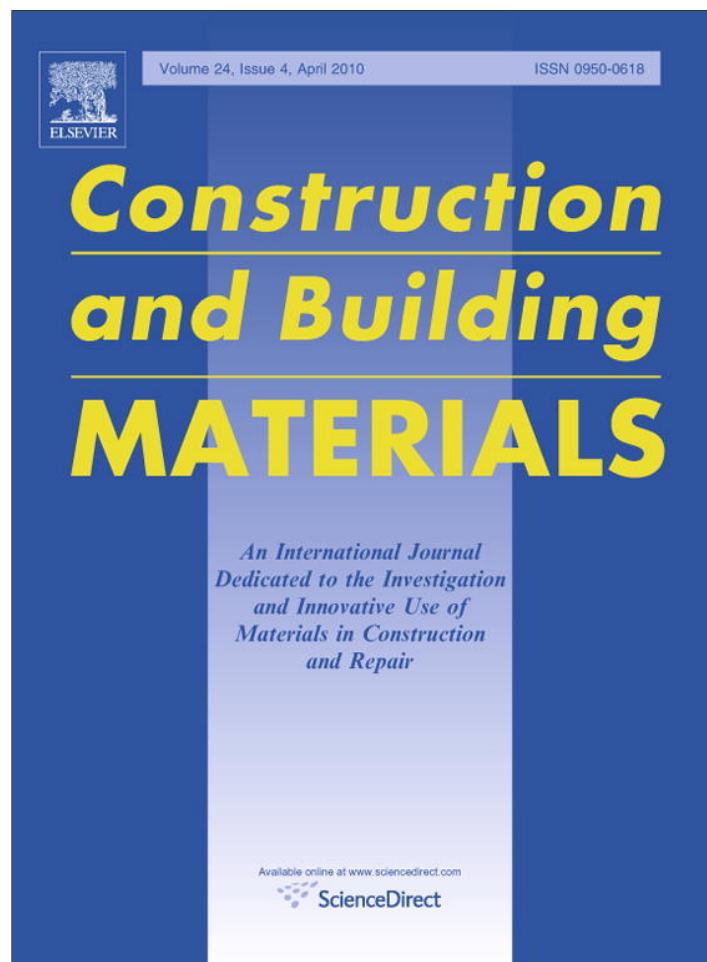


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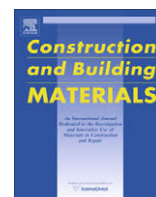
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Investigation of abrasion resistance of cement mortar with different pozzolanic compositions and subjected to sulfated medium

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ABSTRACT

The durability phenomenon for concrete, or cement mortar, has gained attention recently as one of the important mechanical properties. It can be described as concrete's resistance to the destructive influences of a medium containing acid, sulfate and/or various chemicals and mechanical effects, like abrasion. Most of the studies attempted to improve these individual properties in concrete. However, concrete can be subjected to two or more of these effects simultaneously. In this 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 and abrasive effects simultaneously. In this study, several examples were evaluated using samples cured for six different periods throughout one year. This study is supported by thin section and XRPD investigations, in addition to being subjected to the basic tests, such as compression, flexure and abrasion. If the most important findings obtained from the study are summarized, it is seen that a compact cement matrix is more effective against both sulfate and abrasive effects than mineral additives. The mortars subjected to coupled (sulfate and abrasive) effects show less durability if compared to ones cured in water and later abraded.

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1. Introduction

Abrasion of concrete occurs due to scraping, rubbing, skidding or sliding of objects on its surface. The abrasion resistance of concrete is influenced by a number of factors, such as compressive strength, surfacing finish, aggregate properties, types of hardeners, and curing [2].

A number of previous studies [13,10,7] have indicated that the abrasion resistance of concrete is primarily dependent on the compressive strength of the concrete. In order to develop concrete with high abrasion resistance, it is desirable to use a hard surface material, aggregate, and paste with low porosity and high strength [13]. On the other hand, some researchers [4] claim that the abrasion resistance of concrete is mainly dependent on the flexural tensile strength of concrete. They claim that a general relation numerically describing this relation has a linear form in log scale that provides a higher correlation. A stronger relation exists between abrasion and flexural tensile strength than that between abrasion and compressive strength.

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 [12,14,15,18,22]. 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 [8,14]. 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 [12].

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 [21].

The incorporation of supplementary cement materials such as natural pozzolana, blast-furnace slag, fly ash, and silica fume as partial replacements for ordinary cement has been found to be a

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beneficial technique to enhance the resistance of concrete to a sulfate attack [3,11,19,8].

Concrete resistance to environmental attacks is mainly dependent on its permeability, alkalinity and the chemical composition of the cement paste. Certain chemicals or harmful mediums (sulfated, acidic, etc.) have a deleterious effect on concrete. Partial cement replacement with fly ash or silica fume reduces the potential for corrosive effects. Clearly a paste weakened by extended exposure to harmful mediums will abrade relatively easily. Furthermore, its ability to bond with aggregate will be weakened, leading to accelerated abrasion wear in concrete [17].

