STUDY ON THE THERMAL STIMULATION EFFECT ON VARIOUS PROPERTIES OF MORTAR UTILIZING BYPRODUCTS

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ABSTRACT

Previous studies have confirmed that applying thermal stimulation to Superplasticizers improves fluidity and instantaneous mixing without adversely affecting hardening properties. Therefore, this study investigated the effects of varying BFS levels on the freshness and hardening characteristics achieved by utilizing byproducts as thermal stimuli, and confirmed the thermal stimulation effect when utilizing supernatant. The results confirmed that adding BFS improved both fluidity and instantaneous mixing performance under thermal stimulation. However, it was also confirmed that the thermal stimulation effect became less pronounced as the amount of BFS increased. Furthermore, while improvements in fluidity and instantaneous mixing performance were confirmed even when using supernatant water, it was also confirmed that the thermal stimulation effect was less pronounced compared to when using tap water. It was also confirmed that thermal stimulation combined with the use of byproducts does not adversely affect the hardening properties.

KEYWORDS

Thermal stimulation, Superplasticizers, Mortar, Cement paste, Blast furnace slag& Supernatant

1. INTRODUCTION

In recent years, as construction projects such as ultra-high-rise apartment buildings become increasingly complex, there is a growing demand not only for improved concrete quality but also for enhanced workability and productivity. Superplasticizers are used to meet these requirements [1]. Superplasticizers are primarily a type of concrete material, widely used at construction sites and in precast concrete plants. Among these, high-performance polycarboxylate ether-based water-reducing agents and high-performance AE water-reducing agents excel in cement particle dispersion and long-term slump retention, making them suitable for both construction sites and product development [2-4].

The adsorption properties of cement particles by polycarboxylic ether-based superplasticizers vary significantly depending on the combination of molecular structures within the superplasticizers, specifically the hydrophobic main chain and hydrophobic side chains [5-6].

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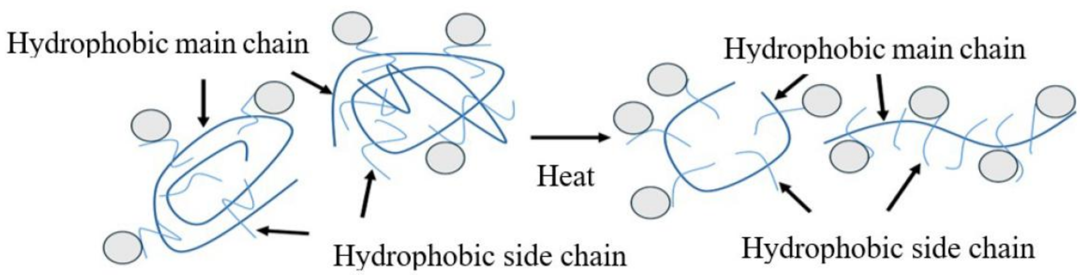
The dispersion of primarily adsorbed cement particles is explained by steric hindrance effects arising from repulsion between polymer molecules within polycarboxylate ether-based superplasticizers [7-8]. Consequently, many products incorporate multiple polymer molecules tailored to maintain target workability and slump values [9].

It is generally known from experience that polycarboxylate ether-based superplasticizers affect fluidity when used in high-temperature environments [10]. However, it is less well known that subjecting the superplasticizers itself to heat treatment or high-temperature environments alters its physical properties, thereby affecting the fluidity of mortar and concrete. Therefore, the hypothesis was proposed that applying thermal stimulation to the superplasticizers itself alters its physical properties, increasing the steric surface area of the polymer molecules, which are the main components of the superplasticizers (hereinafter referred to as thermal stimulation) [11-15]. Applying thermal stimulation causes the polymers within the superplasticizers to fracture and elongate, affecting fluidity due to electrostatic repulsion between cement particles resulting from steric hindrance effects. (Figures 1 shows a schematic illustration of the morphological change in polymers due to thermal stimulation of superplasticizers) Previous studies have confirmed that applying thermal stimulation to polycarboxylate ether-based superplasticizers improves fluidity and the speed of reaching workability (hereafter referred to as mixing instantaneity). Since thermal stimulation enables a reduction in superplasticizers usage, it is expected to contribute to reducing environmental impact.

