Effect of Thermal Stimulation of Admixture to Workability of the Mortar

M. S. Salehi, Z. Tahery, S. Sasaki, and S. Date

***Abstract*—The objective of this research is to study the effects of thermal stimulation of PC ether high performance water-reducing agent on the workability of fresh cement-mortar. For better understanding of the behavior of these admixtures under thermal stimulation condition, two types of water-reducing agents are used, superplasticizer and high range water reducer (Air Entraining type). The chosen admixtures were heated by different temperatures, 40, 50 and 60℃ for two various times, 30 minutes and 24 hours. These conditions experimentally investigated different types of cements, high early strength cement and ordinary Portland cement. As a result, influence of thermal stimulation of admixtures on the workability of fresh cement-mortar is observed. Accordingly, in a specific water cement ratio in cement concrete, the amount of the admixture can be significantly reduced by using thermal simulation technique in comparison to non-thermal stimulated ones. Therefore, it is possible to reduce the economic aspect of production with this technique.**

***Index Terms*—Thermal stimulation, superplasticizer, workability, high-performance AE water reducing agent, high range water reducer, fresh properties, mortar paste.**

I. Introduction

Cement-concrete is the most widely used construction material currently and its impacts on daily life of human are easily visible. Its use can be observed in any developed community. In other words, the development of any society and country can be judged by studying their technologies in use, and the amount and types of concrete they use. Traditional concrete is a composite material made of four components; coarse aggregate, fine aggregate, cement and water, and can only achieve a certain strength limit or be produced for some specific types of concrete. Concrete with these properties does not meeting the needs of the modern world. As a result, a fifth part of concrete composite, additive materials, called admixtures, was invented.

Concrete admixtures are used to improve and modify the behavior and properties of concrete under a variety of conditions.

As it is difficult to bring all concrete admixtures under a single classification covering all their compositions, applications and mechanism of action, they can be categorized into three categories; (1) Surface-active chemicals, (2) Set controlling chemicals, and (3) Mineral admixtures. Surface-active chemicals or surfactants generally cover the air entraining and water reducing admixtures which are usually used for enhancing the workability of concrete. With this understanding that admixtures modify the properties of concrete, huge numbers of products are being produced nowadays. In some countries around 80 percent of their concrete products are produced with one or two admixtures [1].

Superplasticizers and high range water reducer (here in after HRWR) are among the recent admixtures which are widely used as water reducers for enhancement of concrete workability and strength. In comparison to normal water-reducing admixtures, they can reduce mixing water by almost four times, thus the name HRWR [1]. However, in some cases incompatibility between the binder and the superplasticizer may create problems such as poor flow behavior, early slump loss, strong retardation or flash set [2]. But generally the incorporation of superplasticizers in concrete promotes its compressive strength while reducing bleeding, rate of carbonation and risk of drying shrinkage [3].

The mechanism of action of superplasticizers is to disperse the cement particles by electrostatic repulsion (produced by the adsorption negatively charged groups) and steric hindrance effect (produced by the presence of side long graft chains) when adsorbed on the cement particles. [4], [5]. When the flocculated cement particles disperse, the trapped water is released and more water is available for concrete mixing [6]. This causes a decrease in concrete plastic viscosity and increase of its fluidity.

Since workability is one of the most important properties of fresh concrete which is often defined as: the amount of mechanical work required for full compaction of the concrete without segregation [7] and from the fact that consistency and cohesiveness are two primary characteristics of workability, and strength is directly proportionate to the degree of compaction, then the better the workability the higher the strength is. As the matrix of the concrete is bonding aggregates tightly together, which normally controls the characteristics of concrete, thus any positive changes in the matrix properties will result in concrete improvement.

The effects of Polycarboxylic acid (here in after PC), high air entraining (here in after AE) water reducing agent and mixing temperature on the properties of fresh concrete are understood from previous studies, depending on mixing under temperatures of 10℃, some of the properties of fresh concrete are not stable within 15 minutes [8]-[10].