Environmental effects damage the mortar, or concrete, aspect of more chemical than abrasive effect. However, abrasion resistance of the mortar damaged by these effects is reduced, like some other properties. If concrete is simultaneously subjected to environmental effects and exposed to abrasive effects, the coupled effect is in question. These types of coupled effects can occur on structures such as concrete slabs or roads constructed on sulfated ground. Although, this is a common situation, currently there are not any studies to address this issue.

The main objective of this study is to determine the factors that affect the durability of the cement samples exposed to sulfate and abrasive effects together 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 flexion, compression and abrasion tests six different times over the course of a year. The deteriorations due sulfate effects are also determined using XRPD and petrographic investigations.

Two essential cases separating this study from the others are:

1. In other studies, compact (not porous) 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 address this issue.

2. Currently, there is no study examining the abrasion resistance of cement mortars subjected to sulfate. However, in this study, the mortar examples are first cured in a sulfate medium and later abraded.

2. Materials and methods

2.1. 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. 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 C1. 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.

2.2. Cement components

The materials that constitute the cement samples are provided by different sources in Turkey. The chemical and physical properties of these materials and cements are given in Tables 2 and 3. The Portland cement is ordinary CEM I 42.5 R. The natural pozzolan is tuff-type rock and derived from Araklı-Trabzon District [6]. The fly ash has the siliceous fly ash property. Finally, the limestone is derived from Gumushane District.

In addition, the air entrainment material used in the experiments is a product originating from ammonium salt and oil alcohol.

2.3. 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 7, 28, 90, 180, 270 and 360 days. When the curing time is completed, the samples are tested according to related standards. These tests are flexion, compression and Bohme abrasion tests.

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.

2.3.1. Mechanical experiments

The flexion 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 cube specimens were stored in tap or sulfated water until the day of testing. The flexion and compression tests on the

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 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 pozzolana	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 3
Physical properties of cements.

Samples	Initial setting times (min)	Final setting times (min)	Expansion according to Le Chatelier (mm)	Sieve analysis (%)	
				90 µ	200 µ
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

mortar cubes were conducted at 7, 28, 90, 180, 270, and 360 days. Six specimens were tested for each type of mixture at each testing age according to the Rilem-Cembureau method in EN 196.

On the other hand, the abrasion resistance of mortars is determined according to the Bohme method (in Turkish Standard of TS 699 [20]), which is the most commonly used method for determining this resistance in Europe. According to this method, the surface of the mortar is pressed onto a rotating steel plate via a constant load (Fig. 1). Twenty grams of abrasive sand is put between the mortar and the steel plate. The mortar specimen's surface is 40 mm × 40 mm and its height is 50 mm. Later, the plate is rotated 22 times and the specimen and plate are cleaned. This abrasion process is repeated 20 times for each specimen. Thus, the difference between the initial and final height of the specimen gives amount of abrasion.



Fig. 1. Bohme abrasion apparatus.

Table 4
The minerals studied in XRPD investigations and their JCPDS [9] card number.

Mineral name	JCPDS card number	Refs.
Ca ₆ Al ₂ (SO ₄) ₃ (OH) ₁₂ ·26H ₂ O (ettringite)	41–1451	Christensen et al. [5]
	37–1476	Abdel-Wahab [1]
	9–414	Perkins and ve Palmer [16]
CaSO ₄ ·2H ₂ O (gypsum)	33–311	Christensen et al. [5]
	6–0046	Perkins and ve Palmer [16]
CaSO ₄ (anhydride)	6–226	
Ca ₄ Al ₂ O ₇ ·19H ₂ O	14–628	Christensen et al. [5]
Ca ₂ Al ₂ O ₅ ·8H ₂ O		Christensen et al. [5]
Ca ₃ Al ₂ O ₆ ·CaSO ₄ ·13H ₂ O (monosulphate)	11–179	Abdel-Wahab [1]
Ca ₄ Al ₂ O ₆ (SO ₄)·14H ₂ O	42–62	Christensen et al. [5]
Ca ₃ Al ₂ (OH) ₁₂	24–217	Christensen et al. [5]

2.3.2. 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 nine 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, Ca₄Al₂O₇·19H₂O, Ca₂Al₂O₅·8H₂O, Ca₄Al₂O₆(SO₄)·14H₂O, Ca₃Al₂(OH)₁₂ mentioned in the Refs. [5,1,16], are also taken into consideration. JCPDS [9] card numbers of these minerals are given in Table 4.

2.3.3. 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(SO₄)₂ to tap water. Thus, a highly aggressive chemical environment, XA3 exposure class, is constituted according to EN 2006. This medium is renewed every month during a year.

3. Results and discussions

In this study, seven different mortars are first subjected to a sulfated medium and then to abrasive effects during 360 days. As a result of this, both structural and mechanical changes occur.

In this section, the deteriorations due to the sulfated medium are investigated first, and then the mechanical properties of mortars subjected to sulfate and abrasive effects together are discussed.

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. The visible deteriorations occur more obviously in the mortars that include the air-entraining agent, with a decrease in the compressive strength and an increase in the void ratio, which allow increased penetration of the sulfated water.

