

PERFORMANCE OF SULPHOALUMINATE-BELITE CEMENT WITH HIGH $C_4A_3\bar{S}$ CONTENT

IVAN JANOTKA, LUDOVÍT KRAJČI, SUBHASH C. MOJUMDAR*

*Institute of Construction and Architecture, Slovak Academy of Sciences,
Dúbravská cesta 9, 845 03 Bratislava, Slovakia,*

**Faculty of Forestry, University of Toronto,
33 Willcocks Street, Toronto, Ontario, M5S 3B3, Canada*

E-mail: Ivan.Janotka@savba.sk

Submitted September 13, 2006; accepted January 12, 2007

Keywords: Blended cement, Mortar, Hydration, Sulphoaluminate-belite cement

Sulphoaluminate - belite (SAB) cements are an attractive class of low energy cements from the viewpoint of energy saving and less CO_2 releasing into the atmosphere during their production. Their hydraulic activity, however, does not match that of the Ordinary Portland cement (PC) and needs improvement before they can be used on their own. Performance of SAB cement with 50.3 wt. % of C_2S , 20.2 wt. % of $C_4A_3\bar{S}$, 19.5 wt. % of C_4AF and 9.7 wt. % of $C\bar{S}$ has been compared with that of PC having 67.6 wt. % of C_3S , 5.1 wt. % of C_2S , 9.2 wt. % of C_3A , 10.6 wt. % of C_4AF and 5.9 wt. % of $C\bar{S}$, and blast-furnace slag Portland cement (BFSPC) containing 30 wt. % of blast-furnace slag. Mortars with the above cements and siliceous sand with the weight ratio of 1 : 3 and water to cement ratio of 0.5 were manufactured and $40 \times 40 \times 160$ -mm prisms were stored at $20^\circ C$ for 90 days under 100% R.H. - wet air conditions. The physical-mechanical properties (strengths, dynamic modulus of elasticity), shrinkage reducing properties and passivation ability of SAB cement approach to those of BFSPC. With further improvement in the SAB cement quality through better understanding of their characteristics, a genuine competition between SAB cement and BFSPC can be expected in practice.

INTRODUCTION

Economic conditions of many countries in the world are seriously threatened by energy shortage and spiralling fuel prices. These problems are referred to the field of civil engineering too. Production of Portland cement is connected with high energy consumption and excessive release of CO_2 into the atmosphere. The thermal and electric energy is markedly required for firing and grinding of the clinker. Combustion of fossil fuels and decarbonation of limestone contribute to releasing ca 10^9 tonnes of carbon dioxide into the atmosphere annually [1-3]. On the other hand, Portland cements are relatively cheap; economic and technical constraints make it difficult to challenge their dominance.

The pressure to reduce energy consumption and CO_2 emissions during Portland cement manufacture has been one of the factors contributing to the development of novel cements [4, 5]. Such cements are currently attracting a great deal of interest worldwide and a number of different types have been suggested and are at varying stages of development [6, 7]. The greatest level of interest is being shown in cements that contain a high proportion of the mineral belite C_2S . Belite-rich cements have several potential advantages over conventional Portland cement. Except the lower energy

required to manufacture and lower emitted CO_2 [8, 9], the long-term strength and durability of concrete made from belite-based cements can potentially exceed those of Portland cement [4].

Belite itself hydrates slowly [10, 11] and early compressive strengths of pastes, mortars and concretes containing belite cements are generally low as a result. The early strengths can be increased using a number of techniques. The most practical technique is the addition of a reactive component such as calcium sulphoaluminate $C_4A_3\bar{S}$ (in some case together with C_4AF and $C\bar{S}$). These special cements with C_2S , C_4AF , $C_4A_3\bar{S}$ and $C\bar{S}$ are commonly referred to as sulphoaluminate-belite (SAB) cements. Two sulphate phases $C_4A_3\bar{S}$ and $C\bar{S}$ are present in cements instead of high-temperature C_3S and C_3A . Thus, SAB cements have low-energy requirements than PCs.

