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INSULATION PROPERTIES AND PERFORMANCE OF FOAM CONCRETE USING BLAST FURNACE SLAG

KARAKTERISTIKE IZOLACIJE I PERFORMANSE PENO-BETONA SA PRIMENOM ŠLJAKE IZ VISOKE PEĆI

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Ključne reči
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- cigla
- šljaka
- toplotna provodnost
- cement

Abstract

The paper presents studies on foam concrete with density from 600-1700 kg/m³. The authors use ANSYS 18® software to simulate the heat absorption of concrete foam walls and clay brick walls. The ratio of foam concrete mixture is calculated by the absolute volume method. Besides, the mechanical properties of foam concrete are determined by the Russian standard GOST 10180-2012. Water absorption is determined by using cubic specimens of 150×150×150 at 28 days of age, according to Russian standard GOST 12730.3-78. The elasticity modulus of foam concrete is determined by ASTM C 469-2002 at 28 days of age. Research results show that at the age of 28 days with mix number 3, the value of compressive strength obtained is 9.15 MPa, dry density is 918 kg/m³, thermal conductivity 0.24 W/mK. These properties are better than clay bricks. Besides, ANSYS 18 results show that at the same thickness of 100 mm, a wall with foam concrete blocks has a better insulation capacity than walls made of clay bricks.

Izvod

U radu je predstavljena studija o peno-betonu gustine od 600-1700 kg/m³. Autori koriste ANSYS 18® softver za simulaciju apsorpcije toplote zidova od peno-betona i zidova od cigli. Odnos mešavine peno-betona se određuje metodom apsolutne zapremine. Osim toga, određene su i mehaničke osobine peno-betona prema ruskom standardu GOST 1018 0-2012. Apsorpcija vode se određuje korišćenjem kockastih uzoraka 150×150×150 nakon 28 dana starosti, prema ruskom standardu GOST 12730.3-78. Modul elastičnosti peno-betona se određuje prema ASTM C 469-2002 nakon 28 dana starosti. Rezultati pokazuju da se nakon 28 dana starosti za mešavinu pod br. 3 dobija pritisna čvrstoća od 9.15 MPa, gustina u suvom stanju je 918 kg/m³, toplotna provodljivost je 0.24 W/mK. Ove osobine su bolje u odnosu na glinene cigle. Osim toga, rezultati ANSYS 18 pokazuju da pri istoj debljini od 100 mm, zid od blokova peno-betona ima bolji kapacitet izolacije od zidova napravljenih od glinenih cigli.

INTRODUCTION

Blast furnace slag (BFS) is a by-product formed during the production of pig iron. In the process of smelting cast iron, when silicon and aluminium oxides react from barren rock of iron-bearing ore with calcium oxide and magnesium oxide of the flux, a fiery liquid alloy is formed.

Currently, worldwide production of BFS is about 0.5 billion tons, while effective utilization rates are still relatively low /1/. Therefore, the reuse of BFS is an urgent issue. The main application area for waste, such as slag is the construction industry. The use of BFS brings excellent benefits such as increasing the durability of concrete, reduction of heat of hydration and saving natural resources, /2-4/.

Foam concrete consists mainly of cement, air pores with fillers such as fly ash, blast furnace slag, or sand. Besides, coarse aggregates are not used in foamed concrete. Air pores in foam concrete are formed by agitating air with a foaming agent. The size of air bubbles ranges from 0.3 to 0.4 mm. Meanwhile, the volume of air is at least 20 % of the concrete volume. The foam concrete possesses high flowability, low self-weight, low controlled strength, and excellent thermal insulation. The density of foam concrete ranges from 400 to 1600 kg/m³ with compressive strength ranging from 1 to 15 MPa. The high flowability of foam concrete eliminates the need for using mechanical vibration to consolidate the concrete during placing, /5-8/.

Foamed concrete can be produced by combined foaming or pre-foaming. In a pre-foaming manner, the base mix (cement, filler, water) and the stable preformed aqueous foam are produced separately. After that, blending the foam and the base mix. In the mixed foaming method, the active surface agent is mixed with the ingredients of the base mix, and during the mixing, the foams will be formed, /5, 9-10/.

Now, most of the foam concrete applications are related to its thermal insulation properties and mechanical properties /11-12/. Generally, thermal insulation properties increase with decreasing the density of foam concrete, while the mechanical properties are in the same trend as the density variation. In fact, the low compressive strength of foam concrete limits its applications in the thermal insulation field. Therefore, the use of foam concrete has to consider the balance between thermal insulation properties and mechanical properties. Macroscopic thermal insulation properties and mechanical properties are directly influenced by the microscopic pore features, such as porosity, pore size, pore area fraction, pore distribution, pore shape factor, etc /12-13/.

Foam concrete can be applied as follows /14-15/:

– Building blocks: foam concrete can be used to produce building blocks for patriation and load-bearing walls with any dimension.
– Floor screed: foamed concrete can be used to create a flat surface on uneven ground, and it can be used to raise the floor levels.
– Roof insulation: foam concrete possesses excellent thermal and sound insulation properties. The foam concrete can be used for roof insulation. The low self-weight of foam concrete will help reduce the total load in the building.

Recently, with the increasing worldwide demand for energy supply with the precondition of limited energy sources, saving energy or highly efficient use of energy in social activities and industry has become the primary policy of most countries. Therefore, the research on fabrication and application of foam concrete for insulation purposes has recently gained more and more attention than ever.

In Southeast Asian countries in the summer, the outside temperature is very high, sometimes up to 42°C /16/. The temperature on the surface of the building's wall covers can be up to 50°C when considering the effects of solar radiation factors /16-17/. To ensure comfortable use in buildings, the temperature inside the building is between 20-25°C, so the cover structure should ensure low heat transfer requirements.

Currently, there are a few authors studying foam concrete bricks. However, these authors mainly study foam concrete bricks used for non-bearing wall structures. Materials used are mainly cement, fine aggregate (sand, fly ash, bottom ash) foam, additives and water /9, 11-13/. Very rare are research papers on foam concrete using blast furnace slag as a fine aggregate to produce foam concrete bricks to replace clay bricks used for load-bearing wall structures. Also, using ANSYS 18® computer program to analyse the insulation ability of foam concrete brick wall and clay brick wall.