The deteriorations appear at a remarkable level in CI mortars. The CI (AE, SM) sample subjected to the sulfated medium and containing the air-entraining agent has a high amount of gypsum



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

Fig. 2. Deteriorations occurred in mortars.

mineral (Fig. 2). First cracks occurred in the early ages in this sample because the internal stress due to minerals is higher than the sample's flexural strength (approximately 12–14 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.

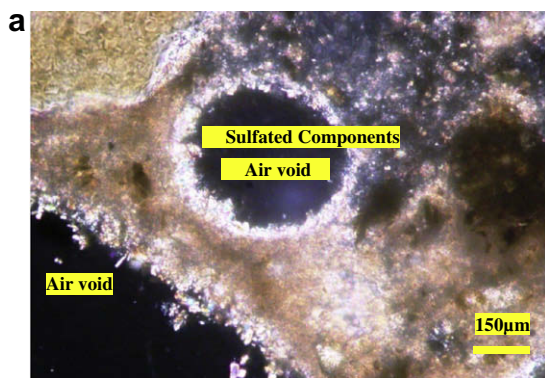
3.1.2. The micro deteriorations

After investigation of visible deteriorations, the micro deteriorations are studied via both thin-section investigation and X-ray Powder Diffraction (XRPD) analysis. Each of the 28 different samples is investigated with these two methods. However, a few samples that are damaged by a significant amount by sulfate are shown in the paper (Fig. 3). It is seen from these investigations that they especially form greater amounts in the samples cured in sulfated

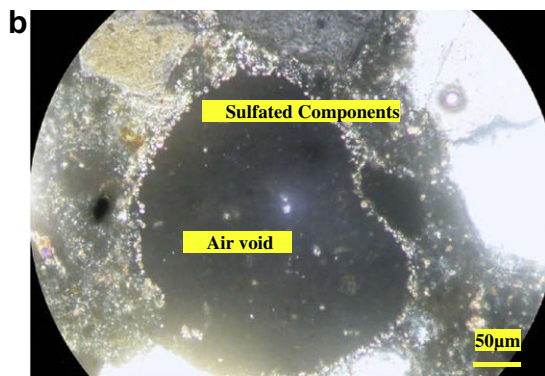
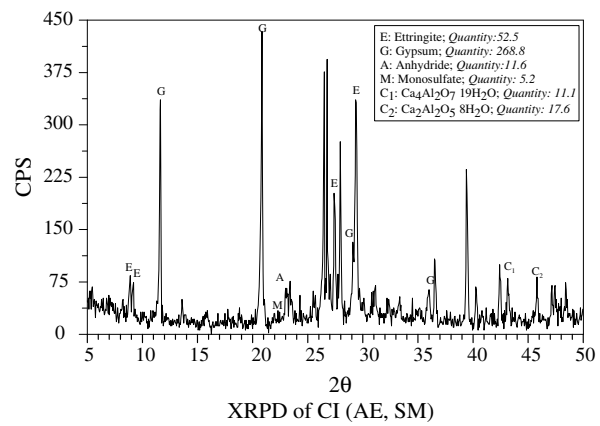
medium, although sulfated components (ettringite, gypsum, etc.) are formed in the mortar samples both in the sulfated medium and in tap water.

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. The minerals are identified using XRPD analysis.

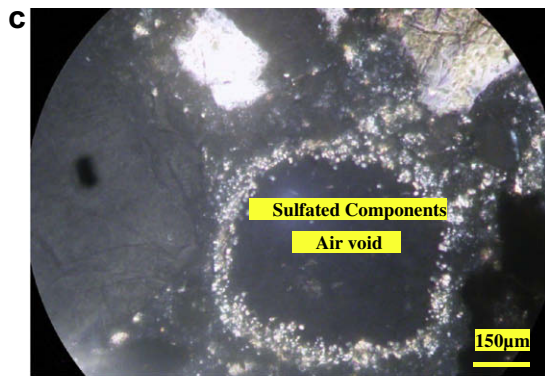
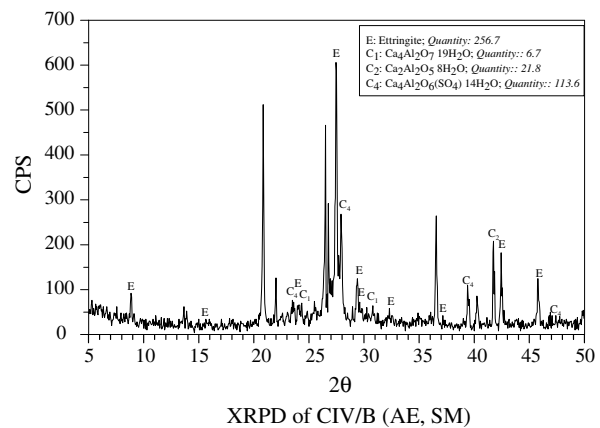
Both ettringite and gypsum minerals are formed in CI, Portland cement, and mortars that are cured in both sulfated and tap water mediums. However, the samples containing the air-entraining agent and cured in the sulfated medium (CI(AE, SM)) deteriorate more from sulfate, and this sample has more gypsum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



