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Effect of Shrinkage-Reducing Admixture Type and Utilization Rate on Shrinkage Behavior and Compressive Strength of Mortar Mixtures

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Abstract

It is known that shrinkage behaviour is one of the most important parameters affecting the dimensional stability performance of cementitious systems. Nowadays, various methods are applied to prevent the shrinkage formation. It was found to be that the most common method is the addition of fiber and/or shrinkage-reducing admixtures (SRA) to the mixture. In this study, the effect of type and utilization rates of SRA on some fresh and hardened state properties of cementitious systems was investigated. For this purpose, a total of 10 mortar mixtures were prepared by adding hexylene glycol (HG)-, neopentyl glycol (NG)- and polypropylene glycol (PG)-based SRA to the control mixture at the ratios of 0.5%, 1% and 2% by weight of cement. CEM I 42.5R type cement and 0-4 mm crushed limestone aggregate were used. In all mixtures, the water/cement ratio and the slump value were kept constant as 0.38 and 220±20 mm, respectively. In order to provide the desired slump value, a polycarboxylate-ether based high-rate water reducing admixture (PCE) was used in different dosages. According to the results, irrespective of the SRA type, the flow performance and drying-shrinkage behavior of the mixtures were positively affected by the increment in the SRA utilization rate. In this context, while the mixture containing the NG showed the highest flowability performance, it was the weakest mixture in terms of drying-shrinkage behavior. It was understood that a similar shrinkage behavior was obtained in the mixtures containing the other two SRA types. Except for the mixture containing 0.5% PG, it was observed that the compressive strength value of the mixtures decreased with the presence of SRA in the systems. This behavior was more pronounced by increasing the SRA utilization rate. The mixture having PG exhibited the highest performance in terms of compressive strength among the mixtures containing SRA.

Key words

Compressive strength, dimensional stability, shrinkage-reducing admixture, slump value

1. INTRODUCTION

One of the various reasons affecting the durability performance of cementitious mixtures is the formation of cracks. It is known that one of the most important causes of crack formation is drying-shrinkage [1]. Drying-shrinkage occurs as a result of evaporation in an environment of insufficient humidity, under high temperature and wind conditions [2, 3]. Evaporation of free and adsorbed water in the concrete causes the formation of meniscus in the pores of the concrete [4, 5]. This meniscus, which is formed due to the surface tension of the water, tries to pull the pore walls inward and creates a shrinkage stress. In concretes with low tensile strength, shrinkage cracks occur due to these stresses [6]. Shrinkage cracks increase the permeability of cementitious mixtures and facilitate the entry of harmful substances. As a result, the durability performance of the mixtures decreases [1].

Shrinkage-reducing admixtures (SRA), pre-wetted lightweight aggregates, fibers and superabsorbent polymers are generally used to reduce drying-shrinkage [7]. The use of SRA is superior to the other methods due to its high shrinkage reduction and practicality. The effect of SRA on the drying-shrinkage behavior is attributed to the pore solution reducing the surface tension and increasing the internal relative humidity [8–10]. On the other hand, it was reported in previous studies that SRA prolongs the setting time and decreases the early age strength [11–13]. Mehdipour et al. [14] investigated the effect of using SRA on setting time, compressive strength and drying-shrinkage behavior of cementitious systems. According to the results, the use of SRA had a positive effect on the drying-shrinkage performance of the mixtures, however, it delayed the initial and final setting time and decreased the strength of the mixtures. Mardani et al. [15] investigated the effect of the use of SRA on the compressive strength and drying shrinkage behavior of mortar mixtures. They reported that the use of SRA decreased the early age compressive strength of mortar mixtures, however increased the 28-day compressive strength. On the other hand, it was observed that the SRA utilization has a positive effect on the drying-shrinkage performance of mortar mixtures.

In the literature, it was seen that glycol ether or polypropylene glycol-based admixtures are mostly used as SRA [16]. However, there is a few studies comparing the shrinkage and mechanical performance of different types of SRAs in the same cementitious system. In this study, the effect of using different types and ratios of SRA on some fresh and hardened state properties of cementitious systems was investigated. For this purpose, the effect of different types of SRAs at 0.5%, 1% and 2% ratios on the drying-shrinkage behavior and compressive strength of mortar mixtures were investigated.

