A Rheological Study of Mortar on the Improvement of Workability by Dry Mixing in High-Strength Concrete Mixtures

AUTHORS

Yasuhiro SAKAMOTO *1
Yuma KAWASAKI *2
Syuya HIRANO *3
Tsuyoshi MISHIMA *4

ABSTRACT

As a manufacturing technique for high-strength concrete, the authors have investigated the improvement of fluidity through dry mixing (the mixing of fine aggregate and cement during the initial stage of the mixing process). In this study, the effect of dry mixing on fluidity was examined based on the rheological properties of mortar, with the aim of assessing workability for practical application. The results showed that a certain dry-mixing period can reduce the dosage of chemical admixture required to achieve the target slump flow. Rheological testing using a rotational viscometer confirmed that the viscosity of the mortar decreased as a result of dry mixing. In contrast, it was confirmed that the viscosity of mortar extracted from concrete varied depending on the dry-mixing time, even when the concrete exhibited the same slump-flow value.

Keywords: High-strength concrete, twin-shaft compulsory mixer, dry mixing, rheology, rotational viscometer, chemical admixture.

1. Introduction

In Japan, efforts to strengthen disaster prevention and mitigation measures, as well as to address the deterioration of aging infrastructure, have been accelerated in response to the increasing severity and frequency of natural disasters. Social challenges such as population decline have also created an urgent need for securing labor resources and improving productivity within the construction industry[1].

Against this background, the use of high-strength concrete in construction projects, as well as the utilization of precast concrete products manufactured with high-strength concrete, is expected to increase further as a means of enhancing national resilience, improving quality, and shortening construction periods. The intent of the 2019 revision of JIS A 5308 explicitly states the promotion of the use of high-strength concrete. As the demand for high-strength concrete continues to grow, optimal production technologies are required not only for construction operations but also for the manufacturing process at batching plants.

In terms of production technology, it has been confirmed that mixing conditions affect the workability of concrete. However, few studies have attempted to clarify the extent of this influence or the underlying mechanisms in high-strength concrete mixtures. From the standpoint of quality control during production, it is essential to understand the differences in workability resulting from variations in mixing conditions. Clarifying the mechanisms involved is expected to contribute to the stable production and supply of high-strength concrete in the future.

In a previous study[2], the authors focused on the presence or absence of dry mixing—the mixing of fine aggregate and cement during the initial stage of the mixing process—and on the duration of dry mixing, and investigated their effects on the workability of high-strength concrete. By conducting experiments using a twin-shaft compulsory mixer under conditions similar to those encountered in practice, the influence of dry mixing and its underlying mechanisms were examined and reported.

In this study, the improvement in workability achieved through dry mixing was first confirmed using a twin-shaft compulsory test mixer. In addition, the influence of dry mixing under conditions where workability was controlled by adjusting the dosage of chemical admixture, assuming practical field applications, was investigated. Furthermore, a rheological approach was adopted to obtain information relevant to the practical usability. The consistency of mortar, concrete, and mortar obtained from concrete by wet screening was measured using dry-mixing conditions and chemical admixture dosage as experimental parameters. Rheological measurements of mortar were also conducted using a rotational viscometer. Based on these results, the improvement in workability resulting from dry mixing was evaluated from a rheological perspective.

In the previous study, chemical admixtures were identified as a key factor. Thus, tests were conducted using both a high-range water-reducing admixture for ultra-high-strength concrete and an air-entraining high-range water-reducing admixture for high-strength concrete. The effect of admixture type on the improvement in workability resulting from dry mixing was also evaluated.

*1 NIKKO Co., Ltd., Technical Headquarters, Development Department, Ph.D. (Engineering) (Regular Member)
*2 Ritsumeikan University, College of Science and Engineering, Department of Civil and Environmental Engineering, Associate Professor, Ph.D. (Engineering) (Regular Member)
*3 FLORIC Co., Ltd., Technical Headquarters, Concrete Research Institute, Principal Researcher, Ph.D. (Engineering) (Regular Member)
*4 FLORIC Co., Ltd., Kansai Branch, Technical Section Manager, Ph.D. (Engineering) (Regular Member)

