論 文

[1201] A Study on Velocity of Deformation of Super Workable Concrete

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1. INTRODUCTION

Intensive studies on deformability and segregation resistance of concrete have been carried out for a purpose of developing a high performance concrete with high filling ability [1,2]. The concrete requires no vibration to fill all corners and spaces in the formwork. However, two concrete mixtures which are judged by a no-consolidation filling test, for example U-shaped filling test [2] to have equal filling ability, may fill a specified formwork at different speed. The process of filling takes time, even though the concrete can fill the formwork perfectly, if the concrete is relatively high in viscosity. This problem occurs since the velocity of deformation is not taken into consideration. The velocity of deformation is essential especially when the speed of construction is concerned. The concrete which has excellent filling ability but takes long time to complete filling is not considered appropriate in practice. It was then regarded that velocity of deformation is one of the parameter which has to be considered in the quality control of the concrete.

In this paper, a method for evaluating the velocity of deformation of super workable concrete was proposed. The super workable concrete here is defined as those which can not be measured the deformability by slump value but by diameter of slump flow. The idea is to propose a method which is simple to carry out and requires no complicated instrument so that it can be applied to the quality control of the concrete at manufacturing as well as at construction.

2. EVALUATION METHOD OF VELOCITY OF DEFORMATION

2.1 TEST METHOD

In actual, for a concrete mixture which is ensured to have no segregation when filling, velocity of deformation varies depending on the boundary condition, such as denseness of the reinforcement and shape of the formwork, etc. In this study, the velocity of deformation was defined as the rate of

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increasing of diameter of a flowing concrete which is allowed to flow without any obstruction to the flow of the concrete, such as the condition of slump flow test. The slump flow test which is known as the test for evaluation of deformational capacity of the super flow concrete was used for evaluating the velocity of deformation of the concrete. The slump flow means the value of diameter of the flowing concrete at the time of measurement. By conducting a slump flow test, the slump flow vs. flow time curve of the concrete can be obtained by continuously recording the flow time at each step of slump flow. The flow time means the elapsed time which is measured starting from when the slump cone was lifted up to let the concrete flow out of the bottom of the cone to when the slump flow of concrete reaches the values required to measured flow time. In this study, the slump flow vs. flow time curve was obtained by video-recording the flowing concrete from the beginning of flow until the flow stopped, then measuring slump flow and the corresponding flow time from the recorded video images.

2.2. LOCAL VELOCITY OF DEFORMATION AND AVERAGE VELOCITY OF DEFORMATION

Considering the slump flow vs. flow time curve in Fig.1, the local velocity of deformation which means the rate of increasing of diameter of flow of concrete at a certain slump flow is defined by the local tangent of the curve as

$$v = dF/dt \qquad (1)$$

where v is the local velocity of deformation, F is value of slump flow and t is the elapsed time from the beginning of flow.

Differentiation with time over the total flow domain of the curve in Fig.1 gives rise to the result of local velocity of deformation vs. slump flow as shown in Fig.2.

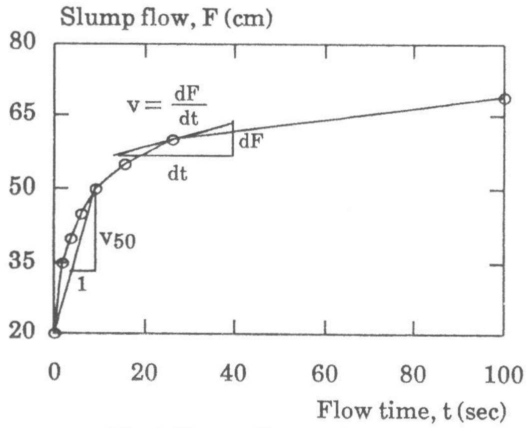

Fig.1 Slump flow vs flow time

Here, the average velocity of deformation (vav) is defined as in the following equation

$$vav = \int_{Fi}^{Ff} v\,dF \Big/ \int_{Fi}^{Ff} dF \qquad (2)$$

where F is the value of slump flow, v is the local velocity of deformation defined in Eq.(1). Fi and Ff mean the initial and final slump flow values considered in the derivation of average velocity of deformation.

