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Research Article

Short-term Effects of Sodium Sulfate and Sodium Chloride Solutions on The Strength and Durability Properties of Hardened Mortars

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Abstract

This study provides an insight for investigating the short-term effects of sodium sulfate and sodium chloride concentrations on the strength and durability characteristics of hardened mortars. For this aim, a comprehensive experimental campaign was conducted on 16 groups of mortar specimens, which were produced with and without reinforcing bars and cured in different environments such as air, water, sodium sulfate and sodium chloride solution. The 12 groups of the specimens, which were produced without reinforcing bars, were then subjected to flexural strength, compressive strength, unit weight, volumetric water absorption, capillary water absorption, ultrasound velocity and length change tests weekly between 7th and 77th days. The remain 4 groups of the specimens, which were produced with reinforcing bars, were then subjected to corrosion activity tests. The destructive and nondestructive test results showed that the specimens were produced with high water/cement ratio and then exposed to NaCl and Na_2SO_4 concentration has lower strength and durability characteristics than that of the specimens produced with normal water/cement ratio were exposed or not exposed to NaCl and Na_2SO_4 concentration.

Keywords: Chloride effect, Concrete, Corrosion, Durability, Mortar, Strength, Sulfate effect.

Sodyum Sülfat ve Sodyum Klorür Çözeltilerinin Sertleşmiş Harçların Dayanım ve Dayanıklılıkları Üzerindeki Kısa Süreli Etkileri

Öz

Sodyum sülfat ve sodyum klorür çözeltilerinin, sertleşmiş betonun dayanım ve dayanıklılığı üzerindeki uzun süreli etkilerini belirlemek için yapılan çalışmaların sayısının fazla olmasına rağmen, bu çözeltilerin sertleşmiş betonun dayanım ve dayanıklılığı üzerindeki kısa süreli etkilerini belirlemek için yapılan çalışmaların sayısı ve kapsamı oldukça dardır. Kapsamı dar olan bu konuda, sodyum sülfat ve sodyum klorür çözeltilerinin kısa süreli olarak sertleşmiş betonun dayanım ve dayanıklılığına ne yönde etki edeceğini belirlemek için bu deneysel çalışma yapılmıştır. Bu çalışma kapsamında, 16 grup sertleşmiş harç numunesinin 4 grubu donatılı ve 12 grubu donatısız olarak üretilmiştir. İki farklı karışım (standart harç ve özel harç) dikkate alınarak üretilen bu numuneler hava, su, sodyum sülfat ve sodyum klorür çözeltisinde kür edildikten sonra teste tabi tutulmuşlardır. Üretilen numunelerin 12 grubu (bunlar donatısız olarak üretilmiş numuneler) üzerinde eğilme ve basınç dayanımı tayini, birim ağırlık değişimi, hacimsel ve kılcal su emme kapasitesi tayini, ultra ses hızı ve boy değişimi tayini deneyleri, kalan 4 grup numune (bunlar donatılı olarak üretilmiş numuneler) üzerinde ise korozyon aktivitesi testi yapılmıştır. Yapılan deneyler sonucunda elde edilen verilere göre, kısa süreli olarak sodyum sülfat ve sodyum klorür çözeltilerine maruz kalan ve yüksek su/çimento oranına sahip sertleşmiş harç numunelerin dayanım ve dayanıklılık karakteristiklerinin normal su/çimento oranına sahip ve bu çözeltilere maruz kalan veya kalmayan numunelerden daha az olduğu görülmüştür.

Anahtar Kelimeler: Beton, Dayanım, Dayanıklılık, Klor etkisi, Korozyon, Sertleşmiş harç, Sülfat etkisi.

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1. Introduction

Sulfate and chloride ions in soil, ground water, sea water and environment cause decay of concrete structures particularly marine structures because of sulfate and chloride attack. Since those ions have been a challenging problem for the structural elements of marine and offshore structures (Neville, 1995; 2004).

Steel reinforcing bars in concrete is shielded from corrosion by the formation of a passive iron oxide film layer which is sustained by the extreme alkalinity of the cement hydrates. Loss of protection occurs if either the alkalinity is lowered to a level at which the passivating film is no longer stable or when corrosion inducing unbound chloride ions are present deficient concentrations in the pore solution of the concrete (Dehwah et al. 2002). This suggests that depassivation is partly manage by the relative concentrations of free corrosion-inducement chloride ions and corrosion inhibiting hydroxyl ions in the pore water of hardened mortar paste. Hence, factors which influence the concentrations of the free chloride and hydroxyl ions in the pore solution are undeviatingly associated in determining corrosion risk (Hansson et al., 1985; Hussain et al., 1994; Andrade and Alonso, 2001; Lee et al., 2002; Fang et al., 2006). Passivation layer of reinforcing steel bar will be assaulted by chloride ions, and disturbance of passive film will start corrosion of reinforcing steel bar, initiating corrosion damage. When the amount of corrosion products might be six times more than the amount of iron, this development of corrosion in hardened concrete causes tensile stress in the hardened mortar that leads to splitting, spalling and loss of cover concrete, and last but not least critical deterioration of structural concrete (Mansfeld, 1981). In addition to structural concrete deterioration, the reduction of the steel cross section and bond strength are all possible results of reinforcing bar corrosion that can prompt to serviceability problems and structural failures (Fig 1). According to the obtained observational and experimental results, chloride-induced corrosion of reinforcing bar in reinforced concrete structures has turned into a broad durability problem many of the structures in the world (Andrade and Alonso, 2001). It is currently certain that it is not the total quantity of chloride in concrete, but the free chloride remaining in the pore solution that is responsible for the corrosion of reinforcing bars. And it is realized that the danger of corrosion increments with a higher proportion of chloride ion to hydroxyl ion concentration in the pore solution (Page et al., 1983). Therefore, the chloride ion concentrations are directly relevant in determining the corrosion risk. As seen in Fig.1, the reinforcing bars of structural elements of Güllük pier exposed to corrosion damage. The corrosion damages stemmed from chloride ions (Elsener and Bohni, 1992; Elsener, 2002; Elsener et al., 2003; Baradan et al., 2013).

