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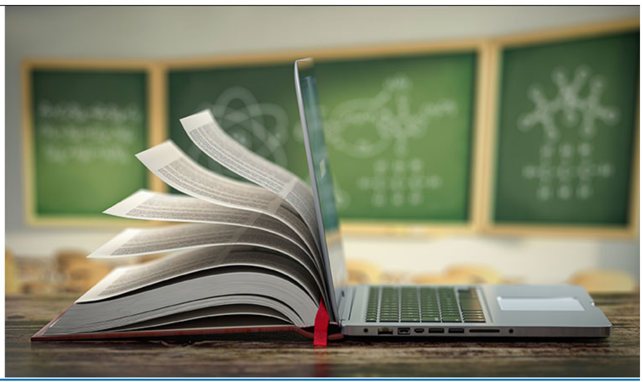

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Sustainable use of industrial-waste as fine-aggregate of Foam Concrete

Dien Vu Kim[1], Sofya Bazhenova[1], Lam Tang Van[2] and Ly Nguyen Cong[3]

[1]Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, Russia
[2]Hanoi University of Mining and Geology, 18 Pho Vien, Duc Thang, Bac Tu Liem, Ha Noi, Vietnam
[3]College of industrial and constructional, Phuong Dong, Uong Bi, Quang Ninh, Viet Nam

E-mail: kimdienxdtb@gmail.com

Abstract. The benefits of using industrial waste as a replacement for natural sand and cement in light-weight concrete are also discussed. The paper presents the use of fly ash and blast furnace slag to replace 100% sand in foam concrete with a wet density of 1700 kg/m^3 and 900 kg/m^3 as well as their mechanical properties. The absolute volume method was used to calculate the ratio of foam concrete mixture. Besides, the foam concrete mechanical properties are determined according to the Russian standard GOST 10180-2012. Research results indicate that at the age of 28 days with Series I, the value of compressive strength obtained from 13.91MPa to 42.35 MPa, flexural strength from 0.53 MPa to 1.06 MPa and water absorption between 0.92% and 5.78% with Series II these values from 1.69 MPa to 8.22 MPa for compressive strength, from 3.25 MPa to 6.72 MPa for flexural strength and the result for water absorption is in the range of 12.35% and 22.16%. Besides that, research results also indicate that the correlation between dry density and compressive strength has a positive linear relationship. The results of this study have proved that foam concrete uses fly ash and blast furnace slag can replace traditional concrete in construction as well as replacing clay bricks will not only improve concrete strength but also reduce costs as well as protect the environment.

1. Introduction

As is well known, foam concrete is a form of lightweight concrete. They are made from cement, fine aggregate, water, foam, and additives. Its density ranges from 300 ÷ 1600 kg/m^3. Its compressive strength at the age of 28 days, ranges from 0.2 to 10 MPa or can go higher [1, 2]. The main difference between the foam concrete and normal concrete is the lower density [3].

In recent years, foam concrete is widely used in the construction industry. Because of its low density, this leads to a reduction in the workload [1, 4]. The use of industrial waste and by-products is increasingly widely used. Fly ash (FA) is a waste of thermal power plants and blast furnace slag (BFS) is the waste of metallurgical plants. [5, 6]. Recycling of fly ash and blast furnace slag had become an increasing concern in recent years. Therefore, the use of FA and BFS to replace natural sand in the foam concrete helps save costs and protect the environment.

Besides that, bricks are man-made construction materials and considered one of the oldest manufactured construction materials in the world. According to TCVN 1450 : 2009 [7] clay bricks used in load-bearing wall structures with compressive strength higher than 7.5 MPa and density of 1600 kg/m^3. On the other hand, TCXD 198 : 1997 has specified compressive strength of traditional concrete used in high-rise

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construction is higher than 30 MPa and density of 2500 kg/m^3 [8]. Therefore, the use of clay bricks and traditional concrete in construction works which leads to an increase in the load applied to the ground.

In recent years, there have been many authors studying the foam and light-weight concrete but there has been little research on the development of high-strength foam concrete as well as research foam concrete is used as an alternative to fired clay bricks for the production of the wall cover in high-rise buildings [2, 9, 10, 11].

