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Model for Predicting Dosage of Superplasticizer for Slump Recovery of Fresh Concrete

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ABSTRACT

This paper aimed to propose a method to estimate the amount of superplasticizer redosing for concrete slump recovery using a type-F naphthalene-based superplasticizer for solving a problem of slump loss. This was achieved by developing equations for calculating the amount of the second dose of superplasticizer needed to recover the concrete slump to its initial values. Fresh concrete properties of OPC concrete having paste volume to void volume ratios of 1.1-1.3, and water to cement ratios in the range of 0.40 to 0.67 and naphthalene-based superplasticizer dosages between 0.25% and 1.6% were tested for initial slump and slump loss at 30-minute interval until 1.5 hours. The concrete mixtures showed slump losses ranging from 10% to 90% and then were redosed to recover their slump back to their initial values. Test results showed that slower slump loss was detected for the mixture with a higher initial dosage of the superplasticizer. The necessary redose of superplasticizer was influenced mainly by water to cement ratio and concrete paste content. The mixture with a lower water to cement ratio and lower paste content needs a larger second dosage of superplasticizer for redosing.

Keywords: Redosing; Slump loss; Slump recovery; Second dosage; Superplasticizer

1. Introduction

The major property of fresh concrete is workability. The workability covers various properties like easiness to deforming, transporting, consolidating, and finishing the surface, as well as sufficient segregation resistance so that the concrete is always uniform before and after placing. It also covers the ability to flow, mold, and have sufficient cohesiveness during the fresh state [1]. In general practice, the mix proportion of concrete is decided based on the slump and

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strength. A slump is usually designed to be compatible with structural member configuration and construction methods. However, the slump can decrease with the elapsed time [2].

Slump loss is a phenomenon after cement hydrates, consuming some free water and producing stiff products such as ettringite, making the fresh mixture stiffer than its initial condition (just-after-mixing condition) and so, causing the concrete to lose some workability. A hydration reaction is a continuous reaction between cementitious material and water. The hydration reaction rate is controlled by ambient temperature. In Thailand and other tropical countries, ambient temperature is high, especially during summer or even for the whole year due to the effects of global warming. Therefore, a quicker rate of reaction and faster slump loss are also expected. Moreover, bad traffic conditions, which cause a delay in concrete delivery, are another concerning issue. In practice, there are two methods frequently employed on-site for the too-severe slump-loss concrete. One is to reject the concrete, and the other is to regain the slump by adding some water or water reducers into the concrete. In the case of adding water, concrete will sacrifice its mechanical and durability performance, while rejecting the concrete is always the last choice to make. It is more reasonable in all aspects to utilize a superplasticizer as the second dose for the solution to regain the fresh concrete slump. Successful redosing of the slump-loss concrete can only be done by experienced concrete engineers. However, there are very few such engineers in only a few construction sites and even if there is, there is still a possibility of failure such as segregation due to overdosing. Therefore, an estimation model to obtain a suitable amount of superplasticizer for redosing will be useful for actual practice, especially for less experienced engineers, and reduce such problems at construction sites.

2. Methodologies

2.1 Materials

Ordinary Portland cement Type I conforming to ASTM C150 [3] was used as the binder in this study. The material properties of the cement are shown in Tables 1-2.

Table 1. Chemical compositions of OPC type I.

Chemical compositions (%)	SiO_2	CaO	Al_2O3	Fe_2O_3	MgO	Na_2O	K_2O	SO_3	LOI
OPC type I	20.35	64.28	5.02	3.18	2.03	0.20	0.48	2.92	1.43

Table 2. Physical properties of OPC type I.

Properties	**Specific gravity**	**fineness (cm^2/g)**
OPC type 1	3.10	3440

River sand passing sieve no.4 was utilized as the fine aggregate while crushed limestone having a 25-mm maximum size was used. The properties of the aggregates conformed to ASTM C33 [4]. The properties of the coarse and fine aggregates used in the tests are listed in Table 3.

A superplasticizer (SP), naphthalene-based, complying with ASTM C494 [5], widely applied in Thailand was selected for being used in the tests. The naphthalene-based superplasticizer was selected due to its low cost, high water-reducing efficiency, and good compatibility with other types of water-reducing and chemical admixtures normally used in concrete.

