

CHEMICAL RESISTANCE OF PORTLAND CEMENT, BLAST-FURNACE SLAG PORTLAND CEMENT AND SULPHOALUMINATE-BELITE CEMENT IN ACID, CHLORIDE AND SULPHATE SOLUTION: SOME PRELIMINARY RESULTS

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Durability of concrete significantly depends on the cement matrix resistance against the aggressive environmental conditions. Information on chemical resistance of the cement in various aggressive media is very useful for the durability assessment of cement based materials. The aim of this contribution is the chemical resistance study of a sulphoaluminate belite (SAB) cement based on fly ash as industrial by-product raw material, exposed to the acid, chloride and sulphate solution for 180 days. For comparison, test specimens made from ordinary Portland cement (OPC), and blast-furnace slag Portland cement (BFSPC) with higher chemical resistance were used. All cement types and materials are of Romanian provenance. The test results show that the fly ash - based SAB cement is similarly resistant against acid, chloride and sulphate attack when compared to OPC and BFSPC. A half-year testing period enables preliminary evaluation of the cements' resistance due to relative short exposure times.

INTRODUCTION

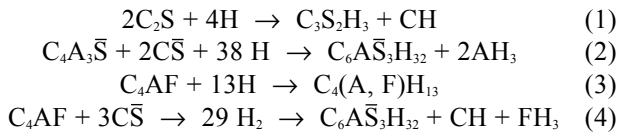
Changing the mineralogical composition of Portland cement clinkers, in order to reduce the CaO content represents a perspective way to the ecological, low energy cements achievement. Combustion of fossil fuels and decarbonation of limestone contribute to releasing approximately 10^9 of CO_2 into the atmosphere annually [1,2]. A possible solution is to replace OPC production by different procedures contributing to reduced energy consumption and lower CO_2 release. One approach is the production of cements with reduced lime standard of the raw meal [3]. A reduction in the lime standard leads to the increased belite, and contrary to decreased alite content. Clinker formation is performed at lower firing temperature [4].

A different approach involves cements based on $\text{C}_4\text{A}_3\bar{\text{S}}$ (calcium sulphoaluminate) often known as Klein's compound. These can be produced at the same clinkerization temperatures as belite cement but lower than those of OPC [5]. One such cement type containing the main phases C_2S , $\text{C}_4\text{A}_3\bar{\text{S}}$, C_4AF and $\text{C}\bar{\text{S}}$ is sulphoaluminate belite (SAB) cement prepared from raw mixes containing industrial process wastes (fly ash, red mud, pyrite ash, etc.) [6 - 11].

SAB cements have very good dimensional stability that can be regarded as primary base for a series of shrinkage-reducing cements. They have hydraulic properties similar to OPC and BFSPC, respectively, and good resistance to atmospheric carbonation although ettringite component in hydrated SAB cement tends to carbonate rapidly [12 - 14].

Chemical resistance represents an important engineering property of cement based materials from the viewpoint of service life assessment of concrete structures. An important key role plays here the type of cement. Information on the chemical resistance of SAB cements compared to those of OPC and BFSPC is still relatively poor though some investigation has been performed already [15]. As observed until now, mineralogical composition of SAB cements varies between 15-60 % of C_2S , 10-40 % of $\text{C}_4\text{A}_3\bar{\text{S}}$, 10-30 % of C_4AF and 5-15 % of $\text{C}\bar{\text{S}}$ [16, 17]. In contrast, average mineralogical composition of OPC is 45-75 % of C_3S , 3-26 % of C_2S , 3-15 % of C_3A and 5-20 % of C_4AF using $\text{C}\bar{\text{S}}\text{H}_2$ as setting regulator [18]. SAB cements differ from OPC in contents of sulphates; therefore hydration reaction and products are quite different from those found in hydrated OPC. For the chemical resistance of SAB cement based materials these reaction products of

hydration are of great importance: poorly crystallised calciumsilicate hydrate (C₃S₂H₃), ettringite (C₆A₃S₃H₃₂), C₄(AF)H₁₃ converting in time to C₃(A,F)H₆, and calcium hydroxide (CH), aluminium hydroxide (AH₃) and ferric hydroxide (FH₃) [19, 20]. In order to understand the chemistry of SAB hydration processes of all its individual clinker minerals, it is necessary to consider their hydration reactions by following formulae:



A variety of chemical attacks are very broad acting on different cement types [21]. The present information on SAB cement behaviour in aggressive media is still unsatisfactory. This fact submits to the research an exacting task to gain basic information on the chemical resistance of SAB cements opposite to well - known OPC and BFSPC. Preliminary results show that SAB cements resistance to hydrochloric acid and sodium chloride solution is similar to that of OPC, and is improved to a sulphate solution. By contrast, the resistance to freezing and thawing is considerably lower when compared to OPC [22-26].