As is well known, buildings often use clay bricks for load-bearing wall structures with density from 1600 to 1800 kg/m³ and compressive strength of 7.5 MPa /18/. However, clay bricks have a large thermal conductivity and density. Therefore, the purpose of this study is to study foam concrete samples with different density to obtain foam concrete with density below 1700 kg/m³, compressive strength above 7.5 MPa, and low thermal conductivity to replace clay bricks used in load-bearing walls structures. Then, use the ANSYS 18 computer program to analyse the insulation of walls built from foam concrete blocks with walls using clay bricks load-bearing walls.

EXPERIMENTAL PROGRAM

Materials

Ordinary Portland Cement (OPC) that meets the requirements of GOST 31108-2016, is used as a binder. The cement compressive strength at the age of 3 days is 27.2 MPa and at the period of 28 days is 46.1 MPa. The experiments are performed according to the standard GOST 310.4-81.

In this study, superplasticizers (SR5000) are used to improve the performance of concrete mixtures with $\rho = 1.1$ g/m³ at a temperature of 25 ± 5 °C. Besides, Silica Fume SF-90 (SF90) 'Vina Pacific' is used as water reducing admixture in the foam concrete mixes.

Blast furnace slag (BFS) is used in this study. Figure 1 presents the XRD pattern of blast furnace slag.

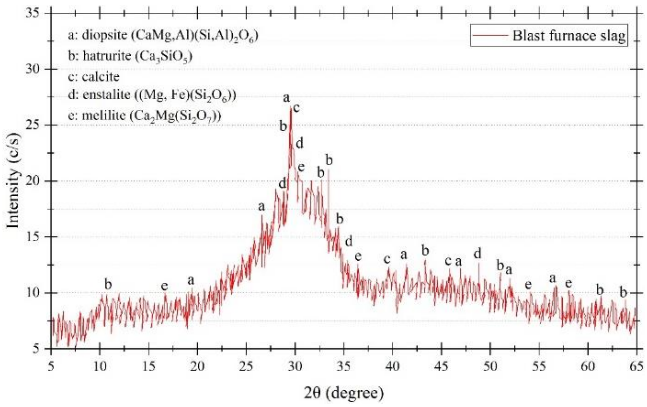


Figure 1. XRD pattern of BFS.

The physical and chemical properties of OPC, SF90 and BFS are shown in Table 1.

Table 1. Properties of OPC, BFS and SF90.

Property		SF90	BFS	OPC
Chemical	SiO_2	90.78	36.01	21.98
	Al_2O_3	2.23	13.77	5.31
	Fe_2O_3	2.51	-	3.46
	CaO	0.52	41.05	62.33
	MgO	-	7.36	2.01
	SO_3	-	0.14	-
	Na_2O	0.57	-	0.14
	K_2O	-	0.28	0.62
	Loss on ignition	3.39	1.39	4.15
Physical	Specific gravity (g/m³)	2.15	2.29	3.12
	Fineness (cm²/g)	10160	4540	3650

EABASSOC Foaming Agent (United Kingdom) is a highly concentrated, highly efficient liquid used in the production of Foamed Concrete. Dosage Rate: 0.3-0.6 l/m³ with $\rho = 1.02$ g/cm³.

Figure 2 shows the types of materials used in the study.

(OPC) (BFS) (SF90) (SR5000) (foam)

Figure 2. Types of materials used in the study.

Mixing water to obtain a concrete mixture meets the requirements of GOST 23732-2011, pH = 7.5.

Object of study

In this study, the authors study the mechanical and physical properties of foam concrete at different densities using blast furnace slag as fine aggregate. Then, use the properties of foam concrete sample with density below 900 kg/m^3 and compressive strength above 7.5 MPa to compare this material's insulation effect with clay brick based on ANSYS software.

The average air temperature in Southeast Asian countries from 11 AM to 5 PM is 38 °C which is used to evaluate the insulation effectiveness of foam concrete and baked clay bricks.

Mixture proportioning

The foam concrete preparation process is illustrated in Fig. 3. Cement, silica fume and blast furnace slag are first mixed at a lower speed of about 40-50 rpm for a short while, followed by the addition of superplasticizer and water to mix for 2 minutes to obtain a wet mixture. Then, the foaming agent is added to the mixture and continues to mix. The mixture is then put into a mould and put in a static state for 24 hours. These foam concrete samples are then tested after 28 days of age, /19/.

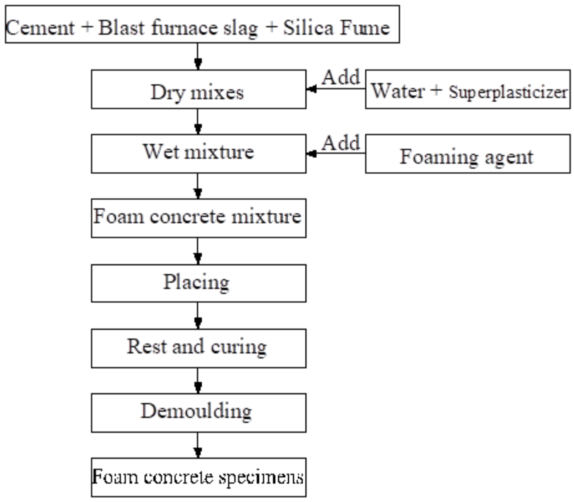


Figure 3. Diagram for foam concrete preparation process.

The initial ratios of raw materials for the production of foam concrete are chosen by us as follows: in this study, the amount of cement is fixed OPC = 350 kg/m^3 /8, 19/, *W/binder* = 0.23 /20/ (binder = OPC + SF90), SR5000/OPC = 0.015 /8/, SF90/OPC = 0.015, /6/, the results of which are presented in Table 2.

Table 2. Compositions mixtures.

