P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : https://tci-thaijo.org/index.php/SciTechAsia
Science & Technology Asia
Vol.28 No.4 October - December 2023
Page: [135-143]

Original research article

Compressive Strength and Setting Times of Slump Recovery Concrete with Fly Ash

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Received 18 August 2023; Received in revised form 27 October 2023
Accepted 15 November 2023; Available online 27 December 2023

ABSTRACT

Slump loss is a major problem of fresh concrete during construction, especially in hot climates. In this study, to retemper the concrete with loss of slump, a 2nd dose of superplasticizer is added to the concrete. With the addition of the 2nd dose of superplasticizer, the problem of slump loss can be solved; however, other concrete properties can be affected. This paper investigated the times of setting and compressive strength of the slump recovery concrete by a type F naphthalene-based superplasticizer. The concrete mixtures tested in this paper were concrete containing fly ash in the range of 0%, 30%, and 50% of the total binder. The paste volume ratios of the tested concrete were 1.2 and 1.3, whereas the water to binder ratios were varied from 0.30 to 0.58, and the initial superplasticizer dosages (SP) were applied between 0.5 to 1.6%. The setting times were tested on the mixtures at the times before and after the redosing by varying the 2nd SP dosage and time for the dosing. The results indicated that both the times of the initial and final sets were delayed by the addition of the 2nd SP dose and delayed more with the increase of the 2nd dosage. The delay was more severe in fly ash concrete when compared to cement-only concrete and the larger the fly ash replacement percentage, the longer the setting times were. The setting times were prolonged to a maximum of about 4 hrs. in the case of 50% fly ash concrete with 2nd SP dosage of 1%, whereas they were 2 hrs. in the case of 30% fly ash concrete with the same 2nd SP dosage. It was found that the incorporation of fly ash yields insignificant differences between the compressive strength of fly concrete with and without SP redosing. On the other hand, the SP redosing caused slightly lower compressive strength of cement-only concrete.

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Keywords: Compressive strength; Fly ash concrete; Setting times; Slump recovery; Superplasticizer

1. Introduction

In practice, mixture proportions of concrete are designed according to slump and strength, so that the concrete is compatible with the method of construction, configuration of the structures, and load-resisting capacity of the structures. Fresh concrete has an undesirable property which is workability loss or usually known as slump loss [1], especially when working in a temperate area. Nowadays, global warming causes a hotter climate [2, 3] in many parts of the world, and this even worsens the slump loss problem. One of the easiest solutions to the slump loss problem is to retemper the concrete using water-reducing admixtures, generally superplasticizers. Workability, usually slump, of fresh concrete can be recovered by adding a 2nd dose of water reducer, and this process is typically applied in most construction sites [4]. However, even though the slump can be effectively recovered, there are doubts about how the other properties of the concrete, other than the workability, change with this 2nd dose of the water reducer. It was reported that the retempering causes some changes in the rheological and mechanical characteristics of the re-dosed concrete depending on the type and amount of the admixture [5].

There have been some research studies regarding the effect of superplasticizer redosing on concrete characteristics [6-8]. In Thailand, there is a lack of information on the influence of superplasticizer redosing on concrete properties. Therefore, it is necessary to explore the effects of the superplasticizer redosing on setting times and compressive strength for proper application in Thailand. The investigation on the effects of superplasticizer redosing on setting times will be useful as a guideline to estimate the workable time (open time) of the slump recovery concrete. The effect on strength is useful for estimating strength development, especially at an early age, which is useful for estimating formwork removal time or time to continue the next step of construction. It should be noted that slump recovery can be conducted before the setting of the concrete and redosing should not affect too much the strength of the slump recovery concrete.

Fly ash is an industrial by-product of coal-fired power plants and has been commonly used as a partial replacement for cement in the Thai concrete industry due to its benefits on workability, long-term compressive strength, and durability properties of concrete. Therefore, this study is aimed at emphasizing the influence of superplasticizer redosing on the fresh and hardened properties of fly ash concrete and comparing their resulting properties with that of ordinary Portland cement type I concrete.

2. Materials and Methods

2.1 Materials

Type 1 ordinary Portland cement complying with ASTM C150 [9] as well as TIS 15 [10] was utilized as the primary binder. Table 1 and Table 2 give the physical and chemical properties of cement.

