metals, natural stone, stained glass and decorative details, colored cement, environmentally friendly paint [4,5,14]. ... Considering Vietnam climate conditions, it is the most reasonable to use surface decoration materials with inorganic adhesives, colored concrete and colored mortar. In order to produce colored concrete materials for interior and exterior decoration, materials like normal concrete are required, but gray cement should be replaced with white or colored cement, aggregate such as macadam and yellow sand should be replaced with smaller sized natural stone particles or even natural stone powder. Besides, it is recommended to use inorganic pigments to create strong themed colors such as red and blue [3,5,6,14].

Lightweight concrete decorative (LWCD) will be the first choice meet the requirements of the quality of tile products such as insulation and decoration. Decorative concrete was first manufactured in the early 20th century (1915) in the United States with the original name of "stamp concrete" or "stamped concrete" and the first person to produce this type of concrete was Brad Bowman in Carmel - California (USA). In addition to B. Bowman, there are M. Archambault (Paris - France), C. Branum and J. Nasvik (USA), who had contributed greatly to the global decorative concrete industry. 1977 [6]., By V.A. Pixkarev [15]. In the Russian Federation, there are documents on decorative materials and decorative finishing materials written by authors who have published definitions and materials for manufacturing concrete and colored stucco [4,14]. Many other authors also introduced concepts of finishing materials and architectural decorative materials such as: Academics. Tutor. Doctor of Science. IU. M. Bazenev, Assoc.Prof.Dr. Bach Dinh Thien, PhD. Tran Ngoc Tinh [4]. Master. Phan Phan Vinh [3]., Tutor. Doctor of Science. Phung Van Lu, PhD. Nguyen Gia Ngoc.

Constructions in Vietnam have also used decorative wall cladding without insulation attribute (Figures 1, 2). Currently, many civil constructions with western facade walls have used ordinary (non-insulating) ceramic tiles (Figure 1).

![Figure 1](image1.png)

**Figure 1.** The facade of the house is decorated with ceramic tiles in a variety of colors

With a very thin wall structure of 100-200 mm, or even reinforced with the external tiles, walls do not meet the insulation requirements and many of the western walls are cracked. To prevent heat and cracks in the floor of the roof, the roof is usually structured as follows: a 200 mm thick reinforced concrete layer; a 150 mm thick insulating mortars layer, creating drainage ditches and clay bricks. However, as a result, the surface of the tile remains damaged (Figure 2).

![Figure 2](image2.png)

**Figure 2.** Tiles in the roof floor cracked due to thermal expansion non-corresponding to concrete (a)Floor roof tiles for high-rise building, (b)150 mm thick insulating mortars layer, (c)Damaged tiles surface
In fact, the red baked clay bricks layer is still fractured (Figure 2) due to not having the same elasticity with the underlying concrete layer. Based on an overview of scientific research, Project RD44-19 choice of lightweight concrete decorated on porous glass aggregates can meet the requirements of insulation and decoration for cladding panels, exterior walls and floor tiles.

2. Materials and test methods

Insulating cladding panels for exterior walls for civil constructions are made from a mixture of insulated decorative concrete using lightweight glass beads (GEDGA). The mixture includes:

2.1. Cement

White or gray Portland cement (PCB 40 or PCW40), Metakaolin, white sand (yellow sand), pigments, additives and water, light concrete decorated on light glass aggregates (GEGA). With a volume of 800-1100kg/m³, panel size, paving 300x200 mm, minimum thickness of 15mm. The project usage of PCW40 Thai Binh white cement meets the requirements of Vietnamese standards 5691: 2000. The main properties of white Thai Binh cement and chemical composition of clinker Thai Binh white cement are shown in table 1 and 2.

| Test                                      | Indicator | Unit | Result | Test method                                      |
|-------------------------------------------|-----------|------|--------|-------------------------------------------------|
| Whiteness (compared to BaSO4)             | %         |      | 80     | Vietnamese standards 5691: 2000                  |
| Standard wate                             | %         |      | 31     | Vietnamese standards                            |
| Setting time                              |           |      |        |                                                 |
| Begin                                      | min       |      | 195    | Vietnamese standards 6017: 2014                  |
| End                                        | min       |      | 325    |                                                 |
| Residue sieve No 009                      | %         |      | 1,10   | Vietnamese standards 4030: 2003                  |
| Specific weight                           | g/cm³     |      | 3,10   | Vietnamese standards 4030: 2003                  |
| Intensity curling 1day                    | MPa       |      | 1,31   | Vietnamese standards 6016: 2011                  |
| 7days                                     |           |      | 3,05   |                                                 |
| 28days                                    |           |      | 5,29   |                                                 |
| Compressive strength                      | MPa       |      |        |                                                 |
| 1day                                      |           |      | 10,92  | Vietnamese standards 6016: 2011                  |
| 7days                                     |           |      | 25,31  |                                                 |
| 28days                                    |           |      | 45,00  |                                                 |

