International Journal on Emerging Technologies **11**(3): 53-58(2020)

**ISSN No. (Print): 0975-8364**
**ISSN No. (Online): 2249-3255**

# Evaluation of Engineering Properties of Ultra-lightweight Foamed Concrete Produced using the Pre-foamed Method

***Trong-Phuoc Huynh[1], Van-Hien Pham[2], Minh-Luan Tran[2] and Nguyen-Trong Ho[3]***

*[1]Lecturer, Department of Rural Technology, College of Rural Development, Can Tho University, Campus II, 3/2 Street, Ninh Kieu District, Can Tho City 900000, Vietnam.*

*[2]Undergraduate student, Department of Civil Engineering, College of Engineering Technology, Can Tho University, Campus II, 3/2 St., Ninh Kieu Dist., Can Tho City 900000, Vietnam.*

*[3]Ph. D. Candidate, Faculty of Civil Engineering, VSB Technical University of Ostrava, Ludvika Podesta 1875/17, 708 33 Ostrava-Poruba, Czech Republic.*

*(Corresponding author: Trong-Phuoc Huynh)*

*(Received 24 January 2020, Revised 01 April 2020, Accepted 03 April 2020)*
*(Published by Research Trend, Website: www.researchtrend.net)*

**ABSTRACT: The major aim of this experimental study is to evaluate the engineering properties of ultra-lightweight foamed concrete produced using the pre-foamed method. Four ultra-lightweight foamed concrete mixtures were designed with the target dry densities of 500, 600, 700, and 800 kg/m$^3$ corresponding to the foam contents of 7.1, 5.3, 4.2 and 2.7%. It is noted that the foam was prepared prior to be used by a foam generator using the foaming agent/water ratio of 1/40. Local materials sourced from Southern Vietnam, including PC40 Portland cement, fly ash, slag, stone powder, superplasticizer, and water were used for this study. All of the ultra-lightweight foamed concrete samples were prepared in the laboratory for the tests of compressive strength, water absorption, dry density, drying shrinkage, and thermal conductivity. Moreover, the microstructure of the ultra-lightweight foamed concrete samples was also observed using a scanning electron microscope. Cost analysis was also performed to further evaluate the potential application of the ultra-lightweight foamed concrete in real practice. Test results show that foam content affected the engineering properties of the ultra-lightweight foamed concrete samples significantly. The increase in foam content resulted in increasing water absorption and drying shrinkage while decreasing compressive strength, dry density, thermal conductivity, and cost. A poorer microstructure was also observed at the ultra-lightweight foamed concrete samples containing more foam. The ultra-lightweight foamed concrete samples with dry densities ranging from 500 – 800 kg/m$^3$ obtained the compressive strength, water absorption, thermal conductivity, and cost in the ranges of 0.78 – 6.88 MPa, 30.7 – 85.8%, 0.103 – 0.231 Wm/K, and 407000 – 693000 VND/m$^3$, respectively. Thus, properties of the ultra-lightweight foamed concrete samples conformed well to the official Vietnamese standard requirements, except for the D500 sample.**

**Keywords:** Ultra-lightweight foamed concrete, Fly ash, Ground granulated blast-furnace slag, Compressive strength, Dry density, Pre-foam method.

**Abbreviations:** ULFC, ultra-lightweight foamed concrete; DD, dry density; SP, superplasticizer; CS, compressive strength; WA, water absorption; DS, drying shrinkage; SEM, scanning electron microscope; FC, foamed concrete.

## I. INTRODUCTION

Foamed Concrete (FC) is referred to as a light-weight and friendly material because of its porous structure with countless of entrapped foaming bubbles. For many countries, FC can be produced by either using foam together with slurry so-called cement-based FC or adding light-weight aggregates into the mixtures so-called light-weight aggregate FC. In the material industry, ultra-lightweight foamed concrete (ULFC) can be manufactured with the target dry densities (DD) ranging between 300 – 1800 kg/m$^3$ [1], but the ideal DD of ULFC is normally below 1000 kg/m$^3$. This density aspect has fascinated many researchers due to its special properties. Noisy and heat isolation are excellent properties of the ULFC that make ULFC a superiority material as compared to the conventional materials. Liu *et al.*, (2018) previously reported that FC with some additives could be produced with a low TC of about 0.049 W/mK, which was about a 48% decrease in comparison with the one without additives [2].