2. Experimental Program

2.1 Materials and Mixture Proportions

Table 1 shows the mixture proportions of the high-strength concrete with a nominal strength of 80 N/mm², as in the previous study. In this study, the required quantities of materials were calculated based on a batch volume of 36 L, which corresponds to the workable mixing capacity of the twin-shaft compulsory test mixer (nominal capacity: 60 L), while also taking into account the amount of mortar to be sampled for the mortar tests described later. All experiments were conducted indoors under conditions of a temperature of 20 ± 2°C and a relative humidity of 60% RH or higher. **Table 2** lists the materials used. Two types of chemical admixtures were employed: a high-range water-reducing admixture (SPU) with enhanced cement-dispersing performance, and an air-entraining high-range water-reducing admixture (SPH) with slump-retention capability. The surface moisture content of the fine aggregate was adjusted to 2.39%, based on the findings of the previous study, which indicated that the optimum surface moisture content ranged from 2% to 3%.

Table 1: Mix Proportions of High-Strength Concrete (Designation: 80-60-20L)

Water-Cement Ratio (%)	Fine Aggregate Ratio (%)	Bulk Volume of Coarse Aggregate per Unit Volume of Concrete (m^3/m^3)	Unit Content (kg/m^3)				
			Water (*W*)	Cement (*C*)	Fine Aggregate (*S*)	Coarse Aggregate (*G*)	Admixture (*SP*)
21.4	44.3	0.521	175	818	620	817	Variable Dosage

2.2 Mixing Procedure

Figure 1 shows the mixing procedure. In this study, from the viewpoint of mixer power consumption, the optimum mixing time was defined as the duration required to achieve a sufficient reduction in power demand during the mortar-mixing stage prior to the addition of coarse aggregate. Based on the results of preliminary experiments, the mortar-mixing stage, including the dry-mixing period, was set at 7 min, followed by 3 min of concrete mixing after the addition of coarse aggregate, resulting in a total mixing time of 10 min.

To investigate the influence of dry-mixing time, the total mortar-mixing time was fixed at 7 min, while the dry-mixing period was varied at three levels: 10, 30, and 90 s. Accordingly, the mortar-mixing time after water addition was adjusted so that the total mortar-mixing time remained constant. Immediately after completion of the mortar-mixing stage, a 3-L mortar sample was collected, and coarse aggregate was promptly added to produce fresh concrete.

Table 2: Materials Used

Material	Type and Properties
Cement(*C*)	Low-Heat Portland Cement, Density: 3.23 g/cm³
Fine Aggregate(*S*)	Crushed Sand (Andesite), Saturated Surface-Dry Density: 2.54 g/cm³, Water Absorption: 1.65%
Coarse Aggregate(*G*)	Crushed Stone (Andesite), Saturated Surface-Dry Density: 2.67 g/cm³, Water Absorption: 0.96%
Admixture(*SP*)	High-Range Water-Reducing Admixture (SPU) and Air-Entraining High-Range Water-Reducing Admixture (SPH); Main Component: Polycarboxylate-Based Compound

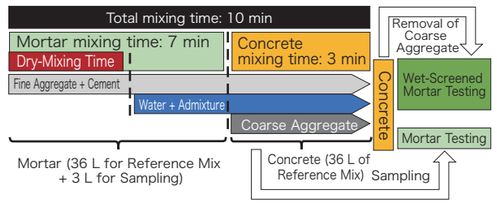


Figure 1: Mixing Procedure

2.3 Test Program

In this study, two experimental conditions were investigated. In the first, only the dry-mixing time was varied while maintaining a constant dosage of chemical admixture corresponding to a target slump flow of 650 mm at a dry-mixing time of 10 s. In the second, the dosage of chemical admixture was adjusted for each dry-mixing time so that the target slump flow of 650 mm was achieved in all cases. Consistency tests and rheological tests were conducted on mortar immediately after mixing, fresh concrete, and mortar obtained from the concrete by wet screening (hereinafter referred to as WS mortar).

For the consistency tests, a mortar flow test (JIS R 5201) was performed for both the mortar and WS mortar, while a slump-flow test (JIS A 1150) was conducted for the concrete. The flow tests were recorded on video, and the time required for the flow diameter to reach 150 mm was determined from the recorded images. Rheological measurements were performed on the mortar and WS mortar using a rotational viscometer. Details of the rheological test are described in Section 3.

