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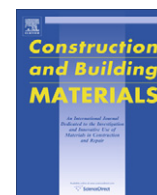
Investigation of mechanical and mineralogical properties of mortars subjected to sulfate

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ABSTRACT

The durability can be described as concrete's resistance to the destructive influences of a medium containing acid, sulfate and/or various chemicals and mechanical effects. The main objective of this study is investigation of mechanical and mineralogical properties of cement mortar with different pozzolanic compositions and subjected to sulfated medium. In the study, the mortars produced with cement samples having seven different compositions and varied with an air-entraining agent were subjected to the influence of sulfate. This study is supported by thin section and X-ray powder diffraction (XRPD) investigations, in addition to being subjected to the basic tests, such as compression and flexure. The most important findings obtained from the study are that the compact structure has more effective properties against sulfate effects for cement mortars than pozzolanic materials' effects and the highest pozzolanic material ratio is restricted about 25–30% by mass because this ratio is a boundary of mechanical properties.

1. Introduction

A sulfate attack is one of the most aggressive forms of environmental deterioration that affect the long-term durability of concrete structures. Concrete attacked by sulfated suffers from expansion, cracking, and deterioration; many engineering structures are exposed to sulfate environment, such as bridges, piers, foundations, or concrete dams. The sulfate ions in solution, which come from the soil, ground water, and seawater, are found in combination with other ions, such as sodium, potassium, magnesium and calcium ions [1–8]. The sulfate attack is generally attributed to the reaction of sulfate ions with calcium hydroxide and calcium aluminate hydrate to form gypsum and ettringite. The gypsum and ettringite formed as a result of a sulfate attack are significantly more voluminous (1.2–2.2 times) than the initial reactants [5,9]. The formation of gypsum and ettringite leads to expansion, cracking, deterioration, and disruption of concrete structures. In addition to the formation of ettringite and gypsum and its subsequent expansion, the deterioration due to a sulfate attack is partially caused by the degradation of calcium silicate hydrate (C–S–H) gel through leaching of the calcium compounds. This process leads to a loss of C–S–H gel stiffness and overall deterioration of the cement paste matrix [4].

The sulfate attack chemical interaction is a complicated process and depends on many parameters including the concentration of sulfate ions, ambient temperature, cement type and composition, water to cement ratio, porosity and permeability of concrete, and the presence of supplementary cementitious materials [10]. The incorporation of supplementary cementitious materials such as natural pozzolan, blast-furnace slag, fly ash, and silica fume as partial replacements for ordinary cement has been found to be a beneficial technique to enhance the resistance of concrete to a sulfate attack [9,11–14].

The main objective of this study is to determine the factors that affect the durability of the cement samples exposed to sulfate and discuss the precautions for expanding this durability. In this study, the mortars are produced with seven different cement types composed with five different pozzolanic components that are also varied by using an air-entraining agent. These mortars are subjected to flexural and compression tests seven different times over the course of a year. The deteriorations due sulfate effects are also determined using XRPD and petrographic investigations.

The essential case separating this study from the others is: because the pozzolanic additives are very fine materials, if they added to concrete, they make concrete more compact. In other studies, when effects of sulfate are investigated, compact (not porous)

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mortars were used. As a result, the reason for the positive effects of the tests is not clearly defined. In other words, are the positive effects because of compact structure or mineral additives? In this study, relatively porous mortars are also produced with an air-entraining agent to separate these two difficulties.

2. Materials and methods

2.1. Materials

2.1.1. Cement components

The materials that constitute the cement samples are provided by different sources in Turkey. The Portland cement, ordinary CEM I 42.5 R, is derived from the Unye Cement Factory. The blast-furnace slag is obtained from Eregli Iron–Steel Factory. The silica fume is from Antalya Eti Elektroferrokrom AS. The natural pozzolan is tuff-type rock and derived from Araklı–Trabzon district [15]. The fly ash has the siliceous fly ash property and is obtained from the Manisa-Soma Thermal Power Plant. Finally, the limestone is derived from Gumushane district.

In addition, the air entrainment material used in the experiments is Micro Air®200 belonging to Degussa Inc. It is a material originating from ammonium salt and oil alcohol.

2.1.2. Cement types

Seven different types of cements are used in the experimental process. These are produced by adding other components (fly ash, silica fume, natural pozzolan, blast-furnace slag, limestone) to ordinary CEM I 42.5 R type cement. The compositions of the cements produced are given in Table 1. The chemical and physical properties of these materials and cements are given in Tables 2 and 3. At least two compositions are comparable to each other when the compositions of the cements were chosen. The samples are named similarly to their classes in EN 197-1, for ease in identification. For example, CEM I 42.5 R is named as CI. In addition, if AE is added next to the sample name, this means the sample contains an air-entraining agent and it has more porous structure. If non-AE is added next to the sample name, this means the sample was produced without an air agent. On the other hand, if SM is added, this mean the sample is exposed to sulfated medium. If W is used next to the sample name, this mean sample is cured in tap water medium.

2.1.3. Sulfated medium

In conformity with the experimental program, some of the mortars are exposed to a sulfated medium. This medium is prepared by adding 6000 mg/kg Na(SO)$_4$ to tap water. Thus, a highly aggressive chemical environment, XA3 exposure class, is constituted according to EN 206. This medium is renewed every month during a year.

2.2. Methods

In accordance with the objective of the study, seven different cement types are prepared and two different types of mortars (with air-entraining agent and without air-entraining agent) are produced with these cements. Later, these mortars are subjected to two different mediums: sulfated medium and tap water. The curing times of the samples are chosen as 2, 7, 28, 90, 180, 270 and 360 days. When the curing time is completed, the flexural and compression tests are realized.

In addition, internal changes of the mortars because of sulfate are investigated via petrographic observations and X-ray powder diffractions by comparing with the samples in water.

2.2.1. Mechanical experiments

The flexural and compression tests were conducted according to the suggested principles in EN 196. The "test mortar" consists of 450 g of the cement mixture, 1350 g of graded standard sand, and 225 g of water, and consequently the water/cement ratio is 0.50. If a more porous mortar is produced, half of the mixing water is first added to the cement and an air-entraining agent is added to the other half of the water. In accordance with the product instructions, 0.4 ml of air-entraining agent is used for 450 g of cement. After the molding process, the molds (with the mortars in them) were placed in the moist room at 23 ± 1.7 °C for 20–24 h and removed at the end of this period, and the mortar prism specimens were stored in tap or sulfated water until the day of testing. The flexural tests on the mortar prisms (40 × 40 × 160 mm) were conducted and compressive test was done on the broken pieces as equivalent cube test at 2, 7, 28, 90, 180, 270, and 360 days according to the Rilem–Cembureau method in EN 196.

2.2.2. Investigation of solid phases

Mineralogical and petrographical properties of the mortar samples were identified under the polarizing microscope by using their thin sections and X-ray powder diffraction (XRPD) analysis of the powdered bulk samples were carried out. Dry powder was sieved in order to separate large aggregates (quartz) from fine materials. The powder XRPD data were collected on a Rigaku D/MAX-IIIC diffractometer, operated at 40 kV and 100 mA, interfaced with an MDI databox and Jade 7 software, using Cu Kα (λ = 1.54059 Å) radiation. By means of the data obtained from this software, a trend is also observed about the quantity (abundance) of the minerals. During investigations, the quartz mineral from fine aggregate is not taken into consideration. The samples studied are 9 months old for thin-section investigations and 10 months old for XRPD analysis.

