Influence of Dry-Mixing on Mortar Flow for High Strength Concrete

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Abstract: Because an increase in construction using high strength concrete is expected, a response in terms of production technology is also necessary. The flowability of high strength concrete varies greatly in some cases depending on the mixing condition, even with the same concrete mix and same environmental conditions. This research focused on changes in flowability when mixing mortar, bearing in mind development to high strength concrete, depending on whether dry-mixing is performed or not and if so, the drying-mixing time. As a result, it was found that the difference in the mortar flow value with and without dry-mixing is approximately 8 cm, and the flow value difference with dry-mixing time is at maximum approximately 10 cm. Based on the results of an analysis of the amount of adsorption of admixtures and amount of Ettringite, it was inferred that flocks are formed by dry-mixing, and then cause variations in the amount and timing of admixture adsorption, resulting in differences in flowability.

Keywords: High-strength mortar, Dry-mixing, Flock formation, Amount of Ettringite

1. Introduction

Various issues have been mentioned as social problems currently confronting Japan, including "how to realize a low carbon society as a countermeasure against global warming," "how to promote efficiency in work and other activities accompanying a declining population" and "how to transfer technologies to younger generations efficiently in an aging society."

Among those challenges, based on the increased intensity and frequency of natural disasters of recent years, the Japanese government has laid out a policy of "building national resilience," which includes disaster prevention/mitigation and countermeasures for aging infrastructure. In line with this, an increase in construction using high strength concrete is also considered likely. Moreover, considering the problems of population decline in Japan as a whole and labor shortages in the construction industry, promotion of the use of precast concrete products is expected accompanying shorter construction work time. In addition, the purpose of the revision of JIS A 5308 (Ready-mixed concrete) in 2019 also stated as for promoting the use of high strength concrete.

Based on this background, a further increase in construction using high strength concrete is expected, and a response to this trend will be required, not only in terms of construction technologies, but also in production by concrete batcher plants. On the other hand, it is known that mixing conditions influence the flowability of concrete, and adsorption of admixtures on cement has been mentioned as one cause of this [1),2),3)]. In comparison with ordinary concrete, the influence of admixture adsorption is larger in high strength concrete, which has a higher content of cement. However, there have been few attempts to clarify this influence in mixes for high strength concrete. Thus, clarification of the differences in flowability depending on mixing conditions is considered to be an urgent issue, and can contribute to a stable supply of high strength concrete in the future.

In this research, the influence of dry-mixing on the flowability of high-strength mortar was discussed focusing on whether dry-mixing of the fine aggregate and cement is performed in the initial stage of mixing or not and if so, the dry-mixing time. Although the coarse aggregate in the final stage is also thought to influence the slump flow value, the target of study in this research was limited to mortar in order to confirm the influence of dry-mixing more clearly. In addition to discussion of the mortar flow value (hereinafter, flow value) under dry-mixing conditions and the adsorption of admixtures and the amount of Ettringite in terms of chemistry, the mechanism of differences in flowability was also estimated.

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Table-1 Mix of high strength concrete used in study

Maximum dimension of coarse aggregate (mm)	Slump flow (cm)	Water-cement ratio (%)	Air content (%)	Fine aggregate ratio (%)	Unit quantities (kg/m³)				
					Water *W*	Cement *C*	Fine aggregate *S*	Coarse aggregate *G*	Admixtures *Pc*
20	60	21.4	2.0	44.4	175	818	650	815	8.18

2. Influence of Dry-Mixing and Dry-Mixing Time on Flow Value

2.1 Overview of Experiments

Because multiple experiments were carried out in this research and the setting conditions necessary in each experiment were different in some cases, the outline and results of each experiment will be described in the following sections. This section presents the outline common to all experiments. **Table-1** shows the mix proportion of the high strength concrete with design strength of 80 N/mm^2 which was the object of the experiments. Since the object of this study is mortar, the various tests described below were performed after calculating the values of the materials necessary per 1 L based on this mix. **Table-2** shows the materials used.

Admixtures were added per unit amount of cement. The added amount of admixtures was set at 0.6 %, at which the extension rate of the slump flow values converged in the results of preliminary tests conducted with various mortar mixes. The mixer used in the experiments was a Hobart mixer (5 L). As the test environment, the tests were carried out indoors under a constant environment with a temperature of 20 ±2 °C and humidity of 50 % or higher.