Table 1. Physical properties of OPC type I cement and fly ash.

Properties	OPC type I	Fly ash
Specific gravity (-)	3.15	2.57
Blaine fineness (cm^2/g)	3054	2057

Fly ash conforming to class 2a in TIS 2135 [11] and class C in ASTM C618 [12], received from Mae Moh electrical plant in Lampang province, was utilized. Its physical and chemical properties are given in Tables 1-2.

Table 2. Chemical compositions of OPC type I cement and fly ash.

Chemical compositions (%)	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O	K_2O	SO_3	LOI
OPC type I	20.35	64.38	5.02	3.18	2.03	0.20	0.48	2.92	1.43
Fly ash	33.41	20.01	18.74	15.03	2.02	1.27	2.92	5.19	0.23

Natural river sand having a maximum size of 4.75 mm. was applied as the fine aggregate while limestone with a 25-mm maximum size was utilized as the coarse aggregate. Both aggregates conformed to ASTM C 33 [13].

The measured properties of the utilized sand and limestone are listed in Table 3.

A naphthalene-based superplasticizer (SP) corresponding to ASTM C494 [14] was used. The 1st dosage of the superplasticizer was different for different tested mixtures to control an initial slump at 10 cm. The re-dosed 2nd superplasticizer dosage was added to regain the slump of the mixtures to this initial slump. The naphthalene-based superplasticizer was used because it is widely applied in the Thai concrete industry.

Table 3. Properties of gravel and sand.

Properties	Gravel	Sand
Absorption (%)	0.70	1.06
Specific gravity (-)	2.71	2.60
Fineness modulus (-)	7.98	2.45

2.2 Paste volume ratio (γ)

The paste volume ratio is a parameter representing the paste content in the concrete and is defined as the ratio between the paste volume and the void volume in the well-compacted coarse-fine aggregate mixture. Fig. 1 demonstrates the void curve derived from void content measurement in the fine-coarse aggregate mixtures with varied sand-to-total aggregate ratios (s/a). The void contents were measured according to ASTM C29 [15]. It was found from the measurements that the lowest void content in the aggregate mixture was achieved at the s/a equal to 0.42.

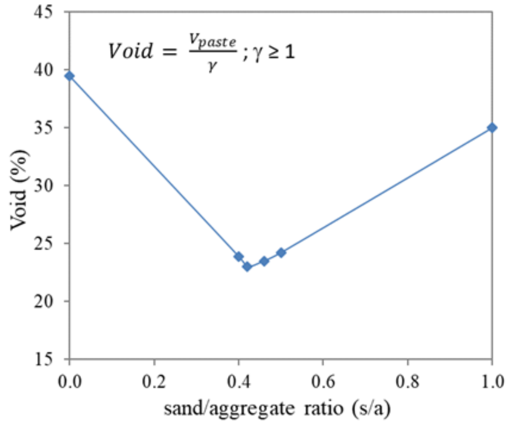

Fig. 1. Relationship between void contents in the aggregate mixtures and s/a.

2.3 Second superplasticizer dosage

Ready-mixed concrete is the concrete mixed at the batching plants and after that delivered to the construction sites. As mentioned, ready-mixed concrete applied in hot climates always faces the slump loss problem. The causes of the loss of slump can be separated into 2 main mechanisms: chemical and physical coagulations. Chemical coagulation is caused by the hydration of the components in the cement while physical coagulation is the result of contacts of the cementitious particles. Slump loss can also be caused by the loss of dispersive capability of the water reducers with the elapsed time [16]. When concrete loses too much slump, it may be rejected. Redosing superplasticizer is typically introduced as a solution to the problem. A study recommended that the adjustment of the slump by superplasticizer redosing should be done no later than 1.5 hours after mixing [17]. Fig. 2 demonstrates the concept of redosing of superplasticizer. In this study, superplasticizer redosing was performed at 30 min, 60 min, 90 min and 120 min after concrete mixing for restoring the concrete slump.

