A PRACTICAL STUDY ON RELIABLE CONCRETE PRODUCTION SYSTEM USING IMMERSION BATCHING OF FINE AGGREGATE

(Translation from Proceedings of JSCE, No.697/V-54, February 2002)

Ryuichi CHIKAMATSU Shigeyuki SOGO

The control of concrete quality begins with precise measurement of the specified quantities of materials before production begins. However, there is no easy way to precisely and quickly measure the surface moisture of fine aggregate in most production systems currently in operation. To solve this problem, the authors have devised an "immersion batching" method for fine aggregate, in which aggregate is immersed in water before being batched in a wet condition. This enables the precise quantities of water and fine aggregate to be calculated independent of fluctuating levels of surface moisture. This paper summarizes the results of verification tests aimed at practical implementation of a concrete production system based on immersion batching of the fine aggregate. Batching control of the fine aggregate immersed in water and specifications of the equipment are also described, and the results of quality confirmation tests on concrete made using this method are reported.

Keywords : *fine aggregate, surface moisture, batching method immersing sand in water, high reliability, concrete production system*

Ryuichi Chikamatsu is a deputy chief civil engineer of Obayashi Corporation, Technical Research Institute, Tokyo, Japan. He received his Master of Engineering Degree from University of Tsukuba in 1989. His research activities include the characteristics of low-heat blended cement, development of Self-Compacting Concrete. He received JSCE Yoshida Research Prize in 1991. He is a member of JSCE and JCI.

Shigeyuki Sogo is a general manager of Obayashi Corporation, Technical Research Institute, Tokyo, Japan. He received his Master and Doctor of Engineering Degree from University of Kyushu Institute of Technology in 1974 and 1991 respectively. He has been occupied with development of special concreting methods, such as Underwater Placing, Mass Concrete, and simplifying with Self-Compacting Concrete. He is a member of JSCE and JCI.

１． INTRODUCTION

The construction of more reliable concrete structures requires that a system of assuring adequate concrete quality be formulated. The new batching method for fine aggregate described in this paper is intended as part of such a quality assurance system. Quality stability is an index for judging the reliability of concrete. The ideal concrete production system is one in which quality fluctuations are minimized, regardless of the actual quality level, and in which the results of production are adequately evaluated.

Production systems currently in use generally assume that aggregate is in a moist condition and require measurement of surface moisture to correct the water content. Various sensor systems have been proposed for making continuous measurements of surface moisture, as needed to allow for correction, including systems based on microwaves, capacitance, and neutrons. Yet, control of surface moisture remains a problem at most plants [1].

With this as the background, the authors have devised a method of batching saturated fine aggregate, obtained by immersion in water, together with the water as a method of precisely controlling fine aggregate and water independently of fluctuating surface moisture levels. This paper summarizes the results of verification tests aimed at putting this immersion batching method into practical use. The method of batching control and specifications of the batching equipment are described, and the method of preparing immersed fine aggregate is given. Finally, the quality of concrete made with fine aggregate prepared using this method is also reported.

２． OVERVIEW OF IMMERSION BATCHING OF FINE AGGREGATE

2.1 Basic concept

The basic concept of this method is that fine aggregate is immersed in water and then the masses of fine aggregate and water are calculated from the total volume and mass based on the difference density between the two components (See **Fig.1**). By this method, the fine aggregate content, which is normally expressed in terms of weight in the saturated surface-dry condition, is determined without adjusting the surface moisture. As a result, concrete of the required quality can be efficiently produced, since no surface moisture control of the fine aggregate is necessary [2].

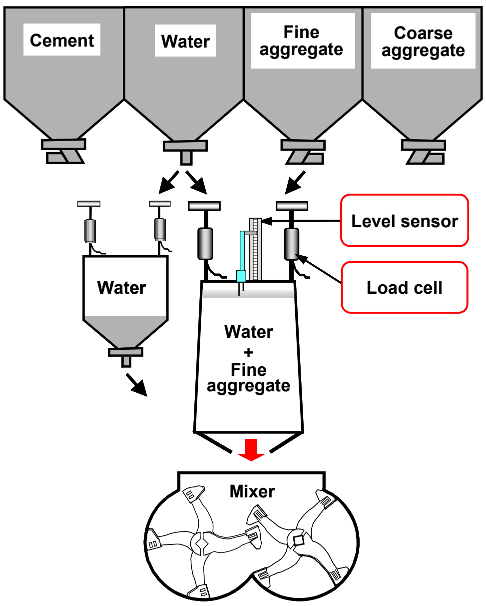


Fig.1 Concept of immersion batching of fine aggregate

The calculations are as given below:

$$M_s + M_w = M_f \tag{1}$$

$$M_s / \rho_s + M_w / \rho_w = V_f \tag{2}$$

Transforming Eqs. (1) and (2),

$$M_s = \rho_s \left(M_f - \rho_w V_f\right) / \left(\rho_s - \rho_w\right) \tag{3}$$

$$M_w = \rho_w \left(\rho_s V_f - M_f\right) / \left(\rho_s - \rho_w\right) \tag{4}$$

where, M_S ; mass of fine aggregate, ρ_S ; saturated surface-dry density of fine aggregate
M_w ; mass of water, ρ_w ; density of water
M_f ; total mass of fine aggregate and water
V_f ; total volume of fine aggregate and water