The rotational viscometer was equipped with a cross-shaped vane (blade thickness: 1 mm; height: 30 mm; width: 15 mm). Approximately 1 L of sample was placed in a container measuring 15 cm in diameter × 10 cm in height, and the measurements were conducted immediately thereafter.

3. Evaluation Method for Rheological Properties

With the rotational viscometer, the relationship between shear rate and shear stress was measured as a hysteresis loop, consisting of an ascending curve, in which the rotational speed of the cross-shaped vane was gradually increased until reaching 50 rpm, and a descending curve, in which the rotational speed was subsequently decreased until reaching 0 rpm. It has been reported that the area $s_{tx.}$. enclosed by the hysteresis loop can be used to provide a simple evaluation of the degree of time lag between the breakdown and recovery of the flocculated structure, namely, the thixotropic behavior of the material[3].

In addition, to estimate the rheological constants of mortar from the flow test results, the yield value τ_y and the plastic viscosity η were determined using the estimation equations (1) and (2) which were proposed by Higashifunamichi et al[4].

$$\tau_y = 2292e^{-0.01833MF} \quad (1)$$

$$\eta = 15.53T_{150} + 155.5\rho - 342.7 \quad (2)$$

where MF is the mortar flow value (mm), T_{150} is the time required for the flow diameter to reach 150 mm (s), and ρ is the density of the mortar (g/cm^3).

4. Experimental Results and Discussion

Table 3 summarizes the results of all test items. The mixture designation shown in the table indicates the combination of admixture type, dry-mixing time (s), and target slump flow (mm). The term "over" denotes mixtures in which the slump flow exceeded 650 mm solely as a result of increasing the dry-mixing time while maintaining the same admixture dosage.

4.1 Properties of Mortar Immediately after Mixing

(1) Effect of Dry Mixing at a Constant Admixture Dosage

Figure 2 shows the relationships between dry-mixing time and both mortar flow and concrete slump flow for each admixture type. For both SPU and SPH, the mortar flow and slump flow tended to increase with increasing dry-mixing time. In particular, the effect of dry mixing became pronounced at a dry-mixing time of 90 s. Compared with the 30-s condition, the slump flow increased by 47 mm for SPH and by 89.5 mm for SPU.

In contrast, the increase in flow was less pronounced for SPH than for SPU, suggesting that the effect of increasing the dry-mixing time on fluidity depends on the type of chemical admixture used.

It was also confirmed that the increase associated with longer dry-mixing times was more pronounced for slump flow than for mortar flow. One possible reason for this difference is that the mortar flow test uses a flow cone with a height of 60 mm, whereas the slump-flow test uses a slump cone with a height of 300 mm. In addition, the sample volume is approximately 344 mL in the mortar flow test and approximately 5,495 mL in the slump-flow test. Consequently, the greater potential energy of the sample in the slump-flow test may also have contributed to this difference.

