Influence of mortar matrix on properties of light weight concrete with foam glass granules

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Abstract: Foam glass granule (FGG) is commonly used as an aggregate for light weight aggregate concrete (LWAC). Because bulk gravity of FGG is much less than that of mortar matrix, segregation is tended to occur in LWAC mixtures. Mortar plays an important role in properties of LWAC with FGG. Therefore, this paper presents research results of influence of mortar matrix to properties of this type of concrete. In the study, the raw materials were FGG, But Son PC40 cement, Pha Lai fly ash and Sikament plasticizer named R4. The experimental results showed that with FGG content of 40% by volume and flow of mortar at 21- 22 cm, the LWC mixture was homogeneous and its slump was at 3.5- 5.5 cm. Simultaneously, the LWAC’s density was 1400-1500 kg/m³ and its compressive strength at 28 days was over 11 MPa.

1. Introduction
FGG is a recycled product of waste glass, with foam porosity and density in the range of 160- 350 kg/m³. The most popular application of the recycled glass product is using as an aggregate in LWAC. FGG could be replaced a part or entire of coarse aggregates and fine aggregates of concrete [1-4]. Depending on FGG content, it could produce structural lightweight concretes or insulating concretes. Currently, glass waste account for 1.5-2% of solid wastes in urban areas of Vietnam [5]. However, few studies mentioned in using this waste.

Normally, LWAC’s density is less than 1900 kg/m³. LWACs have some advantages such as better soundproof, insulation and especially reducing the dead load of constructions. LWAC mixture designs are usually applied for concrete using aggregates of keramzit and agloporit [6-8]. That makes it difficult to design for LWAC’s compositions using other types of lightweight aggregates such as FGG i.e.

Because of difference of density of mortar matrix at about 2.000-2400 kg/m³ and lightweight aggregates (LWA) at the wide range of 15- 1200 kg/m³, segregation of LWAC mixture often occurs. LWA particles tend to move upward and mortar moves to the opposite direction. Three main factors influencing on velocity of the moving are diameter, density of LWA and viscosity of mortar. With a specific LWA, a suitable workability of mortar matrix will keep LWA particles not floating. As a results, that LWAC mixture is homogenous and ensuring other properties of the concrete. Simultaneously, LWA usually has a low strength, therefore the volume and strength of mortar are two important factors affecting the strength of LWAC.

This paper presents results of the study of the influence of mortar matrix on properties of light weight concrete with FGG. The outcome of the research would contribute to determine compositions and to expand application of LWAC using FGG in Vietnam.
2. Materials and Methods

2.1. Materials
PC40 But Son cement (C), Pha Lai fly ash (FA), Sikament R4 (R4), a fine aggregate, and FGG were used as constituent materials in this study. Properties of the materials used are presented below.

2.1.1. But Son PC40 cement: Physical properties of But Son PC40 cement are given in Table 1, the chemical composition of the cement is given in Table 3.

Table 1. Physical properties of But Son PC40 cement

| Properties              | Unit   | Result |
|-------------------------|--------|--------|
| Specific gravity        | g/cm³  | 3.1    |
| Finess                  | %      | 3.5    |
| Retained 0.09mm         | %      | 11.1   |
| Average particle size   | µm     | 29     |
| Normal consistency      | %      | 0.2    |
| Soundness               | mm     | 115    |
| Setting time            | minutes| 225    |
| Initial setting time    | minutes| 115    |
| Compressive strength    | MPa    | 28.7   |
| 3 days                  | MPa    | 47.9   |
| 28 days                 | MPa    |        |

2.1.2. Fly ash (FA): The Class F fly ash from Pha Lai thermal power plant was confirmed to ASTM C 618-19. The properties of the fly ash (FA) listed in Table 2 and Table 3.

Table 2. Physical properties of Pha Lai fly ash

| Properties                          | Unit   | Result |
|-------------------------------------|--------|--------|
| Specific gravity                    | g/cm³  | 2.26   |
| Strength activity index of mineral additives | % | 87     |
| Average particle size               | µm     | 7.87   |

Table 3. Chemical compositions of the PC40 cement and Pha Lai fly ash (%)

|                  | SiO₂   | Fe₂O₃ | Al₂O₃ | CaO   | MgO   | Na₂O  | K₂O   | SO₃   | TiO₂  | LOI   |
|------------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Cement           | 20.3   | 5.05  | 3.51  | 62.81 | 3.02  | -     | -     | 2     | -     | 1.83  |
| Fly ash          | 53.47  | 28.47 | 5.17  | 1.31  | 1.59  | -     | 4.72  | -     | -     | 5.07  |

2.1.3. Foam glass granule: FGG was made from glass waste, limestone powder, liquid glass and water. After pelletized, aggregate particles to be dried in the oven at a temperature of 60-65°C and fired at the highest temperature is about 750°C [9]. FGG properties used in the study are given in Table 4.