2.2 Paste content

Paste volume ratio (γ) was a parameter used for the model for estimating the 2nd dosage for slump recovery. The paste volume ratio (γ) can be determined and is defined as the ratio between paste volume and void content in the aggregate phase. Fig. 1 demonstrates the void curve derived from the void measurement of the fine-coarse aggregate mixtures with varied sand-to-total aggregate ratios. The void content was measured according to ASTM C29 [6].

Table 3. Physical properties of crushed limestone and river sand.

Properties	Specific gravity	Fineness Modulus	Absorption (%)
Crushed limestone	2.71	7.98	0.70
River sand	2.60	2.45	1.06

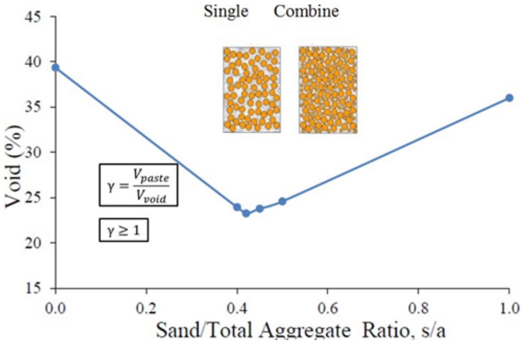

Fig. 1. Void content of aggregate phase with varied s/a ratio.

2.3 Concrete mix design

The tested concrete mixtures were designed based on the corresponding paste content at the minimum void content of the aggregate phase. The water to cement ratio (w/c) of the tested mixtures varied between 0.40 with the target compressive strength at 28 days of 40 MPa to 0.67 with the target compressive strength at 28 days of 21 MPa. The paste volume ratios (γ) were varied at 1.1, 1.2, and 1.3. The s/a ratio (sand to aggregates ratio) was controlled at 0.42. This s/a resulted in a minimum void content of the aggregate phase of 23%. The ranges of the w/c and compressive strength used in the tests in this study are within the typical range of ready-mixed concrete used for construction in Thailand. The slump of the tested fresh concrete mixtures was controlled at 7 cm. for the mixtures with a γ of 1.1 and 10 cm. for the mixtures with γ of 1.2 and 1.3. The conditions of the tested mixture proportions are summarized in Table 4.

Table 4. Conditions of concrete mix design.

Parameter of mix design	Design range
Water to cement ratio (w/c)	0.40 to 0.67
Paste content (γ)	γ = 1.1 in case of slump 7 cm. γ = 1.2 to 1.3 in case of slump 10 cm.
Sand to aggregate ratio (s/a)	0.42
Void content of the aggregate (%)	23%

2.4 Slump measurement

The measurement of the slump was carried out right after completing the mixing according to ASTM C192 [7] and this slump value was treated as the initial slump value as per ASTM 143[8].

2.5 Superplasticizer redosing

Each tested fresh concrete mixture was kept in a container with a cover to prevent moisture loss of mixtures by evaporation after concrete mixing and the initial slump measurement. At 30, 60, and 90 minutes after concrete mixing, the slump of the concrete kept in the container was measured. Before the slump measurement, the concrete sample was re-mixed for 2 min to obtain a homogenous mixture, eliminate thixotropy, and regain the fluidity of the mixture. This measured slump was defined as the slump before the redosing. Then the superplasticizer, as a 2nd dose, was added to the mixture at 30, 60 and 90 minutes after concrete mixing. The mixture was mixed for 2 min to obtain a homogenous mixture after redosing. The slump was measured again, and the slump value was the slump after redosing at 30, 60, 90 minutes after concrete mixing. The 2nd dosage amounts were varied from 0.1% to 1% by cement weight until achieving the initial slump value of the tested mixture. The dosage to regain the initial slump is defined as the required 2nd dosage for slump recovery.