Table 3: Test Results for Each Measurement Item

Sample Name	Admixture Type	Dry Mixing Time [s]	Admixture Addition Rate [C×%]	Concrete SF [mm]	Mortar Sample Name	Mortar MF [mm]	Mortar [s]	Mortar [g/cm^3]	Mortar [Pa]	Mortar [Pa・s]	Mortar [Pa/s]
U-10-650	SPU	10	0.800	664.5	Mortar	344.5	1.14	2.42	4.15	51.42	179.6
					WS Mortar	257.0	1.67	2.41	20.62	57.62	850.1
U-30-over		30	0.800	677.0	Mortar	354.5	1.10	2.42	3.45	50.75	139.6
					WS Mortar	254.5	1.61	2.42	21.59	58.64	838.6
U-90-over		90	0.800	766.5	Mortar	367.5	1.01	2.42	2.72	49.13	73.9
					WS Mortar	293.5	1.60	2.41	10.56	57.19	639.0
U-30-650		30	0.780	634.5	Mortar	336.0	1.46	2.41	4.85	55.24	162.7
					WS Mortar	237.0	2.31	2.40	29.75	66.30	1192.1
U-90-650		90	0.770	640.5	Mortar	353.0	1.17	2.42	3.55	51.12	131.9
					WS Mortar	212.0	2.86	2.41	47.05	76.23	1411.8
H-10-650	SPH	10	0.870	674.5	Mortar	342.5	1.37	2.42	4.30	54.35	231.1
					WS Mortar	256.5	2.19	2.41	20.81	65.83	986.7
H-30-over		30	0.870	676.5	Mortar	349.5	1.27	2.42	3.78	52.86	207.0
					WS Mortar	245.5	2.56	2.41	25.46	71.85	1198.4
H-90-over		90	0.870	723.5	Mortar	359.0	1.22	2.42	3.18	52.57	176.6
					WS Mortar	261.0	2.04	2.42	19.16	65.19	896.0
H-30-650		30	0.865	653.5	Mortar	343.5	1.50	2.41	4.22	55.43	266.4
					WS Mortar	239.5	2.63	2.42	28.42	74.71	1348.1
H-90-650		90	0.855	680.5	Mortar	346.5	1.25	2.42	4.00	52.41	209.9
					WS Mortar	245.5	2.14	2.43	25.46	68.07	901.8

(2) Effect of Dry Mixing at a Constant Target Slump Flow

The improvement in workability resulting from dry mixing was confirmed in the previous section, consistent with the findings of the previous study. Thus, the difference in the required dosage of chemical admixture was subsequently examined under a constant target slump flow of 650 mm. **Figure 3** shows the results. The data labels indicate the measured slump-flow values (mm) of the concrete. The results confirmed that the required dosage of chemical admixture could be reduced with increasing dry-mixing time, as suggested by the trends shown in **Figure 2**.

Furthermore, the reduction in admixture dosage was greater for SPU than for SPH, suggesting that the improvement in workability resulting from increased dry-mixing time is more effective when using SPU.

(3) Influence of Dry Mixing on Thixotropy

The hysteresis loops measured using the rotational viscometer are shown in **Figure 4** for the specimens with a constant admixture dosage and in **Figure 5** for those with a constant target slump flow.

As shown in **Figure 4**, the shear stress τ at a given shear rate $\dot{\gamma}$ tended to decrease as the dry-mixing time increased. This tendency was more pronounced for SPU than for SPH, indicating that the improvement in cement dispersion achieved through dry mixing was greater for

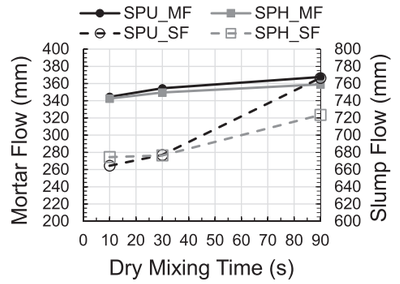


Figure 2: Relationship between Dry-Mixing Time and Mortar Flow and Slump Flow at a Constant Admixture Dosage

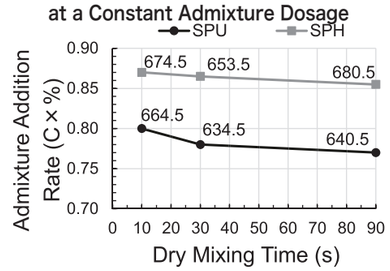


Figure 3: Relationship between Dry-Mixing Time and Admixture Dosage at a Constant Target Slump Flow

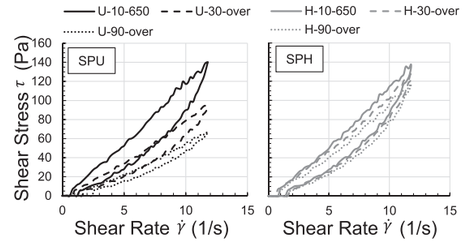


Figure 4: Hysteresis Loops at a Constant Admixture Dosage

SPU. In contrast, SPH was designed to provide a lower level of cement-dispersing performance than SPU, which is considered to have contributed to the difference.

As shown in **Figure 5**, an improvement in dispersion with increasing dry-mixing time was observed for SPU, similar to the trend observed in **Figure 4**. However, this trend was less pronounced than that observed in **Figure 4**, as indicated by the hysteresis loop for the 90-s dry-mixing condition shown by the dashed line. A similar tendency was observed for SPH.

