

The Influence of Combined Application of Two SCMs on the Corrosion and Acid Attack Durability of Mortars

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RESEARCH ARTICLE

Received 18 April 2016; Revised 20 June 2016; Accepted 27 September 2016

Abstract

The improvement of the durability of cement-based materials (mainly mortar and concrete) is a very significant task, because these are the most frequently used building materials. Unfortunately, the environmental effects (acidic rain, chloride ions, sulphate ions, fermentation reactions, etc.) can cause damages on these structures. The (combined) application of different supplementary cementing materials (SCMs) is one possibility to solve this problem due to their special properties (pozzolanic activity, filling effect and influence on the hydration mechanism). In this recent research metakaolin and silica fume were used as SCMs and the influence of combined application of them was also studied. The permeability of the specimens was investigated by chloride ion diffusivity, and the resistance to harmful circumstances (sulphuric acid, pH = 1; acetic acid, pH = 3) was followed by measuring the change in mass up to 390 days. The aim of this research was to expose the main characteristics of the combined application of SCMs primarily in acidic circumstances.

Keywords

Cement, durability, supplementary cementing materials (SCMs), acid attack, chloride migration

1 Introduction

Industrial fields, like agriculture, pharmaceutical industry, leather industry, etc. produce large amount of waste water. These waste waters need to be collected, treated and stored in silos or pools often made of concrete before or during the treatments. Due to chemical and microbiological reactions the pH of the stored materials could be acidic [1–3].

It is well-known, that acidic circumstances effect harmful the cement-based matrix. When these acids come into contact with the cement-based matrix, the reactions with the hydrate phases of the cement paste (portlandite, C–S–H and hydrated aluminates) produce mainly calcium and aluminium salts, whose solubility varies from high to very high in water. The solubility of the salts and the dissociation constant of the acids are known to influence the aggressiveness of the acids [4]. The porosity of the damaged layers increases after the dissolution [5–8]. Resistance of a cement matrix to acid corrosion will depend on pore structure characteristics, the ability of the matrix components to neutralize acid and the products of acid corrosion. Passivation by deposition of reaction products will prevent the matrix from further corrosion [9].

Nowadays the application of supplementary cementing materials (SCMs) in corrosive circumstances is widely investigated due to their advantageous properties (particle size, pozzolanic activity, etc.) [10–14]. The present system for prescriptive specification of cements favours low tricalcium-aluminate clinker contents, combined with low permeability of the matrix, remains the best guidance for the design of sulphate-resistant Portland cement concretes. However these empirical guidelines, based on long experience, are probably inadequate for Portland cement and are almost certainly inadequate for specification of concrete made with high replacement of cement by supplementary materials such as slag and fly ash. Paradoxically, these supplementary materials are often characterised by having high chemical alumina contents yet, when blended with Portland cement, are also reported to enhance sulphate resistance. It is probable that a radical rethink of existing predictive methods and performance based standards is required to take into account the character of these complex matrices [4].

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With enhanced durability the lifespan of cement-based materials could expand.

In this recent research the properties of MK and SF were investigated, because the concrete technology does not have enough information about the behaviour of these materials especially in acidic circumstances. We have attempted to get knowledge about them, because these two SCMs widely used in Hungary in production of high or ultra-high performance concrete (HPC or UHPC) structures (e.g. waste water treating plants). In our country standard FA and GGBS containing cement products are available, but the quality of fly ash is not constant and there is not enough GGBS available as additional SCM for concrete technology.

Some other investigations worked with similar aspects, and they were studied to compare with our results [15–21]. In this recent research different substitution ratios of the cement were followed, and the main properties of the mixture of silica fume and metakaolin (when they were used together at the same mixture) were additionally investigated. The combined application of these two different SCMs, due to their physical and chemical properties (different particle size, specific surface area, pozzolanic activity, etc.), could influence on the behaviour of the whole structure.

Objectives

First objective of this recent research was to study the effects of acidic exposures (sulphuric acid and acetic acid exposure) when different types and amounts of supplementary cementing materials (SCMs) were added replacing the ordinary Portland cement. The applied SCMs were metakaolin (MK) and silica fume (SF). The effect of the acidic circumstances was followed by measuring the change in mass of the mortar specimens. The hardened mortar specimens were stored in one type of inorganic acid (sulphuric acid) and in one type of organic acid (acetic acid) up to 390 days. The different types of acids had different effects on the mortar properties.