Mix number	SR5000/OPC	SF90/OPC	OPC (kg)	SF90 (kg)	SR5000 (kg)	BFS (kg)	W (kg)	Foam (L)	W (*) (kg)
01	0.015	0.1	350	35	5.3	221	89	680.9	132.8
02	0.015	0.1	350	35	5.3	321	89	637.2	152.8
03	0.015	0.1	350	35	5.3	421	89	593.6	172.8
04	0.015	0.1	350	35	5.3	521	89	549.9	192.8
05	0.015	0.1	350	35	5.3	621	89	506.2	212.8
06	0.015	0.1	350	35	5.3	721	89	462.6	232.8
07	0.015	0.1	350	35	5.3	821	89	418.9	252.8
08	0.015	0.1	350	35	5.3	921	89	375.2	272,8
09	0.015	0.1	350	35	5.3	1021	89	331.6	292.8
10	0.015	0.1	350	35	5.3	1121	89	287.9	312.8

Note: W(*) actual amount of water on each 1 m^3 (kg), according to /19/ water(*) calculated by Eq.(1):

$$W(*) = W + \alpha \cdot BFS. \qquad (1)$$

Methods

- Determining the composition of mixture

The ratio of foam concrete mixture is calculated by the absolute volume method /21-22/. The mechanical properties are determined by GOST 10180-2012 /23/ (Figs. 4 and 5). Dry density is determined by using cubic specimens of 150×150×150 at 28 days of age.

Figure 4. Flexural strength test samples.

Figure 5. Compression test samples.

The thermal conductivity is tested at the age of 28 days. Samples are dried at 105 ± 5 °C for 24 hours. The samples are placed between hot and cold plates with temperatures of 40 °C, 18 °C, respectively, to stimulate the outside, inside. Hot and cold plate temperatures are recorded every 10 min. for 24 hours. The average values of temperature recorded are used to calculate thermal conductivity, Fig. 6.

Water absorption is determined by using cubic specimens of 150x150x150 at 28 days of age by the Russian standard GOST 12730.3-78. Water absorption is calculated by the following formula /24/:

$$W_a = \frac{m_b - m_c}{m_c} 100\ \%\,, \quad (2)$$

where: W_a is water absorption (%); m_c is dry sample weight (g); m_b is water-saturated sample weight (g).

The elasticity modulus of foam concrete is determined by ASTM C 469-2002 at 28 days of age.

- Using the finite element method to determine temperature distribution on the wall

With climatic conditions in Southeast Asian countries, especially in the summer, the building walls are affected by temperature stimulation. Due to the difference in outside and inside temperatures, heat transfer occurs through the wall, /25/. The heat transfer process through a wall exists in three different forms: heat conduction, heat convection, and thermal radiation. The thermal behaviour of a wall can be described by the following Eq.(3), /26-27/,

$$\lambda \nabla^2 T = \rho c \frac{\partial T}{\partial t}\,, \quad (3)$$

where: λ is thermal conductivity (W/(m°C); c is specific heat (kJ/kg°C); ρ is density (kg/m^3); $\nabla^2 T =$ div(grad$T$) is the Laplace temperature operator; and t is the time.

The following boundary conditions are used to solve the thermal problem: temperature conditions, heat flow conditions, convection boundary conditions and radiation boundary conditions. In this study, temperature and convection boundary conditions are used as boundary conditions to solve the problem of heat transfer and Eq.(4) can be described as:

$$T = T_{\text{outer envir}} \quad \text{and} \quad \frac{\partial T}{\partial n} = h(T_s - T_{\text{inner room}})\,, \quad (4)$$

where: $T_{\text{outer envir}}$ = 38 °C is the highest average temperature in Southeast Asian countries /28/; n is the outward direction normal to the surface; h is convection coefficient (W/m^2°C); T_s is temperature at boundary nodal points of the wall (°C); $T_{\text{inner room}}$ = 22 °C is average temperature inside the room in use condition.

The sizes of walls (3.3 × 0.1 m) are simulated in ANSYS APDL software with the data given in Table 3.

Table 3. Thermo-physical properties of wall materials.

No.	Properties of materials	Foam concrete	Brick /21/
1	Thermal conduction coef. (W/mK)	0.24	1.25
2	Specific heat (J/kgK)	850	920
3	Density (kg/m^3)	918	(1700)
4	Convection coefficient (W/m^{2}K)	25	25

Furthermore, the foam concrete wall's thermal conductivity is compared with that of brick wall under climatic conditions in Southeast Asian countries to evaluate the foam concrete wall's thermal characteristics.

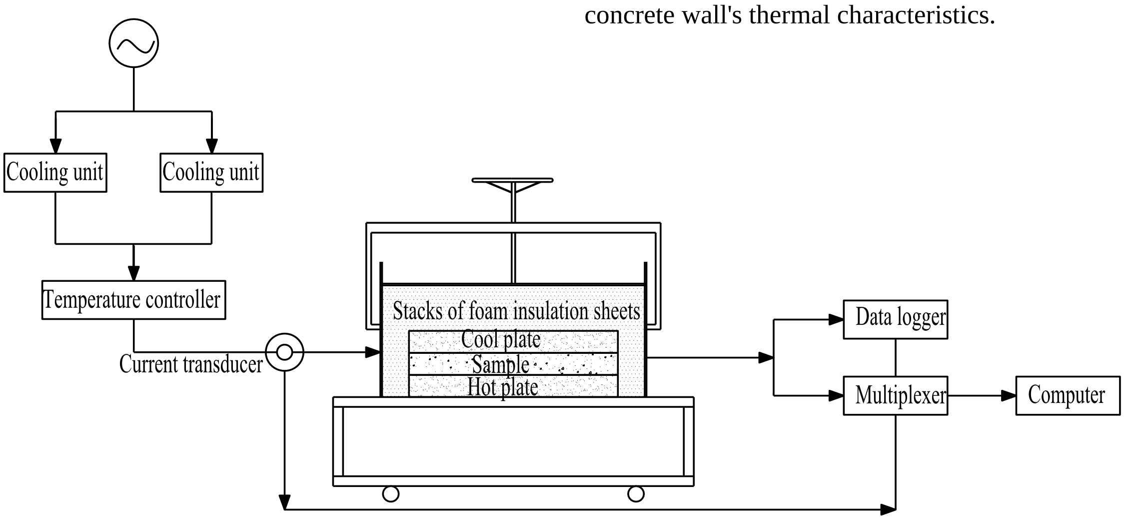


Figure 6. Thermal conductivity test diagram.