Based on these results, **Figure 6** shows the relationship between dry-mixing time and the thixotropy index, $s_{tx.}$, for SPU and SPH. The data labels indicate the admixture dosage (C×%). At all test levels, an increase in dry-mixing time resulted in a reduction in $s_{tx.}$. The dashed line labeled TSF650 represents the data obtained under the constant target slump-flow condition. Compared with the solid-line data, the admixture dosage was reduced, resulting in lower cement-dispersing performance. Consequently, $s_{tx.}$, which reflects the degree of particle flocculation, is presumed to have increased. In practical concrete production, the final adjustment of fluidity is often achieved by modifying the dosage of chemical admixture. Therefore, the results suggest that the reduction in mortar thixotropy resulting from increased dry-mixing time is influenced by the type and dosage of the chemical admixture used.

(4) Influence of Dry Mixing on Rheological Constants

Figures 7 and **8** show the yield value τ_y and the plastic viscosity η estimated from the mortar flow test, respectively.

As shown in **Figure 7,** the solid-line data for both SPU and SPH exhibited a decreasing trend in τ_y with increasing dry-mixing time, with SPU showing lower values than SPH. In contrast, for the dashed-line data representing the constant target slump-flow condition, no decreasing trend in τ_y with increasing dry-mixing time was observed for SPH.

As shown in **Figure 8**, the solid-line data for both SPU and SPH exhibited a decreasing trend in the plastic viscosity, η, with increasing dry-mixing time, with SPU showing lower values than SPH. In contrast, for the dashed-line data representing the constant target slump-flow condition, η increased at a dry-mixing time of 30 s compared with 10 s and then decreased at 90 s.

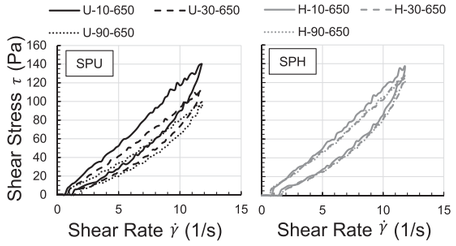


Figure 5: Hysteresis Loops at a Constant Target Slump Flow

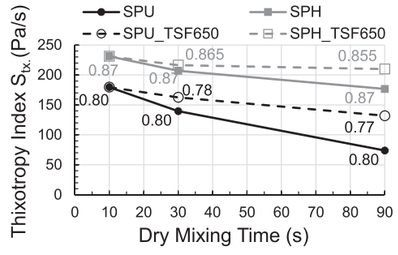


Figure 6: Relationship between Dry-Mixing Time and Thixotropy Index ($s_{tx.}$)

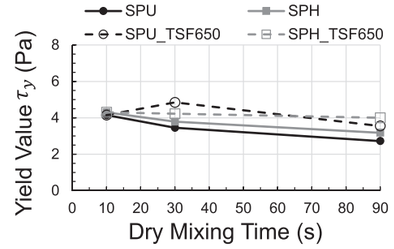


Figure 7: Relationship between Dry-Mixing Time and Yield Value

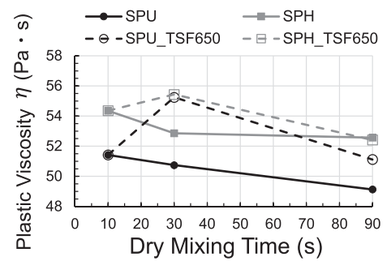


Figure 8: Relationship between Dry-Mixing Time and Plastic Viscosity

According to **Table 3**, the slump-flow values of U-30-650 and H-30-650 were 634.5 mm and 653.5 mm, respectively. It is therefore presumed that the relatively lower fluidity of these mixtures, compared with the other data obtained under the constant target slump-flow condition, influenced the results. Nevertheless, the effect of dry mixing was more pronounced for SPU than for SPH.

Overall, the rheological evaluation of the mortar immediately after mixing confirmed the effectiveness of dry mixing in improving fluidity. In addition, SPU, which has superior cement-dispersing performance, exhibited a greater viscosity-reducing effect through dry mixing than SPH.