Thin section image of CI (AE, SM)



Thin section image of CIV/B (AE, SM)



Thin section image of CV/A (AE, SM)

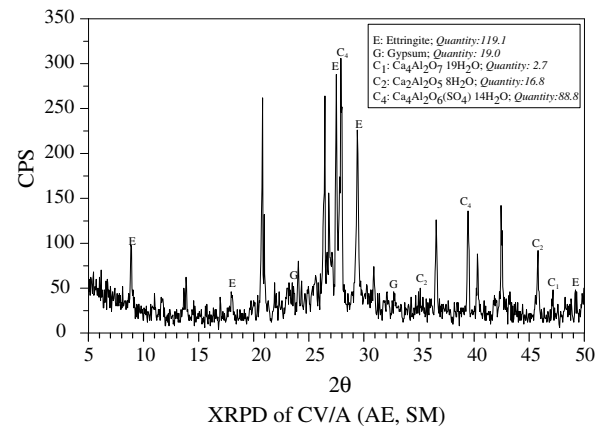


Fig. 3. Thin section images and XRPD of the deteriorated samples.

Table 5

Abrasion depth of the cement samples during a year.

Samples	AE content	Medium	7 days	28 days	90 days	180 days	270 days	360 days
CEM I	Non-AE	TW	7.70	6.12	5.20	4.66	4.56	4.15
		SM	7.80	6.50	5.30	4.12	4.05	3.24
	With AE	TW	18.02	13.14	7.60	5.05	5.36	4.90
		SM	17.5	14.08	11.40	9.80	–	–
CEM II/A-M	Non-AE	TW	10.5	9.12	6.10	4.16	4.00	3.91
		SM	10.8	9.50	6.90	5.00	4.16	4.25
	With AE	TW	14.00	12.10	7.90	6.50	5.76	5.51
		SM	13.89	10.15	7.30	5.74	5.01	5.03
CEM II/B-M	Non-AE	TW	9.26	7.47	5.60	4.89	3.98	3.96
		SM	9.80	7.67	5.90	5.00	3.93	4.25
	With AE	TW	15.84	13.20	8.70	5.96	4.43	4.91
		SM	15.39	13.60	9.40	6.98	5.38	5.96
CEM IV/A	Non-AE	TW	7.80	5.51	4.30	3.76	3.16	3.14
		SM	8.30	6.32	4.90	4.19	3.44	3.80
	With AE	TW	9.80	7.14	6.00	5.41	5.52	4.88
		SM	11.30	8.45	7.20	6.36	6.07	4.98
CEM IV/B	Non-AE	TW	11.10	8.76	6.75	5.00	4.01	3.60
		SM	10.40	7.76	7.30	6.96	4.86	5.05
	With AE	TW	10.20	8.25	7.10	6.50	5.59	4.77
		SM	11.05	9.95	8.45	7.56	6.52	7.75
CEM V/A	Non-AE	TW	11.25	9.53	7.40	6.52	5.38	5.30
		SM	10.76	7.92	7.10	6.70	5.76	5.34
	With AE	TW	15.20	13.29	8.70	7.00	6.62	6.70
		SM	14.80	13.23	9.30	7.94	7.60	7.48
CEM V/B	Non-AE	TW	9.90	9.17	6.90	5.10	5.26	5.30
		SM	9.31	8.45	6.50	5.30	4.76	4.35
	With AE	TW	14.75	12.95	9.40	7.45	7.26	7.25
		SM	17.30	15.40	10.30	7.66	8.01	7.95

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 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. 2 and 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.

3.2. Abrasion resistance of the cement mortars subjected to sulfate

In this section, the mortars produced are first cured in the sulfated medium and later subjected to abrasion via the Bohme apparatus. Abrasion depths of the sample curing are determined for 7th, 28th, 90th, 180th, 270th and 360th days (Table 5). The relationship between abrasion depth and curing time (Fig. 4 and Table 5), com-

pressive strength (Fig. 5), and flexural strength (Fig. 6) are discussed.

In general, the samples cured in sulfated medium of the mortars having air agent are abraded deeper, at a ratio of 6–27%, compared to the ones cured in water. The samples without air agent (3–23%) behave similarly. This shows that the differences of abrasion depth occurred owing to sulfate are higher in the samples having the air agent (Fig. 4). The samples cured in sulfated medium have more sulfated minerals; this is mentioned in previous sections. Consequently, it can be said that sulfated minerals decrease the abrasion resistance.

On the other hand, the samples containing air agent are abraded deeper, at a ratio of 22–37%, than the ones without the air agent. It is understood from this that increments of air agent content are more effective than the sulfated medium effect on abrasion resistance of mortars.

If thought abrasion depths, minimum abrasion depth (<3.5 mm) occurs in CI (non-AE, SM) and CIV/A (non-AE, W) samples at the end of the year (Fig. 4 and Table 5). From the other point of view, the deepest abrasion (>7.5 mm) occurs in the samples of CIV/B (AE, SM) and CV/B (AE, SM) (Fig. 4 and Table 5). Thus, it can be said that the content of the pozzolanic material is restricted to about 25–30%. If these materials are added to the cement more than this ratio, abrasion resistant is negatively influenced.