On the other hand, numerous researchers have studies ULFC using various material compositions. Hou *et al.,* (2019) studied the effect of nanoparticles including nano-$SiO_2$ and graphene on the foaming agent that used to prefabricate foam and FC. The FC with DD of 500 kg/m$^3$ was prepared. Their results show that the inclusion of nanoparticles decreased the pore sizes within FC. In this case, the prefabricated foam showed high stability. Moreover, the proper content of nanoparticles in foaming agents could improve the mechanical properties of as-prepared FC, but it is not significant [3]. Yang *et al.,* (2014) studied the properties and sustainability of alkali-activated slag FC. FC samples with DDs of 300 – 500 kg/m$^3$ were prepared for developing reliable mixing compositions and establishing the significance of the sustainable application of such FC as a thermal insulation material. Various types of alkali activators, including 10% $Ca(OH)_2$ + 4% $Mg(NO_3)_2$, 5% $Ca(OH)_2$ + 6.5% $Na_2SiO_3$, and 2.5% $Ca(OH)_2$ + 6.5% $Na_2SiO_3$ were used to activate slag. They found that alkali-activated slag FC gained higher compressive strength (CS) and more environmentally friendly than ordinary Portland cement-based FC with the same DD [4]. Zulkarnain and Ramli (2011) designed an FC using a protein agent as foam, silica fume, and superplasticizer (SP). The authors found that CS of FC is primarily a function of DD. In addition, the replacement of a high percentage of cement by silica fume affected the CS of the FC insignificantly. It is important to note that FC containing silica fume a pozzolanic additive required a longer time to reach its ultimate strength [5].

The process of producing ULFC is very simple as it lacks aggregates. Using the pre-foamed method to produce the ULFC is one of the common approaches because of the closed air voids and homogeneous distribution. Besides, since ULFC was usually known as a low-strength material, so it can be manufactured by adding some fibers like glass fiber or plastic fiber in other to improve its strength and flexible ability [6]. Sathish *et al.*, (2018) reported that the use of fly ash and slag in ULFC contributed to the improvement of the concrete strength. They found that 20% of cement could be replaced by slag in the production of FC with good properties. In this paper, local materials from Southern Vietnam were used to produce the ULFC by using the pre-foamed method. By the way, the foam was generated so simple with consistent size and easy to combine with the slurry during the mixing process. The ULFC samples were designed with target DD of 500, 600, 700, and 800 kg/m$^3$. The influence of foam content on engineering properties and microstructure of the ULFC was investigated in this study [7].

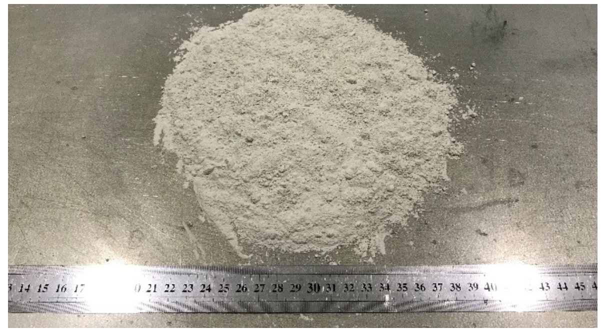
## II. MATERIALS AND METHODS

*A. Materials properties*

The source materials used in this study including PC40 Portland cement, fly ash, slag, stone powder, SP, foaming agent, and water (Fig. 1) with specific gravities of 3.09, 2.20, 2.60, 2.63, 1.07, 1.02 and 1.00, respectively.

(a) Cement

(b) Fly ash



(c) Slag

(d) Stone powder

(e) Foam

**Fig. 1.** The materials used in this study.

It is noted that the foam (Fig. 1d) was pre-generated by a foam generator before adding to the ULFC mixture using a foaming agent/water ratio of 1/40.