The permeability of the structures of the cement-based materials is a very significant parameter. The diffusion of harmful ions could be limited by the compact structure. That is why the second objective of this study was to examine the permeability and thus the chloride ion diffusivity of the mixtures by rapid chloride ion migration test.

Effect of acidic circumstances

The ingress of the harmful ions occurs by diffusion. Diffusion is the slowest and thereby the rate-determining step of the process. The effects of acidic circumstances depend on the type of the acid, the concentration, the pH, the mobility of the ions, the applied water/cement (water/binder) ratio, the type of the cement and the used aggregate.

In case of mortar specimens, the process of the diffusion is slower than in cement paste specimens, because the penetrating ions needed to circle the (non-porous) aggregate particles. This phenomenon is called „labyrinth effect” [22]. In parallel

with this phenomenon the transport and the affinity of the acid decrease. It was suggested that the porosity of the corroded surface was the most significant factor which defined the penetration level to the undamaged bulk phase [7–8].

For cement-based materials, the degree of acidic deterioration depends on the solubility of the calcium and aluminium salts. The passivation effect is predominated by low solubility. Based on these facts, it could be concluded, that the proceeded reactions and processes were very complex [4].

Sulphuric acid

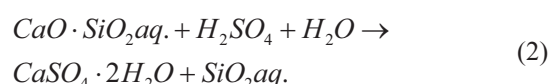
Sulphuric acid is a strong inorganic acid, which occurs in industrial waste waters, sewage systems and groundwater. If the soil or the concrete aggregate contain pyrite, sulphuric acid can be formed by the oxidation of sulphides. In waste waters and sewage, the sulphates formed into sulphides (hydrogen-sulphide by bacterial attack), which further oxidized to sulphuric acid [23–24].

The chemical corrosion by sulphate attack is a complex process, because the corrosion is influenced by sulphate attack and hydrogen ions. It meant the strongly acidic circumstances dissolved calcium ions form the cement paste, and precipitate solids (ettringite and gypsum) as neutralisation products.

During the sulphate attack, the calcium-hydroxide and the calcium-silicate-hydrate (CSH) react with the acid and calcium-sulphate evolving, and the CSH gel convert into amorphous hydrous silica. This process causes an increase in volume by the reaction products. The level of the deterioration could be defined by the width and the porosity of the gypsum layer, which were influenced by the degree of the precipitate [25–26].

The pH of the environment decreases by these reactions between cement paste and acid; the ettringite and monosulphate (which appeared originally in the cement-based materials) destabilize and solubilise, and then convert to gypsum and aluminium-hydroxide. At the same time the crystallization of the ettringite is continuous in the interior of the specimens and formation of calcium-sulphate is also found in this zone. The structure of the mortar specimens damaged seriously by these reactions [4, 27].

The main reactions are the following (1–2):

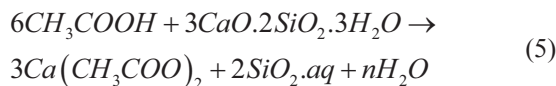
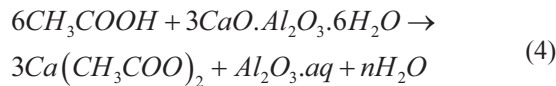
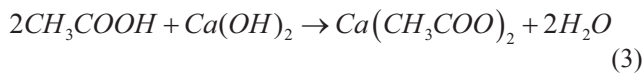


Acetic acid

Acetic acid is an organic acid, ranking to the volatile fatty acid group (VFA or short chain fatty acid molecules of six or fewer atoms of carbon). The acetic acid partly dissociates in water and reacts both with hydrated and anhydrous compounds of the cement paste to give mainly calcium salts or complexes. The primary product of this reaction is calcium-acetate, which

has very high solubility. During the acid attack, the portlandite ($\text{Ca}(\text{OH})_2$) and the calcium-silicate-hydrates (CSH) turned into calcium-salts and silicon-dioxide. On the other hand, the phases containing iron and aluminium also collapse, which proved by the brown colour of the acidic solution [28].