Fig. 1 *Corrosion damage at Güllük pier (Baradan et al., 2013)*

Sulfate attack is the more regular type and typically occurs where water containing dissolved sulfate penetrates the concrete. Before the sulfate attack, the concrete of reinforced concrete structures is regularly seen in cleaned segments typically. After the sulfate attack reaction, the segments of the concrete change, because the concrete matrix of the structures may be attacked by sulfate ions (Liu and Weyers, 1998). At the point of view, when the sulfate ions diffuse in pores of the concrete, chemical reaction between the hydration solution of the concrete and sulfate ions may occur. Subsequently, ettringite crystal may nucleate and develop in the pores of the concrete matrix, and this kind of ettringite is likewise called "postponed ettringite". The development strengths in the reinforced concrete induced by ettringite crystal may prompt to the micro-macro crack and loss of bonding not only between the hardened cement paste-aggregate but also between the concrete-reinforcing bars in the reinforced concrete structures (Zhu et al., 2008; Sirisawat et al., 2014; Xiong et al., 2015). As seen in Fig. 2, a prefabricated beam exposed to sulfate attack damage. These micro and macro cracks in the prefabricated beam stemmed from sulfate ions. Additionally, by the nearness of chloride ions in the nature, expander impact has been made by the sulfate ions are known to diminish with Friedel salt development (Han, 2007).

The deterioration of reinforced concrete structures due to sulfate and chloride attacks, a lot of experimental (long-term effects of those ions) and theoretical study have been carried out on these subjects. The detrimental effects of sulfate and chloride on the hardened mortars, mortars and cement paste has been studied by many researchers (e.g., Gollob and Taylor, 1994; Rasheeduzzafar et al., 1994; Akoz et al., 1999; Brown et al., 2000; Glass et al., 2000; Valls et al., 2001; Hekal et al., 2002; Al-Dulaijan et al., 2003; Kurdowski W., 2004; Neville A., 2004; Zuquan et al., 2007; Tosun et al., 2009; Song et al., 2009; Pack et al., 2010; Piasta et al., 2011; Kunther et al., 2013; Jasniok et al., 2014; Boutiba et al., 2015; Czapik and Owsiak, 2016; Grabowska and Malolepszy, 2016). In state-of-art, to the best of the authors' knowledge, a few researchers conducted experimental study about the short-term effect of sodium sulfate and sodium chloride ions on the strength and durability properties of hardened mortar specimens. Therefore, in this experimental study, the short-term effects of NaCl and Na_2SO_4 solutionss on the strength and durability properties of hardened mortar specimens were investigated and the test results were presented in the fallowing sections.

Fig. 2 *Micro and macro cracks in a prefabricated beam (Baradan et al., 2013).*

2. Aim and Scope

An experimental study was conducted at Building Material Laboratory (BML) of Yildiz Technical University (YTU) for investigating the strength and durability properties of the standard and specific hardened mortar specimens were exposed to NaCl and Na_2SO_4 solutions. In the scope of the study, 16 groups mortar specimens were constructed and cured different conditions. Furthermore, destructive (flexural strength, compressive strength tests) and nondestructive (unit weight, volumetric water absorption, capillary water absorption, ultrasound velocity, length change, and corrosion tests) were then conducted on the specimens weekly between 7th and 77th days.

3. Specimen details and material properties

For evaluation of the short-term effects of Na_2SO_4 and NaCl concentrations on the strength and durability properties of the hardened mortar specimens, 16 group specimens with dimensions 40×40×160 mm were constructed with and without reinforcing bars (Fig. 3c). To investigate the influence of NaCl concentration on the hardened mortars, the specimens produced with reinforcing bars and the NaCl solution was not only added to mixing water of the half of the 4 groups of the specimens but also half of the specimen cured in NaCl solution. The NaCl solution was not added to mixing water of the remain part of the 4 groups specimen and the specimens also cured in air. The properties of used reinforcing bars were S220 type of steel and 8 mm diameter. The specimens produced without reinforcing bars were cured in different environment such as water and Na_2SO_4 solution. In addition to that the amount of NaCl concentration in mixing water is 40000 mg/L and the amount of Na_2SO_4 concentration in cure condition is 40000 mg/L. Chemical analysis results of the NaCl and Na_2SO_4 ions are given in Table 1a.