Therefore, the purpose of the current investigation was to study two types of foam concrete, which produced from complete replacement of fine-aggregate with FA and BFS in Vietnam. Type I with a wet density of 1700 kg/m^3 and compressive strength higher than 30 MPa, which replacing traditional concrete used in high-rise buildings. Type II of foam concrete with a wet density of 900 kg/m^3 and compressive strength higher than 7,0 MPa to replace fired clay bricks for the production of the wall cover.

2. Experimental Program

2.1. Materials

- Materials' physical and chemical properties are presented in Table 1. Ordinary Portland Cement (OPC) "But Son" (Vietnam) with a specific gravity of 3.10 g/cm^3 and a Blaine fineness of 3660 cm^2/g.

- River sand "Da Bac" (SA) with specific gravity = 2.64 g/cm^3, particle size from 0.14 ÷ 1.25 mm, fly ash (FA) specific gravity of 2.34 g/cm^3 from "Hai Phong" (Vietnam) power plant and blast furnace slag (BFS) from the factory "Hoa Phat" (Vietnam), specific weight of 2.29 g/cm^3.

- Silica fume SF-90 (SF90) (Vietnam). In this case, OPC, FA, BFS and SF90 were used as a binder. Fig. 2 shows the particle size distributions of both OPC, FA, BFS and SF90, while their chemical composition is shown in Table 1.