Table 4. Physical properties of the foam glass granule

| Properties                | Unit   | Result |
|---------------------------|--------|--------|
| Maximum particle size     | mm     | 20     |
| Bulk density              | kg/m³  | 260    |
| Relative density (in dry) | kg/m³  | 590    |
| Relative density (in saturated surface dry) | kg/m³ | 685 |
2.1.4. **Fine aggregate:** The fine aggregate from Lo river was used in this study. The properties of the fine aggregate is shown in Table 5.

| Properties            | Unit   | Result |
|-----------------------|--------|--------|
| Specific gravity      | g/cm³  | 2.65   |
| Relative density      | g/cm³  | 2.46   |
| Bulk density          | kg/m³  | 1.65   |
| Water absorption      | %      | 1.24   |
| Fineness modulus      | ~      | 2.5    |
| Content of clay impurities | %  | 1.55   |

2.1.5. **Sikament R4:** R4 is a plasticizer extending the setting time to produce concrete with high workability in conditions of hot climate, and simultaneously is a water reducing agent to significantly increases the strength of the initial and final strength of concrete.

2.2. **Methods**

Besides standard test methods, some methods of experiment and preparation of materials used are described as below:

2.2.1. **Determine binder paste viscosity:** Viscosity experiment of binder paste were carried out using a viscometer SV-10. After mixed, a paste was taken about 35-45 ml to test.

![Viscometer SV-10](image)

**Figure 1.** Viscometer SV-10 to viscosity of binder paste

2.2.2. **Determine flow of binder paste and mortar:** Suttard viscometer was used to investigate the flow characteristics of binder paste and mortar according to TCVN 9204:2012.

2.2.3. **Determine segregation of concrete mixture:** Concrete mixture was compacted in a 5 liter container by a vibration table for 15 sec. Then the density of the lower half part and the upper half part concrete mixture in the container were determined. The segregation of concrete mixture is the ratio of the density difference of the two parts to the average density of concrete mixture in the 5 liter container [10].

2.2.4. **Humidifying method for FGG:** Due to high water absorption of LWAs, amount of water absorbed in aggregates is typically calculated to add to mixing water. On the other hand, LWAs is humidified before mixing. In this study, FGGs were soaked in 24 hours then drained within 1 hour before mixing concrete.

3. **Results and Discussion**

3.1. **Viscosity of binder paste**

Viscosity of binder paste may not only influence rheology properties and but also segregation of concrete mixture. Therefore, the research on the change of the paste viscosity over time is necessary to control workability of concrete mixture. Contents of FA in the binder (B) consisting cement and FA
were 0%, 15% and 30%. The pastes at the ratio of water to binder (W/B) of 0.35 and 0.4 were tested. Ratio of R4 to binder by weight was fixed 0.35%.

As shown in Figure 2, viscosity of all pastes were gradually increased over time. At ratio of W/B= 0.4, viscosity of pastes was much less than that at the rate of 0.35 respectively. The increase of FA content not only caused remarkably decreasing of paste viscosity, but also stably maintaining the viscosity.

3.2. Properties of mortar
The compositions of mortar were used that the ratio of W/B at 0.35 and 0.4. Content of FA in the binder were 0%, 15% and 30% by weight. The ratio of the fine aggregate to mortar by volume (V_{FAgg}/V_M) was 0.4. The ratio of R4 to binder was fixed at 1%. That was also the composition of mortar matrix of concrete in the next experiment. To evaluate effect of fine aggregate on the flow of mortar, flow experiments of pastes were conducted that had the same compositions of mortars deducted fine aggregate. Some properties of pastes and mortars are shown in Table 6.

Table 6. Properties of pastes and mortars

| Note | W/B | R4/B | FA/B | V_{FAgg}/V_M | Flow of pastes (cm) | Flow of mortars (cm) | Density of mortar mixture (kg/m³) |
|------|-----|------|------|--------------|---------------------|----------------------|-------------------------------|
| M1   | 0.35| 1.0% | 0%   | 0            | 27.5                | 19                   | 2249                          |
| M2   | 0.35| 1.0% | 15%  | 0            | 28                  | 20                   | 2171                          |
| M3   | 0.35| 1.0% | 30%  | 0            | 29                  | 20.5                 | 2150                          |
| M4   | 0.4 | 1.0% | 0%   | 0            | 30                  | 21                   | 2187                          |
| M5   | 0.4 | 1.0% | 15%  | 0            | 30.75               | 21.5                 | 2107                          |
| M6   | 0.4 | 1.0% | 30%  | 0            | 33.25               | 22                   | 2076                          |

Figure 2. Change of the paste viscosity over time
3.2.1. Flow of mortar: it can see from test results in Table 6 and Figure 3, the higher content of FA the higher flow of mortar. At W/B=0.35, flow of mortar increased 5.5% with FA/B=15% and 7.9% with FA/B=30% compared with mortar without FA; respectively 2.4% and 4.8% at rate of W/B=0.4.