The various advantages using superplasticizers in concrete production industries has made it an interesting field of research among concrete researchers. The benefits of utilizing superplasticizers has brought a great deal competition to this area of research. This has resulted in the

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producing of a variety of different brands and products. As the use of superplasticizers has had positive effects on fresh and hardened properties of concrete [1], [3].So the outcome from any single improvement among these fresh and hardened properties of concrete can have a large economic or environmental benefit for the world.

TABLE I: MATERIAL USED

Materials		Properties
Cement	N	Ordinary Portland cement, density: 3.16g/cm^{3,} specific surface area 3340 cm^2/g
	H	High early cement, density: 3.14g/cm^3, specific area 4490 cm^2/g
Fine aggregate	S	Crushed sand from Kanagawa density*: 2.63g/cm^3
Superplasticizer	SP1	Superplasticizer (Polycarboxylic acid-based)
	SP2	Superplasticizer (Polycarboxylic acid-based ether)
	HRWR	High range water reducing agent (type of AE): (Polycarboxylic acid-based ether)
*: In saturated surface-dry condition		

TABLE II: ADMIXTURE DOSING RATIO

Cement	Admixture	Ad/C (%)
OPC	SP1	0.56
	SP2	0.84
	HRWR	1
H	SP1	0.58
	SP2	0.95
	HRWR	1.1

This research aimed to study the impacts of thermal stimulation on two different types of superplasticizers (here in after “SP”) and high range AE water reducing agents in different types of cements. The HRWR (Cement × 1%) thermally stimulated with heating temperature of 60 ℃ with a heating time of 24 hours for obtaining flow of the mortar in its 0 and 15 tamps, (0 tamp: 200 mm, 15 tamps: 246 mm).Through experiments, it is found that it is necessary to use unstimulated HRWR (C×2.5%) admixture to achieve the same mortar flow (0 tamp: 200 mm, 15 tamps: 246 mm). Therefore, it is possible to use thermally stimulate the admixture to reduce C×1.5% of the admixture amount. By using thermal stimulation technique, the required workability can be obtained with smaller amount of admixture which directly affects the financial and environmental aspects of concrete productions. In this study the thermally stimulated admixtures were used for mixing the mortar 5-10 minutes after removing them from the heating chamber, and the mortar flow was measured just after the mortar was mixed.

II. RESEARCH OUTLINE

This study is intended to investigate on the effects of thermal stimulation of admixtures on cement mortar flow by changing the heating conditions.
The following cases were the focus the study:

Case 1.Impact of cement types on fluidity effect of thermal stimulation of the admixtures.

Case 2. Influence of different heating temperatures on the fluidity effect of thermal stimulation of the admixtures.

TABLE III: ADMIXTURE HEATING CONDITIONS

	Admixture heating Temp (℃)	Admixture heating Time (h)
Case1	60	0.5
Case2	60	0.5,24
Case3	40,50,60	0.5

Case 3. Influence of heating time of thermal stimulation of the admixtures on fluidity of mortar.

A. Materials Used and Mix Proportions

The materials used for this study are shown in Table I. This experiment was conducted on mortar with a water-cement ratio of 30%, and a sand cement ratio of 2.0.

The admixtures addition rate at the time of non-heating are shown in Table II. The percentages of SP and HRWR are used for obtaining the targeted flow are shown (approximately 120 mm flow at 0 tamp and 200 mm at 15 tamps).

B. Admixture Heating Conditions

The admixture heating conditions are shown in Table III. Heating temperature and heating time were controlled by --using a thermostatic chamber.

The admixtures were heated in three different temperatures, 40℃, 50℃ and 60℃.It was carried out by thermal stimulation with admixture with ± 1 ℃. The keeping time of admixtures in constant heating chamber in the mentioned temperatures were 0.5 hours and 24 hours.

