Journal of Science and Technology in Civil Engineering NUCE 2019. 13 (2): 74–81

# STUDY ON PRODUCING LIGHT WEIGHT CONCRETE WITH FOAM GLASS GRANULES

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***Article history:***
*Received 14/12/2018, Revised 24/01/2019, Accepted 23/04/2019*

**Abstract**

In the world, waste glass is widely recycled, especially in developed countries with a recycling rate of about 30-90%. Currently, in Vietnam glass emissions in urban areas account for 1.5-2% of solid wastes; however, few studies mention this waste. Therefore, light weight concrete (LWC) using foam glass granulates (FGG) is the object of this paper. In the study, the raw materials are FGG, But Son PC40 cement, Pha Lai fly ash and Sikament superplasticizer named R4. The experimental results show that with FGG content of 50% (by volume), the LWC's bulk specific gravity is 1302 kg/m$^3$ and compressive strength at 28 days is 89 kG/cm$^2$.

*Keywords:* waste glass; foam glass granulate; light weight concrete.

https://doi.org/10.31814/stce.nuce2019-13(2)-07 

## 1. Introduction

Nowadays, sustainability is one of the key requirements for construction industry to lower environmental impacts and attentive use of natural resources. In recent years, the construction industry is steadily implementing initiatives to improve sustainability by increasing the use of recycled and/or manufactured aggregates in concrete production. This is mainly because of the depletion of natural aggregates and greater environmental awareness and protection.

For a long time, glass is widely used for many applications and has become a very important material. As a result, a large amount of glass is eliminated every day and tend to increase over time. Every year, the United States has 9.4 million tons of waste glass, in which 8.5 million tons of colored glass is from bottles and jars [1]. In Brazil, there are about 260 thousand tons of waste glass landfilled annually [2]. Glass recycling rates in each country are very different, such as: the rate in Belgium, the Netherlands and Switzerland are more than 90%; in the US, the rate of recycling glass is more than 30%; in Hong Kong, the rate of glass recycling is only 3% [3]. Waste glass amounts gradually become the burden on the environment especially in large urban area.

According to the statistics of Vietnam Environment Administration [4], the total volume of domestic wastes in Vietnam is currently estimated at 12.8 million tons/year, in which 6.9 million tons/year is from big cities (account for 54% of the wastes), the rest gathers in towns and rural areas. Prediction of urban solid wastes by the year 2020 will be about 22 million tons/ year, and waste glass amounts commonly account for about 1.2% of the wastes.

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Various applications of glass cullet are included asphalt paving, glass tiles and bricks, wall panels, fibre glass insulation, glass fibre, road construction aggregate, concrete aggregate and cementing material [5]. FGG is a recycled product from waste glass, with foam porosity and density of 160-350 kg/m$^3$. Over the last decades, the recycled glass has been used as an aggregate in concrete [6–9]. This is the effective treatment and reuse of waste glass, however, in Vietnam a few studies currently mention waste glass for example: Hiep [10] used glass aggregate made from hospital waste to fabricate concrete plates with the size of 50 × 50 × 5 cm; Tu [10] did the research with the code 01C.03/03-2010-2 named "Study on technology using waste glass to produce sound insulation material". Moreover, there is little guide how to determine the LWC mix using FGG. Therefore, this paper presents the results of a research on producing LWC with FGG.

## 2. Materials and methods

### 2.1. Materials

In this study, the constituent materials are PC40 But Son cement (C), Pha Lai fly ash (FA), Sikament R4 (R4) and FGG. The properties of the used materials are presented below.

a. But Son PC40 cement

The physical properties of But Son PC40 cement meet the specification of TCVN 2682-2009 and are given in Table 1, and the chemical composition of the cement is given in Table 2.

Table 1. Physical properties of But Son PC40 cement

| Properties | Unit | Result | Standard Requirements | Test method |
|---|---|---|---|---|
| Fineness | | | | TCVN 4030:2003 [11] |
| - Retained 0.09mm | % | 0.60 | ≤ 10 | |
| - Specific surface | cm$^2$/g | 3870 | ≥ 2800 | |
| Normal consistency | % | 29.5 | - | TCVN 6017:2015 [12] |
| Soundness | mm | 0.2 | ≤ 10 | TCVN 6017:2015 [12] |
| Specific gravity | g/cm$^3$ | 3.15 | - | TCVN 4030:2003 [11] |
| Setting time | | | | TCVN 6017:2015 [12] |
| - initial setting time | minutes | 115 | ≥ 45 | |
| - final setting time | minutes | 225 | ≥ 375 | |
| Loss on ignition | % | | < 3.0 | TCVN 141:2008 [13] |
| Average particle size | $\mu$m | 11.4 | | Lazer Analysis |

Table 2. Chemical composition of But Son PC40 cement (%)

| $SiO_2$ | $Fe_2O_3$ | $Al_2O_3$ | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | $TiO_2$ | MKN |
|---|---|---|---|---|---|---|---|---|---|
| 20.3 | 5.05 | 3.51 | 62.81 | 3.02 | - | - | 2 | - | 1.83 |

b. Pha Lai fly ash

In the study, the fly ash from Pha Lai thermal power plant is used with the properties listed in Tables 3 and 4.

