Effects of Chemical Admixtures and Curing Conditions on some Properties of Alkali-Activated Cementless Slag Mixtures

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Abstract

This paper reports the results of an investigation on the influences of admixtures and curing conditions on some properties of Alkali-Activated Slag (AAS) mixtures with no cement. In the study, Shrinkage-Reducing (SRA) and superplasticizing and set-retarding (WRRe) admixtures were used. For the slag activation, sodium metasilicate was used at two sodium concentrations, 4% and 6% by mass of slag. Setting time, flow loss of fresh mixtures, and shrinkage strain, carbonation, flexural and compressive strength of hardened mixtures were measured. The test results showed that the admixtures generally had no impact on the setting times of AAS pastes. WRRe increased the flow rate of AAS mortars while SRA partially affected the flow values of AAS mortars. WRRe and SRA did not produce an important difference on the carbonation depths of AAS mortars. However, WRRe and especially SRA admixtures decreased the shrinkage values of AAS mortars. Additionally, curing conditions had a significant effect on the mechanical behavior in the hardened state of AAS mortars compared to Normal Portland Cement (NPC) mortars, and the strength development of AAS mortars at early ages was very fast in comparison with NPC mortars when subjected to elevated temperature.

Keywords: _alkali-activated slag, chemical admixtures, curing, setting time, shrinkage_

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1. Introduction

It is widely known that the production of Portland cement consumes sizable energy and emits a large volume of CO_2 to the atmosphere. Therefore, industrial by-products have an important place in today's concrete technology owing to their positive effects on the durability and strength of concrete besides the lower production costs and greenhouse gas emissions. One of these mineral admixtures utilized as an ingredient in cement or concrete manufacturing is Ground Granulated Blast Furnace Slag (GGBS) emerging in the course of the production of pig iron. Due to its high content of silica and alumina in an amorphous state, GGBS shows pozzolanic and binding properties in an alkaline medium (Erdoğan, 2003). The usage of GGBS in concrete has some benefits such as improving the workability and strength in addition to reducing the hydration heat, permeability and porosity of concrete (Aydın, 2008). GGBS has latent hydraulic properties and it can react directly with water, but requires an activator. In concrete, this is the $Ca(OH)_2$ released from the hydration of Portland cement. However, this situation causes the blended cements to develop strength more slowly at early ages compared to NPC. So, the well-known method to activate the hydraulic properties of slag is the chemical activation

of slag by alkalis such as sodium hydroxide, silicate or carbonate (Wang, 2000).

AAS binders, based on 100% GGBS plus activator, have recently attracted much attention from the academic area and many research findings about these materials have been published to produce cementless mortar or concrete. Several studies indicate that AAS mortar and concretes exhibit some superior properties such as high mechanical strength and excellent durability in aggressive environments like chemical attack, freeze-thaw cycles and high temperatures (Jimenez _et al._, 1999; Puertas _et al._, 2002; Bakharev _et al._, 2003; Douglas _et al._, 1992). Also, earlier investigations on AAS have shown that the strength of these binders is dependent on the concentration and type of alkaline activator, and that sodium silicate (water glass) is the best activator in terms of the strength development performance (Jimenez _et al._, 1999; Caijun, 1999; Bakharev _et al._, 1999a). However, it has been revealed by the previous researches that slag mortars and concretes activated by water glass exhibit considerable drying shrinkage and workability loss against elapsed time (Douglas _et al._, 1992; Bakharev _et al._, 1999a; Collins and Sanjayan, 1999a; Collins and Sanjayan, 1999b; Atiş _et al._, 2009). Additionally, it has been reported by Collins and Sanjayan (2000) that microcracks in these materials increase

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under the inadequate curing conditions.

Since AAS binders can offer a possible solution to deal with industrial by-products such as GGBS, these problems mentioned above need to be solved in order to expand the use of AAS binders as construction materials in commercial practice. On the other hand, organic admixtures, which are developed to be used in NPC mortars or concretes, have been extensively investigated in the literature until now. But their effects on other binders such as AAS binders have received less attention and a few researches on AAS binders containing various chemical admixtures have been published (Bakharev *et al.*, 2000; Puertas *et al.*, 2003; Wang *et al.*, 1994). Additionally, since heat treatment provides a significant improvement in volume stability, it can be expected that the curing treatment at elevated temperatures as well as the use of chemical admixtures will have a benefit for the solution of these problems observed in AAS binders. Accordingly, the aim of this study is to determine how curing temperatures and chemical admixtures influence AAS binders. Furthermore, this paper is a part of research work carried out as a contribution to the current state of knowledge on AAS binders, because the enhancement of the use of AAS mortars and concretes in construction industry, which enables the use of large quantities of by products, is dependent on technical information to be obtained from the researches.