RESULTS AND DISCUSSION

Foam concrete mechanical properties

The compressive strength of the concrete foam samples was from 5.85 to 38.25 MPa at 28 days curing time. At this age, flexural strength values are respectively, from 1.02 to 6.56 MPa. The foam concrete mechanical properties at different curing times are shown in Table 4.

Table 4. Foam concrete mechanical properties.

Mix number	Compressive strength at different curing times (MPa)					Flexural strength at curing age of 28 days (MPa)
	3 d	7 d	14 d	28 d	56 d	
01	2.93	4.4	5.02	5.85	6.13	1.02
02	4.48	6.08	6.42	6.87	7.47	1.73
03	6.82	8.08	8.88	9.15	9.44	2.12
04	9.23	10.7	11.85	13.62	14.22	2.97
05	10.81	12.8	13.95	16.04	16.64	3.65
06	12.7	14.91	16.68	18.98	21.57	4.12
07	15.43	17.84	20.36	22.97	25.04	4.67
08	17.22	21.95	23.4	26.22	29.19	5.35
09	21.63	26.56	29.28	32.01	35.44	6.04
10	25.11	30.87	33.8	38.25	41.06	6.56

Table 4 shows the foam concrete mechanical properties and Fig. 7 presents the relationships between compressive strength and curing age.

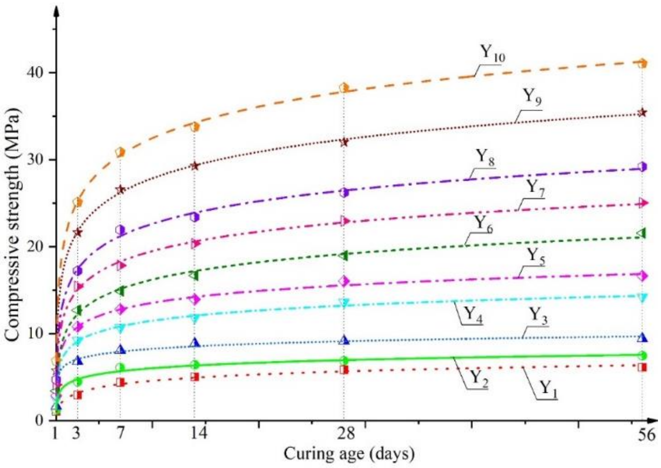


Figure 7. Influence of various curing age on foam concrete compressive strength.

Figure 7 shows the rate of development of compressive strength of foam concrete with curing age. The foam concrete compressive strength in most mixtures shows a continuous increase with age. The growth rate of initial strength is higher and decreases as age increases. The mechanical properties of experimental concrete samples have proven that the use of finely ground BFS significantly improves the concrete's strength. This is also confirmed in the study of Dien Vu Kim et al. /19/.

According to studies /5/, it is shown that for lightweight concrete the relationship between curing age and compressive strength can be described by the following equation:

$$Y = k_1 + k_2 \ln(x + k_3) ,$$

where: Y (MPa) is foam concrete compressive strength at age x (days); k_1, k_2 and k_3 are coefficients.

For this study, the relationship between curing age and compressive strength is given by the following formulas:

Mixtures	Regression equations	(R_2)	Eq.
no. -01:	$Y_1 = 2.357 + \ln(x + 0.734)$	0.982	(5)
no. -02:	$Y_2 = 4.159 + 0.850 \cdot \ln(x + 0.968)$	0.983	(6)
no. -03:	$Y_3 = 6.515 + 0.793 \cdot \ln(x + 0.998)$	0.990	(7)
no. -04:	$Y_4 = 7.994 + 1.587 \cdot \ln(x + 0.969)$	0.995	(8)
no. -05:	$Y_5 = 9.497 + 1.839 \cdot \ln(x + 0.973)$	0.995	(9)
no. -06:	$Y_6 = 10.287 + 2.690 \cdot \ln(x + 0.922)$	0.993	(10)
no. -07:	$Y_7 = 12.893 + 2.998 \cdot \ln(x + 0.946)$	0.997	(11)
no. -08:	$Y_8 = 14.916 + 3.501 \cdot \ln(x + 0.945)$	0.996	(12)
no. -09:	$Y_9 = 18.843 + 4.093 \cdot \ln(x + 0.959)$	0.999	(13)
no. -10:	$Y_{10} = 21.759 + 4.866 \cdot \ln(x + 0.953)$	0.998	(14)

According to literature /16/, it is known that in foam concrete, the relationship between flexural and compressive strength is determined by the following formula:

$$R_{cs} = a(R_{fs})^b , \qquad (15)$$

where: R_{cs} (MPa) is foam concrete compressive strength at age of 28 days; R_{fs} (MPa) is foam concrete flexural strength at the age of 28 days; a, b are coefficients.

The relationship between compressive strength R_{cs} (MPa) and flexural strength R_{fs} (MPa) of foam concrete samples is shown in Fig. 8, with the formula as follows:

$$R_{cs} = 3.223(R_{fs})^{1.284} . \qquad (16)$$

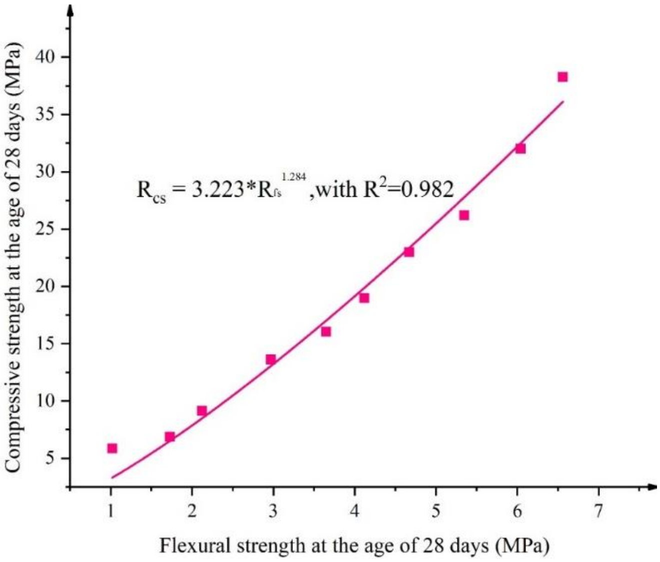


Figure 8. Relationship between foam concrete compressive and flexural strength.

