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Hydration and durability of sulphate-resisting and slag cement blends in Caron's Lake water

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Abstract

The problem of aggressive attack of sulphate and chloride ions has been of considerable scientific and technological interest because this attack is one of the factors responsible for damage to concrete. The corrosive action of chlorides is due to the formation of chloroaluminate hydrates, which causes softening of concrete. Sulphate ions can enter into chemical reactions with certain constituents of concrete, producing sulphoaluminate hydrates and gypsum, which cause the expansion of concrete. The aim of the present work is to study the hydration and the durability of mixed cement (sulphate-resisting and slag cement blends) pastes and mortars in Caron's Lake water. Different mixes of sulphate-resisting cement (SRC) with various proportions of slag cement were prepared and immersed in tap water for 3, 7, 28 and 90 days. The durability of the cement mortars was followed by curing the samples in tap water for 28 days (zero time) then immersed in Caron's Lake water for 1, 3, 6, 9 and 12 months. The hydration behavior was measured by the determination of the compressive strength, free lime, evaporable and nonevaporable water, total chloride and total sulphate contents at each curing time. The increase of substitution of SRC with blast-furnace slag cement (BFSC) up to 30% increases slightly the total pore volume. The free lime contents decrease sharply in the first months of immersion then slightly up to 1 year. The blended cement pastes made of SRC with BFSC up to 30 mass% have lower values of total chloride and total sulphate, while the mortars containing only SRC have lower values of compressive strength than those of all blended cement mortars at all curing ages of immersion under Caron's Lake water. Useful conclusions and recommendations concerning the use of 70 mass% of SRC with 30 mass% slag cement produces a highly durable mixed cement.

Keywords: Durability; Sulphate-resisting cement; Slag cement and aggressive Attack

1. Introduction

Concrete is termed durable when it keeps its form and shape within the allowable limits when exposed to different environmental conditions. The durability of concrete has been a major concern of civil engineering professionals. In addition, it has been of considerable scientific and technological interest over the last few decades.

The effect of seawater on concrete deserves special attention because sea structures are exposed to the simultaneous action of chemical deterioration processes. Concrete exposed to seawater may deteriorate as a result of the combined effects of the chemical action of seawater constituents on cement hydration products and the corrosion of reinforcing steel. The chemical attack of seawater on cement constituents is the reactions between sulphates, as well as chlorides, which are the most aggressive ions with cement constituents [1], because certain constituents of cement can enter into deleterious reactions with SO_4^{2-} and Cl^-, leading to the dissolution of $Ca(OH)_2$ and the formation of sulphoaluminate and chloroaluminate hydrates, which cause expansion and softening of concrete, respectively. The $CaCl_2$ that is formed from the reaction of $MgCl_2$

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with liberated lime increases the solubility of $Ca(OH)_2$ that permits leaching. Thus, $Mg(OH)_2$ dissociates C-S-H and produces $Ca(OH)_2$ and silica gel [2–4]. The latter may react with $Mg(OH)_2$ to form magnesium silicate hydrates. The calcium silicate hydrates (C-S-H) in the set cement are also decomposed by magnesium sulphate in aggressive solutions to give gypsum, hydrated silica and magnesium silicate hydrates, but this, unlike silica gel, has little binding power or no binding properties [5]. All the above mentioned reactions are accompanied by decrease in strength.

Blast-furnace slag cement (BFSC) is used in many countries for its characteristic property of improving sulphate and chloride resistance. Frearson [6] found poor resistance of OPC toward sulphate attack, with lower levels of OPC replacement by granulated blast-furnace slag (GBFS) with different W/C ratios. It was concluded that the influence of slag content is more significant than the action of water cement ratio on sulphate resistance. In a previous work [1], it was reported that the high slag content in concrete increases sulphate resistance due to a decrease in the permeability to different types of ions and water. Improvement in the sulphate and chloride resistance of concrete with sufficient amount of slag content is mainly due to the reduction of C_3A with the increase of slag portion in cement concrete. In addition, the addition of slag to concrete decreases the formed $Ca(OH)_2$ by reaction with slag to form the additional amounts of C-S-H gel, which enhances the compressive strength.

The Cl^- and SO_4^{2-} activate the hydration of slag. The chloride salts act as alkali activated slag, which can activate the slag [7]. Also, SO_4^{2-} acts as sulphate activator in the presence of $Ca(OH)_2$ to give ettringite, which is the main hydration product in supersulphated cement.

Blended cement containing slag showed excellent resistance to sulphate attack [8]. The chemical resistance of blended Portland cement results mainly from the pozzolanic reaction, which leads to the consumption of formed $Ca(OH)_2$ and the formation of additional amounts of calcium silicate and aluminosilicate hydrates. These hydration products fill up the open pores, leading to the formation of a more compact body. Therefore, blended cement paste resists sulphate and chloride attack.