2. Experimental Study

2.1 Materials

The cement used in this study was CEM I 42.5 R conforming to TS EN 197-1 (2012). Chemical composition and physical properties of cement and GGBS obtained from OYAK Adana cement factory are given in Table 1. The particle size distributions of these materials, which were obtained using a laser scattering technique, are presented in Fig. 1. CEN standard sand complying with TS EN 196-1 (2009) and municipal water were used for the preparation of mortar mixtures. While Bilim *et al.* (2013) utilized liquid sodium silicate activator for the slag activation in previous investigation, GGBS was activated by sodium metasilicate with the dry powdered form in this study. SRA based on polypropylenglycol
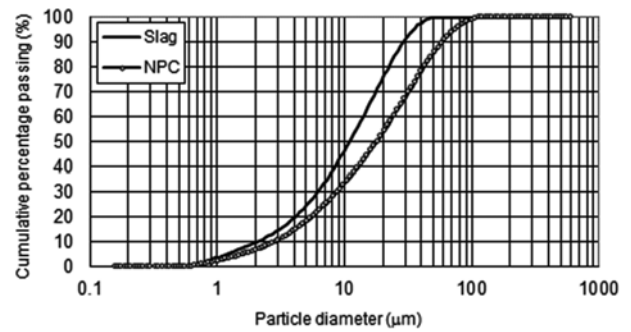

Fig. 1. Particle Size Distributions of Cement and Slag

and WRRe based on modified polymer liquid were used as chemical admixtures. One percent of each admixture by mass of binder was added to the activator solution.

2.2 Experimental Program

Water/Binder (W/B) ratio of 0.5 was used to prepare paste and mortar specimens throughout the experimental program. In the case of mortars, the sand to cementitious binder ratio was 3:1. Sodium concentrations in the mixture proportions containing sodium metasilicate were chosen as 4% and 6% by mass of slag. A summary of the experimental program is presented in Table 2.

According to TS EN 196-3 (2002), automatic Vicat machine was used to measure the initial and final setting times of AAS and NPC pastes.

Flow table tests complying with TS EN 1015-3 (2000) were carried out to determine mortar flowability, with and without admixtures, after 0, 15, 30, 45 and 60 min (end of mixing). For each mortar mixture, the diameter was measured in four directions following the flow of mortar onto the table of test apparatus. The results were expressed by taking the average of three specimens.

Prismatic specimens with $40 \times 40 \times 160$ mm dimensions and shrinkage specimens measuring $25 \times 25 \times 285$ mm were prepared from both fresh NPC and AAS mortar mixtures for the tests. After 24 h, the specimens were demoulded and cured in three

Table 1. Physical, Chemical and Mechanical Properties of Cement and Slag

Chemical Composition (%)	Cement	Slag	Physical properties of Portland cement		Physical properties of slag	
SiO_2	18.69	33.78	Specific gravity	3.12	Specific gravity	2.78
Al_2O_3	5.61	9.55	Initial setting time (min)	190	Specific surface (Blaine) (cm^2/g)	5200
Fe_2O_3	2.52	0.88	Final setting time (min)	225	Pozzolanic activity index (%) of slag	
CaO	62.68	39.80	Soundness (mm)	1.0	7 days	62
MgO	2.63	6.80	Specific surface (Blaine) (cm^2/g)	3200	28 days	94
Na_2O	0.13	0.32	Compressive strength (MPa) of cement			
K_2O	0.77	0.88	2 days	27.2		
SO_3	2.73	1.66	7 days	41.0		
Cl⁻	0.01	0.03	28 days	51.2		
LOI	2.88	2.89				
Insoluble residue	0.96	-				
Free CaO	0.93	-				

Table 2. Summary of Experimental Program

Mix no.	Binder	Activator	Concentration	Admixture
1	NPC (control)	-	-	-
2	AAS	Sodium metasilicate	4% Na (5.4% Na_2O)	-
3	AAS	Sodium metasilicate	6% Na (8.1% Na_2O)	-
4	NPC	-	-	WRRe
5	AAS	Sodium metasilicate	4% Na (5.4% Na_2O)	WRRe
6	AAS	Sodium metasilicate	6% Na (8.1% Na_2O)	WRRe
7	NPC	-	-	SRA
8	AAS	Sodium metasilicate	4% Na (5.4% Na_2O)	SRA
9	AAS	Sodium metasilicate	6% Na (8.1% Na_2O)	SRA

ways until the time of testing; One group of specimens were placed in a humidity cabinet at $23 \pm 2°C$ and 95% relative humidity (Cure 1) while second group of specimens were cured in a humidity cabinet at $23 \pm 2°C$ and 50% relative humidity (Cure 2). In the third method, the specimens were immersed in water and the heater was turned on. The water temperature reached at 65°C in 2 h and the water temperature was maintained at 65°C for 5 h. Subsequently, the heater was turned off and, after the cooling periods of the specimens, they were placed in a humidity cabinet at $23 \pm 2°C$ and 50% relative humidity (Cure 3).