*B. Mixture proportions*

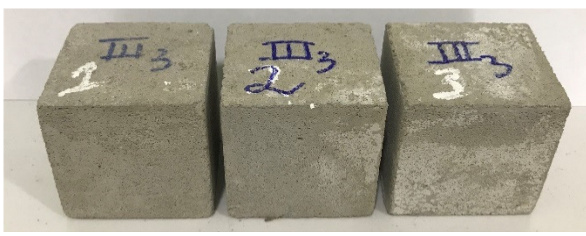
Four ULFC mixtures denoted as D500, D600, D700, and D800 were designed with different target dry densities of 500, 600, 700, and 800 kg/m$^3$, respectively. The same amount of cement, fly ash, and slag of 1050, 150, and 300 g, respectively, were used for all the ULFC mixtures. To produce the ULFC with target dry densities of 500, 600, 700, and 800 kg/m$^3$, the corresponding foam contents of 7.1, 5.3, 4.2, and 2.7% and SP dosages of 0.27, 0.25, 0.24, and 0.15% were used. The ratios of water/(cement + fly ash + slag) and stone powder/(cement + fly ash + slag) were kept constant at 0.35 for all ULFC mixtures.

*C. Samples preparation*

All of the materials were prepared and dry-mixed for 1 minute using a laboratory mixer. Mixing water was gradually added to the dried mixture together with a small amount of SP. Mixing continued for another 2 minutes to create the slurry. The foam was generated by foam generator and immediately poured into the slurry followed by the rest of SP. The final mixture had to be mixed thoroughly for an additional 2 minutes and made sure the foam distributed homogeneously. Right after that, the 50 × 50 × 50 mm ULFC samples (Fig. 2) were casted for the tests of CS, water absorption (WA), DD, and thermal conductivity (TC). Whereas, the 25 × 25 × 285 mm ULFC prisms were prepared for the drying shrinkage (DS) test. All samples were de-molded after one day and cured at room temperature until testing.

(a) D500

(b) D600



(c) D700

(d) D800

**Fig. 2.** The ULFC samples produced in this study.

*D. Test methods*

CS test was conducted at 3, 7, 14, and 28 days in accordance with TCVN 9030-2017 [8]. DD and WA tests were carried out at 28 days according to TCVN 9030-2017 [8] and TCVN 3113-1993 [9], respectively. The DS of the ULFC samples was performed at 1, 3, 7, 14, and 28 days based on ASTM C596 [10]. The microstructure and TC of the ULFC samples were observed at 28 days using a ZEISS EVO 18 SEM and portable thermal analyzer of ISOMET 2114, respectively. Moreover, a cost analysis was also performed in this study.

## III. RESULTS AND DISCUSSION

*A. Compressive strength*

CS is one of the important engineering properties that most of the researchers and users have paid more attention to. The CS development of the ULFC samples is illustrated in Fig. 3. It is observed that CS of the ULFC samples increased with the curing time and significantly increased with increasing density of the samples. For the ULFC samples with densities of 500 and 600 kg/m$^3$, the strength development is unnoticeable. However, the reverse trend was observed for the ULFC samples with densities of 700 and 800 kg/m$^3$. In fact, the 3-day CS values of the D500, D600, D700, and D800 ULFC samples were 0.47, 0.91, 1.68, and 3.77 MPa and these CS values increased respectively to 0.78, 1.68, 4.42, and 6.88 MPa at 28 days. As the CS results, most of the ULFC samples conformed well to the strength requirement of the Vietnamese standard TCVN 9029:2017 [11], except for the D500 sample. Noticeable, the CS development rate was predictable that increased continuously after 28 days of curing, especially for D700 and D800 samples. Fig. 3 further demonstrated the significant effect of foam content on the strength gain of the ULFC samples. It is obvious that the more the foam content, the weaker the ULFC's structure was. It is attributable to the presence of more air bubbles and voids within the system (Fig. 11), causing the loss in CS of the ULFC samples. Furthermore, the relationship between the CS and DD of the ULFC samples will be discussed in the next section.