C. Mortar Mixing Method

The whole procedure was performed in accordance with

JIS R 5201 "Physical testing methods for cement." in the case of using the heated admixture in this experiment, the fine aggregates and cement were prepared in a mixing machine in advance to reduce external factors affecting heated admixture and mixing water as much as possible.

The heated admixtures were mixed with mixing water (5 to 10 minutes) after being removed from a constant temperature chamber. The same procedure was applied to the non-heating admixture. The ambient temperature of mixing was 20±3 ℃.

D. Measurement Equipment

In order to perform the confirmation of the fresh properties, the flow table of JIS R 5201 " Physical testing methods of cement" was used for measuring mortar flow in value of 0 tamp and 15 tamps.

III. Results

A. Impact of Cement Types on the Fluidity Effect of Thermal Stimulated Admixture

The effect of cement types on increasing of flow rate of heat stimulated SP is shown in Fig. 1.

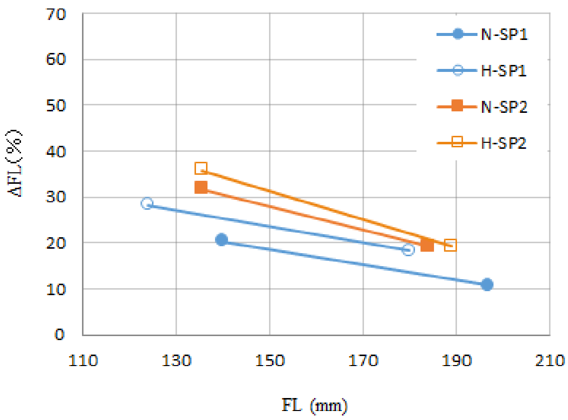

Fig. 1. The effect of cement types on flow of heat stimulated SP.

By applying the heat stimulation technique, the more improvement in flow rate of high early strength cement is observed in its 0 tamp measurement compared to OPC.

In both admixtures, improvement of fluidity confirmed. The effect of cement types on increasing of flow rate by using heat stimulated HRWR is shown in Fig.2. By using HRWR in the both cements, the flow rate improvement in high early strength cement is much bigger than OPC.

As the loss of consistency in the cement paste during the dormant period is mainly attributed to the physical coagulation of cement particles rather than to the chemical processes [11] and while the density of high-early-strength cement is smaller than OPC, its smaller particles can be covered by the widened HRWR at ease, then greater repulsion and steric hindrance effect of admixture results in bigger fluidity. Likewise, when the 0 tamp flow and 15 tamps flow are compared, there is an increase of flow due to heating tends towards 0 tamp.

B. Impact of Heating Temperatures on the Fluidity Effect of Thermally Stimulated Admixture

The influence of temperature differences in flow rate of SP is shown in Fig. 3.

In the case of 0 and 15 tamps in SP1 (PC), the flow rate tends to improve with increasing stimulations' temperatures in all experimented temperature degrees, 40 ℃, 50 ℃ and 60 ℃.In the case of SP2 (PC ether), flow rate 50 ℃ is almost the same as 60 ℃. By comparing SP2 (PC ether) to SP1 (PC), SP2 fluidity seems larger in both 0 tamp and 15 tamps.

The increasing rate of flow in HRWR by applying thermal stimulation technique is shown in Fig. 4**.**

The HRWR (PC ether) shows that flow rate is increasing with the increase of temperatures.

From the experimental results, it seems there are different optimal thermal stimulation degrees for different admixtures.

