Calibration of a Strength Prediction Model for Foamed Cellular Concrete

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Abstract– ***Foamed cellular concrete (FCC) is basically composed by a cement paste or mortar with intentionally incorporated air bubbles and it presents interesting characteristics for the construction industry. To study and understand the material structural behavior, mathematical models have been developed in order to predict its compressive strength. To this end, various researchers have adapted models designed for normal-density (NC) concrete, for considering and include the particular characteristics of FCF. Balshin's Strength-Porosity Model is a case of model adapted from NC to FCC, because of the nature of the latter material is strongly influenced by the void or pore volume. In this work, an experimental campaign is carried to obtain the constants of this model, using the expression of theoretical porosity developed by Nambiar and Ramamurthy for FCC. In this way, a resistance prediction model is calibrated with the materials and methods used in the local industry. Also, the relationship between the material strength and density is evaluated, and a mathematical equation is developed for quantifying it. An experimental campaign was carried out, the aforementioned constants were determined and compared with those obtained in previous investigations of other authors. The results are shown in tables and graphs. Conclusions are drawn.***

Keywords-- mathematical model, prediction of resistance, model calibration, foamed cellular concrete.

I. INTRODUCTION

FCC is a type of cellular concrete (CC) that is made by incorporating air bubbles, through a pre-formed foam, into a cement paste or mortar, which gives the material a porous structure [1]. To this basic components, active or inert mineral additions are usually incorporated [2], chemical additives, fibers [3], among other components, which can accompany or replace them in whole or in part. In this way, a material with particular and highly variable characteristics could be obtained. The density, for example, can vary between 300 and 2100 kg / m³ [1, 4], which depends mainly on the density of the foam and its dosage [5]. Due to its density, it is classified as light concrete (LC) and it has characteristics that generate interest for its application in the construction industry, including high workability and fluidity, high levels of thermal insulation (greater than 0.50 W/mK) and the possibility of developing compressive strengths greater than 20 MPa [6].

As in other concretes, the prediction of the resistance of the material is essential for its design and the quantification of its characteristics, it is therefore necessary to study and develop resistance prediction models. Several investigators have adapted models developed for normal density concretes to predict the resistance of CC such as Feret's model, Balshin's Strength-Porosity Model and Power's Gel-Space Ratio [7], among others.

Power's model relates the compressive strength of concrete to the gel-space ratio of the material, defined as the ratio of the volume of hydrated cement paste to the sum of the volumes of hydrated cement and capillary pores. The latter volume corresponds with the space available for the generation of more quantity of the first volume, and from there comes the name [7]. Nambiar and Ramamurthy [8], adapted this model to determine the compressive strength of the FCC composed of cement, filler (sand and or fly ash), water and preformed foam, with wet curing. In equation 1, Power's gel-space model is presented and in equation 2 the expression developed by Nambiar and Ramamurthy for cellular concrete, where σ is the compressive strength of the FCC; σ_0 is a constant of the model that represents the intrinsic strength of the gel for the type of cement and specimen used for its experimental determination; b is a constant of the model; X is the gel-space ratio; α is the fraction of cement that has been hydrated, which is assumed equal to 0.80; V_c is the cement volume and V_f is the filler volume:

$$\sigma = \sigma_0 (X)^b \tag{1}$$

$$\sigma = \sigma_0 \left(\frac{2.06 \alpha V_c}{1 - V_f - V_c (1 - \alpha)} \right)^b \tag{2}$$

