Effects of air entraining admixture on the properties of lightweight aggregate concrete

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Abstract. In Lightweight Aggregate Concrete manufacturing, there is a stratification of lightweight aggregate during construction process, because bulk density of lightweight aggregates is much smaller than that of cement mortar. This paper presents some research results about the effect of air entrainment additive on the properties of lightweight aggregate concrete. When adding air entrainment admixture into lightweight concrete components with the amount of 0.02 – 0.08% by mass of binder, the stratification and bulk density of fresh concrete reduce, and strength of hardened concrete is also significantly reduced. Therefore, this result indicates that we should only use the air entrainment additive in small amounts (less than 0.02% by mass).

1. Introduction
Lightweight aggregate (LA) in lightweight concrete helps reduce its bulk density, increase the insulation and sound-proofing of the structure, but fresh concrete is easily stratified because lightweight aggregates always tend to float upwards. This can be overcome by using air entrainment additive\textsuperscript{[1, 2]}. The theoretical basis for the use of air entrainment admixtures in lightweight aggregate concrete is Stock’s law and component principle of composite material. In viscous plastic multi-component system like fresh concrete, particles of different sizes and densities can cause sedimentation or stratification that can be described by the Stock equation\textsuperscript{[1, 4]}:

$$v = \frac{2.\pi^2 . g . \Delta \rho}{9. \eta}$$

(1)

In which: $v$ – the movement rate of spherical grains, (m/s);
$r$ – the radius of grain, (m);
$\Delta \rho = \rho_m - \rho_h$;
$\rho_m$ - bulk density of cement paste or mortar, (kg/m$^3$);
$\rho_h$ - particle density of aggregate, (kg/m$^3$);
$g$ - acceleration of gravity, (m/s$^2$);
$\eta$ - dynamic viscosity of cement paste or mortar (Ns/m$^2$).
Considering that lightweight aggregate concrete is as a two-phase composite material, in which, the reinforced phase is lightweight aggregate and the matrix phase is cement mortar, its bulk density, strength and elastic modulus are described according to the equations (2), (3) and (4) as follows [1-4]:

\[
\rho_{dr} = \rho_{v} k = \rho_{vk} \phi + \rho_{vv} (1 - \phi) \quad (2)
\]

\[
\log R_b = \phi \log R_{clr} + (1 - \phi) \log R_v \quad (3)
\]

\[
E_d = v \cdot E_v + \phi \cdot \zeta \cdot E_h = v \cdot E_v + (1 - v) \cdot \zeta \cdot E_h \quad (4)
\]

In which:
- \(\rho_{vk}\): bulk density of lightweight aggregate, (kg/m\(^3\));
- \(\rho_{vv}\): bulk density of dry mortar, (kg/m\(^3\));
- \(v\): The volume of mortar, (m\(^3\));
- \(E_v\): elastic modulus of mortar;
- \(0 < \zeta \leq 1\): coefficient depends on the link between mortar and lightweight aggregate;
- \(\phi\): bulk density of lightweight aggregate in fresh concrete, (m\(^3\)/m\(^3\)).

\(R_b, R_{clr}, R_v\): the strength of concrete, lightweight aggregate and mortar, respectively.

From the equations (1-4), it is possible to replace a part of cement with mineral additives such as fly ash or silicafume, combined with air entrainment admixture to reduce stratification and bulk density of fresh concrete; however, the intensity and elastic modulus are also reduced. In such an interdependent multi-component system, it is necessary to experimentally examine the factors affecting target in designing and manufacturing lightweight aggregate in concrete. This paper presents the research results about the effects of air entrainment additive on workability of fresh concrete and the strength of lightweight aggregate concrete.

2. Materials and Concrete Compositions

2.1. Cement (C)

Cement PC50 Nghi Son is produced according to Vietnam standard, TCVN -2009. The cement clinker characteristics are as follows:

| Chemical composition and mineral composition of PC50 | Chemical composition, % | Mineral composition, % |
|-----------------------------------------------------|-------------------------|------------------------|
| SiO\(_2\) | Al\(_2\)O\(_3\) | CaO | MgO | Fe\(_2\)O\(_3\) | SO\(_3\) | Na\(_2\)O | K\(_2\)O | C\(_3\)S | C\(_2\)S | C\(_3\)A | C\(_4\)AF |
| 20.8 | 4.3 | 64.7 | 2.1 | 3.4 | 3.2 | 0.46 | 0.25 | 59.8 | 14.52 | 5.65 | 10.35 |

