RESEARCH ON THE USE OF RICE HUSK ASH IN FABRICATION OF INSULATING REFRACTORY CONCRETE

Nguyen Van Dung[1]*, Hoang Thi Lieu[2], Nguyen Dinh The[1], Tran Van Dat[1], Trinh Ngoc Dat[3]

[1]*The University of Danang - University of Science and Technology, Vietnam*
[2]*Novaref Refractory Development Joint Stock Company, Vietnam*
[3]*The University of Danang - University of Science and Education, Vietnam*

*Corresponding author: nvdung@dut.udn.vn

(Received: May 01, 2025; Revised: June 04, 2025; Accepted: June 15, 2025)

DOI: 10.31130/ud-jst.2025.23(10B).646E

Abstract - This study focuses on manufacturing insulating refractory concrete using alumina cement with various lightweight aggregates such as perlite and vermiculite. We used rice husk ash to partially replace imported vermiculite in the mix proportions. Experiments were conducted to determine chemical composition, particle size of raw materials, and bulk density, thermal conductivity, mineral composition of insulating concrete. The optimal mixes, M9 and M10 (containing 10% and 15% rice husk ash, respectively) met the requirements for bulk density (from 0.760 to 0.813 g/cm^3), thermal conductivity (from 0.106 to 0.116 W/m.K), as well as compressive strength of samples fired at 800°C and 1000°C. The replacement of 10-15% vermiculite with rice husk ash contributes to reduce production costs, utilize the rice husk ash resource, and foster circular economic development in Vietnam.

Key words - Insulating refractory concrete; alumina cement; perlite; vermiculite; rice husk ash

1. Introduction

Insulating refractory concrete is used as a high-temperature insulation material which reduces heat loss to the external environment and lowers the surface temperature of furnace walls and arches. Insulating concrete has a low bulk density, high porosity and a wide range of used temperatures. Its mix proportions include refractory cement with lightweight aggregates. Globally, insulating refractory concrete has been extensively researched and developed focusing on improving its refractory temperature, insulation capacity, and mechanical strength for better application in high-temperature furnaces.

Many studies have focused on the use of different lightweight aggregates such as perlite and vermiculite. These aggregates help reduce the bulk density of the concrete, improve its insulation properties, and decrease the construction weight [1, 2, 3].

In Vietnam, the research and application of insulating refractory concrete has been receiving increasing attention from scientists and refractory material manufacturers. Domestic research focuses on utilizing locally available raw materials, improving production technology, and enhancing the efficiency of this type of material. For example, studies have been conducted on the development of heat-resistant concrete for construction operating at temperatures between 500-1000°C, on using blended Portland cement (PCB) and industrial waste as finely ground mineral admixtures [4].

Several domestically produced products, such as Cemgun 250 insulating mortar and Vermiculite/Perlite 750, have been developed for industrial constructions, which demonstrate quality comparable to imported products.

Alumina cement is commonly used as a refractory cement. Its main components are Al_2O_3 and CaO, along with small amounts of oxides such as Fe_2O_3, SiO_2, MgO, TiO_2, Na_2O, K_2O, Cr_2O_3 and P_2O_5 [5]. Alumina cement is generally divided into two main types based on the Al_2O_3 content:

- First type: contains > 68% Al_2O_3, with low levels of impurities such as SiO_2 and Fe_2O_3. It commonly used for refractory concrete intended for high temperatures.

- Second type: contains 36-58% Al_2O_3, with higher levels of impurities such as SiO_2 and Fe_2O_3. It commonly used for refractory concrete intended for medium temperatures.

Regarding the mineral composition, alumina cement mainly contains the minerals CA and CA_2, along with a small amount of $C_{12}A_7$ (mayenite). Additionally, it may also contain α-Al_2O_3 (corundum), C_4AF (aluminoferite), C_2AS (gehlenite), β-C_2S (belite), C_6FA_4S (pleochnite) [6, 7].

According to the technical specifications of TCVN 7569:2022, the quality of alumina cement is classified into different levels: ordinary alumina cement (CA40, Al_2O_3 content from 30 to below 46%), high alumina cement (CA50, Al_2O_3 content from 46 to below 60%; CA60, Al_2O_3 content from 60 to below 70%), and special alumina cement (CA70, Al_2O_3 content from 70 to below 77%; CA80, Al_2O_3 content equal to or greater than 77%). In our research, we use high alumina cement CA50 for medium heat-resistant concrete [8, 9].

