Workability analysis of lightweight aggregate concrete mixture use air entrainment admixture

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Abstract

In the production of lightweight aggregate concrete, there is always a tendency to stratify the lightweight aggregates during transportation and construction, because the unit weight of lightweight aggregates is often much smaller than that of the cement mortar in the mix. This paper presents some analysis results on workability, calculating relative stratification reduction and quality factor of LC when using Air Entrainment Admixture (AD) that most of experimental results presented on the referent [5]. Experimental and analytical results show that the effect of AD depends on the amount of use; significantly reduce the stratification of the mix, reducing the density without much effect on the quality factor of the concrete when it is used at the appropriate concentration, in this study it was about 0.02%.

Key words: *Lightweight Aggregate Concrete (LC), Air Entrainment Admixture (AD), Workability of Fresh Concrete, Stratified Index, Quality Factor*

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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 additives [1, 2].

The theoretical basis for the use of air entrainment admixtures in Lightweight aggregate Concrete (LC) 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 [1, 4]:

$$v = \frac{2r^2.g.\Delta\rho}{9.\eta} \quad (1)$$

In which:

v – the movement rate of spherical grains, (m/s); r – the radius of grain, (m);

g - acceleration of gravity, (m/s^2);

ρ_m- bulk density of cement paste, (kg/m^3);

ρ_{LA} - particle density of aggregate, (kg/m^3); $\Delta\rho = \rho_m - \rho_{LA}$

η - dynamic viscosity of cement paste, (Ns/m^2);

Considering that lightweight aggregate concrete is as a two-phase composite material, in which, the reinforced phase is aggregates and the matrix phase is cement paste, its bulk density, strength and elastic modulus are described according to the equations (2), (3) and (4) as follows [1, 4]:

$$\rho_{co} = \rho_{LA}\phi + \rho_m(1 - \phi) \quad (2)$$

$$\log R_{co} = \phi.\log R_{LA} + (1-\phi).\log R_m \quad (3)$$

$$E_{co} = v_m.E_m+\phi.\zeta.E_{LA} = v_m.E_m+(1-v_m).\zeta.E_{LA} \quad (4)$$

In which:

ρ_{co}, ρ_{LA}, ρ_m: dry density of concrete, LA, dry mortar, respectively (kg/m^3);

vm : The volume of mortar, (m3); Em: elastic modulus of mortar;

ϕ : Volume part of LA in fresh concrete, (m^3/m^3).

$0< \zeta \leq 1$: coefficient depends on the link between mortar and LA;

R_{co}, R_{LA}, R_m: the strength of concrete, LA and mortar, respectively.

From the above relationships, it can be seen that, when replacing a part of cement with mineral admixtures whose density is smaller than that of cement, such as fly ash or silica fume, combined with air entrainment admixture, the specific density of the binder will be reduced, thereby limiting the stratification of fresh concrete; However, the mechanical properties of concrete can be changed.

Based on empirical data, much of which has been published in ref. [5], this paper presents the results of analysis and evaluation of the relative stratification reduction of fresh concrete and the quality coefficient of hardened concrete when using air entrainment admixtures with different content.

2. Materials and Concrete Compositions

2.1. Cement (C)

Cement PC50 Nghi Son is produced according to Vietnam standard, TCVN -2009. The properties of cement are shown in Table 1.

Table 1: Properties of cement

Water demand, %	Setting time, min		Compressive strength, MPa		Fineness, cm^2/g	Density, g/cm^3
	Initial	Final	3 days	28 days		
29.5	115	230	33.0	60.7	3870	3.09

2.2. Fine aggregates - Sand (S) and Lightweight Aggregate (LA)

Sand from the Lo River, according to standard TCVN 7570-2006, is used. LA used for the research with two grain sizes: 10 - 20 mm (No 1), 4 – 8 mm (No 2). Mechanical-physical properties of aggregates are shown in Table 2 and Table 3.