The main reactions are the following (3–5) [29]:



2 Materials and methods

In this study, the effects of metakaolin (MK) and silica fume (SF) SCMs on the durability of mortar were investigated. Different amounts of cement were substituted by SCMs. The reference cement was CEM I 42.5 N ordinary Portland cement, the MK was used in form of powder, and the SF in form of slurry. The cement content was 520 kg/m^3 . Seven mixtures of mortar were prepared with the same water to binder ratio ($w/b = 0.4$), and the reference samples were made without SCMs. The water content of the SF slurry was 50 mass% (m%) and it has been considered in the calculation of water to binder ratio. In some cases, where the applied SCMs ratio was high (MK 17, SF 10), superplasticizer was used in the mixtures. Two mixtures were prepared with different amounts of MK (10 and 17 m%), other two with different amounts of SF (5 and 10 m%), while two mixtures contained the combination of MK and SF (7 + 3 m%, 12 + 5 m%) (Table 1). In the specimens quartz sand was used as aggregate with the grain size of 0/2 mm. The ratios of the sand fractions were the following: 40 m% of 1/2 mm, 42 m% of 0.2/1 mm, 18 m% of F36 (0.08–0.25 mm). After mixing prismatic and cylinder specimens were cast. The dimensions of the prismatic specimens subjected to acidic treatment was $40 \times 40 \times 160 \text{ mm}$ and for the chloride ion diffusivity measurement cylindrical specimens were used with dimensions of $100 \times 200 \text{ mm}$.

In our previous research on these mortar mixtures, made with the same materials and mix proportions, the influences of SCMs on fresh and hardened condition were investigated [30]. Differences observed between the properties of the mixtures in the fresh condition are: (i) the addition of SCMs resulted in decrease of consistency, (ii) the change of workability in time is less pronounced for mixtures made with SCMs than that of the reference mixture. The samples were stored in water and at climatic conditions ($20 \pm 1^\circ\text{C}$, $\text{RH} = 65\%$). The consistency of the mixtures was determined by flow table test, and the change in workability was measured until 120 minutes. The hardened properties (flexural and compressive strength, water absorption, bulk density and apparent porosity) were investigated at

the age of 28, 56, 90 days. Different curing conditions resulted differences in the properties of hardened samples. Flexural tensile strength was higher and compressive strength was lower for the specimens stored under water and tested in wet condition when compared to the results obtained from specimens tested in air dry condition. Water absorption and apparent porosity were lower and apparent density was higher for the specimens stored under water than those of the specimens stored in climatic chamber. The differences are attributed on one hand to the presence of the water and on the other hand to the different rates of hydration due to different curing methods. The composition and the cement substitution ratios induced further differences. The specimens with smaller substitution ratio showed more effective utilization of SCMs in the view of strength up to 90 days. The water absorption and apparent porosity were higher, but the apparent density was smaller than those of the mixtures with higher substitution ratios. It is important to find optimum dosage and substitution ratio, because application of SCMs over the optimum amount may reduce the performance both in strength and durability parameters [30].

Table 1 Composition of mortar mixtures

Specimen	Cement [m%]	MK [m%]	SF [m%]	MK+SF [m%]
CEM I	100	-	-	-
MK 10	90	10	-	-
MK 17	83	17	-	-
SF 5	95	-	5	-
SF 10	90	-	10	-
MK/SF 7/3	90	7	3	7+3=10
MK/SF 12/5	83	12	5	12+5=17

After demoulding the prismatic specimens were stored in water under laboratory condition up to 7 days then in climatic chamber up to 28 days ($T = 20 \pm 3^\circ\text{C}$ and $\text{RH} = 65\%$). After 28 days parts of the prismatic specimens were subjected to different environmental conditions: one half of the prism specimens was stored under acetic acid ($T = 20 \pm 3^\circ\text{C}$, $\text{pH} = 3$); and the other half was stored under sulphuric acid until the age of testing ($T = 20 \pm 3^\circ\text{C}$, $\text{pH} = 1$) (Table 2).

After removing the prismatic specimens from the acidic solution the change in mass was measured in different ages.

Average values are obtained by measurements of three individual prismatic specimens.

Table 2 Experimental program for prismatic specimens

Specimen	Curing (between 1 and 7 days)	Curing (between the age of 7 and 26 days)	Treatment (between the age of 28 and 390 days)
CEM I			
MK 10		climatic chamber (T=20±3°C, RH=65%) up to 26 days,	pH=1
MK 17		then 2 days immersed in water (until saturated)	sulphuric acid
SF 5	water curing (T=20±3°C)		or
SF 10			pH=3
MK/SF 7/3			acetic acid
MK/SF 12/5			

After demoulding, the cylindrical specimens were stored in water under laboratory condition up to 27 days (T = 20 ± 3°C). Then the specimens were cut into 3 discs (with height of 50 ± 2 mm) and stored in saturated solution of Ca(OH)₂ until the beginning of the test at the age of 28 days (Fig. 1). The 3 discs were measured in parallel by chloride ion migration method.