3.2.1. Relationship between abrasion resistance and curing time

If abrasion depths of all the samples without considering their composition are determined, it is seen that the abrasion depth shortens by extending the curing time (Table 5 and Fig. 4). This means abrasion resistance increases. While abrasion depths of four types of mortars (with/without air agent and sulfated/tap water medium) produced from every different type of cement are far from each other in the initial days, these values approach each other at the end of a year. The samples are projected to reach

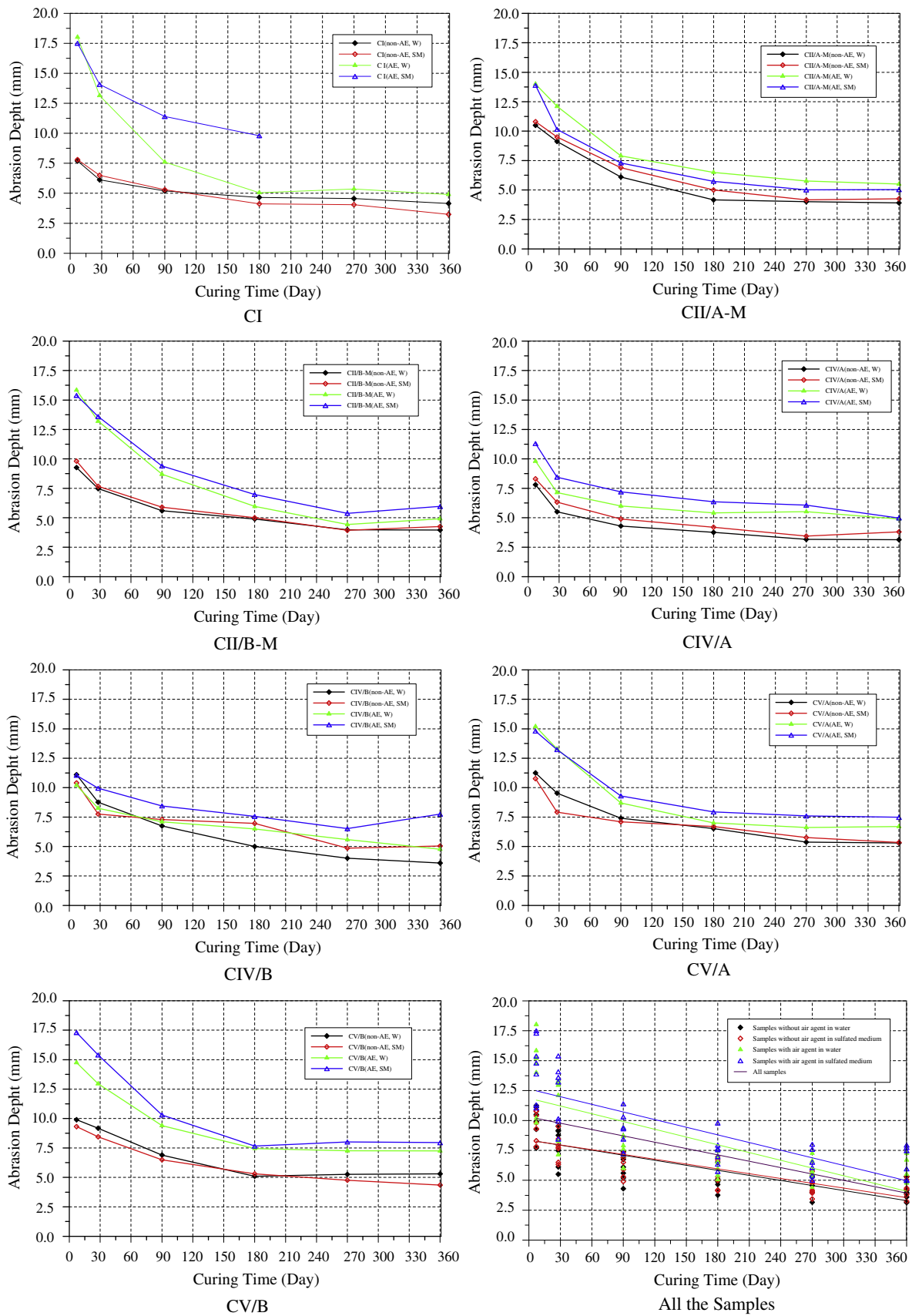


Fig. 4. Relationship between abrasion depth and curing time.

ultimate abrasion depth in 6–9 months. This means the abrasion resistances of the samples improve more slowly after 6–9 months.

If all the mortars are evaluated at the same time, the mortars containing the air agent are abraded more deeply than the ones

with the non-air agent in initial days by about 8% and after a year by about 20%. The samples cured in sulfated medium are also abraded deeply by about 13% compared to samples cured in water at the end of the year. However, sulfate slightly influenced the compact mortars effect on abrasion. The correlation coefficient of the curves in Fig. 4 is about 75–85%, and the curve representing all the samples is about 75%.