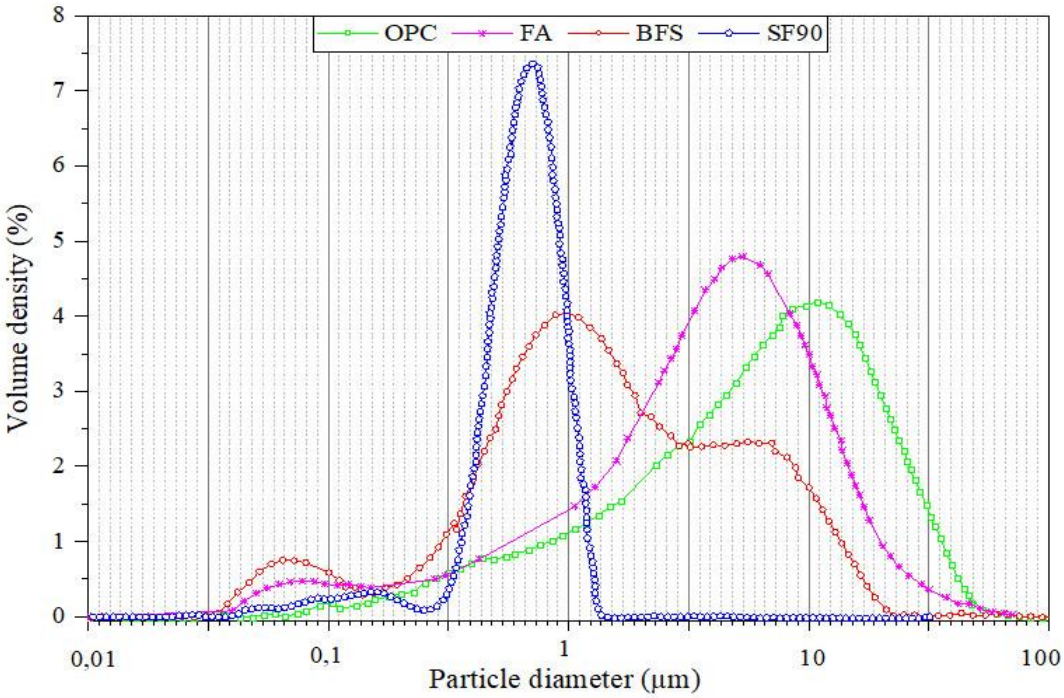


Figure 1. The particle size distribution of OPC, FA, BFS and SF90

Table 1. Properties of materials

Composition	OPC	FA	BFS	SF90
Silicon dioxide (SiO_2) (%)	22.56	56.37	35.45	91.63
Aluminum oxide (Al_2O_3) (%)	5.29	25.48	13.52	2.24
Ferric oxide (Fe_2O_3) (%)	3.47	5.67	-	2.48
Sulfur trioxide (SO_3) (%)	-	1.12	0.14	-
Potassium oxide (K_2O) (%)	0.61	-	0.28	-
Sodium oxide (Na_2O) (%)	0.14	-	-	0.56
Magnesium oxide (MgO) (%)	2.01	1.45	7.89	-
Calcium oxide (CaO) (%)	63.37	1.68	40.88	0.52
Titanium dioxide (TiO_2) (%)	-	-	0,50	-
Loss on ignition (%)	2.55	8.23	1.34	2.57
Specific gravity (g/cm^3)	3.10	2.34	2.29	2.15
Blaine fineness (cm^2/g)	3660	3980	4550	10150

- "SR-5000F SilkRoad" superplasticizer admixture (SP5000) (Vietnam) with specific gravity 1.1 g/cm^3 at 25°C has been used in this study.

- EABASSOC foaming agent manufactured at the factory EABSSOC in the United Kingdom. The foaming additives have the following specifications:

+ Specific weight 1.02 g/cm^3.

+ Dosage rate 0.3 - 0.6 lit/m^3.

- Mixing water (W) conforming to standard requirements GOST 23732-2011 and TCVN 4506:2012.

2.2. Mixture Proportioning

In the present study, the foam concrete mix proportions are given in Table 2. From data of study [12], the content of Portland cement is constant OPC of 450 kg/m^3 for mixtures 1700 kg/m^3 and OPC of 350 kg/m^3 with mixes 900 kg/m^3. For Series I-2, I-3 and II-2, II-3 were made by use SA and BFS as a replacement of 100% sand [13]. Besides, SR5000 and SF90 have been added in mixes (Series I-2, I-3, II-2, II-3) to increase strength and reduce water with ratio SR5000/OPC = 0.015, SF90/OPC = 0.1 [4, 14].

Table 2. Mix proportions of foam concrete

Series	Mix number	Wet density (kg)	OPC (kg)	SA (kg)	FA (kg)	BFS (kg)	SR5000 (kg)	SF90 (kg)	W (kg)	W $^{(*)}$ (kg)	Foam (L)
Series I	1	1700	450	1025	-	-	-	-	225	225	267
	2	1700	450	-	-	1086	6.8	45	113	241	265
	3	1700	450	-	1086	-	6.8	45	113	251	276
Series II	1	900	350	375	-	-	-	-	175	175	571
	2	900	350	-	-	422	5.25	35	88	172	594
	3	900	350	-	422	-	5.25	35	88	130	598

Where: W$^{(*)}$ actual water consumption for per 1m^3 (kg), according to [4] water(*) has been determined by the formula (1):

$$W^{(*)} = \beta*BFS + \alpha*FA + W \quad (1)$$

In which: β and α - respectively, the surface wetting coefficient of BFS and FA. Based on research results [4] showed that α = 10%FA, β = 20%BFS.

- The foam manufacturing process showed in Figure 2. First, the EABASSOC foaming agent is mixed in water in a ratio of 1: 25. This solution is then put into a foaming machine creating foam with a volume of 20 ÷ 25 times higher than the previous foaming solution. Then the foam is combined with the concrete mixture to be put into the mixer to create a foam concrete mixture.