2.4 Tested mix proportions

The tested concrete mix proportions were prepared by varying water to binder ratio (w/b) between 0.30 with the target strength at 28 days of 28 MPa to 0.58 with the target strength at 28 days of 50 MPa, paste volume ratios (γ) of 1.2 and 1.3, and replacement percentage of fly ash of 0%, 30% (FA30), and 50% (FA50). The sand-to-total aggregate ratio (s/a) was maintained at 0.42 where the minimum void in the aggregate phase of 23% was obtained (see Fig. 1). The 2nd SP dosage (SP2) was varied for restoring the concrete slump.

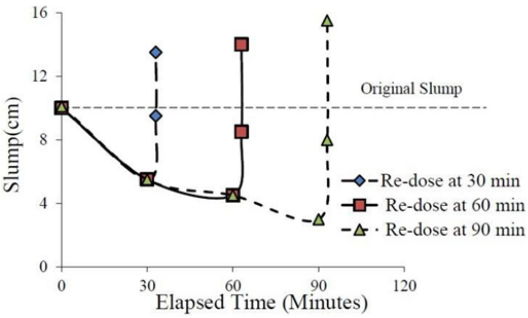

Fig. 2. Conceptual illustration for redosing.

2.5 Test of compressive strength

Compressive strength was tested using ø100×200 mm. cylindrical specimens [18]. The test ages were 1, 7, and 28 days. The demolding of the specimens was conducted 1 day after the casting. After demolding, they were water-cured at 28±2°C until reaching the intended test age.

2.6 Measurement of setting times

Times of initial and final settings were measured following ASTM C403 [19]. The times of the initial and final settings were measured on the mortars sieved from their original concrete after redosing of superplasticizer. The setting times were measured from the elapsed time between the time when mixing water was added to concrete mixtures during mixing and the times when the penetration resistance equals 500 psi (initial setting time) and 4000 psi (final setting time), respectively.

3. Results and Discussion

3.1 Times of setting and compressive strength (OPC Concrete)

The effects of redosing on setting times of high w/c concrete (w/c=0.58) and low w/c concrete (w/c=0.3 and 0.4) are illustrated in Figs. 3-4, respectively. As shown in Fig. 3, the setting times, both initial and final, of the high w/c concrete mixtures were prolonged along with the increases of the 2nd superplasticizer dosage. At the 2nd dosage of 0.8%, the setting times were about 30 min longer when compared to those of the mixture without redosing. Fig. 4 reveals the effect of the 2nd dosage on prolonging the setting times of the low w/c mixtures. It was found that the setting times were slightly delayed when the 2nd superplasticizer dosage increased up to 1.0%, while the setting times were significantly delayed when the 2nd dosage exceeded 1.0%. At the same 2nd dosage, the setting times were shorter when the w/c of the mixtures was lower.

The reason for the setting time prolonging when the mixtures are added with a 2nd dose of superplasticizer is the disturbance (re-dispersion) of the agglomerated cementitious particles, provided the repulsion from the 2nd dose of superplasticizer. In the concrete with high w/c (Fig. 3), the required 2nd dosage of superplasticizer for slump recovering was smaller than the low w/c concrete (Fig. 4). For mixtures with low w/c, the setting times drastically increase when the retempering dosage is higher than about 1.2%. The radical increase in the setting times is considered due to the too high 2nd dosage for slump recovery. This indicates that there should be a limit for redosing the slump-loss concrete so that the properties of the re-dosed concrete are not too much affected. It is anticipated that this limit depends on the initial dosage, and elapsed time after mixing, especially if the time is approaching the final setting time.

For the effects of redosing on the compressive strength of OPC concrete, Figs. 5-6 demonstrate that the compressive strength of the OPC concrete mixtures was insignificantly affected by the redosing of the superplasticizer. However, compressive strength tends to slightly decrease when the 2nd dosage of superplasticizer is increased. Similar to the behavior observed for the setting times, the strength under compression of the concrete with low w/c decreases relatively more significantly when the 2nd dosage of superplasticizer is over 1.2%, indicating also that there should be a limit for redosing the slump-loss concrete as described in the section of setting times.