3.2.2. Relationship between abrasion resistance and compressive strength

It is seen clearly that abrasion depths decrease as the compressive strengths increase for all the mortar samples (Fig. 5). As compressive strengths of the samples containing air agent increase by about five times, their abrasion depths decrease in a ratio of 2/3. These decrease slower for the samples without air agent.

The correlation coefficient of the curves in Fig. 5 is about 70–80% and the correlation coefficient of the curve for all the samples is about 65%.

3.2.3. Relationship between abrasion resistance and flexural strength

Similar to compressive strength, as flexural strength increases, the abrasion resistance increases, or the abrasion depth decreases (Fig. 6). Abrasion depths of the samples in sulfated medium are slightly greater than the samples in water. The correlation coefficient of the curves in Fig. 5 is about 75–85% and the coefficient for all the samples is about 70%.

3.2.4. Relationship between abrasion resistance and pozzolanic components

In this section, the relationship between abrasion depth and the pozzolanic components content is investigated for the samples at the end of the year. It is seen from Fig. 7 that there is a relationship between mineral components and abrasive resistance or depth. In addition, an important factor that influences this relation is curing time. In general, an increase of clinker, limestone and silica fume contents decrease the abrasion depth of cement mortars at the end of the year. Conversely, if the blast-furnace slag, natural

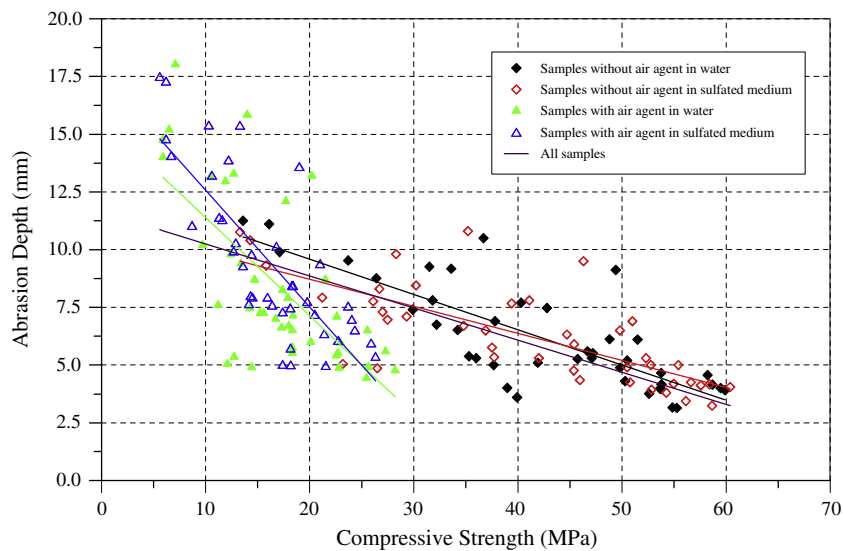


Fig. 5. Relationship between abrasion depth and compressive strength.

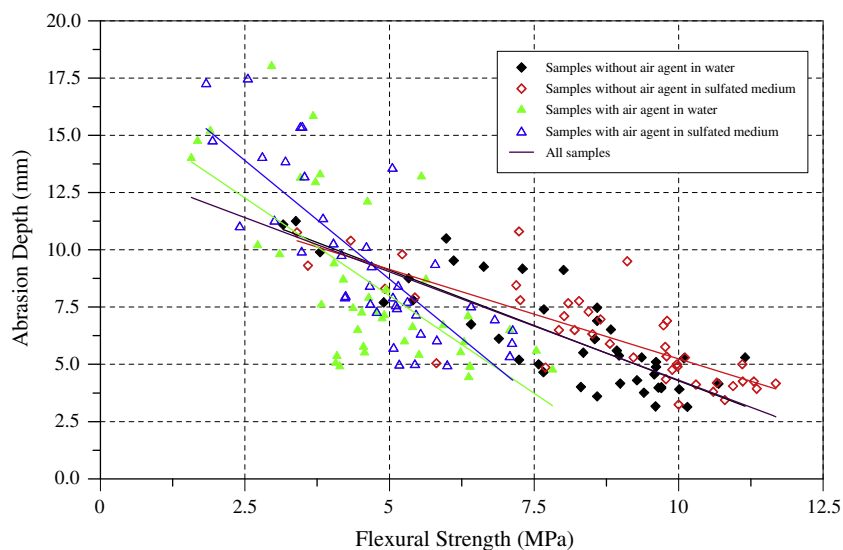


Fig. 6. Relationship between abrasion depth and flexural strength.