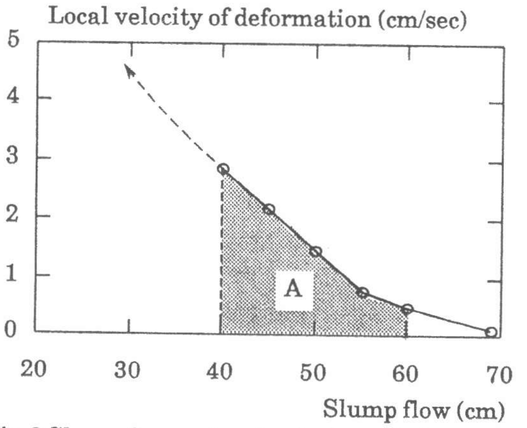

Fig.2 Slump flow vs local velocity of deformation

In this paper, the range of slump flow utilized in the derivation of average velocity of deformation were from 40cm to 60cm. This means that Fi and Ff in Eq.(2) are 40cm and 60cm, respectively. The value of Fi was taken as 40cm because it took few seconds to remove the flow cone so that the flowing concrete could be totally visualized. Furthermore, the flowing speed at very small slump flow can be affected by human error, such as cone removing speed or can not be observed without use of video camera since the flow speed is too fast just after removing the cone. The value of Ff was decided to be 60cm since the velocity of deformation beyond 60cm was very small and was considered ineffective in the practical point of view. It was derived from the test results which were obtained in this study that the values of velocity of deformation beyond 60cm are less than 10% of the average velocity of deformation obtained using Eq.(2). Therefore, by considering Fi=40cm and Ff=60cm, Eq.(2) can be rewritten as

$$v_{av} = \frac{1}{20}\int_{40}^{60}\frac{dF}{dt}\,dF = \frac{1}{20}A \qquad (3)$$

Eq.(3) was utilized to derive the average velocity of deformation. The velocity of deformation of various mixtures of concrete was evaluated based on the average velocity of deformation.

2.3 MIX PROPORTION AND PROPERTIES OF TESTED MATERIALS AND MIXTURES

Shown in Table.1 is the physical properties of the materials used in the test of this study. Mix proportions and properties in fresh state of the tested mixtures were shown in Table 2. The used superplasticizer was naphthalene type. The used viscosity agent was a kind of polysaccharide produced by the process of biotechnology.

Table.1 Physical properties of the materials used in this study

Materials	Specific gravity (g/cm³)	Specific surface area (cm²/g)	Finess Modulus
Cement	3.16	3280	-
Slag	2.90	4270	-
Fly ash	2.24	3150	-
Silica fume	2.35	175000	-
Sand	2.55	-	2.77
Gravel	2.68	-	6.46

Table.2 Mix proportion and properties in fresh state of the tested mixtures

Mix No.	W (kg/m³)	Cementitious material (kg/m³)				s/a (%)	Admixture content (kg/m³)		Air (%)	slump flow (cm)	filling height (cm)
		Cement	Slag	Fly ash	Silica Fume		Superplasticizer	viscosity agent			
1	165	200	200	100	-	45	7.5	0	4.4	59.8	31.0
2	165	200	200	100	-	45	8.4	0.5	4.4	63.5	35.3
3	165	200	200	100	-	45	12.6	1.0	4.2	66.0	36.0
4	165	200	200	100	-	45	20.4	2.0	3.4	65.0	32.0
5	162	225	225	100	50	45	43.2	0.5	2.0	63.0	34.5

It should be noted here that all of the mix proportions shown in Table.2 were obtained by varying the amount of superplasticizer until the largest filling ability, which was measured by filling height, of each mixture could be obtained. The filling height which was introduced to be a parameter for evaluating filling ability of super workable concrete was measured using the U-Shaped filling ability apparatus which was proposed by the authors [2] and the measured values for each mixtures were shown in the final column of table.2.

3. TEST RESULTS AND DISCUSSIONS

3.1 GENERAL TEST RESULTS

Fig.3 demonstrates the results of average velocity of deformation of mix no.1 to mix no.4 which illustrates the effect of amount of viscosity agent on the velocity of deformation of the super workable concrete. Even though the amount of superplasticizer was increased to obtain the mixtures with highest filling ability (indicated by filling height) when the amount of viscosity agent was increased, the average velocity of deformation decreases with the increase of the amount of viscosity agent.