To study the diffusion characteristics HTC method was used [31]. It is a rapid electric migration method which was elaborate to determine the non-steady state migration coefficient (D_{nssm}). Now, this method is covered by the standard of NT BUILD 492 [32], and the above mentioned method was also adopted by other standards [33, 34]. Under this examination we could determine the depth of the chloride ion ingress with colorimetric analysis using AgNO₃ (silver-nitrate) solution. The non-steady state chloride migration coefficient was calculated and the formula was obtained from Fick 2nd law (6) [31]. Average values are obtained by measurements of three discs. From the diffusion coefficient we can deduce for the permeability of the structure.

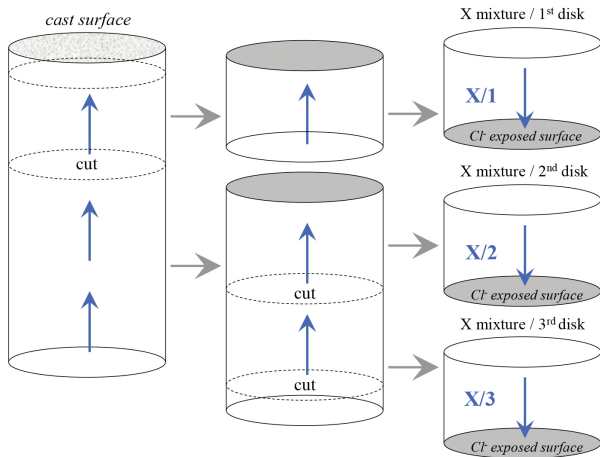


Fig. 1 Cylindrical specimens cut into discs for rapid chloride migration test

The non-steady state migration coefficient could be quantified from the test data with the application of the following formula (equation 6). These coefficients suggest to the permeability of the samples with or without SCMs. To take into account the comparability of the test results the applied DC was 30 V and the duration of tests for each mixture was chosen for 8 hours.

$$D_{nssm} = \frac{0,0239(273 + T)L}{(U - 2)t} \left(x_d - 0,0238 \sqrt{\frac{(273 + T)Lx_d}{U - 2}} \right) \quad (6)$$

- D_{nssm} – diffusion co-efficient, x 10⁻¹² [m²/s],
- U – direct voltage [V],
- T – average temperature [°C],
- L – average thickness of the sample [mm],
- x_d – average penetration depth of ions [mm],
- t – testing time [hour].

The chloride ion diffusion measurements were carried out at the age of 28, 56 and 90 days, while the measurements of the loss of mass due to aggressive solutions were carried out until the age of 390 days.

3 Results and discussion

3.1 Chloride ion diffusivity

The average non-steady state chloride migration coefficients are listed in the Table 3 and the result are visualized in Fig. 2.

According to the results, it could be concluded that in every cases the migration coefficient was reduced by the application of SCMs. The migration coefficients decreased with the ages of specimens because the penetration depths of the chloride ions were inversely proportional with the age of the specimens. These suggested that the permeable porosity decreased and the production of the hydrate phases was continuous.

Table 3 The average non-steady state chloride migration coefficients of the mixtures

Mixtures/days	D _{nssm} (·10 ⁻¹² m ² /s)		
	28days	56 days	90 days
CEM I	8.74	6.60	5.40
MK 10	5.56	4.66	2.97
MK 17	6.92	3.21	2.13
SF 5	4.94	3.13	2.55
SF 10	3.35	1.76	1.27
MK/SF 7/3	4.59	3.72	2.10
MK/SF 12/5	3.67	2.56	1.82

The best results (the lowest migration coefficients) showed by the specimens made with 10 m% SF and by the specimens made with combined substitution rate of the cement (12 m% MK and 5 m% SF). The reason is that the SF had the smallest particle size and the highest specific surface area. This resulted in the early hydration more compact microstructure.