This paper is focused on the chemical resistance study of reference OPC and BFSPC mortars and SAB cement mortar exposed to drink water, hydrochloric acid, sodium chloride and sodium sulphate solution for 180 days.

Table 1. Composition and properties of the materials used

| specifications | SAB (experimental) cement | OPC type I 42,5 | BFSPC type II A-S 32,5 | fly ash | blast furnace slag |
|----------------------------------|--|--------------------------|---------------------------|---------------|-----------------------|
| 0 | 1 | 2 | 3 | 4 | 5 |
| 1. chemical composition (%) | | | | | |
| insol. res. | 1.93 | | | | |
| SiO ₂ | 19.29 | 20.18 | | 55.81 | 37.66 |
| Al ₂ O ₃ | 8.04 | 6.66 | | 25.13 | 9.42 |
| Fe ₂ O ₃ | 3.37 | 3.96 | | 10.45 | 0.38 |
| CaO | 55.13 | 64.34 | | 4.34 | 45.41 |
| MgO | 1.46 | 0.80 | non -estimated | 1.65 | 4.94 |
| Na ₂ O | 0.39 | 0.62 | | | 0.42 |
| K ₂ O | 1.03 | 0.74 | | | 1.75 |
| SO ₃ | 8.64 | 2.18 | | 1.13 | - |
| LOI | 0.36 | - | | 1.39 | - |
| 2. mineralogical composition (%) | | | | | |
| | C ₂ S = 55.2 | C ₃ S = 59.7 | cement (2) | used as | used in |
| | C ₄ A ₃ \bar{S} = 29.0 | C ₃ S = 15.1 | replaced by | one of raw | BFSPC |
| | C ₄ AF = 10.5 | C ₃ A = 10.2 | 15 % wt. | materials for | |
| | C \bar{S} = 5.3 | C ₄ AF = 10.0 | of blast | SAB cement | |
| | | C \bar{S} = 5.0 | furnace slag (5) | | |

EXPERIMENTAL

Materials

Ordinary Portland cement (CEM I 42.5), blast-furnace slag Portland cement (CEM II A-S 32.5) both made in Romania, and laboratory-made sulphoaluminate-belite cement (using Romanian fly ash industrial waste component in the raw mix) were used. The SAB cement was prepared by firing the raw mix in a gas oven at 1250°C for 45 minutes. Composition and basic properties of the materials and cements employed are reported in table 1 and 2, respectively. Mineralogical composition of OPC was: 59.7 % C₃S, 15.1 % C₂S, 10.2 % C₃A, 10.0 C₄AF and 5 % C \bar{S} , and that of SAB cement: 55.2 % C₂S, 29.0 % C₄A₃ \bar{S} , 10,5 % C₄AF and 5.3 % C \bar{S} .

Table 2. Composition and properties of the cements employed

| characteristic | cements | | |
|--|---------------------------------|---------------------|----------------------------|
| | SAB experimen- tal cement | OPC (CEM I 42.5) | BFSPC (CEM II/A-S 32.5) |
| specific gravity (kg/m ³) | 3 050 | 3 250 | 3 030 |
| specific surface (Blaine) (m ² /kg) | 390 | 395 | 398 |
| initial setting time (h - min) | 0 - 10 | 1 - 30 | 2 - 20 |
| final setting time (h - min) | 0 - 25 | 2 - 45 | 3 - 30 |

Casting and curing

Cement mortars (cement to sand ratio 1:3 by weight and water to cement ratio of 0.5) using a standard sand (STAS 2633-76: sand with 98.5% SiO₂, 0.315 ÷ 0.50 mm) were prepared in steel moulds on a vibration table (vibration: intensity 50 Hz, amplitude: 0.35 mm) with vibration time of 30 seconds. After demolding mortar specimens of size 15 × 15 × 60 mm with embedded glass spikes for length changes measurements were kept for 27 days in water at 20°C after initial 24-hour 20°C/95 % R.H - wet air cure. After 28-day basic curing, the specimens were exposed to water (reference), 0.5 % HCl solution, 5 % Na₂SO₄ solution and 10.0 % NaCl solution. The ratio between the surface of specimens and the volume of solutions was 1 cm²: 10 cm³ (10 cm³ of the solution was kept for attacking the surface 1 cm² of mortar specimens; also in reference water). The concentration was maintained by regular control of aggressive components (chloride and sulphate ions). When the concentration by value of 10 % was decreased, the chloride and sulphate solution was restored. Acidity of 0.5 % HCl solution was regularly checked and the solution was restored when pH was increased by 0.5. Temperature was maintained on 20 ± 0.5 °C.