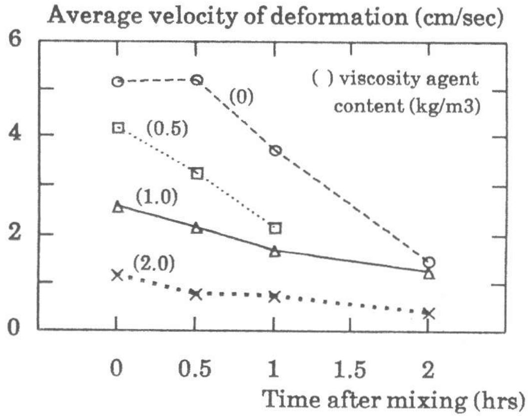

Fig.3 Effect of amount of viscosity agent and time after mixing on velocity of deformation

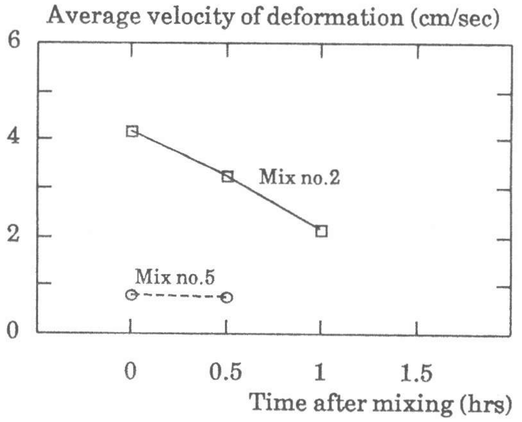

Fig.4 Velocity of deformation of a super workable and a super flow high strength concrete

Also illustrated in the figure was the effect of time after mixing on the average velocity of deformation of the tested concrete. The average velocity of deformation decreases with the length of time after mixing for all mixtures tested in this series. It is noted here that except for the mixture without addition of viscosity agent which encountered flow loss of about 10cm after 2 hours, the other mixtures did not show any significant flow loss (less than 3cm after 2 hours).

Fig.4 compares the average velocity of deformation of a super workable concrete (mix no.2) with that of a super flow high strength concrete which has a 91-day compressive strength of about 900 kg/cm2 (mix no.5). It could be seen from the results of slump flow and filling height that both mixtures have almost equal slump flow and filling height. However, the velocity of deformation of mix no.5 was lower than half of that of mix no.2. This results indicate that only the deformational capacity measured by slump value is not sufficient for evaluating the deformability of super workable concrete.

3.2 RELATIONSHIP BETWEEN VELOCITY OF DEFORMATION AND VISCOSITY

Fig.5 shows the relationship between velocity of deformation of concrete mixtures and the apparent viscosity of their mortars. The apparent viscosity of mortar was measured using the apparatus shown in Fig.6 [2]. The mortar samples tested for viscosity were sieved from the corresponding concrete using a 5-mm sieve. The mortar was filled in a cylindrical vessel with the cross steel blade submerged. The cross steel blade was then pulled upward with 3 levels of constant pulling velocity. The pulling force was measured with a load cell. Viscosity was derived from the slope of pulling force vs. pulling velocity curve. It can be observed from Fig.5 that when the viscosity of the mortar increases, average velocity of deformation of the corresponding concrete decreases and there is a correlation between the values of the reciprocal of average velocity of deformation and the viscosity of mortar which gives the value of standard deviation of 24.9 g/cm/sec. This result suggests that viscosity of mortar should not be excessively increased so that the velocity of deformation of the mixture would not be too slow.

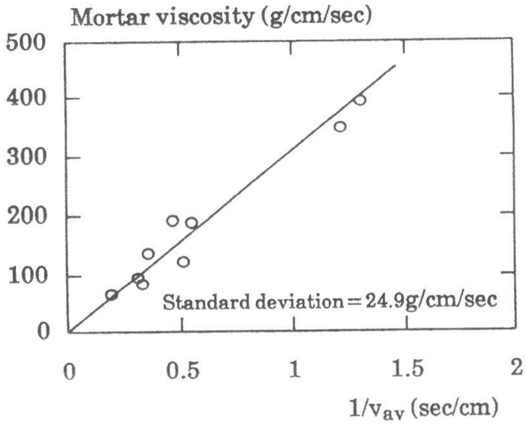

Fig.5 Relationship between the reciprocal of average velocity of deformation of concrete and the viscosity of mortar