2. MATERIALS AND METHODS

2.1. Material

In the scope of the study, CEM 42.5 R type cement was used as binder. The chemical composition, physical and mechanical properties of the cement are given in Table 1.

Table 1. Chemical composition, physical and mechanical properties of cement

Oxide	**(%)**	**Physical properties**		
SiO_2	19.30	Specific gravity		3.18
Al_2O_3	4.38	Blaine specific surface (cm^2/g)		4345
Fe_2O_3	3.74	**Mechanical properties**		
CaO	64.18	Compressive Strength (MPa)	1-day	23.80
MgO	1.68		2-day	33.60
SO_3	2.78		7-day	48.10
$Na_2O+0.658\ K_2O$	0.43			
Cl^-	0.01			
Insoluble residue	0.35			
Loss on ignition	2.86			
Free CaO	1.90			

Crushed limestone aggregate was utilized as an aggregate. The specific gravity and water absorption rate of the sand are 2.64 and 1.1%, respectively. Polycarboxylate-ether based high-rate water reducing admixture (PCE) was used to achieve the target slump values. Within the scope of the study, three different glycol-based SRAs were used: hexylene glycol (HG), neopentyl glycol (NG) and polypropylene glycol (PG). Some chemical properties of SRA and PCE used are shown in Table 2.

Table 2. Some chemical properties of the admixtures used

Admixture type	**Alkali content (%)**	**Density (g / cm^3)**	**Solid content (%)**	**Chloride content (%)**	**pH**
NG	<10	1.06	99.9	<0.1	6.1
HG	<10	0.92	99.9	<0.1	6.4
PG	<10	1.00	99.9	<0.1	6.0
PCE	<10	1.06	32.0	<0.1	4.0

2.2. Method

In all mixtures, the water/cement ratio and the slump value were kept constant as 0.38 and 220±20 mm, respectively. A total of 10 mortar mixtures were prepared, one of which was a control mixture without SRA, and the other mixtures containing 0.5%, 1%, and 2% of SRA by weight of cement. The denomination of the mixtures was made according to the type of SRA and the utilization rate. For example, the mixture containing 1% HG was named as HG1. The amount of material used in the production of 1 dm^3 mortar mixes is given in Table 3.

Table 3. Theoretical mixing ratio for 1 dm^3 mortar mixes

Mixture	Cement (gr)	Crushed limestone aggregate (gr)	Water (gr)	SRA (%) *
C	544.7	1601.7	207.0	0
NG05	544.7	1594.9	207.0	0.5
NG1	544.7	1588.2	207.0	1.0
NG2	544.7	1574.7	207.0	2.0
HG05	544.7	1593.9	207.0	0.5
HG1	544.7	1586.1	207.0	1.0
HG2	544.7	1570.4	207.0	2.0
PG05	544.7	1594.5	207.0	0.5
PG1	544.7	1587.3	207.0	1.0
PG2	544.7	1572.9	207.0	2.0

*By weight of cement

and ASTM C109 Standards, respectively. The drying-shrinkage behavior of mortar mixtures was investigated in accordance with ASTM C596 Standard. For the drying-shrinkage measurement, 4 specimens with dimension of 25x25x285 mm were prepared from each mixture. The specimens prepared to examine the drying-shrinkage behavior were stored in the mold at 20°C and 95% relative humidity for 24 hours. The specimens removed from the mold were cured in lime-saturated water at 20°C for 48 hours. Then they kept in the cabinet where the temperature and relative humidity were 20°C and 55%, respectively, until the test day. The length variation of the specimens was calculated using Equation 1.

$$S = \left(\frac{L1-L}{L0}\right) \times 100 \quad (1)$$

Here, S is the shrinkage percentage of the sample, L_1 is the initial measurement value after it is removed from the curing pool, L is the periodic measurement value according to the elapsed days, L_0 is the effective measurement length.

3. RESULT AND DISCUSSION

3.1. Slump-flow performance

The PCE requirement is given in Table 4 to achieve a target slump value of 220±20 mm in mortar mixes. Regardless of the SRA type and utilization rate, the PCE requirement for the target slump value of the mixtures decreased with the addition of SRA. This situation became more evident with the increase in the use of SRA, regardless of the SRA type.

Among the SRA types, the mixtures containing NG and PG exhibited the highest and lowest performance in terms of slump-flow performance, respectively. The positive effect of the use of SRA on the slump-flow performance of cementitious systems has also been observed in previous studies [17, 18].

