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The segregation tendency in the vibration of high fluidity concrete

Mohammad Ibrahim Safawi*, Ichiro Iwaki, Takashi Miura

Construction Material Laboratory, Department of Civil Engineering, Tohoku University, AzaAoba 06, Sendai 980-8579, Japan

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Abstract

The introduction of superplasticizer (Sp) has produced concrete that could flow easily under its own weight. In balancing the concrete's ability to flow at the same time maintaining the coarse aggregate distribution, the viscosity of concrete must be enhanced. This study aimed to investigate the effect of vibration on such flowable yet viscous concrete. Concrete flowability and viscosity are quantified by the standard slump cone and V-funnel test, respectively. Despite being flowable, the study concluded that concrete viscosity is an important parameter in determining the tendency for coarse aggregates to segregate. Large-sized coarse aggregates are affected more by the vibration process than the small-sized ones.

Keywords: Fresh concrete; Rheology; Vibration; Workability; Stability

1. Introduction

Due to the use of superplasticizers (Sp) in the mixing of concrete, the workability of fresh concrete has changed tremendously. Even at low W/C in the range of 0.20–0.30, adequate dosage of Sp added in the mix causes the concrete to flow easily, thus coined the term "high fluidity concrete." In a standard slump cone test, the fresh concrete spread into a circular shape, instead of retaining the shape of the cone, as is the case for conventional concrete. The perpendicular distance of the circular-shaped concrete spread is known as slump flow. A slump flow of 400 mm and below is deemed as small, while a slump flow above 600 mm is considered as large. In the case of high fluidity concrete, the slump flow is more relevant instead of its slump height. The test method also differs from the conventional one in that there is no rodding applied when the concrete sample is placed into the cone. As the dosage of Sp in the mix increases, the size of the slump flow also increases.

However, as the concrete flowability increases, its stability decreases. This is due to the reduction in viscosity of the fresh concrete. To enhance its stability so that the paste can maintain the coarse aggregates in uniform suspension, higher powder content is required. Other than using Portland cement, fine materials like fly ash, blast furnace slag or limestone powder can also be used. The main target is to enhance the grain size distribution and particle packing, thus ensuring greater cohesiveness. Another approach to enhance stability is adding viscosity-enhancing agent (VEA) [1]. VEA contains water-soluble polymer that can imbibe some of the free water in the system. Physically, the nature of these concrete mixes is thixotropic, meaning that they become fluid when stirred or shaken then returns to a semisolid state at rest.

In the early 1990s, Japanese researchers introduced a new type of concrete that can flow easily and does not require any vibration. It was called high-performance self-compacting concrete (SCC). SCC should not only flow under its own weight but also fill the entire form and achieve consolidation without segregation. Not all concrete that is flowable can be categorized as SCC [2]. Other than being flowable, SCC should have deformability without segregation of materials. This allows SCC to pass between reinforcements without blockage of coarse aggregates. Tests for SCC include the standard slump cone and the so-called V-funnel test. The V-funnel test is incorporated as a Japanese standard test, JSCE-F 512-1999. Fig. 1 shows the dimensions of the V-funnel. The V-shaped funnel is filled with about 12 l of concrete. The V-funnel time (V-time) is the time taken for the concrete mix to flow out

* Corresponding author. Tel.: +81-22-217-7431; fax: +81-22-217-7432.

E-mail address: safawi@mail.cc.tohoku.ac.jp (M.I. Safawi).

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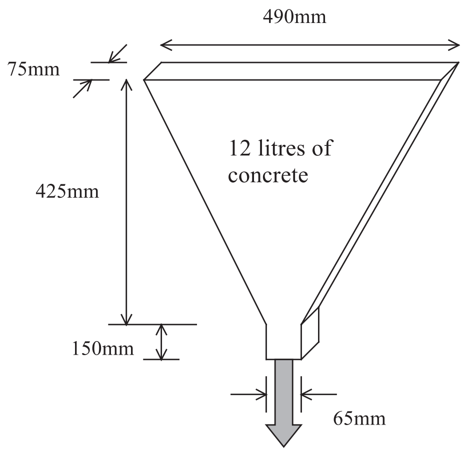

Fig. 1. Dimension of V-funnel.

through the orifice. The target slump flow and V-time applicable for SCC lies in the range of 60 ± 5 cm and 10 s, respectively [3,4]. In SCC mix proportioning, the unit coarse aggregate content is limited to 50% of the solid volume ratio, the volume of sand to mortar is between 40% and 45% and the maximum particle size for coarse aggregates is 20 mm [5].

