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Measurement of cement's particle size distribution by the buoyancy weighing-bar method

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Abstract *- One of the important characteristics of cement quality is particle size distribution. There are several simple methods to measure the particle size distribution of cement based on the Stokes diameter, like Andreasen pipette method, sedimentation balance method, centrifugal sedimentation method, etc. A major disadvantages of these methods are they are time consuming process and require special skills. Particle size distribution also can be analyzed by using a different principle through microscopy, laser diffraction/scattering methods and Coulter counter method. Even these methods produce highly accurate results within a shorter time, however, the equipments are expensive. In the present study, it has developed a new method to overcome the problem. The method is the buoyancy weighing-bar method. This method is a simple and cost-effective. The principle of the buoyancy weighing-bar method that the density change in a suspension due to particle migration is measured by weighing buoyancy against a weighing–bar hung in the suspension, and the particle size distribution is calculated using the length of the weighing-bar and the time–course change in the the apparent mass of the weighing–bar. This apparatus consists of an analytical balance with a hook for underfloor weighing, and a weighing–bar, which is used to detect the density change in suspension. The result obtained show that the buoyancy weighing–bar method is suitable for measuring the particle size distribution of cement, and the result is comparable to that of determined by settling balance method.*

Keywords—*buoyancy, cement, particle size distribution, weighing-bar*

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I. INTRODUCTION

One of the important characteristics of cement quality is the particle size distribution. There are several simple methods to measure the particle size distribution based on the Stokes diameter, like Andreasen pipette method (Society of Eng. Jpn, 1988), sedimentation balance method (Fukui et al., 2000), centrifugal sedimentation method (Arakawa et al., 1984), etc. However, all these methods are time consuming and require special skills. On the other hand, the particle size distribution can be analyzed using a different principle through microscopy (Kuriyama, et al., 2000), laser diffraction/scattering method (Minoshima, et al., 2005), and Coulter counter method (Ohira, et al., 2004). These methods require numerous samples to accurately determine particle size distribution. Although the laser diffraction/scattering and Coulter counter methods produce highly accurate results within a shorter time, the equipments for these methods are extremely expensive. Hence, a simple and cost effective method to determine the particle size distribution of cement is in high demand.

In this study, it was developed a new method to measure the particle size distribution by using the buoyancy weighing-bar method (BWM). In this method, density change in a suspension due to particle migration is measured by weighing buoyancy against the weighing-bar hung in a suspension. Then the particle size distribution is calculated using the length of the weighing-bar and the time-course change in the apparent mass of the weighing-bar (Motoi et al., 2010, Obata et al.,2009, Ohira et al., 2010, Tambun et al., 2011, Tambun et al., 2012a, 2012b).

In this experiment, the initial buoyant mass of the weighing-bar W_0 depends on the particles between the top and bottom of the weighing-bar in a suspension. The initial density of suspension ρ_{S0}, initial buoyant mass of the weighing-bar W_0, and initial apparent mass of the weighing-bar G_0 in a suspension at t = 0 are given by the following equations.

$$\rho_{S0} = \rho_L + \frac{C_0}{\rho_P}(\rho_P - \rho_L), \qquad (1)$$

$$W_0 = V_B \rho_{S0}, \qquad (2)$$

$$G_0 = V_B \rho_B - W_0 = V_B(\rho_B - \rho_{S0}), \qquad (3)$$

where ρ_L and ρ_P are the liquid density and the particle density, respectively. C_0 is the initial solid mass concentration of suspension, ρ_B is the density of the weighing-bar in suspension, and V_B is the volume of the weighing-bar.

The solid mass concentration of suspension C(t) decreases with time because large particles settle. The density of suspension ρ_S, buoyant mass of the weighing-bar W, and apparent mass of the weighing-bar G in a suspension at time t are expressed as

$$\rho_S(t) = \rho_L + \frac{C(t)}{\rho_P}(\rho_P - \rho_L), \qquad (4)$$

$$W(t) = V_B \rho_S(t), \qquad (5)$$

$$G(t) = V_B \rho_B - W(t) = V_B(\rho_B - \rho_S(t)), \qquad (6)$$

The solid mass concentration of suspension C(t) becomes zero once all the small particles also settle. The final density of suspension $\rho_{S\infty}$, final buoyant mass of the weighing-bar W_∞, and final apparent mass of the weighing-bar G_∞ in a suspension at t = ∞ are given by the following equations.