Flow of mortar fell about 25-30% compared to the corresponding flow of paste. That indicated effect of the fine aggregate in increasing shear stress and decreasing workability of mortar.

![Flow of mortar vs. Flow of paste](image)

**Figure 3.** Comparing flow of mortar with flow of paste

3.2.2. Compressive strength of mortar: As shown in Figure 4, the strength of mortar was 38-50 MPa. Compressive strength of mortar was significantly decreased when ratio of W/B and FA replaced content were increased.

![Compressive strength](image)

**Figure 4.** Development of compressive strength of mortars

3.3. Influence of mortar on some properties of concrete

The composition of concrete was based on that of mortars as motioned in section 3.2 and combined with FGG at 40% by volume. Some properties of LWAC using FGG is presented in Table 7.
Table 7. Some properties of LWAC using FGG

| Note | W/B | FA/B | Slump (cm) | Segregation (%) | Density (kg/m³) |
|------|-----|------|------------|-----------------|-----------------|
| C1   | 0.35| 0%   | 1          | 2.7%            | 1500            |
| C2   | 0.35| 15%  | 1.5        | 3.5%            | 1534            |
| C3   | 0.35| 30%  | 2          | 4.0%            | 1453            |
| C4   | 0.4 | 0%   | 3.5        | 8.6%            | 1429            |
| C5   | 0.4 | 15%  | 5.5        | 13.4%           | 1447            |
| C6   | 0.4 | 30%  | 4          | 8.0%            | 1406            |

3.3.1. Influence of mortar flow on slump and segregation of concrete mixture: Based on observation during test, it is mostly clear that the higher flow of mortar the higher slump of concrete mixture. At ratio of W/B=0.35, slump was about 1-2 cm and concrete mixture was incoherent. As a result, porosity of concrete structure could be observed by naked eyes. At ratio of W/B=0.4, slump was increased about 3.5-5.5 cm. However, as presented in Table 7 and Figure 5, at ratio of W/B=0.4 and FA/B=15% slump number was the higher at 5.5, although flow of mortar was not at the highest value. It may be explained by the combination of influence of “ball bearing” effect of FA and redundant water content due to fly ash replacement.

Figure 5. Influence of mortar flow on slump and segregation of concrete mixture

Segregation: As shown in Figure 5, influence of mortar flow on segregation is the same as that on slump of concrete mixture. The higher workability of mortar the higher segregation of concrete mixture. According to GOST P 51263-2012, segregation of LWAC mixture should not be higher than 25%. Segregation of all concrete specimens met that requirement. At rate of W/B=0.4 concrete mixtures were workable and homogeneous with 8-13.4% of segregation.

3.3.3. Influence of mortar on compressive strength of concrete: As presented in Figure 6, compressive strength of concrete was remarkably increased during the first 7 days at 70-85% of that at 28 days of 11-17 MPa. Simultaneously, the strength was reduced when FA content was raised.
As shown in Figure 7, it is clear that compressive strength of LWAC using FGG is decreased remarkably by 25-30% comparing with that of mortar. In addition, the higher compressive strength of mortar the higher strength of concrete. That is due to low strength of FGG, mortar matrix become the main structure of concrete got external force. In addition, FGG took a place of 40% volume of the concrete.

The density of concrete specimens was about 1400-1500 kg/m$^3$. That is decreased 30-35% comparing with that of mortar mixture as shown in Table 6 respectively. Consequently, this type of concrete is classified of lightweight concrete with density less than 1900 kg/m$^3$.

### 4. Concluding remarks

Based on research results, the following conclusions can be drawn:

- The flow of mortar is reduced by 25-30% compared with the flow of the binder paste respectively. When increasing fly ash content will increase the workability of mortar. Therefore, fly ash can be used to adjust the workability of mortar, then ensuring homogeneity of the concrete mixture.

- Concrete mixture with flow of mortar matrix at 21-22 cm and FGG content of 40% by volume was homogeneous and had slump at 3.5-5.5 cm.

- With FGG content accounted for 40% of volume, compressive strength of concrete was only 25-30% of that of mortar matrix.
Compressive strength at 28 days of the LWACs was higher than 11 MPa, and density was about 1400-1500 kg/m³. This type of concrete could be used to produce structural insulating concrete structure.

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