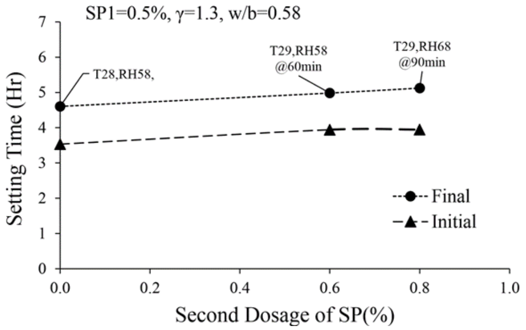

Fig. 3. Relationship between setting times and 2nd superplasticizer dosage (high w/c OPC concrete).

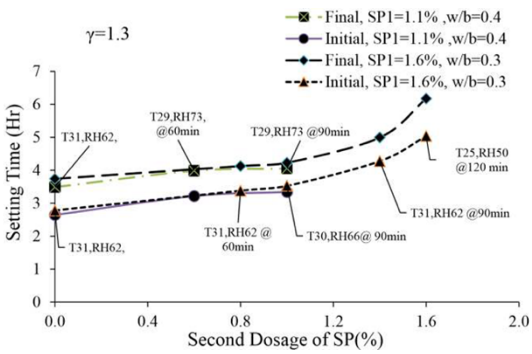

Fig. 4. Relationship between setting times and 2nd superplasticizer dosage (low w/c OPC concrete).

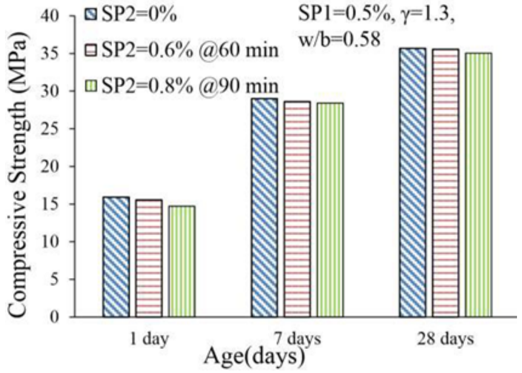

Fig. 5. Relationship between 2nd superplasticizer dosage and compressive strength of high w/c OPC concrete.

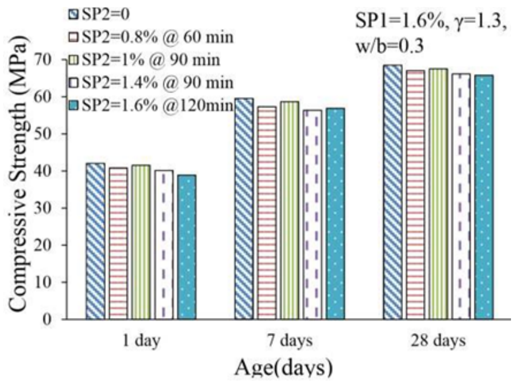

Fig. 6. Relationship between 2nd superplasticizer dosage and compressive strength of low w/c OPC concrete.

3.2 Times of setting and compressive strength (Concrete with Fly Ash)

The initial and final setting times of the tested OPC and concrete mixtures with fly ash, having a w/b of 0.58, before and after re-dosing with various 2nd dosages of superplasticizer, are shown in Fig. 7. From Fig. 7, fly ash concrete mixtures are more sensitive and affected by the redosing in terms of setting times. The setting times of the tested concrete mixtures with fly ash gradually increase until the 2nd dosage of about 0.3% but start to increase drastically at the 2nd dosage of about 0.4% while the setting times of the OPC concrete mixtures increase gradually up to the 2nd dosage of 0.8%. Fig. 8 compares the effects of the 2nd dosage on setting times of fly ash concrete mixtures with 2 different replacement percentages (30% and 50% fly ash). The fly ash concrete mixture with a larger fly ash percentage (50%) shows higher sensitivity to the 2nd dosage of superplasticizer as can be observed from the higher slope of the lines for the mixture with 50% fly ash relative to the slope of the lines of the mixture with 30% fly ash. Together with the results obtained in Fig. 7, it can be mentioned that a mixture with fly ash, especially with a higher fly ash percentage, has a higher sensitivity to the 2nd dosage of superplasticizer on prolonging the setting times.

The increase in setting times might be attributed to the effect of retardation of cement hydration due to adsorption of superplasticizer over the cement surface and the alteration of morphology and kinetics of the hydration products due to strong dispersion action of the superplasticizer [20]. In the case of concrete with higher fly ash content, there are fewer cement particles so the retardation of cement hydration is even more severe; therefore, the setting times are noticeably extended.