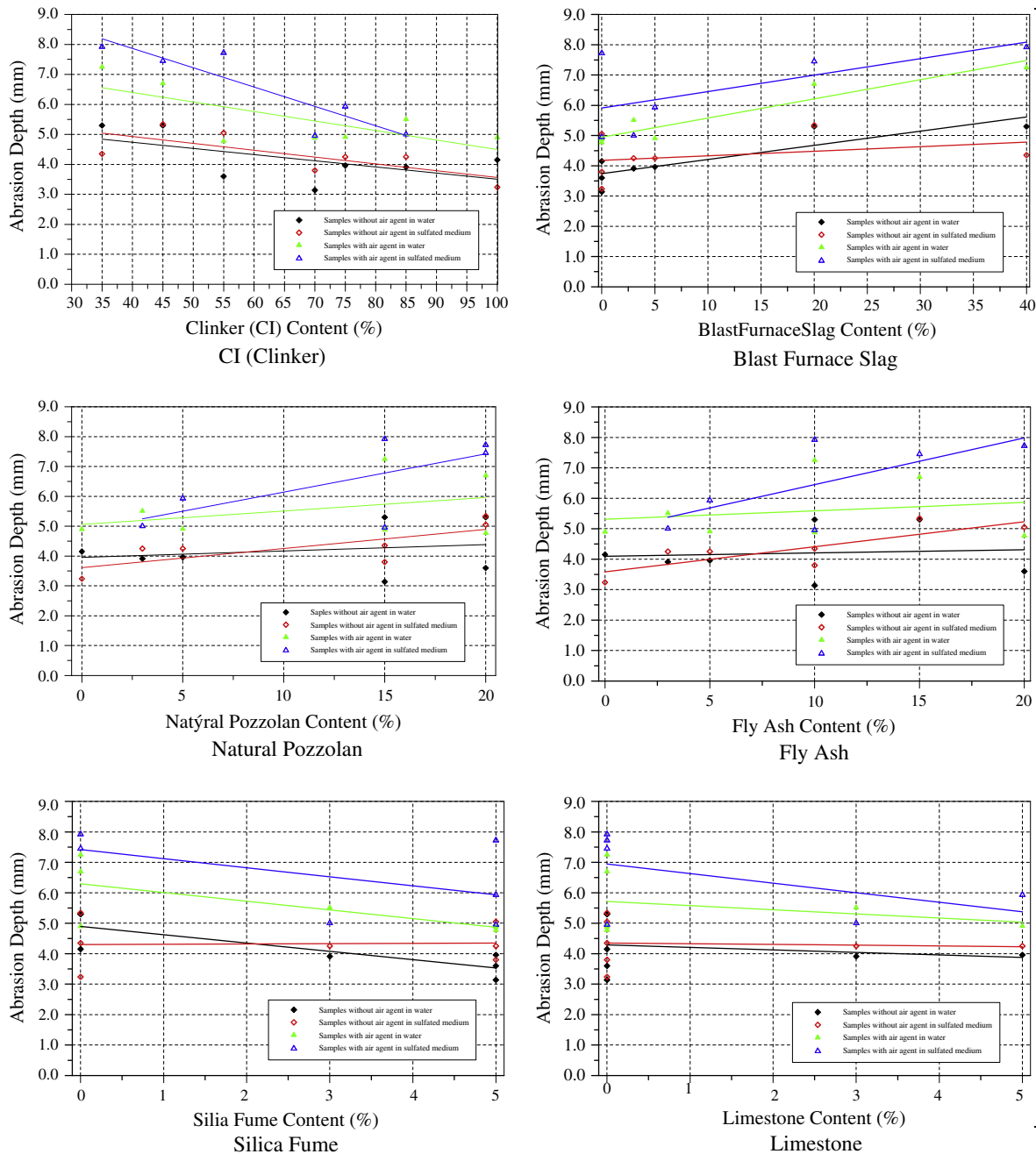


Fig. 7. Relationship between abrasion depth and pozzolanic components content at the end of a year.

pozzolan and fly ash contents are increased, this depth increases for the samples cured in a year. These results parallel the compressive and flexural strength of these samples. The negative effects occur more evidently in the samples cured in sulfated medium.

3.2.5. Relationship between abrasion resistance and chemical compositions

CaO component contribute to the abrasion resistance of the mortars over the course of a year, as do ultimate strength and resistance (Fig. 8). SiO₂ and Al₂O₃ components decrease the abrasion resistance or deepen the abrasion depth in the samples, whether or not they contain the air agent. The samples cured in sulfated medium incur more abrasion resistance losses than the ones cured in water by increasing the SiO₂ and Al₂O₃ content. On the other hand, abrasion resistance losses of the samples within

the sulfated medium are less than the samples in water, while CaO content increases. It is seen that the relations between chemical component in question and abrasion are similar to the relation between compressive strength and chemical components.