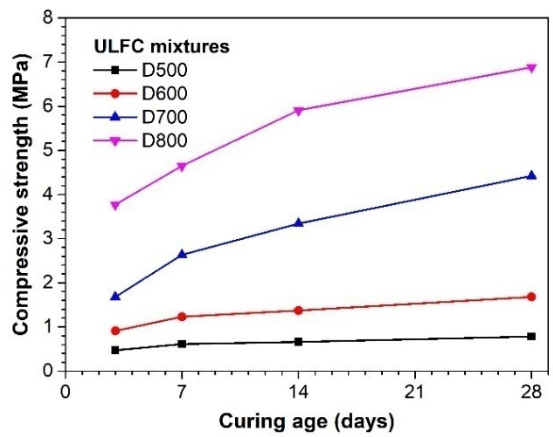



**Fig. 3.** CS development of ULFC samples.

*B. Dry density and water absorption*

Figs. 4 and 5 show the values of DD and WA of the ULFC samples, respectively. The measured DD values were 463, 612, 738, and 844 kg/m$^3$ for the ULFC samples containing 7.1, 5.3, 4.2, and 2.7% of foam, respectively. As stipulated by the official Vietnamese standard [11], the variation of DD that acceptable for the classification of D500, D600, D700, and D800 mixture was in the ranges of 451 – 550, 551 – 650, 651 – 750, and 751 – 850 kg/m$^3$, respectively. Hence, the DD values measured from the ULFC samples felt within the ranges, indicating a suitable amount of foam had been used to get the target of the study. It means that the required density can be obtained by controlling the amount of foam in the ULFC mixture as adding more foam to get a lower density of the product. The reverse trend of DD was observed for the WA of the ULFC samples. It is found that the ULFC samples containing more foam had lower densities and higher WA levels (Fig. 5).

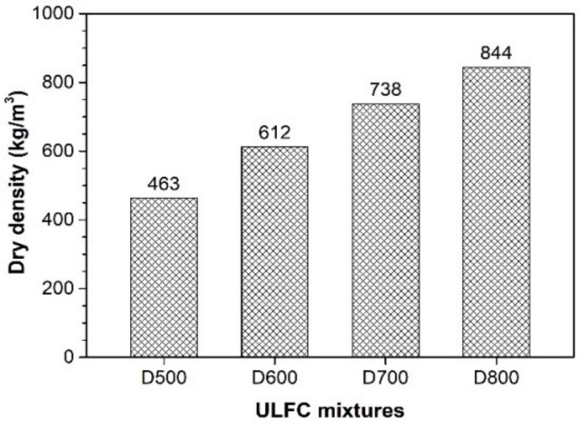



**Fig. 4.** DD of ULFC samples.

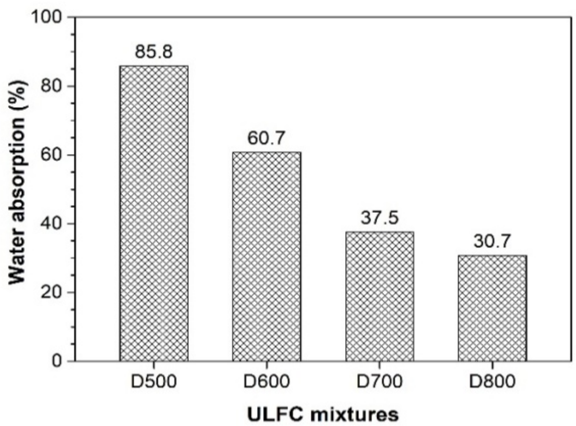



**Fig. 5.** WA of ULFC samples.

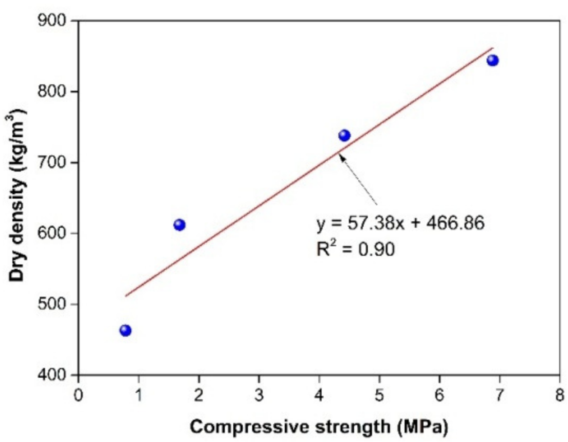



**Fig. 6.** Relationship between DD and CS of ULFC samples.

The WA rates of D500, D600, D700, and D800 samples were approximately 86, 61, 38, and 31%, respectively. It is believed that the inclusion of higher foam contents introduced more pores and voids (Fig. 11), resulting in a looser internal structure and consequently leading to the reduction in DD and the increase in WA of the samples. As aforementioned, the DD had a strong correlation of CS of the ULFC samples, which was expressed by the linear formula of $y = 57.38x + 466.86$ with $R^2 = 0.9$ (Fig. 6). Thus, higher CS values are associated with higher densities of the materials [13]. Fig. 6 further demonstrated a significant influence of foam content on both the density and strength of the ULFC.