| Chemical composition (%)                 | Mineral content calculated |
|------------------------------------------|----------------------------|
| Al₂O₃                                     | C₃S | C₂S | C₃A |
| CaO                                      | 6,42|     |     |
| MgO                                      | 64,1|     |     |
| K₂O                                      | 1,31|     |     |
| Na₂O                                     | 2,5 |     |     |
| SO₃                                      | 1,56|     |     |
| LOI                                      | 1,02|     |     |
| 1,39                                     |     | 59,02| 25,00|
| 12,17                                    |     |     |     |

2.2. Active mineral additives

The activated mineral additives selected for use must achieve the goal of being light-colored and being able to bind well with Ca(OH)₂ formed when hydrating cement. Among the three highly active mineral additives, SF, RHA and MK, MK has the brightest color [7]. MK is also a popular mineral additive in Vietnam due to its proactive and low-cost raw materials, production technology. When white cement stone
has a content of up to 20% Metakaolin (MK), the corresponding amount of lime decreases gradually, partly due to dilution (which reduces the amount of white cement) and partly due to the reaction of MK with lime generated during the hydration of cement according to the following reaction:

\[ \text{Ca(OH)}_2 + 3\text{AS}_2 + \text{H}_2\text{O} \rightarrow \text{C}_2\text{ASH}_8 + \text{C-S-H} \]

Therefore, the research project uses MK as an activated mineral additive for decorative lightweight concrete (LWC). The composition and properties of MK in table 3.4 [6].

| SiO₂  | Fe₂O₃ | Al₂O₃ | CaO | MgO | SO₃ | K₂O | Na₂O | TiO₂ | LOI | Total |
|-------|-------|-------|-----|-----|-----|-----|------|------|-----|-------|
| 55,10 | 1,09  | 40,46 | 0,53| 0,56| 0,00| 0,54| 0,10 | 0,13 | 0,82| 99,33 |

**Table 4. Properties of MK Lam Dong**

| Test | Indicator | Unit Result | Test method |
|------|-----------|-------------|-------------|
| Smoothness | % | 95,46 | Vietnamese standards 4030 : 2003 |
| + Surface area rate | cm²/g | 4500 | |
| Amount of water required (compared to the control sample) | % | 102,5 | Vietnamese standards 8827: 2011 |
| Active strength: with PC cement | % | 101 | Vietnamese standards 8827: 2011 |
| + 7days | % | 103 | |
| Active strength of Pozzolanic: With lime – 7 days | MPa | 8,2 | Vietnamese standards 3735: 2011 |

**Figure 3.** Particle distribution diagram of mineral admixture MK Lam Dong

**Figure 4.** The influence of MK content on Ca(OH)₂ (%) content of colored cement stone.

### 2.3. Aggregate

The requirement of small aggregates has met Vietnam Standards 7572: 2006. Through surveys and researches, the project has selected yellow sand in Lo River - Phu Tho with the given physical properties in Table 5.

| Test | Indicator | Unit Result | Test method |
|------|-----------|-------------|-------------|
| Density of sand | gram/cm³ | 2,63 | Vietnamese standards 7572 - 4: 2006 |
| Density of porous mass of sand | kg/m³ | 1500 | Vietnamese standards 7572 - 6: 2006 |
| Magnitude module of sand | - | 2,00 | Vietnamese standards 7572 - 2: 2006 |
2.4. Aggregate lightweight glass beads

Lightweight spherical glass aggregate (Figure 5 is a form of foam glass (FG), or also known as Cellular Glass or Foam Glass), is a material with a honeycomb structure in which there are many small pores, in which CO, CO₂, SO₂ are stored... Spherical granules are obtained by processing pellets and air bubbles. Light glass bead is an insulating, soundproof material which is ideal for small volume, has low thermal conductivity, has especially low water absorption rate, relatively high mechanical strength [2,8,9,12], and it is a 6-inorganic chemical composition which is fire resistant, alkali resistant, durable with chemical agents and eliminates the growth of mold and microorganisms, particles with small, tight pore structure should reduce water absorption and water vapor permeability.