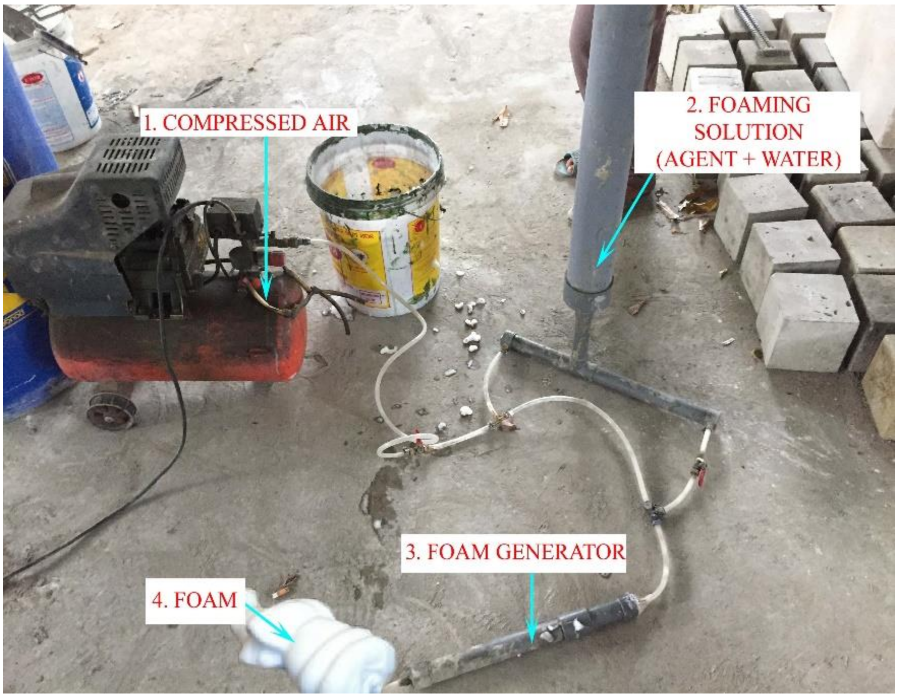


Figure 2. Foam Generator

2.3. Method

a) The foam concrete mechanical properties are determined according to the standard GOST 10180-2012. Density was determined at 28 days of age by 150x150x150 mm cubes.

b) Water absorption: Specimens with 150x150x150 mm cubes are oven-dried at the temperature 105 ± 5°C until constant and weighed after cooling under laboratory conditions. The specimen after dry, cooling and place in the water at 20 ± 3°C approximately for 24h and until the sequential weighted is closed less than 0.5%. Then this weight is considered wet, before measuring the weight of units after removing from a water towel is used to remove surface moisture [15]. Therefore, water absorption is calculated using the following equation (2):

$$W_a = \frac{m_b - m_c}{m_c} * 100\% \qquad (2)$$

In which: W_a is the water absorption (%);

- m_c is the mass of the dried sample (g);
- m_b is the mass of the sample in the water-saturated state (g).

c) Autogenous and Dry Shrinkage

In this case, the authors used six samples (100x100x100 mm) for each mixture to test autogenous shrinkage.

- For self-shrinkage shrinkage specimens, its upper surface is sealed with polyester film immediately after casting concrete to avoid moisture loss. After 24 hours, the test pieces are separated and immediately sealed with aluminum tape.

- For samples measuring shrinkage during drying, the samples are checked without sealing them. Measurements were determined continuously for 28 days. All samples were stored and tested in a room with temperature and humidity at 20 ± 5°C and 45 ± 5%, respectively.

3. Results and Discussion

As is mentioned above, this work was studied two types of foam concrete mix with a wet density of 1700 kg/m^3 and 900 kg/m^3. The test results about the properties of all mixtures of tested foam concrete are presented in Table 3.

Table 3. Results of compressive strength, flexural strength, dry density and water absorption of foam concrete

Series	Mix number	Dry density	Compressive strength at different curing times (MPa)					Flexural strength at 28 days (MPa)	Water absorption at 28 days (%)
			1 - day	3 - day	7 - day	14 - day	28 - day		
Series I	1	1620	2.25	5.62	8.46	12.36	13.91	3.25	5.78
	2	1680	12.79	32.81	35.82	40.56	42.35	6.72	1.06
	3	1650	11.96	31.11	34.96	39.47	40.59	6.51	0.92
Series II	1	850	0.54	1.03	1.10	1.38	1.69	0.53	22.16
	2	880	2.47	6.76	7.76	8.07	8.22	1.06	14.23
	3	865	2.38	6.37	7.14	7.68	7.89	1.03	13.35