*C. Drying shrinkage*

The change in length of the ULFC samples is monitored up to 28 days and presented in Fig. 7. It is clear that all of the ULFC samples shrunk during the curing time. At a very early age (before 14 days), the rate of length change was remarkable for all mixtures. However, it became more stable after 14 days. The change in length of the samples varied from -0.018% to -0.099%. In which, the length change was found to be more significant at the ULFC samples containing a higher percentage of foam. The incorporation of a higher amount of foam resulted in a less compactness structure (Fig. 11) due to the presence of more pores, leading to the higher potential of length change of the samples. However, the change in length of all ULFC samples was recorded at a low rate of less than -0.1%, indicating that the ULFC samples produced in this study well conformed to the requirement of TCVN 9029-2017 [11].

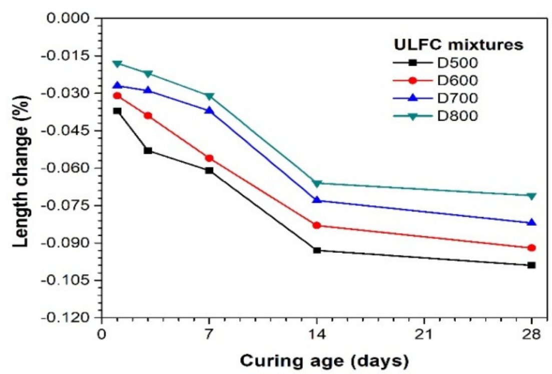



**Fig. 7.** DS of ULFC samples.

*D. Thermal conductivity*

In this study, TC values are used to indicate the thermal behavior of the ULFC samples. The measurement of TC of all the ULFC samples was performed with the result as presented in Fig. 8. The measured TC values ranged from 0.103 W/mK to 0.231 W/mK. The ULFC samples with lower foam content registered a higher value of TC. Thus, the inclusion of higher content of foam was beneficial in terms of heat isolation. This is one of the outstanding properties of the ULFC in comparison to the others. A similar finding was reported by Li *et al.*, [12]. Owing to the presence of entrapped air voids, so they greatly contribute to the insulation of heat transfer through the ULFC. On the other hand, TC was found to have a close relationship with the DD of the ULFC samples. This strong relationship could be expressed by the linear equation of $y = 2657.45x + 239.72$ ($R^2$ = 0.89) (Fig. 9). Gökçe *et al.*, previously found that a slight increase in DD led to a great increase in TC of the foam concrete [13].

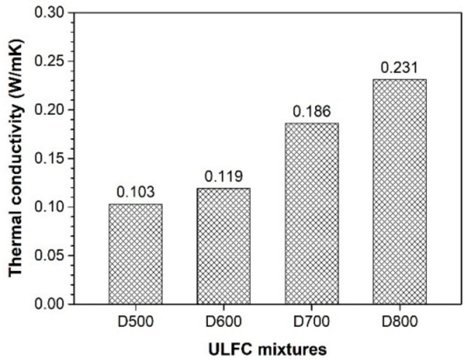



**Fig. 8.** TC values of ULFC samples.

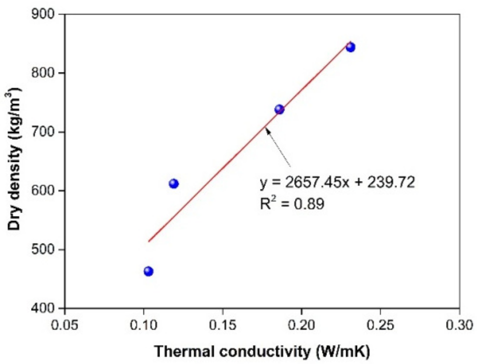



**Fig. 9.** Relationship between DD and TC of ULFC samples.

*E. Cost analysis*

This study only calculates the cost of the materials used for producing each ULFC cubic meter with the result as presented in Fig. 10. It is noted that the materials cost is based on the monthly price announced by the local Government. It can be seen from Fig. 10 that the cost of each ULFC cubic meter increased remarkably with its DD, meaning that the addition of more foam to the mixture contributed to reducing the cost of the final products. In fact, the D500 mixture achieved the lowest price of 407.000 VND/m$^3$, whereas the D800 mixture got the highest price of 693.000 VND/m$^3$. The inclusion of very-low-density foam increased the total volume of the ULFC mixture significantly, reducing the cost for each m$^3$ of the product. Hence, there is a high potential application of the cheaper cost ULFC compared to other conventional materials. However, the cost and CS should be balanced to raise the applicability of this ULFC type in real practice.