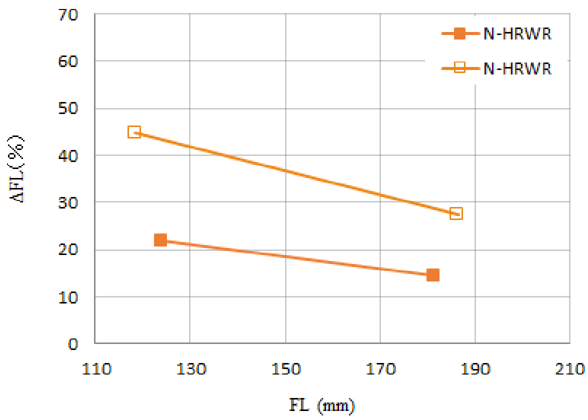

Fig. 2. The effect of cement types on flow of heat stimulated HRWR.

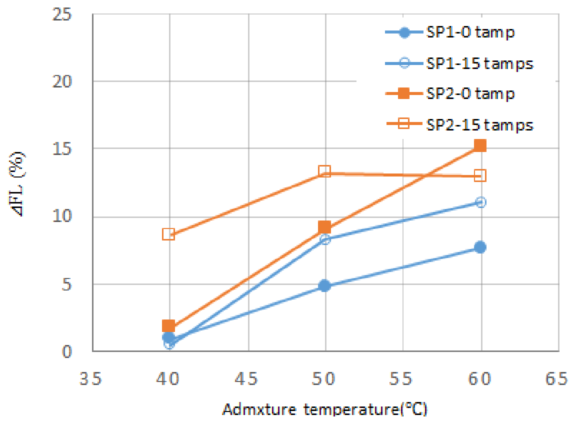

Fig. 3. Influence of temperature differences in flow rate of SP.

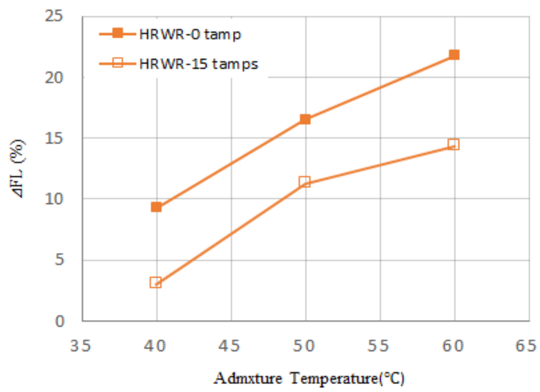

Fig. 4. The increasing rate of flow in HRWR by application of thermal stimulation technique.

C. Effect of Heating Time on the Fluidity Effect of Thermal Stimulation of Admixture

The influence of heat stimulation of the admixtures on the fluidity of mortar was considered by changing the heating time.

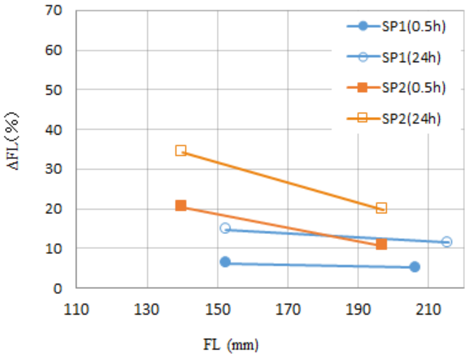

Fig. 5. The effect of heating time of stimulation on fluidity of SP.

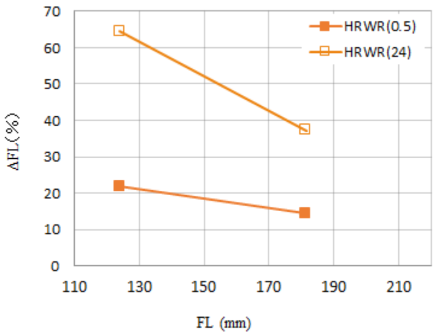

Fig. 6. The effect of heating time of stimulation on fluidity of HRWR.