3.1. Correlations between dry density and compressive strength

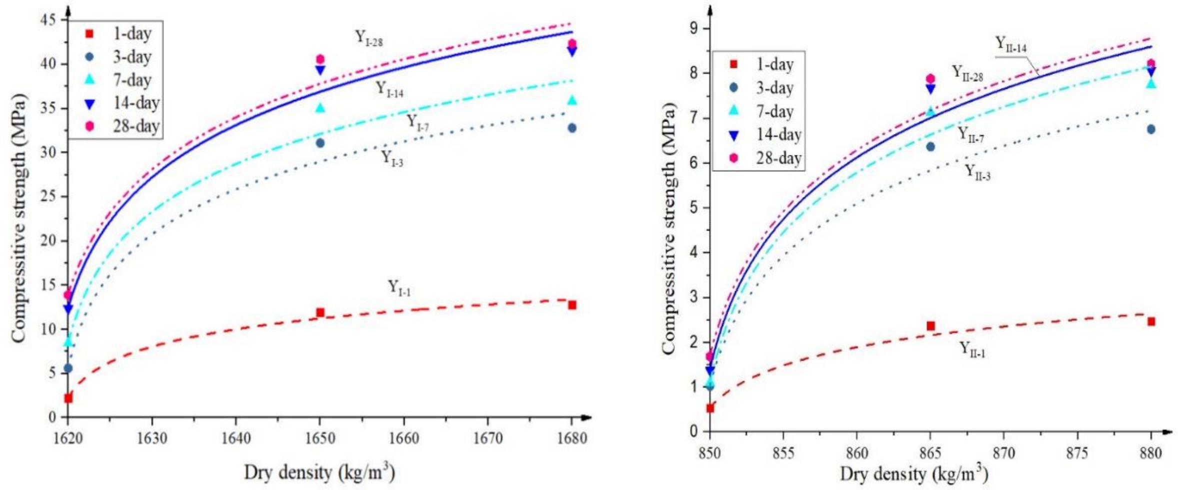
The relationship between foam concrete compressive strength and density is shown in Figure 3. The dry density was determined by cubes that were dried for 28 days before drying. From Fig. 3, it can be seen that there seems to be little difference between the strengths obtained from mixtures containing fly ash and blast furnace slag. The mixtures containing sand seem to have much smaller strengths than the mixtures containing fly ash and blast furnace slag.

Based on the research [16] indicates that the relationship between dry density and compressive strength of foam concrete can be expressed as follows.

$$y = a*\ln(x-b) \tag{3}$$

In which: y is the foam concrete compressive strength (MPa);

- x is the dry density of foam concrete (kg/m^3);
- a and b are coefficients.



(a) For series I of tested foam concrete (b) For series II of tested foam concrete

Figure 3. The relationship between dry density and compressive strength

Besides, the relationship between dry density and compressive strength of two series mixes of tested foam concrete is presented given in formulas from (4) to (13) (in Table 4) and shown in Figure 3.

Table 4. Content of Fig. 3.

Mixture	Curing age	Regression equation	Correlation coefficient (R^2)	No
+ For Series I:	1 days	Y_{I-1} = 3.244*ln(x-1818)	0.975	(4)
	3 days	Y_{I-3} =8.374*ln(x-1618)	0.968	(5)
	7 days	Y_{I-7} = 9.229*ln(x-1617)	0.944	(6)
	14 days	Y_{I-14} = 10.532*ln(x-1617)	0.958	(7)
	28 days	Y_{I-28} = 10.748*ln(x-1616)	0.948	(8)
+ For Series II:	1 days	Y_{II-1} = 0.762*ln(x-848)	0.934	(9)
	3 days	Y_{II-3} = 2.078*ln(x-848)	0.955	(10)
	7 days	Y_{II-7} = 2.363*ln(x-848)	0.969	(11)
	14 days	Y_{II-14} = 2.488*ln(x-848)	0.948	(12)
	28 days	Y_{II-28} = 2.536*ln(x-848)	0.939	(13)

The correlation between dry density and compressive strength having a positive linear relationship follows the formula (3) with a correlation coefficient of more 0.9 (R^2 > 0.90), which indicated an excellent relationship.