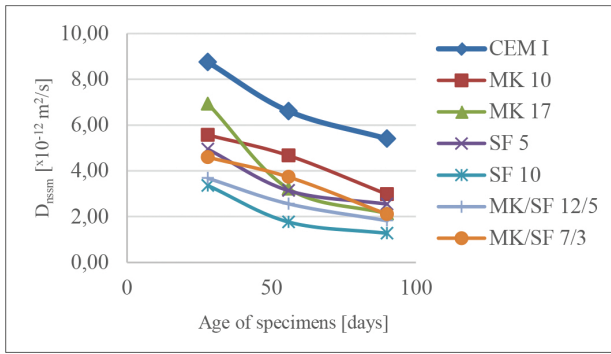


Fig. 2 Average non-steady state chloride ion migration coefficients (D_{nssm}) as a function of time of testing

Fig. 3 shows the relatively high difference between the penetration depth of the reference specimens and the specimens made with 10 m% silica fume.

In the case of the other mixtures (MK 10, SF 5, and MK/SF 7/3) the addition of SCMs resulted in the decrease in migration coefficient as a function of the substitution rate. At the age of 90 days all of the results were about or less than the half of the value in case of reference mixture. Determining the optimal replacement ratio is concerning the durability and also a very significant economic point of view. Based on the results, it could be concluded, that the smallest diffusion coefficients were not presented by the mixtures with the highest replacement rate. According to Ghosh and Tran the measured coefficient highly depends on also the type of the constituents [35]. Therefore, during the application it has to be considered, that the price of the SCMs is different.

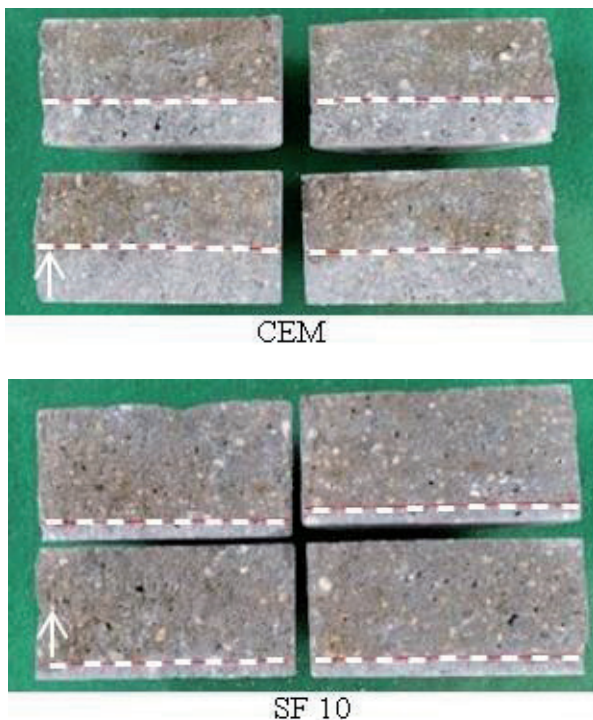


Fig. 3 Penetration depths of the chloride ions after 8 hours migration tests (DC: 30 V, HTC method); (up) reference sample without SCM, (bottom) specimen containing 10 m% SF replacement of cement. The white arrow shows the direction of the chloride penetration

3.2 Change in mass

Three mortar specimens from each mixture were stored in acetic or sulphuric acid solutions. The pH value of the sulphuric acid solution was pH = 1 and for the acetic acid solution was pH = 3. The exposure of the specimens in acidic solutions has been started at the age of 28 days. The specimens were fully water saturated before immersing them into the solutions (Table 2). The pH value of the solutions was checked on a daily basis and regularly concentrated acid was added into the solution to keep the intended pH level. On the other hand, we have to mention that the static storage of the specimens in acidic solutions in our experiments is different from the flowing exposure. As the reaction produce increasing amount of salt solution, this could accelerate the effect of harmful circumstances. The mass of exposed individual specimens were measured after soaking up the excessive solution from the surface. The measurement was performed in four different ages of specimens (56, 90, 270 and 390 days). After measurement the specimens were immediately put back into the exposure solution.

The change in mass of the specimens could be calculated from the measured data in mass% (7). Results are illustrated on Fig. 4 and 8 as a function of time.

$$w_s = \frac{m_s - m_{ds}}{m_{ds}} 100\% \quad (7)$$

w_s – changing of mass [m%],

m_s – mass of the specimen after acidic curing [g],

m_{ds} – mass of the water saturated specimen at the start of the test [g].