The strength tests of the specimens were conducted at 2, 7 and 28 days of age according to TS EN 1015-11 (2000). The compressive strength test was performed on six broken pieces left from flexural strength test. The flexural strength was determined by taking the average of three test results while the compressive strength was determined by taking the average of six test results.

A phenolphthalein method was used to monitor the pH of mortar specimens in the carbonation experiments, and the tests were conducted at 2, 7 and 28 days of age. At the time of measurement, a 1% phenolphthalein solution in alcohol was sprayed on a broken surface of the mortar prism after flexural strength test, and the depth of neutralization was measured. The values were expressed by taking the average of three specimens.

For shrinkage measurements, two prismatic specimens with 25 × 25 × 285 mm dimensions were prepared from both fresh NPC and AAS mortar mixtures and demoulded the day after. The initial lengths of the shrinkage specimens were measured before they were subjected to three different curing environments. The shrinkage values of mortars were measured until 180 days according to ASTM C596 (2005) and the results were given by taking the average of two specimens for each mixture.

3. Results and Discussion

3.1 Flow Tests

The flow values of mortar mixtures are presented in Fig. 2.

As seen in Fig. 2, the flow values of mortars decreased in time due to some reasons such as the evaporation of mixing water and the setting of binder paste depending on the environmental conditions. It was also observed that the workability of AAS
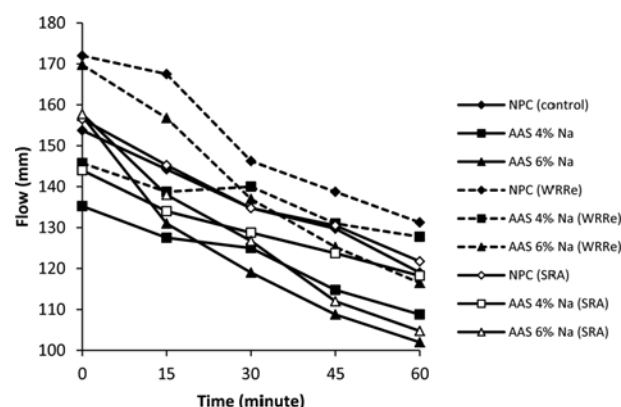

Fig. 2. Flow Values of AAS and NPC Mortars (mm)

binders was sensitive to the alterations in Na concentration as reported by other researchers (Collins and Sanjayan, 1999b; Douglas *et al.*, 1991). Accordingly, even though an increase in the Na dosage increased the flow values in the first quarter for the slag mortars, the fluidity after 15 min. was badly affected by the dosage increment due to quick reaction and hardening of AAS (Bakharev *et al.*, 1999a).

The results showed that the flow values obtained from AAS mortars with or without admixture were lower than those of NPC control mortar. However, WRRe admixture increased the flow rate of AAS mortars, showing a positive effect on mortar workability when compared to the slag mortars with no admixtures. Also, SRA admixture slightly improved the workability of AAS mortars. On the other hand, except for SRA, WRRe addition into the mixture enhanced the flow values of NPC mortar as expected.

3.2 Tests on Setting Times

Table 3 shows the initial and final setting times obtained from Vicat measurements on AAS and NPC pastes.

As seen in Table 3, SRA and especially WRRe admixture lengthened the setting times of pastes containing NPC. However, these chemical admixtures were not effective enough on AAS pastes although the influence of WRRe admixture was more than that of SRA in terms of increasing the setting times of AAS

