Construction and Building Materials 76 (2015) 10–15

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Viscosity influence on rising behavior of model air bubbles in fresh mortar

Dongyeop Han [a,1], Gun-Cheol Lee [b,*], Seung-Joe Yoon [b,2], Kyoung-Min Kim [c]

[a] Research Institute of Industrial Sciences, Cheongju University, Cheongju, Chungbuk, Republic of Korea
[b] Department of Architectural Engineering, Korea National University of Transportation, Chungju-si, Chungbuk, Republic of Korea
[c] Architectural Eng Research Team, DAEWOO E&C, Suwon, South Korea

HIGHLIGHTS

- Presenting idea about the relation between vibration and air bubbles migration.
- Using model bubbles, the effect of viscosity on air bubble migration was evaluated.
- As the vibration time duration was extended, air bubble was floated and migrated.
- As viscosity of fresh mortar was increased, the migration of bubble was prevented.

ARTICLE INFO

Article history:
Received 21 September 2014
Received in revised form 5 November 2014
Accepted 12 November 2014
Available online 8 December 2014

Keywords:
Fresh state cement mortar
Model air bubble
Viscosity
Rheological property

ABSTRACT

In this paper, the migrating behavior of air bubbles in fresh state cement mortar was studied. Since the air content of fresh concrete and further hardened concrete influences the durability and surface conditions of concrete after formwork is removed, the air content of fresh state concrete is a very important factor in determining durability of hardened concrete. To evaluate the influence of viscosity in fresh cement paste on air bubbles' migrating behaviors under vibrating conditions, various viscosity conditions were controlled with Viscosity Modifying Admixtures (VMA) and vibration was applied for various time durations. Modeling of the air bubble migration was conducted with expandable polystyrene (EPS) beads where distribution of EPS was measured along with density according to the unit volume weight of three divided layers in a cylinder. Results showed that air bubbles migrate with and without vibration achieving relatively stable conditions with increased viscosity. Therefore, this study was designed to add to the knowledge of how viscosity influences the quality of hardened state cementitious materials.

1. Introduction

During the concrete placing process, vibrators are used to achieve better performance of fresh and hardened state concrete during the filling of formworks to prevent the formation of rock pockets [1]. Generally, the mechanism of applied vibration on concrete creates better fluidity of the concrete matrix through changing of the rheological properties of fresh state concrete mixture [2]. During the vibration process, the rapid oscillatory motion collapses of the inner arching microstructure formed by friction and cohesion between heterogenous concrete components, otherwise known as liquefying [3]. During the liquefying process, the yield stress of concrete is reduced or removed so the concrete flows by its weight [2,4]. This makes it easy to pour the concrete into formworks of complex shapes. On the other hand, when the vibration time is exceeded, segregation occurs with rising of the subjects with low density such as lightweight aggregates, and air bubbles [5] while settling of the subjects with high density coarse aggregate. Segregation causes loss of workability [6] and results in poor quality of strength and durability. Especially, the migration of air bubbles is more apt to occur than migration of aggregates due to over-vibration during the placing process causing problems with freeze–thaw resistance [7]. Despite the adverse effect on concrete performance, there is no reliable formula to calculate the desired consolidation level [3] and segregation is hard to check with field inspections based only on observation. Hence, although appropriate regulations or standards are required, there are no regulations or standards to limit the properties of concrete materials.

* Corresponding author. Tel.: +82 43 841 5207.
E-mail addresses: donald.dyhan@gmail.com (D. Han), gclee@ut.ac.kr (G.-C. Lee).
[1] Tel./fax: +82 43 229 8379.
[2] Tel.: +82 43 841 5207.

http://dx.doi.org/10.1016/j.conbuildmat.2014.11.016
0950-0618/

Most research [1,3,4,8,9] regarding vibrating and properties of fresh concrete has focused on improving the compressive strength or durability of concrete by removing entrapped air voids; therefore, more research on vibration and changing properties of fresh state concrete is needed, and a theoretical foundation for a standard measuring of rheological properties based on the vibration of concrete during mixing would be helpful.

Rheology is a well-known area of study covering the flow and deformation of materials [10]. Using the rheological test results, it is possible to evaluate the behaviors of fresh state concrete more accurately. Normally, to measure the rheological properties of cementitious materials, the Bingham model is used for flow curve measurement. The Bingham model is defined as follow:

$$\tau = \tau_0 + \mu\dot{\gamma} \quad (1)$$

where τ is the shear stress, $\dot{\gamma}$ is shear rate, τ_0 is yield stress, and μ is plastic viscosity or Bingham viscosity.

From the Bingham model, plastic viscosity and yield stress values can be obtained. Using these two parameters, it is possible to define the flow behavior of cementitious materials. First, yield stress is the minimum stress of the materials to start flowing. Therefore, vibrating energy should overcome the concrete yield stress to make it flow. Plastic viscosity is the resistance to flow and segregation, which causes a non-uniform mix. Therefore, it is important to have enough viscosity to satisfy stable concrete microstructure requirements without segregation for highly-flowable concrete in the production of self consolidating concrete (SCC) [11]. Previous research [2] has indicated that applying the appropriate degree of vibration produces little or no yield stress and higher viscosity than concrete without vibration. This means as the vibration is applied, the concrete can start flowing and attain a more stable microstructure.