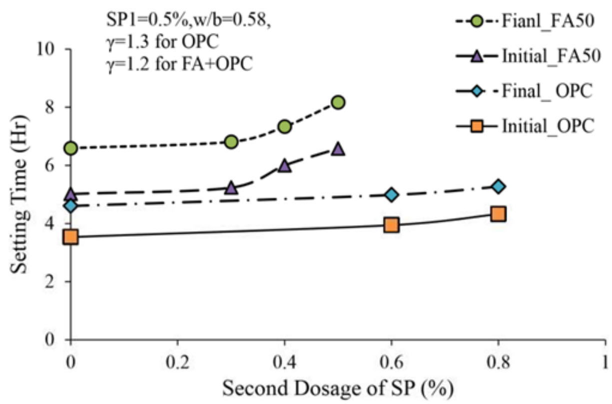

Fig. 7. Comparison between effects of 2nd superplasticizer dosage on setting times of OPC and fly ash concrete mixtures.

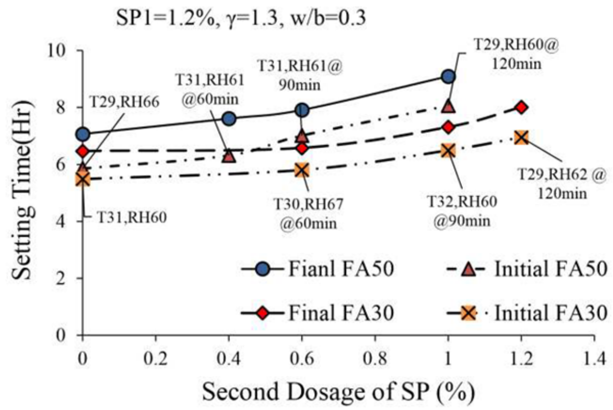

Fig. 8. Effects of 2nd dosage on setting times of fly ash concrete with different fly ash replacement percentages.

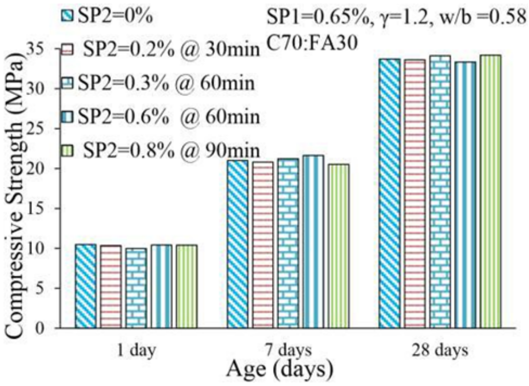

Fig. 9. Effect of 2nd superplasticizer dosage on compressive strength of high w/b concrete with 30% fly ash replacement.

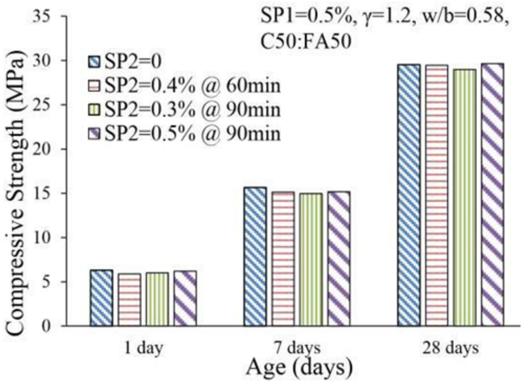

Fig. 10. Effect of 2nd superplasticizer dosage on compressive strength of high w/b concrete with 50% fly ash replacement.

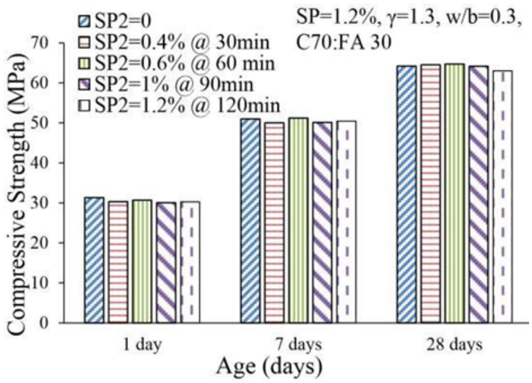

Fig. 11. Effect of 2nd superplasticizer dosage on compressive strength of low w/b concrete with 30% fly ash replacement.