Table 4. Slump-flow values and PCE requirements of mixtures

Mixture	Slump-flow (cm)	PCE (%)*
C	20.75	0.85
NG05	24.00	0.75
NG1	23.00	0.70
NG2	21.00	0.60
HG05	23.50	0.80
HG1	23.25	0.75
HG2	24.00	0.70
PG05	23.00	0.80
PG1	22.25	0.80
PG2	22.75	0.75

* By weight of cement

3.2. Drying-Shrinkage Behavior

The drying-shrinkage values of the mortar mixtures exposed to drying-shrinkage for 28 days are shown in Figure 1. In addition, the relative drying-shrinkage values of the mixtures containing SRA compared to the control mixture are shown in Figure 2. Regardless of the type of SRA and the rate of utilization, the drying-shrinkage behavior of the mixtures was positively affected by the utilization of SRA. In addition, the amount of shrinkage decreases with the increase in the utilization rate of SRA. In this context, the mixtures containing NG admixture exhibited the weakest performance in terms of drying-shrinkage behavior. It was found that the other two types of SRA performed similarly in terms of shrinkage behavior.

Collepardi et al. [18] stated that the utilization of SRA increased the shrinkage performance in cementitious systems due to two effects. First, the tensile stresses arising from the meniscus formed by the surface tension of the water were reduced by the utilization of SRA. Second, due to the fact that SRA increased the viscosity of the pore solution and reduced moisture diffusion.