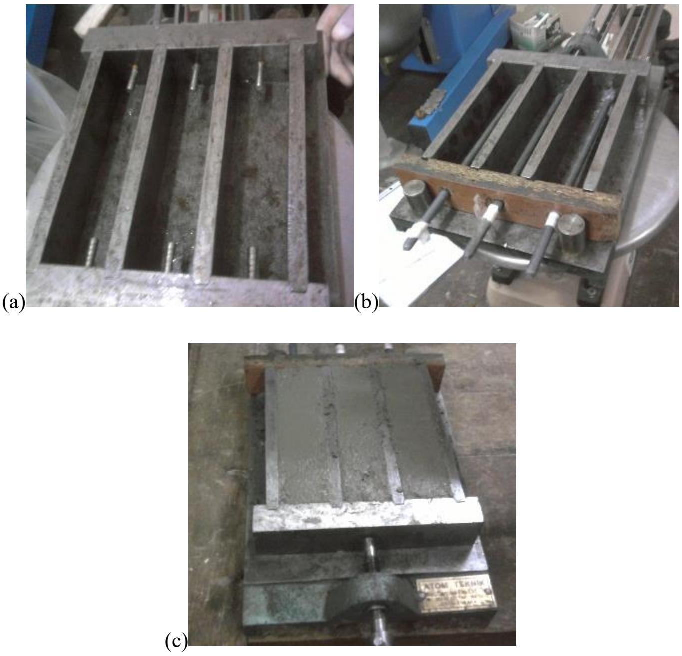

Fig. 3 *Mold of specimens (a) Without reinforcement, (b) With reinforcement, (c) General appearance*

Furthermore, in this experimental campaign, two different mortar mixture such as standard and specific mortar were used. Water/Cement (w/c) ratios of standard and specific mortar mixtures are 0.5 and 0.8, respectively. The standard mixture consists of 1350 g standard CEN sand, 450 g CEM-I 42.5N cement, 225 g water and the specific mixture contains 1350 g standard CEN sand, 450 g CEM-I 42.5N cement, 360 g water. Chemical, physical properties of the cement and sieve analysis of the standard CEN sand are given in the following Table 1b and 1c, respectively. In addition to that the cement was used in the mortar mixture compositions was suitable for TS EN 197-1 according to its physical and chemical properties.

Table 1 (a) *Chemical analysis of NaCl and Na_2SO_4, (b) Physical and chemical properties of cement, (c) Sieve analysis of sand*

Chemical analysis of sodium sulfate		Chemical analysis of sodium chloride	
Ph değeri (%5 water)	Min 5.2-8.0	Ph	5-7,5
Cl	Max %0.001	Br	<0,005 %
PO_4	Max %0.001	$Fe(CN)_6$	<0,0001 %
N	Max %0.0005	I	<0,001 %
Pb	Max %0.0006	PO_4	<0,0025 %
As	Max% 0.0001	SO_4	<0,01 %
Ca	Max% 0.005	Pb	<0,0005 %
Fe	Max % 0.0005	NH_4	<0,002 %
K	Max & 0.002	As	<0,0001 %
Mg	Max % 0.001	Ba	<0,001 %
		Cu	<0,002 %
		Fe	<0,0002 %
		K	<0,01 %
		Mg	<0,001 %

(a)

Physical properties of cement		Chemical properties of cement	
Specific surface (m^2/kg)	328	Components	%
Residue on 90 lm (%)	0.20	SiO_2	20.63
Residue on 200 lm (%)	0.00	$Al2O_3$	4.71
Specific weight (g/cm^3)	3.16	Fe_2O_3	3.41
Normal consistency water (%)	30%	CaO	63.64
Total volume expansion mm	2.50	MgO	1.24
Initial setting time h:min	2.30	SO_3	2.98
Final setting time h:min	4.00	K_2O	0.91
		Na_2O	0.23
		Cl	0.03
		TiO_2	0.31
		LOI	2.75

(b)

Mesh Width	Retained on sieve (%)
0.08	98
0.16	87
0.50	67
1.00	33
1.60	9
2.00	0

(c)

A simple notation was used for the designation of the test specimens (Table 2). The first character represents the standard mixture (M1) and specific mortar (M2) compositions, the second numeral indicates the cure conditions such as water (W), air (A) and sulfate solution (S). In addition to that the Cl denotes the addition of NaCl solution to the mixing water of the M1 and M2 mixtures. Hence, the specimen name "M2A" indicates the specimen was produced with specific mortar and cured in air, respectively.

***Table 2** Notation of the specimens*

M1W :	Produced with standard mortar and cured in water	**M2W :**	Produced with specific mortar and cured in water
M1S :	Produced with standard mortar and cured in Na_2SO_4 solution	**M2S :**	Produced with specific mortar and cured in Na_2SO_4 solution
M1Cl :	Produced with standard mortar and reinforcing bars, addition of NaCl to the mixing water	**M2Cl :**	Produced with specific mortar and reinforcing bars, addition of NaCl to the mixing water
M1A :	Produced with standard mortar and cured in Air	**M2A :**	Produced with specific mortar and cured in Air

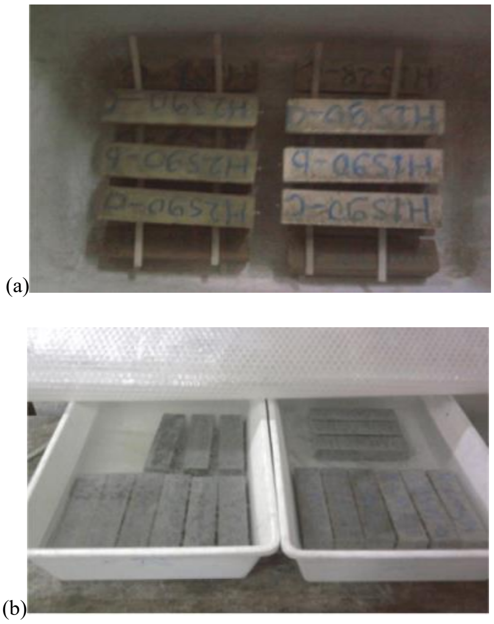

***Fig. 4** General appearance of specimens, (a) Curing in sulphate solution, (b) Curing in water*

4. Evaluation of experimental results

The parameters under investigation included mortar mixture compositions (standard and specific), cure conditions such as Na_2SO_4 solution, air, water and addition of NaCl to the mixing water, aiming to determine how these factors influence the compressive strength, flexural strength, unit weight, corrosion activity, length change, ultrasound velocity, volumetric water absorption and capillary water absorption of the hardened mortar specimens.