2.2 Equipment for immersion batching

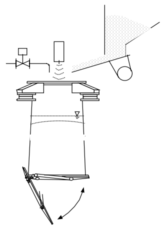
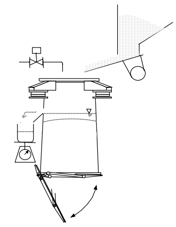
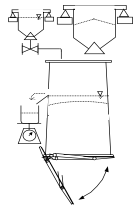
Table 1 shows a typical example of the equipment and control methods needed for immersion batching of fine aggregate. Equipment may be of the volume-measurement or volume-control type. **Photo 1** shows an example of volume-measurement type equipment. The specifications of the equipment are described as follows:

a) Batching range for fine aggregate
As a rule, this method is used for batching the total quantity of fine aggregate to be used in the concrete. Since it is based on the same principles as in JIS A 1111-2001 (Method of testing for surface moisture of fine aggregate), the surface moisture can also be calculated. In cases where it is impossible to immerse the all of the fine aggregate required in the batch, as a result of the low water content, batching can be carried out by immersing only part of the fine aggregate. In this case, the surface moisture content is calculated, and then the remaining amount of fine aggregate is adjusted to correct the batch.

b) Method of controlling batching
Though material batching may be controlled by either mass or volume, as in conventional batching, mass-based control may be more practical. With volume-measuring type equipment, the mass of immersed fine aggregate is weighed under control, and its volume is measured. Even if the mass of immersed fine aggregate is weighed as specified, the measured volume of immersed fine aggregate may vary depending on its surface moisture, changing the calculations in terms of volume in a saturated surface dry condition.

On the other hand, volume-controlling type equipment simultaneously controls the mass and volume of immersed fine aggregate. The as-batched volume of immersed fine aggregate is set beforehand, and water is replaced with fine aggregate while maintaining the set volume. The weight measurement increases according to the mass of fine aggregate added to the water. When the mass of immersed fine aggregate reaches the set value, batching of fine aggregate and water at the specified quantities is completed. This method permits quick and efficient production of concrete with the target quality and quantity. There are some variations of the method using different combinations of measurements. With Type B, shown in **Table 1**, the masses of water and wet fine aggregate are weighed and the immersed fine aggregate is obtained by charging both into a container of known capacity.

Table 1 Typical examples of equipment and control method for immersion batching of fine aggregate

Type of equipment		Volume-measurement	Volume-control A	Volume-control B
Schematic outline				
Special feature	Fine aggregate for immersion batching	Total quantity[*1]	Total quantity[*1]	
	Control method	Mass controlling, volume measuring	Mass and volume also controlled	
	Adjusting of mix	Required	Not required	
Batching item	Water with immersed fine aggregate	△[*1]	△[*1]	○
	Mass of wetted fine aggregate	–	–	○
	Mass of immersed fine aggregate	○	○	–
	Volume of immersed fine aggregate	○ (Measuring)	○ (Controlling)	○ (Controlling)
Caluculation item	Water with immersed fine aggregate	○	○	○
	Fine aggregate in terms of saturated surface condition	○	○	○
	Surface moisture	△[*1]	△[*1]	○

＊1 In case of measuring the surface moisture of sand, possible to batch a part of fine aggregate

c) Container for measuring immersed fine aggregate
The capacity of the container for immersion batching is similar to that used with conventional methods. There are no particular limitations on the container shape. However, when determining the volume of immersed fine aggregate from a displacement measurement, a tall container with a small cross-sectional area is desired to enhance the accuracy of measurement. The cross section should be circular rather than rectangular, and the diameter should be slightly greater (rather than smaller) towards the base to facilitate easy discharge of the wet fine aggregate. In consideration of these requirements, a batcher in the shape of a frustum of a cone and having a height 4 times the base diameter was selected as the model. Its capacity was 40 liters.

