Use of Ground Black Rice Husk Ash for Improving Resistance of Mortars to Sulfates Attacks

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Abstract

We reported the results of the resistant properties of cement mortars mixed with ground black rice husk ash (hereinafter referred to as RHA) under Na_2SO_4 and $MgSO_4$ attacks. These properties studied included strength loss, weight loss and length change. In this work, the RHA as received came from electricity generating power plant at which rice husk/hull was used as a principal fuel to boil water. It was ground to finer particles for 4 hrs (Blaine fineness equal to 5400 cm^2/g) by means of mechanical grinding with comparatively low cost grinding machine. The water-to-binder ratios of mortars were varied in the range of water requirement conforming to the flow value of 110 ± 5%. The main parameters were the replacement levels of RHA in Portland cement Type 1 and 5 (0, 10, 20, 30, 40 and 50% by weight), and 5 % Na_2SO_4 and $MgSO_4$ solutions. Furthermore, the test results of cement-RHA mortars were compared with the specification criteria of the ASTM and standard and the properties of sulfate resisting cements were also taken into consideration in details. It was the replacement level of the RHA up to 20% wt. yielded lower strength loss, weight loss and length change of mortars than those of the normal cement mortars, whereas at the higher RHA levels it caused adversely effects to mortar resistance.

1. Introduction

For a hundred years that the United States Bureau of Reclamations [1] identified that external sulfates attack was one of the major problems upon the durability of long-term concrete serviceability as well as carbonation and chloride corrosion of reinforcing steel embedding in bulk concrete. By definition of sulfate attacks, all of researchers and specialists [2-3] classified chemical degradation into two main concepts. The one concept expressed damaging taken place if sulfates involved. The other one limited based on the concept of the sequence of chemical reactions between sulfate ions ($SO_4^{2}, \overline{S}$) and hydrated cement paste. A set of reactions between sulfate ions of Na_2SO_4 ($N\overline{S}$) and $MgSO_4$ ($M\overline{S}$) and hydrated cement paste were showed in Eq. (1) and (2), respectively [4-5].

Normally, in fact, $N\overline{S}$ reacted mainly to Portlandite (CH), whereas $M\overline{S}$ reacts with all the products of cement hydration; the resulting compounds were calcium sulfate ($C\overline{S}H_2$) and magnesia (MH).

$$\begin{aligned}
&CH + N\overline{S} + 2H \rightarrow C\overline{S}H_2 + NH \\
&C_4AH_{13} + 3C\overline{S}H_2 + 14H \rightarrow C_6A\overline{S}_3H_{32} + CH \\
&C_4A\overline{S}H_{12-18} + 2C\overline{S}H_2 + (10\text{-}16)H \rightarrow C_6A\overline{S}_3H_{32} \\
&C_3A + 3C\overline{S}H_2 + 26H \rightarrow C_6A\overline{S}_3H_{32} \qquad (1)
\end{aligned}$$

$$\begin{aligned}
&CH + M\overline{S} + 2H \rightarrow C\overline{S}H_2 + MH \\
&C_XS_YH_Z + xM\overline{S} + (3x + 0.5y - z)H \rightarrow C\overline{S}H_2 + xMH + 0.5yS_2H \\
&4MH + SH_2 \rightarrow M_4SH_{8.5} + (n - 4.5)H \qquad (2)
\end{aligned}$$

Due to these reactions reduced service life of concrete structure, therefore the study for understanding in sulfate attack mechanisms was essential activity. Numerous research works [6-10] had been carried out extensively in the points of view both experiments and theories for improving cement-based materials to withstand these attacks.

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Unfortunately, with complicated factors affected sulfates attack mechanisms leading to partially understanding in these phenomena. However, as priority, water-to-cement ratio [11-15], permeability [16], compositions of cement [17], supplementary materials [18-19], immersion time, curing effect [20] and surrounding conditions [21] were parameters identified to determine the potential resistance.

Two essential guidelines were commonly performed to control the resistance of a given cement-based materials under sulfate environments. One was to control the cement compositions, that is limited on the C_3A and $2C_3A+C_4AF$ content as 5% and 25%, respectively [1,22]. The other one was to control the properties of concrete. Especially, low permeability, lower w/c ratios and pozzolan materials added were recommended to utilize widely [23-25].

Black rice husk ash (RHA) was markly taken into consideration as a potential supplementary material for improving the resistance ability to sulfate attack. Up to the present time, the RHA was a main by- product in agricultural countries producing rice for consuming in domestic and exported commodity such as Thailand, Sri Lanka, Vietnam and so on. A main by-product from production was rice husk which comprises cellulose, lignin and silica containing a large amount of silica [26] when it passed though burning process. The difference in properties of rice husk ash depened not only on temperature and duration of burning [26] but also the content and feeding rate of oxygen in burner. Two common colors were black- and white RHA. The black RHA occurred from buring process under the surrounding of low oxygen content, whereas the white RHA was burnt in sufficient oxygen content. The black RHA was ground easily by means of mechanical grinding due to it consists of soft grains when comparing the white one. Also the previous research indicated that black RHA was high reactive more than the white one. The reactive components in black RHA leaded to improving concrete properties because of pozzolan reaction that consumed Portlandite and then reducing the porosity of internal structure of concrete. Therefore, the aim of this study was to investigate the resistance of black RHA- cement mortars under Na_2SO_4 and $MgSO_4$ solutions attack.

2. Experimental Program

2.1 Raw Materials

Rice husk ash: The RHA was a main material as received from electrical generating power plant using rice husk as fuel. It was finely ground by means of mechanical grinding method with grinding machine as shown in Figure 1 [24]. This machine consisted of two parts including a cylindrical feature having 60 cm in diameter and three sizes of rolled bar i.e., diameters of 0.9 cm, 1.2 cm and 1.5 cm in amounts of 45, 45 and 35 bars, respectively.