3.2.1 Effect of the sulphuric acid

The mass of the specimens increased during the first 90 day long exposure due to the exposure of sulphuric acid by the formation of gypsum and ettringite. Ettringite is the product of the reaction between calcium-aluminates or calcium-aluminate hydrate phases and sulphate ions. The ettringite formation in the outer layer of the specimen increased the mass, because by this process the water adsorption capacity of the outer layer also increased. The water adsorption capacity of the ettringite was investigated by Dermatas and Meng in case of soil stabilization [36]. On the other hand, $\text{Ca}(\text{OH})_2$ react with sulphate ions creating gypsum.

According to the visual observation it was concluded that the volume of the specimens increased, and this expansion caused cracks. The acidic solution could penetrate deeply inside the specimens via these cracks. During this effect, the pH value of the cement stone decreased, destabilized and started to peel off. The same phenomenon was observed in our previous investigation on cement pastes [37]. After 90 days the change in mass was resulted by the loosening and delaminating of structure. The deterioration was progressive and was not showed a finalized stage during the experiments; however, the rate of change in mass is apparently decreasing (Fig. 4 and 6).

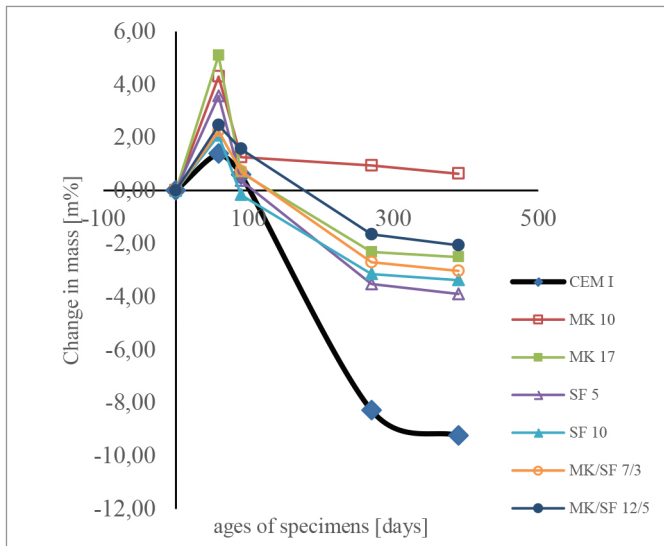


Fig. 4 Change in mass of specimens by sulphuric acid (pH = 1) exposure. Average values are obtained by measurements of three individual specimens

This behaviour can be attributed to the testing condition in which the solution was static without any flowing. In the case of concrete samples storing in similar conditions the same behaviour was found [38]. The same tendency could be seen on Fig. 5 according to Torii and Kawamura [26] comparing with our results (Fig. 4).

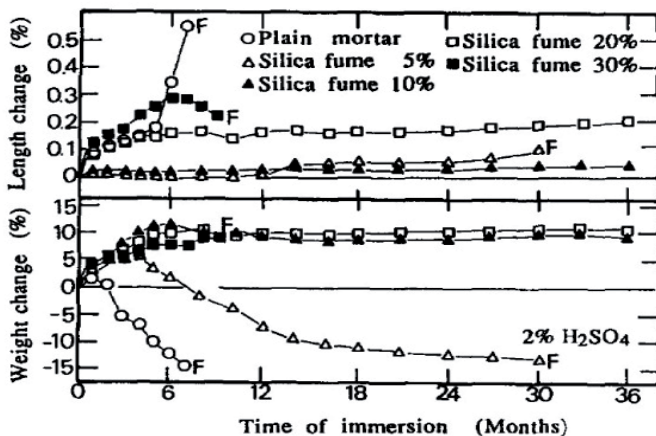


Fig. 5 Change in mass of silica fume mortars when immersed in sulphuric acid [26]

However, the degradation rate decreased with time by salt formation (gypsum, anhydrite) because this layer had a protective effect and could prevent the release of calcium ions and the dissolution of other chemical elements [9].

After the 390 day long sulphuric acid exposure the most deteriorated specimens with the highest mass decrease were the specimens of the reference mixture, with about 10 m% of change in mass. The application of SCMs resulted in lower average of change in mass, between 2 and 4 m%. The best result was shown in case of 10 m% MK replacement of cement where a slight increase of the mass was found.