![Figure 5. Slightly spherical glass beads](image)

Due to its structure, spherical light glass (light glass beads) has properties such as being light aggregate, so it is used to produce heat insulating, soundproofing and decorative composite materials. Light glass as well as light glass beads had been studied and applied in the world as heat insulating, soundproofing materials, as air conductor wrapped materials in industrial manufacturing plants, ... [10,11,13]. The glass used in the project is a waste glass product of Eurowindow glass factory [5].

### Table 6. Chemical composition of glass waste

| SiO₂ | Al₂O₃ | Fe₂O₃ | CaO | MgO | Na₂O | K₂O | SO₂ |
|------|-------|-------|-----|-----|------|-----|-----|
| 72,8 | 1,10  | 8,47  | 3,13| 0,1 | 13,58| 0,3 | 0,5 |

![Figure 6. Thermal processing curve](image)

Materials for manufacturing light glass in spherical shape in the University of Architecture project are waste of construction glass (tempered glass, box glass) and gas, light powder additives. Glass waste in Vietnam can reach hundreds of thousands of tons annually. The production technology and heat-processing curve are described in Figure 6.7.

![Figure 7. Description of light spherical glass fabrication technology](image)

Light spherical glass products (Figure 5) are tested for mechanical properties and the results are shown below, Figure 8,9 and table 7,8:
Table 7. Experiment results on some light glass beads properties by percentage of foaming agent (% compared with aggregate powder)

| The content of hollow-creating additives, % | 0,5 | 0,75 | 1,0 | 1,25 | 1,5 | 1,75 | 2,0 | 2,25 | 2,5 |
|------------------------------------------|-----|------|-----|------|-----|------|-----|------|-----|
| Particle mass by particle volume, kg/m³  | 370 | 350  | 320 | 300  | 285 | 270  | 250 | 220  | 170 |
| Porosity, %                              | 85.2| 86   | 87.2| 88   | 88.6| 89.2 | 90  | 91.2 | 93.2|
| Thermal conductivity, W/m.°C             | 0.097| 0.088| 0.076| 0.067| 0.063| 0.057| 0.050| 0.040| 0.024|

Figure 8. Glass beads product after calcination and microsphere (Russian Federation)

Table 8. Volumetric weight of light glass beads spherical

| Property                  | Particle size, mm |
|---------------------------|-------------------|
|                           | <0.14  | 0.14-0.315 | 0.315-0.63 | 0.63-1.25 | 1.25-2.5 | 2.5-5.0 | 5.0-10.0 | >10 |
| Porous mass, kg/m³        | 450    | 430       | 400       | 350       | 320       | 270      | 230      | 200 |

2.5. Additives. Super flexible additives
Using the dark brown Polycarboxylate-based Glenium ACE 388 superplasticizer made by BASF; density: 1.019 (gram/cm³); pH: 6.6; 30% reduction in water; The content uses 1% binder. Additive stabilizer: To improve the structural stability of an insulated decorative concrete mixture based on lightweight glass aggregate (LWGA), the project uses HPMC cellulosic additives which have the following properties:
Table 9. Specification of HPMC viscosity-changing additive

| Chemical property | Hydroxyl propyl methyl cellulose (HPMC) |
|-------------------|----------------------------------------|
| Formula           | C₆H₇O₂(OH)₂OCHCOONa                     |
| Form              | White fine powder                      |
| Humidity          | Not greater than 8%                    |
| Viscosity         | 35000-47000 mPas                       |
| Maximum particle size | 0,125mm with content <10%              |

2.6. Color powder.
Two colored pigments, chromium oxide Cr₂O₃, which is green in color, specific weight 5.2 (g/cm³) and iron oxide Fe₂O₃ in red, specific weight 5.3 (g/cm³) and conform to US standards ASTM C979-10 are used. The chemical composition of pigments is given in Table 10,11.