Figure 1 A comparatively low cost grinding machine [24]

After varying the grinding time from 1.0 up to 6.0 hrs with the rate of rotation at 52 rpm, the chemical compositions and physical properties of ground RHA were tested as shown in Table 1. It showed that mechanical grinding did not change the chemical compositions of RHA. However, for duration from 4.0 up to 6.0 hrs, the Blaine fineness values of RHAs have similar size distribution. Furthermore, the RHA has rough surface and high porosity as shown in Figure 2.

When considering the particle size distribution of RHAs at varying grinding time, it was found that increasing the grinding time (up to 6.0 hrs) resulted in small size of particles. On average, the particle sizes of unground RHA was 800 μm, whereas its sizes at grinding time of 1.0, 2.0 and 3.0 hrs were 70 μm and grinding time more than 4.0 hrs having the size similar to cement particles as shown in Figure 3.

In addition results for determining an optimal grinding time, it can be related to a relationship of percentage replacement of RHA in Type 1 Portland cement and water-to-binder ratios required corresponding to the flow value of 110 ± 5% [27]. Those results indicated that the values of flow value throughout RHA replacement. Therefore, the 4 hrs was the optimal time of grinding and having Blaine fineness equal to 5400 cm^2/g.

Portland cement: Portland cement Type 1 and 5 were investigated and compared with RHA cement. The chemical compositions are provided in Table 2.

Graded standard sand: Sand conformed to the ASTM C 778 [28].

Water: Tap water was used throughout the study.

Table 1 Chemical compositions and physical properties of RHA at vary grinding time

Chemical Compositions (% by weight)	Grinding Time (hrs)					
	1	2	3	4	5	6
SiO_2	90.6	91.8	91.0	90.6	93.1	90.6
Al_2O_3	0.5	0.5	0.5	0.5	0.5	0.5
Fe_2O_3	1.4	1.4	1.4	1.4	1.4	1.4
CaO	0.8	0.8	0.9	0.9	0.8	0.8
MgO	0.5	0.5	0.5	0.2	0.4	0.3
K_2O	1.9	1.9	2.0	1.9	2.0	1.9
Na_2O	0.02	0.02	0.02	0.01	0.02	0.02
SO_3	0.03	0.03	0.03	0.03	0.04	0.04
TiO_2	0.9	0.08	0.09	0.09	0.09	0.09
Free CaO	0.06	0.06	0.06	0.06	0.06	0.06

Table 1 (Cont.) Chemical compositions and physical properties of RHA at vary grinding time

Physical Properties	Grinding Time (Hrs)					
	1	2	3	4	5	6
LOI (%)	0.8	0.6	0.6	0.8	0.6	0.6
Moisture Content (%)	1.1	1.2	1.0	1.1	1.0	1.0
Specific Surface Area						
Blaine (cm^2/g)	2700	3000	4800	5400	5600	5700
Specific Gravity	2.13	2.18	2.30	2.30	2.35	2.38
Fineness (Particle						
Size, % Retained)						
≥ 75 μm	15.6	11.3	7.9	1.0	0.6	0.3
75 μm	23.0	20.8	20.5	6.1	6.3	3.5
45 μm	7.9	7.0	7.2	5.5	4.6	3.8
≤ 36 μm	53.5	60.9	64.5	87.5	88.5	92.3
Fineness (% Retained)						
on 45 μ (No. 325)	38.6	32.1	28.4	7.0	6.9	3.9
Strength Index						
(% of control)						
7 days	71	77	77	79	87	91
28 days	63	73	73	77	88	91
Water Requirement						
(%)	112	110	110	103	103	103
Bulk Density (kg/l)	0.66	0.67	0.68	0.70	0.71	0.72