The properties of cement are shown in Table 2:

| Water demand \(N_w\), % | Setting time \(T_{ds}\), min | Compressive strength \(R\), MPa | Fineness, \(\text{cm}^2/\text{g}\) | \(\rho\), g/cm\(^3\) |
|-------------------------|-------------------------------|-----------------------------|-----------------------------|---------|
| 29.3 | 115 | 230 | 33.0 | 60.7 | 3870 | 3.09 |
2.2. Fine aggregates - Sand (S)
Sand from the Lo River (Vietnam), according to standard TCVN 7570-2006, is used. The properties of sand are shown in Table 3.

| Properties                      | Result |
|---------------------------------|--------|
| Specific density, g/cm³         | 2.47   |
| Bulk density, kg/dm³            | 1.57   |
| Porosity, %                     | 37.2   |
| Scale module                    | 2.65   |

2.3. Lightweight Aggregate (LA)
LA used for the research made in Vietnam with two grain sizes: 10 - 20 mm (No 1), 4 – 8 mm (No 2). Mechanical-physical properties of two LA types are shown in Table 4.

| Properties                              | No 1 | No 2 |
|-----------------------------------------|------|------|
| Particle size, mm                       | 10 – 20 | 4 – 8 |
| Bulk density, kg/dm³                    | 0.63  | 0.75  |
| Compacted density, kg/dm³               | 0.69  | 0.81  |
| Apparent density (particle density), kg/dm³ | 1.44  | 1.35  |
| Compressive strength in cylinder, MPa   | 1.4   | 1.9   |
| Water absorption 24h, %                 | 25    | 23    |

2.4. Fly ash (FA)
Fly ash is floated from Phalai thermo-electric plant’s coal ash, F type according to TCVN 10302:2014. The chemical compositions of Phalai fly ash are shown in Table 5:

| Properties                              | Symbol | Result |
|-----------------------------------------|--------|--------|
| Specific density, g/cm³                 | ρT     | 2.3    |
| Moisture, %                             | w      | 0.5    |
| Loss of weight on ignition, %           | LOI    | 4.5    |
| Sieve remission (screen size 45μm), %   | -      | 23     |
| Fineness (Blaine), cm²/g                | S      | 3250   |
| Activity intensity index after 28 days, % | -    | 84     |
| (SiO₂+ Al₂O₃+ Fe₂O₃) content, %         | -     | 81     |
| SO₃ content, %                          | -     | 0.15   |

2.5. Silicafume (SF)
Silicafume used in this study is granular, according to ASTM C1240-00, silicafume properties are shown in Table 6.

| Properties                              | Result |
|-----------------------------------------|--------|
| Specific density, g/cm³                 | 2.2    |
| Moisture, %                             | 2.76   |
| Loss of weight on ignition, %           | 2.82   |
| SiO₂ content, %                         | 88.15  |
| SO₃ content, %                          | 0.05   |
| CaO content, %                          | 0.66   |
| Cl’ content, %                          | 0.01   |
2.6. **Super-plasticizer (SP)**

Super-plasticizer based on Polycacboxylate, type F according to TCVN 8826:2011. Its properties are as follows:

- Existence form: liquid
- Colour: pale yellow
- Specific density: 1.1 – 1.2 g/cm³
- pH = 6.6

2.7. **Air-entraining admixture (AD)**

This study uses Bifi, meeting TCVN 12300:2018 with the following characteristics:

- Existence form: liquid
- Colour: pale yellow
- Solute content: 40 – 45%
- Specific density: 1.02 – 1.06 kg/l.

2.8. **Water (W)**

Clean water, meeting the requirement of TCVN 4506:2012.

2.9. **Lightweight Aggregate Concrete Compositions**

After the process of calculation and experiment, we gave the experimental concrete compositions as follows:

| Symbol | C (kg) | FA (kg) | S (kg) | LA (kg) No 1 | LA (kg) No 2 | SF (kg) | SP (%) | W (kg) | AD (%) |
|--------|--------|---------|--------|-------------|-------------|---------|--------|--------|--------|
| K3     | 395    | 108     | 871    | 255         | 170         | 38      | 0.8    | 195    | 0      |
| K4     | 395    | 108     | 871    | 255         | 170         | 38      | 0.8    | 195    | 0.02   |
| K5     | 395    | 108     | 871    | 255         | 170         | 38      | 0.8    | 195    | 0.04   |
| K6     | 395    | 108     | 871    | 255         | 170         | 38      | 0.8    | 195    | 0.06   |
| K7     | 395    | 108     | 871    | 255         | 170         | 38      | 0.8    | 195    | 0.08   |

### 3. Results and Discussion

3.1. **Effects of air entrainment additive on bulk density of fresh concrete**

Table 8 shows the results of the study on the effect of air-entraining admixture on the properties of fresh concrete, such as: dry bulk density ($\rho_{\text{db}}$), bulk density ($\rho_v$), slump (SN) and slump after 1 hour (SN1).