Table 2: Properties of fine aggregate

Properties	Result
Specific density, g/cm^3	2.47
Bulk density, kg/dm^3	1.57
Porosity, %	37.2
Scale module	2.65

Table 3: Properties of lightweight aggregate

Properties	No 1	No 2
Particle size, mm	10 – 20	4 – 8
Bulk density, kg/dm^3	0.63	0.75
Compacted density, kg/dm^3	0.69	0.81
Particle density), kg/dm^3	1.44	1.35
Compressive strength in cylinder, MPa	1.4	1.9
Water absorption 24h, %	25	23

2.3. Fly ash (FA) and Silica Fume (SF)

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 4.

SF used in this study is granular, according to ASTM C1240-00, properties of SF are shown in Table 5.

Table 4: Properties of Phalai fly ash

Properties	Symbol	Result
Specific density, g/cm^3	ρ_{fa}	2.3
Moisture, %	w	0.5
Loss of weight on ignition, %	LOI	4.5
Sieve remission (screen size 45μm), %	-	23
Fineness (Blaine), cm^2/g	S	3250
Activity intensity index after 28 days, %	-	84
(SiO_2+ Al_2O_3+ Fe_2O_3) content, %	-	81
SO_3 content, %	-	0.15

Table 5: Properties of Silica Fume

Properties	Result
Specific density, g/cm^3	2.2
Moisture, %	2.76
Loss of weight on ignition, %	2.82
SiO_2 content, %	88.15
SO_3 content, %	0.05
CaO content, %	0.66
Cl^- content, %	0.01

2.4. Super-plasticizer (SP)

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

liquid form; pale yellow; specific density: 1.1-1.2 g/cm^3; pH = 6.6

2.5. Air-entraining admixture (AD)

This study uses Bifi, meeting TCVN 12300:2018 with the following characteristics: liquid form; pale yellow; solute content: 40-45%; Specific density: 1.02 – 1.06kg/l.

2.6. Water (W)

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

2.7. Lightweight Aggregate Concrete Compositions

After the process of calculation and experiment, experimental concrete compositions as follows (Binder is total of cement, fly ash and silica fume by mass ratio 70, 25 and 5%, respectively): [5]

Table 6: Concrete Compositions

Symbol	Binder	S	LA (kg)		SP	W	AD
	(kg)	(kg)	No1	No2	(%)	(kg)	(%)
LC0	540	870	255	170	0.8	195	0
LC2	540	870	255	170	0.8	195	0.02
LC4	540	870	255	170	0.8	195	0.04
LC6	540	870	255	170	0.8	195	0.06
LC8	540	870	255	170	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 (ρvd), bulk density (ρv), slump (SN) and slump after 1 hour (SN1).

Table 7: Bulk density (ρ_v) and slump (SN) of fresh concrete

Symbol	AD content, %	ρ_v, kg/m^3	SN, mm	SN1, mm
LC0	0	1895	78	63
LC2	0.02	1725	80	75
LC4	0.04	1714	85	70
LC6	0.06	1627	95	60
LC8	0.08	1595	105	68