In this study, ettringite and gypsum minerals are studied. However, some other minerals, such as anhydrite, monosulfate, $Ca_4Al_2O_7 \cdot 19H_2O$, $Ca_2Al_2O_5 \cdot 8H_2O$, $Ca_4Al_2O_6(SO_4) \cdot 14H_2O$, $Ca_3Al_2(OH)_{12}$ mentioned in the Refs. [16–18], are also taken into consideration. JCPDS [19] card numbers of these minerals are given in Table 4.

Table 1
Material composition of cements (% mass).

Samples	CEM I 42.5	Blast-furnace slag	Silica fume	Natural pozzolan	Fly ash	Limestone
C I	100	–	–	–	–	–
C II/A-M	85	3	3	3	3	3
C II/B-M	75	5	5	5	5	5
C IV/A	70	–	5	15	10	–
C IV/B	55	–	5	20	20	–
C V/A	45	20	–	20	15	–
C V/B	35	40	–	15	10	–

Table 3
Physical properties of cements.

Samples	Initial setting times (min)	Final setting times (min)	Expansion according to Le Chatelier (mm)	Sieve analysis (%)	
				90μ	200μ
C I	205	260	2	1.2	0.1
C II/A-M	205	265	4	2.5	0.1
C II/B-M	225	295	6	2.4	0.1
C IV/A	220	270	2	4.1	0.1
C IV/B	235	295	3	9.4	2.5
C V/A	230	275	2	2.4	0.1
C V/B	210	275	4	4.4	0.2

Table 2
Chemical compositions of cements and other materials (% mass).

Sample	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	CaO	MgO	SO$_3$	LOI	Total
C I	18.81	5.43	3.05	58.75	1.21	2.94	5.14	95.33
C II/A-M	23.13	6.14	3.24	54.83	1.43	2.48	4.50	95.75
C II/B-M	34.83	6.56	3.29	40.33	2.32	2.45	4.51	94.29
C IV/A	30.29	6.31	3.17	50.17	2.21	2.11	3.86	98.12
C IV/B	45.03	12.69	3.77	28.08	1.74	1.40	3.40	96.11
C V/A	40.05	7.84	2.54	41.63	2.77	1.41	3.11	99.35
C V/B	36.76	10.12	2.92	36.28	1.75	1.44	2.52	91.79
Blast-furnace slag	36.7	14.68	0.96	34.61	9.63	0.98	–	97.56
Silica fume	87.02	3.82	0.93	1.96	0.85	0.87	1.12	96.57
Natural pozzolan	63.54	13.67	5.91	4.59	2.06	0.48	3.90	94.15
Fly ash	64.43	17.06	4.19	8.59	1.38	1.60	0.91	98.16
Limestone	4.55	1.89	1.57	48.95	1.06	–	40.57	98.59

Table 4
The minerals studied in XRPD investigations and their JCPDS [19] card number.

Mineral name	JCPDS card no.	References
$Ca_6Al_2(SO_4)_3(OH)_{12} \cdot 26H_2O$ (ettringite)	41-1451	Christensen et al. [17]
	37-1476	Abdel-Wahab [16]
	9-414	Perkins and Palmer [18]
$CaSO_4 \cdot 2H_2O$ (gypsum)	33-311	Christensen et al. [17]
	6-0046	Perkins and Palmer [18]
$CaSO_4$ (anhydride)	6-226	
$Ca_4Al_2O_7 \cdot 19H_2O$	14-628	Christensen et al. [17]
$Ca_2Al_2O_5 \cdot 8H_2O$		Christensen et al. [17]
$Ca_3Al_2O_6 \cdot CaSO4 \cdot 13H_2O$ (monosulphate)	11-179	Abdel-Wahab [16]
$Ca_4Al_2O_6(SO_4) \cdot 14H_2O$	42-62	Christensen et al. [17]
$Ca_3Al_2(OH)_{12}$	24-217	Christensen et al. [17]

3. Results and discussions

In this study, 28 different conditioned samples are subjected to different tests procedures during 360 days. As a result of this, both structural and mechanical changes occur.

3.1. The effects of sulfated medium on the mortars

Various mineralogical and structural changes occur in the cement mortars because of sulfate. These changes are examined using naked-eye observation, thin-section investigation and X-ray powder diffraction.

3.1.1. The visible deteriorations

When the cement mortars are subjected to sulfated medium, a lot of mineralogical deteriorations form. However, few of these deteriorations develop visibly (Fig. 1). The visible deteriorations occur more obviously in the mortars that include the air-entraining agent. This is because of a decrease in the compressive strength and an increase in porosity, which allow increased penetration of the sulfated water.

The deteriorations appear at a remarkable level in CI mortars. CI cement that constitutes CI mortar has highest CaO ratio (58.75% by mass) and SO_3 ratio (2.94% by mass). So the CI (AE, SM) mortar sample subjected to the sulfated medium and containing the air-entraining agent can have a high amount of gypsum mineral. First cracks occurred after 8 months in this sample because the internal stress due to minerals is probably higher than the sample's flexural strength (approximately 3–4 MPa). On the other hand, superficial spalling and textural deteriorations are observed in the samples of CIV/B(AE, SM) and CV/A(AE, SM). These samples have a high ettringite content (Figs. 2 and 3).

3.1.2. The micro deteriorations

After investigation of visible deteriorations, the micro deteriorations are studied via both thin-section investigation (Fig. 2) and X-ray powder diffraction (XRPD) analysis (Fig. 3). Each of the 28 different samples is investigated with these two methods. It is seen from these investigations that sulfated minerals (ettringite, gypsum, etc.) especially form greater amounts in the samples cured in sulfated medium, although they are also formed in the mortar samples cured in tap water.

The white sulfated minerals are seen especially around the air void in the mortar on thin section images. In addition, these minerals are in the mortar paste. However, they are not clearly distinguished from each other during the thin-section investigation (Fig. 2). The minerals are identified using XRPD analysis (Fig. 3).

Both ettringite and gypsum minerals are formed in CI, Portland cement, and the mortars that are cured in both sulfated and tap water mediums. However, the samples containing the air-entraining agent and cured in the sulfated medium (CI(AE, SM)) deteriorate more from sulfate, and this sample has more gypsum mineral than ettringite mineral (Figs. 2 and 3). It is thought that the gypsum mineral in the samples cured in tap water is from the gypsum added during cement production stage. However, if there are more ettringite minerals than gypsum mineral for these samples, this means ettringite is transferred into gypsum for CI samples.

It is thought that because C2/A-M and C2/B-M samples have limestone as pozzolanic material, ettringite and gypsum minerals are formed abundantly in the samples cured in both the sulfated medium and tap water. However, there are no detrimental effects that can be seen with the naked-eye in these samples.