3.2. *Compressive strength*

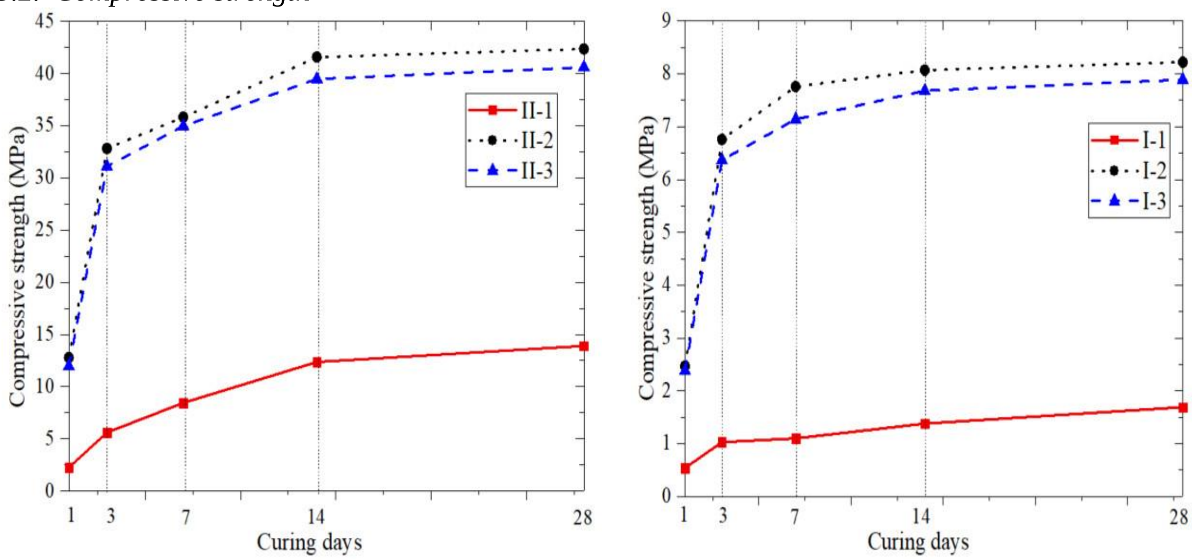


Figure 4. Compressive strength versus time for foam concrete

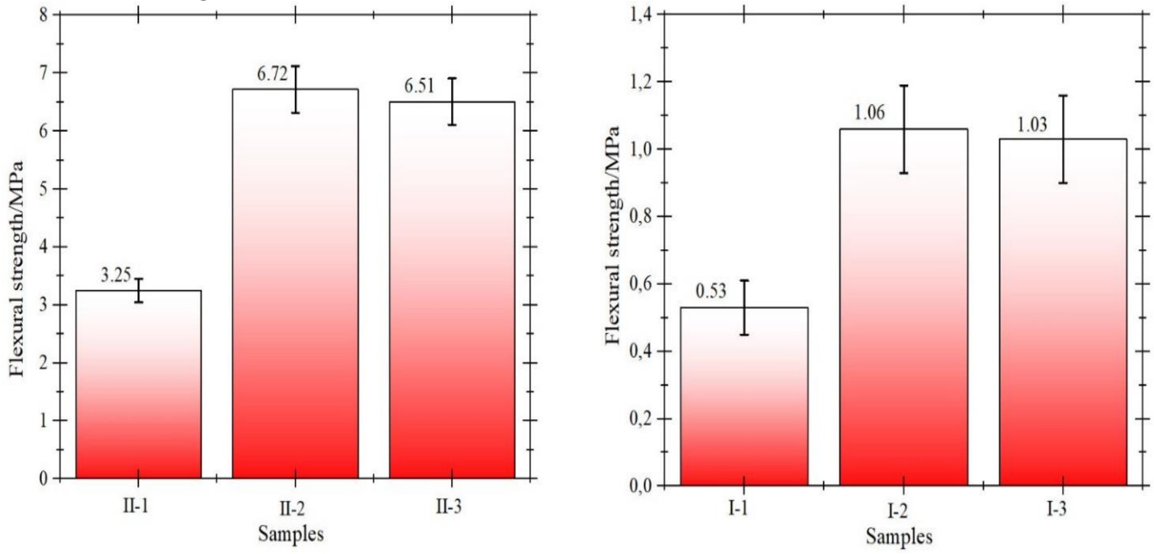
From Figure 4 we see that:

(1) The development of compressive strength with different ages of foam concrete, which contains varying amounts of SF90, FA and BFS (Vietnam). It can be seen that the compressive strength in almost all samples a continuous rise with age. The rate of force development was taller initially and reduce with age. However, a comparison of strengths over 7 days showed that (Series I-1 and Series II-1) developed almost 60–65% of the 28-day strength, while (Series I-2, I-3, and Series II-2, II-3) containing silica fume, superplasticizer, and blast furnace slag, fly ash replaced sand developed almost 85–95% of the corresponding 28-day strength. The increase in strength is due to the increased content of hydrated products (calcium silicate hydrate - CSH), combined with hydration of cement with active silica from a mixture of SF90, FA and BFS [17, 18, 19].

(2) The compressive strength at 28 days age of Series II-2 and Series I-2 are highest. This is explained that the blast furnace slag has hydraulic properties and can react with water; however, dense

layers rich in silica form in the grain surface, which prevents further reactions with water. Besides, this increase is also because the mineral additive has a significantly smaller size, which leads to the filling of pores in the cement stone, which increases the mechanical properties of the foam concrete samples [20].

3.3. *Flexural strength*

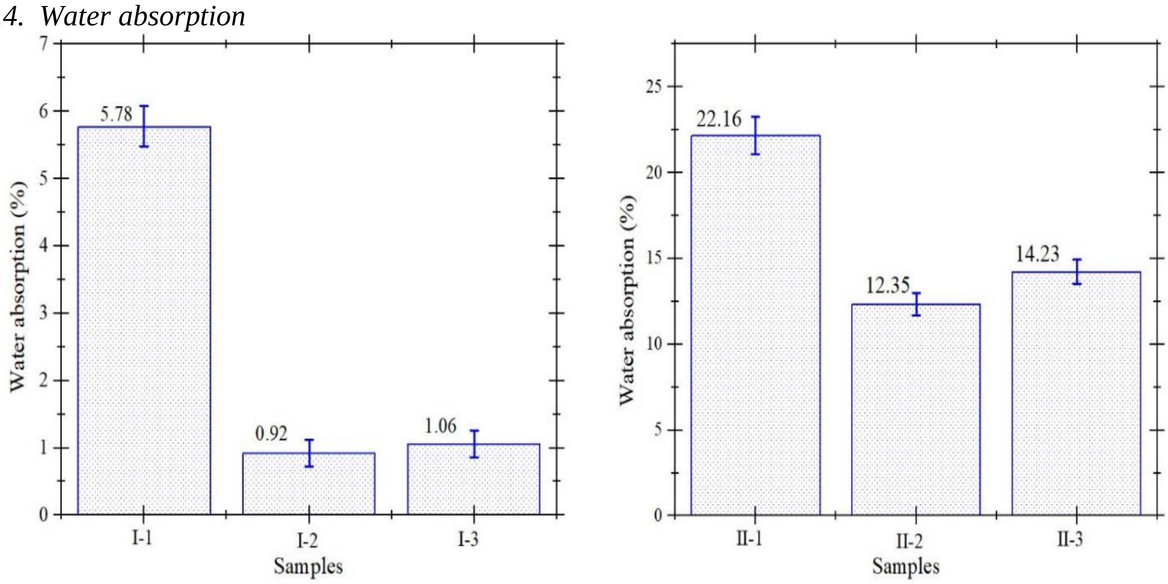


(a) For series I of tested foam concrete (b) For series II of tested foam concrete

Figure 5. Foam concrete flexural strength at age 28 days

Data from Figure 5 shows, when FA, BFS replace sand and add additives. which increases the bending strength ((series I-2, I-3 increases by 103,4% and 100,2%; series II -2, II-3 and an increase of 100% and 97,2% compared with series I-1 and series II-1). It is directly related to the compressive strength results. When the compressive strength increases, the flexural strength increases. The flexural strength of all samples varied from 3.25 to 6.72 MPa (Series I) and from 0.53 to 1.06 MPa (Series II).