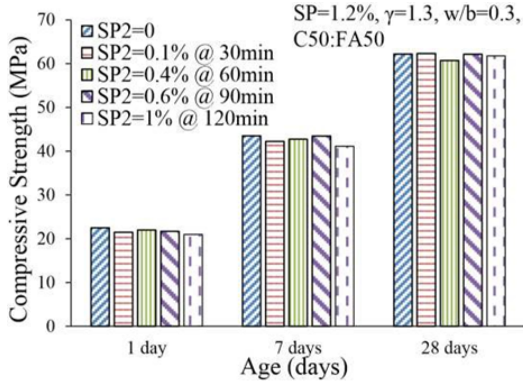

Fig. 12. Effect of 2nd superplasticizer dosage on compressive strength of low w/b concrete with 50% fly ash replacement.

The effects of the 2nd dosage of superplasticizer on the compressive strength of the re-dosed fly ash concrete mixtures are depicted in Figs. 9-12 for the tested concrete with high w/b (w/b = 0.58) containing 30% fly ash, concrete with high w/b (w/b = 0.3) containing 50% fly ash, concrete with low w/b (w/b= 0.3) containing 30% fly ash, and concrete with low w/b (w/b = 0.3) containing 50% fly ash, respectively. The 1st superplasticizer dosages to control the slump of the 4 mixtures were 0.65%, 0.58%, 1.2%, and 1.2%, respectively. Figs. 9-12 demonstrate that the effect of redosing on the compressive strength of the tested fly ash concrete mixtures is insignificant. When comparing the results in Figs. 9-12 with the results in Figs. 5-6, the effect of redosing on the compressive strength of concrete with fly ash is less significant when compared to that on OPC concrete, having an opposite trend to the setting times.

From all test results in this study, it can be said that though the setting times are slightly delayed by the addition of the 2nd dose of superplasticizer to restore the slump, the re-dosed concrete mixtures still perform satisfactorily in terms of strength performance. The results of this study can be used to ensure the merits of using the superplasticizer for slump restoration instead of using water which can endanger the quality of the restored concrete.

4. Conclusions

The following conclusions can be made according to this study's results.

1) For setting times of OPC concrete, the times of initial and final settings of the high w/c concrete mixtures were prolonged along with the increases of the 2nd dosage of the superplasticizer. The lower w/c concrete requires a larger 2nd dosage for slump recovery. At the same 2nd dosage, the setting times were shorter when the w/c of the mixtures was lower.

2) For setting times of concrete with fly ash, the initial and final setting times of the concrete are also longer with the larger 2nd dosage. Fly ash concrete mixtures are more sensitive and affected by the redosing in terms of setting times than OPC concrete. The fly ash concrete mixture with a larger fly ash percentage shows a higher sensitivity to the 2nd superplasticizer dosage. The extended setting times might be attributed to the effect of retardation of cement hydration.

3) For the compressive strength of the OPC concrete, the compressive strength was insignificantly affected by the redosing of the superplasticizer. However, compressive strength tends to slightly decrease when the 2nd dosage is increased. The compressive strength of the concrete having low w/c decreases relatively more significantly when the 2nd dosage of superplasticizer is over 1.2%.

4) For the compressive strength of the concrete with fly ash, the consequence of redosing on the compressive strength is insignificant. The effect of redosing is less significant relative to the OPC concrete, which is opposite to the trend of the setting times.

5) Although the setting times are slightly prolonged by the re-dosing, the re-dosed concrete mixtures perform satisfactorily in terms of strength performance. The results ensure the merits of using the superplasticizer for slump restoration instead of using water which can endanger the quality of the restored concrete.

Acknowledgements

The research funds from the Center of Excellence in Material Science, Construction and Maintenance Technology, Thammasat University (THAILAND), and the Chair Professor Program (P-19-52302), the National Science and Technology Development Agency (NSTDA), Thailand are acknowledged.

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