This investigation aims to study the hydration characteristics and durability of mixed cement pastes and mortars made from sulphate-resisting cement (SRC) and BFSC in Caron's Lake water, Fayoum, Egypt as aggressive medium.

2. Experimental techniques

The materials used in this investigation were SRC and BFSC provided from Bene-Suef Cement, Egypt. In addition, Caron's Lake water Fayoum, Egypt, was used as aggressive medium. The surface areas of SRC and BFSC were 306.1 and 352.8 m^2/kg, respectively. The chemical composition of these cements is listed in Table 1. The C_3A content of SRC is 1.456 mass%. In addition, the chemical analysis of Caron's Lake water is shown in Fig. 1. The main soluble salts in Caron's Lake water are NaCl, Na_2SO_4, $MgCl_2$, $MgSO_4$ and $CaCl_2$. The pH of this water is 6.50. The mix composition of the investigated mixes is seen in Table 2.

Table 1
Chemical composition of the starting material (mass%)

Oxides	BFSC	SRC[a]
SiO_2	21.78	20.88
Al_2O_3	6.08	3.70
Fe_2O_3	3.18	4.94
CaO	59.06	64.57
MgO	2.11	2.00
SO_3	2.37	1.62
Na_2O	0.5	0.02
K_2O	0.11	0.04
Cl^-	0.01	0.01
S^{2-}	1.20	–
L.O.I.	–	2.27

[a] $C_3S=67.5$, $C_2S=11.498$, $C_3A=1.456$ and $C_4AF=15.09$.

Each dry mix was homogenized in a porcelain ball mill with two balls for 1 h using a mechanical roller to assure complete homogeneity. The mixing was carried out as described in a previous work [9]. The water of consistency and setting times for each mix were determined according to ASTM specifications [10,11]. The pastes were mixed with the required water of standard consistency. The compressive strength was measured on cement mortars according to ASTM method using 50-mm cubic molds [12]. Two series of cement mortars were treated with different solution. The first series was cured in a humidity chamber at 23 ± 1 for 24 h, and then cured under tap water for 90 days. The second series was cured under tap water for 28 days (zero time), then immersed in Caron's Lake water for 1, 3, 6, 9 and 12 months. The hydration was stopped for the cement pastes as described elsewhere [13].

The hydration behavior of each mix was followed by the determination of free lime and evaporable and nonevaporable water contents at each time of testing. The free lime content was determined by an ammonium acetate method [13]. The nonevaporable water content was determined from the ignition loss of the dried sample on the ignited weight basis. The total water content, W_t, is determined from the ignition of the saturated sample. The evaporable water content, W_e, of the hardened paste was calculated from the total water minus nonevaporable water content. The total pore volume is calculated as $0.99W_e$.

The aggressive attack was determined through the measurements of compressive strength, total sulphate, total chloride and free lime content at each time of testing. The total sulphate content was estimated gravimetrically by using 1 g of powdered sample dissolved in 5 m1 of concentrated HCl, 100 ml of distilled water was added, then boiled for 5 min, then was filtered and washed several times with distilled water. Ten milliliters of 10% $BaCl_2$ was added

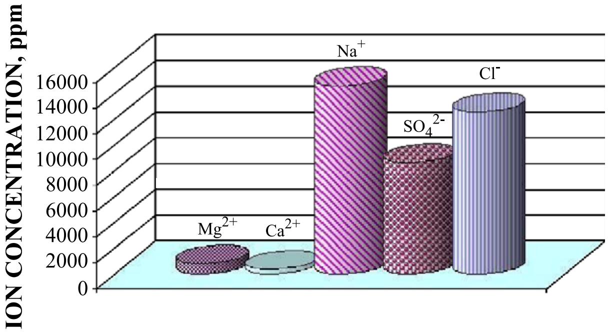

Fig. 1. The chemical analysis of Caron's Lake water (ppm).

to the filtrate, which was digested, filtered and ignited. The total sulphate content was calculated.

Total chloride content was determined in the hardened pastes by weighing 2 g sample into a stopper conical flask. The specimen was dispersed with 25 ml water and then added with 10 ml of nitric acid (sp. gr. 1.42). Fifty milliliters of hot water was added, heated to near boiling and kept warm for 10 to 15 min. If the supernatant liquid is turbid, it was filtered through a rapid paper (41 filter paper) and washed with hot water and then cooled to room temperature. An excess of standard 0.1 N $AgNO_3$ (16.98 g pure dry $AgNO_3$, in liter) was added, and 2–3 ml of nitrobenzene to stopple the flask, and was shaken vigorously to coagulate the precipitate, then 1 ml ammoumium ferric alum as indicator and titrate against standard 0.1 N ammonium thiocyanate [14].