In recent years, global SDGs aimed at sustainable development have been promoted, and the utilization of byproducts such as blast furnace slag (hereinafter referred to as BFS) and supernatant water is being sought from the perspectives of CO_2 reduction and waste volume reduction. In actual concrete construction, blast furnace cement is used because it can enhance long-term strength, reduce hydration heat, and improve chemical resistance. However, the effect of varying the amount of BFS contained in blast furnace cement on thermal stimulation effects has not yet been confirmed. Furthermore, the supernatant discharged from ready-mixed concrete plants is generally considered suitable for use as mixing water, equivalent to potable water, and its effective utilization is being promoted. Nevertheless, the impact of using supernatant as mixing water on thermal stimulation effects remains unconfirmed.

Therefore, in this study, to confirm the thermal stimulation effect on mortar utilizing by products such as BFS and supernatant water, evaluation tests for fresh properties specifically fluidity and instantaneous mixing were conducted, along with compressive strength tests to evaluate hardening characteristics.



Figures 1 Schematic illustration of the morphological change in polymers due to thermal stimulation of superplasticizers

2. EXPERIMENTAL PROCEDURE

2.1. Material Used

Table 1 shows the materials used. In this experiment, polycarboxylate ether-based superplasticizers were used. Two types of superplasticizers were employed: a high-performance water-reducing agent (hereinafter referred to as the PCa type) used in precast concrete plants, which excels at dispersing cement particles, and a high-performance AE water-reducing agent (hereinafter referred to as the RMC type) used on-site, which excels at maintaining slump. BFS was used with a fineness of 4000 mesh, replacing ordinary Portland cement. Two types of water were used: tap water, commonly used for mixing, and supernatant water, classified as recovered water from returned concrete.

2.2. Heating Method

All superplasticizers used in this study were heated using a water bath method at 60°C for 24 hours. To prevent changes in superplasticizers concentration due to moisture evaporation during heating, the superplasticizers were placed in polypropylene vials, sealed, and then heated in a constant-temperature bath.

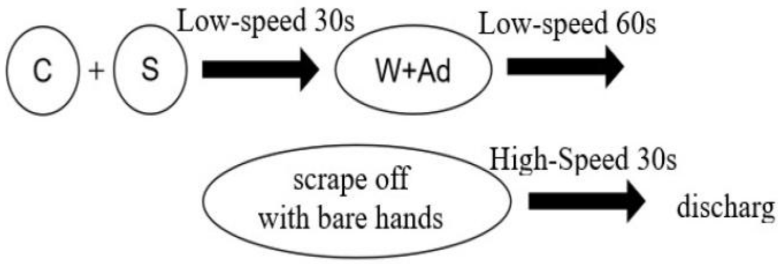
Table 1. Materials used

Materials	Symbol	Properties
Cement	C	Ordinally portland cement Density:3.16g/cm^3
Fine aggregate	S	River sand Density: 2.64g/cm^3 Water absorptivity:1.46%
Water	W_1	Tap water
	W_2	Supernatant water
Admixture	BFS	Blast furnace slag fine powder (4000 brain)
Superplasticizer	PCa	High range water reducing agent (PCE-Type)
	RMC	High range AE water reducing agent (PCE-Type)

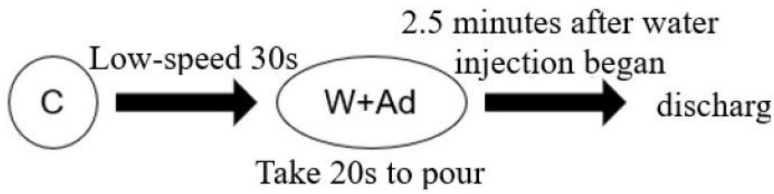
Table 2. Mixing conditions and levels

Test materials	Test items	Super plasticizer	W/C (%)	S/C	Ad (C×%)	BFS rate (C×%)
BFS	Mortar Flow Compressive Strength	PCa	30	2.0	1.0	0, 15, 45, 65
		RMC	35		1.1	
	Instantaneous Mixing	PCa	23	-	1.0	
		RMC	26			
Supernatant water	Mortar Flow Compressive Strength	PCa	30	2.0	1.0	-
		RMC	35		1.1	
	Instantaneous Mixing	PCa	23	-	1.0	
		RMC	26			

2.3. Test conditions



Figures 2 The mixing methods for mortar



Figures 3 The mixing methods for cement paste

Table 2 shows the mixing conditions. In this study, mortar flow tests, instantaneous mixing test, and compressive strength tests were conducted to confirm the effects of utilizing byproducts on mortar workability, mixing instantaneousness, and strength.