Another model that has been applied to the determination of the compressive strength of FCC is Feret's, which relates this characteristic of the material to the volumes of water and air cement, through 2 constants [7]. Tam et al. [9], worked with this model to study the dependence of CC resistance on water-cement and air-cement relationships, theoretically and experimentally. Additionally, they included in this model the degree of hydration used in the Power model, already analyzed, to obtain an expression with a better experimental correlation. In the equations 3 and 4, the models of Feret and Tam et al., respectively, are shown. In them, σ is the compressive strength of the concrete; K is a constant of the model; K_3 is a factor that represents the increased volume of the hydrated cement gel relative to the original volume of cement that has been hydrated; n is a constant to be determined experimentally; α is the fraction of cement that has been hydrated and; c, w and a are the volumes of cement, water and air, respectively:

$$\sigma = K\left(\frac{c}{c+w+a}\right)^2 \tag{3}$$

$$\sigma = K\left(\frac{K_3\alpha c}{\alpha c+w+a}\right)^n \tag{4}$$

Due to the influence of porosity on the compressive strength of FCC, one of the strength-prediction models that has been adapted to this material is Balshin's Strength-Porosity Model, which uses the theoretical porosity of concrete, to estimate its compressive strength through the expression shown in equation number 5 [7]. Developed for normal concrete (NC), it has been adapted to various types of material variations. In this expression: σ is the compressive strength of the NC, σ_0 and b are the model constants, and n is the theoretical porosity, equal to the ratio between the volume of voids to the volume of fills of the material:

$$\sigma = \sigma_0(1-n)^b \tag{5}$$

In this line of work, Hoff adapted this model to FCC made with cement paste and pre-formed foam [10]. By quantifying the space occupied by the evaporable water plus the air intentionally incorporated through the foam, he obtained equation number 6 which, depending on the density of the cellular concrete, its water-cement ratio and the specific density of the cement, allows estimating the compressive strength of the material. In this equation: σ is the compressive strength of the FCC, σ_0 and b are the model constants, d_c is the density of cellular concrete, ρ_c specific density of cement, Υ_w is the density of water and k is the water-cement ratio by weight:

$$\sigma = \sigma_0\left(\frac{d_c(1+0.20\rho_c)}{(1+k)\rho_c\gamma_w}\right)^b \tag{6}$$

Nambiar and Ramamurthy, modified Hoff's model to consider the inclusion of sand and fly ash to the FCC as inert and active aggregates, respectively [8]. This way, they obtained the expression shown in equation number 7. Where: σ is the compressive strength of FCC, σ_0 and b are the model constants, d_c is the density of cellular concrete, ρ_c specific density of cement, Υ_w is the density of water, k_s is the water-solids ratio by weight, s_w is the filler-cement ratio by weight, s_v is the filler-cement ratio by volume.

$$\sigma = \sigma_0\left(\frac{d_c(1+0.20\rho_c+s_v)}{(1+k_s)(1+s_w)\rho_c\gamma_w}\right)^b \tag{7}$$

In these models, the constant σ_0 represents the theoretical resistance of the ideal paste, without porosity, and is mainly a function of the chemical composition of the cement [7, 10]. The properties of the paste or mortar only influence this coefficient, while they do not affect b [11]. Through numerical modeling, Nguyen et al. [12] (2019) observed that the value of the exponent b is slightly affected by the size of the pores, which indicates that the same expression can be used for mixtures with different radii of them. This is in accordance with what was expressed by Hoff, who also stated that it is possible to obtain the same porosity in materials with different pore sizes [10]. Preliminary studies in this regard suggest that the distribution of the pore radii, that is, heterogeneity in the size of the pores for the same mixture, significantly affects the value of this exponent [11].

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The American Concrete Institute (ACI) proposes in its Guide for cellular concretes [1] the model shown below, in equation number 8, for the determination of its compressive strength. In it, σ is the compressive strength of the FCC and Υ_f is the as-cast density of the material, which is determined from the expression presented in the equation 9, where c is the cement content by weight, *w/c* is the water-cement ratio by weight and *s/c* is the cement sand ratio by weight:

$$\sigma = 0.34 \times e^{0.0022\times\gamma_f} \tag{8}$$

$$\gamma_f = c\left(1+\frac{w}{c}+\frac{s}{c}\right)^2 \tag{9}$$

Kiani *et al.* [13], proposed an empirical model for predicting the compressive strength of preformed-foam cellular concrete using genetic programming:

$$f_c = \frac{\ln\left(C^{\sqrt{C}}\right) \times \ln\left(F^{\sqrt{F}}\right)^3}{-5.435\left(\frac{W}{B}\right)^{0.8}} \tag{10}$$

Where C is the mass of cement, *W/B* is ratio of water to binder by weight and F is the absolute volumetric proportion of foam. There, the effect of the pozzolans is captured in the binder.