3. Results and discussion

3.1. Hydration characteristics in tap water

3.1.1. Water of consistency and setting times

This part deals with the effect of BFSC content on the hydration behavior and physico-mechanical properties of SRC in tap water. The required water of standard consistency and setting times are graphically represented as a function of BFSC replacement in Fig. 2. It is clear that the water of consistency of cement pastes containing BFSC is lower than that of only SRC. This is due to the fact that the BFSC has low hydraulic properties than SRC does. Mehta [15] reported that a coating film of aluminosilicate forms on the surface of slag grains within a few minutes of exposure to water, which inhibits further hydration. The rate of hydration is very slow, but it increases in the alkaline media. Portland cement clinker or formed lime is normally used to provide this alkalinity [16]. The setting times are extended with BFSC content, due to the lower hydraulic properties of BFSC in comparison with SRC.

Table 2
Mix composition of the investigated mixes

Mix number	SRC	BFSC
M.1	100	0
M.2	90	10
M.3	80	20
M.4	70	30
M.5	60	40
M.6	50	50

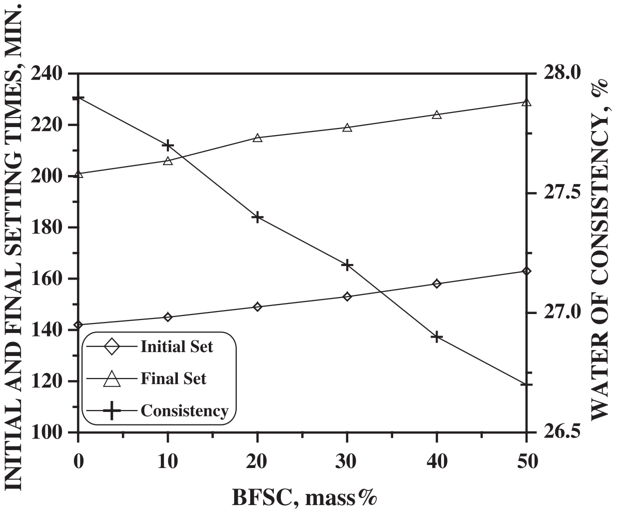

Fig. 2. Water of consistency and setting times of blended cement pastes with various proportions of BFSC.

3.1.2. Free lime contents

The results of free lime of SRC and blended cement pastes cured up to 90 days are illustrated as a function of curing time and BFSC content in Fig. 3. The free lime contents increase with curing time for all cement pastes. This is attributed to the continuous hydration of the main cement phases such as β-C_2S and C_3S producing free lime.

The SRC has 67.5% C_3S and 11.5% β-C_2S. Therefore, SRC pastes produced high values of portlandite. On the other side, the granulated slag has low pozzolanic activity. The rate of formation is higher than its consumption by

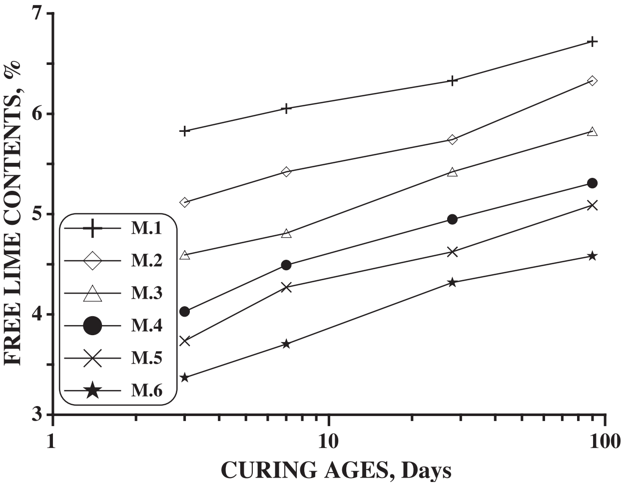

Fig. 3. Free lime contents of SRC with various proportions of BFSC immersed in tap water up to 90 days.

GBFS. Hence, the increase of slag content decreases the amount of portlandite up to 90 days, as seen in Fig. 3.

At a given time, the lime contents decrease with the BFSC content in the blends. There are two processes, one tending to increase the lime content and the other tending to decrease it. This is due to the reaction of granulated slag component with formed lime during the pozzolanic reaction. Therefore, BFSC consumes some of formed $Ca(OH)_2$ during the hydration of blended cement pastes to activate the hydration of BFSC portion forming additional C-S-H.

3.1.3. Total pore volume

The values of total pore volume of the hydrated cement pastes are plotted as a function of curing time in Fig. 4. The total pore volume of hardened cement pastes decreases with curing time, due the continuous hydration of cement clinker and the accumulation of hydration products in the pores of cement paste. Therefore, the bulk density increases, thus increasing the bulk density and decreasing the total pore volume. As the BFSC content increases, the total pore volume increases. This is mainly due to the decrease of the hydration rate of BFSC in comparison with SRC.