On the construction site, however, the production of SCC can be affected by several factors like the moisture condition of aggregates, mixing efficiency, slump loss, Sp–cement compatibility, among others. As such, there are bound to be concrete mixes that cannot fulfill all the SCC criteria. More often than not, such concrete is flowable and highly viscous [6]. Concrete that does not fulfill these self-compactability criteria can still be placed with the use of vibration. The question of whether or not such concrete could accept the use of vibrators without incurring detrimental effects has been the motivation of this study. The result of the study can be useful for contractors to determine the level of vibration allowable for such high fluidity concrete.

In this study, high fluidity concrete is made in the laboratory. Both the slump cone and the V-funnel tests are used to quantify the fresh properties of concrete. The slump cone test describes the flowability of the concrete, while the V-funnel test quantifies the different viscous conditions. Because the V-funnel test does not measure absolute viscosity, the V-time value serves as an indicator of the viscous condition of the mix. A short V-time means the viscosity of concrete is low, while a long V-time implies high viscosity mix. A pencil vibrator is used to vibrate the concrete. The study aims to investigate the effect of vibration on such high fluidity concrete. The slump flow and V-time are used to characterize the fresh concrete. By applying vibration on concrete of different slump flow and viscosity, the significance of flowability and viscosity with respect to segregation tendency can be understood.

2. Experimental program

There are two phases of the work:

A. Three concrete mixes, C-1, C-2 and C-3, are made in the laboratory. The mixes have different slump flow values from 400 to 600 mm. The mix with the lowest viscosity is C-1, while C-2 has the highest viscosity. For every mix, three specimens were prepared. The first and second specimens are vibrated for 10 and 20 s, respectively, while the third specimen is left without vibration.
B. Two groups of concrete are vibrated. One group has varying V-time and the other has varying slump flow values. A pencil vibrator is used to vibrate all concrete for 20 s.

In all cases of vibration, the coarse aggregate profiles were drawn and the degree of segregation was calculated.

2.1. Materials and mix proportion

The concrete mixes investigated in this study were prepared with ordinary Portland cement. Continuously graded crushed granite, with saturated surface dry (SSD) density of 2.86 g/cm^3, was used as coarse aggregate. A maximum aggregate size of 20 mm was employed for coarse aggregates, as is commonly the case in SCC mixes. Coarse aggregates were washed to remove fine sandy particles that can hinder rheological properties. Well-graded pit sand, with SSD density of 2.60 g/cm^3 and a fineness modulus of 2.63, was employed as the fine aggregate. A new generation of copolymer-based Sp, containing air-entraining agent, was used. The admixture was measured as percentage by mass of powder. Because it was in an aqueous condition, the amount of Sp used was added into the amount of mixing water.

Table 1 summarizes the mix proportion and their respective volumetric ratios used in both Phases A and B of the experiment. Concrete mixes were prepared in 0.05 m^3 batches and mixed in an open pan mixer in the laboratory. The mixing sequence consisted of homogenizing the sand and cement for 0.5 min before adding water and Sp. The mortar was mixed for 2 min before adding the coarse aggregates. Once the coarse aggregates were added, the concrete was mixed for another 2 min. The slump flow and V-time were taken at the end of mixing.

2.2. Experimental procedures

Researchers to determine the aggregate profiles of vibrated concrete have adopted different methods. Khayat and Guizani [1] determined the segregation profile from hardened concrete cut into small sections. They used plywood forms of smooth interiors measuring 20×30 cm in cross section and 50, 70 and 110 cm in height. The hardened rectangular columns were vertically sawn into 10-cm-high

Table 1
Mix proportion for both Stages 1 and 2

Label	Water (kg/m^3)	Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	Sp (% × C)	W/C	s/m	V_w/V_c
Phase A								
C-1	175	600	750	850	1.5	0.29	0.44	0.82
C-2	175	640	650	750	2.0	0.27	0.40	0.86
C-3	175	600	750	850	2.0	0.29	0.41	0.92
Phase B (1): mix adjusted to obtain varying slump flow								
F-1	175	600	750	850	1.5	0.29	0.44	0.92
F-2	175	600	750	850	2.5	0.29	0.44	0.92
F-3	165	570	750	850	2.0	0.29	0.45	0.92
F-4	175	600	750	850	2.8	0.29	0.44	0.92
Phase B (2): mix adjusted to obtain varying V-time								
V-1	165	611	750	850	2.2	0.27	0.45	0.85
V-2	175	630	750	850	2.0	0.28	0.44	0.88
V-3	175	641	650	750	2.0	0.27	0.40	0.86
V-4	175	600	650	750	2.0	0.29	0.41	0.92
V-5	165	570	750	850	2.0	0.29	0.45	0.91