2.2 Influence of Dry-Mixing

(1) Outline

To confirm the influence of early hydration by the cement and surface water of the fine aggregate, mixing of the fine aggregate and cement (hereinafter, dry-mixing) was performed, after which mortar was prepared by mixing the admixtures and mixing water, after subtracting the surface water of the fine aggregate (hereinafter, main mixing), and the flow values were compared. A diagram of this mortar mixing method is shown in **Figure-1**.

Table-2 Materials used

Material	Type and quality
Cement *C*	Low-heat Portland cement Density: 3.23 g/cm³
Fine aggregate *S*	Crushed sand Rock type: Andesite; Density in saturated surface-dry condition: 2.54 g/cm³
Admixtures *Pc*	High performance water reducing agent Main component: Polycarboxylic acid compound

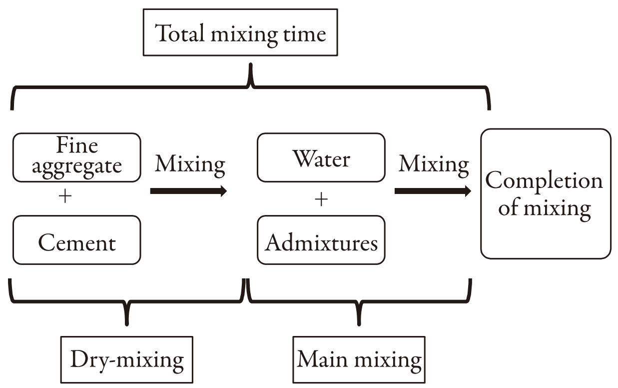


Figure-1 Mortar mixing method

As test patterns, the basic conditions were three patterns: Without dry-mixing, with dry-mixing and with dry-mixing using fine aggregate in the bone-dry condition. When dry-mixing was performed, the dry-mixing time was 30 seconds. Flow measurements of each batch were performed for the total mixing times of 3, 4, 7, 10, 15 and 20 minutes. The experiments were performed with the surface water ratio of the fine aggregate in the wet condition unified on 3 %.

Furthermore, to also investigate the contribution to the flow difference in dry-mixing with/without admixtures, the flow value was measured for the two patterns of with and without dry-mixing for a mix without admixtures. Since mixing of the mix without admixtures was not possible using the necessary material values per 1 L calculated for the mix with admixtures, the test was carried out under the condition of a water-cement ratio of 42.8 %, which is 2 times the unit water amount, so that a comparison of the flow measurements was possible.

(2) Experimental results and discussion

The flow values for each mixing time are shown in **Figure-2**. From the mixer power data measured in a preliminary experiment, mixing for 7 minutes was necessary for complete mixing. After 7 minutes, i.e., after the completion of mixing, there was no difference in the flow values between without dry-mixing and with dry-mixing using the fine aggregate in the bone-dry condition, and both of them have not reached the flow value with dry-mixing even when the mixing time was increased, and a constant difference (approximately 8 cm) was maintained.

From these results, if the fine aggregate is in the bone-dry condition, the result with dry-mixing is substantially the same as the flow value without dry-mixing. Therefore, as the influence of dry-mixing on the flow value, it is thought that advance contact of the surface water of the fine aggregate with the cement particles in the initial stage of mixing contributes to an increase in the flow value.

In addition, **Figure-3** shows the results of the comparison with/without dry-mixing for the mix without admixtures. The test described above showed that flow value increases by about 8 cm from the case without dry-mixing when dry-mixing is performed with the mix containing admixtures. However, in the case without admixtures, no effect of dry-mixing on the flow value was observed.

From the results in the above **Figure-2** and **Figure-3**, it is thought that the cement and surface water of the fine aggregate cause early hydration, while admixture (water-reducing agent) added during the following main mixing contribute to the flow value.

Thus, it was possible to verify that whether dry-mixing is performed or not influences the flowability of mortar, even with the same mix and same environmental conditions. As to the reason, it is estimated that the slight moisture on the fine aggregate surface and the influence of admixtures on early hydration of the cement make large contributions.