Table 10. Chemical composition of iron oxide Fe₂O₃ (%)

| SiO₂  | Fe₂O₃ | Al₂O₃ | MnO | MgO | SO₃ | K₂O | Na₂O | TiO₂ | LOI | Total |
|-------|-------|-------|-----|-----|-----|-----|-----|-----|-----|-------|
| 0,1   | 98,81 | 0,16  | 0,2 | 0,0 | 0,0 | 0,0 | 0,0  | 0,93 | 100,20 |

Table 11. Chemical composition of chromium oxide Cr₂O₃ (%)

| SiO₂  | Cr₂O₃ | Al₂O₃ | CaO | MgO | SO₃ | K₂O | Na₂O | TiO₂ | LOI | Total |
|-------|-------|-------|-----|-----|-----|-----|-----|-----|-----|-------|
| 0,46  | 92,89 | 0,28  | 0,21| 0,3 | 0,0 | 0,25| 0,2  | 0,15 | 5,26 | 100,00 |

3. Research method
Using theoretical research methods to calculate and mix heat-insulating decorative cladding tiles and combining with standard testing methods to determine the mechanical and physical properties of manufacturing materials; Vietnam standard 6220-1997 requires light aggregate technique for concrete and mortar; Vietnam standard 6221-1997 Test method, light aggregate for concrete; Vietnam standard 7572-2006 Test method for determining grain composition; ГОСТ 32496-2013 Hollow aggregate for lightweight concrete; EN13055-1: 2004, NEQ and EN206-1: 2000, NEQ. Light weight ASTM C330. Design process of mixing lightweight glass concrete is based on light glass aggregates according to ACI211.2-98. The coefficient of thermal conductivity is determined by HFM 300 devices (Institute of Building Materials).

Figure 10. HFM 300 device and chart for determining insulation coefficient

4. Experimental results
Mixing process: Mix dry cement, meta-cement, yellow sand powder and HPMC additives according to the above ratio. Mix 1% of Sikament NN additive into water then mix with the dry mixture above until it
becomes flexible paste. Then pour the light glass aggregate granules into the paste tank and continue to mix (do not mix too long to avoid concrete being separated from the light glass beads). Pour slowly the mixture into the mold jab with iron rods or light vibrator similarly to polystyrol concrete or keramzite concrete. Remove the mold and maintain the moisture.

Research results on gradation and mechanical properties of decorative lightweight concrete as well as cladding products are shown in Table 12, 13 and Figure 7, 9.

**Table 12.** Material composition distribution for lightweight concrete decorated on porous glass aggregates

| Grade notation | Cement (kg) | Metakaolin (MK), kg | Sand, kg | Light beads, kg | Color powder, kg | Super flexible additives, kg | HPMC (gram) | Water, kg |
|----------------|-------------|---------------------|---------|----------------|----------------|----------------------------|-------------|-----------|
| G1             | 335,8       | 59,3                | 908,2   | 91             | 18,8           | 3,75                       | 5,63        | 158       |
| G2             | 335,8       | 59,3                | 777,2   | 104            | 18,8           | 3,75                       | 5,63        | 158       |
| G3             | 335,8       | 59,3                | 646,2   | 117            | 18,8           | 3,75                       | 5,63        | 158       |
| G4             | 335,8       | 59,3                | 515,2   | 130            | 18,8           | 3,75                       | 5,63        | 158       |
| G5             | 335,8       | 59,3                | 384,2   | 143            | 18,8           | 3,75                       | 5,63        | 158       |

**Table 13.** Experimental results

| Grade notation | Flow rate, mm | Bulk volume of concrete mixture, kg/m³ | Dried concrete sample mass, kg/m³ | Compressed Mortar Sample Strength (N/mm²) | Bended mortar sample strength (N/mm²) | Bended cladding tiles sample strength (N/mm²) | Insulation coefficient R, m².K/W |
|----------------|---------------|----------------------------------------|----------------------------------|------------------------------------------|----------------------------------------|-------------------------------------------|-------------------------------|
| G1             | 263           | 1585                                   | 1480                             | 27,5                                     | 4,2                                    | 3,1                                       | 1,76                          |
| G2             | 254           | 1466                                   | 1362                             | 25,8                                     | 3,5                                    | 3,3                                       | 2,8                           |
| G3             | 210           | 1357                                   | 1244                             | 22                                       | 3,3                                    | 3,2                                       | 2,6                           |
| G4             | 195           | 1224                                   | 1126                             | 21                                       | 2,9                                    | 2,2                                       | 2,2                           |
| G5             | 180           | 1130                                   | 1008                             | 20                                       | 2,7                                    | 1,9                                       | 2,8                           |

5. Application of spherical light glass in making thermal insulating and decorative cladding

From the results of the study of spherical light glass, the authors used light glass as aggregates for manufacturing lightweight concrete (15 - 50 mm in thickness) insulating - decorative cladding panels, Figure 11.