$$\rho_{S\infty} = \rho_L, \qquad (7)$$

$$W_\infty = V_B \rho_L, \qquad (8)$$

$$G_\infty = V_B \rho_B - W_\infty = V_B(\rho_B - \rho_L), \qquad (9)$$

Equation (10) shows the mass balance of settling particles in a suspension (Allen., 1990).

$$C_0 - C(t) = C_0 \int_{x_i}^{x_{max}} f(x)\mathrm{d}x + C_0 \int_{x_{min}}^{x_i} \frac{v(x)t}{h} f(x)\mathrm{d}x, \qquad (10)$$

The left side in Eq. (10) is the quantity of particles that move onto the bottom side of the weighing-bar. The first term on the right side represents the mass of particles larger than particle size x_i among the particles that move, while the second term on the right side is the mass of particles smaller than particle size x_i among the particles that move. From Eqs. (2), (5), (8), and (10),

$$W_0 - W(t) = (W_0 - W_\infty)\int_{x_i}^{x_{max}} f(x)\mathrm{d}x + (W_0 - W_\infty)\int_{x_{min}}^{x_i} \frac{v(x)t}{h} f(x)\mathrm{d}x, \qquad (11)$$

where v(x) is the settling velocity of the particle and f(x) is the mass frequency of the particle size x. Differentiating Eq. (11) with respect to the time t gives

$$-\frac{dW}{dt} = (W_0 - W_\infty)\int_{x_{min}}^{x_i} \frac{v(x)}{h} f(x)dx, \qquad (12)$$

From Eqs. (11) and (12),

$$W = W_R + \left(\frac{dW}{dt}\right)t, \qquad (13)$$

The apparent mass of the weighing-bar, which is given by Eq. (6), gradually increases from G_0 to G_∞. The volume and density of the weighing-bar are constant values. Differentiating Eq. (6) with respect to time t gives

$$\frac{dG}{dt} = -\frac{dW}{dt}, \qquad (14)$$

Therefore, according to Eqs. (6), (13), and (14),

$$G = V_B \rho_B - W_R + \left(\frac{dG}{dt}\right)t = G_R + \left(\frac{dG}{dt}\right)t, \qquad (15)$$

where $G_R = V_B\rho_B - W_R$. The value of G_R is calculated from the tangent line based on Eq. (15). The cumulative mass oversize is

$$R = 100\int_{x}^{x_{max}} f(x)dx = \frac{G_0 - G_R}{G_0 - G_\infty} \times 100 = 100 - D, \qquad (16)$$

where D is the cumulative mass undersize.

Particle size x is given by Stokes formula

$$x = \sqrt{\frac{18\mu_L v(x)}{g(\rho_L - \rho_P)}}, \qquad (17)$$

The settling velocity of the particles v(x) is calculated using Eq. (18)

$$v(x) = \frac{h}{t}, \qquad (18)$$

where h is the length of the weighing- bar and t is the time lapse.

From Eqs. (17) and (18), time t is an inverse function of particle size x. The particle size distribution of the suspended particles is calculated using the particle size at each time and then plotting the corresponding cumulative mass undersize D.

II. Material and Method

Figure 1 schematically illustrates this experiment. The weighing–tools was weighing–bar (diameter: 10.0 mm, length: 210.0 mm, submerged length: 200.0 mm) which was composed of aluminum (density: 2700 kg/m^3).