4.1 Unit weight of hardened mortar

Unit weight tests were conducted on M1W, M2W, M1S and M2S specimens at 7^{th}, 28^{th} and 77^{th} days. The unit weight values of the specimens were calculated using Eq. (1).

$$\beta = \frac{W}{V} \qquad (1)$$

where *W (gr)* is the weight of the specimens, *V (cm^3)* is the volume of the specimens. The obtained unit weight-time relationships of the specimens are shown in Fig 5b. As seen from the figure, unit weight of M1W and M1S specimens are higher than that of the M2W and M2S specimens. It should be noted from the results that the high w/c ratio had a significant adverse effects on the unit weight of the specimens. It can also be concluded from the figure that as the w/c ratio decreased the unit weight value of the specimens increased regardless from the curing conditions (Fig. 5b). The test results further indicated that the M2W and M2S specimens has a hallow structure resulting from the high w/c ratio. It is also obvious from the figure that while the unit weight values of standard mortar specimens, which were cured in water and sulfate solution, decreased until the 28^{th} test days, the unit weight values of the specific mortar specimens, which were cured in water and sulfate solution, increased till the 28^{th} test day. After the test day, although the unit weight values of the standard mortar specimens increased rapidly, the unit weight values of the specific mortar specimens were almost same until the 77^{th} test day.

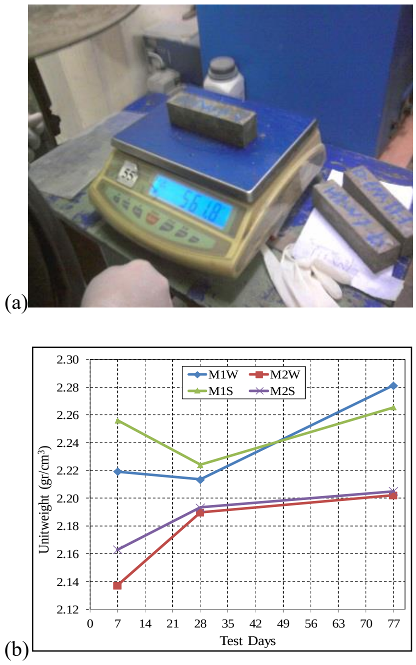

***Fig. 5** (a) Test setup, (b) Test results of unit weight*

4.2 Ultrasound velocity of hardened mortar

Ultrasound velocity (UV) tests were conducted on M1W, M2W, M1S and M2S specimens at 7^{th}, 28^{th} and 77^{th} days. The UV values was obtained based on the tests on the rectangular prism specimens (40×40×160 mm). The UV values of the specimens were calculated using Eq. (2).

$$V(km/s) = \frac{S}{t}10^3 \qquad (2)$$

In this equation, *S*, *t* and *V* refer to the distance between probes (km), the duration of the ultrasonic waves pass through the specimen (s) and the ultrasonic pulse velocity (km/s), respectively. The UV values of the specimens are shown in Fig. 6b. As seen from the figure, the UV values of the M1W and M1S specimens are higher than that of the UV values of the M2W and M2S specimens and the result is mostly valid on all test days. It can also be concluded from the results that not only high w/c ratio but also curing condition (sulfate solution) had a negative impact on the UV values of the specimens. It was also obvious from the figure that while the UV values of the standard mortar specimens cured in water were almost similar until the last test day, the UV values of the standard mortar specimens cured in sulfate solution decreased to result the sulfate attack after the 28^{th} test day. It should be also clearly noted that the UV values decreased with the increasing w/c ratios and curing in sulfate solution. These results can be explained by the porosity of mortar causes a decrease in the ultrasound wave propagation. According to the evaluation of UV values based on the "Recommendations for Testing Concrete by The Ultrasonic Pulse Method" reported by Jones and Facaoaru (1969), it can be indicated that while the 4km/s of UV indicated fair quality mortar strength and did not contain important cracks and gaps, the 3km/s of UV indicated poor quality mortar strength and consisted of crack and gaps.

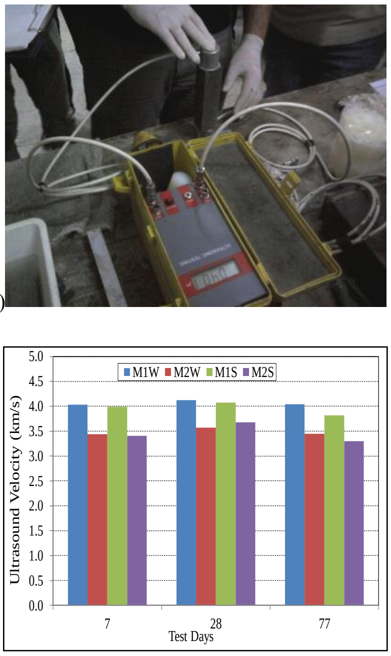

Fig. 6 *(a) Test setup, (b) Test results of ultrasound velocity*

4.3 Length change of hardened mortar

Length change tests were conducted on M1W, M2W, M1S and M2S specimens between 7th and 77th days from week to week. The length change values of the hardened specimens are presented in Fig. 7b. As seen from the figure, the length change values of the M1S and M2S specimens are higher than that of the length change values of the M1W and M2W specimens. Furthermore, while the length change values of the M1W and M2W were different until the 21th test day, the length change values of the specimens were almost similar after the test day (21th day). It can also be concluded from the results that the high w/c ratio did not have an adverse effect on the length change of the specimens. It was also obvious from the figure that while the length change values of the specimens with the except of M2W and M2S decreased until the 21th test day, the length change values of all specimens increased after the 21th test day. But the increasing ratio of the length change value of the M2S specimen was the highest ratio in the all specimens. Because not only curing in sulfate solution but also high w/c ratio had an adverse impact on the M2S specimen. These results can be explained by the permeable structure of the specimens, which were produced with high w/c ratio and cured in sulfate solution.