Table 3. The Initial and Final Setting Times obtained from AAS and NPC Pastes

Mix no.	Binder	Admixture	Initial setting time (min)	Final setting time (min)
1	NPC (control)	-	390	475
2	AAS, 4% Na	-	125	263
3	AAS, 6% Na	-	101	157
4	NPC	WRRe	845	1150
5	AAS, 4% Na	WRRe	250	450
6	AAS, 6% Na	WRRe	126	220
7	NPC	SRA	468	588
8	AAS, 4% Na	SRA	155	275
9	AAS, 6% Na	SRA	98	161

pastes. Additionally, the activator dosage increasing from 4% to 6% reduced the initial and final setting times of AAS pastes since an increase in the sodium concentration accelerated the activation of slag. Accordingly, these admixtures lost their efficiency when high dosages of Na was used. For example, the initial and final setting times of AAS paste with 6% Na, in the absence of admixtures, were measured as 101 and 157 min, respectively. But 1% SRA addition into the mixture had no impact on the setting times of AAS paste with 6% Na, and the initial and final setting times for this paste became 98 and 161 min. This situation may be resulting from the modifications that high alkaline media induced in the chemical structures of the admixtures used (Palacios and Puertas, 2005). Consequently, the setting times of AAS pastes were much shorter than those of NPC control paste. These results agree with those reported elsewhere (Jimenez *et al.*, 1999; Atiş *et al.*, 2009; Caijun and Yinyu, 1989; Wang *et al.*, 1995).

3.3 Compressive Strengths

The compressive strength values measured at the age of 2, 7 and 28 days of AAS and NPC mortars are presented in Fig. 3, Fig. 4 and Fig. 5 for three different curing conditions, respectively.

The results indicated that the compressive strengths of AAS mortars increased with an increase in the Na dosage of activator. This finding is valid for each curing age and curing regimes. For example, as seen in Fig. 3, the compressive strength at the age of 28 days of AAS mortar with 4% Na subjected to $23 \pm 2°C$ and 50% relative humidity was 24.88 MPa, while the compressive strength at the age of 28 days of AAS mortar with 6% Na under the same curing conditions was 37.38 MPa. This is attributed to the chemical reaction that takes place between slag and activator. The strength development of AAS binders is greatly influenced by the synthesis of the anions of GGBS and the cations of the alkaline activators. The chemical reaction occurring by ion exchange between the silicate anions of slag and cations of alkaline activators leads to the formation of silica gel. This silica gel may turn into silica-rich calcium silicate hydrates gel (C-S-H) by further reacting with calcium ion of GGBS (Yang *et al.*,
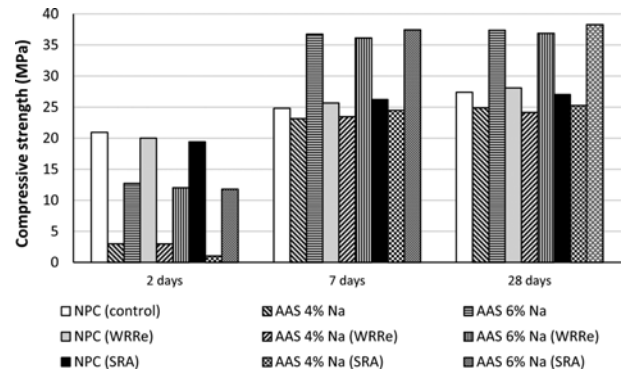

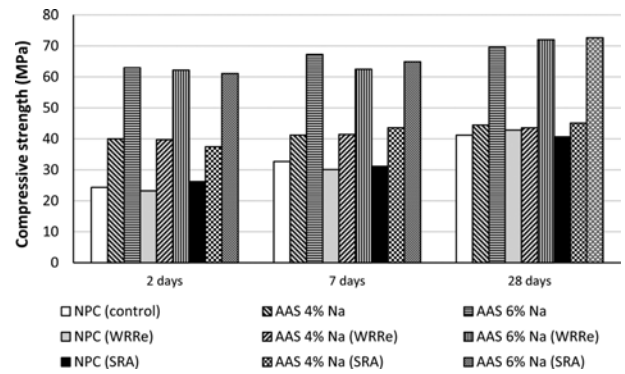Fig. 3. Compressive Strengths of AAS and NPC Mortars Exposed to Dry Curing (MPa)

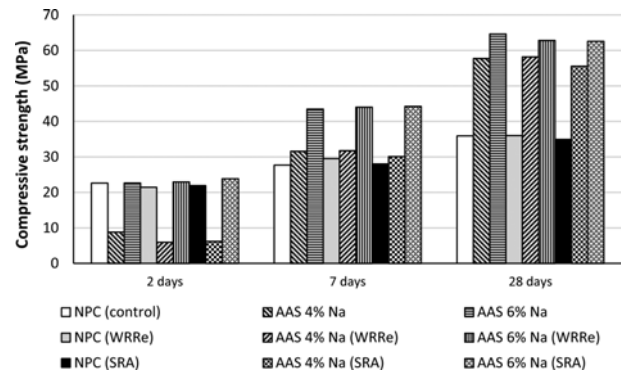Fig. 4. Compressive Strengths of AAS and NPC Mortars Exposed to Heat Curing (MPa)

Fig. 5. Compressive Strengths of AAS and NPC Mortars Exposed to Moist Curing (MPa)

2008).