A characteristic of alumina cement is its high grade and high heat resistance, but it sets quickly, with the majority of the hydration process occurring within 24 hours. This results in a dense and very hard cement structure. However, over the long term, the calcium aluminate hydrate minerals like CAH_{10} and C_2AH_8 are unstable and transform into the thermodynamically stable phases C_3AH_6 and AH_3, which have a cubic crystal lattice. The reaction process is as follows:

$$3CAH_{10} \rightarrow C_3AH_6 + 2AH_3 + 18H$$

$$3C_2AH_8 \rightarrow 2C_3AH_6 + AH_3 + 9H$$

This process reduces the molar volume, increases porosity and water permeability, consequently decreasing the strength of the material [6].

Rice husk ash contains a very high content of SiO_2 (90-98%), has high reactivity and low bulk density [10]. Therefore, using rice husk ash to partially replace the lightweight aggregate vermiculite in the fabrication of insulating refractory concrete is very promising [11]. The utilization of rice husk ash in the fabrication of insulating refractory concrete contributes to the treatment of a large-volume by-product from agricultural production in Vietnam.

2. Experiments

2.1. Raw materials

2.1.1. Alumina cement

In this study, we used CA50-A900 alumina cement from China, which is a type of high alumina cement suitable for medium heat-resistant insulating refractory concrete. The chemical composition of alumina cement is shown in Table 1 and its image is shown in Figure 1.

Table 1. *Chemical composition of alumina cement CA50-A900 (wt %)*

Al_2O_3	CaO	SiO_2	MgO	Fe_2O_3	Na_2O
53.5	39.5	6.0	0.5	1.2	0.5

Figure 1. *Alumina cement CA50-A900*

2.1.2. Perlite

Perlite from Yongqing Beifang Company (China) was used. Perlite has a low bulk density of 0.09 g/cm^3, making it suitable for use as an aggregate to reduce the bulk density and increase the porosity of insulating refractory concrete. However, perlite has a low melting point, so it is necessary to limit the amount used in the mix design.

The thermal conductivity of perlite is 0.146 W/m.K.

The chemical composition of perlite is shown in Table 2 and its image is shown in Figure 2.

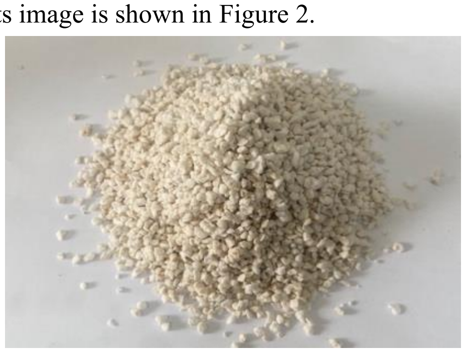

Figure 2. *Perlite*

Table 2. *Chemical composition of perlite (wt %)*

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O
68-74.5	11-15	0.15-1.5	0.15-0.5	0.1-2.0	2.5-5.0	3.0-6.0

The particle size distribution of perlite is shown in the graph in Figure 6.

2.1.3. Vermiculite

Vermiculite from Yongqing Beifang Company (China) was used. Vermiculite is a mica-like mineral with a layered structure, exhibiting low thermal conductivity and high porosity [2], making it also an essential material in lightweight insulating refractory concrete. The bulk density of vermiculite is 0.12 g/cm^3. Its thermal conductivity is 0.080 W/m.K. The chemical composition of vermiculite is shown in Table 3 and its image is shown in Figure 3.

Table 3. *Chemical composition of vermiculite (wt %)*

SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	Ti_2O
44.89	14.59	16.36	8.14	2.01	1.12	4.75	1.37

Figure 3. *Vermiculite*

The particle size distribution of vermiculite is shown in the graph in Figure 6.

2.1.4. Rice husk ash

We used rice husk ash from Thai Binh Rice Husk Charcoal Company (Vietnam) for this research. The rice husk ash has a bulk density of 0.15 g/cm^3. Its thermal conductivity is 0.145 W/m.K. The chemical composition of rice husk ash is shown in Table 4 and its image is shown in Figure 4.

Table 4. *Chemical composition of rice husk ash (wt %)*

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	MKN
87.56	1.61	0.7	1.7	1.6	0.58	0.01	2.18	2.86

Figure 4. *Rice husk ash*

The analysis results show that SiO_2 is the main component of the rice husk ash, accounting for 87.56%.