3.1.4. Nonevaporable combined water contents

The nonevaporable water contents for SRC and blended cement pastes are graphically represented as a function of curing time in Fig. 5. Generally, it can be seen that the nonevaporable water contents increase with curing time for all hardened cement pastes due to the continuous hydration of cement compounds, in addition to slag portion in presence of liberated $Ca(OH)_2$. The BFSC–SRC blended cement pastes give lower values of nonevaporable water than do those containing only SRC. This is attributed to the lower hydraulic properties of BFSC in comparison with SRC. It was found that the nonevaporable water contents of hydrated slag cement pastes are lower than those of plain cement paste [17]. This is due to the fact that the C-S-H formed in the presence of blended cement is C-S-H (II), which has lower water content than C-S-H (I) does, which formed from plain cement paste, besides the removal of $Ca(OH)_2$ by pozzolanic reaction, which leads to the decrease in nonevaporable water content.

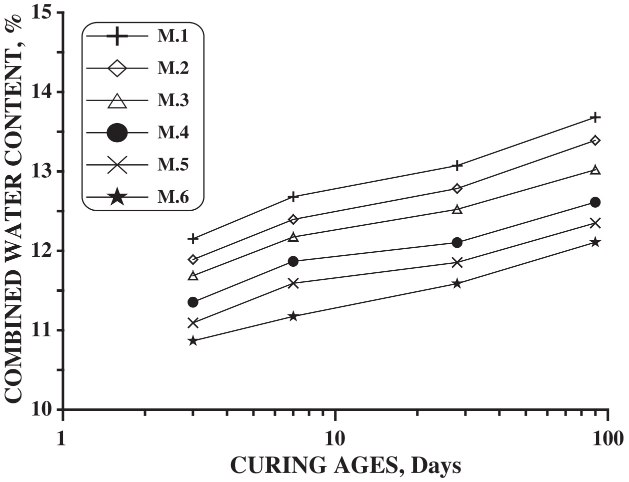

Fig. 5. Combined water contents of blended cement pastes with various proportions of BFSC.

3.1.5. Compressive strength

The compressive strength of the hardened SRC mortars with BFSC is graphically depicted in Fig. 6. It is clear that the compressive strength for all cement mortars increases with curing time due to the increase of the amounts of hydration products, such as calcium silicate and alumino-silicate hydrates. As the hydration proceeds, more cementing materials are formed and accumulated in water-filled pores to give a more compact body. The substitution of 10 mass% of SRC with BFSC increases the compressive strength at all ages of hydration. This may be due to BFSC acting as a nucleating agent and improving the transition zone between the binder and cement, which activates the

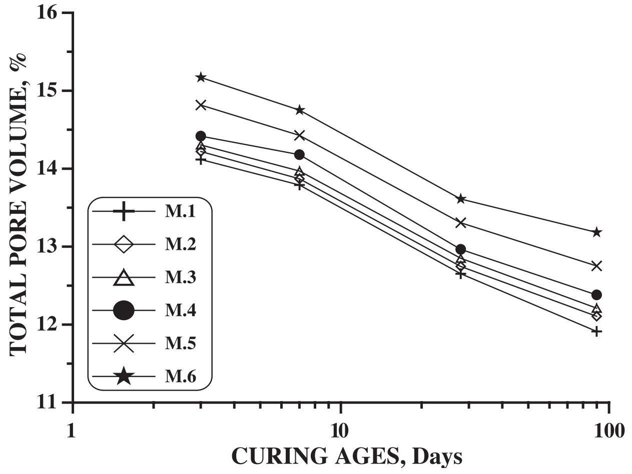

Fig. 4. Total pore volume of blended cement pastes with various proportions of BFSC in tap water up to 90 days.

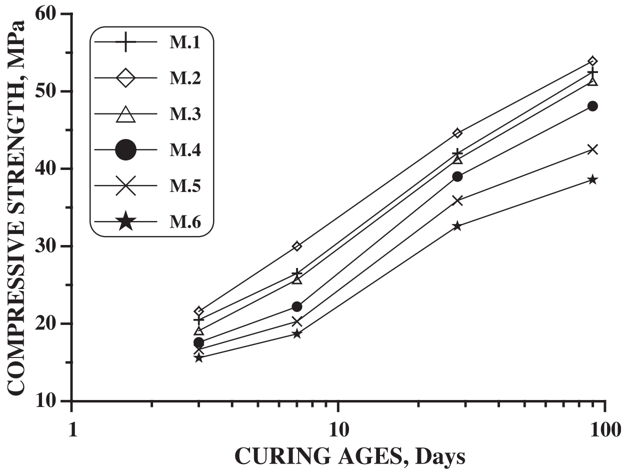

Fig. 6. Compressive strength of blended cement mortars with various proportions of BFSC in tap water up to 90 days.

hydration of SRC. Therefore, more calcium silicate, as well as calcium aluminosilicates, hydrates are formed and accumulated to fill up the available pore volume between the cement particles. With the increase of the substitution of SRC with BFSC (more than 10%), the compressive strength decreases. This is mainly attributed to the decrease of the clinker portion, which has higher hydration characteristics. In addition, CaS present in the slag portion hydrates form $Ca(OH)_2$ and $Ca(SH)_2$ or H_2S. Both $Ca(SH)_2$ and H_2S decrease the pH value of the blended cement mortar. Therefore, the strength diminishes.