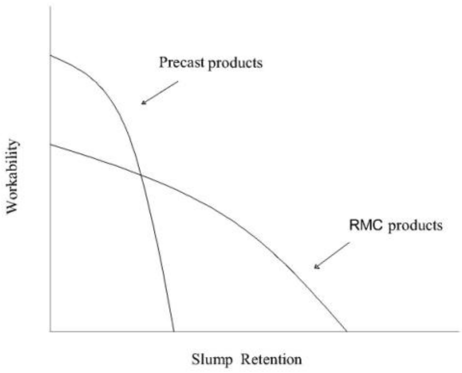

Fig. 7. The schematic of performance of the two used products.

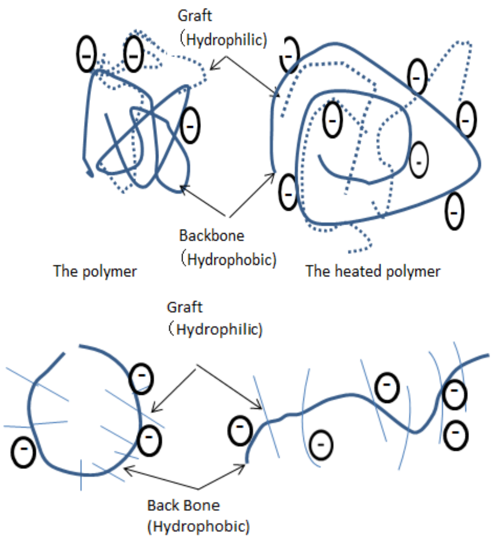

Fig. 8. Dispersion model of heated copolymer graft.

The effect of heating time on increasing of flow rate of SP is shown in Fig. 5. In the figure, the 24 hours heating time of (SP1 and SP2) are compared to their 30 minutes heating time. The figure shows an improvement of more than 8% in their fluidity properties. By comparing SP2 to SP1 at their 24 hours heating condition, SP2 water-reducing effect is seemed increase.

One of the reasons for this flow effect difference in heat simulated SP2 (PC ether) and SP1 (PC) is believed to be much molecular bonding on cement particles in SP2 than SP1. This causes expanding cement suction surface and results in reduction of water. Therefore, it functions to disperse the cement particles quickly. The effect of heating time of stimulation on fluidity of HRWR is shown in Fig. 6.

By comparison of the 0 tamp of HRWR at 24 hours heating condition to its 30 minutes heating condition, an improvement approximately 44% is observed. While the improvement of its 15 tamps with 24 heating condition is approximately 23% compared to its 30 minutes heating condition.

The performance of the two used products in this research are shown in schematic Fig. 7.

In this study, for better distinguishing of the thermal stimulation effects on the admixtures ,invitations curried out on two type of products; precast type products(Here in after “PCa type”) and ready-mix concrete (RMC) products. In precast type, after mixing up, dispersion effect of cement is exerted from the initial period. This is to be fill quickly cement into a mold elaborately, it is in order to increase the turnover of PCa product manufacturing.

The other one is RMC (called a hold-type) .Compared to PCa type, dispersing effect of the cement is exerted late for adapting on-site.

It is believed that workability of thermal stimulated Superplasticizer to be improved early than non-stimulated ones. Also, by applying thermal stimulation to water reducing agents, in Fig. 7 reaching to the position of peak of workability is faster. So, Slump life is the future challenges.

As per kind of application requirements for RMC, there is necessity of choosing the admixtures containing slump -keeping polymers in its formation.

IV. Discussion

A. Graft Structure at the Time of Heating

Dispersion model of heated graft copolymer is shown in Fig.8. The new generation of superplasticizers are comb--shaped PC polymers with enhanced properties.

PC water reducing agent is a copolymer having a different graft chain length. Copolymer is a water-soluble polymer electrolyte having a carboxyl group and a sulfonic group as an anionic group in its molecule which usually spreads by taking a random coil structure in an aqueous solution [12].They are adsorbed on the cement particles and act as dispersant mainly by steric repulsion effects [5].