4.2 Properties of Wet-Screened Mortar

In this section, the effect of dry mixing on the fluidity of WS mortar sampled from concrete was investigated.

(1) Effect of Dry Mixing at a Constant Admixture Dosage

Figure 9 shows the relationship between dry-mixing time and both the WS mortar flow and mortar flow for each admixture type. The WS mortar flow of SPU exhibited a tendency to increase significantly at 90 seconds of dry mixing. Compared with SPH, the improvement in fluidity resulting from an increase in dry-mixing time was more pronounced for SPU. In contrast, for SPH, the influence of dry mixing on WS mortar flow was limited, and no clear trend was observed.

The reason the WS mortar flow showed lower values than the mortar flow is that, although WS mortar is obtained by removing coarse aggregate from concrete, the adhesion of mortar to the surface of the coarse aggregate progresses over time, resulting in reduced fluidity.

(2) Effect of Dry Mixing at a Constant Target Slump Flow

Figure 10 shows the relationship between dry-mixing time and both the WS mortar flow and mortar flow for the same target slump flow. The data labels indicate the admixture dosage (C × %). The measured slump flow ranged from 634.5 mm to 680.5 mm, which was considered to satisfy the target value.

The WS mortar flow of SPU showed a decreasing trend with increasing dry-mixing time, decreasing by approximately 17.3% at 90 s compared with that at 10 s. This may be because the admixture dosage decreased with

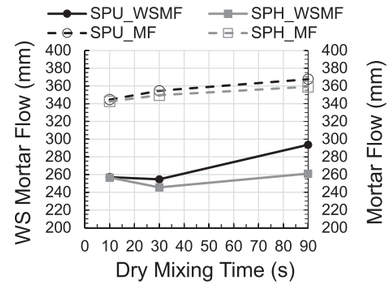


Figure 9: Relationship between Dry-Mixing Time and WS Mortar Flow and Mortar Flow at a Constant Admixture Dosage

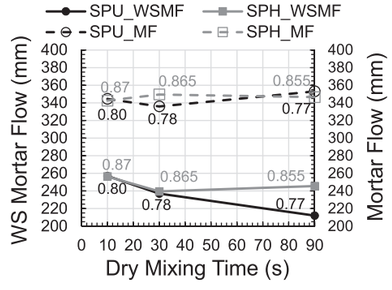


Figure 10: Relationship between Dry-Mixing Time and WS Mortar Flow and Mortar Flow at a Constant Target Slump Flow

increasing dry-mixing time, and the time required for sampling the WS mortar may also have contributed to a decrease in the cement-dispersing effect over time. The WS mortar flow was measured approximately 7 min after the mortar flow test conducted immediately after mixing.

In contrast, the WS mortar flow of SPH decreased by only approximately 4.3% at a dry-mixing time of 90 s compared with that at 10 s. This may be attributed to the higher admixture dosage for SPH than for SPU, which resulted in a smaller change in fluidity over time.

(3) Effect of Dry Mixing on Thixotropy

The hysteresis loops measured using a rotational viscometer are shown in **Figure 11** for the specimens with the same admixture dosage and in **Figure 12** for the specimens with the same target slump flow. In both figures, the shear stress (τ) on the ascending curve increased rapidly in the low shear-rate (γ) region and then increased more gradually with increasing shear rate. This behavior is considered to be attributable to an increase in flocculation after the WS mortar had been placed in the measuring container. Such a tendency was not observed in

the mortar immediately after mixing, as shown in **Figures 4** and **5**.

As shown in **Figure 11**, for SPU, the shear stress (τ) at a given shear rate (γ) tended to decrease at a dry-mixing time of 90 s compared with that at 10 s. In contrast, for SPH, only a slight decrease in τ at a given γ was observed at 90 s relative to 10 s, while τ tended to increase at 30 s. This is considered to be attributable to the fact that SPH was formulated to have lower cement-dispersing performance than SPU.