Raw mixes for $C_4A_3\bar{S}$ clinkers differ from those for Portland cement in that they contain significant amount of sulphate. Therefore the reactions and products are quite different from those normally found in Portland cement production [12, 13]. The total lime requirement to produce such cement is about 50 wt.% as against about 65 wt.% for Portland cement. Moreover they can be prepared at lower temperature at about $1200^\circ C$, rather than the $1400^\circ C$ to $1500^\circ C$ for Portland cement.

It is conceived that cement containing calcium sulphoaluminate and reactive C_4AF can derive its early strength and other physical properties from the formation of hydrates. The hydration of the $C_4A_3\bar{S}$ phase is a very rapid reaction leading to the formation of needle-like ettringite, which is responsible for the quick setting of the sulphoaluminate-belite cements.

Production of sulphoaluminate-belite cements is well-known in China. Current production exceeds 1 million tonnes per year and these "Third Cement Series" materials have been used in a wide range of structural and non-structural applications [14]. The clinker is manufactured by heating a mixture of limestone, bauxite and $CaSO_4$ at 1 250-1 350°C. This reportedly allows clinker output to be increased by more than 20 % and coal consumption reduced by about 15 % in comparison with Portland cement. The cement clinkers are ground with other components such as gypsum. By varying the proportions of clinker, calcium sulphate and additives, a number of different types of cement can be produced [15]. The most of these compositions have very good dimensional stabilities and good resistance to atmospheric carbonation, although the ettringite in hydrated cement tends to carbonate [16-18]. It was found that resistance of sulphoaluminate-based cements to hydrochloric acid, sodium sulphate and sodium chloride solutions are very similar to that of PC [19] but their resistance to freezing and thawing is considerably reduced [20]. Macro-defect free (MDF) materials based on SAB clinkers were prepared and showed sufficient moisture resistance [21, 22]. Upgrading of SAB cement systems and the improvement of composites properties were also obtained by blending with Portland cement [23, 24]. This work is the continuation of our previous works on construction materials and their various properties [25-43].

This paper is concerned with the effect of SAB cement on the physical-mechanical properties of mortar specimens, the development of hydrated phases and pore structure as well as the ability of mortars to protect steel reinforcement against corrosion.

EXPERIMENTAL

Materials

Portland cement CEM I 42.5 (PC), blast furnace slag Portland cement (BFSPC) with 30 wt. % of blast furnace slag, and sulphoaluminate-belite (SAB) cement were used in tests. Basic characteristics of the cements are listed in Table 1 and Table 2. One constituent of the raw meal for SAB cement was bauxite. Three cements (PC, BFSPC, SAB) were used to prepare cement pastes (20×20×20 mm) with water to cement ratio (w/c) of 0.5 and mortar specimens (40×40×160 mm) with cement to

sand proportion of 1:3 and w/c of 0.5. Siliceous sand in fractions of 0-0.5 mm, 0.5-1.0 mm and 1.0-2.0 mm in weight ratio of 1 : 1 : 1 was used. The SAB cement was fired at 1250°C for 30 minutes.

Test methodologies

Mortar specimens were stored at 20°C/100 % R.H. - wet air for 90 days and then tested for compressive strength, absorption capacity, specific gravity, volume density and total porosity. Water absorption capacity was determined from the decrease in weight of the specimens saturated by water and then dried at 105°C to constant weight. The results are expressed in weight percent (wt.%). Total porosity was calculated from the volume density and specific gravity values using the formula:

$$TP = \left(1 - \frac{\rho_{VD}}{\rho_{SG}} \right) 100 \quad (1)$$

where TP is total porosity as the content of pores and voids in the specimens (wt.%), ρ_{VD} is volume density (kg/m^3) and ρ_{SG} is specific gravity (kg/m^3). The volume density was estimated on the specimens of regular shape by weighing at calculated volume of the prisms. The specific gravity was ascertained by a pycnometric method as the weight of the volume unit of solid constituents of the mortar specimen in powdered stage.