The mix design was set to achieve a flow value of 120±5 mm when measuring the zero-hit flow without applying thermal stimulation and adding byproducts. As a result, a W/C ratio of 30% was adopted for the PCa type and a W/C ratio of 35% for the RMC type. BFS was replaced with cement, and verification was conducted simulating blast furnace cement types A, B, and C. Furthermore, in the supernatant water test, the supernatant portion of recovered water from a ready-mix concrete plant and tap water were used to compare the thermal stimulation effects.

In the instantaneous mixing test, the PCa type and RMC type were selected based on achieving maximum interparticle bonding and maximum mixing resistance during mixing. Furthermore, for the instantaneous mixing test, a low-horsepower tabletop kitchen mixer was used to facilitate observation of current changes, and cement paste was employed for evaluation to prevent significant numerical variation in the results.

2.4. Conditions of Mixing Procedure

Figures 2 and 3 show the mixing methods for mortar and cement paste. In this study, mixing was performed using the same procedure for both mortar flow test and instantaneous mixing test, regardless of the presence or absence of thermal stimulation. Figures 4 show schematic diagram of the measurement using an AC/DC clamp meter. For checking mortar workability, a hobart-type mixer was used for mixing, and a tabletop hobart-type mixer was used for the instantaneous mixing test. Additionally, in the instantaneous mixing test, an AC/DC clamp meter was used, and to stabilize the current measurement baseline, the sample was initially dry-mixed for 30 seconds, followed by the injection of mixing water containing the superplasticizers over a 20-second period. Subsequently, torque values were measured from the moment water contact occurred until 2 minutes and 30 seconds, when the torque value peaked and stabilized. Regardless of thermal stimulation, the superplasticizers was mixed into mixing water at 20°C (±2°C) before addition. In addition, BFS was added simultaneously with cement and fine aggregate during mixing. The mixing and fresh test environments were maintained at 20°C and 60% humidity.

2.5. Test Items

2.5.1. Mortar Flow Test

To confirm the thermal stimulation effect on fluidity, a mortar flow test was conducted in accordance with JIS R 5201 "Physical Test Methods for Cement." In this experiment, the thermal stimulation effect on the mortar flow value was evaluated using the following Equation (1).

$$\Delta FL(\%) = \frac{Fs - Fi}{Fi} \times 100 \qquad (1)$$

Fs: Value without thermal stimulation
Fi: Value with thermal stimulation

2.5.2. Instantaneous Mixing Test

$$\text{Reduction rate}(\%) = \frac{Xi - Xs}{Xs} \times 100 \qquad (2)$$

Xi: Value without thermal stimulation
Xs: Value with thermal stimulation

It is said that the more difficult a material is to mix when preparing concrete, the greater the power consumption of the mixing mixer. Therefore, to confirm the thermal stimulation effect on instantaneous mixing power, measurement tests were conducted using the test method with a tabletop kitchen mixer, which was also used in previous studies. Figure 4 shows a schematic diagram of the measurement using an AC/DC clamp meter. The tabletop kitchen mixer was connected to an extension cord with a safety plug, and the current flowing through the cord was measured using an AC/DC clamp meter. Furthermore, it was assumed that when mixing cement caused the current to reach its maximum value, a capillary state was achieved, and this maximum value equaled the maximum resistance value during mixer mixing. Concurrently, the time from the initial contact between cement and water during mixing to the point where the current reached its maximum was measured. The reduction rate in instantaneous mixing was evaluated using the following Equation (2).

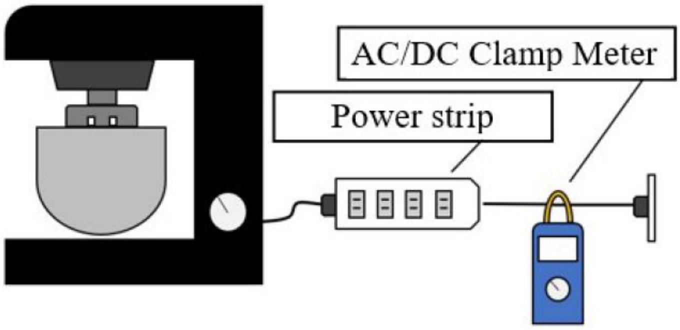
2.5.3. Compressive Strength Test

This test was conducted in accordance with JIS R 5201 "Compressive Strength Test for Concrete" to confirm the effects of thermal stimulation and byproducts on the hardening characteristics of mortar.