There are also, other proposed models, rather than the exposed [14]. In this work, the procedure carried out to obtain the constants of the Balshin's Strength-porosity model is presented, involving materials, methods and production technology of FCC from the local industry. The target of this work was to generate a tool that allows knowing the resistance of the material for each proposed mix. For this, 18 FCC dosages were designed, and 30 cylindrical specimens were casted, according to IRAM 1534 Standard and compression tested according to IRAM 1546 Standard. Next, the expression of Nambiar and Ramamurthy [8] was used for the determination of the theoretical porosity of each dosage. Comparing the results obtained for compressive strength and theoretical porosity, the constants of the Balshin's Strength-porosity model were obtained. Also, the relationship between

FCC strength and density is evaluated, obtaining a mathematical expression for relating both.

II. MATERIALS AND METHODS

To calibrate the proposed model, the dosages shown in table 1 where used. In them the material parameters vary for achieving different mixture designs. The dosages were arranged in order of increasing theoretical density, detailing the amounts of each of the FCC component materials.

TABLE I
DESIGN MIXES PROPORTIONS.

Mix	Cement [kg/m³]	Water [kg/m³]	Sand [kg/m³]	Foam [kg/m³]	Target Density [kg/m³]
1	349	139	191	35	713
2	343	137	240	35	755
3	321	321	129	32	804
4	277	628	155	36	1108
5	297	119	596	30	1042
6	270	613	152	37	1072
7	290	659	163	37	1144
8	343	137	686	34	1201
9	397	209	596	30	1232
10	320	735	160	32	1246
11	514	231	514	26	1286
12	439	237	660	27	1364
13	477	210	953	29	1668
14	408	310	938	16	1673
15	483	217	966	24	1691
16	448	206	1030	18	1702
17	443	270	1019	17	1749
18	555	267	1111	11	1944

A Composite Portland Cement CPC 50, locally available commercial brand, with a specific density equal to 3.09, experimentally determined according to IRAM 1624 standard was used. Fine river sand, with specific density equal to 2.65, obtained according to IRAM 1520 standard was used too. To generate the pre-formed foam, a synthetic type of foaming agent, water and compressed air were used. The relative density of the foam was assumed to be known for the dosage of each sample. Then, during the preparation of the specimens, it was measured by determining its weight in a container of known volume. In figure 1, a series of test specimens is shown.

Figure 1. FCC specimens been prepared for testing.

The determination of the resistance of each specimen was carried out by simple compression test, according to IRAM 1546 Standard, on a 1000 kN Shimadzu Universal Testing Machine, with load control. This procedure is shown below in figure 2.

Figure 2. Compression testing in 1000 kN Shimadzu Universal Testing machine.

In each batch, the water content of each mixture was adjusted with the natural moisture content of the sand. A total of 31 cylindrical specimens of 15 cm in diameter by 30 cm in height were obtained, which were used for the experimental determinations described below. 3 test specimens of dosages 6, 8, 11, 13 and 18 were made; 2 test specimens of dosage 7, 10 and 15; and 1 specimen of dosages 1, 2, 3, 4, 5, 9, 12, 14, 16 and 17, following the guidelines of the IRAM 1534 Standard.

III. RESULTS

The results obtained for each test specimen are shown below, in table 2.

In it, dry-density, breaking stress, and theoretical porosity are presented. Dry density was calculated prior to compression test; breaking stress and theoretical porosity were determined in accordance with the Balshin´s strength-porosity model, adopted with the expression of Nambiar and Ramamurthy, showed in equation 7, for each or 31 specimens.

TABLE II
RESULTS.