In **Figure 12**, for SPU, the shear stress (τ) at a given shear rate (γ) tended to increase as the dry-mixing time increased. In addition, at a dry-mixing time of 90 s, τ exhibited a peak value in the low shear-rate region of the ascending curve, and a similar indication was also observed in the hysteresis loop at a dry-mixing time of 30 s. In **Figure 12**, the admixture dosage was reduced as the dry-mixing time increased to maintain a slump flow of 650 mm. As a result, the cement-dispersing effect is presumed to have gradually decreased over time before the WS mortar was sampled, leading to increased flocculation and particle interlocking in the low shear-rate $\dot{\gamma}$ region. These results indicate that, even when the slump flow was equivalent, differences existed in the flow characteristics of the mortar constituting the concrete.

In contrast, the hysteresis behavior of SPH showed a tendency for flocculation in the low shear-rate $\dot{\gamma}$ region to be mitigated compared with SPU. This may be attributable to the fact that SPH was designed to provide better dispersion retention than SPU.

Based on these results, **Figure 13** shows the relationship between dry-mixing time and the thixotropy index $s_{tx.}$ for SPU and SPH. The data labels indicate the admixture dosage (C × %). For the solid-line data for SPU, a decrease in $s_{tx.}$ with increasing dry-mixing time was observed. In contrast, for SPH, $s_{tx.}$ increased at a dry-mixing time of 30 s and then decreased at 90 s. On the other hand, for the data at the same target slump flow (dashed lines), a pronounced increasing trend in $s_{tx.}$ with increasing dry-mixing time was observed for SPU.

The trend shown in **Figure 13** differs from that observed for the mortar immediately after mixing in **Figure 6**. When comparing the results for SPU_TSF650 at a dry-mixing time of 90 s in both figures, the $s_{tx.}$ of the WS mortar was approximately 10.7 times that of the mortar immediately after mixing. Because SPU

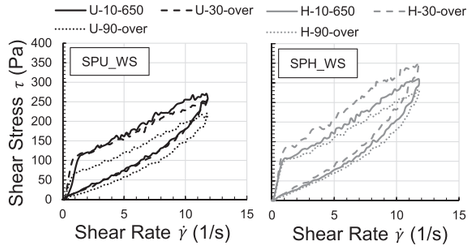


Figure 11: Hysteresis Loops at a Constant Admixture Dosage

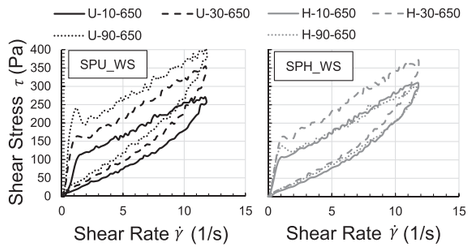


Figure 12: Hysteresis Loops at a Constant Target Slump Flow

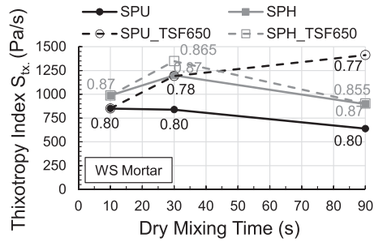


Figure 13: Relationship between Dry-Mixing Time and Thixotropy Index ($s_{tx.}$)

possesses high cement-dispersing performance as a high-range water-reducing admixture for ultra-high-strength concrete, the $s_{tx.}$ of the mortar immediately after mixing was relatively low. However, the results suggest that, during the time elapsed before the WS mortar was sampled, adhesion of the mortar to the surface of the coarse aggregate was promoted, while the cement-dispersing performance may have decreased.

(4) Effect of Dry Mixing on Rheological Constants

The yield value τ_y and plastic viscosity η determined from the WS mortar flow test are shown in **Figures 14** and **15**, respectively. Compared with the results for mortar immediately after mixing shown in **Figures 7** and **8**, the larger values of τ_y and η obtained for the WS mortar can be attributed to the lower mortar flow and longer T_{150} values, as shown in **Table 3**.

For SPU in **Figure 14**, τ_y tended to decrease with increasing dry-mixing time under the same admixture dosage condition (solid lines). In contrast, under the same target slump flow condition (dashed lines), τ_y tended to increase because the admixture dosage was reduced as the dry-mixing time increased. In particular, a marked increase in τ_y was observed at a dry-mixing time of 90 s.

A similar tendency was observed for η in **Figure 15**.