More than one type of fine aggregate is normally blended to produce ready-mixed concrete. In immersion batching, a second fine aggregate can be batched as in conventional methods, though separate batching increases accuracy. A batching rate comparable to conventional methods can be achieved by adjusting the setting of fineness for other materials or by adopting volume-controlling equipment

d) Measuring method and accuracy of mass and volume
As with conventional methods, a load cell is used. A compression-type load cell, as used in the model equipments, solves the problem of container oscillation and allows precise detection of liquid displacement when making volume measurements. A variety of methods are available for measuring volume, such as float displacement gauges, mechanical displacement gauges, and contact-free microwave displacement meters. Among volume-controlling equipment, one type includes a movable weir is fitted to the container so as to allow water replaced by fine aggregate to overflow. Another type entails pumping excessive water out through an adjustable hose set at the specified level.

The specifications for the model batcher include a load cell with an accuracy of 1/2000 and an electrode level sensor attached to a mechanical slider, which is capable of measuring displacement to an accuracy of 0.1 mm.

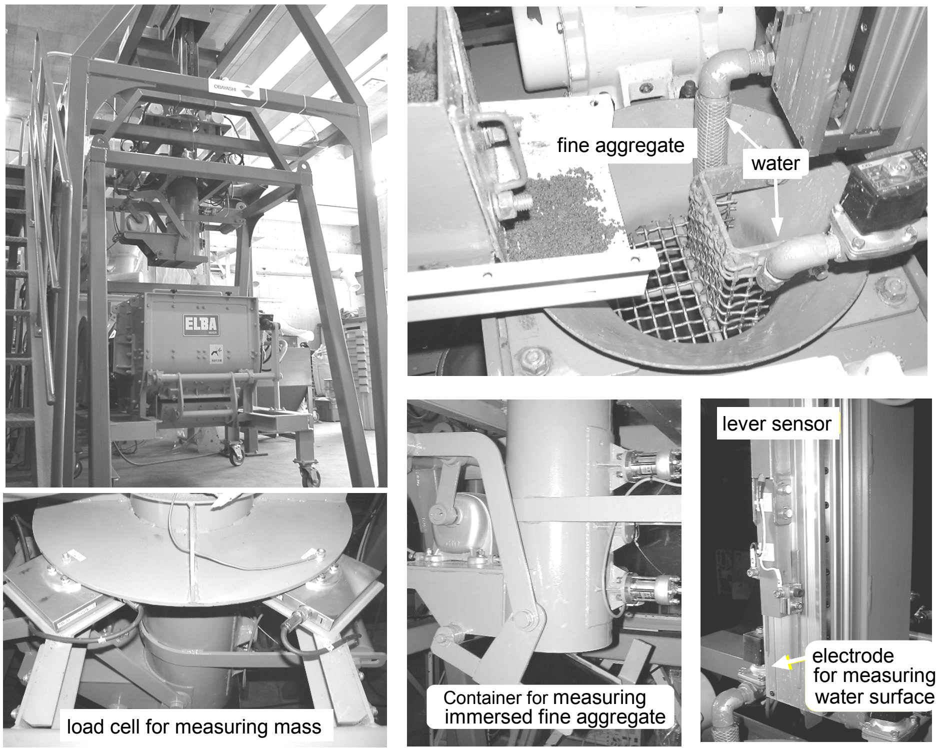


Photo 1 Overview of model equipment for immersion batching (volume-measuring type)

３． INVESTIGATION OF IMMERSION BATCHING

3.1 Trial calculation of batching error of immersed fine aggregate

JIS A 5308-1998 specifies the tolerances for batching aggregate and water to be ±3% and ±1%, respectively. The smaller tolerance for water represents its greater effect on concrete quality. It is therefore necessary to batch the water as precisely as possible to ensure the required unit water content. The possible reasons for batching errors in immersion batching include entrapped air bubbles in the fine aggregate and fluctuations in fine aggregate density, as well as instrumentation errors.

The batching error of water, Δw, can be expressed using the mass batching error, αw, and the volume batching error, αv, as follows:

$$Ms' + Mw' = M_f(1 + \alpha w) \quad (1')$$

$$Ms'/\rho s + Mw'/\rho w = V_f(1 + \alpha v) \quad (2')$$

$$\Delta w = (Mw' - Mw)/Mw = (\alpha v - k\alpha w)/(1 - k) \quad (5)$$

where, $k = f + (1 - f)\rho_w / \rho_s$

As an example, the batching error due to entrapped air is calculated by assuming that $f = 0.60$ and ρ_s (saturated surface-dry density of fine aggregate) = 2.60 g/cm^3, while also making the assumption that there is no instrumentation error. According to Eq. (5), the volume batching error should be limited to 0.3% or less, in order to limit the batching error of water to not more than approximately 1.0%. The batching error due to fluctuations in sand density is expressed as follows:

$$\alpha v = f\left(1 - 1/\left(1 + \Delta\rho s/\rho s\right)\right) \quad (6)$$

where, $\Delta\rho s$; fluctuation in saturated surface-dry density of sand

This indicates that a fluctuation in sand density of 0.01 leads to an error of around 0.2% in volume batching. It should be noted that the effect of fluctuations in sand surface moisture is expressed as follows:

$$\alpha v = f\left(\rho s - 1\right)\Delta\beta sw \quad (7)$$

where, $\Delta\beta sw$; error in surface moisture setting

In light of the calculations made using Eq. (5), the error in surface moisture setting should be controlled to within ±0.3% so as to limit the batching error for mixing water, including surface moisture on the fine aggregate, to 1% or less.

3.2 Effect of fine aggregate conditions on batching errors

Immersed fine aggregate was prepared using fine aggregates with different moisture contents to examine the effects on batching errors of such factors as the ratio of fine aggregate to water, cumulative batching, timing for the addition of fine aggregate, and fine aggregate compaction. The immersion batching equipment shown in **Photo 1** was used for the experiment. The surface moisture of the fine aggregate to be used was measured in advance to determine the batching settings for fine aggregate and water (primary water + surface moisture) and compared with the values determined from the batched mass and volume of the immersed fine aggregate.

The difference between the experimental settings and the actually batched values includes such error factors as the measurement error of the load cell and of the displacement gauge, errors in setting the surface moisture of the fine aggregate, and errors due to entrapped air. In reporting the test results, these measurement errors are shown by being converted to surface moisture values. Typical results are shown in **Fig. 2** to **Fig.7**.

The experiment was prone to greater error than when using actual equipment because the sample quantity was small, with as little as 30 liters of immersed fine aggregate. With this size of batch, a difference in displacement of 1 mm leads to a volume difference of around 0.2%. Nevertheless, batching errors were found to be restricted to ±0.3% in terms of surface moisture of the fine aggregate regardless of its water absorption, the percentage of fine aggregate immersed, and involvement of vibratory compaction. This suggests that fine aggregate measurement is feasible by this method with practically sufficient accuracy.