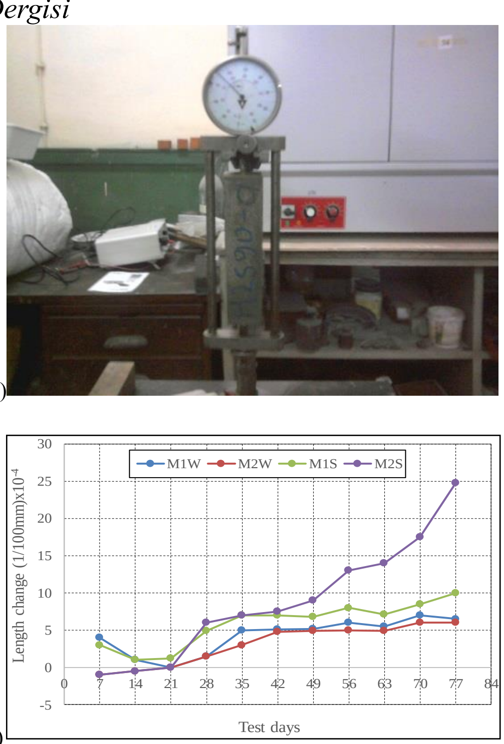

Fig. 7 *(a) Test setup, (b) Test results of length change*

4.4 Compressive strength of hardened mortar

Compressive strength test was performed on M1W, M2W, M1S and M2S specimens. The compressive strength value of the specimens is shown in Fig. 8b. As seen from the figure that the compressive strength value of the standard hardened mortars was higher than that of the specific hardened mortar specimens. It can be concluded from the results that the w/c ratio had an important impact on the compressive strength of the specimens. While the compressive strength of the specific mortar specimens increased until the 28th test day, the compressive strength value of the specimens decreased to result from the sulfate ions attack in the hardened mortar composition after the test time. Furthermore, the test results indicated that the sulfate ion has the positive impact on the compressive strength of the standard hardened mortar specimen. The result can also be explained by the fact that the sulfate ion in the hardened mortar specimens structure filled in the gaps of the specimens. It was also obvious from the figure that the compressive strength of the standard hardened mortar specimens increased regardless from the cure conditions until the last test day (77th day). The test results also indicated that impact factor of the w/c ratio was more important than that of the cure condition on the compressive strength behavior of the specimens.

The compressive strength of the concrete can be determined by ultrasonic wave velocity within a concrete structural element is measured with an appropriate equipment speedily, reliably and economically, without any harm to the building (Bal et al., 2008). To obtain the characteristic compressive strength of concrete with non-destructive tests, an empirical formula is proposed by Uyanik and Tezcan (2012) (Eq. 3).

$$f_{ck} = 2.6V^{1.8} \qquad (3)$$

In this equation, V and f_{ck} refer to the ultrasound velocity (km/s) and characteristic compressive strength of concrete (MPa).

The ultrasound velocities of the standard and specific hardened mortar specimens (a total of 48 specimens) were measured by an ultrasound wave recording instrument as explained in detail in previous section 4.2, afterwards these specimens were subjected to compression test with the universal testing machine at the BML of YTU (Fig. 8a). The obtained compressive strength values by the Eq.3 and compression tests of the specimen are given in Table 3.

Table 3 *Compressive strengths (MPa)*

	f_{ck} (Experimental)				f_{ck} (Calculated from Eq.3)			
Test Days	M1W	M2W	M1S	M2S	M1W	M2W	M1S	M2S
7th	22.43	8.29	28.34	6.22	31.95	24.03	31.39	23.66
28th	28.31	19.85	29.97	16.69	33.25	25.69	32.53	27.13
77th	32.09	12.78	36.83	12.62	32.10	24.16	29.02	22.30

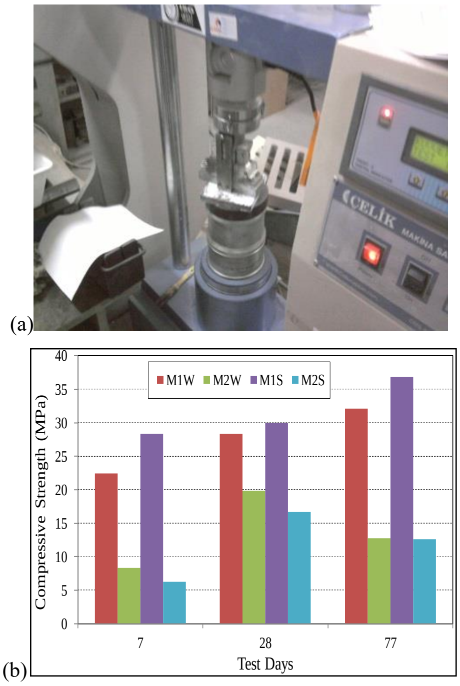

Fig. 8 *(a) Test setup, (b) Test results of compressive strength*

According to the determined results, the w/c ratio has an important impact on the compressive strength behavior of the specimens under the axial load regardless from the cure conditions (sulfate solution and water). It was also obvious from the Table 3 that the compressive strength of standard hardened mortar specimens was estimated better than the specific hardened mortar specimens by the Eq. 3. Especially, the experimental compressive strength in 77th of M1W was almost similar with the compressive strength of M1W calculated by Eq. 3. On the basis of these results, the w/c ratio made a negative effect on the estimation of compressive strength between the experimental and equational results (Table 3).