The XRD analysis results (Figure 5) indicate that the studied rice husk ash sample mainly exists in the crystalline phase of SiO_2 (cristobalite). This result is entirely consistent with the chemical composition presented in Table 4.

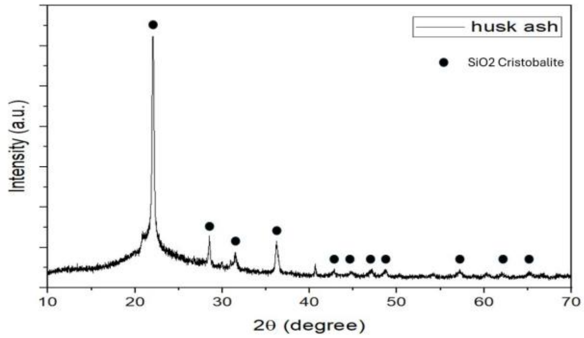

***Figure 5.** XRD patterns of rice husk ash*

The particle size distribution of rice husk ash is shown in the graph in Figure 6.

The particle size analysis results in Figure 6 show that perlite has a particle size ranging from 2 to 4 mm, vermiculite has a particle size ranging from 1 to 3 mm, and rice husk ash has a particle size smaller than 0.2 mm.

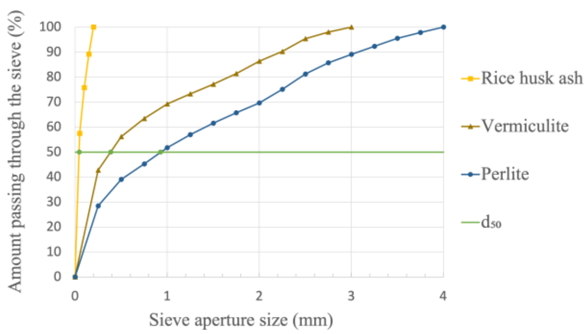

***Figure 6.** Particle size distribution curve of perlite, vermiculite and rice husk ash*

Thus, we observe that perlite has a relatively large particle size (the largest particles have d = 4 mm, average particle diameter d_{50} = 0.93 mm).

Comparing vermiculite and rice husk ash, we see that:

Vermiculite has a larger particle size than rice husk ash (the largest particles have d = 3 mm, average particle diameter d_{50} = 0.39 mm). Vermiculite has a bulk density of 0.12 g/cm^3 and a thermal conductivity of 0.080 W/m.k.

Rice husk ash has a smaller particle size (the largest particles have d = 0.2 mm, average particle diameter d_{50} = 0.048 mm). Rice husk ash has a bulk density of 0.15 g/cm^3 and a thermal conductivity of 0.145 W/m.K.

Although rice husk ash has a higher thermal conductivity than vermiculite, it is still considered to have low thermal conductivity, and the difference in bulk density between rice husk ash and vermiculite is not significant, suggesting that rice husk ash can be used to partially replace vermiculite in the mix design.

2.1.5. Water

In this research project, the water used is tap water from the Hoa Mac Industrial Park, Duy Tien town, Ha Nam province.

2.2. Experimental procedure

We chose to fabricate Class N insulating refractory concrete with a refractory temperature of 925°C and a bulk density of less than 0.88 g/cm^3. The manufacturing process is described in Figure 7.

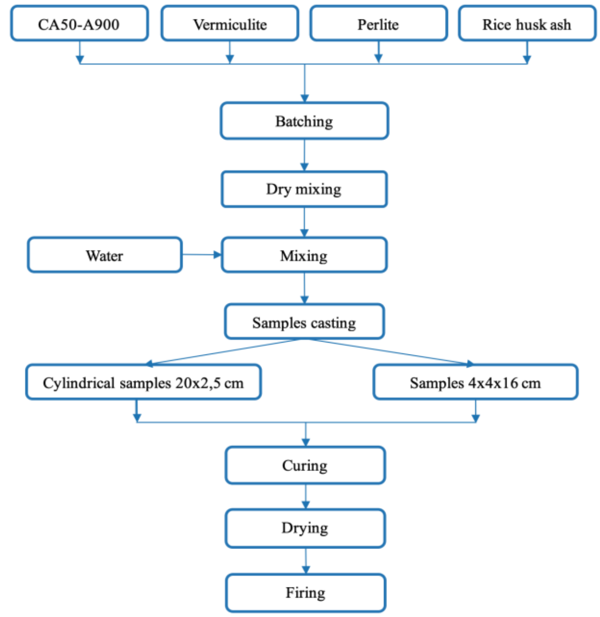

***Figure 7.** Manufacturing process of insulating refractory concrete*

The CA50-A900 refractory cement with lightweight aggregates (perlite, vermiculite and rice husk ash) were weighed according to the proportions in the mix design tables. They were then dry-mixed twice for 3 minutes each time using a planetary mixer until the mixture was homogeneous.