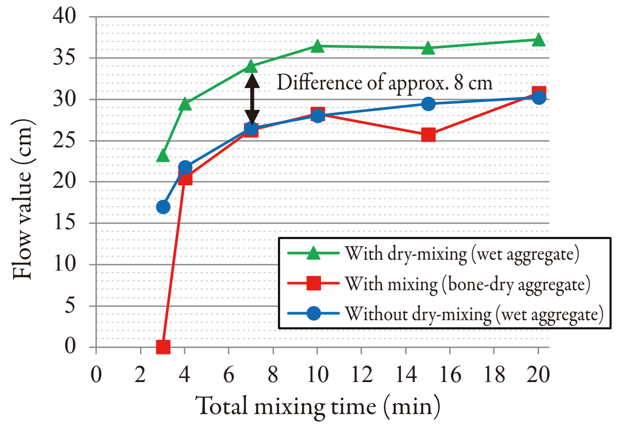


Figure-2 Flow values with /without dry-mixing

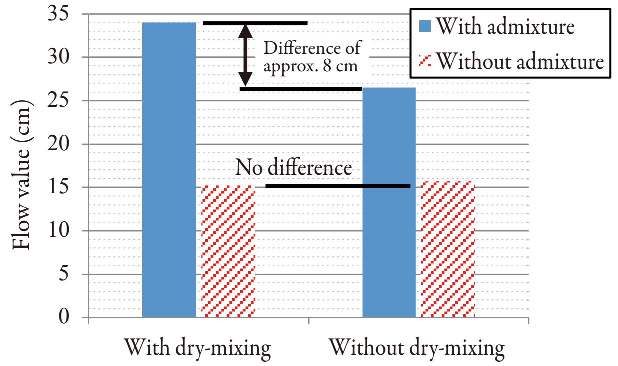


Figure-3 Flow values with dry-mixing with /without admixture

2.3 Influence of Dry-Mixing Time

(1) Outline

As the influence of dry-mixing on flowability, the relationship of early hydration of cement and the effect of the admixture could be inferred from the study in the previous section. In this section, the influence of the dry-mixing time on mortar flowability was confirmed.

The dry-mixing time was set in four patterns of 0, 30, 60 and 90 seconds. The total mixing time was fixed at 7 minutes, and the main mixing time was varied corresponding to the dry-mixing time. As other conditions, as in the outline of the test in the previous section, the Hobart mixer (5 L) was used, and the test was carried out indoors under a constant environment with a temperature of 20 ±2 °C and humidity of 50 % or higher as the test environment. Fine aggregate with a surface water ratio of 3 % was used.

(2) Experimental results and discussion

Figure-4 shows the results of the flow value for each dry-mixing time. Results in which the flow values became larger as the dry mixing time increased were obtained, suggesting the possibility that an increase in contact time between the surface water of the fine aggregate and the cement before the admixture is added contributes to an increase in the flow value. Here, because the degree of transfer of the surface water of the fine aggregate to the cement by dry-mixing is unknown, this was studied in the next chapter.

3. Mechanism of Influence of Dry-Mixing on Flowability

From the results in Chapter 2, it was found that whether contact between the surface water of the fine aggregate and the cement occurs or not (i.e., whether dry-mixing is performed or not), and if so, the contact time (dry-mixing time), influence the flow value. Therefore, as a physical test, a simple experiment was conducted in this chapter to determine the degree of transfer of the surface water on the fine aggregate to the cement, and the amount of flock formation caused by the transferred surface water. In addition, measurement of the adsorption of admixtures and measurement of the amount of Ettringite formation were also performed as chemical tests.

3.1 Experiment on Transfer of Surface Water of Fine Aggregate

(1) Outline

In order to quantify the degree to which the surface water of the fine aggregate is transferred and adsorbed on cement particles corresponding to the dry-mixing time, a test was carried out using an infrared multicomponent meter. The materials used in this experiment were the fine aggregate and calcium carbonate (density: 2.71 g/cm^3), which is a white powder that was used in place of cement. Calcium carbonate was used as it was thought that this would make it possible to evaluate the pure dispersion of the powder and fine aggregate without reaction with water. Although the physical properties of calcium carbonate are different from those of cement, the authors judged that this difference would not influence the evaluation of dispersion because the powder is significantly smaller that the diameter of the sand particles of the fine aggregate.