As seen in all figures, WRRe and SRA chemical admixtures did not produce a remarkable difference in the compressive strength of NPC mortars. Similarly, WRRe and SRA did not show any negative effect on the compressive strengths of AAS mortars.

The results showed that the curing conditions were very important in terms of the strength development of AAS mortars. In comparison with other curing conditions given in Fig. 4 and Fig. 5, when subjected to $23 \pm 2°C$ and 50% relative humidity, all mixtures with and without chemical admixtures exhibited the

lowest compressive strengths as shown in Fig. 3, and these mixtures did not show a sufficient strength development after the age of 7 days. For instance, the compressive strength at the age of 7 days of AAS mortar containing 4% Na and 1% WRRe exposed to dry curing was 23.46 MPa whereas the compressive strength value at 28 days for the same mortar was 24.15 MPa. This situation arises from the loss of water in mixture depending on dry curing conditions (Neville, 1981). Additionally, under dry curing conditions, the Na dosage of 4% could not provide a sufficient activation for GGBS mortars with and without chemical admixtures. This is attributed to presence of water that provides ion exchange between materials. Since dry curing causes quick drying of sample, absence of water stops ion exchange. Accordingly, the strengths of AAS mortars with 4% Na was lower than the values obtained from NPC mortars at all ages of curing. But, under the same dry curing conditions, the Na dosage increasing from 4% to 6% became effective in terms of the reach to the higher compressive strengths than those of NPC mortars as of the seventh day. On the other hand, the curing treatment performed at 65°C in water for 5 h significantly increased the strength values at the early ages of AAS mortars by accelerating the activation of slag. Accordingly, the highest compressive strengths at 2 and 7 days were obtained from AAS mortars subjected to heat curing as seen in Fig. 4. Also, it was observed that when cured at high temperatures, the strength development at the early stage of AAS mortars was much faster than that of NPC mortars. These results conform to those of another study (Bakharev *et al.*, 1999b). However, after the hot curing, since the specimens were kept under dry curing conditions at $23 \pm 2°C$ and 50% relative humidity, this situation badly influenced the strength development at later ages. Thus, the maximum strength development after 7 days were obtained from AAS mortars continuously exposed to $23 \pm 2°C$ and 95% relative humidity as seen from Fig. 5. These findings are in accordance with those of other researchers (Collins and Sanjayan, 1999a; Collins and Sanjayan, 2001; Kutti *et al.*, 1992; Chi, 2012) reporting that the strength development of AAS binder was susceptible to the type of curing environment.

3.4 Flexural Strengths

The flexural strengths at the age of 2, 7 and 28 days of AAS and NPC mortars are presented in Fig. 6, Fig. 7 and Fig. 8 for three different curing conditions, respectively.

As seen in all figures, when compared to the mortars without admixture, SRA or WRRe addition into the mixture did not produce a negative effect on the flexural strengths of AAS and NPC mortars.

On the other hand, the lowest flexural strength values at 2, 7 and 28 days were obtained from AAS mortars subjected to $23 \pm 2°C$ and 50% relative humidity as seen from Fig. 6. It was also observed that the flexural strengths of AAS mortars were affected from the dry curing conditions more than the compressive strength values, and that the flexural strengths of AAS mortars containing the high Na concentration decreased with time.
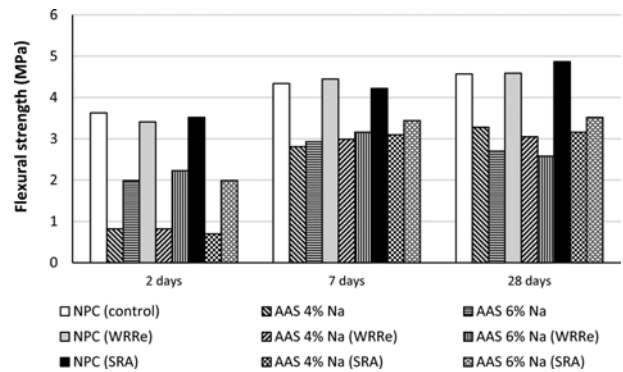