Testing

Specific gravity was ascertained by a pycnometric method as the weight of the volume unit of solid constituents of cements used. Volume density of mortars was estimated on the specimens of regular shape by weighting at calculated volume of tested prisms. Compressive strength was tested according to SR EN 196 on prisms. Length changes of mortars were measured by a Graf-Kaufmann apparatus and were expressed in per mille (‰). Chemical analysis of mortars was performed by wet analytical methods described in ČSN (STN) EN 196-2 Methods of testing cement; Chemical analysis of cement.

RESULTS AND DISCUSSION

Mortar characterisation

To study behaviour of three cement types reference OPC and BFSPC mortars, and SAB cement mortar were chosen as shown in table 3. The type of cement considerably influences differences in 28-day compressive strength and chemical composition of the mortars. The OPC mortar is characterised by slightly increased CaO and slightly decreased SO₃ contents relative to SAB cement mortar. This is due to CaO-rich alite occurrence

in OPC, and higher amounts of sulphates (C₄A₃S̄, C₃S̄) in the SAB cement used in OPC mortar and SAB cement mortar, respectively. The CaO content in BFSPC mortar is similar to that of OPC mortar due to the replacement of cement by a blast-furnace slag also containing CaO. The SO₃ content is lower than that in OPC mortar, and markedly decreased compared to the SAB cement mortar. A marked compressive strength dependence on chemical composition of the cements is found. The OPC mortar with alite content indicates the highest 28-day compressive strength. The compressive strength of BFSPC mortar lowers by 28 % relative to that of OPC mortar. The decline in compressive strength values of SAB cement mortar is 60 % and 47 % relative to OPC mortar and BFSPC mortar, respectively. This is caused by different mixture composition of the cements at the same manufacture and curing conditions of the mortars. Calcium sulphoaluminate C₄A₃S̄ synthesised along with belite C₂S and ferrite C₄AF at the temperature 1250°C relative to C₃S with clinkerization temperature between 1400°C - 1450°C gives in the final effect lower 28-day compressive strength of the SAB cement mortar than that of alite - rich OPC mortar. The above results have been interpreted to indicate that SAB cement mortar contains ettringite and hydrated ferrite phase (see equations No. 2, 3, 4) as main hydration products at 28-day basic curing in water. At the same time main hydration product in OPC and BFSPC mortar is C-S-H gel (calcium silicate hydrate phase) coming from C₃S. C₄AF forms hydration products giving a little contribution to the mechanical strength. The C₂S generates C-S-H gel (calciumsilicate hydrate phase, see equation No. 1) in a pronouncedly slower rate than C₃S. Therefore it strongly contributes to the strength of SAB cement at medium and longer ages. Significant difference in the strength of OPC and BFSPC mortar on the one hand, and SAB cement mortar on the other hand, is being diminished with a time of exposure.

Table 3. Chemical composition and strength characteristics of the mortars.

| characteristic composition (%) | SAB mortar | OPC mortar | BFSPC mortar |
|-------------------------------------|------------|------------|--------------|
| insoluble residue | 71.14 | 69.94 | 71.47 |
| CaO | 13.23 | 14.61 | 13.41 |
| SO ₃ | 1.37 | 1.02 | 0.88 |
| Cl | 0.0114 | 0.0124 | 0.012 |
| volume density (kg/m ³) | 2100 | 2130 | 2120 |
| compressive strength (MPa) | 16.50 | 42.00 | 30.20 |

Action of HCl solution

Evident signs of acid attack represented by 0.5 % solution of hydrochloric acid in water (0.5 % HCl solution) are crumbling of the surface, volume density decrease, and shrinkage of the test mortars connected with strength loss (figures 1 and 4). The effect of the hydration products decomposition and cement matrix degradation of the mortars is proved by insoluble portion and Cl⁻ content increase together with CaO content decrease (tables 4, 7 and figures 1, 4).