In this research, using forming styrene as a model air bubble, the behaviors of air bubbles in fresh state mortar during vibration were evaluated to provide insight into the behaviors of moving and changing pore structure inside of fresh state concrete under vibrating conditions. This paper assesses the influence of viscosity of mortar matrix on the rising behavior of air bubbles to investigate whether or not the consolidating performance of mortar during the vibrating process could be dominated by fluidity or viscosity of fresh state mortar.

2. Experiment

2.1. Experimental plan

The experimental plan of this study is shown in Table 1. Based on the experimental plan, the mix design of mortar is provided in Table 2. For the control mortar mixture, water-to-cement ratio was fixed to 0.45, and other mix distributions were designed to satisfy 280 ± 10 mm of mini-slump flow with the following dimensions of mini-slump cone: upper diameter of 50 mm, lower diameter of 100 mm, and height of 150 mm. Based on the control mortar mixture, to evaluate the influence of viscosity, the viscosity modified admixture (VMA) was added with different dosages of 0.025%, 0.05%, and 0.075% of cement by weight to change the viscosity of the mortar. Furthermore, the applied vibrating time was changed to 0, 5, 10, 15, and 20 s to examine the bubble-rising behavior depending on the vibrating times.

Table 1
Experimental plan.

Mixture	w/c (%)	45
	Target flow (mm)	280 ± 10[a] Mini slump flow (mm)
	VMA/C (%)	0, 0.025, 0.05, 0.075
	Contents of model bubble (%)	5
	Vibrating times (sec.)	0, 5, 10, 15, 20
Experiment		Mini slump flow test Flow table test Rheology test Area ratio of model bubble

[a] Slump flow value using 1/2 sized slump test.

As a model bubble, reference material of 1.9 mm of mean diameter expanded polystyrene beads (EPS beads) was used to simulate the behaviors of the air bubbles and provide visualization of those behaviors in actual concrete mixture. The movement of these EPS beads were assumed as the behavior of air bubbles and measured to evaluate it. Since the entrapped air is lighter than EPS bead, it is possible to infer from the behavior of EPS if the EPS shows enough behavior change under the vibrating conditions. The amount of EPS beads added to the concrete mixture was 5% of the entire concrete volume, which is the general air content of normal concrete mixture.

For the fresh state mortar properties tests, mini-slump flow, flow table, and rheology tests were performed with differently applied VMA and vibrating time durations. For the rheology test, the viscosity of mortar mixtures was measured with a rotational viscometer to evaluate the influence of different dosages of VMA. To observe air bubble rising behaviors under differently applied vibrations, a hardened mortar cylinder was used to measure the amount of model bubbles at different heights. Model bubbles were examined after being formed in the 100 mm × 200 mm cylinder and produced under differently applied vibration conditions before the mortar hardened.

2.2. Materials

The physical properties of the materials used in this study are summarized in Table 3. Type I ordinary Portland cement and fine aggregates made up of washed sea sand (both made in South Korea by different companies) were used. For the chemical admixtures, a polycarboxylate-based superplasticizer was used, which is another commercially available product in South Korea wherein the air entrainment effect was removed with anti-forming agent. The shape of EPS beads for the model bubble is shown in Fig. 1. The EPS beads used were made by the South Korean "D" company. According to information provided by the manufacturer, the density of an EPS bead is 0.02 g/cm^3, and the mean diameter is 1.9 mm.

Table 2
Mix proportions.

w/c (%)	s/c (%)	SP/c (%)	EPS bead (%)	Unit weight (kg/m^3)		
				W	C	S
45	2.0	0.3	5	292	648	1296

w/c: Water-to-cement ratio, s/c: sand-to-cement ratio, and SP/c: superplasticizer-to-cement ratio.

Table 3
Physical properties of materials.

Materials	Physical properties
Cement	Kind: OPC (Korean). Density: 3.15 g/cm^3 Blaine: 3265 cm^2/g
Fine aggregate	Kind: Incheon sea sand. FM 2.90 Surface dry density: 2.57 g/cm^3
Admixture	Superplasticizer (non AE type)
EPS beads	Mean diameter: 1.9 mm. Density: 0.02 g/cm^3 Water absorption ratio: 0%

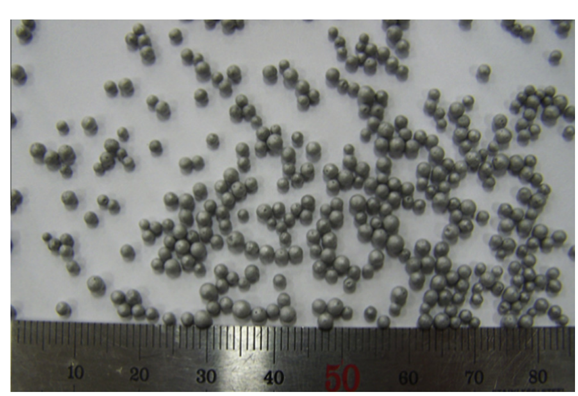

Fig. 1. Expanded polystyrene beads.