The increase of the substitution of SRC with BFSC increases slightly the total pore volume of cement pastes. This is due to the fact that the BFSC has less hydraulic properties than SRC does; therefore, the free water increases with BFSC.

Ten mass percent of BFSC containing granulated slag reacts with some portlandite, forming C-S-H as well as CAH, which are deposited in the pores of the cement pastes, in addition to that formed from the hydration of SRC. Therefore, the compressive strength increases. As the amount of BFSC increases and SRC decreases, the rate of hydration decreases, and then, the compressive strength of cement pastes decreases up to 50 mass%, as shown in Fig. 6.

3.2. Aggressive attack of cement pastes and mortars in Caron's Lake water

The chemical action of seawater on concrete is mainly due to the presence of $MgSO_4$, $MgCl_2$ with NaCl, as well as other dissolved salts. The presence of chloride and sulphate ions, together with Na^+, Mg^{2+} and Ca^{2+}, constitutes a major corrosive action on concrete. The progress of attack was estimated through the measurements of free lime, total chloride and total sulphate contents, as well as total pore volume of the hardened cement pastes. The progress of the chemical attack was also determined from the changes of the compressive strength of the hardened cement mortars in aggressive water (Caron's Lake water).

3.2.1. Total pore volume

Fig. 7 shows that, for the all hardened cement pastes immersed in the aggressive water, the values of total pore volume decrease with curing time due to the filling up of the available pore volume. The increase of substitution of SRC with BFSC up to 30% increases slightly the total pore volume. But above 30% BFSC, the total pore volume increases with BFSC content. This is mainly attributed to the lower hydraulic properties of BFSC in comparison with SRC.

3.2.2. Free lime contents

Fig. 8 shows the free lime contents of blended cement pastes with curing time. The free lime content decreases continuously with curing time up to 1 year. This is mainly due to the reaction of produced lime with $MgCl_2$ and $MgSO_4$. In addition, the presence of NaCl increases the solubility of $Ca(OH)_2$ [18]. The reaction of produced lime in the aggressive solution is considered by many investigators as one of the most important factors determining the deterioration of cement pastes. The sulphate and chloride ions react with hydrated lime as follows:

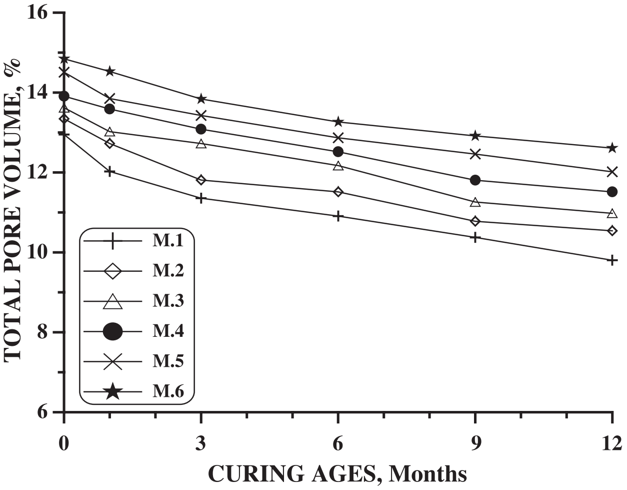

Fig. 7. Total pore volume of blended cement pastes with various proportions of BFSC immersed in aggressive water up to 1 year.

$$Ca(OH)_2 + MgSO_4 \rightarrow CaSO_4 + Mg(OH)_2$$

$$Ca(OH)_2 + MgCl_2 \rightarrow CaCl_2 + Mg(OH)_2$$

$$Ca(OH)_2 + 2NaCl \rightarrow CaCl_2 + 2NaOH$$

In addition, it is clear that the free lime content decreases sharply in the first months of immersion then slightly up to 1 year. The rate of the formation of free lime is higher in the first month of immersion. After 1 month of immersion, the hydration of alite is decreased; therefore, the produced lime is also diminished. This leads to the sharp decrease of free lime in the first month and slight decrease up to 1 year due to the reaction of sulphate and chloride in the immersing water. Bonen and Cohen [19] investigated the effect of magnesium sulphate attack and found that magnesium ion forms a layer of brucite at the exposed surface. Because of the low solubility of brucite, the penetration of Mg^{2+} beneath the brucite layer into the interior of the paste is restricted. The brucite formation consumes a high amount of $Ca(OH)_2$ released from hydration, once the available $Ca(OH)_2$ is depleted.