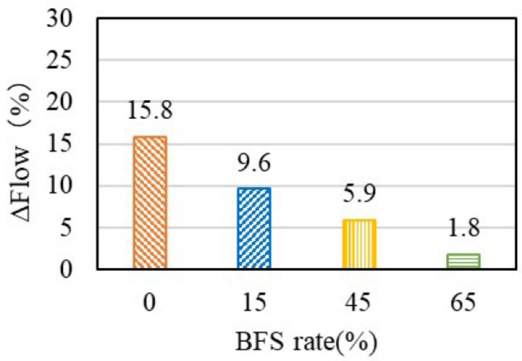
3. Experimental Results and Discussion

3.1. Thermal Stimulation Effect When Changing BFS Addition Rate

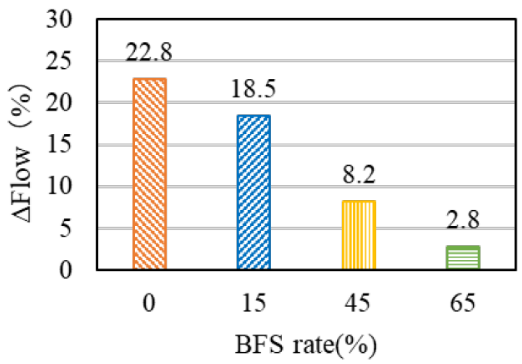
Figures 5 and 6 show the thermal stimulation effect on mortar flow values for different BFS dosages in PCa and RMC types, respectively. Figures 5 and 6 confirm that, consistent with previous studies, the thermal stimulation effect appears regardless of the PCa type, RMC type, or BFS addition rate. However, the effect becomes less pronounced as the replacement rate increases, and no effect was observed even with thermal stimulation when the BFS replacement rate was 65%. Furthermore, at the same BFS replacement rate, comparing PCa and RMC types revealed that the RMC type exhibited the thermal stimulation effect more readily. Tables 3 and 4 show the effect of BFS content on instantaneous mixing. Tables 3 and 4 confirm that at a BFS replacement rate of 15%, both PCa and RMC types showed improved instantaneous mixing due to thermal stimulation. However, no thermal stimulation effect was observed at BFS replacement rates of 45% and 65%.



Figures 4 Schematic diagram of the measurement using an AC/DC clamp meter



Figures 5 The effect of thermal stimulation on mortar flow values for different BFS dosages (PCa)



Figures 6 The effect of thermal stimulation on mortar flow values for different BFS dosages (RMC)

Table.3 The effect of BFS content on instantaneous mixing (PCa)

Superplasticizer	**BFS rate (%)**	**Time until thoroughly mixed**		**Reduction rate (%)**
		No heat (s)	**Heat (s)**	
PCa	0	66	54	22.2
	15	82	74	10.8
	45	72	71	1.4
	65	65	64	1.6

Table.4 The effect of BFS content on instantaneous mixing (RMC)

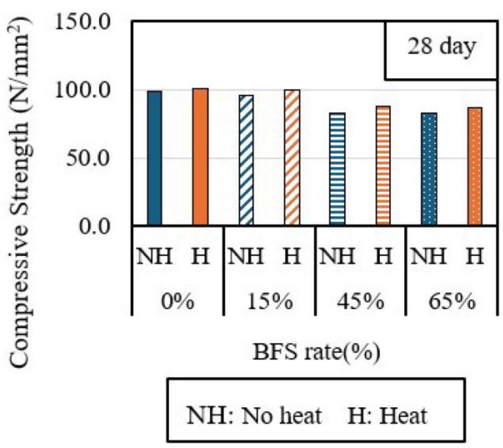
Super plasticizer	BFS rate (%)	Time until thoroughly mixed		Reduction rate (%)
		No heat (s)	Heat (s)	
RMC	0	64	53	20.8
	15	78	67	13.4
	45	64	62	3.2
	65	58	59	-1.7

These results suggest that the silica component in BFS inhibits adsorption between the polymer in the polycarboxylate ether-based superplasticizers and cement particles, making it difficult for the thermal stimulation effect to manifest. Furthermore, while PCa type showed improved instantaneous mixing compared to RMC type at 0% BFS replacement rate, adding BFS resulted in RMC type exhibiting superior instantaneous mixing. This is thought to be due to the variation in polymer adsorption rates upon thermal stimulation caused by the differing lengths of the hydrophobic main chain and hydrophobic side chains contained within superplasticizers, resulting in changes observed between the PCa type and RMC type.