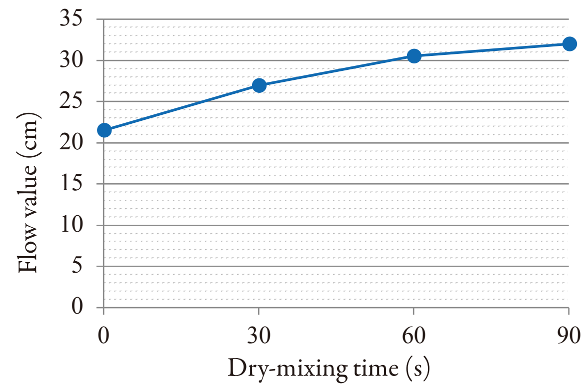


Figure-4 Dependence of flow value on dry-mixing time

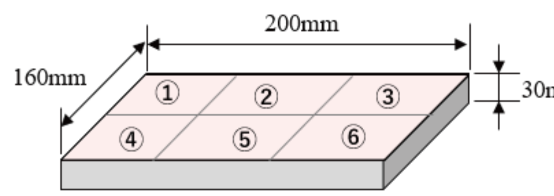


Figure-5 Absorbance measurement positions

The targets of measurement by the infrared multicomponent meter were the wavelength of color and the wavelength of water. Absorbance was measured from the wavelengths of the material surface after dry-mixing. Since the difference in the wavelength of the true color of calcium carbonate and the surface water of the fine aggregate is slight, fine aggregate in the bone-dry condition was allowed to absorb water colored with red food coloring to a surface water content of 3 % in order to measure the color wavelength difference with the calcium carbonate more clearly.

For the measured values of the materials, the necessary values of the materials per 1 L were calculated from the standard mix proportion shown in **Table-1**. As the measurement conditions, the dry-mixing time was set to three patterns of 30, 60 and 90 seconds, and the object of measurements was only dry-mixing before performing main mixing. Immediately after dry-mixing, the samples were transferred to a stainless steel tray, the sample surface was smoothed, and the tray was divided into six sections, as shown in **Figure-5**. The surface color wavelength and water wavelength were then measured three times in the center of each section, for a total of 18 measurements of each sample.

(2) Experimental results and discussion

Figure-6 and **Figure-7** show the results of the color absorbance and water absorbance, respectively, measured for each of the dry-mixing times.

Larger values of absorbance show that the number of colored spots increases, and water also exists on the surface. In the color absorbance results in **Figure-6**, absorbance becomes higher as the dry-mixing time increases, and a large number of colored spots of calcium carbonate are detected. Likewise, as shown in **Figure-7**, results similar to those for color absorbance were also obtained for water absorbance, as water absorbance also increased with increasing dry-mixing time.

From the results of both types of absorbance, it was found that the surface water of the fine aggregate was transferred to the calcium carbonate as the contact time (dry-mixing time) between the fine aggregate and the calcium carbonate was extended.

Furthermore, the variations between the measurement positions also became smaller with increasing dry-mixing time, which can be interpreted as showing more uniform dispersion of the surface water.