3. Results and Discussions

3.1 Slump loss

In this study, the slump of all the tested mixtures was controlled for mixtures with all tested w/c values. However, it was varied according to the paste volume ratio. The initial slump measured right after completing mixing was controlled at a lower value for the mixtures having a lower paste volume ratio (slump 7 cm. for γ =1.1 and slump 10 cm. for γ =1.2 and 1.3). At stipulated times of 30, 60, and 90 minutes after concrete mixing, the slump value of the concrete was measured again as shown in Fig. 3 and Fig.4. As paste content decreases (γ =1.1), meaning a larger aggregate content, slump loss is faster (Fig. 3). The lower value of paste content (γ) causes a lower slump due to increased interparticle surface forces caused by smaller distances among solid particles. When considering mixtures with an equal initial slump, a mixture with a lower w/c but a higher superplasticizer dosage has a slower slump loss as can be seen in Fig.4. This can be attributed to the increase of dispersion effect of superplasticizer as the superplasticizer dosage is higher. It causes the disturbance of hydration reaction and a lower slump loss rate [9]. This also means that the effectiveness of superplasticizer to disperse the cement particles is more effective and lasts longer than that of the water. It should be noted that in this study, the environmental conditions, cement type, and superplasticizer type are controlled to be the same. It is reported that both chemical and physical processes contribute to the slump loss mechanisms [1], whereas the consistency loss during the dormant stage of the cement paste is mainly caused by the physical coagulation of the cement particles rather than the chemical effects [10].

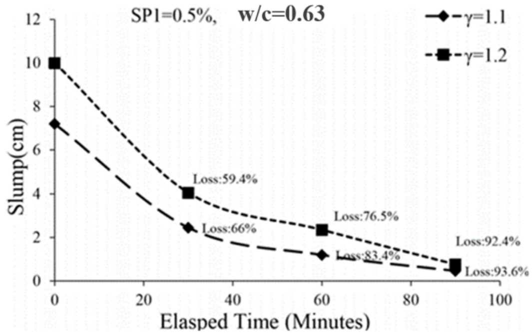

Fig. 3. Slump versus elapsed time of concrete mixtures having equivalent w/c and initial dosages of superplasticizer.

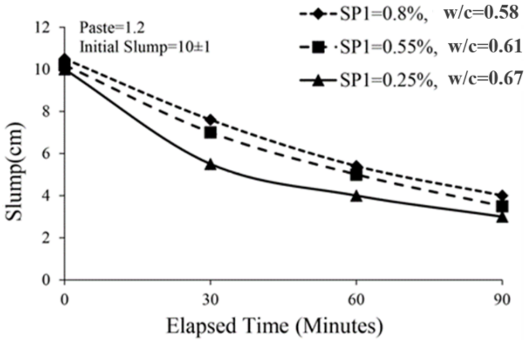

Fig. 4. Slump versus elapsed time of concrete mixtures having equivalent paste volume ratio and initial slump but different w/c.

3.2 2nd dosage of superplasticizer

Slump loss can be determined by storing concrete mixtures inside the container until reaching the time of measurement. In this experiment, the assigned redosing times were 30, 60, and 90 minutes after mixing.

Then the 2nd dose of superplasticizer was added to the concrete that had lost some slump. The added naphthalene-based superplasticizer provided electrostatic repulsive forces to increase slump. With a certain second dosage of the superplasticizer, the original slump was regained [10]. Fig. 5 illustrates the concept of superplasticizer redosing at 30, 60, and 90 minutes after mixing, for regaining the original slump.

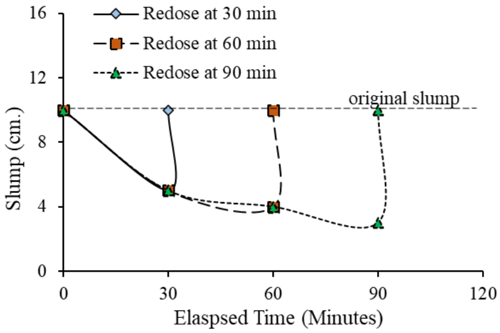

Fig. 5. Conceptual illustration for redosing.

3.3 Factors Affecting Required 2nd Dosage

The effects of the paste content and the initial dosage of superplasticizer are seen in Fig.6. The results in Fig.6 show that the mixtures require a larger 2nd dosage when the slump loss percentage becomes higher. The slump loss percentage is the percentage of the loss relative to the initial slump.