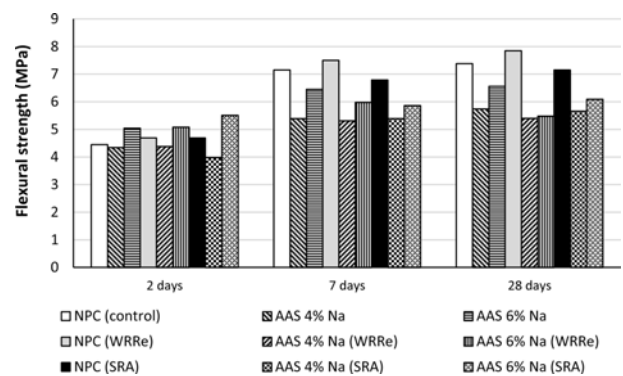Fig. 6. Flexural Strengths of AAS and NPC Mortars Exposed to Dry Curing (MPa)

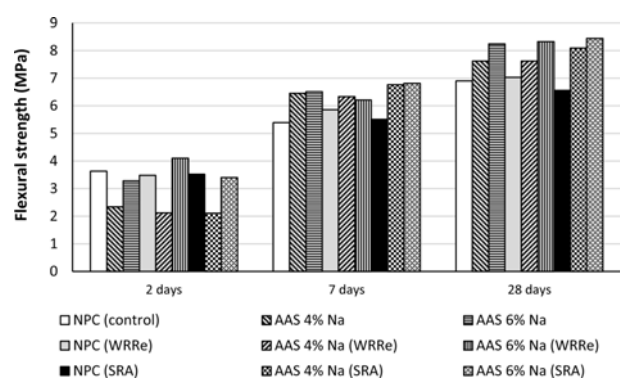Fig. 7. Flexural Strengths of AAS and NPC Mortars Exposed to Heat Curing (MPa)

Fig. 8. Flexural Strengths of AAS and NPC Mortars Exposed to Moist Curing (MPa)

Namely, for the mixtures without admixtures, the flexural strength values at the age of 2, 7 and 28 days of AAS mortar with 6% Na cured at $23 \pm 2°C$ and 50% relative humidity were 1.99 MPa, 2.93 MPa and 2.70 MPa respectively. The possible reason for such behavior is the expansion of cracks (Collins and Sanjayan, 2000; Collins and Sanjayan, 2001). As well as the dry curing conditions, the micro-cracks which are developed due to the higher magnitude of shrinkage cause a decrease in the flexural strength by reducing a valid area of cross-sections. Furthermore, since the heat treatment in water at 65°C for 5 h

increased the flexural strengths at early ages for AAS mortars, the highest flexural strengths at 2 days were obtained from AAS mortars subjected to heat curing (see Fig. 7). However, after the hot curing, since the samples were exposed to 23 ± 2 °C and 50% relative humidity, this situation negatively affected the flexural strengths at later stages. Accordingly, the highest flexural strengths at 7 and 28 days were obtained from AAS mortars subjected to 23 ± 2 °C and 95% relative humidity as seen from Fig. 8.

For AAS, the fast early strength development of heat-treated AAS mortar and its later slow strength gain are similar to results reported elsewhere (Bakharev *et al.*, 1999b). The rapid improvement in early term strength values by way of heat treatment could be attributed to the formation of a finer pore size distribution, denser and compact structure of matrix, increase of hydrated parts of slag grains, and stronger aggregate-matrix interface, since AAS mortar had a well-packed structure when cured under heat treatment compared to standard curing conditions (Aydın and Baradan, 2012). Similar to NPC, the later slow strength development of heat-cured AAS mortar could be correlated with an inhomogeneity of microstructure leading to coarse pore structure (Verbeck and Helmuth, 1968).

3.5 Carbonation

Carbonation is a very important durability problem for the concrete structures because it leads to a decrease in the alkalinity of the concrete, which makes the steel reinforcement more unprotected against corrosion.

The carbonation depths of AAS and NPC mortars measured throughout 28 days are given in Table 4.