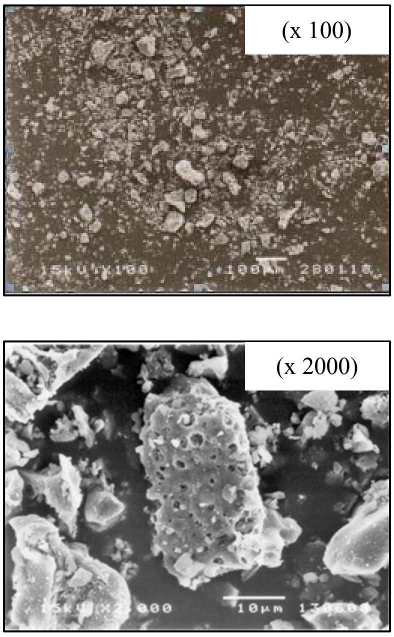


Figure 2 RHA Particles at the grinding time of 4.0 hrs

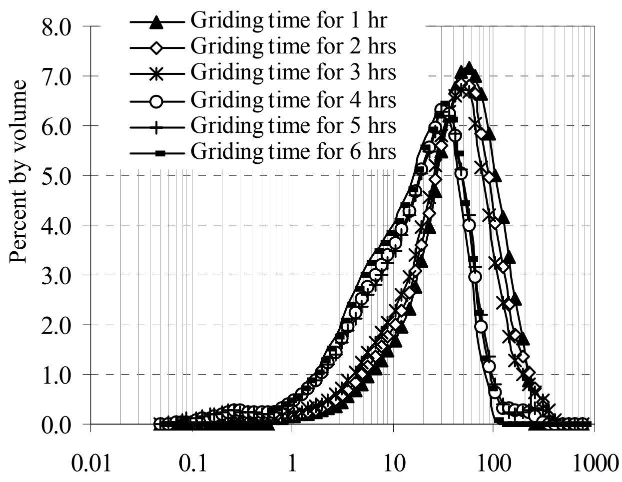


Figure 3 Particle size distributions of RHA particles

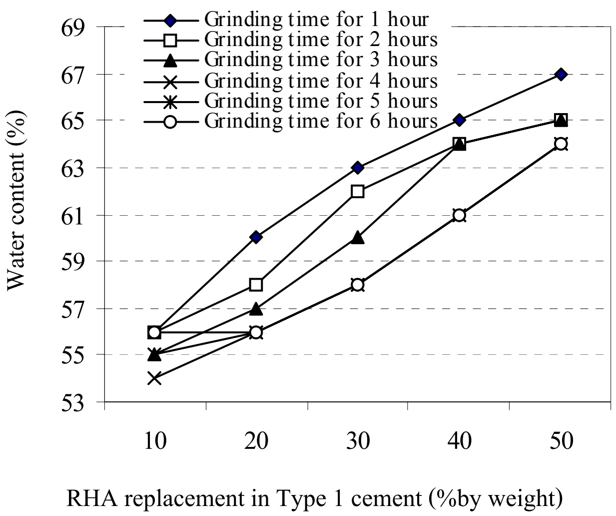


Figure 4 Water requirement of mortar containing RHA

Table 2 Chemical compositions of the Portland cements

Chemical Compositions (% by weight)	Type 1	Type 5
SiO_2	20.8	18.4
Al_2O_3	5.2	4.8
Fe_2O_3	3.2	3.5
CaO	66.3	60.5
MgO	1.2	1.0
K_2O	0.2	0.4
Na_2O	0.1	0.3
SO_3	2.4	2.6
Free CaO	1.0	1.3

2.2 Mix Proportions

The sulfate resistance of mortars which were made from four binders (Portland cement and RHA, namely Type 1, Type 1 plus RHA, Type 5 and Type 5 plus RHA) were evaluated. In the RHA cement binder, the replacement levels of RHA were 0, 10, 20, 30, 40 and 50 % by weight as shown in Table 3.

Table 3 Mix proportions (mass units)

Symbol	Cement		RHA	Sand	Water[1]
	Type	Content			
1-RHA0	1	1.0	0.0	2.75	0.58
1-RHA10	1	0.9	0.1	2.75	0.60
1-RHA20	1	0.8	0.2	2.75	0.61
1-RHA30	1	0.7	0.3	2.75	0.64
1-RHA40	1	0.6	0.4	2.75	0.66
1-RHA50	1	0.5	0.5	2.75	0.67
5-RHA0	5	1.0	0.0	2.75	0.60
5-RHA10	5	0.9	0.1	2.75	0.64
5 -RHA20	5	0.8	0.2	2.75	0.67
5 -RHA30	5	0.7	0.3	2.75	0.67
5 -RHA40	5	0.6	0.4	2.75	0.67
5 -RHA50	5	0.5	0.5	2.75	0.69

Remark: [1] conforms to flow value at 110 ± 5%

2.3 Preparation of Specimens

2.3.1 Strength and weight loss

Strength and weight loss tests were carried out by using three 5.0 x 5.0 x 5.0 centimeter cubic specimens [29-30]. Strength loss was calculated as the difference between the strength of normal-cured specimens at any time and the strength under soaking in sulfate at the same time. Also, weight loss can be calculated as the difference in percentage between the weight of specimen at the specific time and just before immersion in the sulfates.

2.3.2 Length change

The sulfate resistance was determined by measuring the length change of the three mortar specimens. The testing specifications and procedures conformed to the ASTM C 1012 [31].

3. Results and Discussion

3.1 Physical Properties

3.1.1 Time to Reach the Strength Required

The times to reach the required strength (20.0 ± 1.0 MPa) of Type 1 and 5 mortars which blended with RHA are shown in Table 4. It was found that increasing RHA replacement levels affect the strength development of the mortar due to the fact that the effectiveness in pozzolanic reaction of RHA is lower than the hydration of Portland cement [32]. Besides, Type 5 mortars are also influenced by the amount of RHA replacement. However Type 5-mortars used the time to the required strength more than Type 1-mortars due to the lower content of C_3S.

Figure 5 shows a relationship between the time reached at the strength required and water-to-binder (cement mixed with/without RHA) ratios.

Table 4 Time to reach the strength required of mortar

Type of Portland Cement	Time to reach at 20.0 ± 1.0 MPa (hrs)					
	RHA replacement by weight					
	0	10	20	30	40	50
Type 1	95	105	130	180	270	430
Type 5	115	180	230	350	370	530

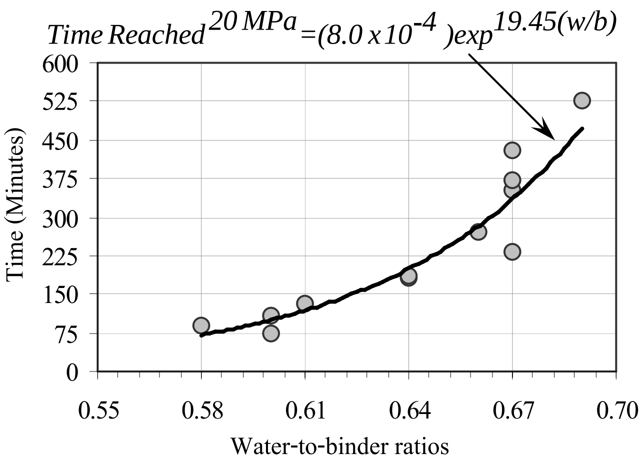


Figure 5 Relationship of times to reach the strength required

3.1.2 Strength Index

The effects of RHA on the strength development of Type 1- and 5 mortars at 7 and 28 days are shown in Table 5 and a number in bracket indicated the strength in percent which is normalized to Type 1 and Type 5 mortars, respectively. As discussed in the influence of RHA replacement, it affects significantly on the reduction of the rate of strength development of mortar. However pozzolanic reaction of the presence of RHA progresses in a high rate by replacing of 20% RHA, whereas thereafter the replacement of 30% RHA up to 50%, it yielded slower rate.

After determining relationships of the ratio of relative strength development at 7 to 28 days as a function of water-to-binder materials ratios (w/b) of the mortars, an empirical formula of the strength index of Type 1 and 5 mortars with/without RHA can be illustrated in Figure 6 and written as Eqs. (3) and (4), respectively.