Table 1. Chemical composition and basic properties of the cements and bauxite.

Chemical composition (wt. %)	Cements and bauxite employed			
	PC	BFSPC	bauxite	SAB
Humidity	0.02	0.24	0.60	0.10
Ignition loss	1.40	1.02	18.48	0.60
Insoluble residue	1.66	1.51	0.00	3.06
SiO ₂	19.51	24.88	2.94	17.17
CaO	63.60	55.18	4.06	48.12
MgO	1.49	4.70	0.00	1.66
Fe ₂ O ₃	3.48	4.70	20.41	6.16
Al ₂ O ₃	5.67	4.27	53.00	15.25
SO ₃	3.01	3.22	0.50	7.88
CaO free	0.10	0.00	0.00	0.00
Specific gravity (kg/m^3)	3 168	3 047	no data	3 217
Surface area (m^2/kg)	443	342	no data	643
Initial set (min)	125	160	-	35
Final set (min)	205	245	-	45

Table 2. Mineralogical composition of the cements.

Type of cement	Portion of clinker minerals (%)					
	C ₃ S	C ₂ S	C ₃ A	C ₄ AF	C ₄ A ₃ \bar{S}	C \bar{S}
PC (Bogue)	67.6	5.1	9.2	10.6	none	5.9
BFSPC	no calculation was done					
SAB	none	50.3	none	19.5	20.2	9.7

Ultrasonic pulse velocities were measured on an ultrasonic apparatus (UNIPAN type 543, Poland) calculating the dynamic modulus of elasticity by the formula

$$E_{bu} = \rho_{VD} \cdot \gamma_L^2 \cdot 10^{-6} \quad (2)$$

where E_{bu} is dynamic modulus of elasticity (MPa), ρ_{VD} is volume density (kg/m^3) and γ_L is impulse speed of longitudinal ultrasonic waves (m/s).

Change of electrical resistance of steel class 10 425 embedded in mortar specimens was ascertained by standard stabilized power supply and digital voltmeter.

The length changes of prisms were measured by a portable mechanical strain gauge apparatus (in a glass tube to minimize extraneous effects). The gauge length was 100 mm, with a measuring accuracy of 0.001 mm. Changes in length of mortar specimens are expressed in per mille (‰). The relation of per mille to microstrain: $1 \mu\text{s} = 0.001 \text{‰}$.

Powder X-ray diffraction patterns were recorded on a Philips X-ray diffractometer coupled with an automatic data recording system. $\text{CuK}\alpha$ radiation and Ni - filter were used. The chemical composition of the mortars was estimated by analytical methods. The oxide content in the soluble portion relating to the cement binder in wt.% was calculated. Simultaneous thermogravimetry (TG) and differential thermal analysis (DTA) were conducted from 20°C to 1 000°C using a T.A.I. SDT 2960 Instrument (sample mass 10-20 mg, heating rate 10°C/min, in flowing air). The pore structure was investigated by the mercury porosimetry test using the high - pressure porosimeter model 2000 and macroporosimetry unit 120 (both Carlo Erba, Italy). The following pore structure characteristics were estimated: volume of micropores (to 7 500 nm); volume of total open pores (to 0.06 mm); portion of macropores above 7 500 nm; micropore and pore median radius and total porosity ranged between pore radius 3.75 nm and 0.06 mm. Pore size distribution was characterized as well.