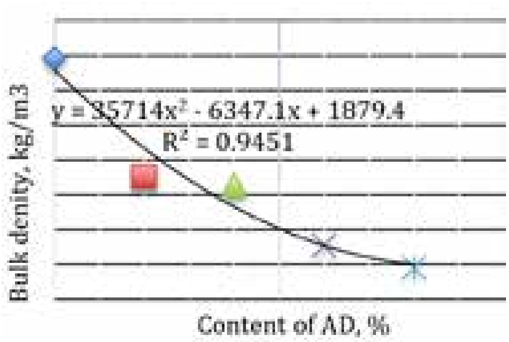

Figure 1: Bulk density of fresh concrete, kg/m^3

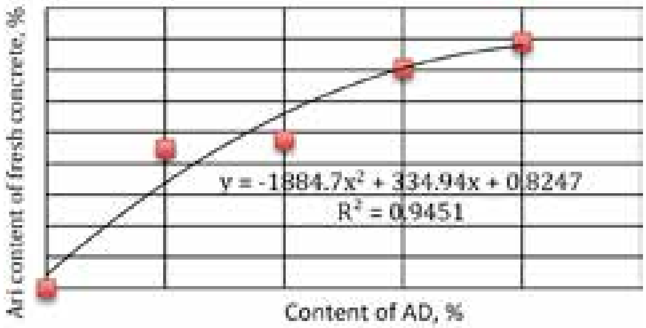

Figure 2: The amount of air entrained into the fresh concrete, %

Table 9 shows the amount of air entrained into the fresh concrete (air content) according to AD content used (Ignore air content in LC0 mixture). [5]

Table 8: The amount of air entrained into fresh concrete

Symbol	LC0	LC2	LC4	LC6	LC8
AD content, %	0	0.02	0.04	0.06	0.08
Bulk density, kg/m^3	1895	1725	1714	1627	1595
Air content, %	-	9.0	9.6	14.1	15.8

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-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. Workability Analysis of fresh concrete

The results of 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. [5]

We can see that when the air-entrained admixture content in concrete, the slump of mixtures 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-entrained 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

Table 9: Stratified index of fresh concrete

Symbol	AD content, %	Volume part of LA in LC	Density of fresh LC, ρ_{oc}, kg/m^3	Mortar density, Dm, kg/m^3	Relative Stratified Index, v_i/v_0, %
LC0	0	0.30	1920	2108	100
LC2	0.02	0.30	1725	1864	65
LC4	0.04	0.30	1714	1849	63
LC6	0.06	0.30	1627	1724	45
LC8	0.08	0.30	1595	1678	39

Table 10: Compressive strength of hardened concrete

Symbol	AD content, %	Dry density, ρ_{co}, g/cm^3	Compressive strength, MPa,			Quality factor, R_{28}/ρ_{co}
			R_3	R_7	R_{28}	
LC0	0	1.870	21.3	27.3	33.5 (*)	17.9
LC2	0.02	1.630	21.5	25.3	28.8	17.7
LC4	0.04	1.600	16.3	19.0	23.0	14.4
LC6	0.06	1.550	15.9	17.7	21.9	14.1
LC8	0.08	1.530	16.4	17.4	21.2	13.9

(*) This value has been checked and adjusted, different from the reference [5], after a writing error was detected.