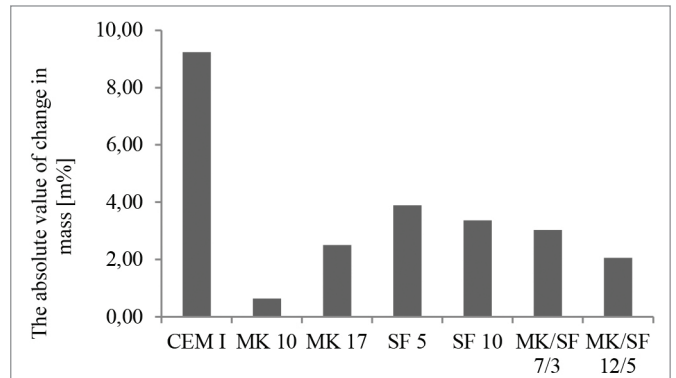


Fig. 6 The absolute value of change in mass of specimens by sulphuric acid exposure (pH = 1, 390 day long exposure)

3.2.2 Effect of the acetic acid

It has already been shown that the attack by organic acids (pH = 3), results in a well-marked mineralogical and chemical zonation of the immersed specimens. The alteration is translated into a decalcification of the altered zone, and a modification of the microstructure manifesting itself by the progressive dissolution of all the crystallized phases and the formation of a probable silica gel enriched with silicon, aluminium and iron in the superficial layer. The altered zone thus constituted has poor mechanical resistance but is not dissolved and then constitutes a semipermeable membrane that slows down the alteration kinetics [39].

In acetic acid a considerable loss of mass as well as change in volume (shrinkage) was recognized for every specimen of each mixture (Fig. 7).



Fig. 7 Deteriorated specimen by acetic acid of pH = 3 (left), undamaged specimen (right)

It can be observed, that the combined use of SF and MK did not result better resistance, than for the other mixtures. In the beginning of the acid exposure, the SCMs containing samples performed better and indicated higher resistance against the acetic acid attack. On the other hand after almost one year of exposure, the differences are not significant. In case of expected exposure of acetic acid the application and benefits of SMCs should take into account (Fig. 8).

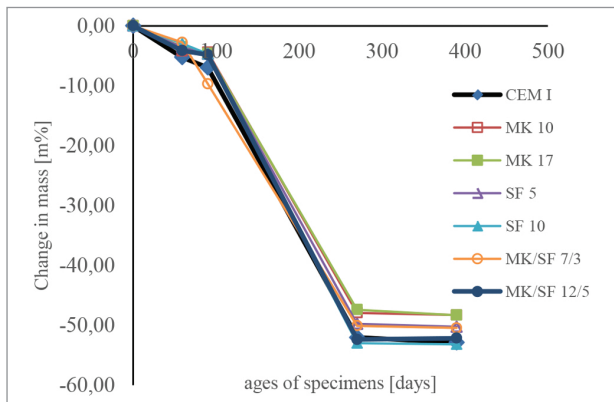


Fig. 8 Change in mass of specimens by acetic acid (pH = 3) exposure. Average values are obtained by measurements of three individual specimens

Calcium-acetate and decalcined hydrate products were formed by the acid attack, but no precipitation of salt was seen for acetic acid. The solubility of the calcium-acetate salt is high, and the deterioration is due to the dissolution of calcium-acetate formed in the hardened cement paste due to the acetic acid exposure [40–41]. The same phenomenon was observed in our previous investigation on cement pastes [37].

This is confirmed by our test results: the change in mass was the highest in the case of the reference samples (Fig. 9), because these specimens had the highest content of calcium-ions which originated from the Portland cement. On the other hand the SCMs containing specimens had lower calcium-ion content therefore the change in mass was less. The lower calcium-ion content is the consequence of the diluting effect of the replacement of cement by SCM. Despite all of this, the differences between the results are not remarkable. It suggests that the application of SCMs in mixtures did not live up the expectations, because they did not increased the resistivity against the exposure of acetic acid.