3.2.3. Total chloride contents

The total chloride contents of blended cement pastes are graphically represented as function of curing time in Fig. 9. The results show that the total chloride content increases gradually with curing time for all hardened cement pastes. This is due to the reaction between chlorides and $Ca(OH)_2$ to produce $CaCl_2$, and also tricalcium aluminate as well as

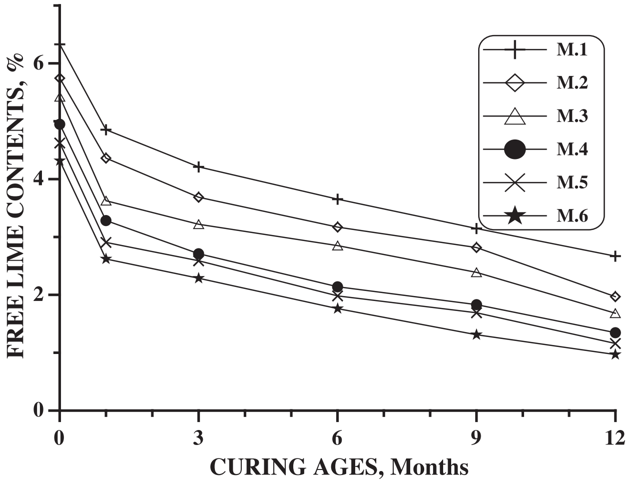

Fig. 8. Free lime contents of blended cement pastes with various proportions of BFSC immersed in aggressive water up to 1 year.

calcium aluminoferrite hydrates, giving chloroaluminate hydrate. Sometimes, the total chloride contents decrease with the amount of BFSC up to 30%; that is, the blended cement pastes made of SRC with BFSC up to 30% have lower values of total chloride than SRC. This is mainly due to the high resistivity of BFSC towards chloride ions. But, above 30 mass% BFSC, the total chloride content increases with the amount of BFSC in the blends. This is may be due to the increase of total pore volume with the amount of BFSC (above 30%). Therefore, the diffusion of chloride ions through cement pastes increases. In a previous work [20], it was found that the blending of plain cement with a pozzolanic material is beneficial to the prevention or the decrease of chloride ions diffusion. This blending leads to the formation of more compact and finer pore structure.

3.2.4. Total sulphate contents

Fig. 10 shows the total sulphate contents of blended cement pastes. The total sulphate contents increase with curing time for all cement pastes, especially at early ages of hydration. This is due to the migration of the sulphate ions from the aggressive water to the cement paste, which reacts with aluminate, ferrite or/and $Ca(OH)_2$ of the cement paste, forming calcium trisulphoaluminate hydrates (ettringite), which have 227% volume, leading to the expansion of the resulting products [21]. Sulphoaluminate hydrates are formed at early ages of hydration, which need high amount of sulphate ions, precipitate, close the pores and hinder the penetration of more sulphate ions. Therefore, the total sulphate content increases sharply at 1 month and gradually at the later ages of hydration. Sometimes, the blended cement pastes containing BFSC show lower values of the total sulphate content than do those of only SRC. This is due to the high resistivity of BFSC towards sulphate ions and the low capillary pores of pozzolanic cements [22].

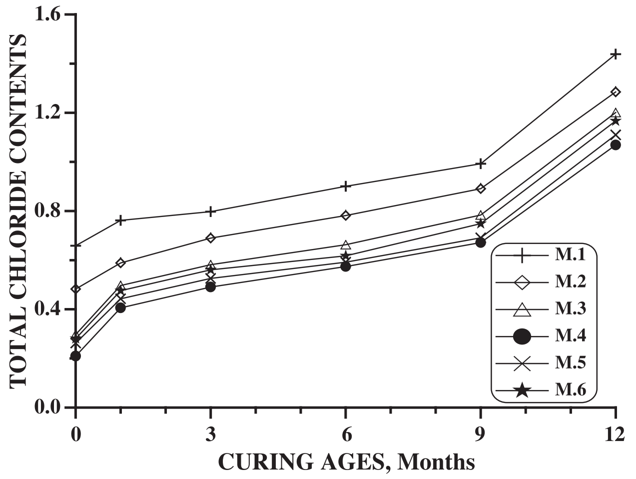

Fig. 9. Total chloride contents of blended cement pastes with various proportions of BFSC immersed in aggressive water up to 12 months.

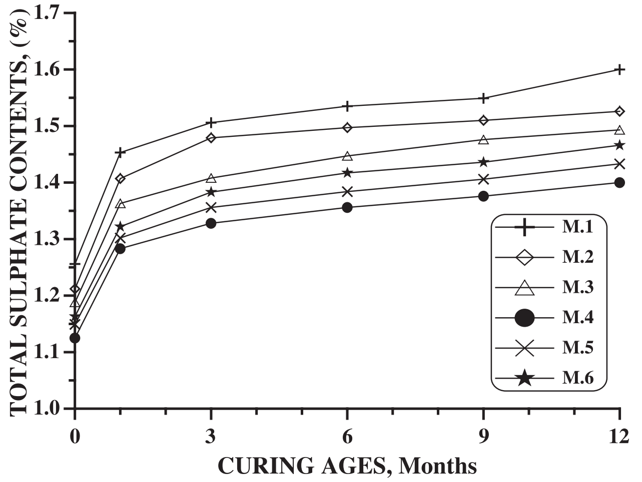

Fig. 10. Total sulphate contents of blended cement pastes immersed in aggressive water up to 12 months.