4. Conclusions

In this study, the abrasion resistance of the cement mortars having different a pozzolanic composition and matrix are subjected to mediums containing sulfate is 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 void ratio; consequently there is an increase

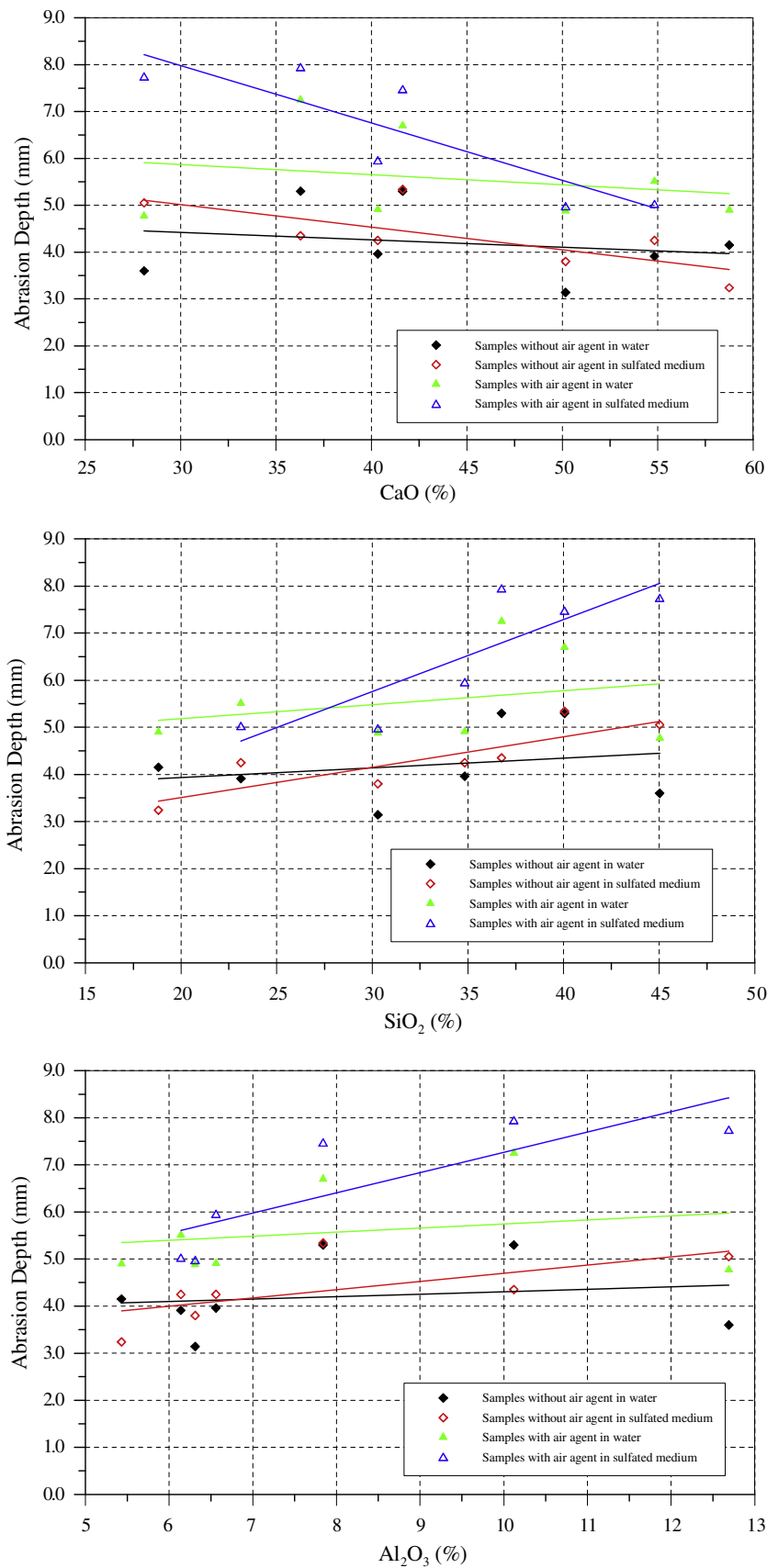


Fig. 8. Relationship between abrasion depth and chemical components content at the end of a year.

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.

After all the comparisons, it can be said that abrasion depths of the samples decrease while the curing time increases. Compressive strength and flexural strength increase relative to the curing time. The samples approach the ultimate abrasion depth or abrasion resistance in 6–9 months.

In general, the samples cured in sulfated medium of the mortars having the air agent are abraded deeper at a ratio of 6–27% compared to the ones cured in water. Similarly, the samples without air agent are abraded to a greater depth (3–23%). This shows that the differences of abrasion depth occurred owing to sulfate are higher in the samples having the air agent. On the other hand, the samples having air agent are abraded deeper at a ratio of 22–37% than the ones without air agent. It is understood from here that the increment of air agent content is more effective than the sulfated medium effect on the abrasion of mortars. The ettringite and gypsum minerals occur in the sulfated medium abundantly. It is thought that this result is an effect that increases abrasion depth.

The highest pozzolanic material ratio is restricted to about 25–30% by mass because this ratio is a boundary of abrasion resistance. The increase of clinker, limestone and silica fume ratios increases the abrasion resistance at the end of the year. On the other hand, blast-furnace slag, natural pozzolan and fly ash conversely affect the resistance. Negative effects on abrasion resistance occur more evidently in the samples cured in sulfated medium.

The samples cured in sulfated medium incur more abrasion resistance losses than the ones cured in water by increasing SiO_2 and Al_2O_3 content. On the other hand, abrasion resistance losses of the samples within the sulfated medium are less than the samples in water, while CaO content increases.

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