Mix	Dry Density [kg/m³]	Strength [MPa]	(1-n)
1	642	0.33	0.25
2	676	0.57	0.26
3	796	0.17	0.29
4	1110	0.90	0.38
5	1043	1.61	0.44
6	1075	1.11	0.37
7	1149	1.91	0.42
8	1201	4.44	0.46
9	1235	3.00	0.44
10	1247	1.60	0.41
11	1287	6.06	0.47
12	1360	6.47	0.48
13	1666	15.32	0.61
14	1670	4.71	0.58
15	1692	11.07	0.64
16	1705	12.73	0.67
17	1752	9.47	0.62
18	1944	26.56	0.71

IV. DISCUSSION

The discussion of the obtained results is divided into two sub-sections. In the first one, concerning the relationship between the material compression strength vs its theoretical porosity and so, the calibration of the strength-porosity model. In the other side, a sub-section is considered for the analysis of the relationship of the material compression strength and its density.

A. Relationship between compression strength and theoretical porosity.

Placing the results obtained in a cartesian graph, the constants of the Balshin’s strength-porosity model are obtained [10]. The value obtained for theoretical porosity of each sample, determined through the model of [8], was located on the abscissa axis and the corresponding compressive strength value on the ordinate axis. Next, a potential fitting curve was applied, in the form y = a*x^b, with which the constants σ_0 and b of the strength-porosity model were determined. Figure 3 shows the location of each ordered pair in the Cartesian graph, the potential fit curve, the values of the constants obtained and the value of the coefficient of determination R^2. The interpretation of the determination coefficient indicates that 87.21% of the compressive strength of the material under study is explained by the parameters contemplated by the model, the rest is due to other factors. The R^2 value obtained is typical for this type of models, and is very close to those determined by other researchers for this type of model [8, 11].

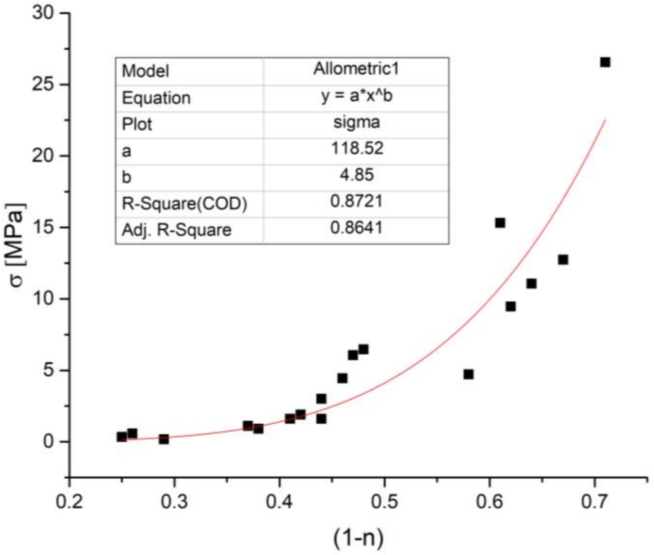

Figure 3. Power fitting for de relationship between compression strength (σ) and theoretical porosity (n) of the FCC.

In this way, the model constants were obtained. Applying them to Balshin's strength-porosity model, the expression presented in equation 4 is obtained.

$$\sigma = 118.52(1-n)^{4.85} \tag{11}$$

In this expression, σ is the material compression strength and *n*, the theoretical porosity. Applying the obtained constants to the Nambiar and Ramamurthy expression for the theoretical porosity of the FCC, equation 12 is obtained.

$$\sigma = 118.52\left(\frac{d_c(1+0.20\rho_c+s_v)}{(1+k_s)(1+s_w)\rho_c\gamma_w}\right)^{4.85} \tag{12}$$

There, σ is the compressive strength of FCC, σ_0 and *b* are the model constants, d_c is the density of cellular concrete, ρ_c specific density of cement, Υ_w is the density of water, k_s is the water-solids ratio by weight, s_w is the filler-cement ratio by weight, s_v is the filler-cement ratio by volume.