In this experiment, a stiffening tendency was observed in concrete with a target slump flow of 650 mm produced using SPU and a dry-mixing time of 90 s. As described above, the $s_{tx.}$, τ_y, and η values of the WS mortar increased significantly. Therefore, for the practical application of fluidity-improvement technology based on dry mixing, it is necessary to optimize the admixture not only in terms of cement-dispersing performance but also from the perspectives of dispersion retention and rheological control.

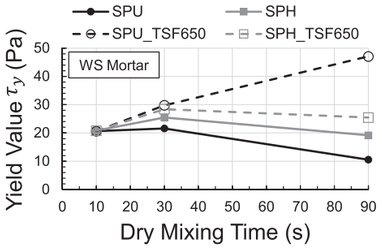


Figure 14: Relationship between Dry-Mixing Time and Yield Value

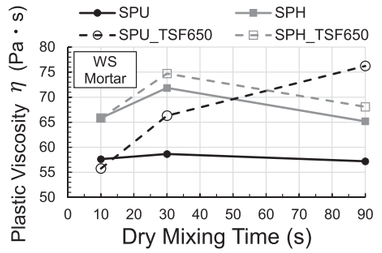


Figure 15: Relationship between Dry-Mixing Time and Plastic Viscosity

4.3 Improvement of Fluidity by Dry Mixing

As previously reported[2], increasing the dry-mixing time improved the fluidity of high-strength concrete. The present study also showed reductions in mortar thixotropy, yield value, and plastic viscosity. Furthermore, the dosage of admixture required to achieve the same target slump flow could be reduced.

On the other hand, when the admixture dosage was reduced, the duration over which fluidity was maintained became shorter, resulting in a slight stiffening of the concrete.

Therefore, when dry mixing is employed to enhance the fluidity of high-strength concrete, it is important to adjust both the dosage and composition of the admixture so that the required fluidity can be achieved at the time the concrete is used.

5. Conclusions

The findings obtained in this study are summarized as follows:

(1) For high-strength concrete incorporating low-heat Portland cement, an appropriate dry-mixing time improved fluidity, and the effect was more pronounced for the high-range water-reducing admixture for ultra-high-strength concrete than for the air-entraining high-range water-reducing admixture for high-strength concrete.

(2) By utilizing the fluidity-improvement technique based on dry mixing, the dosage of admixture required to achieve a target slump flow could be reduced.

(3) In the fluidity-improvement of high-strength concrete by dry mixing, differences in properties that could not be captured by the concrete slump-flow test were observed. The results suggest that such differences can be quantified through rheological testing of wet-screened mortar.

Acknowledgments

The authors would like to express their sincere gratitude to Mr. Kobayashi of Ritsumeikan University for his cooperation in this study. The authors also wish to thank Mr. Akiyama and Mr. Shimizu of FLORIC Co., Ltd., as well as the members of the Concrete Research Institute, for their cooperation.

REFERENCES

1) Ministry of Land, Infrastructure, Transport and Tourism. (2021). *White Paper on Land, Infrastructure, Transport and Tourism in Japan 2021*, Chapter 2, Section 2, "Increasing Disaster Risks and Aging Infrastructure," 45–53.
2) Sakamoto, Y., Kawasaki, Y., Fukuyama, T., & Kim, Y. (2023). Influence of Flocculation with Dry-Mixing on Slump Flow of High-Strength Concrete. *Proceedings of the Japan Concrete Institute, 45*(1), 826–831.
3) Akiyama, G., Hirano, S., Nishi, H., & Tomoyose, A. (2022). A study on the rheological properties of fresh mortar using volcanic glass powder for concrete. *Proceedings of the Japan Concrete Institute, 44*(1), 166–171.
4) Higashifunamichi, Y., Yamada, Y., & Hirano, S. (2023). STUDY ON THE RHEOLOGICAL CONSTANTS ESTIMATION METHOD OF CEMENT PASTE AND MORTAR BY FLOW TEST. *Journal of Structural and Construction Engineering (Transactions of AIJ), 88*(803), 1–11.

AUTHOR



Yasuhiro SAKAMOTO

Ph.D. (Engineering)

Joined in 2012

Development Department,
Development Section 2

MEMO