As seen in Table 4, any carbonation was not determined in the mortars at age of 2 days. Also, AAS mortars exposed to 23 ± 2 °C and 95% relative humidity showed no carbonation throughout 28 days since the pores largely filled with water made the CO_2 penetration into the mortar difficult. However, carbonation was observed in the mortars after at the age of 7 days because the CO_2 ingress became easier owing to relative humidity decreasing from 95% to 50%. Accordingly, the highest carbonation values

during the tests of 28 days were obtained from AAS mortars exposed to 23 ± 2 °C and 50% relative humidity. In addition to this, since the heat treatment improved the resistance of AAS mortars to carbonation, the carbonation depths of AAS mortars exposed to 65 °C temperature in water for 5 h were lower than those of AAS mortars exposed to the dry curing conditions with 50% relative humidity. This result shows the useful effect of heat curing in decreasing the drying shrinkage (Aydın and Baradan, 2012). As carbonation in AAS progresses mainly along shrinkage cracks at the surface (Bakharev *et al.*, 2001), heat curing reduces these cracks, thereby causing the lower CO_2 ingress. Furthermore, it was shown that WRRe and SRA did not produce a meaningful difference on the carbonation resistance of NPC and AAS mortars during 28 days for both curing conditions.

On the other hand, the results indicated that an increase in the Na concentration of activator produced a decrease in the carbonation depths of AAS mortars. This behavior may be relevant to the denser paste structure occurring as a result of the acceleration in the slag activation due to the increment in the Na concentration. Addition to this, the carbonation depths of NPC control mortars were lower than those of AAS mortars throughout the carbonation measurements. These findings also are in agreement with other researches (Bakharev *et al.*, 2001; Bernal *et al.*, 2011; Puertas *et al.*, 2006; Bilim and Atiş, 2012) reporting that AAS binders have the higher susceptibility to carbonation in comparison to conventional cements.

3.6 Shrinkage

The shrinkage values of NPC and AAS mortars are presented in Fig. 9, Fig. 10 and Fig. 11 for three different curing conditions, respectively.

As seen in all figures, an increase in the Na concentration of sodium metasilicate activator increased the shrinkage of AAS mortars. Also, it was observed that the chemical admixtures had an important effect on the volume stability of AAS mortars. Compared to AAS mortars without admixtures, 1% WRRe addition somewhat decreased the shrinkage of AAS mortars. This result conforms to that of another study (Bakharev *et al.*, 2000). But the use of this admixture did not have a significant

Table 4. The Carbonation Depths of AAS and NPC Mortars (mm)

| Mix no.	Binder	Admixture	2-days			7-days			28-days		
			Cure1	Cure2	Cure3	Cure1	Cure2	Cure3	Cure1	Cure2	Cure3
1	NPC (control)	-	0	0	0	0	2.07	1.06	0	5.19	2.10
2	AAS, 4% Na	-	0	0	0	0	2.70	2.36	0	7.36	4.36
3	AAS, 6% Na	-	0	0	0	0	2.18	1.30	0	6.20	2.18
4	NPC	WRRe	0	0	0	0	2.22	0.85	0	5.40	1.94
5	AAS, 4% Na	WRRe	0	0	0	0	2.62	2.51	0	6.95	4.95
6	AAS, 6% Na	WRRe	0	0	0	0	2.21	1.42	0	6.08	2.61
7	NPC	SRA	0	0	0	0	2.32	1.39	0	5.01	2.36
8	AAS, 4% Na	SRA	0	0	0	0	2.57	2.48	0	6.94	4.88
9	AAS, 6% Na	SRA	0	0	0	0	2.05	1.14	0	5.91	2.20
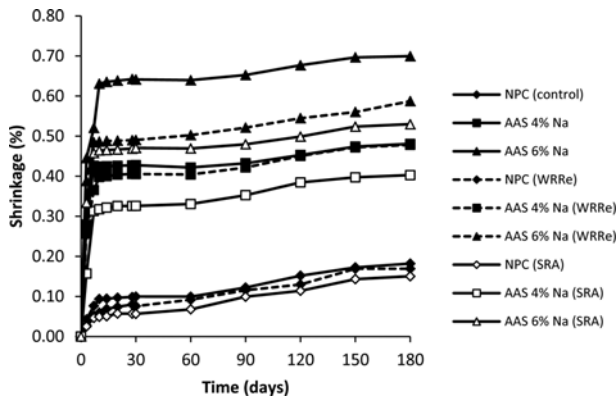
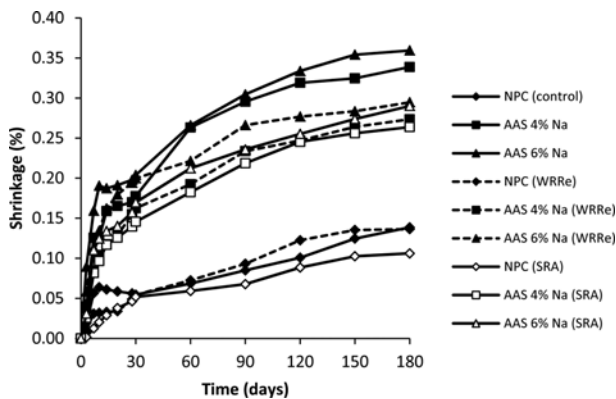Fig. 9. Shrinkage of AAS and NPC Mortars Exposed to Dry Curing (%)