The length of their side chains has influence in rheology of cement-PC combinations. Yamada et al. [13] found that longer side chains gave lower yield stress and lower plastic viscosities. In previous research [14], rheology was improved with increasing side chain length for PC ether type with quite short side chains. In the presence of an inorganic salt, such as cement, dispersion is conceivable to shrink into a random coil likely solubility. In this research, it is believed that by thermal stimulation of PC water reducing polymer, the random coil structure of the graft chains open and increase in their lengths. It is also thought that the available cement suction surface increases. Therefore, in thermally stimulated case, more SP and HRWR adsorbed to cement particles than in the non-stimulated case and causes more dispersion and at a result improve water-reducing effect of SP and HRWR.

In general, the ether type PC superplasticizers showed more sensitivity to thermal stimulation than none ether ones. The main reason is believed to be the existence of slump retention polymers in the structure of ether type superplasticizers which are activated after hydrolysis in alkali environment of cement-water solution. The thermal stimulation affects these polymers and opens the clustered structure, resulting in extra fluidity.

TABLE IV: THE ADMIXTURE THERMAL STIMULATION RESULTS

	0 tamp	15 tamp	Temperature (℃)	Heat Temp (℃)	Heat Time (h)	Admixture decreasing rate (%)
HRWR (Cx1%)	200	246	21.5	60	24	1.5
HRWR (Cx2.5%)	204	249	20	20	0	

B. Reduction of Admixture Rate by Using of Admixture Thermal Stimulation Technique

This study shows increases in flowability of mortar when the thermal stimulation technique is used.

Therefore, it is considered that there is the possibility of reducing the amount of the admixture needed to obtain a determined mortar flow by thermal stimulation of admixture.

The results of thermal stimulation effects on flowability of mortar are shown in Table IV. Differences in HRWR amounts are compared when thermal stimulation is used and not used.

With OPC cement mortar, HRWR (C×1%) thermal stimulated for 24 hours at 60 ℃, the flow of mortar recorded (0 tamp: 200 mm: and 15 tamps: 246 mm). The flow result of heated admixture given as target and then the amount of non-heated admixture was found, HRWR (C×2.5%), corresponded to the targeted flow (0 tamp: 206 mm: and15 tamp: 246 mm) by a trial error experimenting, which shows a reduction of C×1.5% in the admixture usage.

V. CONCLUSION

1) By applying thermal stimulation to the admixture, the fluidity of mortar improved in comparison to non-heated admixture.
2) There is a high tendency for increasing of the mortar fluidity in 0 tamp flow of heated high-performance AE water reducing agent in comparison to its 15 tamp flow.
3) The effect of fluidity of the thermally stimulated superplasticizers varies with heating time. Longer heating time increases the tendency of liquidity compared to non-stimulated ones.
4) The effect of thermally stimulated admixtures in 60 ℃ is greater compared to 40 ℃, 50 ℃.
5) In any of the admixtures, by applying the thermally stimulated admixture in high early strength cement, observation of higher fluidity was confirmed in comparison to ordinary cement,
6) Depending on the admixture, there is an optimum thermal stimulation temperature in order to improve the thermal stimulation effects.

From the results achieved, each superplasticizer has its own optimum heating degrees and keeping time. By knowing the behavior of each admixture under heating conditions and finding their optimums, they can be heated prior to mixing of mortar to improve the fluidity of the mortar paste. Therefore, by applying this thermal stimulation technique, the amount of admixtures (SP and HRWR) can be reduced to obtain the same slump and fluidity, which will result in the admixture reduction leading to dropping of production cost.

In this study the thermally stimulated admixtures were used for mixing the mortar 5-10 minutes after removing them from the heating chamber and the mortar flow was measured just after the mortar mixed. Therefore further experiments and investigations could be conducted on the following:

a) Effect of keeping time of heated admixture when removed from the heating chamber untill mixed to mortar.

b) Effect of keeping time between mixing the mortar and measuring its fluidity.

c) Effect of thermal stimulation on slump keeping time.

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