subsections. The total area of aggregates greater than 5 mm with respect to the total area of the cut surface was measured. Petrou et al. [7] used a unique experimental method to monitor aggregate settlement in concrete in real time. A scintillation camera was utilized to observe and record settlement of radioactively "tagged" aggregate in mortar and concrete in real time. Rols et al. [8] in studying the segregation resistance of concrete used a cylindrical mould 110 mm diameter × 400 mm height. They divided the fresh concrete into three 50-mm portions from the top, middle and bottom. However, no mention was given on how they divided the fresh concrete. The fresh concrete was then washed out through a 5-mm mesh screen and weighed. In the present study, a direct method of measurement, similar to that used by Rols et al., was adopted except that the form was bigger in size and rectangular in shape. The fresh concrete was divided into five sections from top to bottom at 80-mm intervals.

The experimental steps are schematically shown in Fig. 2. The form was made of plywood of smooth interiors. The dimension of the form is 250 × 250 × 400 mm. All sides were pasted with silicon bond and bolted together to prevent leakage. One side of the form was loosely tightened so that it could be taken off easily. At the end of mixing, both slump flow and V-time were taken. These values are given in Table 2.

In Phase A, the fresh concrete was put into three forms. Using a pencil vibrator, two samples were vibrated for 10 and 20 s while a third sample was left without vibration. The pencil vibrator has a frequency of 10,200 rpm and amplitude of 1.0 mm. In Phase B, only one form was prepared and vibrated for 20 s. In applying vibration, the vibrator was immersed vertically and quickly (about 30 cm/s) but withdrawn slowly (about 60 cm/s). After vibration, the concrete was left to set for 1 h or so depending on the mix. A low viscosity mix was left for longer time. The form was then covered and tightened by means of rods and bolts. The form was slowly made to lay 90° from original position. Based on the study by Petrou et al. [9], aggregate settlement stops immediately after vibration is terminated. The loosely bonded sidewall was carefully pried open. The fresh concrete in the form was divided into five equal parts by using metal slides. The sides of the formwork have guides to ensure vertical insertion (Fig. 3). Metal slides were inserted through the guides into the fresh concrete. Four pieces of slides were used to divide the concrete into

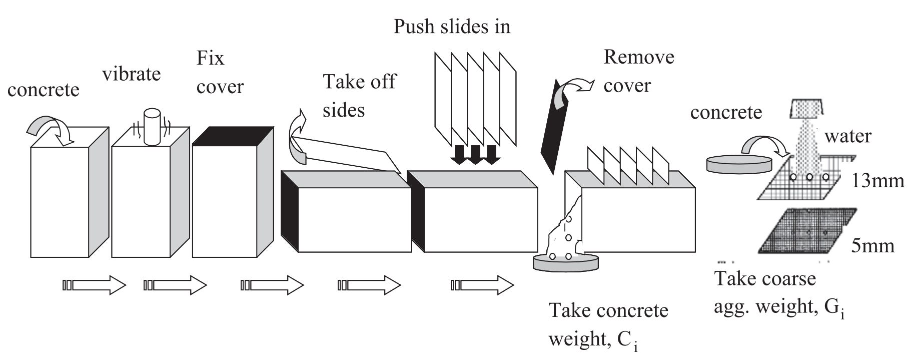

Fig. 2. Schematic diagram of experimental procedure.

Table 2
Values of slump flow, V-time and segregation coefficient

Label	Slump flow (mm)	V-time (s)	Segregation coefficient (%)		
			0 s	10 s	20 s
Phase A					
C-1	486	9.9	0.02	0.15	0.25
C-2	546	24.0	0.03	0.07	0.17
C-3	606	16.0	0.02	0.10	0.18
Phase B (1)					
F-1	486	9.9			0.25
F-2	645	9.2			0.30
F-3	542	10.3			0.26
F-4	750	12.0			0.24
Phase B (2)					
V-1	635	60.1			0.08
V-2	575	45.0			0.08
V-3	546	24.0			0.17
V-4	606	16.0			0.18
V-5	542	10.3			0.26

five portions (Fig. 4). The concrete from the different portions was put into individual trays and the respective concrete weights, C_i, were taken. Finally, the concrete in the tray was washed out using water. Two sieves, 5 and 13 mm size, one on top of the other were used to collect the coarse aggregates. Using a hose, flowing water washed away the powdered materials, leaving coarse aggregates on the sieves. The aggregates retained in the sieves were wiped using a cloth until a SSD condition was obtained. The weight of the coarse aggregate, G_i, was taken. The percentage of coarse aggregates at level i was calculated as a weight ratio of coarse aggregate retained in the sieve to that of the concrete $(G/C)_i$. The coarse aggregate profile was drawn by plotting the value of $(G/C)_i/(G/C)_{\text{ave.}}$ against the height of the form. The $(G/C)_{\text{ave.}}$ is the total weight of coarse aggregates retained divided by the total weight of concrete in the form.