4.5 Flexural strength of hardened mortar

Flexural strength test was performed on M1W, M2W, M1S and M2S specimens. The test results of the specimens are given in Fig. 9b. As seen from the figure that the flexural strength value of the standard hardened mortars was higher than that of the specific hardened mortar specimens. It can be concluded from the results that the w/c ratio had a significant effect on the flexural strength of the specimens. Although the flexural strength of the specific mortar specimens especially cured in sulfate solution increased until the 28th test day, the flexural strength value of the specimens decreased to result from the sulfate attack after the 28th test day. The test results also indicated that the sulfate ion has the positive impact on the flexural strength of the standard hardened mortar specimen. The result can also be explained by the fact that the sulfate ion in the hardened mortar specimens structure filled in the gaps of the specimens.

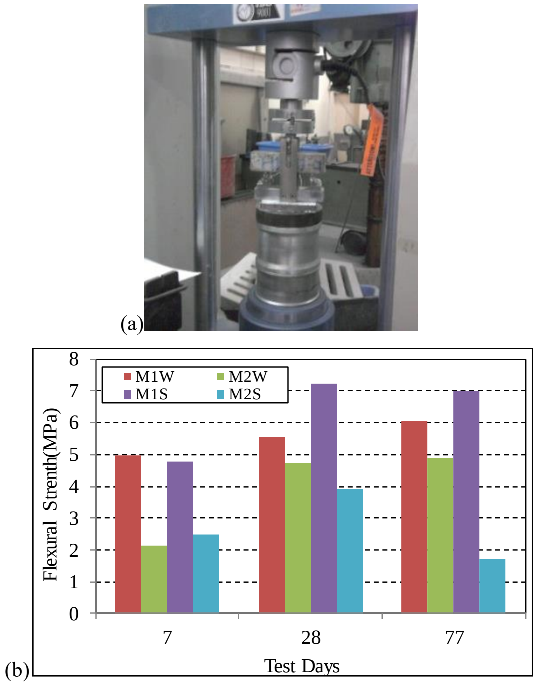

Fig. 9 *(a) Test setup, (b) Test results of flexural strength*

The situation was not valid for the specific hardened mortar specimens. Because the flexural strengths of the specific hardened mortar specimen cured in sulfate solution was the lowest at the end of the test. It was also obvious from the figure that the flexural strength of the standard hardened mortar specimens increased regardless from the cure conditions until the last test day (77th day). It should also be noted that although the sulfate solution has a positive effect on the flexural strength of the standard hardened mortar specimens, the compound of the high w/c ratio and sulfate solution has an important adverse effect on the flexural strength behavior of the specific hardened mortar specimens.

4.6 Volumetric water absorption of hardened mortar

Volumetric water absorption (V_w) tests were conducted on M1W, M2W, M1S and M2S specimens at 7th, 28th and 77th days. The test values of the specimens were calculated using Eq. (4).

$$V_w = \frac{W_{wa} - W_0}{W_{wa} - W_{ww}} \cdot 100 \qquad (4)$$

where V_w denotes the volumetric water absorption, W_{wa} is the weight of saturated specimen in air, W_0 is dry weight of the specimen and W_{ww} is the weight of saturated specimen in water. The obtained volumetric water absorption capacities of the specimens are shown in Fig 10. As seen from the figure, the V_w of the specific hardened mortar specimens are higher than that of the

V_w of the standard hardened mortar specimens. It should be noted from the results that not only the high w/c ratio but also curing condition (sulfate solution) had a significant adverse effects on the V_w of the specimens. It can also be concluded from the figure that as the w/c ratio decreased the V_w ratio of the specimens decreased regardless from the curing conditions (Fig. 10). The test results further indicated that the M2W and M2S specimens has a hallow structure resulting from the high w/c ratio. It is also obvious from the figure that the V_w of the standard hardened mortar specimens, which were cured in water and sulfate solution, was almost similar till the end of the test days. Moreover, while the V_w of the specific hardened mortar specimens cured in water was almost same during the all test days, the mortar specimens cured in sulfate solution decreased as the w/c ratio increased. It can also be concluded from the results that the specimens produced with high w/c ratio had a hallow structure. For that water entered the specimens quickly and easily, and the specimens kept more water in their structure. By the way, the V_w of the standard hardened mortar specimens was lower than that of the specific hardened mortar specimens, since the specimens produced by low w/c ratio had less porous structure compared to the specific hardened mortar specimens.