Table 3. Physical properties of Pha Lai fly ash

| Properties | Unit | Result | Test method |
|---|---|---|---|
| Specific gravity | g/cm$^3$ | 2.26 | TCVN 4030: 2003 |
| Strength activity index of mineral additives | % | 87 | TCVN 10302:2014 [14] |
| Average particle size | $\mu$m | 8.26 | - |
| Specific surface<br>- Blaine<br>- BET | cm$^2$/g | <br>3650<br>5800 | |

Table 4. Chemical composition of Pha Lai fly ash (%)

| $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | MnO | $K_2O$ | $Na_2O$ | MKN |
|---|---|---|---|---|---|---|---|---|
| 53.47 | 28.47 | 5.17 | 1.31 | 1.59 | - | 4.72 | - | 5.07 |

c. Sikament R4

R4 is a superplasticizer extending the setting time to produce concrete with the high workability in conditions of hot climate, and simultaneously is the water reducing agent to significantly increase the intensity of the initial and final strength of concrete.

d. Foam glass granulate

FGG is made from waste glass, limestone powder, liquid glass and water (see Fig. 1). Waste glass from window-glasses is crushed and ground to a particle size < 1 mm. Then the mixture of glass

(a) Waste glass (b) FGG (c) Fire oven Elektro Therm

Figure 1. A material and equipment to produce FGG

powder, limestone powder, glass liquid and water at a respective ratio of 97 : 3 : 2 : 22 were mixed and granulated. Next, aggregate particles were dried in the oven at a temperature of 60-65°C and fired with the mode as shown in Fig. 2.

The thermal process has an important influence on the ability of glass granulate to swell out. The highest temperature of the process should be chosen to generate a large amount of gas. It is also higher than the temperature at which the glass granulate is softens. When using limestone as the gas producing substance, the highest temperature is about 750°C [15]. Based on the experiments, the suitable thermal process is determined as given in Fig. 2.

FGG properties used in the study are given in Table 5.

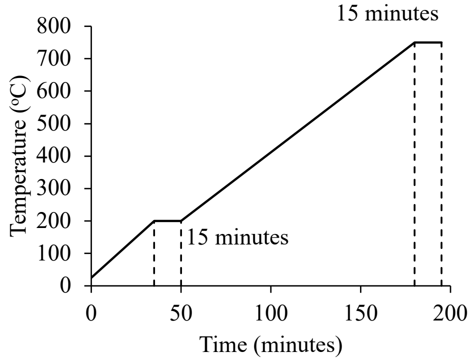


Figure 2. Thermal processing mode to produce FGG

Table 5. Physical properties of foam glass granulate

| Properties | Unit | Result | Test method |
|---|---|---|---|
| Maximum size | mm | 20 | TCVN 7572-2:2006 [16] |
| Bulk density | kg/m$^3$ | 216 | TCVN 7572-6:2006 [17] |
| Bulk specific gravity | kg/m$^3$ | 339 | TCVN 7572-4:2006 [18] |
| Bulk specific gravity (saturated surface dry) | kg/m$^3$ | 383 | TCVN 7572-4:2006 [18] |
| Voids | % | 36.4 | TCVN 7572-6:2006 [17] |

### 2.2. *Methods*

In the study, the standard methods used for determining physical properties of C-FA pastes and LWC are listed in Table 6.

Table 6. Standard methods used in the study

| No | Properties | Test method |
|---|---|---|
| 1 | Flowability | TCVN 9204:2012 [19] |
| 2 | Compressive strength of cement-fly ash paste | TCVN 6016:2011 [20] |
| 3 | Slump number | TCVN 3106:1993 [21] |
| 4 | Compressive strength of concrete | TCVN 3118:1993 [22] |
| 5 | Bulk specific gravity of concrete | TCVN 3115:1993 [23] |

Besides, the coefficient of thermal conductivity of LWC is defined according to the empirical formula of Necrasov [24]:

$$\lambda = \sqrt[2]{0.0169 + 0.22\gamma_0^2} - 0.14 \quad (1)$$

where $\lambda$ is coefficient of thermal conductivity of materials (kCal/m.°C.h); $\gamma$ is Bulk specific gravity of materials (kg/m$^3$).