As seen from XRPD analysis, ettringite mineral occurs more than gypsum mineral in the CIV/A and CIV/B samples. However, sulfated minerals cannot be clearly seen in thin-section investigation. It is thought because of low CaO content, large minerals do
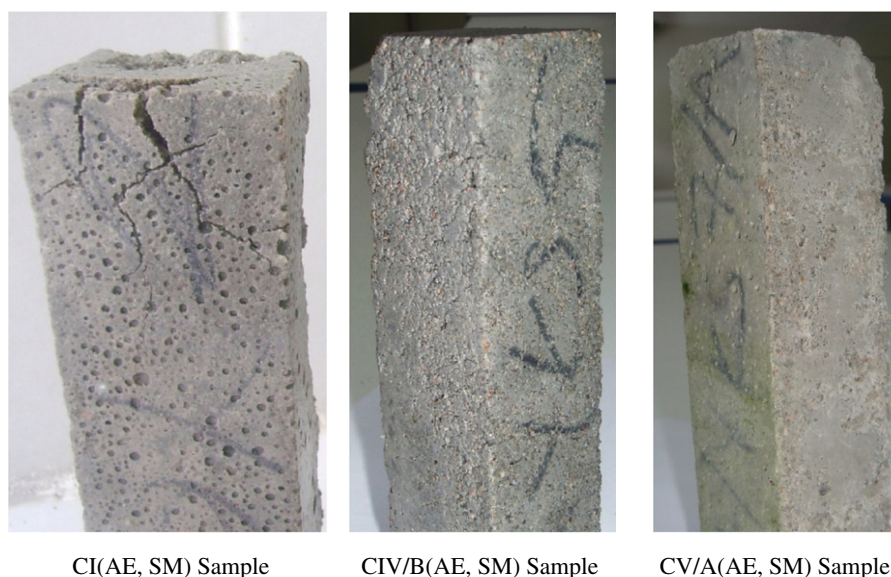

CI(AE, SM) Sample   CIV/B(AE, SM) Sample   CV/A(AE, SM) Sample

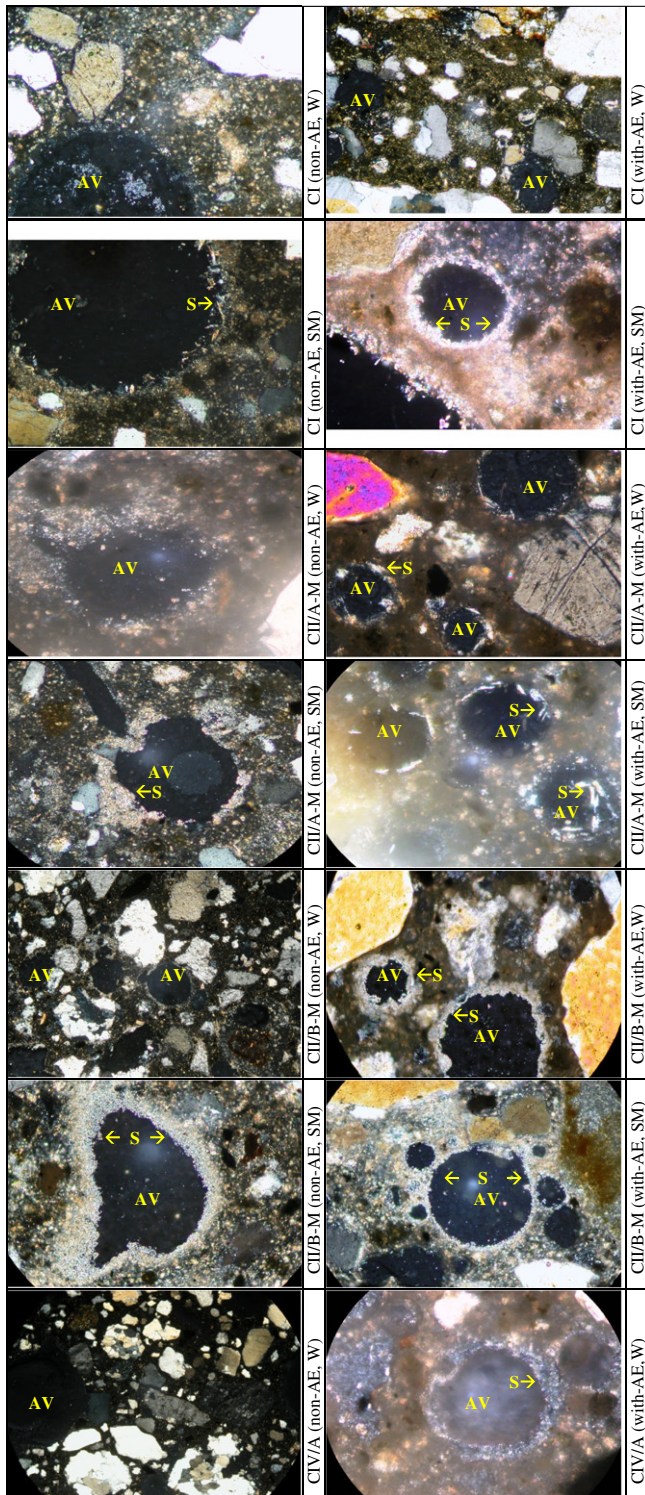**Fig. 1.** Visible deteriorations occurred in mortars.

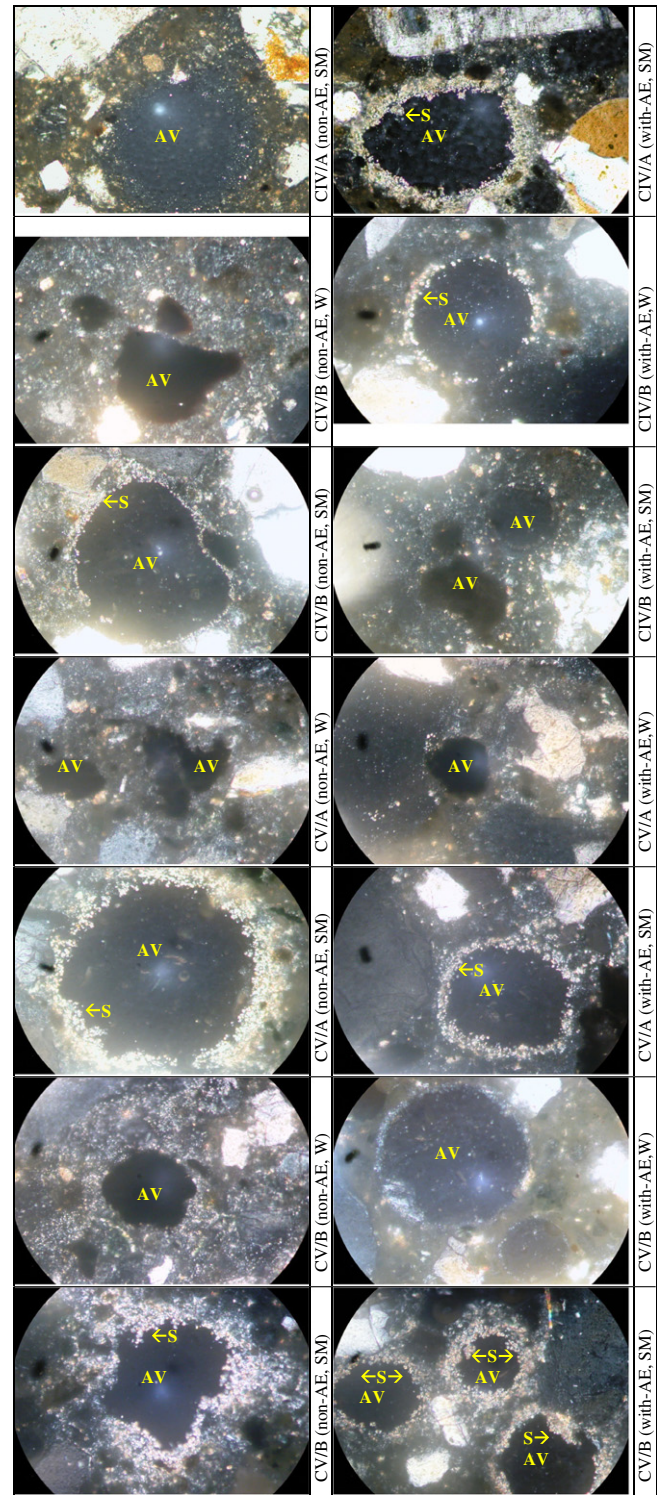**Fig. 2.** Thin section images of the mortars.