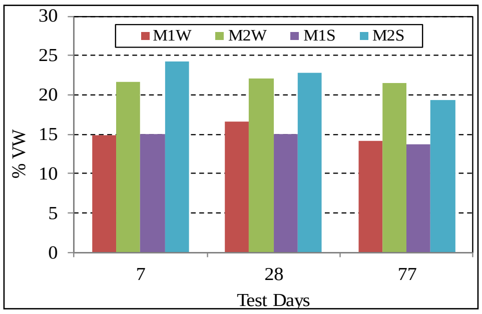

Fig. 10 *Test results of volumetric water absorption (%)*

4.7 Capillary water absorption of hardened mortar

Capillary water absorption (Cw) tests were conducted on M1W, M2W, M1S and M2S specimens at 7th, 28th and 77th days. The test values of the specimens were calculated using Eq. (5).

$$C_w(cm^2/s) = \frac{Q^2}{A^2.t} \qquad (5)$$

where C_w denotes the capillarity water absorption, Q is the amount of absorbed water, A is the surface of tested area, t is the measuring time. The obtained capillary water absorption capacities of the specimens are shown in Fig 11. As seen from the figure, the C_w of the specific hardened mortar specimens are higher than that of the C_w of the standard hardened mortar specimens. It should be noted from the results that not only the high w/c ratio but also curing condition (sulfate solution) had a significant adverse effects on the C_w of the specimens. The test results also indicated that impact factor of the curing condition (sulfate solution) was more important than that of the w/c ratio on the capillary water absorption behavior of the specimens. Moreover, the C_w ratio regardless from the w/c ratio were almost similar for the M1W, M2W and M1S specimens during the test. The test results further indicated that the M2S specimens has a hallow structure resulting from the not only high w/c but also mostly sulfate attack reaction. Finally, the C_w capacity of the specimens was the highest in the other specimens. For that water progressed in veins of the specimens quickly and easily.

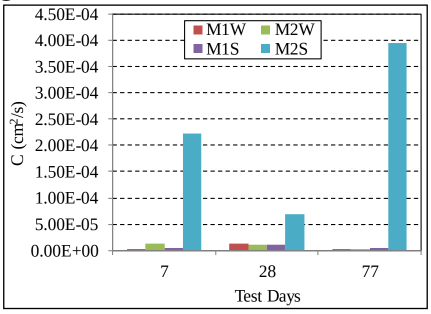

Fig. 11 Test results of capillary water absorption (cm^2/s)

4.8 Corrosion activity of hardened mortar

Corrosion activity tests were conducted on M1Cl, M2Cl, M1A and M2A specimens. NaCl was only added to the mixing water of the specific hardened mortar specimens (M1Cl and M2Cl) and the specimens were cured in NaCl solution. The remain part of the specimens (M1A and M2A) were cured in air and the NaCl was not added to the mixing water of the specimens. The results of the corrosion activity tests of the specimens were given in fig. 12, Table 4, Fig. 13 and Table 5. As seen from the Fig.12b and Table 4 that the specific hardened mortar specimens cured in NaCl solution (M2Cl) was exposed to further corrosion compared to other specimens. The results can be explained by the not only poor mortar strength but also hallow structure of the specimens. Because the chloride ions can be easily reached to reinforcing bars results from poor mortar strength and hallow structure of the specimens. It was also obvious from the Fig.12a and Table 4 that the half-cell potentials of the standard hardened mortar specimens were lower than that of the half-cell potentials of the specific hardened mortar specimens. Since the standard specimens has a gapless structure result from the low w/c ratio according to the specific specimens. For that chloride ions did not enter easily to the specimen structure.

(a)

(b)

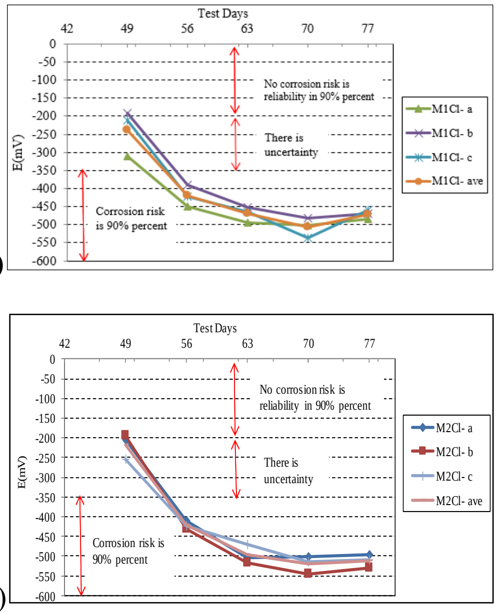

Fig. 12 *Corrosion test results of (a) M1Cl and (b) M2Cl*

Table 4 *Corrosion test results (*mV)*

Specimens		49th	56th	63th	70th	77th
M1Cl-	a	-311.0	-449.8	-494.5	-501.2	-484.8
	b	-192.5	-390.8	-451.2	-482.8	-469.7
	c	-210.5	-421.4	-464.8	-536.7	-458.9
	ave	-238.0	-420.7	-470.2	-506.9	-471.1
M2Cl-	a	-204.3	-409.7	-503.2	-501.2	-497.0
	b	-194.2	-430.3	-517.1	-545.4	-530.0
	c	-255.4	-422.8	-470.5	-515.8	-510.0
	ave	-218.0	-420.9	-496.9	-520.8	-512.3

*: millivolt; ave: average

As seen from the Fig.13b and Table 5 that the corrosion tendency of the specific hardened mortar specimens cured in air (M2A) was higher than that of the standard hardened mortar specimen (M1A). The results can be explained by the high w/c ratio had a significant effect on the corrosion behavior of the mortars. Because the chloride ions can be easily reached to reinforcing bars stemmed from poor mortar strength and hallow structure of the specimens. It was also obvious from the Fig.13 and Table 5 that the half-cell potentials of the standard and specific hardened mortar specimens generally were in uncertainty region. The test results also indicated that impact factor of the cure condition was more important than that of the w/c ratio on the corrosion tendency of the specimens.