The SAB cement mortar has the highest strength increase when kept 180 days underwater (figure 1) though 28-day compressive strength of SAB cement mortar is the lowest when compared to OPC and BFSPC mortar. However, the comparison of measured compressive strength values and calculated relative strength values reported in table 4 shows that the loss in compressive strength of SAB cement mortar with the exposure in 0.5 % HCl solution is the most evident. This is also confirmed by the highest shrinkage of SAB cement mortar opposite to those found in OPC and BFSPC mortar. The more expressed losses in volume density and CaO content in SAB cement mortar relative to those of OPC and BFSPC mortar give an evidence of strongly attacked cement matrix of SAB cement mortar (table 7). By contrast, Cl⁻ content in the SAB cement mortar is the lowest when compared to OPC and BFSPC mortar. This can be explained by the absence of C₃A indicating a high sensitivity to the reaction with free Cl⁻ ions.

Mechanical and chemical degradation of all three mortars is evident. We conclude that OPC, BFSPC and SAB cements have similarly markedly decreased resistance to acid attack. In general, highly alkaline cements are good willing partner for acid attack. The above results show that acid resistance of the used SAB cement is lower than acid resistance of the used OPC and BFSPC.

Action of NaCl solution

The effect of chloride solution on the mortars represented by 10 % solution of sodium chloride in water (10 % NaCl solution) is similar to that of HCl solution but is less aggressive than acidic attack by 0.5 % HCl solution. The NaCl attack is characterised by a slight decrease in CaO content, and contrary by slight increase in insoluble portion values (table 8). No significant amounts of CaO - rich hydrate phase are leached out of the cement matrix. This is confirmed by stable volume density values of the mortars indicating no evident weight losses of the specimens. Contrary, the Cl⁻ contents are extremely increased, even more than in mortar specimens exposed to 0.5 % HCl solution (table 7).

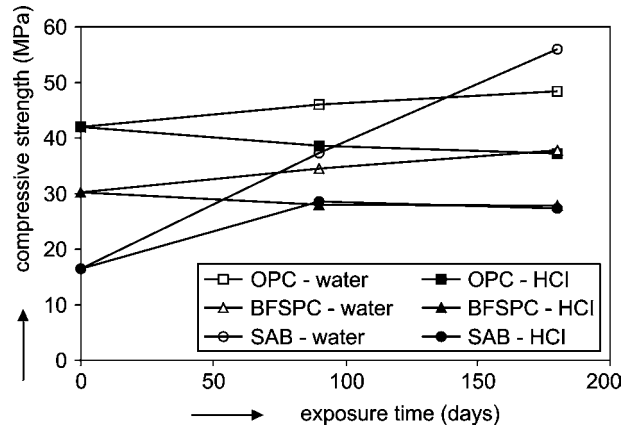


Figure 1. Compressive strength development of OPC, BFSPC and SAB cement mortars kept for 180 days in water and 0.5 % HCl solution after 28-day basic curing in water at 20 ± 0.5 °C.

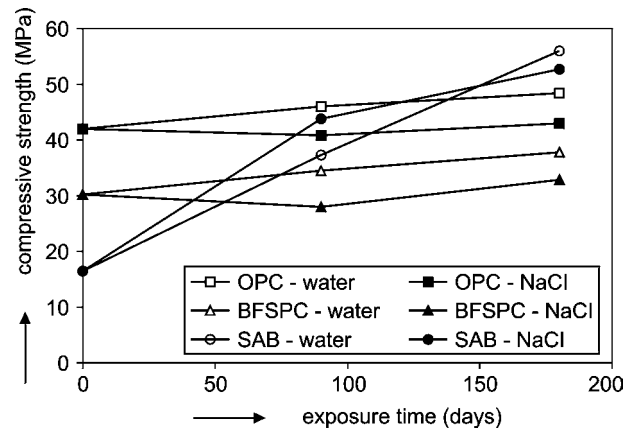


Figure 2. Compressive strength development of OPC, BFSPC and SAB cement mortars kept for 180 days in water and 10 % NaCl solution after 28-day basic curing in water at 20 ± 0.5 °C.