## 3. Results and discussion

### *3.1. Influence of contents of fly ash and R4 to properties of C-FA paste*

Based on the literature review and some preliminary tests, the composition of pastes at the rate is W/B = water/(cement + fly ash) = 0.28. The fly ash is used to reduce the shrinkage and to increase flowability for mixtures. Content of fly ash used in the experiment was FA/B = 40%, 50% and 60%. R4 was used at ratio of R4/B = 0.1 to 0.9% in order to adjust the flowability of the pastes. Based on the properties of the pastes, the mixture compositions of LWC using FGG will be determined.

a. Influence of R4 content on flowability of C-FA paste

The flowability of the mixture of pastes with different ratios of FA/B and R4/B is given in Table 7.

Table 7. Influence of contents of R4 on flowability of C-FA pastes

| FA/B | Ratio of R4/B (%) | | | | |
|---|---|---|---|---|---|
| | 0.1 | 0.3 | 0.5 | 0.7 | 0.9 |
| 40% | 8.35 | 10.75 | 12.60 | 21.45 | 26.25 |
| 50% | 10.30 | 12.45 | 16.45 | 23.75 | 26.45 |
| 60% | 11.50 | 12.75 | 15.40 | 26.50 | 27.65 |

In generally, the test results show that the higher ratio of FA/B, the greater the flowability of the paste mixtures is obtained. This is due to spherically smooth surface particles of fly ash. Fig. 3 also demonstrates that when R4/B ratio was greater than 0.7% the saturation phenomenon of additives was occurred. That means the higher content of R4 is not really the higher mix flow and the phenomenon of water separation begins to appear.

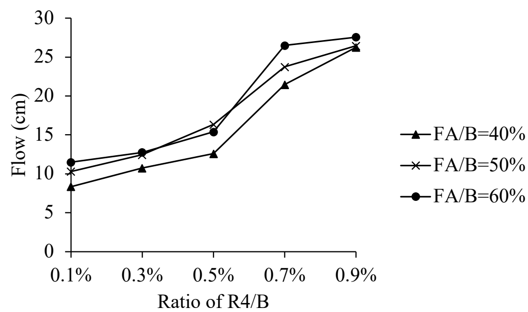


Figure 3. Influence of contents of R4 on flowability of C-FA pastes

b. Influence of fly ash content on compressive strength of C-FA paste specimens

Paste specimens with N/B = 0.28, R4/B = 0.5% and FA/B = 40%, 50%, 60% were prepared to determine the influence of fly ash content on compressive strength of C-FA paste. The test results are given in Table 8 and Fig. 4.

Table 8. Compressive strength of C-FA paste specimens

| FA/B | Compressive strength (MPa) | | |
|---|---|---|---|
| | $F_{c,7}$ | $F_{c,14}$ | $F_{c,28}$ |
| 40% | 44.7 | 52.0 | 69.4 |
| 50% | 33.6 | 38.9 | 51.9 |
| 60% | 24.6 | 31.7 | 48.8 |

The experimental results clearly show that when the fly ash content is increased, the compressive strength of samples is decreased. Corresponding to the ratio FA/B of 40%, 50% and 60%, the compressive strength of specimens at 28 days was 69.4 MPa, 51.9 MPa and 48.8 MPa, respectively. This result agrees with many previous studies, namely, and the higher fly ash content causes the lower compressive strength in the early age due to a low hydration capacity of fly ash.

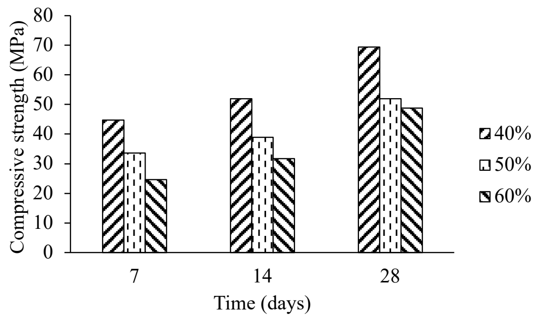


Figure 4. Compressive strength of C-FA paste specimens

### *3.2. Mixture composition and physical properties of LWC using FGG*

LWC using FGG is supposed as a composite with two different components. Therefore, determining the paste/mortar matrix with suitable flowability, viscosity and strength is necessary to ensure not only consistency and without segregation but also the strength of concrete mixtures.