3.2.5. Compressive strength

The compressive strength of the different hardened cement mortars are plotted as a function of curing time in aggressive water in Fig. 11. The course of the curves shows that, for all cement mortars, the strength increases up to 6 months and then decreases up to 1 year. This is mainly due to the presence of Cl^- and SO_4^{2-} activating the hydration of slag portion in the SRC and blended cement mortars.

Generally, the increase of the compressive strength up to 6 months is mainly due to the acceleration effect of $MgSO_4$ and $MgCl_2$ on the hydration of cement. Parts of the Mg^{2+} ions is adsorbed and incorporated into the particles of calcium silicate hydrates. This process stabilizes and enhances its crystallization, as well as the strength of cement pastes. This activation leads to the formation of calcium silicate, chloroaluminate and sulphoaluminate hydrates. The amount of C-S-H increases during the first 6 months. Therefore, the compressive strength enhances. The presence of NaCl in aggressive water increases the solubility of $Ca(OH)_2$, enhancing the stability of calcium silicate hydrates and, consequently, the strength of the

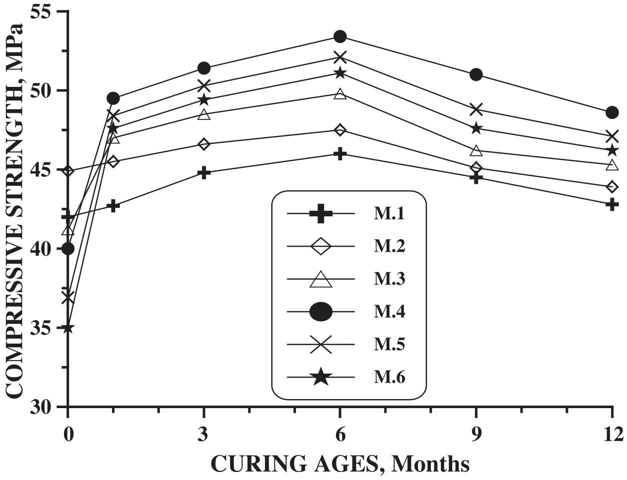

Fig. 11. Compressive strength of blended cement pastes immersed in aggressive water up to 12 months.

cement mortars. In addition, part of the Na^+ tends to be absorbed by the particles of C-S-H and to be incorporated into its interlayer space [2,3,23]. Therefore, in the presence of NaCl, better ordered calcium silicate hydrates are formed, and the strength increases. On the other side, the decrease of compressive strength after the first 6 months and up to 1 year is mainly due to the aggressive attack of chloride and sulphate ions.

The penetration of sulphate ions into the mortars would result in the conversion of calcium aluminate hydrate and monosulphate aluminate hydrate into ettringite, which expands, resulting in internal stresses, causing the cracking and deterioration of cement mortars. In addition, magnesium sulphate reacts with the formed $Ca(OH)_2$, forming gypsum and $Mg(OH)_2$, which has low solubility and precipitates as a gel. At later ages, it attacks C-S-H to form $Ca(OH)_2$ and magnesium silicate hydrates, which have no binding properties [2,3,5]. On the other hand, chloride ions attack the major constituents of cement mortar, forming chloroaluminate hydrates, which causes softening. Magnesium chloride also reacts with produced $Ca(OH)_2$, forming $CaC1_2$ and $Mg(OH)_2$. Calcium chloride reacts with calcium aluminate hydrates, producing calcium chloroaluminate hydrates, which has deleterious effect on cement mortars and may explain the continuous decrease in the strength after 6 up to 12 months. In addition, the results show that the blended cement mortars containing SRC with BFSC up to 30 mass% have higher values of compressive strength than do those of blended cements containing more than 30 mass% BFSC, while the mortars containing only SRC have lower values of compressive strength than do those of all blended cement mortars. This may be due to the fact that the presence of SO_4^{2-} and Cl^- activates the hydration of slag portion in the blended cement mortars, leading to the formation of additional amounts of calcium silicate hydrates, which precipitate in water-filled pores to give a more compact closed body structure with very low capillary pores. Therefore, the compressive strength increases.