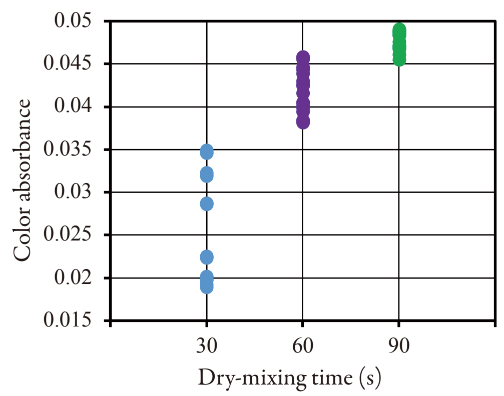


Figure-6 Color absorbance at various dry-mixing times

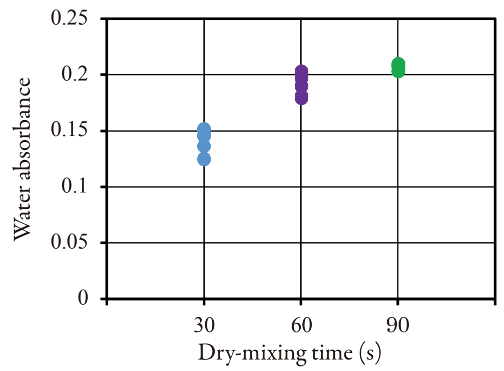


Figure-7 Water absorbance at various dry-mixing times

	Dry-mixing time	
	30 s	90 s
Under-screen weight (g)	204.0	175.3
Over-screen weight (g)	1275.2	1301.0

Table-3 Results of sieve analysis test

3.2 Experiment on Cement Flocks
(1) Outline

When cement is hydrated, a positive electrical charge is generated on the surface of the cement particles by the hydration reaction, and the particles become unstable and adhere to each other, forming flocks. Therefore, in this report, the amount of flock formation was measured using a sieve to confirm the influence of the fine aggregate surface water transferred to the cement particles corresponding to the dry-mixing time.

As the measurement method, the full amount of the sample after performing only dry-mixing was sieved, and the amounts that passed through the sieve (under-screen weight) and amount that remained on the sieve (over-screen weight) were measured. Samples which were not dry-mixed were not evaluated because stirring itself was not performed.

In order to screen the cement particles which were not in contact with water, measurements were performed using a screen with a mesh of 0.15 mm.

(2) Experimental results and discussion

Table-3 shows the sieve test results for each dry-mixing time. As was also expected from the experimental results of surface water transfer in the previous section, the amount of transferred surface water increased as the dry-mixing time was extended. Therefore, results in which flock formation increased with dry-mixing time were obtained. Visual inspection also showed that the number of lumps increased as the dry-mixing time became longer, and a difference in the amount that passed through the sieve was confirmed.

3.3 Experiment on Adsorption of Admixture
(1) Outline

From sections 3.1 and 3.2, it was found that the surface water of the fine aggregate influences the cement particles. Therefore, in this section, measurements of adsorption of admixtures corresponding to the dry-mixing time were carried out to confirm the degree of influence of the surface water of the fine aggregate from the dry-mixing stage on the adsorption of admixtures added in the main mixing stage.

For the measured values of the respective materials, the mortar used here was prepared by calculating the necessary material values per 1 L from the standard mix proportion shown in **Table-1**. As shown in **Figure-8**, the liquid phase and solid phase were separated with a centrifugal separator, and the remaining amount of admixtures in the liquid phase was measured by performing a thermal analysis of the extracted liquid phase.

As the measurement conditions, the dry-mixing time was set to the three patterns of 0, 30 and 90 seconds. Since the total mixing time was fixed at 7 minutes, the main mixing time was adjusted corresponding to the dry-mixing time. The liquid phase was sampled from the prepared mortar, and measurements were performed five times for each measurement condition.

(2) Experimental results and discussion

Figure-9 shows the results of the remaining amount of admixtures from the mortars prepared under each dry-mixing time. From the results of the remaining amounts, it was found that the amount of admixtures remaining in the liquid phase was small with the dry-mixing time of 0 s, but increased as the dry-mixing time increased. Based on these facts, the results obtained in this experiment showed that the amount of admixtures adsorbed on the solid phase is large when the dry-mixing time is short, and conversely, the adsorbed amount decreases when the dry-mixing time is long.

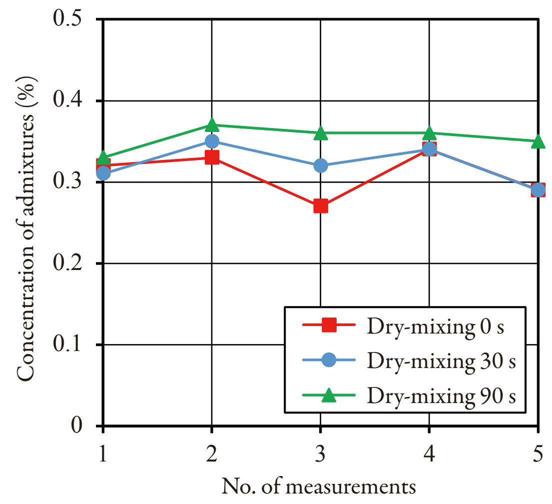


Figure-9 Amount of remaining admixtures with various dry-mixing times

3.4 Experiment on Amount of Ettringite
(1) Outline

Because Ettringite is formed by a hydration reaction, it was thought to be an index for confirming the existence of the flocks in the experiment carried out in section 3.2. As the measurement method, X-ray diffraction (XRD) was performed using the sample separated into the solid phase