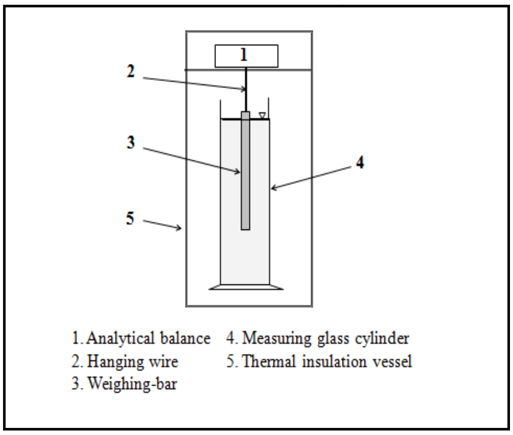


Figure 1. Schematic diagram of the experimental apparatus

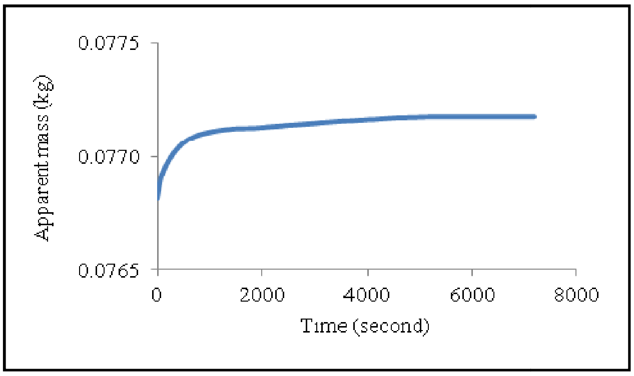
The particle suspension was placed in a 1000 ml measuring glass cylinder (diameter: 65.0 mm). The analytical balance (minimum readout mass 0.1 mg) had a below–balance–weighing hook for hanging measurement.

The sample material was cement (density: 2500 kg/m^3). Ethanol and methanol were used as a dispersion liquid, and the influence of etanol and methanol concentrations were investigated. The etanol and methanol concentrations were 99.8% (p.a), 70%, 50% and 30%. The suspensions had a solid concentration of 10 kg/m^3 (ca. 1 wt.%) (Ohira et al., 2010). To prepare a suspension, a 1000 ml liquid and the particles to be tested were mixed in a glass cylinder. Using a hanging wire, which did not extend due to the weight of the weighing-bar, the weighing-bar was hung from the analytical balance. The room temperature was approximately 298 K. After thoroughly stirring the suspension using an agitator, the weighing-bar was set with the balance. The measuring data, which consist of time t and the corresponding mass of the bar G_B, were recorded. The measuring time was two hours and the data were collected every 60–second intervals. After the measurement, the particle size distribution was calculated based on the above–described theory. As comparison method, the particle size distributions were also measured by using the settling balance method.

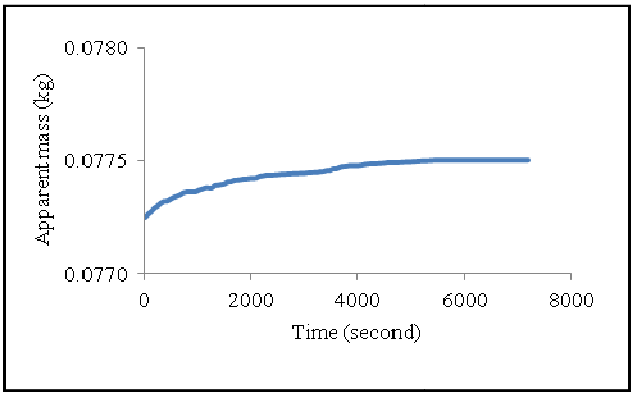
III. RESULT AND DISCUSSION

Figure 2 shows the change with time in the apparent mass of weighing-bar GB when cement was used. Figure 2(a) was the the apparent mass of the weighing-bar as a function of time using etanol (p.a) as liquid, and Figure 2(b) was the the apparent mass of the weighing-bar as a function of time using methanol (p.a) as liquid. Both of the figures show that the apparent mass of the weighing-bar increased until all the cement particles settled below the lower end of the weighing-bar, and then the apparent mass of the weighing-bar became constant. The change in the apparent mass was due to the change in the buoyant mass against the weighing-bar as well as particle settling.

Figure 3 and figure 4 show the influence of ethanol and methanol concentration at determination of cement particle size distributions by using the BWM. The solid line indicates the distribution measured by the settling balance method. The result obtained show that the concentration of ethanol and methanol influence the particle size distributions of cement. The ethanol (p.a) and methanol (p.a) gave the close result to that measured of settling balance method. Hence, BWM can measure the particle size distribution of cement by using ethanol and methanol as liquid.