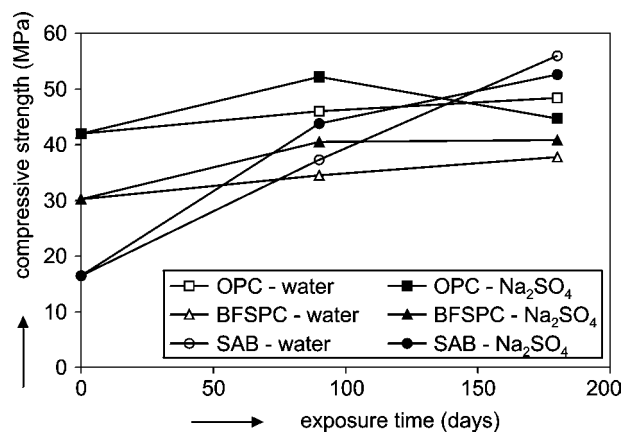


Figure 3. Compressive strength development of OPC, BFSPC and SAB cement mortars kept for 180 days in water and 5 % Na₂SO₄ solution after 28-day basic curing in water at 20 ± 0.5 °C.

Such increase in Cl⁻ contents can be explained by a high reaction sensitivity of C₃A occurred in OPC and BFSPC on Cl⁻ ions causing the formation of complex voluminous salts in the cement matrix. This evokes in the final effect a slight expansion (figure 5) and decline in compressive strength (table 5, figure 2) of the mortars with the exposure in chloride solution. The lower binding of Cl⁻ ions into the cement matrix of SAB cement mortar (table 8) compared to those found in OPC and BFSPC mortar indicates that the SAB cement due to the absence of C₃A is less sensitive to NaCl attack compared to OPC and BFSPC. It is proved by the decreased compressive strength loss of SAB cement mortar relative to OPC and BFSPC mortar specimens.

Mechanical and chemical degradation of all three mortars is found at the 10 % NaCl solution attack but it is significantly lower than that in 0.5 % HCl solution. The main difference between HCl and NaCl solution attack lies in mechanism of the cement matrix degradation. Mortars attacked by hydrochloric acid are preferably dissolved, whereas the main degradation process of the mortars kept in sodium chloride is the reaction of calciumaluminate hydrate phase with Cl⁻ ions forming voluminous reaction products. We conclude that OPC; BFSPC and SAB cements have similarly decreased resistance to sodium chloride attack. The above results show that the resistance of the used SAB cement to sodium chloride is higher than the resistance of the used OPC and BFSPC. We assume that a reason of this is lower inclination of SAB cement hydrated minerals to form voluminous reaction products with NaCl, mainly because of the absence of C₃A.

Action of Na₂SO₄

Typical symptoms of sulphate attack represented by 5 % solution of sodium sulphate in water (5 % Na₂SO₄) are the increase in SO₃ content bound in cement matrix of the mortars followed by expressed expansion and steady weight increase up to a crack propagation. This is accomplished by the loss of structural integrity of the mortars. The process of sulphate action is characterised by a transient increase in compressive strength of mortar specimens replaced by sudden or lasting decrease. This is caused by the formation of voluminous reaction products in the mortars as a consequence of SO₃ binding into the cement matrix. At a certain distinct point the structural integrity of the mortars is deteriorated and compressive strength becomes lower. The duration of this process depends upon time, mortar mixture composition (type of cement) and exposure conditions.

Volume density values of OPC mortar are evidently increased between 28-day basic curing (2 288 kg/m³) and 180-day exposure in 5 % Na₂SO₄ solution (2 337 kg/m³)

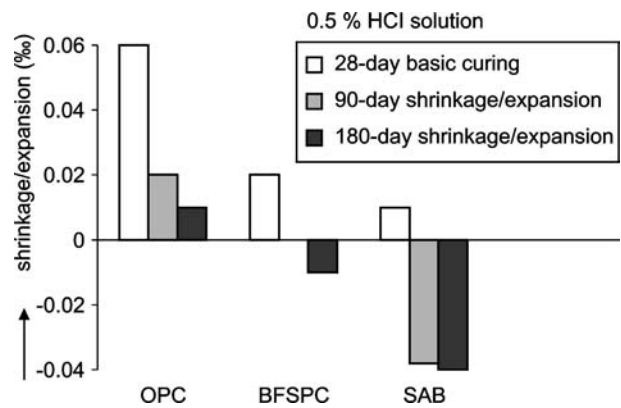


Figure 4. Length changes of OPC, BFSPC and SAB cement mortar exposed to 0.5 % HCl solution after basic curing (initial values) for 90 and 180 days.