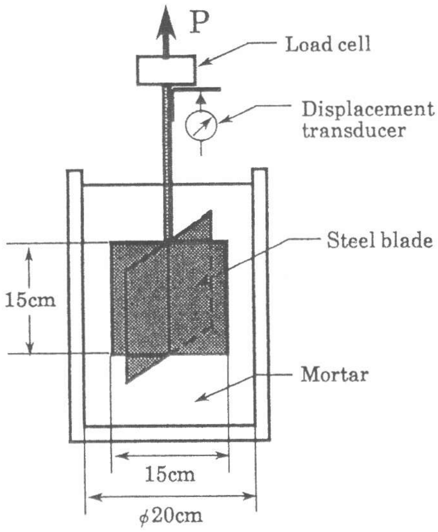

Fig.6 Apparatus for evaluating viscosity

3.3 SIMPLIFIED TEST FOR FIELD APPLICATION

One can imagined that in the case of field practice, it is not convenient to utilize the value of average velocity of deformation, vav, as the parameter for evaluating the velocity of deformation of the concrete. This is because various measuring points from 40cm to 60cm of flow must be measured. In addition, the calculation of average velocity of deformation using Eq.(3) has to be performed. Therefore, the simpler method was proposed to be used in field practice as in the following.

Define v50 as the 50cm-secant velocity of deformation as illustrated in Fig.1 and by the following equation

$$v50 = (F50 - F20)/T50 = 30/T50 \quad (4)$$

where F50 and F20 are slump flow values of 50cm and 20cm, respectively, and T50 is the flow time when the concrete flow reaches 50 cm.

Fig.7 is the plot of the average velocity of deformation (vav) vs. the 50-cm secant velocity of deformation (v50). The figure shows that there is a good linear correlation between vav and v50 which gives the standard deviation of 0.126 cm/sec. This result indicates that it is possible to utilize v50 as a simplified parameter for evaluating the velocity of deformation of the super workable concrete. The parameter v50 is considered useful for the quality control of super workable concrete in practice because it is easier to be obtained than the value of average velocity of deformation. Therefore by only observing the flow time when the concrete flow reaches 50cm with a stop watch, the velocity of deformation of the concrete can be easily evaluated. It can be therefore considered that the method is suitable for evaluating concrete with flow greater than 50cm.

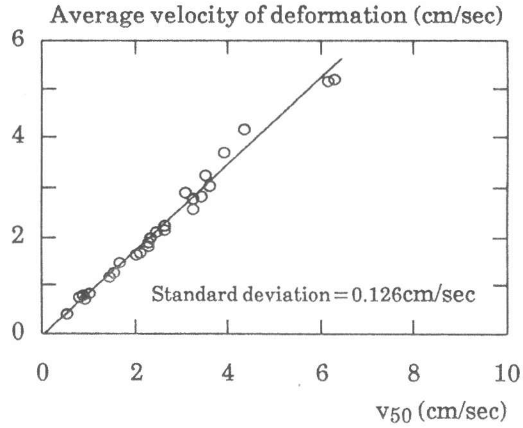

Fig.7 Relationship between v_{50} and average velocity of deformation of concrete

4. CONCLUSIONS

The following conclusions can be drawn on the basis of the content of this study.

1. A method for evaluation of velocity of deformation of super workable concrete was propose by adopting the slump flow test.
2. The velocity of deformation was defined as the average velocity of deformation measured from 40cm to 60cm of the concrete flow.
3. The velocity of deformation decreases with the increase of amount of viscosity agent even though the amount of superplasticizer was increased to obtain mixtures with maximum filling ability for each content of viscosity agent.
4. The velocity of deformation decreases with the increase of time after mixing.
5. There is a correlation between velocity of deformation of the concrete and viscosity of the corresponding mortar.
6. There is a good linear correlation between the v50 which was defined as the secant velocity of deformation at slump flow of 50cm and the average velocity of deformation, vav. Therefore, the v50 was utilized as the simple parameter for evaluating velocity of deformation in our study.

REFERENCES

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