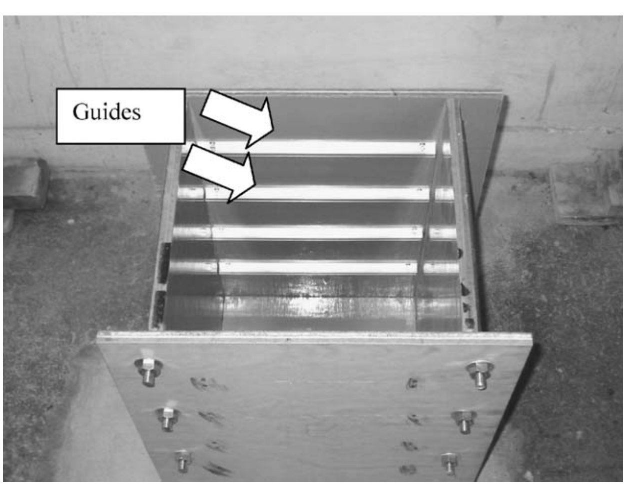

Fig. 3. Photo of form with aluminum guides to ensure vertical insertion of metal slides.

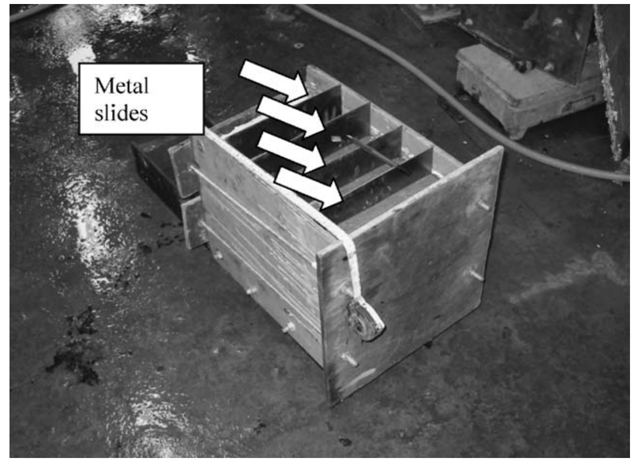

Fig. 4. Photo of fresh concrete after insertion with metal slides.

To quantify the degree of segregation, a segregation coefficient, SC was defined as Eq. (1).

$$\mathrm{SC} = \sqrt{\frac{s\sum_{i=1}^{i=5}(1-x_i)^2}{H}} \qquad (1)$$

$$x_i = \frac{(G_i/C_i)}{(G/C)_{\text{ave.}}}$$

$$(G_i/C_i) = \frac{\text{weight of coarse aggregate in each tray}}{\text{weight of concrete in each tray}}$$

$$(G/C)_{\text{ave.}} = \frac{\text{total weight of coarse aggregate}}{\text{total weight of concrete}}$$

Height of form, $H = 400$ mm

Distance between slides, $s = 80$ mm

In this experimental study, the value of SC ranges between 0.05 and 0.35. A low value of SC indicates minimal segregation, while a higher value indicates significant segregation.

3. Results and discussion

3.1. Phase A: vibration of high fluidity concrete with different vibration times

Concretes of different flowability and viscosity were vibrated for different vibration times of 0, 10 and 20 s. The results of slump flow, V-time and segregation coefficient, SC, for the vibrated concrete are shown in Table 2.

Fig. 5 shows the segregation profiles for cases of no vibration. All profiles lied in the region close to 1.0, which

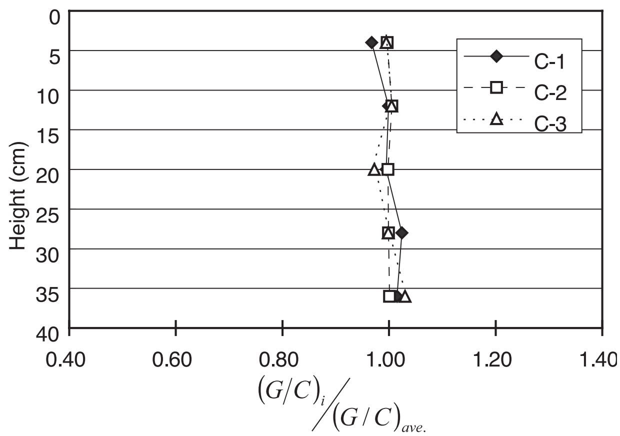

Fig. 5. Segregation profiles for concrete without vibration.