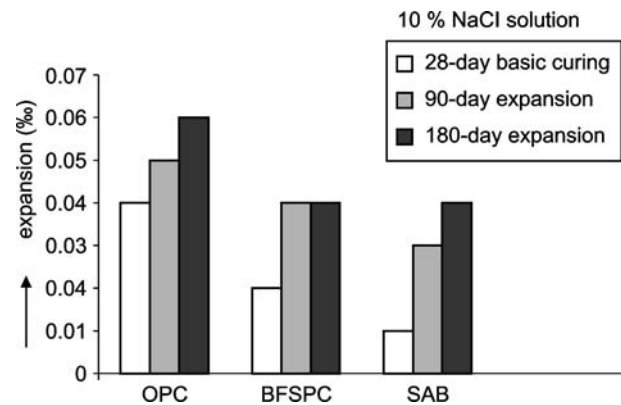


Figure 5. Expansion of OPC, BFSPC and SAB cement mortar exposed to 10 % NaCl solution after basic curing (initial values) for 90 and 180 days.

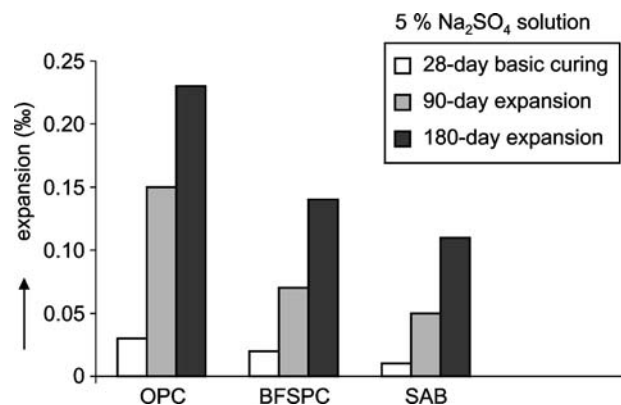


Figure 6. Expansion of OPC, BFSPC and SAB cement mortar exposed to 5 % Na₂SO₄ solution after basic curing (initial values) for 90 and 180 days.

compared to the increases observed in BFSPC and SAB cement mortar (table 9). This confirms a transient weight increase of the OPC mortar due to the formed voluminous reaction products, and indicates an expressed expansion evidently higher than that in BFSPC and SAB cement mortar (figure 6) followed by crack propagation proved by visual observations. The SO_3 content increase in OPC mortars is markedly higher than that in BFSPC and SAB cement mortar (table 9). Compressive strength of the OPC mortar kept in 5 % Na_2SO_4 solution is markedly decreased when compared to the strength of BFSPC and SAB cement mortar (table 6).

A significant difference in behaviour of SAB cement mortar relative to that of OPC mortar is found. This proves a beneficial effect of the SAB cement use in the mortar when exposed to a sulphate attack. The above results reveal that the resistance of the used SAB cement to 5 % Na_2SO_4 solution is very similar to that of the used BFSPC, and is markedly improved relative to that of the used OPC.

CONCLUSION

The 180-day study of chemical resistance of the mortars with Portland cement, blast-furnace slag Portland cement and sulphotoaluminate-belite cement based on the obtained results shows that:

1. All three cements are highly vulnerable to acid attack. The resistance of SAB cement to 0.5 % HCl solution is even lower than that of low - resistant OPC and BFSPC. The primary reason of cements' low resistance is their high alkalinity.
2. The OPC, BFSPC and SAB cement has similarly decreased resistance to chloride attack. The resistance of SAB cement to 10 % NaCl solution is higher than that of OPC and BFSPC. This is the consequence of lower inclination of hydrated SAB cement free of C_3A to form voluminous salts with NaCl causing structural integrity degradation of mortars compared to those made with OPC and BFSPC.

Table 4. Compressive strength of mortars kept for 180 days in water and 0.5 % HCl solution.

| type of cement mortar | strength | | | | | | | |
|-----------------------------|-------------------|------|----------|------|--------------|------|----------|------|
| | compressive (MPa) | | | | relative (%) | | | |
| | 90 days | | 180 days | | 90 days | | 180 days | |
| | water | HCl | water | HCl | water | HCl | water | HCl |
| OPC | 46.0 | 38.6 | 48.4 | 37.2 | 100 | 83.9 | 100 | 76.9 |
| BFSPC | 34.5 | 28.0 | 37.8 | 27.8 | 100 | 81.2 | 100 | 73.5 |
| SAB | 37.3 | 28.6 | 56.0 | 27.3 | 100 | 76.8 | 100 | 48.8 |