The dry-mixed material was transferred to a small planetary mixer along with water for 3 minutes. After mixing, the concrete was poured into molds and vibrated for 15 seconds.

Samples were cast in 4x4x16 cm molds to measure parameters such as bulk density, compressive strength of dried samples, samples fired at 800°C and at 1000°C. Cylindrical samples of 20x2.5 cm were cast to measure thermal conductivity.

After casting, the samples were cured by covering their surface with a damp cloth for 1 day, then demolded and dried at 110°C for 24 hours, followed by firing at 800°C or 1000°C.

The firing curves at 800°C and 1000°C are shown in Figure 8 and Figure 9.

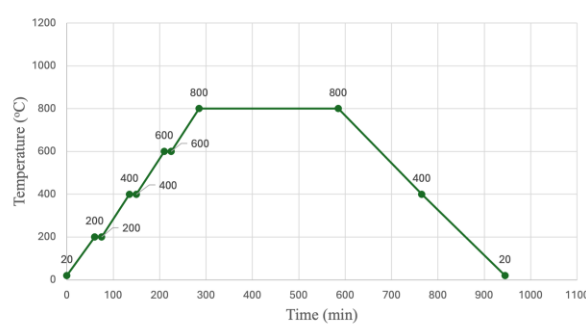

***Figure 8.** Firing curve of the samples at 800°C*

For firing the samples at 800ºC, the heating time from 20-800ºC was 285 minutes, the holding time was 300 minutes, and the cooling time from 800-20ºC was 360 minutes.

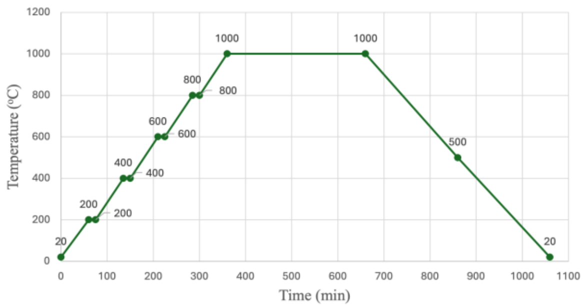

Figure 9. *Firing curve of the samples at 1000ºC*

For firing the samples at 1000ºC, the heating time from 20-1000ºC was 360 minutes, the holding time was 300 minutes, and the cooling time from 1000-20ºC was 400 minutes.

The technical properties and characteristics of some raw materials, dried and fired samples were determined, such as:

- Bulk density (ρ_v, g/cm^3), measured using the XQK – 04 apparent porosity and bulk density meter at the Quality Control Department of Novaref Refractory Development Joint Stock Company.

- Compressive strength of dried samples (σ_{ns}, MPa), compressive strength of samples fired at 800ºC (σ_{n800}, MPa), and compressive strength of samples fired at 1000ºC (σ_{n1000}, MPa) according to TCVN 10685-6:2018.

- Thermal conductivity (λ, W/m.K) using the Guarded-Hot-Plate Apparatus according to ASTM C177:2019.

- Chemical composition according to TCVN 6533:2016.

- Mineral phase identification using X-ray Diffraction (XRD) on D8 Advance Eco (Bruker-Germany).

- Surface morphology determination using Scanning Electron Microscope (SEM) Jeol JSM-IT200 (Jeol-Japan).

3. Results and discussions

3.1. Mixes d esign and technical properties

First, we designed mix proportions including alumina cement with one type of lightweight aggregate: mixes M1 and M2 comprised alumina cement with perlite; mixes M3 and M4 comprised alumina cement with vermiculite; and mixes M5 and M6 comprised alumina cement with rice husk ash. The alumina cement content in the mixes was 50% and 55%. The mix proportions for the samples are shown in Table 5.