means the concentration of coarse aggregates in the concrete is homogeneous from top to bottom of the form. The standard deviations calculated for the ratio of coarse aggregates in concrete, G/C, are 2.2%, 3.0% and 2.1% for C-1, C-2 and C-3, respectively. The SC values lies between 0.03 and 0.02. These values can be regarded as indicating insignificant segregation of coarse aggregates. The fact that all three values show little deviation from one another also proves that the experimental procedure is acceptable. Without any vibration, the coarse aggregates are homogeneously distributed in the suspension.

The SC values for 0, 10 and 20 s vibration are shown in Fig. 6. Throughout all three cases of different segregation coefficients, C-1 shows the most segregation while C-2 shows the least. For example, in the case of 10-s vibration, the SC values are 0.15, 0.10 and 0.07 for C-1, C-3 and C-2, respectively. Despite having different slump flow and V-time, the segregation tendency is more closely associated to the viscosity of concrete than its flowability. With respect to viscosity of concrete, C-1 has the lowest viscosity because it has the shortest V-time. The reason for this can be understood by considering the rheology of concrete.

The rheology of fresh concrete can be described in terms of the "Bingham" model. In this model, the shear stress of a material is expressed in terms of yield stress and plastic viscosity. The Bingham equation is given as:

$$\tau = \tau_0 + \mu\gamma \tag{2}$$

where τ is shear stress (in Pa) applied to the fresh concrete, γ is shear strain rate (also called the strain gradient, in s^{-1}), τ_0 is yield stress (in Pa) and μ is plastic viscosity (Pa s).

The yields stress and plastic viscosity characterize the flow properties of the fresh concrete. If a shear stress is applied to the system, a deformation may appear if the stress is high enough to overcome the friction between particles. When concrete is vibrated, stresses are introduced in the mix. These stresses set the particles into motion, thus eliminating the internal friction.

The slump test is a manifestation of the level of yield stress in a concrete mix. Hu et al. [10] and Ferraris and de Larrard [11] proposed a general formula relating the slump to the yield stress. Ferraris and de Larrard's formula is given below:

$$\tau_0 = \frac{\rho}{347}(300 - s) + 212 \tag{3}$$

where ρ (density) is expressed in kg/m^3, τ_0 is in Pa and slump, s, is in mm.

When vibration is applied, the vibratory stress is always greater than the yield stress of concrete. On the other hand, the viscosity of the mix is responsible to maintain the coarse aggregates in suspension. Thus, the segregation tendency follows the trend in viscosity more closely than the yield stress. This notion will be further tested in Phase B of the work.

Fig. 7 shows a typical profile for concrete applied with 0, 10 and 20 s vibration time. The longer the vibration time, the greater the value of SC; thus, the more segregation has occurred. The SC values for case C-3 are 0.02, 0.10 and 0.18 for 0, 10 and 20 s vibration, respectively.

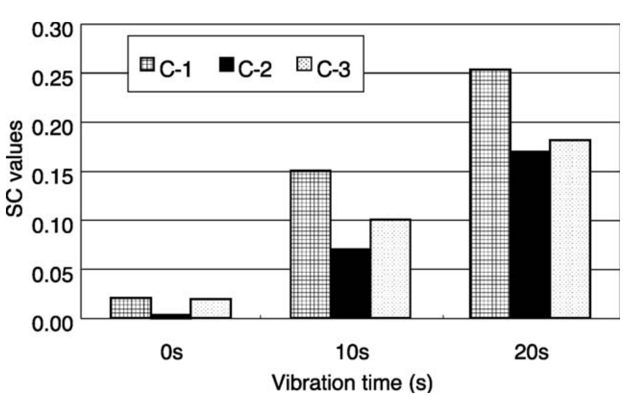

Fig. 6. SC values for vibrated high fluidity concrete in Phase A.