Table 5 Strength index of various mortars

Types of Mortar (Type I Ordinary Portland Cement)	Compressive Strength	
	ksc [% wrt. Type 1 Ordinary Portland Cement Mortar]	
	At 7 days	At 28 days
1-RHA0	271.3[100]	383.8[100]
1-RHA10	250.5[92.3]	343.1[89.4]
1-RHA20	214.3[79.2]	297.1[77.4]
1-RHA30	188.5[69.5]	256.0[66.7]
1-RHA40	175.5[64.7]	239.5[62.7]
1-RHA50	128.6[47.4]	173.9[45.3]
Types of Mortar (Type V Sulfate Resisting Portland Cement)	ksc [% wrt. Type 5 Portland Cement Mortar]	
	At 7 days	At 28 days
5-RHA0	236.3[100]	334.6[100]
5-RHA10	206.8[87.5]	276.4[82.6]
5-RHA20	176.8[74.8]	230.5[68.9]
5-RHA30	154.1[65.2]	210.1[62.8]
5-RHA40	140.8[59.6]	186.4[55.7]
5-RHA50	106.8[45.2]	140.9[42.1]

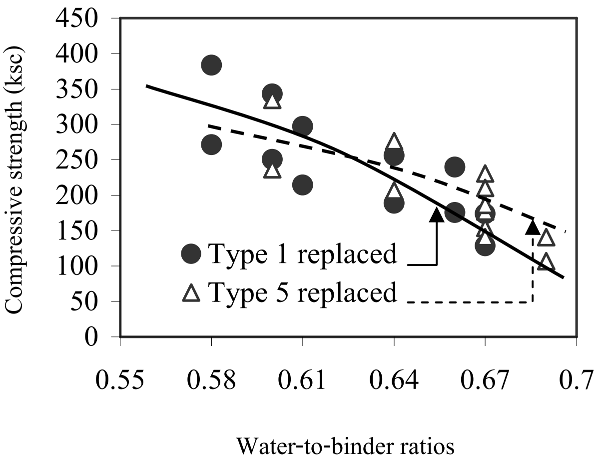


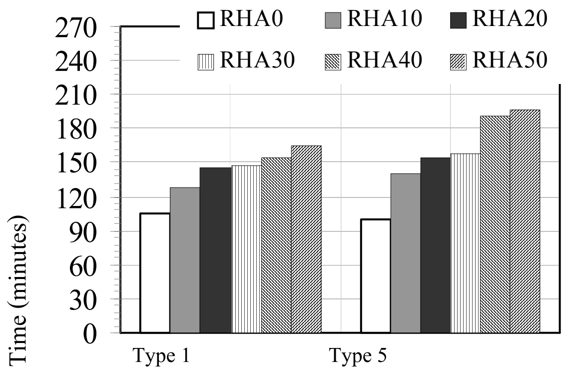
Figure 6 Relationship of water-to-binder ratios and compressive strengths

$$\phi_{Type\ 1} = \frac{Rel.Strength^{7\,days}}{Rel.Strength^{28\,days}} = 1.25(w/b)^{0.94} \quad (3)$$

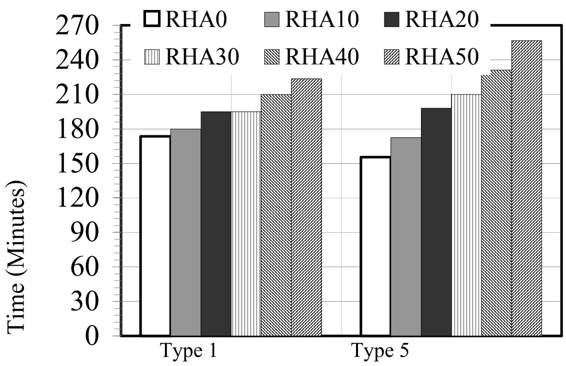
$$\phi_{Type\ 5} = \frac{Rel.Strength^{7\,days}}{Rel.Strength^{28\,days}} = 1.30(w/b)^{0.90} \quad (4)$$

3.1.3 Setting Time

As for the same reasons, the replacing levels of RHA in Portland cement up to 50% result in decreasing the rate of setting and hardening of mortars. Figure 7 shows both the initial, especially in a point of view of setting time, the increase of RHA replacement can decrease the rate of total reaction taking place within the mortar. Also, these reactions which consist of hydration and pozzolanic reactions are diminished inversely with incremental proportion of RHA in cement. The reasons of this phenomenon lie on the surface of RHA particles which influence to cohesive bond between the bulk paste and RHA particle surface. In addition, the higher absorption of water of the RHA surface when comparing with cement surface can increase largely interfacial transition zone between them [3]. This occurrence relates to ability of the crystallization of C-S-H from hydration reaction [2] which leads also to occurrence of weak zone.