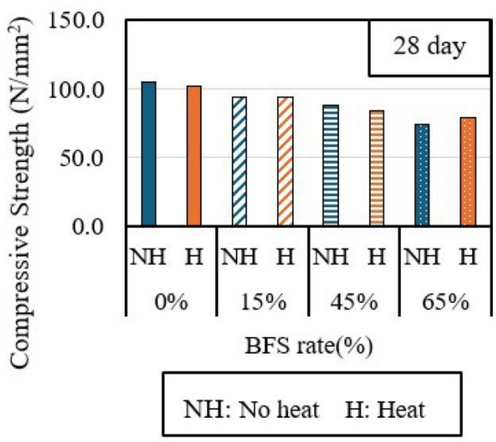
Figures 7 and 8 show the thermal stimulation effect on the compressive strength of BFS-blended mortar for PCa and RMC types, respectively. At the replacement level of BFS, no significant difference in compressive strength due to thermal stimulation was observed for either the PCa type or the RMC type. This result is consistent with previous studies indicating that thermal stimulation does not adversely affect hardening properties, suggesting that similar outcomes would occur even when varying the BFS replacement rate.

3.2. Thermal Stimulation Effect When Using Supernatant

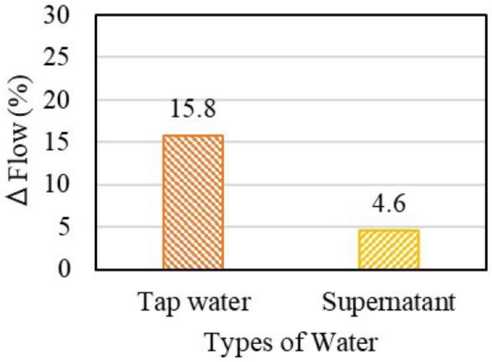
Figures 9 and 10 show the relationship between thermal stimulation effects on mortar flow values and water type for PCa and RMC types, respectively. Figures 9 and 10 confirm that the thermal stimulation effect occurs even when using supernatant water. However, it was confirmed that the thermal stimulation effect is less pronounced with supernatant water compared to tap water. This is thought to be due to polymer shrinkage caused by the higher pH of the supernatant compared to tap water, although the exact reason remains unclear, necessitating further analysis.



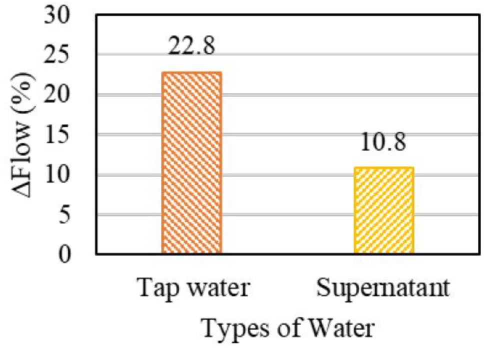
Figures 7 The thermal stimulation effect on the compressive strength（PCa）



Figures 8 The thermal stimulation effect on the compressive strength（RMC）



Figures 9 The relationship between thermal stimulation effects on mortar flow values and water type (PCa)

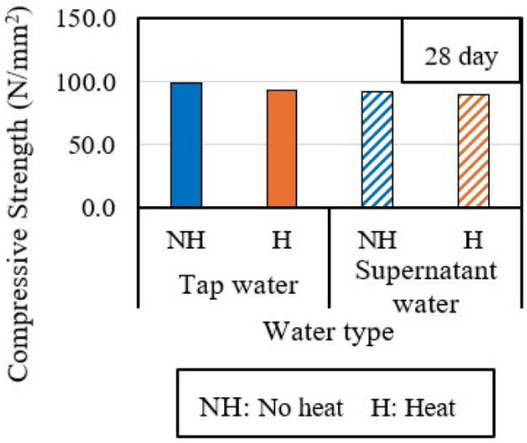


Figures 10 The relationship between thermal stimulation effects on mortar flow values and water type (RMC)