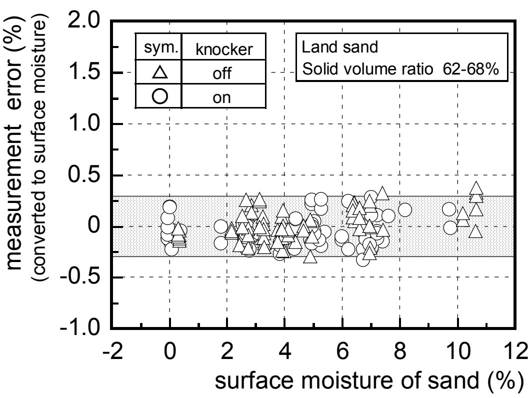


Fig. 2 Influence of surface moisture on immersion batching error

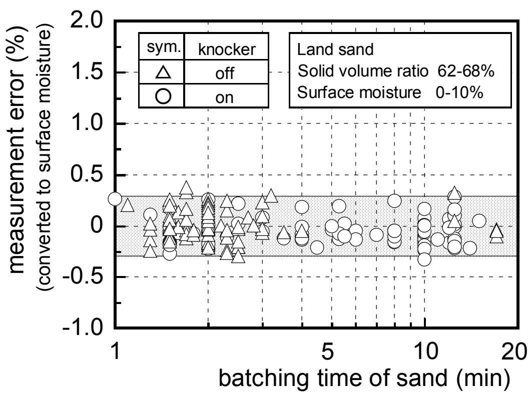


Fig. 3 Influence of batching time of fine aggregate on measurement error

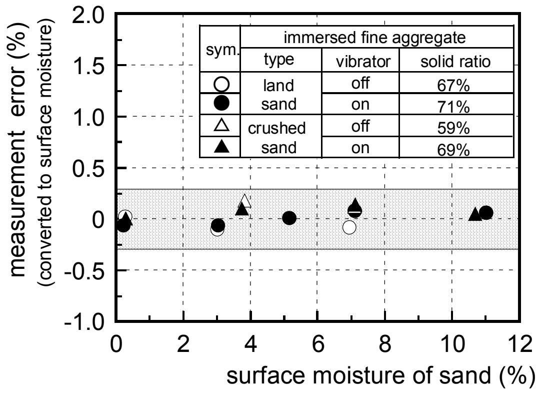


Fig. 4 Influence of surface moisture on immersion batching error

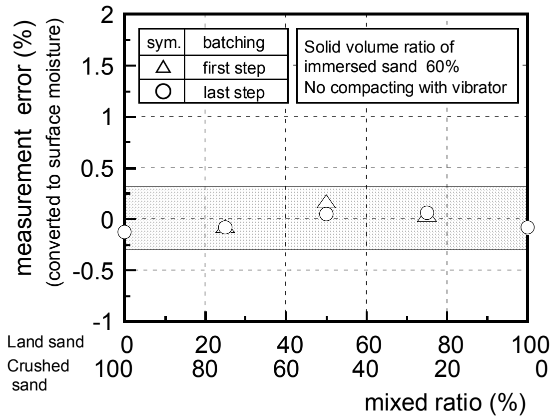


Fig. 5 Influence of cumulative batching on measurement error

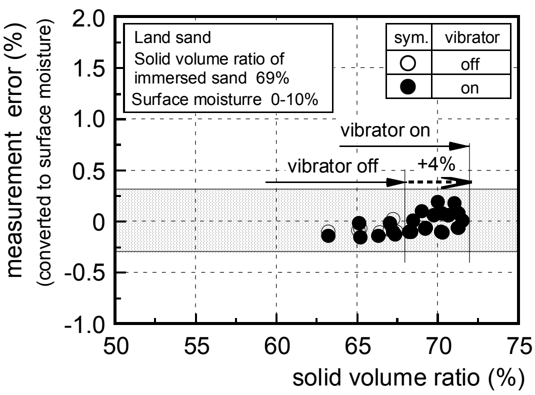


Fig. 6 Influence of immersed fine aggregate solid volume on measurement error (1)

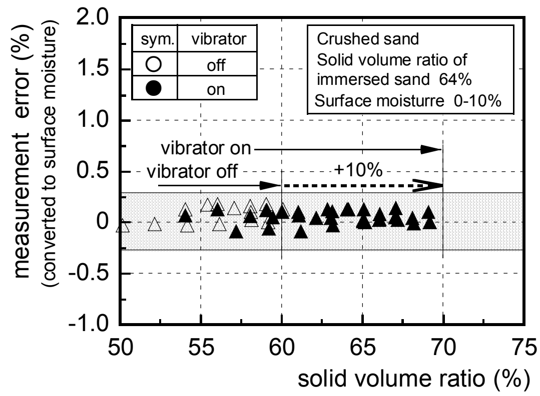


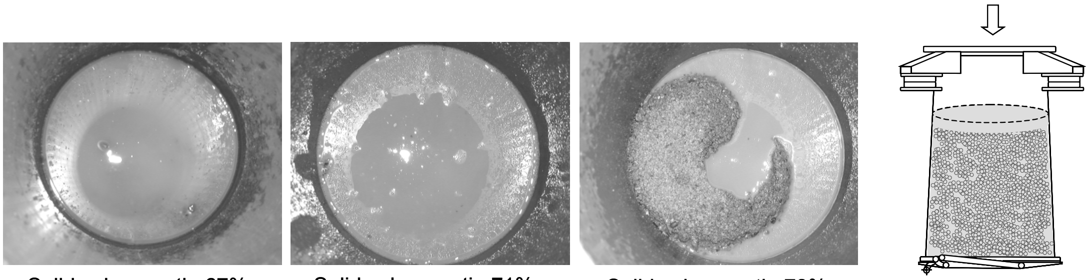
Fig. 7 Influence of immersed fine aggregate solid volume on measurement error (2)

3.3 Compaction of immersed fine aggregate

Immersion batching is premised on batching less than the total amount of primary mixing water with the fine aggregate. Reducing the amount of water batched with the fine aggregate would allow the amount of secondary water to be increased, facilitating the addition of chemical admixtures. To look into reducing the amount of water used for batching with the fine aggregate, the effect of vibratory compaction of the fine aggregate in water was examined using an internal vibrator while preparing immersed fine aggregate.

Photo 2 shows the surface state of the immersed fine aggregate at each percentage of fine aggregate in the batch. Land sand with a solid volume percentage of 69% could not be immersed without vibration at a fine aggregate percentage of 67%. When compacted using a vibrator, the fine aggregate again became impossible to immerse at a fine aggregate percentage of 71%. The effect of compaction depended on the type of fine aggregate. As shown in **Fig. 6** and **Fig. 7**, the compacting effect improved as the solid volume percentage of the aggregate decreased.