Foam concrete physical properties

The physical properties of foam concrete, such as water absorption, thermal conductivity, elasticity modulus and dry density, are presented in Table 5.

Table 5. Physical properties of foam concrete.

Mix no.	Thermal conductivity (W/mk)	Water absorption at 28 days (%)	Elasticity modulus at 28 days (MPa)	Dry density (kg/m^3)
01	0.17	25.77	2353	693
02	0.21	20.11	2943	806
03	0.24	15.57	4113	918
04	0.27	14.55	5990	1030
05	0.35	11.41	6959	1142
06	0.42	9.64	8981	1253

07	0.46	8.24	9995	1364
08	0.54	3.56	12992	1475
09	0.66	2.57	15570	1585
10	0.72	1.76	16641	1695

- Effect of density on the thermal properties

Foam concrete can be produced with a wide range of density. Each density has a different effect on the properties of foam concrete. The mass of foam concrete is influenced by the amount of foam added into the mix. In this study, different densities of foam concrete are cast and tested. The results show that the foam concrete thermal conductivity is directly proportional to the density (Fig. 9). Thermal conductivity for foam concrete samples from 0.17 to 0.72 W/mK corresponds to the density from 693 to 1695 kg/m^3. According to research /29/ particle shape and size play an important role in the formation of pores. The use of blast furnace slag as a fine aggregate in foam concrete helps to form tiny holes, which increases the insulation efficiency. Compared with other foam concrete components in the study /30/ it is found that concrete heat absorption capacity has a close relationship with its density. The foam concrete low density shows low thermal conductivity (more air volume). As a result, the thermal conductivity varies significantly with the foam concrete dry density. Air is the worst conductor compared to solids and liquids due to its molecular structure.

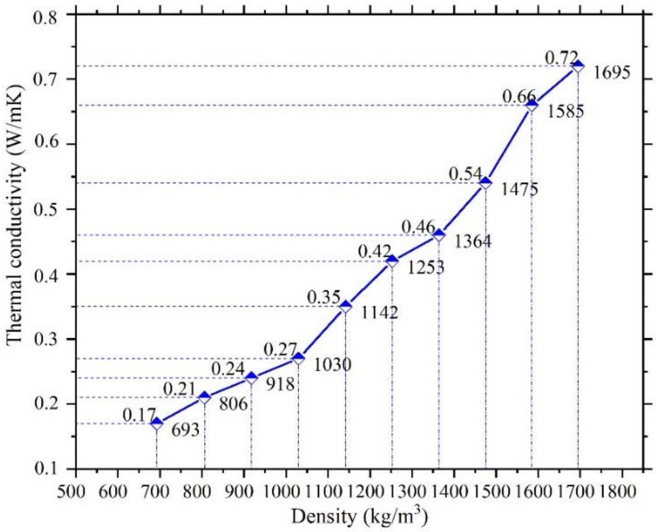


Figure 9. Thermal conductivity vs. density of foam concrete.

- The density and the water absorption

The relationship between water absorption and dry density of foam concrete is shown in Fig. 10. The dry density of foam concrete seems to decrease with increasing water absorption of the samples. The linear function better describes the relationship between dry density and water absorption for all foam concrete samples after 28 days and is shown by Eq.(17):

$$Y = 1672.6 - 41.107x, \quad R^2 = 0.962, \qquad (17)$$

where: Y is foam concrete dry density (kg/m^3); x is water absorption (%).

According to research /31/, it is shown that foam concrete has a higher water absorption capacity than traditional concrete due to its lower density. When the density of foam concrete increases, water absorption of foam concrete decreases. This completely coincides with the author's study. When the concrete density increases from 693-1695 kg/m^3, the water absorption decreases from 25.77 to 1.76 %.

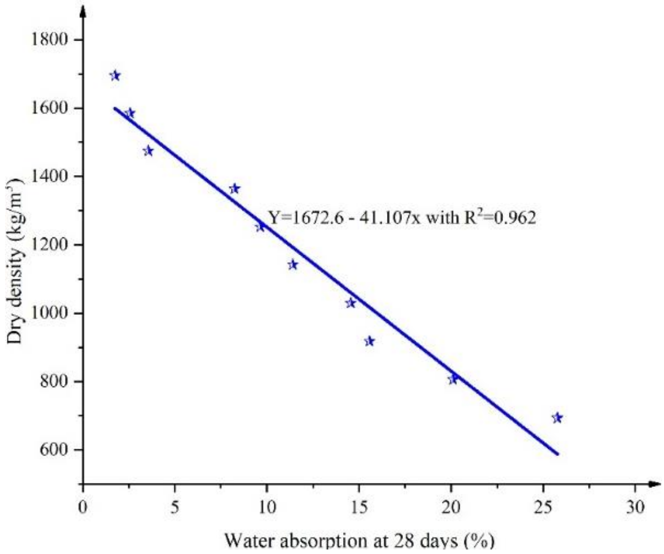


Figure 10. Foam concrete dry density vs. water absorption.

- Elastic modulus vs. compressive strength and dry density

Figure 11 presents the dependence of elasticity modulus E of foam concrete dry density. It is clear from Fig. 11 that an increase in the elasticity modulus follows an increase in dry density and compressive strength. The relationship between elasticity modulus, dry density, and compressive strength of foam concrete is shown in Fig. 11, and is shown in Eq.(18):

$$Y = 3.379x - 2290 \quad \text{with} \quad R^2 = 0.990. \qquad (18)$$

The value $R^2 = 0.990$ indicates a robust correlation between the three comparative parameters of elastic modulus, dry density, and foam concrete samples' compressive strength.