Fig.7 shows that a mixture with a lower paste content needs a higher second superplasticizer dosage to regain its initial slump. The 2nd dosage is larger for the mixture with a lower paste content because the mixture has a greater number of aggregates, encountering higher interlocking and frictional effects among the aggregate particles. It is well-known that the slump of normal concrete with water-reducing admixtures depends largely on the friction among the large solid particles but less on the friction among the powder particles as the water-reducing admixture has the capacity to disperse the powder particles but not the large solid particles like the aggregates. Therefore, a mixture with a low paste content would need more repulsive action when compared to one with a high paste content. It is interesting to note that the mixtures with paste volume ratios of 1.1 and 1.2, low paste contents, require equivalent 2nd dosages of superplasticizer for their slump recovery, regardless of the percentage of the slump loss. (see Fig. 6).

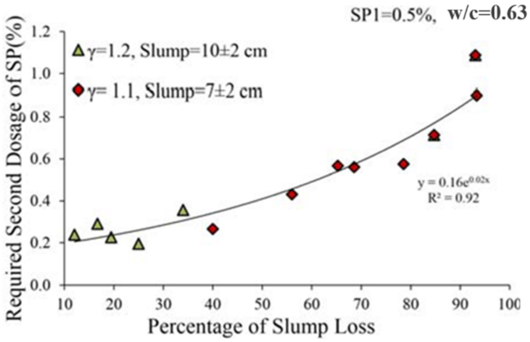

Fig. 6. Required 2nd superplasticizer dosages for mixtures with paste volume ratios of 1.1 and 1.2.

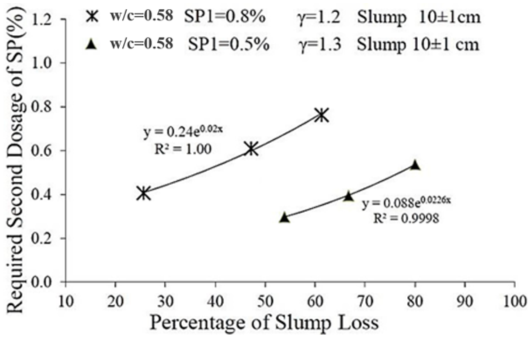

Fig. 7. Effects of paste volume ratio and initial superplasticizer dosage on required 2nd dosage.

Test results in Fig.8 show that a mixture with a lower w/c requires a higher 2nd superplasticizer dosage compared to that with a higher w/c to regain initial slump. This is because the lower w/c concrete has higher cement content, resulting in a larger total powder surface area, larger inter-particular friction, and a stiffer mixture.

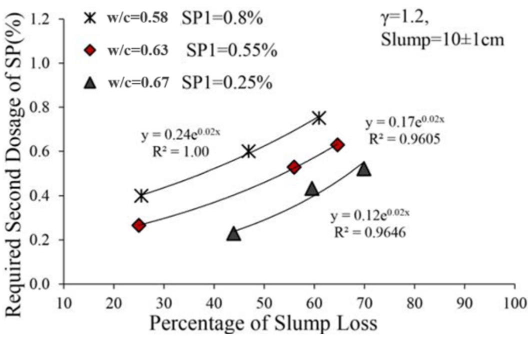

Fig. 8. Effects of w/c and initial superplasticizer on required 2nd dosage.

3.4 Equations for estimating required 2nd dosage

According to the results in Figs. 6 to 8, a relationship between the required 2nd dosage of superplasticizer and the slump loss percentage can be derived as:

$$SD = a_{opc}e^{bSL}, \quad (3.1)$$

where SD is the 2nd dosage of superplasticizer (% of cement), SL is the slump loss percentage (%), b is a constant which is equal to 0.02, and a_{opc} is a multiplier function for the effects of w/c and paste volume ratio.

$$a_{opc} = \left[-1.255(w/c) + 0.97\right] \times erf\left\{\left[\gamma - 1.32\right] \times \left[-16.56(w/c) - 8.15\right]\right\}. \quad (3.2)$$

Fig. 9 shows the relationships between a_{opc} and γ of mixtures with different w/c. When the paste volume ratio increases, the required 2nd dosage of superplasticizer is reduced. As the mixtures with paste contents of 1.1 and 1.2 have equivalent required second dosages of superplasticizer, the values of a_{opc} are constant in the range of γ from 1.1 to 1.2. The value of a_{opc} is lower for the mixture with a higher w/c.