Photo 3 shows the discharge of immersed fine aggregate from the batcher. When prepared without vibratory compaction, the fine aggregate particles were discharged as a flow, whereas under compaction they formed into a dense mass. In both cases, a water membrane is formed between the fine aggregate and the batcher, permitting easy discharge. The amount of fine aggregate remaining as residue in the batcher is practically negligible, so this poses no problem as regards quality



Solid volume ratio 67% (no compaction)
Solid volume ratio 71% (compaction)
Solid volume ratio 73% (compaction)

Photo 2 State of top surface of immersed fine aggregate

Discharge of immersed fine aggregate
Immersed fine aggregate produced without compaction
Immersed fine aggregate produced with compaction

Photo 3 Discharge of immersed fine aggregate from the batcher

4. QUALITY VERIFICATION OF CONCRETE PRODUCED BYIMMERSION BATCHING

4.1 Effects of immersion batching parameters on concrete qualities

The quality of concrete produced by the immersion batching process was compared with that of concrete according to conventional practice. The following batching parameters were experimentally examined for their effect: surface moisture of fine aggregate, fine aggregate percentage in the batch, and use of an internal vibrator. The cement was used ordinary portland cement, the fine aggregate was land sand with a saturated surface dry density of 2.60 g/cm^3, a fineness modulus of 2.72, and a solid volume percentage of 69%, and crushed sand with a saturated surface dry density of 2.66 g/cm^3, a fineness modulus of 2.55, and a solid volume percentage of 64%, the coarse aggregate was crushed stone with a saturated surface dry density of 2.66 g/cm^3 and a fineness modulus of 6.72. An air-entraining and water-reducing admixture and air-entraining and high-range water-reducing admixture were used. All these materials were charged simultaneously into a biaxial forced-action mixer with a capacity of 100 liters and mixed for 120 seconds.

Fig. 8 compares quality of the concretes produced by immersion batching and conventional batching. Both methods were found to produce concrete of equivalent quality over a range of different mix proportions for different water-cement ratios and slump levels.

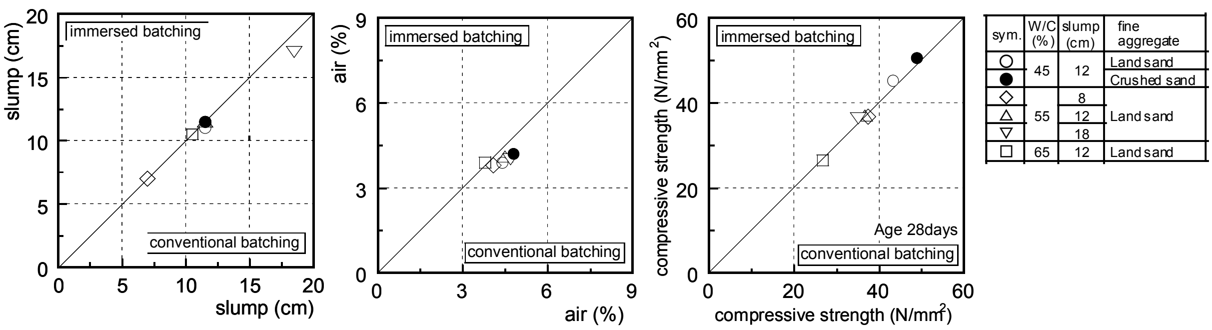


Fig. 8 Differences in concrete qualities produced by immersion and conventional batching method

Table 2 Mix proportions of concrete

Type	W／C (%)	s／a (%)	Unit weight (kg/m^3) Water	Cement	Sand	Gravel	A1	A2
Normal	45.0	40.0	169	376	697	1066	0.94	—
SCC	33.0	45.6	175	530	726	887	—	7.69

※ A1：Water reduing air-entraining agent, A2：High-range water reducing air-entraining agent

Table 3 Test cases for immersed batching of fine aggregate

Type	Fine aggregate moisuture	Immersed fine aggregate solid volume ratio 62%	63%	65%	67%	70%	Conventional method
NC	3%	—	○	○●	○	●	○
	7%	○	○	○	—	—	○
SCC	3%	—	○	○●	○	●	○
	7%	—	○	○	○	—	○