| Symbol | $\rho_{\text{db}}, \text{kg/m}^3$ | $\rho_v, \text{kg/m}^3$ | SN, mm | SN1, mm |
|--------|----------------------------------|------------------------|--------|---------|
| K3     | 1400                             | 1895                   | 78     | 63      |
| K4     | 1420                             | 1725                   | 80     | 75      |
| K5     | 1415                             | 1714                   | 85     | 70      |
| K6     | 1434                             | 1627                   | 95     | 60      |
| K7     | 1464                             | 1595                   | 105    | 68      |
Table 9 shows the amount of air entrained into the fresh concrete (air content) according to AD content used.

| AD content, % | 0.02 | 0.04 | 0.06 | 0.08 |
|--------------|------|------|------|------|
| Bulk density, kg/m³ | 1895 | 1895 | 1895 | 1895 |
| (after using Bifi) | 1725 | 1714 | 1627 | 1595 |
| Air content, % | 8.97 | 9.55 | 14.15 | 15.83 |

The research results show that the amount of air entrained into the fresh concrete reduces its bulk density. The bulk density decreases markedly when the Bifi content is from 0.04 – 0.06%. Experiments also show that when the air air-entraining admixture content is more than 1% by mass (compared to the amount of binder), the bulk density of fresh concrete decreases slightly.

3.2. Effects of air air-entraining admixture on workability of fresh concrete

The results of the the study on the effect of air-entraining admixture on the slump of fresh concrete are shown in Table 8. Its slump is tested according to TCVN 3016 : 1993, measured immediately after mixing and 1 hour later. The slump loss is also calculated, the results are shown in Figure 3 and 4.
We can see that when the air-entraining admixture content in concrete, the slump increases. This result is most evident when measuring intermediately after mixing. The reason may be due to the small evenly distributed air bubbles creating a “ball bearing” effect to reduce internal friction, on the other hand, it limits the stratification of aggregates, so the slump increases. However, when the air-entraining admixture content in concrete is greater than 0.02% by mass, the slump after 1 hour (SN1) tends to decrease quite clearly. It can be explained that the air bubbles entrained into concrete only exist for a short time if we do not mix the mixture continuously. When these bubbles escape, a part of the “ball bearing” effect disappears, so the slump decreases sharply. The above results show that the air-entraining admixture content should be used in minimum quantities.

Through experiments measuring the stratification of fresh concrete and visual observations, we can see that when using air-entraining admixture, the homogeneity of fresh concrete is significantly improved, so mixing, molding and shaping concrete samples are much easier than samples without this additive. Figure 5 visually shows the sample surface using (a) and not using Bifi (b).

![Figure 3. The slump of fresh concrete](image1)

![Figure 4. The slump loss after 1h](image2)

3.3. Effects of air-entraining admixture on strength of hardened concrete

Compressive strength of hardened concrete at ages 3, 7, and 28 days is determined according to TCVN 3118 : 1993. The research results about the effects of air-entraining admixture on strength of hardened concrete are presented in Table 10 and Figure 6.

| Symbol | Compressive strength, MPa |
|--------|--------------------------|
|        | R₃  | R₇  | R₂₈ |
| K3     | 21.3| 27.3| 42.0|
| K4     | 21.5| 25.3| 28.8|
| K5     | 16.3| 19.0| 23.0|

![Table 10. Compressive strength of hardened concrete](image3)
In the range of air-entraining admixture content studied in this report, when the additive content increases, compressive strength of hardened concrete decreases, but the level of reduction is not the same at different ages. The reason is that the porosity of concrete is significantly increased by the presence of entrained air bubbles.

Concrete strength at the early ages (3 and 7 days) is not much reduced when air-entraining admixture content is at 0.02% as well as at 0.04–0.08%. The strength at 28 days of age is the largest decrease, which is evident in all samples using air-entraining admixture when compared to the control sample (about 30% reduction). This may be due to the effect of intensity reduction with increasing porosity at different strength levels, whereby the higher the concrete strength, the higher the reduction at a certain porosity.

When the air-entraining admixture content increases from 0.04% to 0.08%, the level of strength reduction slows down. This may be due to the air entraining performance of this additive has nearly reached saturation threshold.

4. Conclusions
The results of this study show that the use of air-entraining admixture in lightweight aggregate concrete reduces bulk density and the aggregate stratification of fresh concrete. This additive helps fresh concrete easier to work, shaping without floating lightweight aggregate on top.

Air-entraining admixture reduces the strength of hardened concrete, the level of reduction depends on the amount of additive and curing time. Specifically, the level of intensity reduction at the age of 3 and 7 days is significantly lower than that of the 28 days.

Therefore, air-entraining admixture should be used at the minimum content, depending on the purpose of strength and bulk density as well as the ease of construction of fresh concrete.

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