In table 3, values obtained for the constants of the Strength-porosity model for FCC are compiled [8, 10, 15]. There is also included de valued obtained by Narayanan and Ramamurthy [14], who worked with not-autoclaved aerated cellular concrete (ACC) and the ones of Nguyen et al., who worked with numerical modeling of the FCC through the discrete elements method (DEM) [11, 12].

TABLE III

VALUES OF STRENGTH-POROSITY MODEL'S CONSTANTS.

Author	FCC Components	σ_0	b
[8]	Cement, sand.	155.66	4.30
[8]	Cement, sand, fly ash.	105.14	2.68
[10]	Cement.	115.00 – 290.00	2.70 – 3.00
[12]	Fly ash.	369.51	3.80
[14]	Cement, sand.	26.60	3.20
[14]	Cement, sand, fly ash.	24.28	1.80
[15]	Cement with and without fly ash.	188.00	3.10
[15]	Cement with high content of fly ash	321.00	3.60
Present work	Cement, sand.	118.52	4.85

The obtained results confirmed that the compressive strength of FCC is profoundly affected by its porosity, as stated by [15, 16]. Steshenko et al., concluded that, the greater the dispersion of the pore diameters generated by the foam, the lower the mechanical properties of the material [17]. Nguyen et al., evaluated the influence of voids on the compressive behavior of CC, through numerical and experimental methods [11]. They concluded that the porosity and the type of voids of HCE have a profound influence on its resistance to compression capacity, while that of micro-porosity is much lower. They also found high consistency between the experimental and numerical results with those of the resistance-porosity models.

In figure 4, a piece of FCC test specimen is shown. There, the internal texture of the material can be appreciated.

Figure 4. FCC specimen internal appearance.

The size of the pores has been shown to influence the resistance to breakage of the material. A decrease in the pore size leads to an increase in the compressive strength of the material and this influence is greater in FCC with low porosity [12]. Nambiar and Ramamurthy, worked on the characterization of the voids in FCC [18]. They observed that the volume, size and spacing between pores influences the strength and density of the material. That mixtures with smaller pore sizes present greater resistance. For higher foam contents, the mixture between bubbles generates larger sizes of voids and greater variability between their sizes, which reduces the mechanical resistance of the material. They also concluded that the shape of the pores has no influence on the properties of FCC, since the voids have approximately the same shape, even for different foam contents.

The volume of pores artificially included through the foam directly affects the density of the CC and its resistance [19]. In turn, the density of the foam and its volume in relation to the rest of the components of the mixture determine the number and volume of pores. The lower the density and the higher the amount of foam, there will be a greater incorporation of air into the cement paste and, therefore, a smaller surface of solids to absorb stress. This leads to the resulting material having a lower resistance to compression.

B. Relationship between compression strength and dry-density.

One of the distinguishing features of the FC is its wide range of possible densities and with them, varies the characteristics of the material. In any cement paste or mortar, density changes as the components vary, but within limited values. In FCC, however, the incorporation of the preformed foam generates very large changes in the characteristics of the mixture. Foam dosage has large influence in the material density. In addition, density of foamed concrete has a direct correlation with the foam content of the mixture [5]. In this way, densities close to 300 kg/m³, or even lower, can be obtained as well as densities close to those of NC [20]. In spite of that, its usual working with maximum values of self-weights equal to or less than 2 100 kg/m³.

To evaluate the relationship between the FCC density and its strength, the values of both variables were putted in a cartesian graph, as is shown in figure 5. Then, a series of different equations of approximation for this relationship were tested, finding that the one with a higher value for de coefficient of determination R^2 is the linear fitting.