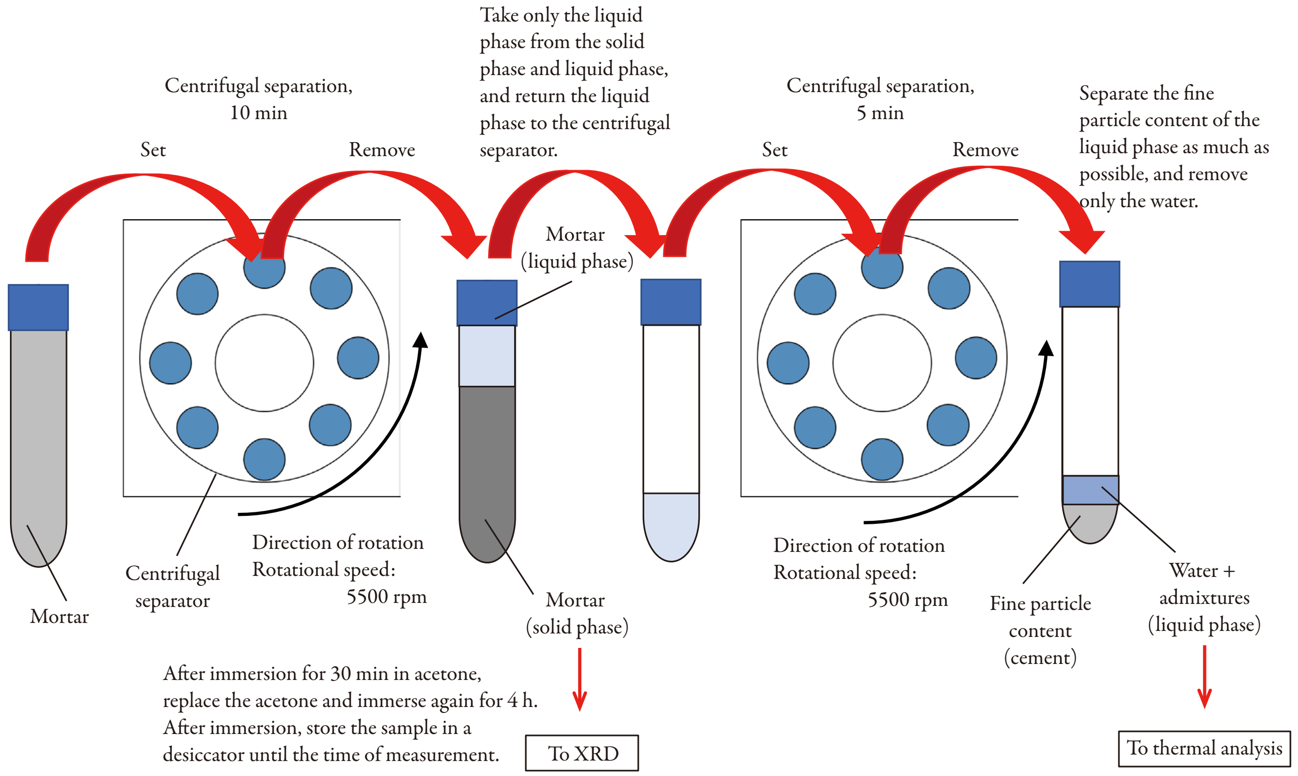


Figure-8 Sample preparation procedure in chemical test

by the centrifuge when measuring the adsorption of admixtures, as shown in **Figure-8**. In order to conduct the comparison immediately after mixing, the hydration reaction was stopped with acetone.