(a) Initial Setting Time



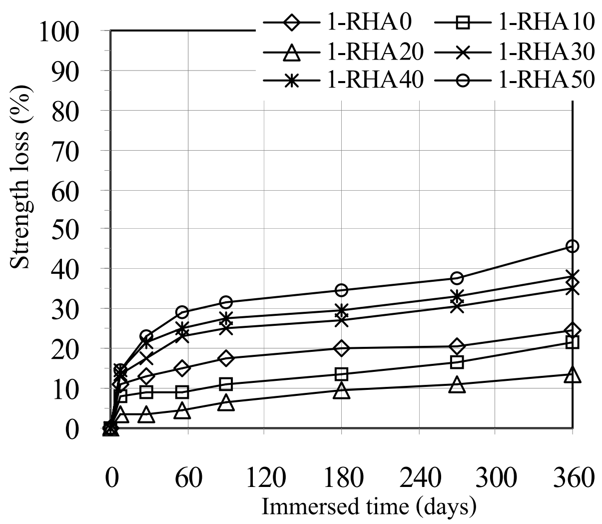
(b) Final Setting Time

Figure 7 Setting time of mortars

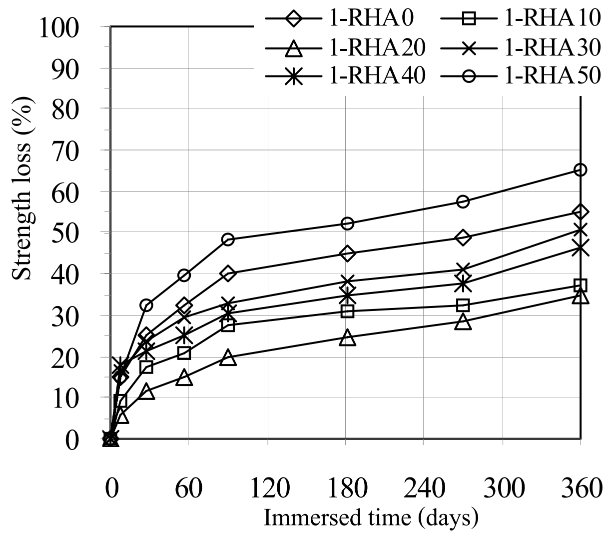
3.2 Na_2SO_4 Solution Attack

3.2.1 Strength Loss

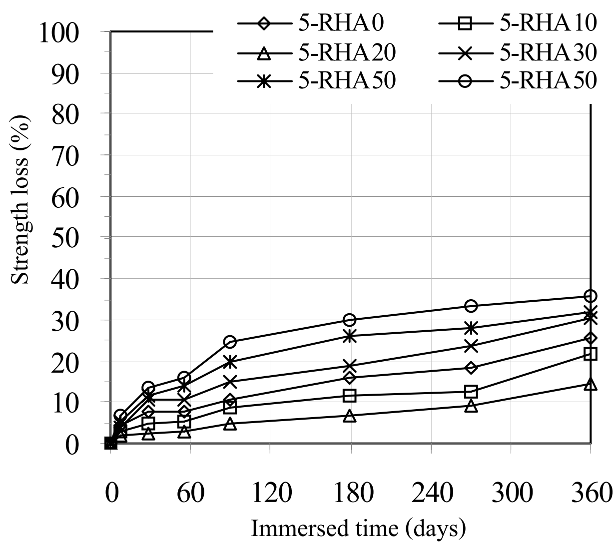
According to the ASTM C 1012 [31], the 5% Na_2SO_4 and 5% $MgSO_4$ solutions can develop loss in strength of the mortar. In other words, strength development of mortar under immersion in sulfate solution with respect to initial strength (20.0 ± 1.0 MPa) can be also represented. Test results are the average of three values for the compressive strength of mortars illustrated in Figure 8. It can be seen that the loss of strengths of Type 1 and 5 containing 10 and 20% RHA mortars are decreased and lower than those of the normal ones. In addition the 20% RHA replacement is the lowest strength loss of mortar. This is because of the effects of pozzolanic reaction reducing the amount of $Ca(OH)_2$ which is a main reactant of sulfate reaction [33]. Also at 20% RHA replacement resulted in gaining C-S-H, as a result the mortar structure is densified whereas the replacement of RHA more than 20% leads to increase the porosity of mortar.



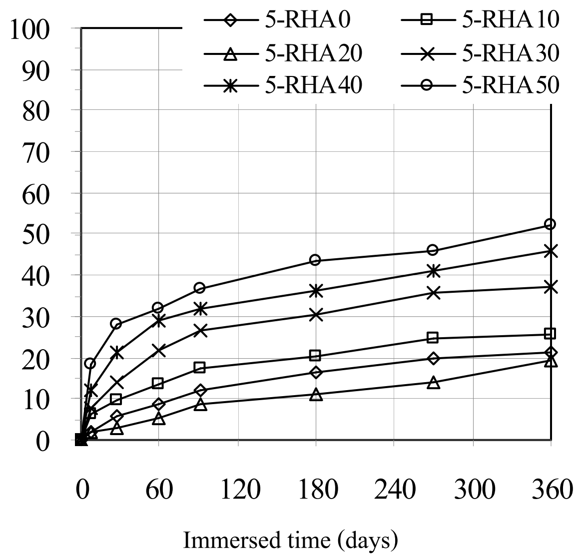
(a) Type 1 Mortars immersed in Na_2SO_4 solution



(b) Type 1 mortars immersed $MgSO_4$ solution



(c) Type 5 mortars immersed Na_2SO_4 solution



(d) Type 5 mortars immersed $MgSO_4$ solution

Figure 8 Strength losses of mortars

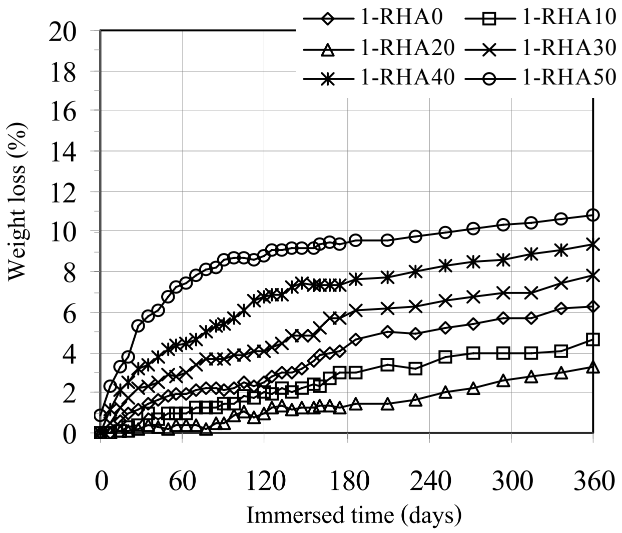
3.2.2 Weight Loss

As shown in sulfate attack reactions in Eqs. (1) and (2), the weight losses of mortars take place due to disintegration within mortar structure. Figure 9 illustrates the weight losses of the mortars that are plotted against immersed time in sulfate solution. The overall results showed that the weight loss of the mortars containing 10 and 20% RHA are lower than the normal mortar without RH while the replacements of RHA at 30 up to 50% are adversely affected on weight loss of the mortars. In addition, the 20% RHA mortar shows the lowest weight loss or the best performance.