Table 5. *Concrete mix designs using one type of lightweight aggregate (wt %)*

Raw materials	M1	M2	M3	M4	M5	M6
CA50-A900	50	55	50	55	50	55
Perlite	50	45	0	0	0	0
Vermiculite	0	0	50	45	0	0
Rice husk ash	0	0	0	0	50	45

The technical properties of samples M1 - M6 are summarized in Table 6.

Table 6. *Concrete properties using one type of lightweight aggregate*

Properties	M1	M2	M3	M4	M5	M6
ρ_v (g/cm^3)	1.065	0.938	0.456	0.525	0.978	1.019
σ_{ns} (MPa)	4.90	4.97	-	-	4.05	4.30
σ_{n800} (MPa)	2.98	3.40	-	-	1.69	1.40
σ_{n1000} (MPa)	2.69	2.79	-	-	1.76	1.31

Thus, we observe that samples M1, M2, M5 and M6 do not meet the requirements for Class N insulating refractory concrete according to ASTM C401-91 (because their bulk densities are not less than 0.88 g/cm^3). The two samples M3 and M4 have a bulk density less than 0.88 g/cm^3 but their strength are too low, so they also do not meet the requirements.

We then designed mixes M7, M8, M9, M10, and M11 using a combination of different lightweight aggregates (see Table 7). The initial basic mix was M7, which did not use rice husk ash. From mix M7 to M11, the rice husk ash content increased from 0 to 20%, while the vermiculite content decreased from 20 to 0%. The alumina cement content was 55%, and the perlite content was 25%.

Table 7. *Concrete mix designs using three type of lightweight aggregate (wt %)*

Raw materials	M7	M8	M9	M10	M11
CA50-A900	55	55	55	55	55
Perlite	25	25	25	25	25
Vermiculite	20	15	10	5	0
Rice husk ash	0	5	10	15	20

The technical properties of samples M7 – M11 are presented in Table 8.

Table 8. *Concrete properties using three types of lightweight aggregate*

Properties	M7	M8	M9	M10	M11
ρ_v (g/cm^3)	0.590	0.725	0.760	0.813	0.937
σ_{ns} (MPa)	0.19	1.70	2.02	3.07	3.24
σ_{n800} (MPa)	0.13	1.01	1.27	1.66	1.93
σ_{n1000} (MPa)	0.07	0.93	1.05	1.54	1.72

Sample M7 did not meet the requirements due to its very low strength (0.07 MPa). Sample M11 did not meet the requirements because its bulk density was greater than 0.88 g/cm^3. Samples M8, M9, and M10, with rice husk ash contents of 5%, 10%, and 15% respectively, met the requirements for Class N insulating refractory concrete. We selected two optimal mixes, M9 and M10, because they utilized a significant amount of rice husk ash in their composition (10% and 15%).

The influence of rice husk ash content on the quality of insulating refractory concrete can be clearly seen in Figure 10.

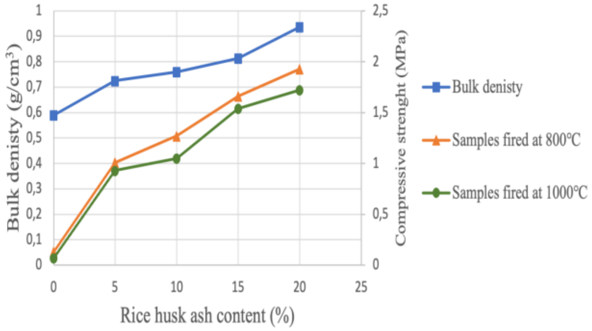

Figure 10. *The effect of rice husk ash content on the properties of insulating refractory concrete*

As the rice husk ash content increases, the bulk density, compressive strength of samples fired at 800°C and 1000°C also increases. However, the compressive strength of samples fired at 1000°C is lower than fired at 800°C. This is consistent with Class N insulating refractory concrete (used temperature should not exceed 925°C).

Images of samples M9 and M10 after drying, fired at 800°C, and fired at 1000°C are shown in Fig 11.