※ In case of using compaction in production of immersed fine aggregate ：●

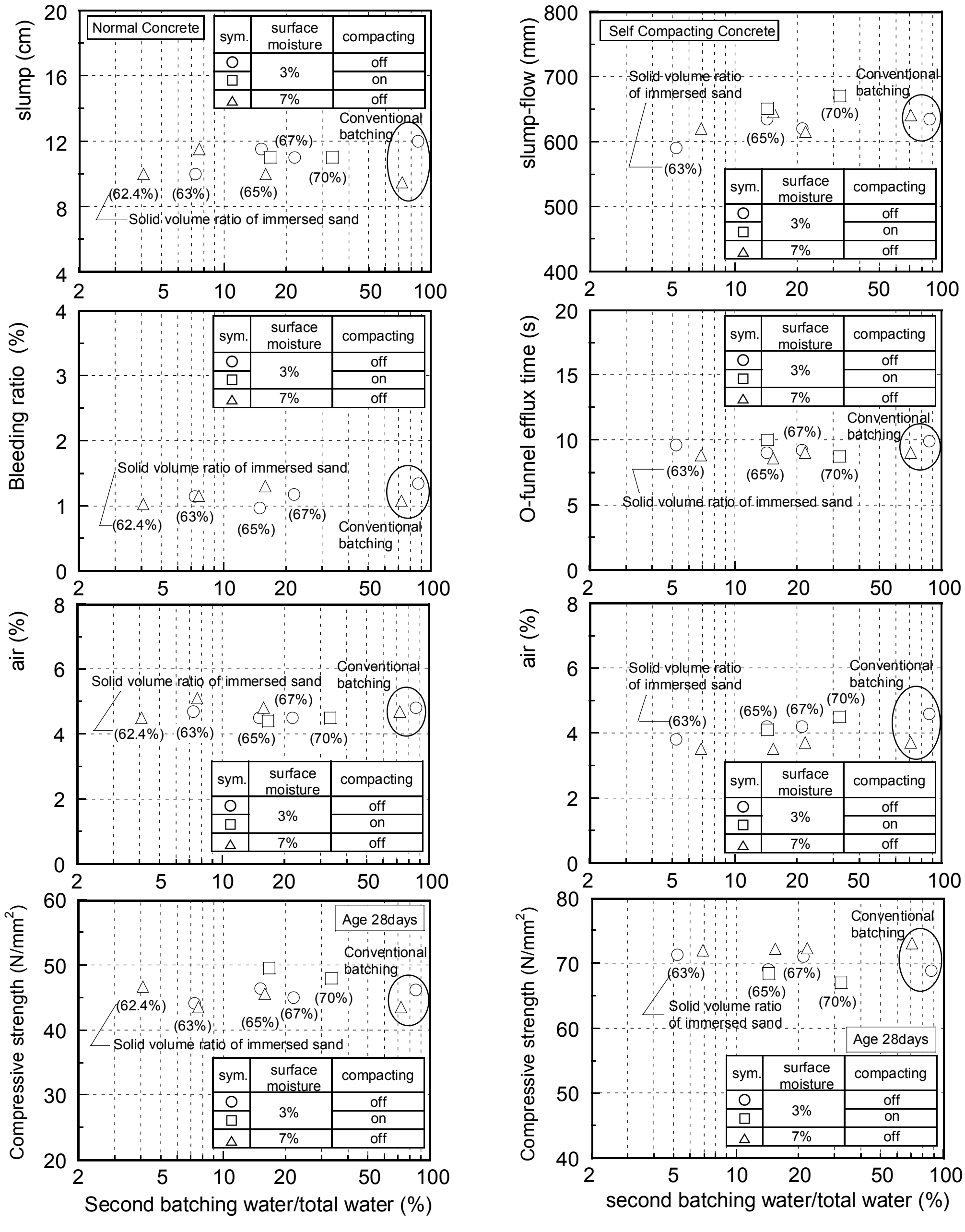


Fig. 9 Qualities of various concretes produced by immersion batching of fine aggregate

Tables 2 and **Table 3** give the trial mix proportions and combinations of parameters, respectively. **Fig. 9** shows the quality of concretes produced using fine aggregates with different moisture characteristics and with varying proportions of fine aggregate in immersion. When implementing immersion batching, the amount of water batched with the fine aggregate depends on moisture conditions and fine aggregate percentage. The deficit from the specified quantity of mixing water is added separately as secondary water, and chemical admixtures are added to this second batch of water. For this reason, **Fig. 9** is arranged according to the ratio of additional (secondary) water to total mixing water.

In immersion batching, changes in the ratio of secondary water to total water cause variation in the concentration of diluted chemical admixtures. It was considered possible that this might affect self-compacting concrete, in particular, because it contains a high dosage of an air-entraining and high-range water reducing admixture. However, the concentration of the diluted admixture scarcely affected the quality of the resulting concretes, regardless of the mix proportion. Various compaction conditions during immersion batching also had no appreciable influence on the quality of the concrete, despite the difference in the appearance of the discharged concrete mentioned above.

4.2 Verification of quality stability of concrete produced by immersion batching

Experiments were conducted to verify that concrete could be produced to a specified quality by use of immersion batching; that is, without measuring the surface moisture of the fine aggregate. The mix proportions for the experiments are given in **Table 4**. The fine aggregate was used with no prior adjustment of the surface moisture. The surface moisture measured after the experiments for reference purposes ranged between 3.5% and 8.5%.