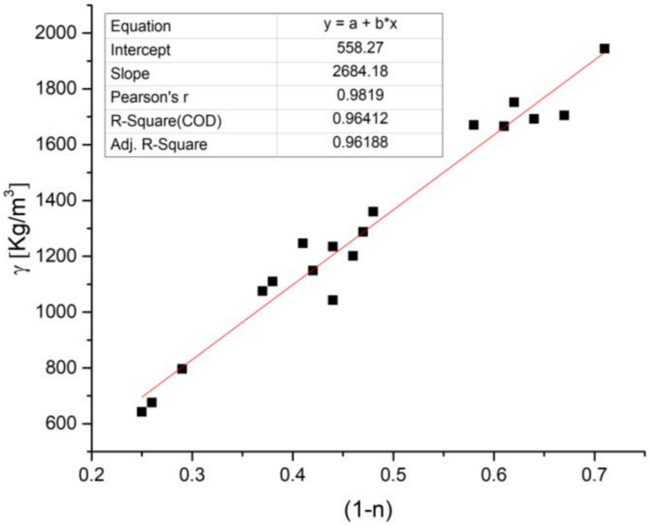

Figure 5. Linear fitting for the relation between compression strength and density of the FCC.

This way, an analytical expression, that relates these two characteristics of the material was achieved, and is shown in equation 13:

$$\sigma = 2684.18\gamma + 558.27 \tag{13}$$

In it, σ is the compression strength and ϒ the dry-density of the FCC. As it can be seen, there is a linear relation between them. Shapiro-Wilk normality test was conducted and the normality of the data series was confirmed. So, Pearson's correlation coefficient was calculated, obtaining a value of 0.98, which indicates a strong correlation or association between these 2 variables, for the FCC.

It is common to refer to the density of the FCC according to its state, that is: as-cast density, air-dry density, oven-dry density, as the most common [1]. As-cast density is obtained at the fresh state of the material, by determining its weight in a tared container of known volume. Its determination is essential to ensure the quality of the mix at the time of its elaboration. Dry densities differ from this one by the amount of water evaporated from the mixture, which will be a function of the curing conditions.

In the works of Hoff and Nambiar and Ramamurthy, a value of the volume of non-evaporable water equal to 80 % of the cement weight in the mixture was adopted [8, 10]. On the other hand, Legatski and Fouad determined that the dry density is approximately 80 kg/m³ less than the wet one, being able to be up to 160 kg/m³ less than that one [21, 22].

V. CONCLUSIONS

An experimental campaign was carried out to calibrate Balshin's strength-porosity model, adapting it for been used in FCC through the expression of theoretical porosity developed by Nambiar and Ramamurthy, in order to use it with materials and methods of local industry. With this, the following conclusions were reached:

1) In order for the strength-porosity model to adequately estimate the resistance of FCC made with local industry materials and methods, it must be calibrated. Otherwise, the values obtained with the constants determined by other researchers are not consistent with the results of the tests of local materials.
2) It is possible to obtain the constants of Balshin's strength-porosity model, utilizing the mathematical expression developed by Nambiar and Ramamurthy for adapting it to FCC, for its use with the materials and methods of the local industry.
3) The values obtained from the constants are within the range of those determined by other researchers, but with different values from the previous ones.
4) The adjustment curve obtained presents a high value of the determination coefficient R², consistent with the values obtained by other researchers for this type of resistance prediction model.
5) In this way, it is shown that it is possible to obtain a mathematical model that reflects the behavior of the FCC produced in the local industry.

6) In spite of what has been said, a percentage of the compressive strength value will depend on variables that are not included in the model. This fact is usual in this type of mathematical models.
7) The values of the constants obtained are within the expected values, in comparison with those obtained in previous investigations presented and shown in table number 3.
8) It is possible to obtain a mathematical expression for relating density and compression strength of the FCC. In the present work, linear fitting shown a higher Determination coefficient R² than others evaluated.

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REFERENCES

[1] ACI (American Concrete Institute). (2014). Guide for cellular concretes above 50 lb=ft3 (800 kg=m3). ACI 523.3R-14. Farmington Hills, MI: ACI.

[2] Nambiar, E. K., & Ramamurthy, K. (2006). Influence of filler type on the properties of foam concrete. Cement and concrete composites, 28(5), 475-480.