**Figure 11.** Porous glass beads and cladding tiles as products of the project RD44-19.
Table 14. Comparison of decorative insulating cladding panels and baked clay cladding

| Product type                  | Specific  | Size DxRxH, mm | 1 tablet mass, kg/tablet | Flexural strength, MPa | Insulation coefficient λ, W/m².K | water absorption, % |
|-------------------------------|-----------|----------------|-------------------------|------------------------|----------------------------------|---------------------|
| Insulation panels, tiles      |           | 250x250x15     | 1.0                     | 1.9                    | 0.204                            | 7.8                 |
| - decorative                  |           |                |                         |                        |                                  |                     |
| Terracotta cladding panels    |           | 250x250x15     | 1.5                     | 1.9                    | 0.658                            | 6.5                 |

6. Conclusion

The study showed that the manufacture of heat-insulating panels and tiles with a volume of 1000-1200 kg/m³ using white cement, grinded sand, additives and light weight glass beads with a mass concentration of 200-250kg/m³ has brought high effectiveness in the matter of buildings insulating and decorating.

Research results showed the influence of properties and materials composition on some cladding and insulating panels properties- such as flexural strength, thermal conductivity, water absorption, etc. When the light glass particle size reduces, the density of the sheet and the bending strength are reduced, thus, the heat insulating capability increases about 3-5 times in comparison to traditional panels and tiles.

References

[1] Engineer. Nguyen Van Loi, Assoc. Dr. Nguyen Van Tu; Scientific research report summarizing the research topic of foam glass production technology. No. 01C-03- 2010-2, 2011;
[2] Nghiem Thi Thu Thao. Calculation of granulated composite panels taking into account heat transfer. Hanoi University of Science-Vietnam National University Master's thesis, 2011;
[3] Mater Phan The Vinh, MSc. Tran Huu Bang. Textbook of Building Materials. Construction Publishing House, 2009;
[4] Tutor. Doctor of Science. IU. M. Bazhenov, Assoc.Prof. Dr. Bach Dinh Thien, PhD. Tran Ngoc Tinh. Concrete technology Construction Publishing House. Hanoi, 2004;
[5] PhD. Nguyen Minh Ngoc, PhD. Nguyễn Duy Hiệu, Engineer. Nguyen Huu Nhan, Architect. Ngo Minh Thinh, Engineer. Dinh Ba Lo, Master. Architect. Nguyễn Tuấn Hải. Construction materials and architectural decoration materials. Construction Publishing House, Hanoi 2012;
[6] PhD. Nguyen Gia Ngoc. Research using Vietnam Metakaolin to make decorative concrete. Doctoral thesis in 2018;
[7] Le Trung Thanh, Nguyen Van Tuan, Le Viet Hung and Nguyen Cong Thang. Mineral additives for cement and concrete. Construction Publishing House 2019.
[8] Assoc.Prof. Dr. Bach Dinh Thien. Construction glass technology. Construction Publishing House 2004.
[9] Hussein abdel Fattah Mohamed Ramadan elkersh, Innovative cleaner production technique: Foam glass production from lead crystal glass Sludge, B.Sc. Mechanical Power Engineering, The American university in Cairo, 2014
[10] N. STITI, A. AYADI, Y. LERABI, F. BENHAOUA, R. BENZERGA và L. LEGENDRE, Preparation and Characterization of Foam Glass Based Waste, Asian Journal of Chemistry; Vol. 23, No. 8 (2011), 3384-3386.
[11] Yigit Attila, Mustafa Guden, Alper Tasdemirci, Foam glass processing using a polishing glass powder residue, Ceramics International 39 (2013) 5869–5877
[12] N. M. Bobkova, S. E. Barantseva, and E. E. Trusova, *Production of foam glass with granite siftings from the mikhashevichi deposit*, Glass and Ceramics Vol. 64, Nos. 1 – 2, 2007.

[13] Petersen, Rasmus Rosenlund; König, Jakob; Smedskjær, Morten Mattrup; Yue, Yuanzheng, *Viscous Control of the Foam Glass Process*, Aalborg Universitet, 2014.

[14] V.A. Pixkarev. Dekerativno – otdelchnûe xtoitelную materialy.NXB Vuxsaia skola. Maxcova, 1977.

[15] M Popov, L Zakrevskaya, V Vaganov, S Hempel and V Mechtcherine. Performance of Lightweight Concrete based on Granulated Foamglass. Vladimir State University, 2019.