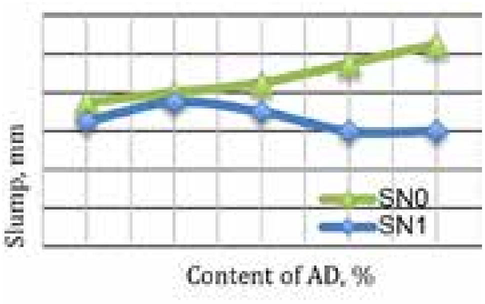

Figure 3: Effect of AD on slumps

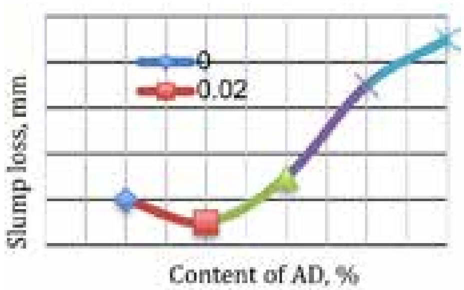

Figure 4: Effect of AD on slumps loss

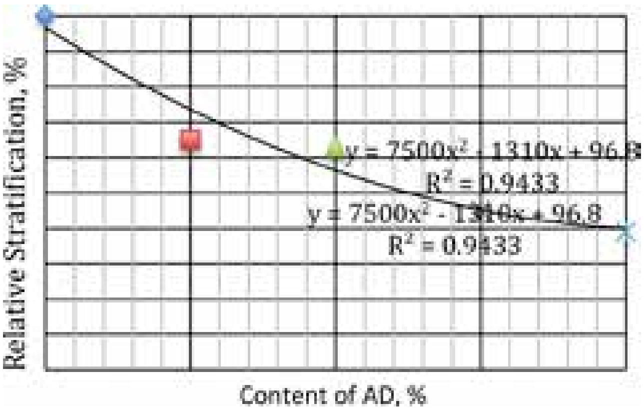

Figure 5: Effect of AD on Stratification of fresh concrete

additive. Figure 6 visually shows the sample surface using (a) and not using Bifi (b).

The results in Table 7, the graphs in Figure 3 and Figure 4 show that the impact of AD on the slump of fresh concrete is not much: in the range of 8-10 cm for SN; 6-7cm for SN1. Research experience shows that the presence of AD does not significantly change the flowability of the cement paste, that is, has a negligible effect on the dynamic viscosity of the cement slurry [3]. The slight increase in slump of the concrete mix when the presence of AD may be mainly due to the stratification reduction effect of the lightweight aggregates. In the subsequent analysis, it can be considered that the relative change ratio of the viscosity (η) of the mixtures LC to the viscosity of the mixture LC0 is negligible.

Obviously, the movement rate of LA in fresh concrete can be used to assess the stratification of the mix. Call the movement speed of LA in the mixtures of LC0, LC2, LC4, LC6, LC8 is vi (i = 0, 2, 4, 6, 8), from equation (1) we have

$$\frac{v_i}{v_0} = \frac{\Delta\rho_{(i)}}{\Delta\rho_0} = \frac{\rho_{m(i)} - \rho_{LA}}{\rho_{m0} - \rho_{LA}} \quad (5)$$

In which:

$\rho_{m(i)}$ - bulk density of cement mortar in LC(i), (kg/m^3);

ρLA - particle density of aggregate, (kg/m^3)

From equation (2) infer to:

$$\rho_{m(i)} = \frac{\rho_{co(i)} - \varphi\rho_{LA}}{1-\varphi} \quad (6)$$

In which: $\rho_{co(i)}$ - bulk density of LC(i), (kg/m^3)

From (6) and (5) assuming that stratification of LC0 is 100%, we calculate the relative stratified index of LC mixes (i) as shown in Table 9 and shown in Figure 5.

Calculation results show that, when using air-entraining admixtures with the content of 0.02 - 0.08%, the stratification of the concrete mixture has been reduced by about 35 - 60% compared to the control sample LC0. From the graph or regression equation in the Figure 5, it is possible to approximate the AD content for the purpose of reducing stratification; and then, estimate the bulk density and the rate of entrained air and slump of the fresh LC according to the graph or the regression function in Figure 1, Figure 2 and Figure 3.

3.3. Quality factor analysis of hardened concrete

Compressive strength and dry density of hardened concrete is determined according to TCVN 3118:1993 and TCVN 3115:1993 respectively. The research results about Factor of quality of LC are presented in Table 10.

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.

The quality factor of concrete is calculated as the ratio of strength to dry density. The results show that at the level of using AD 0.02%, the quality coefficient of LC does not change, but this coefficient will decrease when the content of AD increases higher.

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 bulk density and the strength of LC, 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. In this study, the most reasonable AD content is at 0.02% by weight of the binder.

And it is worth noting that the method as presented can be used to evaluate the relative stratification reduction effect of AD for lightweight concrete mixes./.

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Limit and shakedown analysis of kirchhoff-love plates...

(tiếp theo trang 17)

us calculate limit load fators. This example is investigated in [5-6] for case of normal distribution of strength.

In this analysis, the plate is modelled by 768 DKQ (discrete kirchhoff quadrilateral) elements. Figure 2 shows the convergence of the upper bound and lower bounds for simple supported case. Table 1 shows the results in comparison with Le [7] and Tran [15]./.

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