(a)

(b)

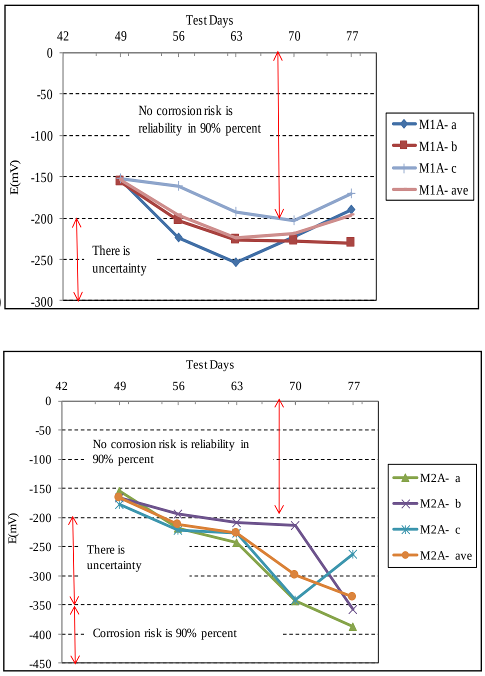

Fig. 13 *Corrosion test results (a) M1A and (b) M2A*

Table 5 *Corrosion test results (*mV)*

Specimens		49th	56th	63th	70th	77th
M1A-	a	-154.1	-223.6	-253.9	-222.8	-190.0
	b	-156.0	-203.8	-226.0	-228.3	-230.0
	c	-152.5	-161.9	-193.4	-203.8	-170.0
	ave	-154.2	-196.4	-224.4	-218.3	-196.7
M2A-	a	-155.4	-218.8	-242.8	-343.3	-387.3
	b	-166.0	-194.4	-209.3	-213.3	-357.9
	c	-177.0	-221.5	-226.8	-341.3	-262.2
	ave	-166.1	-211.6	-226.3	-299.3	-335.8

*: millivolt; ave: average

(a) (b)

Fig. 14 *Corrosion activity of reinforcing bars (a) M1Cl, (b) M2Cl*

(a) (b)

Fig. 15 *Corrosion activity of reinforcing bars (a) M1A and (b) M2A*

5. Conclusions

This paper presents the results of an experimental study carried on hardened mortar specimen for investigating the short-term effects of sodium sulfate and sodium chloride solutions on the strength and durability properties of the hardened mortar specimens. The study differentiates from the available studies in the state-of-art due to evaluation of short-term effects of the sodium sulfate and sodium chloride solutions on the standard and specific hardened mortars. Sixteen groups hardened mortar specimens were constructed and subjected to different test programs. The following conclusions are reached at the end of the experimental campaign.

Although the high w/c ratio had a significant adverse effects on the unit weight of the specimens, the cure condition (Sulfate solution) did not have an adverse effect on the unit weight of the specimens. As the w/c ratio decreased the unit weight value of the specimens increased regardless from the curing conditions. Moreover, while the unit weight values of standard mortar specimens decreased until the known test days, the unit weight values of the specific mortar specimens increased till the known test day.

Not only high w/c ratio but also curing condition (sulfate solution) had a negative impact on the UV values of the specimens. while the UV values of the standard mortar specimens cured in water were almost similar until the last test day, the UV values of the standard mortar specimens cured in sulfate solution decreased to result the sulfate attack. Moreover, the UV values decreased with the increasing w/c ratios and curing in sulfate solution.

The high w/c ratio did not have an adverse effect on the length change of the specimens. While the length change values of the specimens with the except of specific hardened mortar specimens decreased until the known test day, the length change values of all specimens increased after the known test day. Either curing in sulfate solution or the high w/c ratio had an adverse impact on the specific hardened mortar specimen cured in sulfate solution.

The w/c ratio had an important impact on the compressive strength of the specimens. While the compressive strength of the specific mortar specimens increased until the known test day, the compressive strength value of the specimens decreased to result from the sulfate ions attack in the hardened mortar composition. Furthermore, the sulfate ion has the positive impact on the compressive strength of the standard hardened mortar specimen. The compressive strength of the standard hardened mortar specimens increased regardless from the cure conditions. The impact factor of the w/c ratio was more important than that of the cure condition on the compressive strength behavior of the specimens.

The w/c ratio had a significant effect on the flexural strength of the specimens. Although the flexural strength of the specific mortar specimens especially cured in sulfate solution increased until known test day, the flexural strength value of the specimens decreased to result from the sulfate attack after the known test day. The sulfate ion has the positive impact on the flexural strength of the standard hardened mortar specimen. Moreover, the compound of the high w/c ratio and sulfate solution has an important adverse effect on the flexural strength behavior of the specific hardened mortar specimens.

Not only the high w/c ratio but also curing condition (sulfate solution) had a significant adverse effects on the V_W of the specimens. As the w/c ratio decreased the V_W ratio of the specimens decreased regardless from the curing conditions. While the V_w of the specific hardened mortar specimens cured in water was almost same during the all test days, the mortar specimens cured in sulfate solution decreased as the w/c ratio increased.

Either the high w/c ratio or curing condition (sulfate solution) had a significant adverse effects on the C_w of the specimens. The curing condition (sulfate solution) was more important than that of the w/c ratio on the capillary water absorption behavior of the hardened mortar specimens.

The corrosion tendency of the standard hardened mortar specimens was lower than that of the half-cell potentials of the specific hardened mortar specimens. The specific hardened mortar specimens cured in NaCl solution was exposed to further corrosion compared to other specimens. The impact factor of the cure condition was more important than that of the w/c ratio on the corrosion tendency of the hardened mortars.

While it is believed that this detailed study addressing the short-term effects of NaCl and Na_2SO_4 on the hardened mortars regarded as worthful, further researches are necessary for validation of these test results in a more general sense.

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