Table 5 gives the results of immersion batching and the quality of the concrete produced using the immersed fine aggregate. Through this process of batching the fine aggregate in an immersed state and adjusting the job mixture based on the batching results, constant rheological properties were achieved: a slump-flow ranging between 600 and 650 mm and an O-funnel efflux time ranging between 8 and 9 seconds. The strength properties of the hardened concrete were also found to be constant and independent of the original moisture content of the fine aggregate. These results demonstrate that the immersion batching method is capable of producing concrete of constant quality.

The strength test results for each batch are shown in **Fig.10**. The batch-to-batch variance in strength from the average is less than the deviation between specimens taken from the same batch. These results prove that materials are accurately batched by the immersion method. At the same time, elimination of the need to measure the surface moisture of the fine aggregate makes this a worthy step forward.

Table 4 Mix proportions of concrete

Type	W／C (%)	s／a (%)	Unit weight (kg/m^3)					
			Water	Cement	Limestone powder	Sand	Gravel	A1
SCC	33.0	47.0	175	530	50	720	828	6.67

※ A1：High-range water reducing air-entraining agent

Table 5 Test results of immersion batching of fine aggregate and concrete

No.	Measured value		Calculated value		Mixed volume	Slump-flow	O-funnel time	Air	compressive strength
	Mass (kg)	Volume (L)	Water W_1 (kg)	Sand S (kg)	(L)	(mm)	(s)	(%)	(N/mm^2)
1	60.93	29.86	10.57	50.36	69.9	600	8.7	5.1	59.9
2	60.95	29.91	10.63	50.32	69.9	610	8.1	5.1	59.1
3	60.85	29.77	10.46	50.39	70.0	590	9.1	5.1	60.0
4	60.84	29.95	10.76	50.08	69.5	600	8.8	5.2	59.1
5	67.01	33.37	12.48	54.53	75.7	600	8.9	4.6	61.9
6	60.94	29.75	10.38	50.56	70.2	635	7.6	4.7	60.8

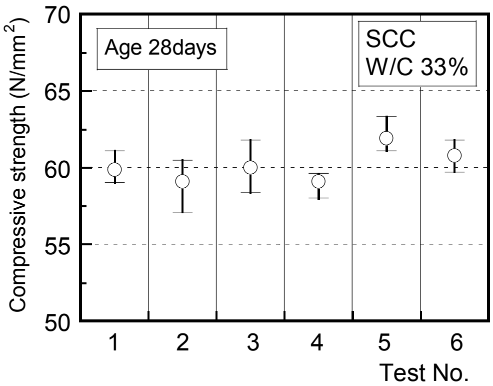


Fig.10 Fluctuation in compressive strength between test batches

5．CONCLUSIONS

The practical utility of a concrete production system involving immersion batching, whereby the fine aggregate and water can be precisely batched independently of the surface moisture, has been verified through various experiments. Within these experiments, the following conclusions were reached:

(1)Material batching can be controlled by either mass or volume. If using volume-measuring equipment, each batch needs to be adjusted depending on the variable level of surface moisture, even if the mass of immersed fine aggregate is batched according to the specifications. On the other hand, volume-controlling equipment enables the operator to batch the specified amounts of both fine aggregate and water at the point when the combined mass reaches a set value, since the fine aggregate is immersed and the total volume of fine aggregate and water is fixed.

(2)In order to limit the water batching error to not more than 1% during immersion batching, it is necessary to control the volume batching error to within approximately 0.3%. Tests to verify batching errors by immersion batching under various conditions indicated that the fluctuation remained within ±0.3% in terms of surface moisture of fine aggregate, regardless of the original moisture content of the fine aggregate, the percentage of fine aggregate in the immersion, and whether vibratory compaction of the immersion was carried out. Immersion batching was thereby shown to be feasible with accuracy sufficient for practical use.

(3)When batching the fine aggregate by immersion, vibratory compaction can increase the density of the immersion, particularly when the solid percentage of the fine aggregate is low.

(4)Concrete of nearly constant quality can be produced regardless of such conditions as the state of immersion of the fine aggregate and the concentration of chemical admixtures in the secondary water during immersion batching.

(5)Immersion batching of fine aggregate makes available to the purchaser precise material batching results. For this reason, immersion batching is expected to form part of an effective and reliable production system that also offers quality assurance.

The authors intend to apply immersion batching at concrete plants to produce concrete for actual projects, thereby accumulating further data on quality fluctuations.

References

1) Japan Concrete Institute; Research Report on Concrete Production System, pp.1-21, 1992. (in Japanese)
2) Chikamatsu, R., and Sogo, S.; Study on High-Reliability Concrete Production System with New Batching Method by Immersing Sand in Water, Journal of Materials, Concrete Structures and Pavements, No.676/V-51, pp.19-26, 2001. (in Japanese)