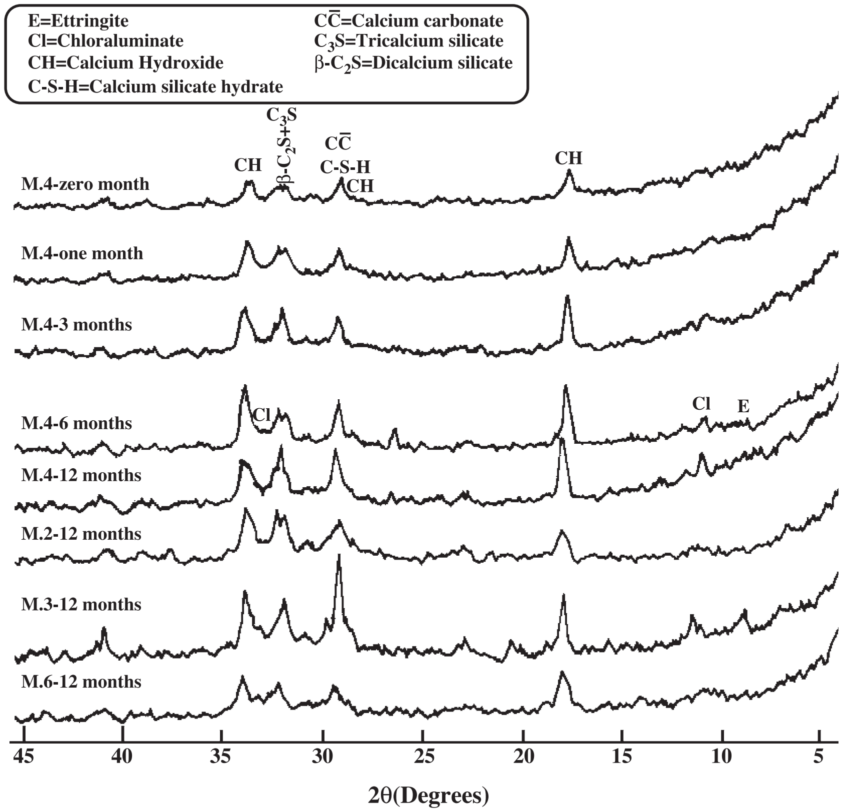

Fig. 12. XRD patterns of M.4 at 0, 1, 3, 6 and 12 months and of M.2, M.3 and M.6 at 12 months.

The addition of 30 mass% BFSC tends to improve the durability of SRC pastes in the aggressive solution. SRC pastes give the lower compressive strength values at all immersing ages. This is mainly due to the high content of portlandite, which formed during the hydration. As a result of this, $CaCl_2$ and $CaSO_4$ are formed. The chloro- and sulphoaluminate hydrates are formed, which make softening and expansion.

3.2.6. XRD

Fig. 12 illustrates the XRD patterns of M.4 at 0, 1, 3, 6 and 12 months and of M.2, M.3 and M.6 at 12 months. $Ca(OH)_2$, $CaCO_3$, C-S-H, β-C_2S and C_3S decrease with curing time increases due to hydration process. Calcium chloroaluminate hydrate is not formed during immersion in tap water (zero time). On the prolonged hydration, the intensity of the peaks corresponding to the calcium chloroaluminate hydrate increases, where the intensity of the peaks corresponding ettringite decreases. Caron's Lake water contains 12543 ppm Cl^- and 8680 ppm SO_4^{2-}; therefore, the effect of chloride on the cement pastes is higher than the effect of sulphate. This is also due to the small radius of Cl^- in comparison with SO_4^{2-}. The competition exists between sulphate and chloride ions. Hence, sulphate ions decrease the chloride-binding capability greatly. Obviously, the lower sulphate content of BFSC is one of the reasons that BFSC has perfect performance to resist the chloride-induced corrosion because the effect of sulphate ions on the chloride binding is less [24].

The microstructure analysis shows that BFSC can form more calcium chloroaluminate hydrate, thus, BFSC can bind more chloride ions. The sulphates influence the chloride-binding capability because of the preferential reaction between sulphates and C_3A. More C_3A reacts with sulphates; less C_3A can bind the chloride to form calcium chloroaluminate hydrates. The structure of C_4AH_{13} and its homogeneous hydrate, e.g., the hydrated products of C_3A, can be denoted as $2[Ca_2Al(OH)_6OH.H_2O]$. The OH^- ion is very weak and can be exchanged for some other negative ions, such as chloride ion, because the OH^- ion is attracted by the electrovalent bond to form calcium chloroaluminate hydrate [25].

4. Conclusion

The present work concerns the durability of sulphate-resisting slag cements in Caron's Lake water. The results show that the blending of SRC with BFSC up to 30 mass% improves the durability of SRC. This is mainly due to the decrease of total pore volume, free lime content, total chloride, total sulphate contents and, subsequently, increase in the resistivity towards sulphate and chloride ions. The blends containing SRC with BFSC up to 30 mass% show higher values of compressive strength than do those of only SRC. More than 30 mass% BFSC in the blends leads to decrease the durability and increase the deterioration of cement mortars. The increase of BFSC content (up to 30 mass%) leads to increases in the total pore volume, as well as chloride and sulphate attack. Therefore, the compressive strength diminishes, but it is still higher than SRC. It can be concluded that the mix containing SRC with 30 mass% BFSC is the suitable durable mix for using in Caron's Lake water.

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