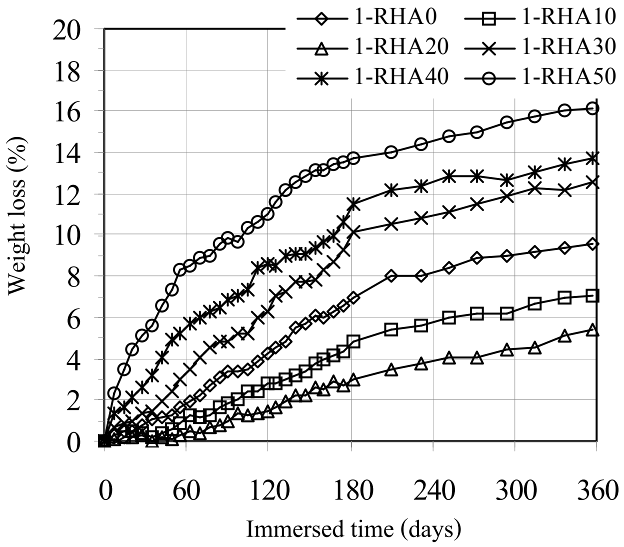
When considering a case of 5% Na_2SO_4 sulfate (Figure 9(a)), the weight losses of Type 1 mortars with/without RHA are increased with a high rate in early age. After that, consequently the rate reached to constant plateau. This is due to at the early age of immersion in sulfate, the high $Ca(OH)_2$ content leads to sulfate reactions occurring in a high rate. Whereas, in long term immersion, the lower rate of weight losses of mortars diminishes which can be explained by the change of sulfate reactants and porosity of mortar structure; this is low $Ca(OH)_2$ content associated with high density from increasing of C-S-H content and additional C-S-H from pozzolan reaction of RHA.

Furthermore Type 5 mortars with/without RHA (Figures 9(c) and 9(d)) yield lower weight loss than those of Type 1 mortars because Type 5 cement has lower C_3A and C_4AF content when comparing with Type I cement.

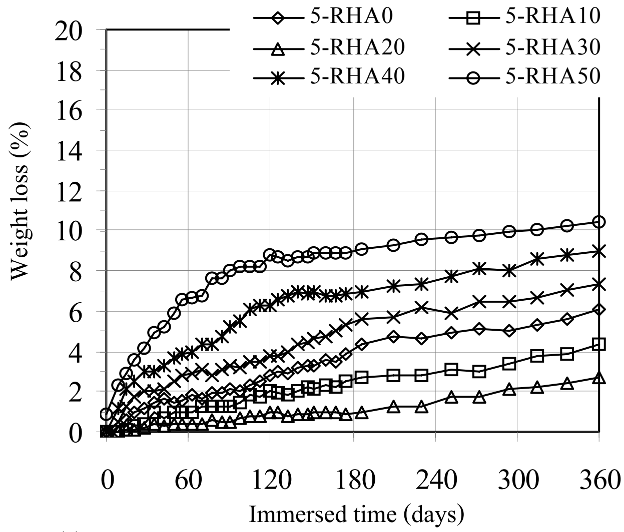
For immersion in 5% $MgSO_4$ sulfate solution (Figure 9(d)), it shows similar trend compared to the results of weight loss of 5% Na_2SO_4 sulfate but the values of Type 5 mortar are lower than those of Type 1 mortar ones with the same influences.



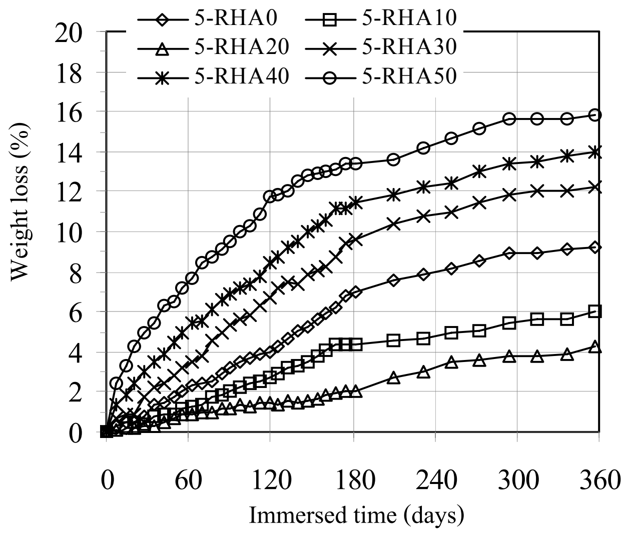
(a) Type 1 mortars immersed in Na_2SO_4 solution



(b) Type 1 mortars immersed in $MgSO_4$ solution



(c) Type 5 mortars immersed in Na_2SO_4 solution



(d) Type 5 mortars immersed in $MgSO_4$ solution

Figure 9 Weight losses of mortars

Typical mortar samples after immersion in Na_2SO_4 and $MgSO_4$ solutions are shown in Figures 10 and 11, respectively. Overall, after soaking in sulfate solution for 360 days, the surface texture of 20 to 50% RHA mortar is light black and do not show any significant difference in color in comparison with the normal mortar, as well as the color of mortar surface of Type 1 and 5. While, the 0% and 10% RHA mortar is dark black because of the color of sulfate products, that is Na(OH) and $Mg(OH)_2$ in reaction of Na_2SO_4 and $MgSO_4$ solutions, respectively.