[3] Jhatial, A. A., Goh, W. I., Mohamad, N., Alengaram, U. J., & Mo, K. H. (2018). Effect of polypropylene fibres on the thermal conductivity of lightweight foamed concrete. In MATEC Web of Conferences (Vol. 150, p. 03008). EDP Sciences.

[4] Chica, L., & Alzate, A. (2019). Cellular concrete review: New trends for application in construction. Construction and Building Materials, 200, 637-647.

[5] Kozłowski, M., & Kadela, M. (2018). Mechanical characterization of lightweight foamed concrete. Advances in Materials Science and Engineering, 2018.

[6] Jones, M. R., & McCarthy, A. (2005). Preliminary views on the potential of foamed concrete as a structural material. Magazine of concrete research, 57(1), 21-31.

[7] Neville, A. M. (1995). Properties of concrete (Vol. 4). London: Longman.

[8] Nambiar, E. K., & Ramamurthy, K. (2008). Models for strength prediction of foam concrete. Materials and structures, 41(2), 247-254.

[9] Tam, C. T., Lim, T. Y., Sri Ravindrarajah, R., & Lee, S. L. (1987). Relationship between strength and volumetric composition of moist-cured cellular concrete. Magazine of Concrete Research, 39(138), 12-18.

[10] Hoff, G. C. (1972). Porosity-strength considerations for cellular concrete. Cement and Concrete Research, 2(1), 91-100.

[11] Nguyen, T. T., Bui, H. H., Ngo, T. D., & Nguyen, G. D. (2017). Experimental and numerical investigation of influence of air-voids on the compressive behaviour of foamed concrete. Materials & Design, 130, 103-119.

[12] Nguyen, T. T., Bui, H. H., Ngo, T. D., Nguyen, G. D., Kreher, M. U., & Darve, F. (2019). A micromechanical investigation for the effects of pore size and its distribution on geopolymer foam concrete under uniaxial compression. Engineering Fracture Mechanics, 209, 228-244.

[13] Kiani, B., Gandomi, A. H., Sajedi, S., & Liang, R. Y. (2016). New formulation of compressive strength of preformed-foam cellular concrete: an evolutionary approach. Journal of Materials in Civil Engineering, 28(10), 04016092.

[14] Narayanan, N., & Ramamurthy, K. (2000). Structure and properties of aerated concrete: a review. Cement and Concrete composites, 22(5), 321-329.

[15] Kearsley, E. P., & Wainwright, P. J. (2002). The effect of porosity on the strength of foamed concrete. Cement and concrete research, 32(2), 233-239.

[16] Hajimohammadi, A., Ngo, T., & Mendis, P. (2018). Enhancing the strength of pre-made foams for foam concrete applications. Cement and Concrete Composites, 87, 164-171.

[17] Baranova, A., Shustov, P., & Yazina, O. (2018). Structural and heat-insulating foam concrete of non-autoclaved hardening based on microsilica. In MATEC Web of Conferences (Vol. 212, p. 01003). EDP Sciences.

[18] Nambiar, E. K., & Ramamurthy, K. (2007). Air-void characterisation of foam concrete. Cement and concrete research, 37(2), 221-230.

[19] Schober, G. (2011, September). Porosity in autoclaved aerated concrete (AAC): A review on pore structure, types of porosity, measurement methods and effects of porosity on properties. In 5th International Conference on Autoclaved Aerated Concrete (No. 39–43, pp. 351-359). Bydgoscsz Poland.

[20] Mohd Zahari, N., Abdul Rahman, I., & Ahmad Zaidi, A. M. (2009). Foamed concrete: potential application in thermal insulation.

[21] Legatski, L. A. (1994). Cellular concrete. In Significance of Tests and Properties of Concrete and Concrete-Making Materials. ASTM International.

[22] Fouad, F. H. (2006). Cellular concrete. In Significance of Tests and Properties of Concrete and Concrete-making Materials. ASTM International.