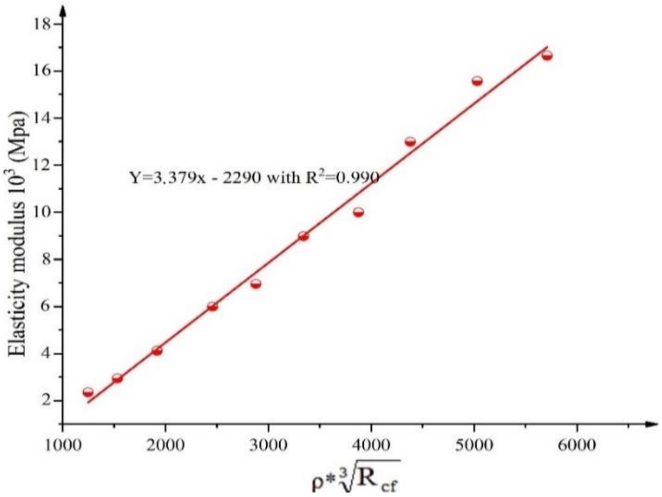


Figure 11. Relationship between elasticity modulus, dry density, and compressive strength of foam concrete.

The elastic modulus of foam concrete is reported to be significantly lower than that of conventional concrete. Amritha Raj et al. report an elastic modulus of foam concrete from 1-15 kN/m^2 with density from 500 to 1500 kg/m^3 /32/. Compared with the authors' research results, the elasticity modulus is from 2.35 to 16.64 kN/m^2 with density from 693 to 1695 kg/m^3. Therefore, the results measured in this study are completely consistent.

Thermal behaviour of walls

Based on research results Mix number-3 has a compressive strength 9.47 MPa > 7.5 MPa, density of 918 kg/m^3 < density of clay brick (1700 kg/m^3). Therefore, the author will use Mix number-3 to evaluate the foam concrete wall's insulation ability and clay brick wall.

To create finite elements in ANSYS APDL software, we need to complete many tasks for the model to run correctly. In this study, we use PLANE55 thermal element to describe the elements in the wall /33/. This element is available in the library of ANSYS APDL as shown in Fig. 12. Besides, nodes from 1 to 6 on the walls' width are marked to compare the temperature development between brick walls and foam concrete walls. The temperature distribution on the walls is shown in Figs. 13 and 14. Assuming that the air's average temperature in Southeast Asian countries from 11 AM to 5 PM is equal to 38 °C.

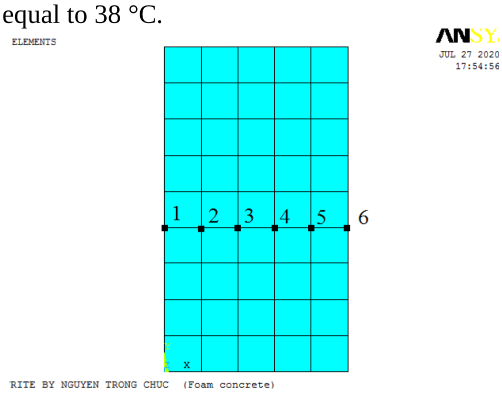
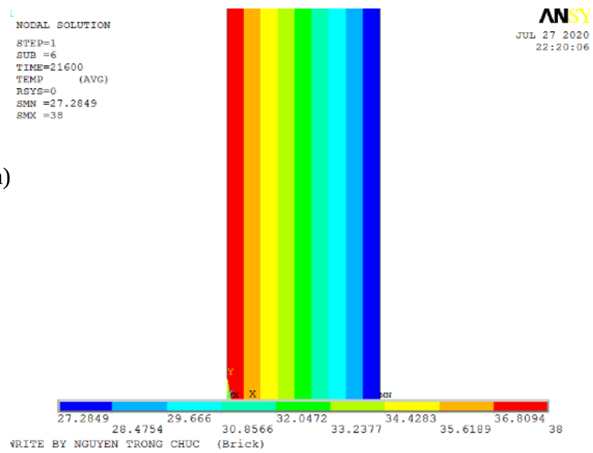


Figure 12. Finite element models (FEM) for 2-D walls.

From Figs. 13 and 14, the following observations can be made. Due to the temperature difference between the outside and the inside of the wall, there is heat energy transfer. The temperature distribution inside the walls depends on space and time. So, all elements inside the walls have a temperature that increases with time. At 13 h the nodes in the wall reach a steady temperature and do not change much.

It is easy to see that the temperature development of 6 nodes on a foam concrete wall is smaller than on a brick wall. The most considerable difference can be reached at approximately 4 °C with the 6th node (wall's inside surface).

(a)



(b)

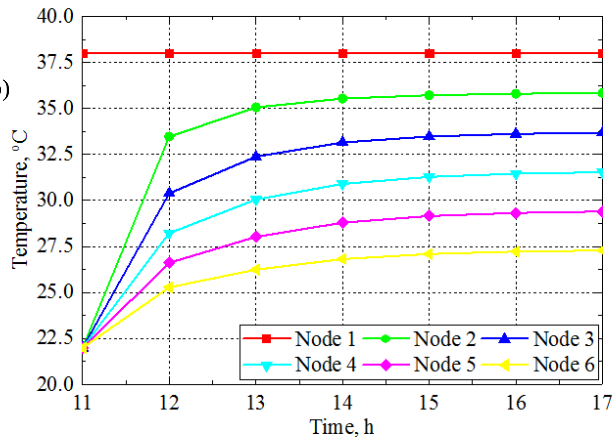
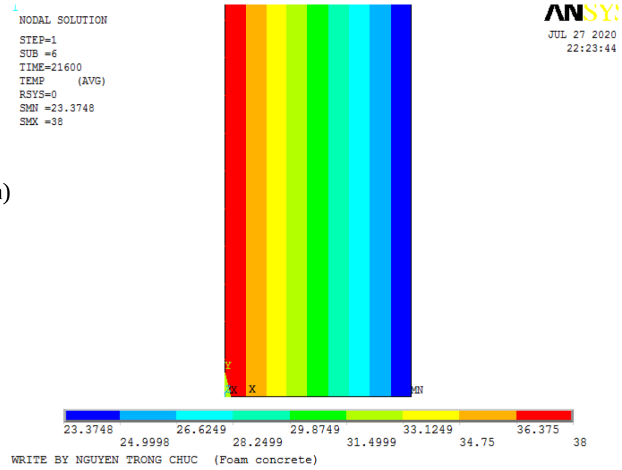


Figure 13. Temperature distributions: a) in brick wall at 17 h; b) in nodes (1, 2, 3, 4, 5 and 6) of the brick wall over time.