Table 5. Compressive strength of mortars kept for 180 days in water and 10 % sodium chloride solution.

| type of cement mortar | strength | | | | | | | |
|-----------------------------|-------------------|------|----------|------|--------------|------|----------|------|
| | compressive (MPa) | | | | relative (%) | | | |
| | 90 days | | 180 days | | 90 days | | 180 days | |
| | water | NaCl | water | NaCl | water | NaCl | water | NaCl |
| OPC | 46.0 | 40.8 | 48.4 | 43.0 | 100 | 88.7 | 100 | 88.8 |
| BFSPC | 34.5 | 28.0 | 37.8 | 32.8 | 100 | 81.2 | 100 | 86.9 |
| SAB | 37.3 | 43.8 | 56.0 | 52.7 | 100 | 117 | 100 | 94.1 |

Table 6. Compressive strength of mortars kept for 180 days in water and 5 % sodium sulphate solution.

| type of cement mortar | strength | | | | | | | |
|-----------------------------|-------------------|--------------------------|----------|--------------------------|--------------|--------------------------|----------|--------------------------|
| | compressive (MPa) | | | | relative (%) | | | |
| | 90 days | | 180 days | | 90 days | | 180 days | |
| | water | Na_2SO_4 | water | Na_2SO_4 | water | Na_2SO_4 | water | Na_2SO_4 |
| OPC | 46.0 | 52.2 | 48.4 | 44.7 | 100 | 111 | 100 | 92.5 |
| BFSPC | 34.5 | 40.5 | 37.8 | 40.8 | 100 | 117 | 100 | 107 |
| SAB | 37.3 | 43.8 | 56.0 | 52.6 | 100 | 122 | 100 | 94.0 |

Table 7. Chemical composition and volume density values of mortars at 180-day exposure in hydrochloric acid solution.

| component/ property measured | time of exposure (days) | type of the cement mortar | | | | | |
|------------------------------------|-------------------------------|---------------------------|--------------|----------|--------------|----------|--------------|
| | | OPC | | BFSPC | | SAB | |
| | | measured | relative (%) | measured | relative (%) | measured | relative (%) |
| insoluble | 28* | 69.4 | 100 | 71.5 | 100 | 71.1 | 100 |
| portion | 90 | 72.1 | 103 | 73.8 | 103 | 72.6 | 102 |
| (%) | 180 | 75.5 | 108 | 75.5 | 106 | 75.8 | 107 |
| CaO | 28* | 14.6 | 100 | 13.4 | 100 | 13.2 | 100 |
| content | 90 | 13.9 | 96 | 12.9 | 96 | 12.7 | 96 |
| (%) | 180 | 13.7 | 94 | 11.9 | 89 | 11.6 | 88 |
| Cl ⁻ | 28* | 0.01 | 100 | 0.01 | 100 | 0.01 | 100 |
| content | 90 | 0.07 | 590 | 0.09 | 760 | 0.04 | 375 |
| (%) | 180 | 0.15 | 1 230 | 0.18 | 1 550 | 0.05 | 520 |
| volume | 28* | 2 288 | 100 | 2 255 | 100 | 2 267 | 100 |
| density | 90 | 2 235 | 98 | 2 220 | 97 | 2 188 | 96 |
| (kg/m ³) | 180 | 2 215 | 96 | 2 167 | 95 | 2 135 | 94 |

* values after 28-day basic curing at 20°C

Table 8. Chemical composition and volume density values of mortars at 180-day exposure in sodium chloride solution.

| component/ property measured | time of exposure (days) | type of the cement mortar | | | | | |
|------------------------------------|-------------------------------|---------------------------|--------------|----------|--------------|----------|--------------|
| | | OPC | | BFSPC | | SAB | |
| | | measured | relative (%) | measured | relative (%) | measured | relative (%) |
| insoluble | 28* | 69.4 | 100 | 71.5 | 100 | 71.1 | 100 |
| portion | 90 | 70.6 | 101 | 71.5 | 100 | 71.7 | 101 |
| (%) | 180 | 72.2 | 103 | 71.7 | 100 | 73.5 | 103 |
| CaO | 28* | 14.6 | 100 | 13.4 | 100 | 13.2 | 100 |
| content | 90 | 14.3 | 98 | 13.3 | 99 | 12.9 | 98 |
| (%) | 180 | 14.0 | 96 | 13.2 | 99 | 12.6 | 95 |
| Cl ⁻ | 28* | 0.01 | 100 | 0.01 | 100 | 0.01 | 100 |
| content | 90 | 0.58 | 4 675 | 0.50 | 4 165 | 0.28 | 2 400 |
| (%) | 180 | 0.65 | 5 310 | 0.62 | 5 185 | 0.32 | 2 800 |
| volume | 28* | 2 288 | 100 | 2 255 | 100 | 2 267 | 100 |
| density | 90 | 2 326 | 101 | 2 255 | 99 | 2 262 | 99 |
| (kg/m ³) | 180 | 2 330 | 102 | 2 250 | 99 | 2 262 | 99 |