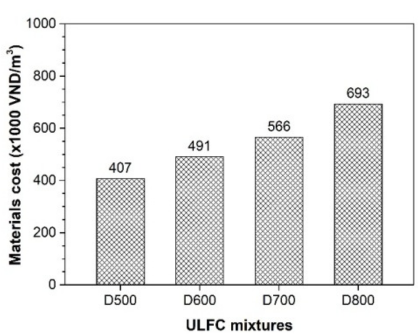
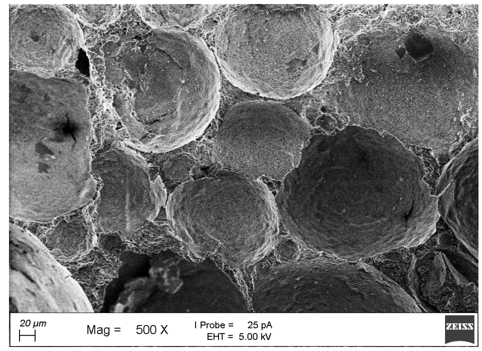


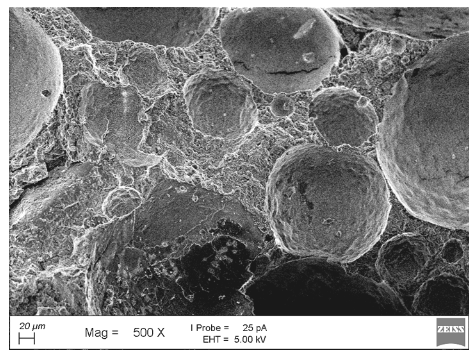

**Fig. 10.** Materials cost of ULFC mixtures.

*F. SEM observation*

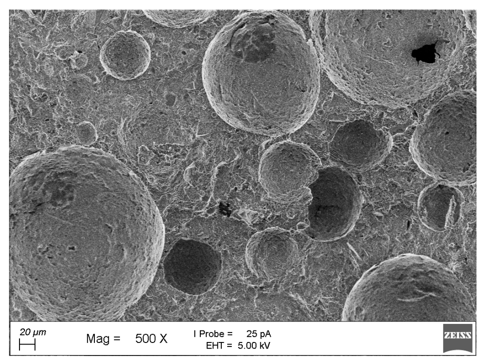
The microstructure characteristics of the ULFC samples can be observed through the SEM images as displayed in Fig. 11.



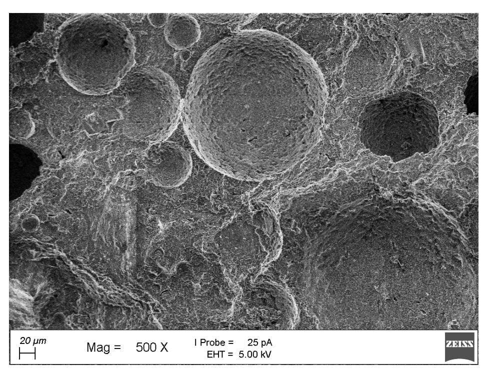

(a) D500




(b) D600




(c) D700




(d) D800

**Fig. 11.** SEM morphologies of ULFC samples.

It is observed that the number of pores and voids increased with increasing the foam content in the ULFC mixtures. Taking note that 2.7, 4.2, 5.3, and 7.1% of foam were used for producing the ULFC samples with DD of 800, 700, 600, and 500 kg/m$^3$, respectively. The inner microstructure indicated that D500 (Fig. 11a) seemed to be weaker because of containing too many pores due to the inclusion of the highest foam content as compared to the other mixtures. Thus, reducing foam content resulted in the reduction in both the number and size of pores (Fig. 11b – d). This observation can be explained for the variation of engineering properties of the ULFC with different foam content as above discussion.