Fig. 2 (*continued*)

not form in this cement's mortar. The superficial spalling occurs in the CIV/B (AE, SM) owing to ettringite.

Although CV/A and CV/B samples have more pozzolanic components than the clinker, a detrimental level of ettringite and gypsum minerals are formed. Textural deteriorations occur in CV/A(AE, SM) samples (Figs. 1–3).

It is seen that the mortars containing the air-entraining agent (AE), which have a more porous structure, are easily affected by the sulfated medium compared to more compact mortars. In addition, it can be mentioned that the compact structure is more

effective against sulfate effects for cement mortars than pozzolanic materials' effects. For example, CV/A cement has 55% pozzolanic material; however, the more porous mortar (CV/A(AE, SM) sample) deteriorates from sulfate.

3.1.3. Some important findings obtained from thin section and XRPD investigations

Some important findings obtained from thin section and XRPD investigations are must to be mentioned:
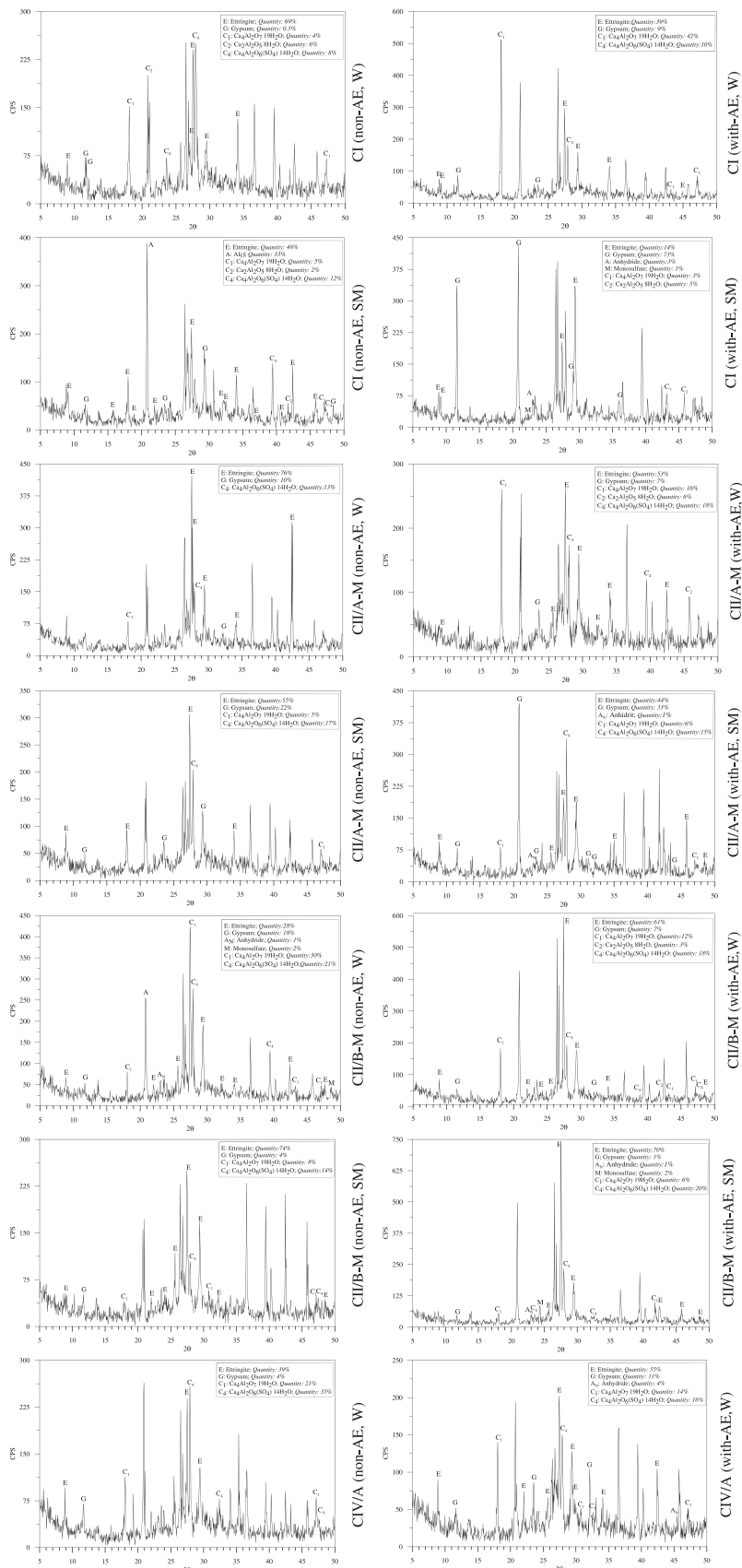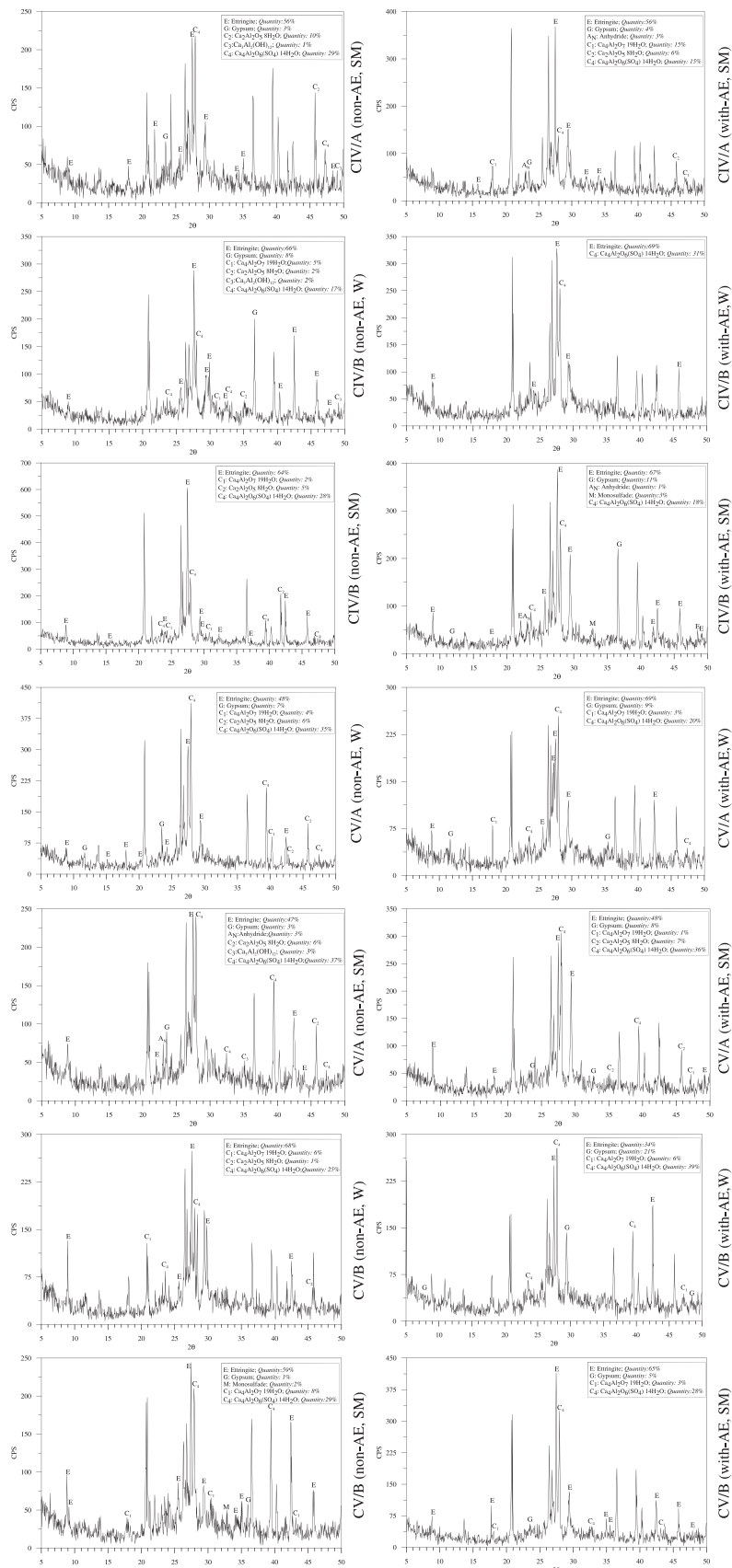
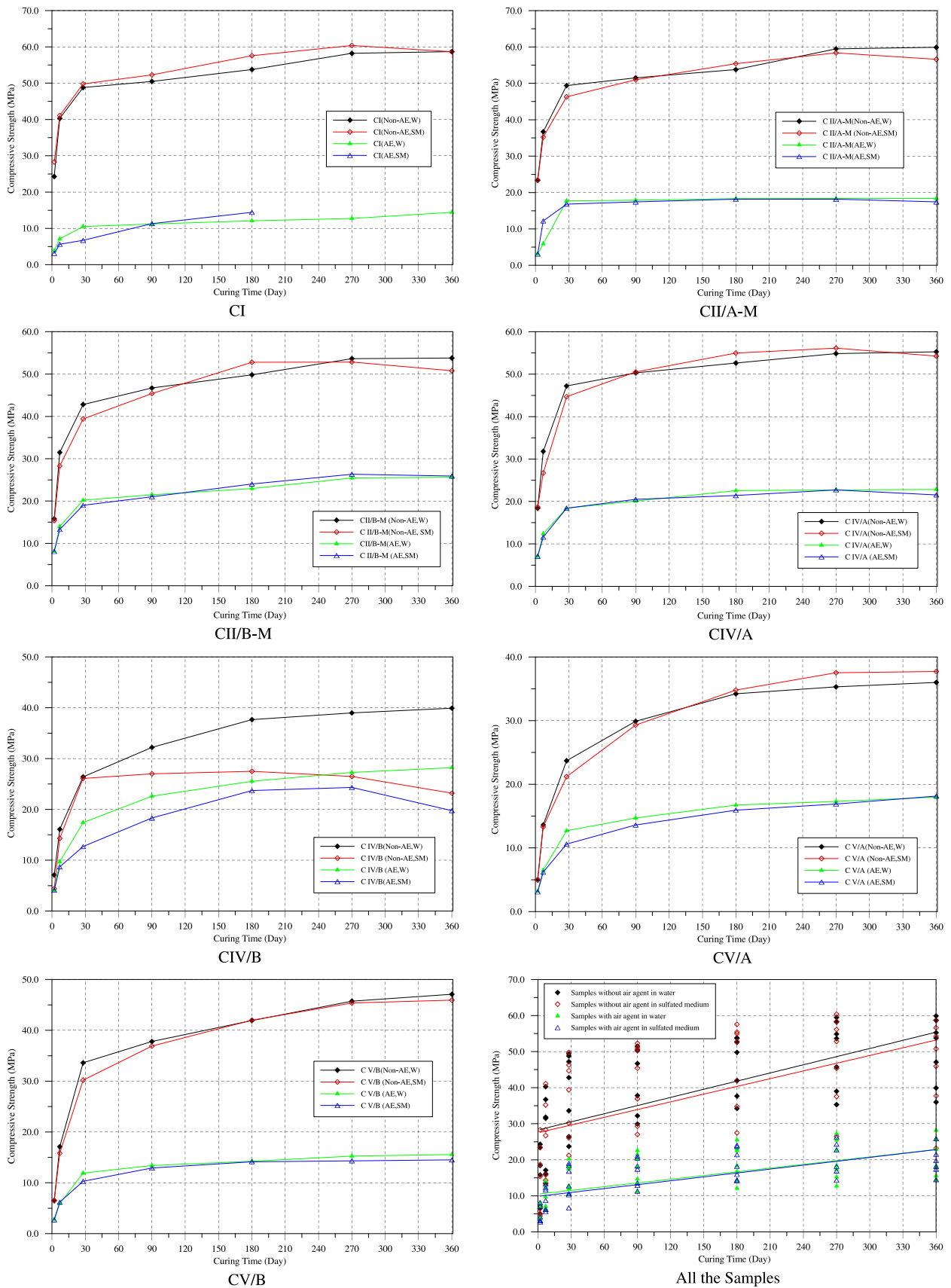**Fig. 3.** XRPD of the mortars.