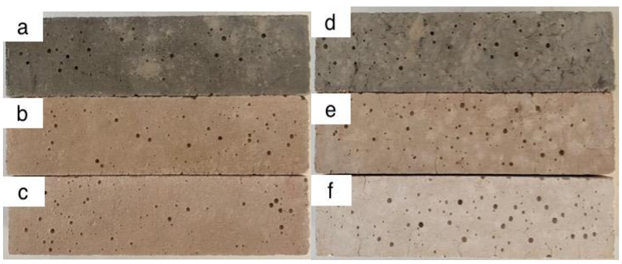

Figure 11. *Images of samples M9 and M10. a) Sample M9 after drying, b) Sample M9 after firing at 800°C, c) Sample M9 after firing at 1000°C, d) Sample M10 after drying, e) Sample M10 after firing at 800°C, f) Sample M10 after firing at 1000°C*

The thermal conductivity of samples M9 and M10 was determined according to ASTM C177:2019. The test results and images of the samples prepared for thermal conductivity testing are shown in Table 12 and Figure 12.

Table 12. *Thermal conductivity of M9 and M10 samples (W/m.K)*

M9	M10
0.106	0.116

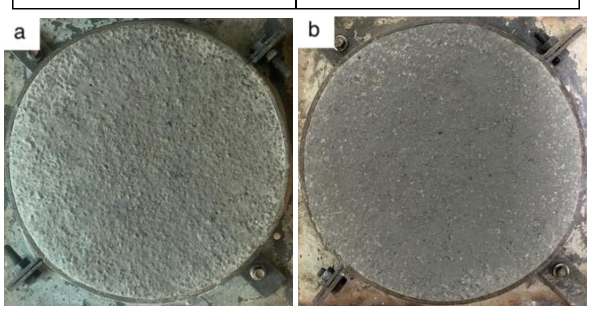

Figure 12. *Images of the samples for thermal conductivity experiment. a) M9 sample, b) M10 sample*

Thus, the thermal conductivity of samples M9 and M10 meets the thermal conductivity requirements for insulating refractory materials (0.11 – 0.18 W/m.K) [1].

To save on alumina cement, which is the most expensive raw material, we also designed mixes M12 and M13 with a lower alumina cement content (50%), a higher perlite content (30%), and the same rice husk ash and vermiculite content as in mixes M9 and M10. The technical properties of samples M12 and M13 also meet the requirements for Class N insulating refractory concrete, although their strength is lower.

3.2. Determination of mineral composition by XRD analysis

The mineral composition of sample M10 fired at 1000°C was determined by X-ray diffraction (XRD) analysis on D8 Advance Eco (Bruker-Germany) with Cu-Kα radiation, scanning angle 2θ=10-80°. The XRD pattern is shown in Figure 13.

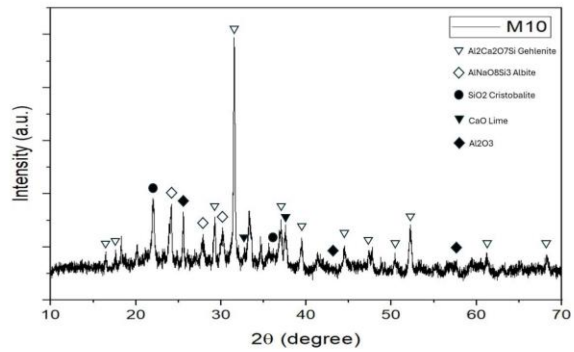

Figure 13. *XRD patterns of the M10 sample*

The XRD patterns show the presence of CaO, Al_2O_3, gehlenite, albite and cristobalite minerals. For products made with raw materials such as alumina cement, perlite, vermiculite and rice husk ash, these are the minerals typically found after firing at 1000°C [2, 7, 11].

3.3. Surface morphology characteristics determination

The surface morphology characteristics of sample M10 were determined using Scanning Electron Microscopy (SEM). The images are shown in Figure 14.

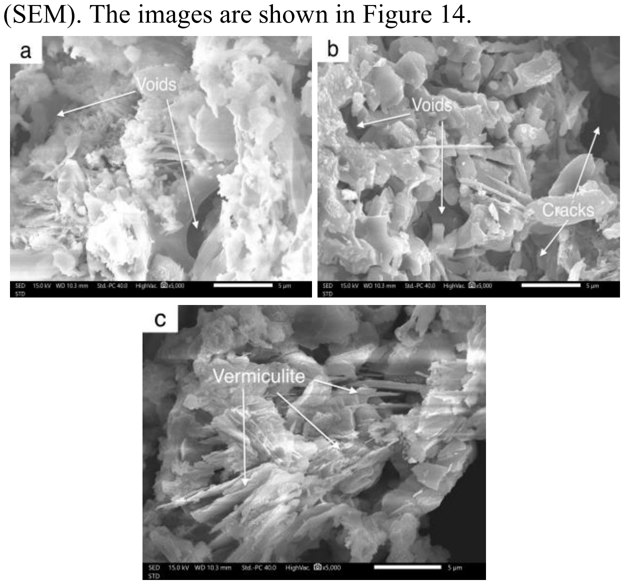

Figure 14. *SEM images of M10 sample*

The SEM images reveal the presence of voids (Figure 14a), voids and cracks (Figure 14b) as well as the lamellar aluminosilicate structure characterized for vermiculite (Figure 14c).