## IV. CONCLUSION

The present study evaluated the effect of foam contents on the engineering properties of ULFC produced using the pre-foamed method. The following conclusions can be made based on the experimental results: (1) The amount of foam added to the ULFC mixtures affected all engineering properties of the final ULFC products significantly as increasing foam content led to the lower CS, DD, TC, materials cost, and the higher WA and DS; (2) The 28-day ULFC samples produced for this study had the CS, WA, and TC values of 0.78 – 6.88 MPa, 30.7 – 85.8%, 0.103 – 0.231 W/mK, respectively; (3) The addition of more foam was beneficial for ULFC products in terms of mass reduction, heat isolation, and cost reduction. The use of 7.1, 5.3, 4.2, and 2.7% of foam could produce the ULFC with the target DD of 500, 600, 700, and 800 kg/m$^3$, respectively; (4) The ULFC samples incorporating higher percentages of foam exhibited the looser internal microstructure and larger DS; (3) Properties of the ULFC samples conformed well to the standard requirements, except for D500 sample. The results of this study further pointed out the high potential of producing and applying the ULFC in construction activities for different purposes

## V. FUTURE SCOPE

The large size of concrete specimens could be prepared and double-checked for the industrial-scale applications.


## ACKNOWLEDGMENTS

The authors would like to acknowledge the assistance of Ms. Le Thi Thanh Tam at Hong Duc University, Vietnam in conducting the SEM observation

**Conflict of Interest.** The authors declare that there is no conflict of interest regarding the publication of this paper.


## REFERENCES


[1]. Jiang, J., Lu, Z., Niu, Y., Li, J., & Zhang, Y. (2016). Study on the preparation and properties of high-porosity foamed concrete based on ordinary Portland cement. *Materials and Design*, *92,* 949−959.

[2]. Liu, S., Zhu, K., Cui, S., Shen, X., & Tan, G. (2018). A novel building material with low thermal conductivity: Rapid synthesis of foam concrete reinforced silica aerogel energy performance simulation. *Energy and Buildings, 177,* 385−393.

[3]. Hou, L., Li, J., Lu, Z., Niu, Y., Jiang, J., & Li, T. (2019). Effect of nanoparticles on foaming agent and foamed concrete. *Construction and Building Materials, 227,* 116698 (open access).

[4]. K. H., Lee, K. H., Song, J. K., & Gong, J. K. (2014). Properties and sustainability of alkali-activated foamed concrete. *Journal of Cleaner Production, 68*, 226−233.

[5]. Zulkarnain, F. & Ramli, M. (2011). Rational proportion for mixture of foamed concrete design. *Jurnal Teknology, 55*, 1−12.

[6]. Falliano, D., Domenico, D. D., Ricciardi, G., & Gugliandolo, E. (2019). Compressive and flexural strength of fiber-reinforced foamed concrete: Effect of fiber content, curing conditions and dry density. *Construction and Building Materials, 198*, 479−493.

[7]. Sathish, P., Neeladharan, C., Ilakkiya, K., Jeevitha, N., Mageshwari, R., & Nivetha, P. (2018). Behaviour of light weight foam concrete block by using ggbs and foaming agent. *International Journal of Advanced Research Trends in Engineering and Technology, 5(5)*, 109−111.

[8]. TCVN 9030:2017. *Lightweight concrete – Test methods*. *Ministry of Science and Technology*, 2017 (Vietnamese standard).

[9]. TCVN 3113:1993. *Heavy concrete – Method for determination of water absorption*. Ministry of Science and Technology, 1993 (Vietnamese standard).

[10]. ASTM 596-18 (2018). *Standard test method for drying shrinkage of mortar containing hydraulic cement*. ASTM International, West Conshohocken, PA.

[11]. TCVN 9029:2017. *Foam concrete and non-autoclaved aerated concrete products - Specifications*. Ministry of Science and Technology, 2017 (Vietnamese standard).

[12]. Li, T., Huang, F., Zhu, J., Tang, J., & Liu, J. (2020). Effect of foaming gas and cement type on thermal conductivity of foamed concrete. *Construction and Building Materials, 231*, 117197.

[13]. Gökçe, H. S., Hatungimana, D., & Ramyar, K. (2019). Effect of fly ash and silica fume on hardened properties of foam concrete. *Construction and Building Materials, 194*, 1–11.



**How to cite this article:** Huynh, Trong-Phuoc, Pham, Van-Hien, Tran, Minh-Luan and Ho, Nguyen-Trong (2020). Evaluation of Engineering Properties of Ultra-lightweight Foamed Concrete Produced using the Pre-foamed Method. *International Journal on Emerging Technologies, 11*(3): 53–58.