Fig. 3 (*continued*)

Fig. 4. Relationship between compressive strength and curing time.
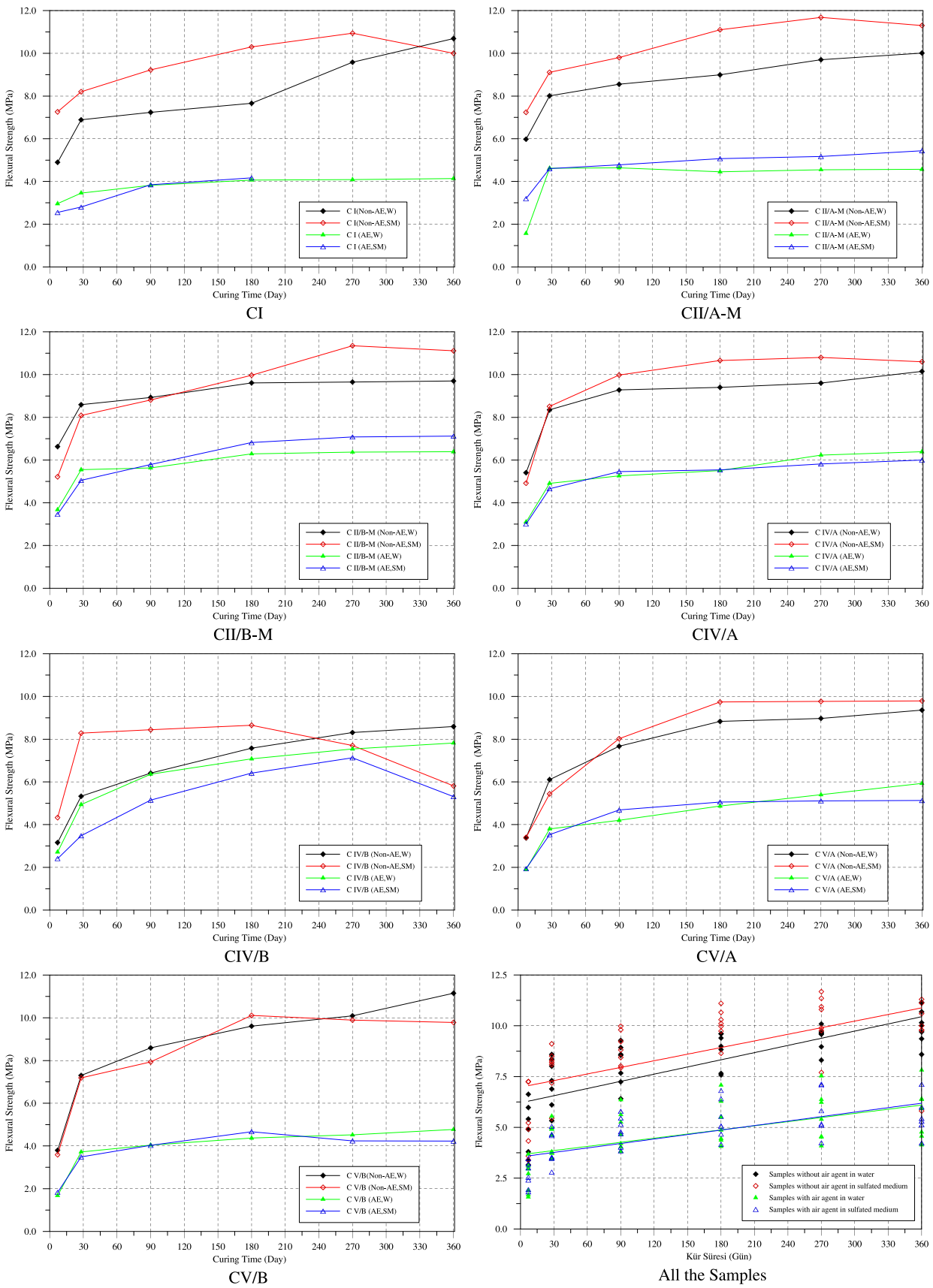
Fig. 5. Relationship between flexural strength and curing time.

- If the cement samples contain limestone as supplementary material, ettringite and especially gypsum formation increase connected with addition amount.
- The ettringite and gypsum minerals are also formed in the mortars cured in water not only sulfated medium (Figs. 2 and 3). If so, these minerals are generally available in the paste because sulfate is come from cement composition to these samples. However, in the samples cured in sulfated medium, sulfate come into structure generally with curing water. So mineral formations are dense around air voids in which water is accumulate.

- It is investigated that the gypsum formed abundantly causes cracks in mortar, while ettringite causes superficial spalling.

3.2. Mechanical properties of mortars

After investigated deteriorations of cement mortars subjected to sulfated medium, it is discussed changes in mechanical effects in this medium. It was mentioned that some minerals expanding can be occurred in the concrete in sulfated medium. The effects of the internal stresses caused by these expanding minerals on

Table 5
Compressive strengths of mortars.

Samples	AE content	Medium	2 Days	7 Days	28 Days	90 Days	180 Days	270 Days	360 Days
C I	Non-AE	TW	24.3	40.3	48.8	50.50	53.76	58.22	58.69
		SM	28.3	41.1	49.8	52.30	57.57	60.40	58.66
	With AE	TW	3.8	7.1	10.5	11.20	12.10	12.74	14.42
		SM	3.1	5.6	6.7	11.30	14.42	–	–
C II/A-M	Non-AE	TW	23.4	36.7	49.4	51.50	53.80	59.49	59.91
		SM	23.4	35.2	46.3	51.00	55.42	58.40	56.62
	With AE	TW	3.1	5.9	17.7	17.90	18.33	18.34	18.34
		SM	3.1	12.2	16.8	17.40	18.16	18.17	17.40
C II/B-M	Non-AE	TW	15.8	31.5	42.8	46.70	49.81	53.65	53.77
		SM	15.4	28.3	39.4	45.40	52.78	52.83	50.77
	With AE	TW	8.1	14.0	20.2	21.50	22.96	25.46	25.63
		SM	8.1	13.3	19.0	21.00	24.04	26.32	25.90
C IV/A	Non-AE	TW	18.4	31.8	47.2	50.30	52.60	54.85	55.26
		SM	18.7	26.7	44.7	50.50	54.97	56.13	54.25
	With AE	TW	7.1	12.4	18.4	20.10	22.55	22.72	22.83
		SM	7.1	11.6	18.4	20.50	21.40	22.74	21.54
C IV/B	Non-AE	TW	7.1	16.1	26.4	32.20	37.66	38.98	39.92
		SM	4.4	14.3	26.1	27.00	27.48	26.49	23.19
	With AE	TW	4.1	9.7	17.4	22.60	25.54	27.27	28.22
		SM	4.1	8.7	12.7	18.30	23.70	24.33	19.76
C V/A	Non-AE	TW	5.0	13.6	23.7	29.90	34.21	35.30	36.00
		SM	5.0	13.3	21.2	29.30	34.79	37.52	37.72
	With AE	TW	3.2	6.5	12.7	14.70	16.73	17.30	17.98
		SM	3.1	6.2	10.6	13.60	15.94	16.40	18.14
C V/B	Non-AE	TW	6.5	17.1	33.6	37.80	41.92	45.74	47.10
		SM	6.5	15.8	30.2	36.90	42.01	45.37	45.95
	With AE	TW	2.8	5.9	11.9	13.40	14.25	15.25	15.56
		SM	2.7	6.2	10.3	12.90	14.15	14.32	14.50

Table 6
Flexural strengths of mortars.