Based on the preliminary testing, the flow of paste is reckoned about 12-13 cm to meet the requirement of consistency of the LWC. Therefore, the paste matrix was chosen with FA/B of 40%, W/B of 0.28 and R4/B of 0.5%. With the goal of producing construction insulating concrete with $\gamma \leq 1400$ kg/m$^3$, $f_c$ = 35-100 kG/cm$^2$ [25], the contents of FGG were determined at 40, 45 và 50% (by volume of the concrete mixture). Mixture compositions and physical properties of the LWC are presented in Table 9.

Table 9. Mixture composition and physical properties of LWC using FGG

| | Mixture composition | | | | Slum (cm) | Compressive strength (kG/cm$^2$) | | |
|---|---|---|---|---|---|---|---|---|
| | $V_{FGG}$ (%) | FA/B (%) | W/B | R4/B (%) | | $f_{c,7}$ | $f_{c,14}$ | $f_{c,28}$ |
| CP40 | 40 | 40 | 0.28 | 0.5 | 24 | 139 | 187 | 273 |
| CP45 | 45 | 40 | 0.28 | 0.5 | 21.5 | 85 | 112 | 152 |
| CP50 | 50 | 40 | 0.28 | 0.5 | 11 | 68 | 73 | 89 |

The workability test results show a noticeable phenomenon, namely, when FGG volume increases from 45% to 50%, the slump of the concrete mixture decreases quickly from 21.5 cm down to 11 cm. This may demonstrate that the reduction of paste thickness among the aggregates rapidly causes the drop of concrete workability in the ranges of the FGG content.

Table 9 and Fig. 5 show that the higher amount of FGG would decrease the compressive strength of LWC such as the compressive strength at 28 days of 273, 152 and 89 kG/cm$^2$ with $V_{FGG}/\Sigma V$ = 40%, 45% and 50%, respectively. It could be explained that FGG with the high porosity are the

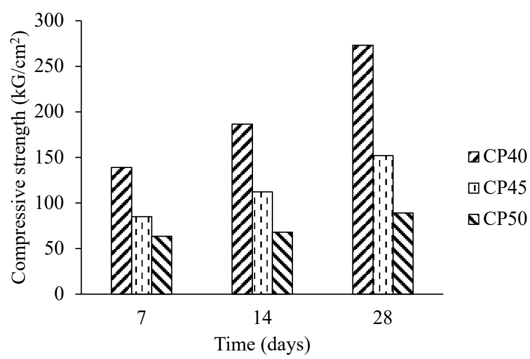


Figure 5. Influence of FGG content to compressive strength of LWC

main factors influencing the strength loss of concrete compared with that of paste matrix. Furthermore, compressive strength of concrete was rapidly decreased to 44% at the age of 28 days when the FGG volume amount was increased from 40% to 45%. The stress transferred to FGG with low strength instead of high strength paste. That is simultaneously responsible for the strength of concrete which is fallen markedly.

### *3.3. Bulk specific gravity and thermal conductivity of LWC with FGG*

The bulk specific gravity and the thermal conductivity of concrete samples were calculated by the empirical formula of Nekrasov [24]. The results are given in Table 10.

Table 10. Bulk specific gravity and thermal conductivity of LWC with FGG

| No | Bulk specific gravity (kg/m$^3$) | Thermal conductivity $\lambda$ (kcal/m°C.h) |
|---|---|---|
| CP40 | 1527 | 0.59 |
| CP45 | 1395 | 0.53 |
| CP50 | 1302 | 0.49 |

Based on the test results and the classification [25], the CP50 specimen with $V_{FGG}/\Sigma V = 50\%$ could attain a compressive strength at 89 kG/cm$^2$ and a bulk specific gravity at 1302 kg/m$^3$, that can be classified as structural insulated concrete. Furthermore, the CP40 specimen with $V_{FGG}/\Sigma V = 40\%$ with a compressive strength at 273 kG/cm$^2$ and a bulk specific gravity at 1527 kg/m$^3$ should be classification of structural concrete.

## 4. Concluding remarks

Based on the tested materials and testing methods used in the research, the following conclusions can be drawn:

- Determining an appropriate heat process with the highest temperature which is 750°C to produce foam glass granulates.

- Reasonable flow of pastes determined according to TCVN 9204:2012 should be about 12-13 cm to ensure the consistency and workability of the concrete mixtures.

- In range of 45-50% FGG content by volume, the sudden decline of the slump of the concrete mixture from 21.5 to 11 cm.

- Structure insulating concrete contained 50% volume of FGG was produced, which obtained 89 kG/cm$^2$ of compressive strength at 28 days and approximate 1300 kg/m$^3$ of a bulk specific gravity.

## Acknowledgement

The author would like to thank TDC Group for supporting and using the results of this research to experiment lightweight wall panels.

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