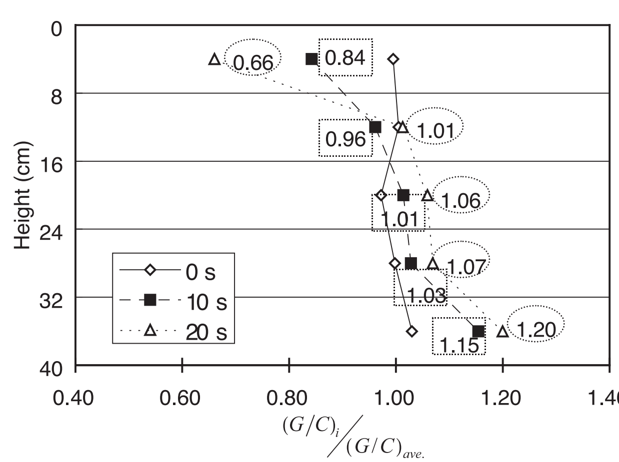

Fig. 7. Typical segregation profiles for C-3 with 0, 10 and 20 s vibration.

The vibration process attempts to fluidized the concrete. The longer the vibration time, the longer the concrete is fluidized. Therefore, the greater the chances for heavier aggregate to settle downward. The investigation technique employed in this study enabled the amount of coarse aggregate transfer from one level to another to be calculated. The height of the form can be divided into five levels, namely, 0–8 (top level), 8–16, 16–24, 24–32 and 32–40 (bottom level) cm levels. By considering the segregation profile for vibrated concrete closely, it is obvious that the 20-s profile has more coarse aggregate falling downward from the 0–8-cm (first) level to the 16–24-cm (second) level. The subsequent transfer of coarse aggregate from the 16–24-cm (third) level to the next lower level is proportionately the same in both cases. Thus, the overall downward movement of coarse aggregate in a vibrated concrete depends on the initial amount that falls from the top portion of the concrete to a lower portion.

Fig. 8 shows the profile of two different sizes of coarse aggregate, 5–13 mm (s) and 13–20 mm (b), for concrete with 20-s vibration. Between the two sizes, settlement of small-sized aggregate was not as obvious as that of the larger-sized ones. The pattern of lines for the large-sized aggregates is also similar to that of vibrated concrete shown in Fig. 6. This shows that the degree of segregation is mostly due to the segregation of the larger-sized aggregates. Although the concrete was vibrated for 20 s, its viscosity was able to maintain the uniform suspension of smaller-sized aggregates in the mortar. The pattern of segregation profile for the small-sized aggregates is similar to that for non-vibrated concrete shown in Fig. 5.

The settlement of particle in a fluid with Bingham plastic behavior has been predicted by Beris et al. [12]. They concluded that a spherical sphere will settle when the dimensionless group referred to as the yield stress parameter, Y_g, defined below, is less than 0.143.

$$Y_g = \frac{3\tau_0}{2R(\rho_s - \rho_f)g} \tag{4}$$

where ρ_s and ρ_f refer to the density of solid and fluid, respectively, R is the radius of sphere and g is gravitational acceleration.

Assuming coarse aggregates to be spherical in shape, the settlement of coarse aggregates will be dependent on its radius. A large value of R in the above equation gives a lower value of Y_g. A lower value of Y_g means more chances for the aggregate to settle. That explains the reason for the different profiles for the two sizes of aggregates. In the context of this study, the bigger-sized aggregate, 13–20 mm, exhibited greater segregation tendency whereas the smaller-sized aggregate, 5–13 mm, showed little segregation.

3.2. Phase B: vibration of concrete of different slump flow and V-time

In this phase of the work, the vibration of high fluidity concrete of different slump flow and V-time was compared. All the concrete mixes were vibrated for 20 s using the pencil vibrator. SCC targeted V-time of 10 s was taken as a reference value. The concrete mixes can be divided into two categories. Phase B (1) consists of high fluidity concrete having V-time within the range of 10 ± 2 s but the slump flow lies in the 480–750-mm range. By maintaining the same viscosity, the relationship between flowability and segregation tendency can be investigated. Phase B (2) consists of high fluidity concrete having slump flow in a range of 580 ± 50 mm but having broad range of V-time between 10 and 60 s. The relationship between different V-