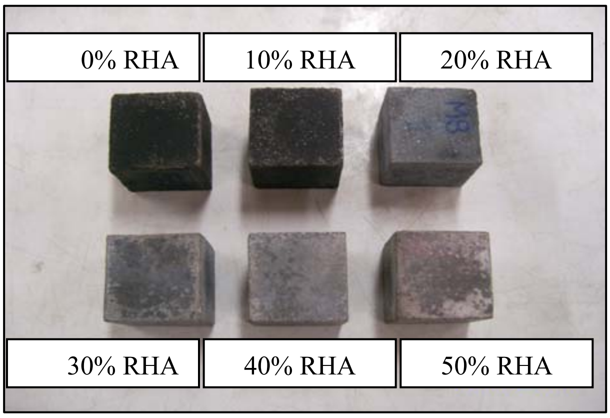


Figure 10 Feature of mortar samples in weight loss testing after immersion in Na_2SO_4 solution for 360 days

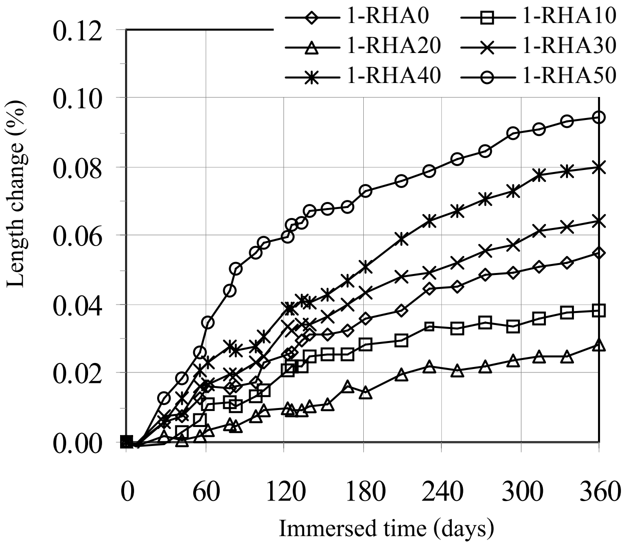
Figure 11 Feature of mortar samples in weight loss testing after immersion in $MgSO_4$ solution for 360 days

3.2.3 Length Change

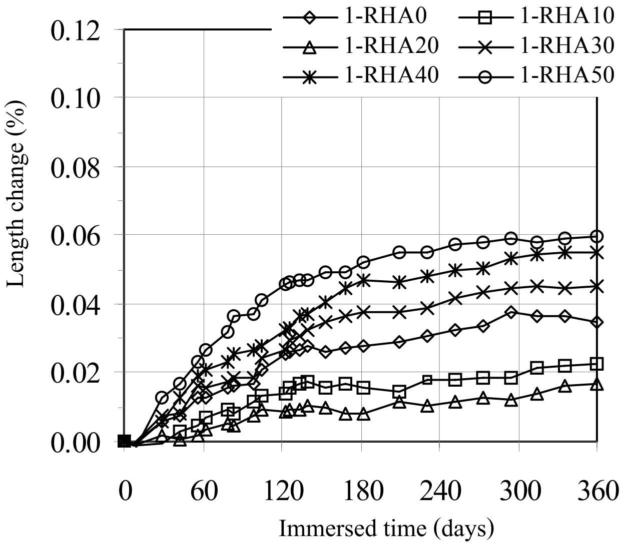
The developments of length change subject to Na_2SO_4 and $MgSO_4$ solutions are often apparent in expansion, of the mortar made with Type 1 and 5 Portland cement containing RHA was showed in Figure 12. The data presented are for a period of 1 to 360 days. Under sulfates attack, the expansion of mortar with 10 and 20% RHA is lower than that of the normal mortar without RHA.

Due to the decrease of $Ca(OH)_2$ content from pozzolanic consumption, the expansion of Type 1 mortars containing RHA is decreased. Principally the 20% RHA mortar (Figure 13(a)) shows the best performance of using RHA replacing in cement for improving sulfate resistance. However, more than 20% RHA replacement lead to increase expansion in comparison with 20% RHA replacement. This is because of the porosity of mortar structure is increased, as a result of sulfate ion reacting with $Ca(OH)_2$ in high rate [31].

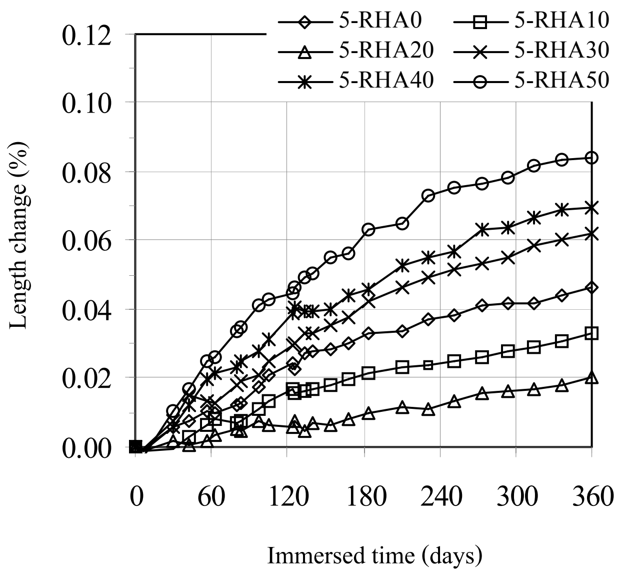
In the point of view the differences of mortar specimen under Na_2SO_4 and $MgSO_4$ attack on are showed in Eqs. (1) and (2). The reactions of Na_2SO_4 produce ettringite and calcium sulfate causing expansion, while the $MgSO_4$ reacts principally with C-S-H for degrading their structures, which are often linked to loss of adhesion and strength rather than to expansion.