Samples	AE content	Medium	2 Days	7 Days	28 Days	90 Days	180 Days	270 Days	360 Days
C I	Non-AE	TW	24.3	40.3	48.8	50.50	53.76	58.22	58.69
		SM	28.3	41.1	49.8	52.30	57.57	60.40	58.66
	With AE	TW	3.8	7.1	10.5	11.20	12.10	12.74	14.42
		SM	3.1	5.6	6.7	11.30	14.42	–	–
C II/A-M	Non-AE	TW	23.4	36.7	49.4	51.50	53.80	59.49	59.91
		SM	23.4	35.2	46.3	51.00	55.42	58.40	56.62
	With AE	TW	3.1	5.9	17.7	17.90	18.33	18.34	18.34
		SM	3.1	12.2	16.8	17.40	18.16	18.17	17.40
C II/B-M	Non-AE	TW	15.8	31.5	42.8	46.70	49.81	53.65	53.77
		SM	15.4	28.3	39.4	45.40	52.78	52.83	50.77
	With AE	TW	8.1	14.0	20.2	21.50	22.96	25.46	25.63
		SM	8.1	13.3	19.0	21.00	24.04	26.32	25.90
C IV/A	Non-AE	TW	18.4	31.8	47.2	50.30	52.60	54.85	55.26
		SM	18.7	26.7	44.7	50.50	54.97	56.13	54.25
	With AE	TW	7.1	12.4	18.4	20.10	22.55	22.72	22.83
		SM	7.1	11.6	18.4	20.50	21.40	22.74	21.54
C IV/B	Non-AE	TW	7.1	16.1	26.4	32.20	37.66	38.98	39.92
		SM	4.4	14.3	26.1	27.00	27.48	26.49	23.19
	With AE	TW	4.1	9.7	17.4	22.60	25.54	27.27	28.22
		SM	4.1	8.7	12.7	18.30	23.70	24.33	19.76
C V/A	Non-AE	TW	5.0	13.6	23.7	29.90	34.21	35.30	36.00
		SM	5.0	13.3	21.2	29.30	34.79	37.52	37.72
	With AE	TW	3.2	6.5	12.7	14.70	16.73	17.30	17.98
		SM	3.1	6.2	10.6	13.60	15.94	16.40	18.14
C V/B	Non-AE	TW	6.5	17.1	33.6	37.80	41.92	45.74	47.10
		SM	6.5	15.8	30.2	36.90	42.01	45.37	45.95
	With AE	TW	2.8	5.9	11.9	13.40	14.25	15.25	15.56
		SM	2.7	6.2	10.3	12.90	14.15	14.32	14.50

compressive and flexural strength of cement mortars are investigated (Figs. 4 and 5, Tables 5 and 6).

It is seen that the samples cured in water shows more compressive strength than the samples cured in sulfated medium. Strength gaining rate (slopes of lines in Fig. 4) is also slowly for these samples cured in sulfate. These rates decrease for the samples in sulfated medium after 6–9 months. The samples with air agent show similar properties for both in water and in sulfated medium.

If the flexural strengths are investigated, it is seen that the ones in sulfated medium of the samples without air agent show highly flexural strength than the ones in water (Fig. 5). However, the samples in water indicate speeder strength gaining. Because the sulfated medium does not influence the samples with air agent, they show similar properties.

The sulfate in the medium works like the gypsum coming from cement. Thus it helps realizing the hydration perfectly and occurring binding crystals flawless in the initial days. The gypsum and ettringite minerals fill the voids in the matrix initial times. Therefore, they help increasing the strength. It can be said that sulfated minerals contribute to increase strength by filling micro-voids in matrix. If this filling ratio exceeds a certain amount, this causes partially breaking in the matrix and decreases the strength. Especially increase in flexural strength of the samples cured in sulfated medium is thought to be connected to this situation (Fig. 5).

The samples with air agent present 50–70% less compressive strength (Fig. 4) and 35–55% less flexural strength (Fig. 5) than the samples without air agent. For the samples containing air-entraining agent, the samples cured in water present 2–6% higher
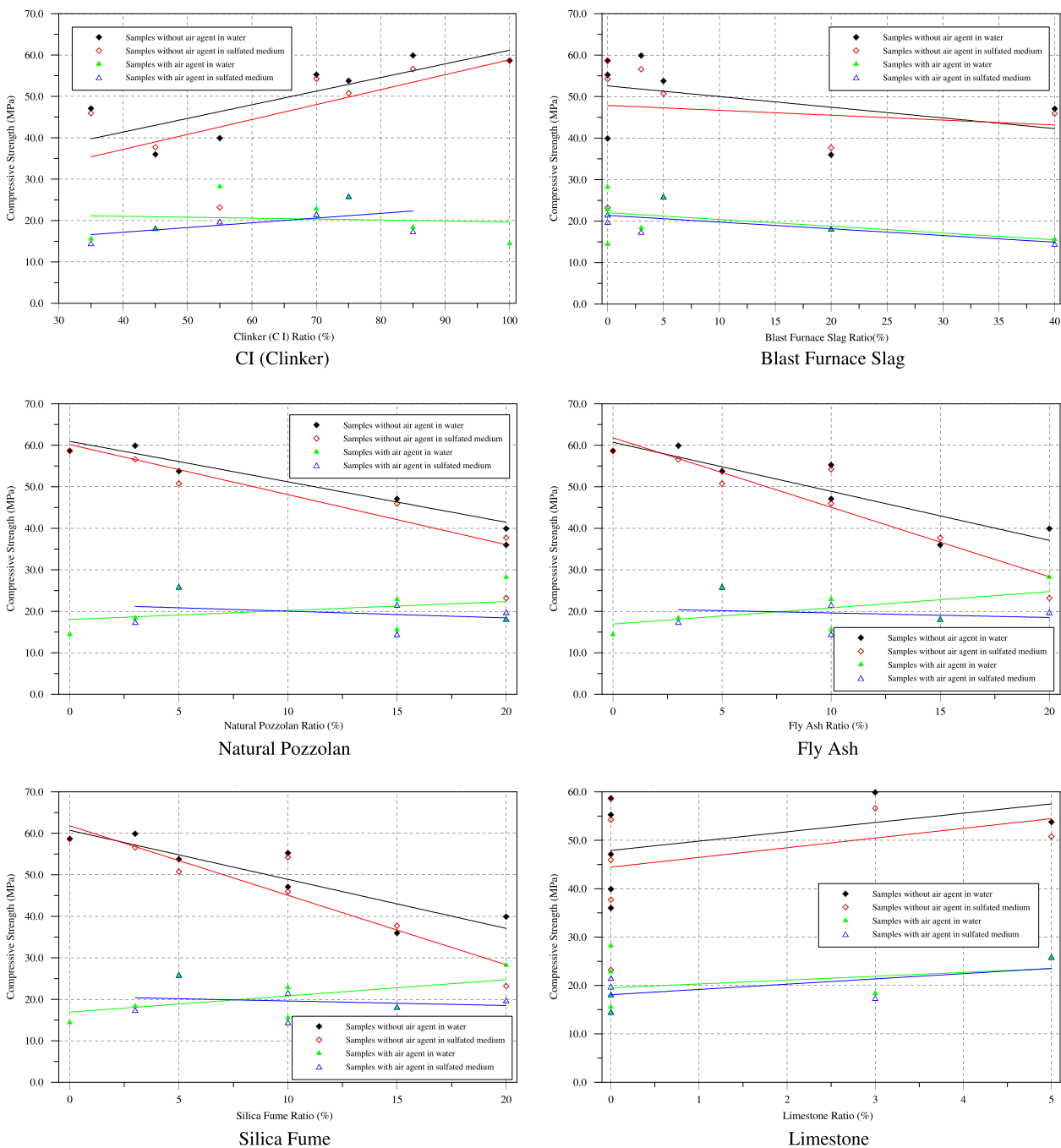

Fig. 6. Relationship between compressive strength and pozzolanic components content at the end of a year.

compressive strength than the samples in sulfated medium (except for C IV/B). For the more compact samples (without air agent), the ones in sulfated medium of CI, CII/B-M, CV/A mortars show higher compressive strength than the others (Fig. 4).