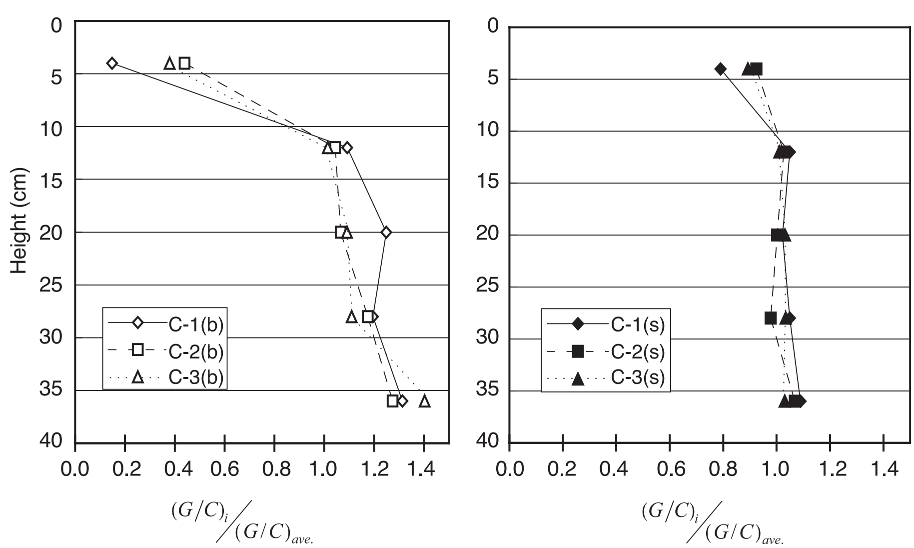

Fig. 8. Segregation profiles showing 13–20 mm (b) and 5–13 mm (s) sizes.

time and segregation tendency can be investigated. Tables 1 and 2 show the respective mix proportion and fresh properties of concrete, respectively.

Fig. 9 shows the graph of SC values against slump flow. A horizontal line describes the data well with an equation of SC = 0.26. The plot of data shows that changes in flowability of concrete does not affect the segregation of high fluidity concrete when vibration is applied.

All concrete mixes have the same W/C and the same viscous condition as shown by the same V-time. The increase in flowability was achieved by increasing the dosage of Sp. The use of Sp causes dispersion into smaller agglomerates of cement particles, which predominate in the cement paste of the concrete mix. Because of the dispersion effect, there is a fluidity increase in the cement mixture. The dispersion mechanism differs according to the type of Sp used. Collepardi [13] summarized the mechanisms into four different categories, namely, (1) electronic repulsion, (2) polymer adsorption, (3) reduction in surface tension of mixing water and (4) lineup of linear polymers along the concrete flow direction. The dispersion of these cement particles effectively increases the flowability of the mix.

The dispersion effect of Sp on cement particles reduces the yield stress of high fluidity concrete to almost zero. As already mentioned in Section 3.1, the vibratory stress imposed on the concrete is always greater than its yield stress. The work by Alexander [14], on the mechanics of motion of fresh concrete during vibration, proved that concrete mixtures behave like a fluid during vibration. During the period of vibration, the concrete changes from Bingham plastic to a fluidized state. In the case of high fluidity concrete, the condition of fresh concrete is partly like a fluid already. As such, the different level of flowability that is primarily due to the dispersion of cement particles does not have significant bearing on the segregation tendency when vibration is applied.

However, this result is also limited by the vibrator parameter. The use of a pencil vibrator is generally known to have higher amplitude compared with other types of vibrator. It has a gravitational acceleration above 100 *g*. A high *g* means

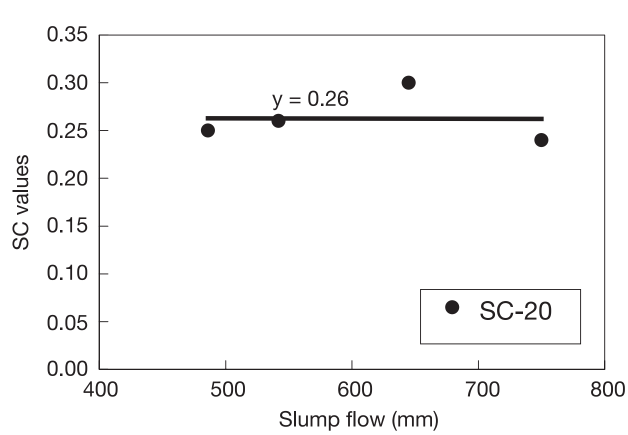

Fig. 9. Variation between SC values with slump flow.

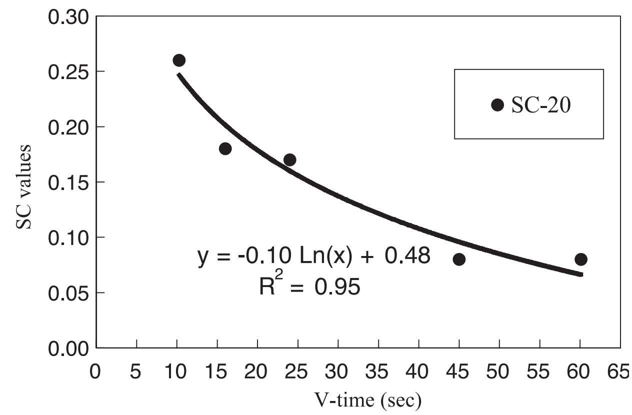

Fig. 10. Variation between SC values with V-time.

high vibrating force. Such high range of amplitude would generally affect the coarse aggregates. Finer particles like sand and cement, however, are mostly affected by the frequency of vibration rather than the amplitude [15].