2(a). Using ethanol as liquid



2(b). Using methanol as liquid

Figure 2. Apparent mass of the weighing-bar as a function of time using ethanol and methanol

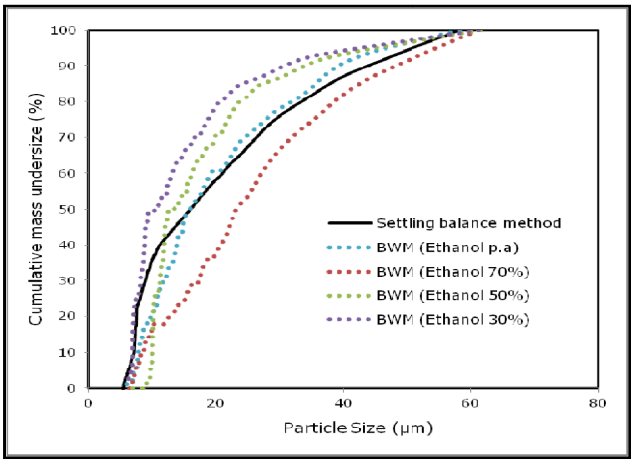


Figure 3. Influence of ethanol concentration at cement's particle size distributions measurement by using BWM

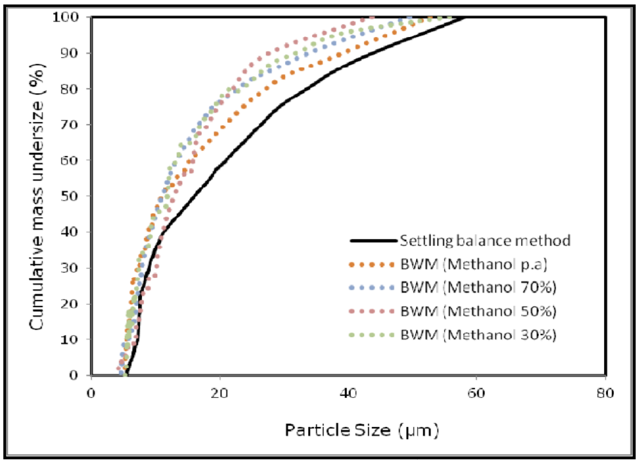


Figure 4. Influence of methanol concentration at cement's particle size distributions measurement by using BWM

Figure 5 shows the particle size distributions determination of cement by BWM using ethanol (p.a) and methanol (p.a). The results show that the ethanol (p.a) gave the closer result to that measured by settling balance than methanol (p.a). Hence, the ethanol is more suitable as liquid in determination of cement's particle size distributions by using BWM.

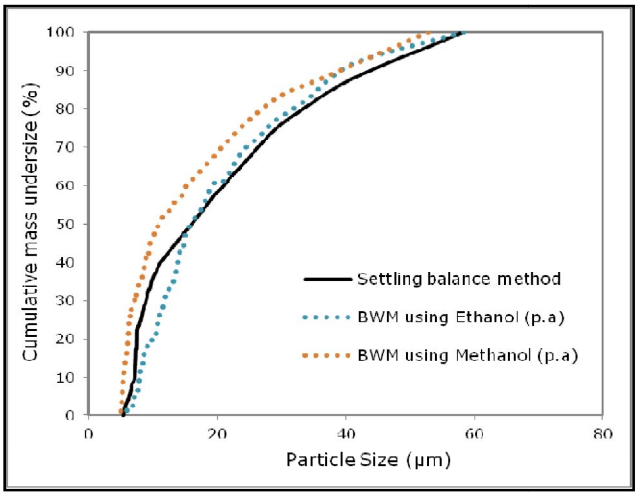


Figure 5. Particle size distributions measurement of cement using ethanol (p.a) and methanol (p.a)

IV. CONLUSIONS

The study investigates the influences of concentration of ethanol and methanol as liquid in particle size distribution measurement of cement by BWM. From this study, the following results were concluded:

1. The particle size distributions of cement could be measured by BWM using ethanol and methanol as liquid, and the particle size distributions obtained were comparable to those measured by settling balance.
2. The higher concentration of ethanol and methanol gave the better result than the lower concentration.
3. The particle size distributions of cement by BWM using ethanol (p.a) as liquid gave the closer result to that measured by settling balance method than methanol (p.a) as liquid.

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