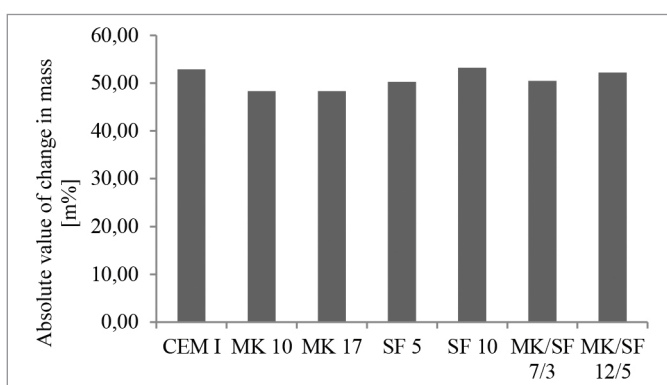


Fig. 9 Absolute value of change in mass of specimens by acetic acid exposure (pH = 3, 390 day long exposure)

After the 390 day long acetic acid exposure the deterioration rate was quite similar for all mixture. The loss of mass was about 50 m%. In this long term static exposure of acetic acid the application of SCMs did not result significant enhancement in durability.

4 Conclusions

In this study, the influence of combined application of two SCMs on the durability of mortar specimens was investigated. Different amounts of cement were substituted by metakaolin (MK) and silica fume (SF). The hardened mortar specimens were exposed to two different types of acidic solutions: (i) to sulphuric acid (mineral acid) and to acetic acid (organic acid) up to 390 days. The different types of acids had different effects on the mortar properties. In our recent research, the effects of two different acids on the durability of SCMs containing mortar specimens were investigated.

According to our test results, it was found that the application of metakaolin and silica fume SCMs reduced the chloride migration coefficient comparing with the reference mixture. The migration coefficients decreased with the ages of specimens. These suggested that the production of the hydrate phases was continuous and meanwhile the permeable porosity decreased. The best results (the lowest chloride migration coefficients) showed by the specimens made with 10 m% SF and by the specimens made with combined substitution rate of the cement (12 m% MK and 5 m% SF). The reason is that the SF had the smallest particle size and the highest specific surface area comparing with the metakaolin and cement used in the experiments. The results of our previous study proved that addition of silica fume resulted in more compact microstructure in the early hydration [30].

In the case of the other mixtures (MK 10, SF 5, and MK/SF 7/3) the addition of SCMs resulted in decrease of migration coefficient as a function of the substitution rate. At the age of 90 days all of the results were about or less than the half of the value of non-steady state migration coefficient obtained on the reference mixture.

The mass of the specimens increased during the first 90 day long treatment due to the exposure of sulphuric acid by the formation of gypsum and ettringite. According to the visual observation it was found that the volume of the specimens increased in the first 90 days of exposure, and this expansion caused cracks. During this effect, the pH value of the cement stone decreased, destabilized and started to peel off. After 90 days the change in mass was resulted by the loosening and delaminating of structure. The deterioration was progressive and did not show a finalized stage during the whole experiments; however, the rate of change in mass is apparently decreased. The decreasing degradation rate is the consequence of the precipitated salt formation (gypsum, anhydrite).

In acetic acid a considerable loss of mass and change in volume (shrinkage) was recognized for every mixture. It can be observed, that the combined use of SF and MK did not result better resistance, than for the other mixtures. In the beginning of the acid exposure, the SCM containing samples performed better and indicated higher resistance against the acetic acid attack. On the other hand after almost one year of exposure,

the differences were not significant. The differences between the results of SCM containing and reference mixtures were not remarkable. It suggests that the application of SCMs in mixtures did not live up our expectations.

Comparing the effect of the two acidic exposures, the sulphuric acid caused increase in mass until 90 days then the decrease of mass has started. The maximum decrease in mass was about 10 m% for the reference mixture meanwhile for the SCM containing mixtures less than 4 m%; the best results were provided by the MK 10 mixture. The acetic acid induced significant change in mass and shrinkage from the beginning of acidic exposure and the average decrease of mass for all mixture was about 50 m%. It could be stated, that the two types of acid has different effect on the cement-based materials by their particular reactions and mechanisms.

The combined application of SCMs influenced the various properties (chloride ion diffusivity, acid resistivity) of hardened cement-based materials in different extent. Unfortunately application of these materials in cementitious composition did not endure totally the long-term effects of acidic environment. We can conclude that further investigations about the application of SCMs in aggressive circumstances are indispensable.

Acknowledgement

We acknowledge to MC Bauchemie Company that our experiments were supported by providing the SCMs and to Danube-Drava Cement Ltd. supporting us by providing the cement. The authors are grateful to Mr. Adorján Borosnyói, Ms. Noémi Patyi and Ms. Viktória Rónaky for their help in specimen preparation, laboratory tests and discussion. Authors are grateful to the Hungarian Scientific Research Fund (OTKA) for the financial support of the OTKA K 109233 research project.

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