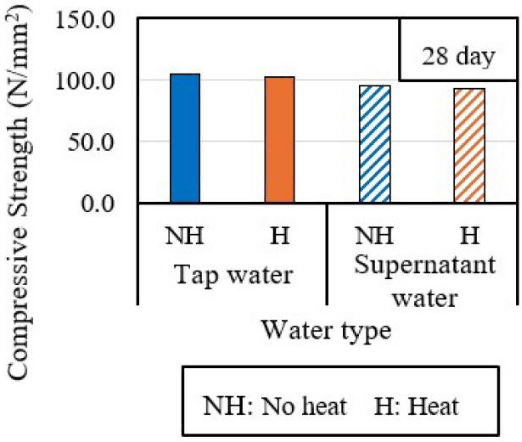
Table 5 shows the relationship between the thermal stimulation effect on instantaneous mixing and the use of supernatant water. Table 5 confirms improved mixing instantaneity for both PCa and RMC types. However, similar to the mortar flow test, the supernatant water showed a reduced thermal stimulation effect compared to tap water. It was confirmed that the supernatant obtained when using PCa type, regardless of the presence or absence of thermal stimulation, required a longer mixing time compared to tap water. Conversely, using RMC type with supernatant water shortened mixing times compared to tap water. This difference in thermal stimulation effect is attributed to the varying tendency of polymer shrinkage in PCa and RMC types, due to differences in the length of the hydrophobic main chain and hydrophobic side chains within the superplasticizers. Furthermore, while using supernatant with the RMC type made the thermal stimulation effect less apparent, it was confirmed that the instantaneous mixing performance improved compared to tap water.

Table.5 Relationship between Thermal Stimulation Effects on Kneading and Instantaneous Power and Supernatant

Superplasticizer	Types of Water	Time until thoroughly mixed		Reduction rate (%)
		No heat (s)	Heat (s)	
PCa	Tap water	74	62	19.4
	Supernatant	108	103	4.9
RMC	Tap water	100	76	31.6
	Supernatant	71	65	9.2



Figures 11 The relationship between thermal stimulation effect and compressive strength (PCa)



Figures 12 The relationship between thermal stimulation effect and compressive strength (RMC)

Figures 11 and 12 show the relationship between thermal stimulation effect and compressive strength for PCa type and RMC type, respectively. For both PCa and RMC types, no significant difference in compressive strength was observed with or without thermal stimulation even when using supernatant water, confirming that thermal stimulation does not affect the hardening characteristics of the mortar. This result is consistent with previous research, which confirmed that thermal stimulation does not affect hardening characteristics, suggesting that the same outcome occurs even with supernatant water.

4. SUMMARY

As a result of verifying the use of thermally stimulated polycarboxylic ether-based high-performance water-reducing agents and high-performance AE water-reducing agents in each by-product, the following findings were obtained within the scope of this study.

(1) In comparisons using BFS, both PCa and RMC types showed improved fluidity and mixing instantaneity when subjected to thermal stimulation. However, it was confirmed that the thermal stimulation effect becomes less pronounced as the BFS replacement rate increases.
(2) Comparing the replacement rates of BFS, it was confirmed that the RMC type exhibited the thermal stimulation effect more readily than the PCa type.
(3) Although compressive strength decreased with increasing BFS replacement rate, no significant difference in hardening characteristics was observed between samples with and without thermal stimulation, confirming that thermal stimulation does not adversely affect strength.
(4) When using supernatant water, it was confirmed that the thermal stimulation effect appeared even when applied to both PCa and RMC types. However, it was also confirmed that the thermal stimulation effect was less pronounced with supernatant water compared to tap water.
(5) When comparing PCa and RMC types using supernatant water, it was confirmed that the RMC type exhibited the thermal stimulation effect more readily.
(6) When using supernatant water, an improvement in mixing instantaneousness was confirmed for the RMC type.
(7) No significant difference in compressive strength was observed even when using supernatant, confirming that the presence or absence of thermal stimulation does not adversely affect compressive strength.

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