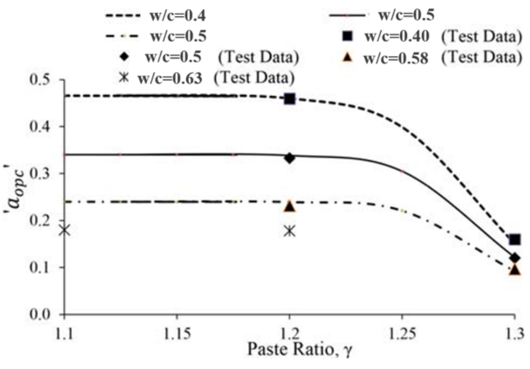

Fig. 9. Effects of w/c and γ on a_{opc}.

4. Equation Verification

By comparing the computed results of the 2nd dosage obtained from Eqs. (3.1)-(3.2) with the measured 2nd dosages, the precision of the estimation equation can be evaluated.

Figs. 10-12 reveal that the predicted and tested required 2nd dosage for mixtures with paste volume ratios of 1.1, 1.2, and 1.3, respectively. It can be seen from the three figures that the 2nd dosage of superplasticizer for slump restoration could be well estimated by using the developed equations and the obtained prediction precision was within ±10%. It is noted that though the proposed equations are still limited for applying to normal and cement-only concrete, they are the basis and can be extended to include many other factors that have significant impacts on the retempering dosage of superplasticizer.

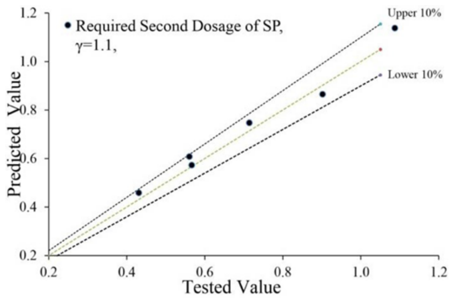

Fig. 10. Verification results of the estimated and measured 2nd dosages for mixtures with γ = 1.1.

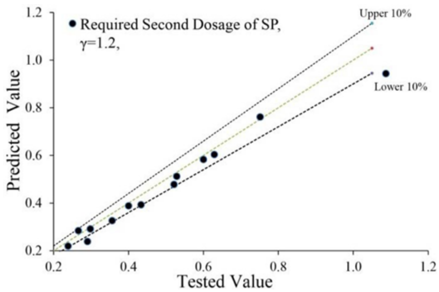

Fig. 11. Verification result of the estimated and measured 2nd dosages for mixtures with γ = 1.2.

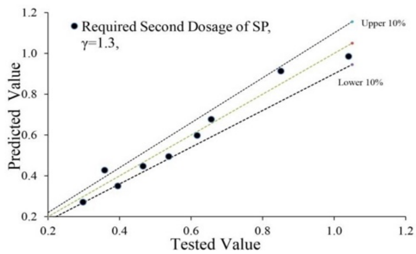

Fig. 12. Verification results of the estimated and measured 2nd dosages for mixtures with γ = 1.3.

5. Conclusions

This study attempted to achieve a procedure to retemper the fresh concrete that has lost its slump and propose a preliminary set of equations to estimate the 2nd dosage of a naphthalene-based superplasticizer to recover the initial slump. Some essential conclusions received from the results of this study are listed as follows:

1) When considering mixtures with an equal initial slump, a mixture with a lower w/c but a higher superplasticizer dosage has a slower slump loss. This is due to the increase in the dispersion effect of the superplasticizer when the superplasticizer dosage is higher.

2) For slump recovery, the concrete mixture requires a larger 2nd dosage when its slump loss percentage is higher.

3) A mixture with a lower paste content needs a higher second superplasticizer dosage to regain its original slump since the mixture has a greater number of aggregates, encountering higher interlocking and frictional effects among the aggregate particles.

4) A mixture with a lower w/c requires a higher 2nd superplasticizer dosage compared to that with a higher w/c to regain the original slump. This is because the lower w/c concrete has higher cement content, resulting in a larger total powder surface area, larger inter-particular friction, and a stiffer mixture.

5) Equations for estimating the 2nd dosage of superplasticizer to recover slump to the initial slump value were proposed. The 2nd dosage of superplasticizer for slump restoration could be well estimated by using the developed equations and the obtained prediction precision was within ±10%.

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