4. Conclusions

This research utilized rice husk ash as a substitute for vermiculite in the fabrication of Class N insulating refractory concrete according to ASTM C401-91. The optimal mix designs, M9 and M10, incorporated 10% and 15% rice husk ash, respectively, with a corresponding reduction in vermiculite to 5-10%. These mixes, M9 and M10, met the requirements for bulk density (ranging from 0.760 to 0.813 g/cm^3), compressive strength of samples fired at 800^{o}C (achieving 1.27 to 1.66 MPa), compressive strength of samples fired at 1000^{o}C (achieving 1.05 to 1.54 MPa), and exhibited relatively low thermal conductivity (ranging from 0.106 to 0.116 W/m.K). The study also determined the mineral composition of the insulating refractory concrete using X-ray Diffraction (XRD) and the surface morphological characteristics of the material using Scanning Electron Microscopy (SEM). Rice husk ash is a substantial agricultural by-product in Vietnam, so the utilization of mix designs containing rice husk ash holds significant economic and environmental benefits, particularly in the current context where Vietnam is promoting a green and circular economy.

Acknowledgements: The authors extends their gratitude to Mr. Nguyen Dinh Nghi, General Director and the staff of Quality Control Department of Novaref Refractory Development Joint Stock Company for their support in conducting this study.

REFERENCES

[1] A. Ehsani and I. Ehsani, "Usage of vermiculite as a high-temperature insulating refractory material", *Adana Science and Technology University Journal of Science*, vol. 1, no. 2, pp. 13-19, 2018.

[2] A. Terzic, J. Stojanovic, L. Andric, and Z. Radojevic, "Performances of Vermiculite and Perlite based thermal insulation lightweight concretes", *Science and Sintering*, no. 52, pp. 149-162, 2020.

[3] S. A. Suvorov and V. V. Skurikhin, "High-temperature heat-insulating materials based on vermiculite", *Refractories and Industrial Ceramics*, vol. 43, nos. 11-12, pp. 383-389, 2002.

[4] N. V. Dong, N. N. Hoa, N. N. Lam, B. T. Hoa, and V. M. Duc, "Reseaching on production of heat-resistance concrete from blended Portland cement", *Journal of Building Science and Technology*, vol. 8, no. 11, pp. 102-110, 2010.

[5] V. D. Luong, *Chemistry and Technology of Cement Production*. Hanoi: Science and Technics Publishing House, 2008.

[6] P. Rovnanikova, P. Bayer and L. Vitek, "Hlinitanovy cement jako pojivo konstrukcniho betonu-stav betonu z konstrukce mostu po padesati letech", *Beton-technolgie-konstrukce-sanace*, no. 3, pp. 48-51, 2007.

[7] H. Pöllmann, "Calcium aluminate cements–raw materials, differences, hydration and properties", *Reviews in Mineralogy and Geochemistry*, vol. 74, no. 1, pp. 1-82, 2012.

[8] Technical Standards: Hanoi, Vietnam, *Alumina cement*, TCVN 7569:2022, 2022.

[9] W. Khaliq and H. A. Khan, "High temperature material properties of calcium aluminate cement concrete", *Construction and Building Materials*, no. 94, pp. 475-487, 2015.

[10] V. H. Le, C. N. H. Thuc, and H. H. Thuc, "Synthesis of silica nanoparticles from Vietnamese rice husk by sol-gel method", *Nanoscale Research Letters*, vol. 8, no. 58, 2013.

[11] E. M. M. Ewais, R. M. Elsaadany, A. A. Ahmed, N. H. Shalaby, and B. E. H. Al-Anadouli, "Insulating refractory bricks from water treatment sludge and rice husk ash", *Refractory and Industrial Ceramics,* vol. 58, no. 2, pp. 136-144, 2017.