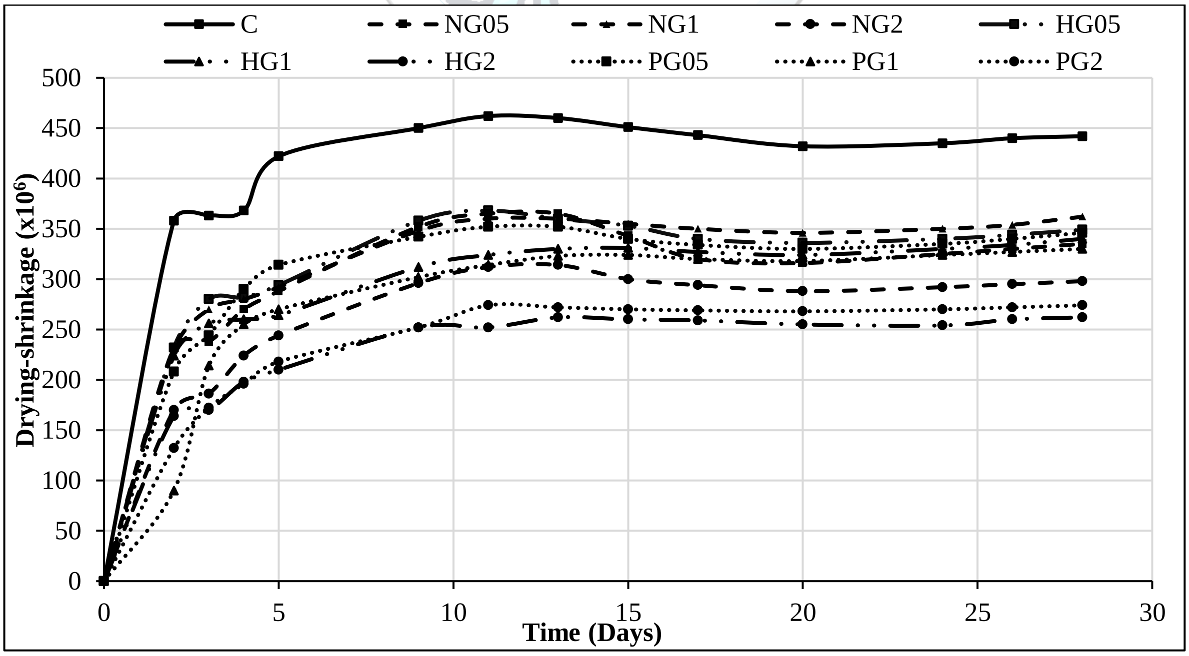

Figure 1. 28-day shrinkage behavior of mixtures

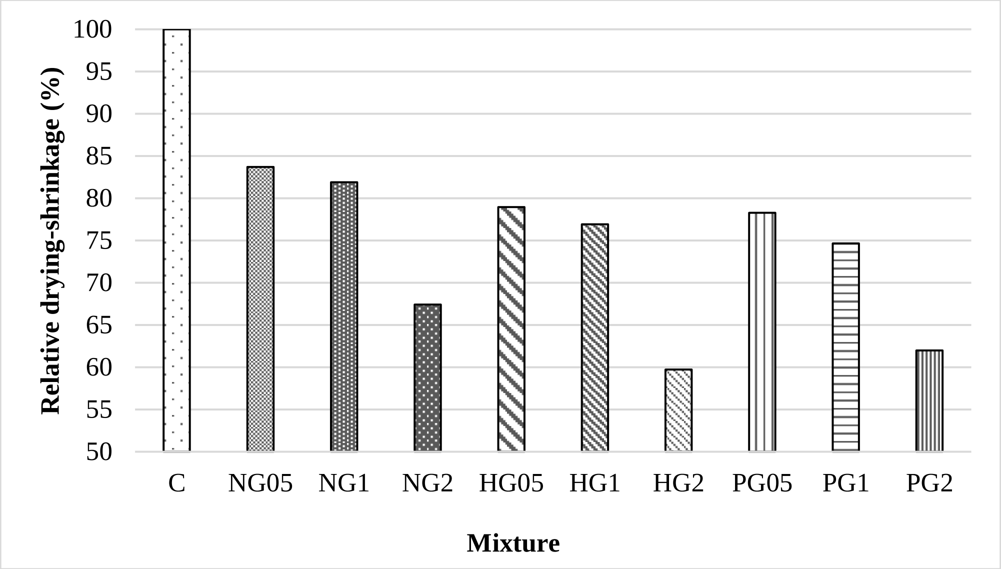

Figure 2. Relative drying-shrinkage rates of mortar mixes

3.3. Compressive Strength

The 7- and 28-day compressive strengths of the mixtures are shown in Table 5. Regardless of the SRA type and utilization rate, 7- and 28-day compressive strengths of the mixtures were lower compared to the control mixture with the utilization of SRA. When the 7-day compressive strength results were examined, the mixtures containing PG, HG, and NG were decreased by approximately 7%, 12%, and 14%, respectively, compared to the control mixture. In the 28-day compressive strength results, PG, HG, and NG exhibited 5%, 11% and 4% lower compressive strength performance compared to the control mixture. As can be seen from the results, the negative effect on the compressive strength of SRA decreased with the increase of curing time. There were also studies in the literature in which SRA negatively affects the early age compressive strength performance in cementitious systems [14]. In the mentioned studies, it was stated that the negative effect of SRA on the early age compressive strength was due to the prolongation of the setting time by decreasing the alkalinity of the pore solution. Within the scope of the study, it was thought that the negative effect of the utilization of SRA on the 7-day compressive strength performance is due to the delay in setting time as stated in the literature.

Table 5. Compressive strength results of mixtures

Mixtures	**Compressive Strength (MPa)**		**Relative Compressive Strength (%)**	
	7-d	**28-d**	**7-d**	**28-d**
C	87.3	97.7	100.0	100.0
NG05	78.2	93.7	89.6	95.9
NG1	77.6	96.3	88.9	98.6
NG2	72.1	90.8	82.6	92.9
HG05	82.4	87.4	94.4	89.5
HG1	76.8	86.4	88.0	88.5
HG2	72.5	89.1	83.0	91.2
PG05	86.1	94.6	98.6	96.8
PG1	82.3	90.8	94.3	92.9
PG2	76.6	94.4	87.7	96.7

4. CONCLUSION

In the study, the effect of using different types and ratios of SRA on the slump-flow performance, drying-shrinkage behavior and compressive strength of cementitious mixtures were investigated. The results are given below:

- Regardless of the SRA type and utilization rate, the PCE requirement and drying-shrinkage behavior for the target slump value were positively affected, while the 7 and 28-day compressive strength was negatively affected by the SRA utilization.
- Slump-flow performance and drying-shrinkage behavior of the mixtures were positively affected by the increase in the SRA utilization rate.
- The negative effect of SRA on compressive strength decreased with the increase of curing time.
- HG and PG admixtures showed similar performance in terms of drying-shrinkage behavior, while NG admixture showed the lowest performance in terms of drying-shrinkage behavior.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

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