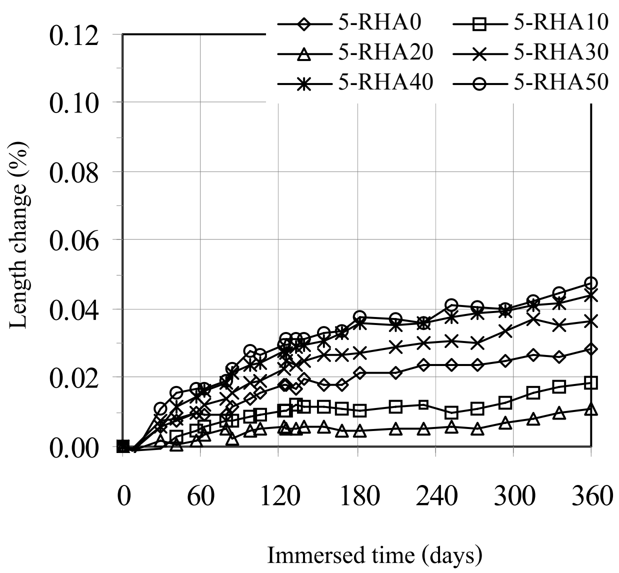
(a) Type 1 mortars immersed in Na_2SO_4 solution



(b) Type 1 mortars immersed in $MgSO_4$ solution



(c) Type 5 mortars immersed in Na_2SO_4 solution



(d) Type 5 mortar immersed in $MgSO_4$ solution

Figure 12 Length changes of mortars

As shown in expansion pattern, it can be classified into two parts that at early age test time, trend of expansion has increased sharply, consequently approached to constant rate at the long term, after 120 days approximately.

Comparison of expansion between Type 1 (Figure 12(a)) and Type 5 mortars (Figure 12(c)), it is found that decreasing of expansion confirms that the compositions of the binder have major influence on the sulfate resistance. As expected, Type 1 Portland cement with higher C_3A content is higher expansion than Type 5 cement mortars.

Figure 13 shows typical mortar specimens after immersion in 5% Na_2SO_4 solution exposing for 360 days. An essential feature taking place is the mortar specimen was bended. This is because of exceeding expansion of contacting surface and within mortar structure [34].

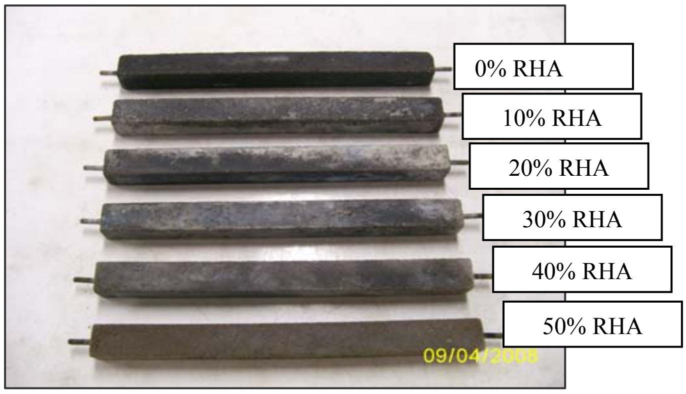


Figure 13 Mortar samples in length change testing after immersion in Na_2SO_4 solution for 360 days

4. Comparison to the Standard [34]

By comparing the test results to the specification criteria in accordance with the ASTM C 1157 standard [34] by using the conditions are conformed to the standard, it can be summarized as shown in Table 6. By evaluating to the standard [34], the expansions of Type 1 and 5 mortars with/without RHA do not exceed 0.10 % for immersion in 5% of Na_2SO_4 and $MgSO_4$ solutions at 6 and 12 months.

Table 6 Comparison of the test results in expansion and the standard [34]

Class of Sulfate Resistance	Expansion (%) under immersed time for	
	6 months	12 months
Moderate	0.100	-
High	0.050	0.100

Table 6 (Cont.) Comparison of the test results in expansion and the standard [34]

Expansion (%) with for months of					
Type 1 Mortar			Type 5 Mortar		
Mix	6 months	12 months	Mix	6 months	12 months
RHA0	0.036	0.055	RHA0	0.033	0.046
RHA10	0.028	0.038	RHA10	0.021	0.033
RHA20	0.015	0.028	RHA20	0.010	0.020
RHA30	0.044	0.065	RHA30	0.042	0.062
RHA40	0.051	0.080	RHA40	0.046	0.070
RHA50	0.073	0.094	RHA50	0.063	0.084
Moderate sulfate resistance					
Type 1 Mortar			Type 5 Mortar		
Mix	6 months	12 months	Mix	6 months	12 months
RHA0	Pass	NA	RHA0	Pass	NA
RHA10	Pass	NA	RHA10	Pass	NA
RHA20	Pass	NA	RHA20	Pass	NA
RHA30	Pass	NA	RHA30	Pass	NA
RHA40	Pass	NA	RHA40	Pass	NA
RHA50	Pass	NA	RHA50	Pass	NA
High sulfate resistance					
Type 1 Mortar			Type 5 Mortar		
Mix	6 months	12 months	Mix	6 months	12 months
RHA0	Pass	Pass	RHA0	Pass	Pass
RHA10	Pass	Pass	RHA10	Pass	Pass
RHA20	Pass	Pass	RHA20	Pass	Pass
RHA30	Pass	Pass	RHA30	Pass	Pass
RHA40	Fail	Pass	RHA40	Pass	Pass
RHA50	Fail	Pass	RHA50	Fail	Pass

5. Conclusions

The test results of the resistance of the mortars made from four binders (Type 1, Type 1 plus RHA, Type 5 and Type 5 plus RHA) Na_2SO_4 and $MgSO_4$ solutions attacks and varying the replacement levels of RHA in cement of 0, 10, 20, 30, 40 and 50 % by weight. It can be concluded that the replacement percentages of RHA up to 20% yielded lower strength loss, weight loss and length change of mortar than those of the normal cement mortars. Whereas at higher RHA replacing levels from 30 up to 50%, it causes adversely effect to mortar resistance. In addition when comparing to the ASTM C 1157 standard, the expansion of mortar with/without RHA do not exceed 0.10 % for immersion in 5% of Na_2SO_4 and $MgSO_4$ solutions at the immersed time for 6 and 12 months, respectively.

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