3.4. *Water absorption*



(a) (b)

Figure 6. Flexural strength of foam concrete at age 28 days: (a) – for series I and (b) – for series II

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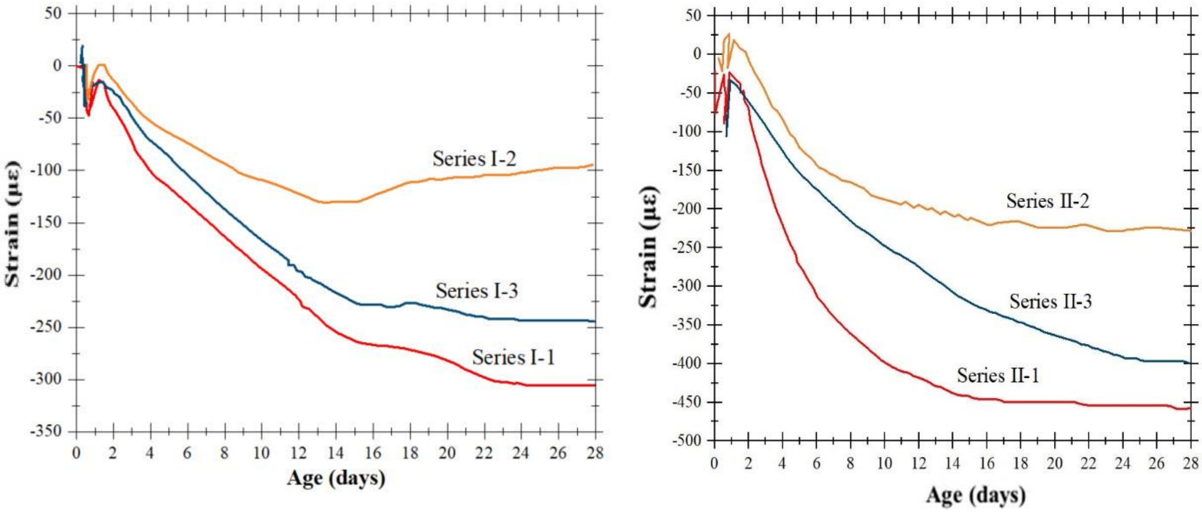
Water absorption of foam concrete depends on the state of the water content [21]. Foam concrete water absorption is shown in Fig. 6. As mentioned earlier, silica fume can improve foam concrete compressive and flexural strength. The addition of silica fume also reduces the foam concrete water absorption.

Besides that, water absorption of series I-2 and series II-2 are the lowest. This is explained that blast furnace slag has been used as a substitute for sand in series I-2 and series II-2. While Blaine fineness of blast furnace slag is 4550 cm^2/g. This implies that Pore structure in foam concrete will be smaller than leads to a decrease in water absorption.

3.5. Drying Shrinkage

The drying shrinkage of the tested foam concrete was illustrated in Figure 7. For all samples, the shrinkage curve stops after 28 days. These results relate to the amount of potential hydration material in foam concrete. From the data of Figure 7, it's easy to see that the effects of complete replacement of fine-aggregate with FA and BFS decreased the foam concrete shrinkage.



(a) For series I (b) For series II

Figure 7. Results of drying shrinkage at age 28 days

4. Conclusion and future work

Based on experimental results, we can draw conclusions below:

+ Foam concrete can be prepared with the use of FA and BFS as a replacement of natural sand, so it not only used to reuse industrial waste but also can protect the environment.

+ Foam concrete with density 1700 kg/m^3 (Series I-2, I-3) can replace traditional concrete in construction. Series (II-2, II-3) can study the production of foam concrete bricks to replace clay bricks. This leads to reduced work-load, so it can reduce the cost price.

+ Water resistance of (Series I-2, I-3) and Series (II-2, II-3) is significantly improved by the introduction of silica fume, superplasticizer as well used blast furnace slag and fly ash.

+ Both FA and BFS concretes showed greater autogenous shrinkage than OPC. The use of FA and BFS instead of fine-aggregate decreased the shrinkage of the foam concrete.

+ Based on the research results, it shows that using blast furnace slag and fly ash to replace sand in foam concrete will not only increase the compressive and bending strength but also can reduce costs as well as protect the environment such as green concrete or other environmental-friendly materials in future work.

Acknowledgments.
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