3.2.1. The effects of cement components on mechanical properties

While clinker contributes to strength of mortar from beginning, pozzolanic materials contribute with binding compounds after $Ca(OH)_2$ is occurred in medium [15]. Consequently, it is expected that the cements whose clinker ratio is higher, present higher compressive strength in early ages. However, the cements whose pozzolanic material content is relatively higher are expected to show higher compressive strength in later ages. This situation is seen in CII/A-M sample after 12 months (Fig. 4). As similar to this,
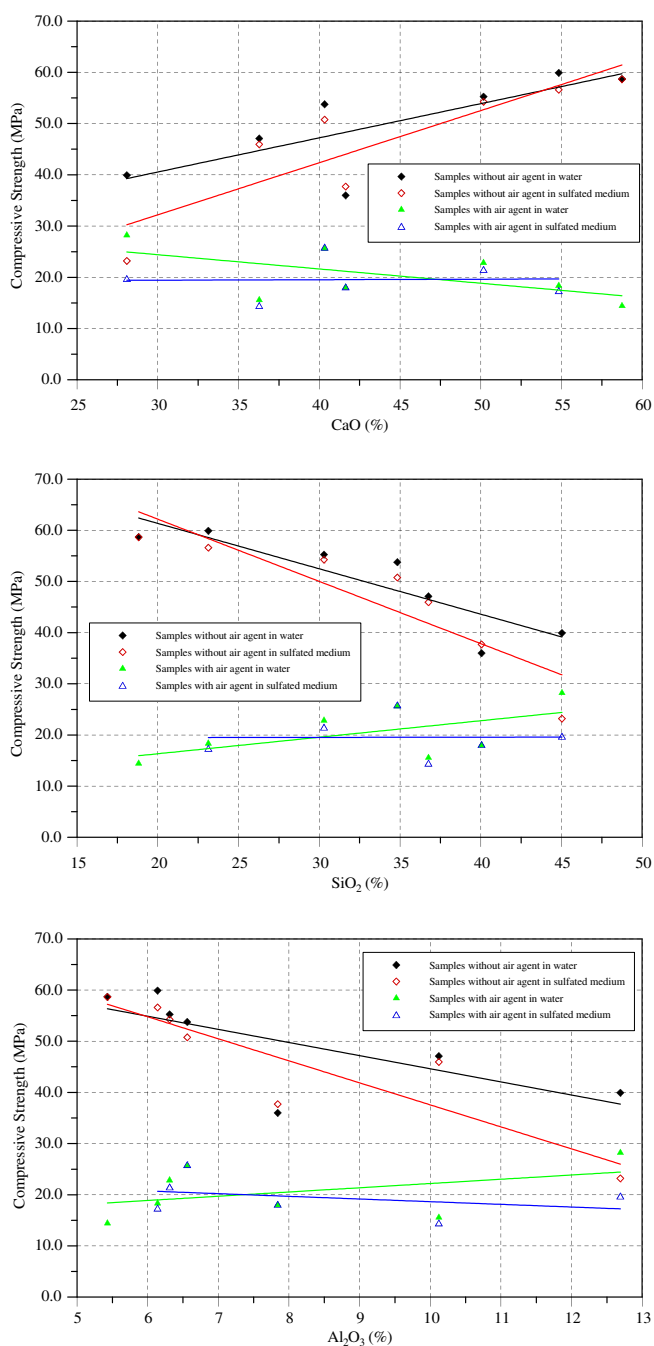

Fig. 7. Relationship between compressive strength and chemical components content at the end of a year.

CIV/A and CIV/B samples whose pozzolanic material content is about 25–30% have close compressive strength result to CI sample after a year.

For both with and without air agent of the mortars produced with the cements whose pozzolanic content under 25% by mass, flexural strengths of the samples in sulfated medium are 3–17% higher than the samples in water (Fig. 5). On the other hand, flexural strengths of the mortars in water are 7–20% higher than the samples in sulfate for the cement samples have pozzolanic component more than 25% (Fig. 5). These mean that formation of gypsum contribute flexural strength for the cement mortar samples whose pozzolanic component content under 25% by mass. Sulfate ions can exist in paste's own structure or they can enter the structure by way of environmental effects. Low concentration sulfate ions can cause occurring ettringite minerals, while high concentration ones can cause taking place gypsum minerals [20–22]. For this study, even the pozzolanic component substituted higher than 25% by mass do not reduce the sulfate coming from exterior, they decrease the sulfate coming from cement production stage with gypsum. Consequently, the mortars having pozzolanic material higher than 25% are occurred relatively more ettringite minerals and less flexural strength. And the mortars having pozzolanic materials less than 25% are occurred relatively more gypsum minerals and higher flexural strength.

Increase in some pozzolanic material content as limestone and silica fume for the samples without air agent increase compressive strength. However, natural pozzolan, fly ash and blast-furnace slag those are added higher amount than formers decreases compressive strength (Fig. 6).

As seen from Fig. 7, CaO compound contributes compressive strength positively, and increase in SiO_2 and Al_2O_3 compounds contents decrease the compressive strength. These relations are not evident in samples with air agent or cured in sulfated medium. CaO and free CaO are even inconvenient for durability; it is very important aspect of binding.

4. Conclusions

In this study, the mechanical and mineralogical properties of the cement mortars having different a pozzolanic composition and matrix are subjected to mediums containing sulfate are investigated.

Various mineralogical and structural changes occur in the cement mortars because of sulfate. The visible deteriorations occur more evidently, especially in the mortars including an air-entraining agent, parallel with the decrease in the compressive strength and the increase of the porosity; consequently there is an increase in penetration of the sulfated water. In addition, it can be mentioned that the compact structure has more effective properties against sulfate effects for cement mortars than pozzolanic materials' effects.

It is investigated that the gypsum formed abundantly causes cracks in mortar, while ettringite causes superficial spalling.

It is seen that the samples cured in water shows more compressive strength than the samples cured in sulfated medium. If the flexural strengths are investigated, it is seen that the ones in sulfated medium of the samples without air agent show highly flexural strength than the ones in water. It can be said that sulfated minerals contribute to increase strength by filling micro-voids in matrix. If this filling ratio exceeds a certain amount, this causes partially breaking in the matrix and decreases the strength. The samples approach the ultimate compressive and flexural strength in about 6–9 months.

The highest pozzolanic material ratio must be restricted about 25–30% by mass because this ratio is a boundary of mechanical properties.

Acknowledgments

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