Because the mortars used in the measurements of the adsorption of admixtures were also used here, the dry-mixing time was set to 0, 30 or 90 seconds as measurement conditions. Since the peak value of the amount of Ettringite was determined to be a diffraction angle of 8.7 to 9.4° by a preliminary test, the comparison was carried out for the integrated intensity of that diffraction angle range.

(2) Experimental results and discussion

The results of the amount of Ettringite for each dry-mixing time are shown in **Figure-10**. From these results, it was found that the amount of Ettringite is large at the dry-mixing time of 0 s, but decreases as the dry-mixing increases. Based on this, when the dry-mixing time is short, it can be inferred that the specific area of the cement particles in contact with mixing water is large because flock formation is small; therefore, the effect of the admixture at the end of mixing is slight, and as a result, the flow value is small. Conversely, when the dry-mixing time is long, the specific area of the cement particles in contact with the mixing water is reduced by the large amount of flock formation, and in this case, the flow value increases because the effect of the admixture at the end of mixing is large.

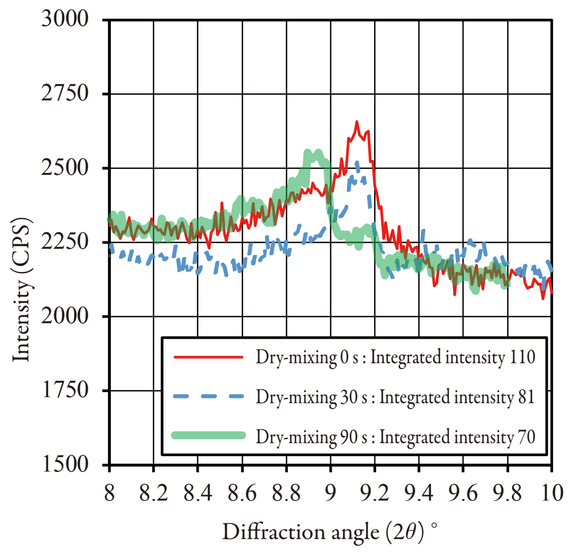


Figure-10 Amount of Ettringite formation with various dry-mixing times

3.5 Mechanism of Influence of Dry-Mixing on Mortar Flow Value

Table-4 presents summary of the results of the study of the transfer of the surface water of the fine aggregate and the amount of flock formation in sections 3.1 and 3.2, and the adsorption of admixtures and the amount of Ettringite in sections 3.3 and 3.4.

From the results of these tests, it is considered that flocks are formed by contact of the surface water of the fine aggregate with cement particles when dry-mixing is performed, and as a result, the specific surface area of the cement particles decreases, reducing adsorption of the admixture. If large number of particles form flocks at an early stage in mixing, it is thought that the amount of cement particles in contact with the water added during main mixing will decrease, and this will cause a difference in the amount of Ettringite. The mechanism of this process is shown in stages in **Figure-11**.

The results described above clarified the fact that whether dry-mixing is performed or not, and if so, the dry-mixing time, have an influence on the mortar flow value. In particular, because the amount of admixture adsorption changes due to the formation of flocks by the surface water of the fine aggregate and the cement particles, and as a result, the flow value immediately after mixing differs, it can be inferred that the flow value immediately after mixing can be controlled by controlling flock formation. However, simply extending the dry-mixing time is not important. The important point is whether the condition necessary for accepting the admixtures added during main mixing is created by dry-mixing. For example, it is thought that the performance of the mixer, etc. has an influence in creating this state.

4. Conclusion

The knowledge obtained through this research is summarized below.