Fig. 10. Shrinkage of AAS and NPC Mortars Exposed to Heat Curing (%)
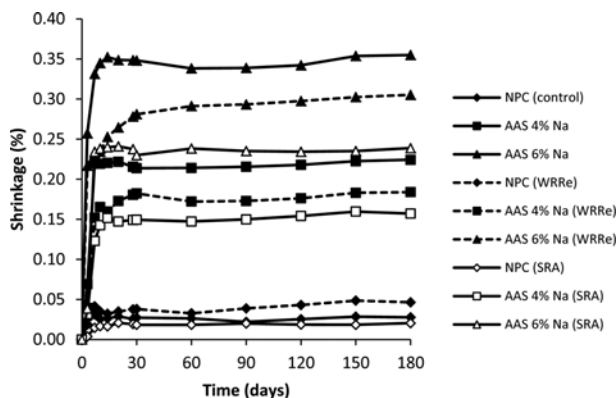

Fig. 11. Shrinkage of AAS and NPC Mortars Exposed to Moist Curing (%)

effect on the shrinkage of NPC mortar as reported in a previous study (Al-Saleh and Al-Zaid, 2006). Furthermore, SRA admixture, which decreased the shrinkage values of NPC mortar as expected, considerably reduced the shrinkage of AAS mortars. The positive effect which is observed in the shrinkage values at the consequence of the use of this admixture may be explained in this way: SRA decreases the surface tension of the pore water in the mortar, thereby lowering the capillary tension within the pore

structure and therefore reducing shrinkage during the evaporation of water (Palacios and Puertas, 2005; Palacios and Puertas, 2007).

The results showed that the shrinkage values of moist cured AAS mortars were lower than those of dry cured AAS mortars because the curing environment with high relative humidity reduces the vaporization of free water within the mortar. According to this, the highest shrinkage values were obtained from the mortars exposed to $23 \pm 2°C$ and 50% relative humidity. Additionally, the heat curing process at 65°C in water for 5 h considerably decreased the shrinkage values of mortars at especially early ages, since the curing treatment performed at elevated temperatures made the concrete dimensionally more steady and less sensitive to shrinkage (Bakharev *et al.*, 1999b; Kjellsen *et al.*, 1990; Taylor, 1990; Radjy and Richards, 1973). Also, various researchers (Bakharev *et al.*, 1999b; Aydın and Baradan, 2012) performing microstructure investigations on AAS mortars reported that C–S–H formed during heat curing had less water content. This situation is possibly the reason why low shrinkage was obtained from heat-treated AAS and NPC mortars.

While previous investigation of Bilim *et al.* (2013) on AAS mortars utilized liquid sodium silicate for the slag activation, sodium metasilicate with the dry powdered form was used as slag activator in the current study. Since the mechanism of activation was not the same for these activators (Bakharev *et al.*, 2000), consequently, the findings obtained from both studies were somewhat different. When the results of the two studies were compared, it was shown that the workability losses of AAS mortars were more than those of NPC mortar regardless of activator type, and the flow values of AAS mortars also decreased with an increase in the sodium dosage of the alkali activator. Additionally, the other properties such as setting times, mechanical strengths, carbonation and shrinkage of AAS mortars activated by sodium metasilicate with the dry powdered form were a bit better than those of AAS mortars activated by liquid sodium silicate activator.

4. Conclusions

According to the test results, WRRe enhanced the flowability of AAS mortars while SRA slightly improved the flow values of AAS mortars. Also, both admixtures generally did not create a significant difference on the initial and final setting times of AAS pastes. On the other hand, it was seen that curing conditions had an important effect on the development of the mechanical properties in the hardened state of AAS mortars in comparison with NPC mortars. Accordingly, the lowest results in terms of strength were obtained from AAS mortars subjected to $23 \pm 2°C$ and 50% relative humidity. When cured at high temperatures, the strength development at the early stage of AAS mortars was much faster than that of NPC mortars, and the heat treatment decreased the carbonation depths and shrinkage values of AAS mortars. Finally, WRRe and SRA did not show any negative

effect on the strengths of AAS mortars and these admixtures had no effect on the resistance of AAS mortars to carbonation. However, WRRe and especially SRA admixtures reduced the shrinkage values of AAS mortars.

Acknowledgements

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