* values after 28-day basic curing at 20°C

Table 9. Chemical composition and volume density values of mortars at 180-day exposure in sodium sulphate solution.

| component/ property measured | time of exposure (days) | type of the cement mortar | | | | | |
|------------------------------------|-------------------------------|---------------------------|--------------|----------|--------------|----------|--------------|
| | | OPC | | BFSPC | | SAB | |
| | | measured | relative (%) | measured | relative (%) | measured | relative (%) |
| insoluble | 28* | 69.4 | 100 | 71.5 | 100 | 71.1 | 100 |
| portion | 90 | 72.1 | 103 | 71.6 | 100 | 71.6 | 101 |
| (%) | 180 | 73.4 | 105 | 72.9 | 102 | 73.7 | 103 |
| CaO | 28* | 14.6 | 100 | 13.4 | 100 | 13.2 | 100 |
| content | 90 | 14.6 | 100 | 13.4 | 100 | 12.9 | 97 |
| (%) | 180 | 15.1 | 103 | 13.2 | 99 | 12.2 | 93 |
| Cl ⁻ | 28* | 1.02 | 100 | 0.88 | 100 | 1.37 | 100 |
| content | 90 | 1.75 | 171 | 0.12 | 127 | 1.82 | 132 |
| (%) | 180 | 3.12 | 305 | 0.82 | 207 | 2.96 | 216 |
| volume | 28* | 2 288 | 100 | 2 255 | 100 | 2 267 | 100 |
| density | 90 | 2 328 | 101 | 2 250 | 99 | 2 270 | 100 |
| (kg/m ³) | 180 | 2 337 | 102 | 2 255 | 100 | 2 270 | 100 |

* values after 28-day basic curing at 20°C

3. The resistance of SAB cement to sulphate attack when exposed to 5 % Na₂SO₄ solution is higher than that of sulphate non-resistant OPC, and equivalent to the well - known sulphate resistant BFSPC. It seems that ettringite formation as an integral element of hydration process at the ambient conditions, and contemporarily the absence of C₃A in SAB cement contribute to avoiding structural deterioration caused by extreme development of voluminous reaction sulphate - based products.
4. Topics connected with reliable evaluation of chemical resistance of low-energy SAB cements compared to well-known OPC and BFSPC are worthy of more detailed research, and need further study of the hydrate phase and pore structure formation in the future.

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CHEMICKÁ ODOLNOSŤ PORTLANDSKÉHO CEMENTU, PORTLANDSKÉHO TROSKOVÉHO CEMENTU A SULFOALUMINÁTOVÉHO BELITOVÉHO CEMENTU OPROTI KYSLÉMU, CHLORIDOVÉMU A SÍRANOVÉMU ROZTOKU: NIEKTORÉ PREDBEŽNÉ VÝSLEDKY

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Prešetrovala sa chemická odolnosť troch rumunských cementov oproti účinku 0,5 % roztoku kyseliny chlorovodíkovej (HCl), 10 % roztoku chloridu sodného (NaCl) a 5 % roztoku síranu sodného (Na₂SO₄). Všetky roztoky danej koncentrácie sú na cementový kameň silne agresívne média. Pre skúšky sa použili vzorky rumunského priemyselne vyrábaného Portlandského cementu (OPC) a Portlandského troskového cementu (BFSPC) a experimentálny nízkoenergetický sulfoaluminátový belitový cement (SAB) zhotovený za použitia rumunského popolčeka ako vstupnej suroviny pre výpal SAB cementu v laboratórnej peci pri teplote 1 250°C počas 45 minút. Cieľom práce bolo zistiť na základe porovnávacej štúdie chemickú odolnosť SAB cementu a túto porovnať s výdržou OPC a BFSPC.