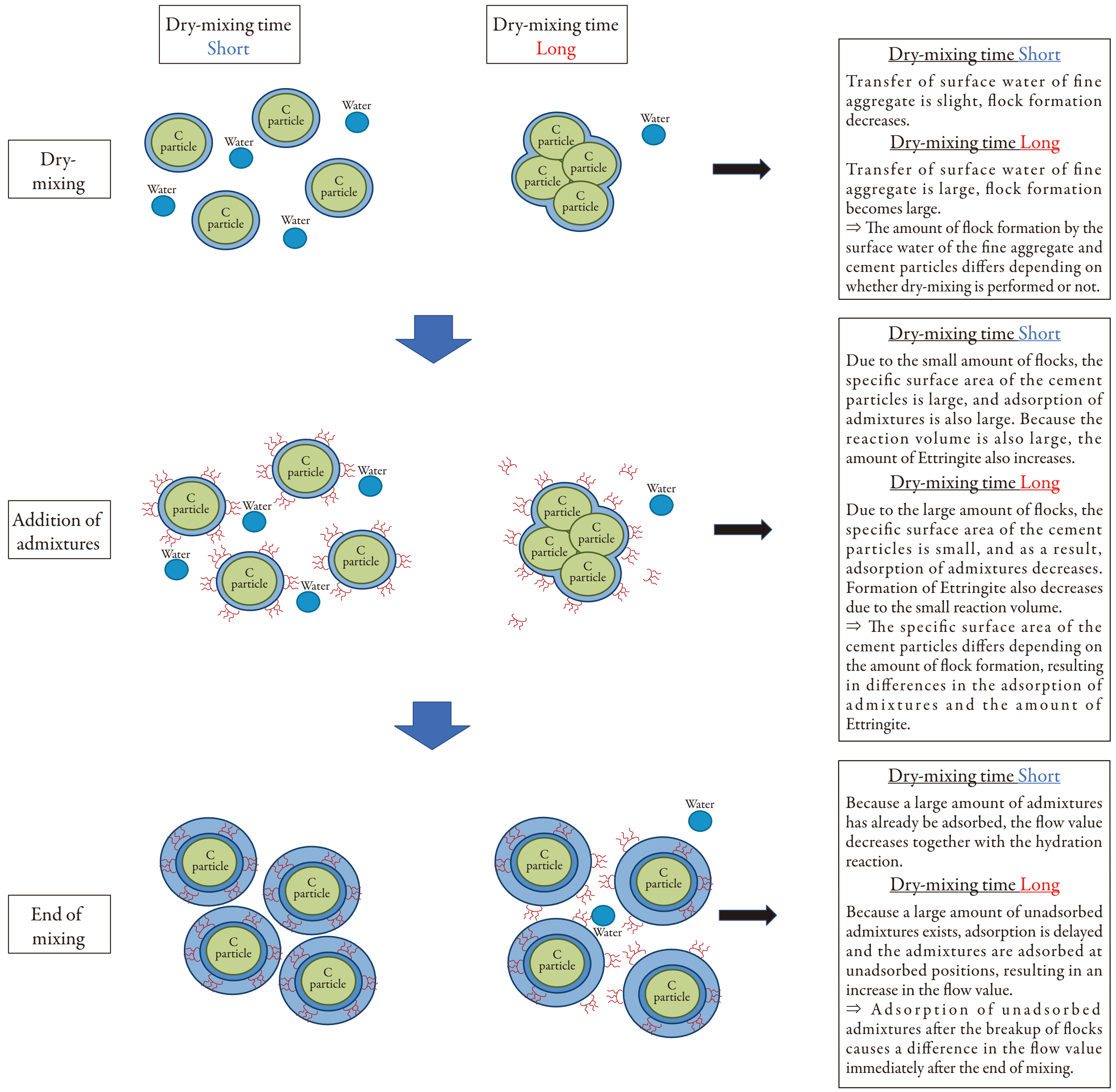
(1) This study confirmed that whether dry-mixing is performed or not has an influence on the flowability of mortar, even with the same mix and environmental conditions, and the slight amount of moisture on the fine aggregate surface and the effect of admixtures on early hydration of the cement make a large contribution.

(2) It was confirmed that the mortar flow value becomes large as the dry-mixing time increases, as an increase in the contact time between the cement and the surface water on the fine aggregate before the admixtures are added contributes to an increase in the flow value.

(3) As a result of dry-mixing, flocks are formed by contact between the cement and the surface water of the fine aggregate, and it is thought that this reduces adsorption of the admixtures by decreasing the specific surface area of the cement particles.

Table-4 Comparison of effects of dry-mixing time

	Dry-mixing time	
	Short	Long
Transfer of fine aggregate surface water	Small	Large
Formation of cement particle flocks	Small	Large
Adsorption of admixtures	Large	Small
Amount of Ettringite	Large	Small



igure-11 Mechanism of difference in adsorption of admixtures by dry-mixing

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