(a)



(b)

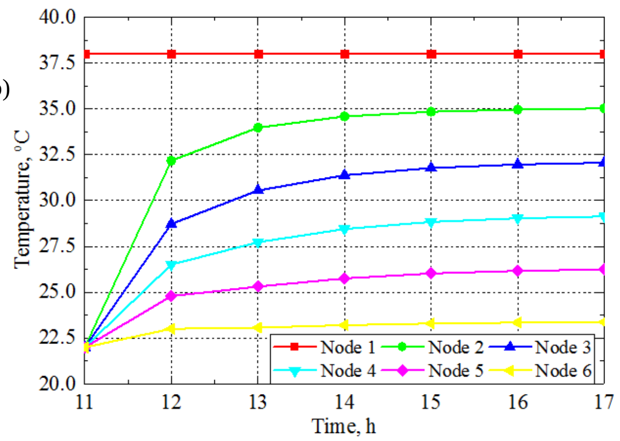


Figure 14. Temperature distribution in: a) foam concrete wall at 17h; b) in nodes (1-6) of foam concrete wall over time.

Assessment of thermal insulation of foam concrete walls and the temperature distribution on the thickness of the two types of walls are shown in Fig. 15.

It is easy to observe the significant difference in temperature distribution on foam concrete walls and brick walls. The temperature difference is reached on the inside surface of the wall: (27.28 – 23.37)/27.28 ≈ 14.33 %. As expected, the foam concrete wall has better insulation performance than the standard wall brick. This result of the study is consistent with results of previous studies, /33, 34/.

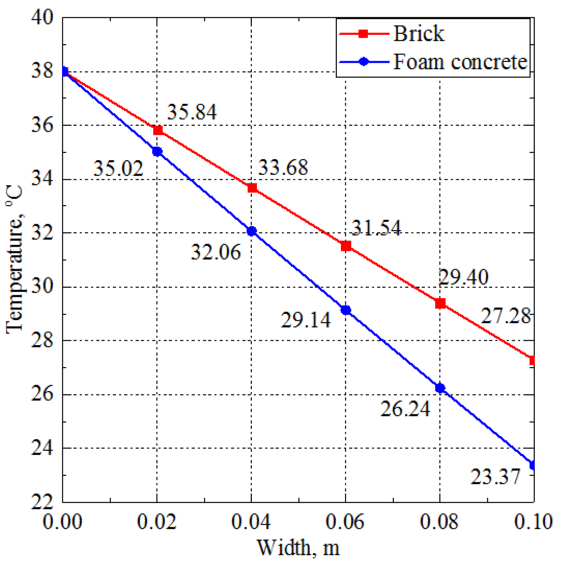


Figure 15. Temperature distribution in the walls at 5 PM.

CONCLUSIONS

From the experimental results, it can be concluded as follows.

The use of blast furnace slag as a fine aggregate in foam concrete as it improves mechanical properties such as compressive and flexural strength, ... This would lead to the development of eco-friendly foam concrete materials with significant environmental benefits.

From the experimental results a relationship between the compressive strength and curing age of foam concrete is found (in Eqs.(4-14)), for compressive and flexural strength at the age of 28 days (in Eq.(16)). Besides that, the relationship between elasticity modulus, compressive strength - density is also given in Eq.(16).

Experimental results also show that the foam concrete thermal conductivity using blast furnace slag as a fine aggregate is directly proportional to the density. As the density increases, the thermal conductivity increases, and vice versa.

The relationship between dry density and water absorption is also given in Eq.(17). The relationship indicates that water absorption increases as density decreases.

Experimental results and analysis using ANSYS software have shown that foam concrete brick walls with low density and low conductivity can be used to replace clay brick walls in hot climates. The use of foam concrete brick walls reduces the load applied to the foundation and creates a comfortable mode for indoor living.