Phase B (2) aims to investigate the relationship between segregation tendency and viscosity of concrete mixes. In this case, the various viscous conditions are quantified by the different V-time obtained from different mixes. The volumetric coarse aggregate content is small in these mixes. Thus, the contribution of coarse aggregate interactions in determining V-time is small. The viscosity of the mortar is mainly responsible for the V-time. The V-time is dependent on the interaction between fine constituents like cement and sand. The ratio of sand over mortar (s/m) by volume and W/C are two important parameters in determining V-time [16].

Fig. 10 shows the vibration results of high fluidity concrete of varying V-time. A logarithmic relationship describes the data accurately with an R^2 value of 0.95. The equation is given below:

$$SC = -0.10 \ln(V - \text{time}) + 0.48 \tag{5}$$

The segregation coefficient has a direct relationship with V-time. When concrete is vibrated, the force from the vibrator introduces shear stresses in the mix. Because the coarse aggregates are kept in its position due to the viscosity of mortar, the effects of the vibratory shear stress on the mortar is important.

Basically, viscosity is the resistance a material has to change in form. This property can be thought of as an internal friction. When fresh concrete flows, the particles slide over one another. However, there is some friction between the molecules being past each other. The more the particles cling to one another, resisting flow, the higher the friction between flow. This amount of clinginess is called viscosity.

Concrete can be assumed to consist of coarse aggregates in a mortar suspension. The interactions between finer particles, like cement and sand, constitute to the viscous condition of mortar. The relative distance between cement and fine aggregate particles are closer to one another in high viscosity as compared with low viscosity mix. This can be assumed from the high volumetric volume ratio of s/m in the case of high viscosity mix. With respect to interparticle lubrication in the presence of water, a low W/C as in high viscous mix means that there are less lubrication. Because a low viscous mix have high W/C, interparticle lubrication is better. Both the above-mentioned variables, s/m and W/C, are important in determining the viscosity of concrete.

When concrete is vibrated, the vibratory forces displace the particles one over another and move in the direction of the force. In the case of high viscosity concrete, the relative displacements are small because the particles are close to one another. The coarse aggregates are therefore kept in position with minimal movement during the vibration. On the other hand, the interactions between particles are less frequent in low viscosity concrete and their relative displacements are bigger. As such, the chances for the coarse aggregates to settle downward are greater. That could be a possible reason for a higher segregation tendency in low viscosity mix as compared with a high viscosity one.

In a V-funnel test, concrete is filled in the funnel. By opening the bottom gate, the concrete flows out under its own weight. Considering the region near the orifice, constituent particles slide over one another to reach the exit. In the case of high viscosity concrete, the interactions between particles are more and it takes longer time to reach the exit. Likewise, such interactions are lesser in low viscosity concrete and it become easier to flow out of the V-funnel. That accounts for a shorter V-time in low viscosity concrete. These particle interactions near the orifice could be representative of similar interactions of the particles in the case of vibration, as already explained in the preceding paragraph. Thus, the degree of segregation as shown by SC values has a close relationship to the V-time.

As a summary, it is possible to apply vibration in high fluidity concrete provided that its viscosity is not too low. A concrete with V-time 10 s or less will segregate easily when vibrated. Despite having different range of flowability, as shown by the slump flow, the segregation tendency is not affected by the flowability factor. This result, however, is limited to the use of high amplitude vibration in the case of a pencil vibrator.

4. Conclusion

(1) It is important to understand the effects of vibration on high fluidity concrete. This work has shown, however, that vibration of such concrete is still a viable option by considering the viscosity of the mix. Despite its ability to flow, vibration could still be applied on such concrete without causing any detrimental effects.

(2) From this study, the relative viscosity of concrete estimated from the V-funnel test is shown as being a more important parameter than flowability when considering vibration. Despite the concrete's ability to flow, the viscosity of concrete is responsible for maintaining the distribution of coarse aggregate. An estimation of concrete flowability is shown by the slump flow and the concrete viscosity can be quantified by the V-time. There is a logarithmic relationship between the V-time and the segregation tendency of concrete. At low V-time, the tendency to segregate is higher than at high V-time.

(3) By means of the experimental technique, larger-sized aggregate is more dominant in determining the segregation pattern as compared with smaller ones. In this experiment, the vibration of high fluidity concrete caused more segregation of 13–20-mm aggregate size than 5–13 mm-aggregate size.

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