REFERENCES

1. Essamei, M.A., Doctoral Thesis, University of Belgrade, Faculty of Mechanical Engineering, 2000.
2. Tsakiridis, P.E., Papadimitriou, G.D., Tsivilis, S., Koroneos, C. (2008), *Utilization of steel slag for Portland cement clinker production*, J Hazard. Mater. 152(2): 805-811. doi: 10.1016/j.jhazmat.2007.07.093
3. van Deventer, J.S.J., Provis, J.L., Duxson, P., Brice, D.G. (2010), *Chemical research and climate change as drivers in the commercial adoption of alkali activated materials*, Waste Biomass Valor. 1(1): 145-155. doi: 10.1007/s12649-010-9015-9
4. Nochaiya, T., Wongkeo, W., Pimraksa, K., Chaipanich, A. (2010), *Microstructural, physical, and thermal analyses of Portland cement-fly ash-calcium hydroxide blended pastes*, J Therm. Anal. Calorimetry, 100(1): 101-108. doi: 10.1007/s10973-009-0491-8
5. Cheah, C.B., Chung, K.Y., Ramli, M., Lim, G.K. (2016), *The engineering properties and microstructure development of cement mortar containing high volume of inter-grinded GGBS and PFA cured at ambient temperature*, Constr. Building Mater. 122: 683-693. doi: 10.1016/j.conbuildmat.2016.06.105
6. Kim, D.V., Ly, N.C., Tang, V.L., Bazhenova, S.I. (2020), *Foamed concrete containing various amounts of organic-mineral additives*, J Physics: Conference Series, 1425: 012199. doi: 10.1088/1742-6596/1425/1/012199
7. Lewis, D., Interlocking Stabilised Soil Blocks, United Nations Human Settlements Programme (UN-HABITAT), 2009.
8. Rassokhin, A.S., Ponomarev, A.N., Figovsky, O.L. (2018), *Silica fumes of different types for high-performance fine-grained concrete*, Magaz. Civ. Eng. 78(2): 151-160. doi: 10.18720/MCE.78.12
9. Kim, D.V., Bazhenova, S.I., Tang, V.L. (2020), *Influence of mineral additives fly ash blast furnace slag on the mechanical properties of foam concrete*, Stroitelnie materiali i tehnologii, 88(2): 25-34. doi: 10.33979/2073-7416-2020-88-2-25-34
10. Steshenko, A.B., Kudyakov, A.I. (2018), *Cement based foam concrete with aluminosilicate microspheres for monolithic construction*, Magaz. Civ. Eng. 84(8): 86-96. doi: 10.18720/MCE.84.9
11. Rybakov, V.A., Kozinetc, K.G., Vatin, N.I., et al. (2018), *Lightweight steel concrete structures technology with foam fiber-cement sheets*, Magaz. Civ. Eng. 82(6): 103-111. doi: 10.18720/MCE.82.10
12. Nambiar, E.K.K., Ramamurthy, K. (2007), *Models for strength prediction of foam concrete*, Mater. Struct. 41(2): 247-254. doi: 10.1617/s11527-007-9234-0
13. Ivanov, A.N., Trembitskiy, M.A. (2011), *Foam concrete of certain average density for thermal insulation of attic floors*, Magaz. Civ. Eng. (8): 19-24. doi: 10.5862/MCE.26.3
14. Kumar, R., Bhattacharjee, B. (2003), *Porosity, pore size distribution and in situ strength of concrete*, Cement Concrete Res. 33(1): 155-164. doi: 10.1016/S0008-8846(02)00942-0
15. Amran, Y.H.M., Farzadnia, N., Ali, A. (2015), *Properties and applications of foamed concrete; a review*, Constr. Build. Mater. 101(1): 990-1005. doi: 10.1016/j.conbuildmat.2015.10.112
16. Ramamurthy, K., Kunhanandan Nambiar, E.K., Ranjani, G.I.S. (2009), *A classification of studies on properties of foam concrete*, Cement Concrete Compos. 31(6): 388-396. doi: 10.1016/j.cemconcomp.2009.04.006
17. Tang, V.L., Dihn, T.V., Kim, D.V., et al. (2018), *Properties and thermal insulation performance of light-weight concrete*, Magaz. Civ. Eng. 84(8): 173-191. doi: 10.18720/MCE.84.17
18. TCVN 4605 : Heating techniques - Insulating components - Design standard, 1988, (3): 27 p.
19. Hollow clay bricks. Standard Viet Nam. TCVN: 1450-2009. 2009, 9p.
20. Kim, D.V., Bazhenova, S., Tang, V.L., Ly, N.C. (2020), *Sustainable use of industrial-waste as fine-aggregate of Foam Concrete*, IOP Conf. Ser.: Mater. Sci. Eng. 869: 10. doi: 10.1088/1757-899X/869/3/032022
21. Qin, H.G., Geng, S.S., Pang, C.M., Tao, Y.H. (2014), *Preparation and mixture ratio design of foam concrete with light-weight tailings*, Appl. Mech. Mater. 665: 172-178. doi: 10.4028/www.scientific.net/AMM.665.172
22. Bazhenov, Yu.M., Tekhnologiya betona (Technology of Concrete), Moscow, ASV Publ., 2011, 524 p. (In Russian)

23. Tang, V.L., Dinh, T.V., Kim, D.V., et al. (2018), *Combined effects of bottom ash and expanded polystyrene on light-weight concrete properties*, MATEC Web Conf. 251: 01007. doi: 10.1051/matecconf/201825101007
24. Concretes. Methods for strength determination using reference specimens. Standard Russian, GOST 10180-2012. 2012. 36p.
25. Concretes. Method of determination of water absorption. Standard Russian, GOSST: 12730.3-78 1980. 6p.
26. Kanellopoulos, G., Koutsomarkos, V.G., Kontoleon, K.J., Georgiadis-Filikas, K. (2017), *Numerical analysis and modelling of heat transfer processes through perforated clay brick masonry walls*, Procedia Envir. Sci. 38: 492-499. doi: 10.1016/j.proenv.2017.03.112
27. Peng, C., Wu, Z. (2008), *Thermoelectricity analogy method for computing the periodic heat transfer in external building envelopes*, Appl. Energy, 85(8): 735-754. doi: 10.1016/j.apenergy.2008.02.003
28. Oluwole, O.O., Joshua, J.S., Nwagwo, H.O. (2012), *Finite element modeling of low heat conducting building bricks*, J Miner. Mater. Charact. Eng. 11(8): 800-806. doi: 10.4236/jmmce.2012.118069
29. Huynh, T.P., Nguyen, T.C., Do, N.D., et al. (2019), *Strength and thermal properties of unfired four-hole hollow bricks manufactured from a mixture of cement, low-calcium fly ash and blended fine aggregates*, IOP Conf. Ser.: Mater. Sci. Eng. 625: 012010. doi: 10.1088/1757-899X/625/1/012010
30. Del Coz Diaz, J.J., Garcia-Nieto, P.J., Alvarez-Rabanall, F.P., et al. (2014), *The use of response surface methodology to improve the thermal transmittance of lightweight concrete hollow bricks by FEM*, Constr. Build. Mater. 52: 331-344. doi: 10.1016/j.conbuildmat.2013.11.056
31. Öner, M. (2000), *Study of intergrinding and separate grinding of blast furnace slag cement*, Cement Concrete Res. 30(3): 473-480. doi: 10.1016/S0008-8846(00)00197-6
32. Chundakus, H., Kuncoro, D., Prabang, S., Prasasto, S. (2018), *Physical, mechanical and thermal properties of lightweight foamed concrete with fly ash*, IOP Conf. Ser.: Mater. Sci. Eng. 420: 012062. doi: 10.1088/1757-899X/420/1/012062
33. Amritha, R., Dhanya, S., Mini, K.M. (2019), *Physical and functional characteristics of foam concrete: A review*, Constr. Build. Mater. 221: 787-799. doi: 10.1016/j.conbuildmat.2019.06.052
34. Huynh, T.P., Pham, V.H., Do, N.D. et al. (2021), *Performance evaluation of pre-foamed ultra-lightweight composites incorporating various proportions of slag*, Periodica Polytechnica Civ. Eng. 65(1): 276-286. doi: 10.3311/PPci.16996