RESULTS AND DISCUSSION

Comparison of cements

The results reported in Tables 1 and 2 show that PC, BFSPC and SAB cements differ mainly in CaO, SiO₂ and Al₂O₃ contents. Mineralogical composition of SAB cement is therefore quite different than that of PC. The SAB cement is characterized by a relatively high content of main clinker mineral C₂S, C₄A₃S̄ and C₄AF. Portions of C₂S, C₄AF and C₃S̄ are higher than those in PC. The cements differ markedly in chemical and mineralogical composition that results in different initial and final setting of PC and BFSPC on the one hand and SAB cement on the other hand. Rapid setting of SAB cement is mainly due to quick conversion of C₄A₃S̄ to hydration products during early age hydration.

Mechanical properties and passivation ability

Mortar specimens (that with PC indicated as MPC; with BFSPC indicated as MBFSPC, and with SAB cement indicated as MSAB) were tested on compressive strength, water absorption capacity, dynamic modulus of elasticity and length changes. The 90-day compressive strength, water absorption capacity and total porosity of the mortar with SAB cement are similar to those of the mortar made with BFSPC (Table 3). The SAB cement and BFSPC are from this point of view comparable. Slightly increased absorption capacity and total porosity of SAB cement mortar relative to that of BFSPC mortar are attributed to rapid setting and hardening of the SAB cement. Shrinkage compensating pro-

Table 3. Physical - mechanical properties and total porosity of mortars after 90 days at 20°C/100 % R.H. - wet air.

Property of cement mortar	Type of cement mortar		
	MPC	MBFSPC	MSAB
Compressive strength (MPa)	66.2	40.2	33.8
Absorption capacity (wt.%)	7.1	8.0	9.4
Specific gravity (kg/m^3)	2 636	2 678	2 781
Volume density (kg/m^3)	2 286	2 274	2 210
Total porosity (vol. %)	13.3	15.1	20.9

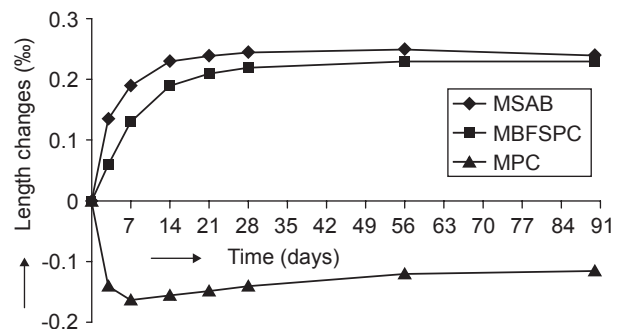


Figure 1. Development in length changes of studied mortars cured at 20°C/100 % R.H. - wet air.

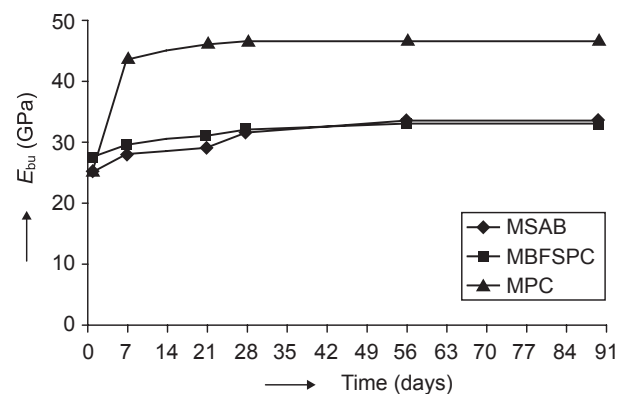


Figure 2. Changes in dynamic modulus of elasticity (E_{bu}) of studied mortars cured at 20°C/100 % R.H. - wet air.

properties of SAB cement mortar compared to those of PC and BFSPC are evident from Figure 1. PC mortar shows a slight shrinkage under wet air cure. Contrary, BFSPC and SAB cement mortar tend to expand a little. The difference in 90-day value of length change between SAB cement mortar and PC specimen is approximately 0.34 %. Dynamic modulus of elasticity of SAB cement mortar is lower than that of PC mortar (Figure 2). Elasticity properties of SAB cement mortar are comparable with those of BFSPC mortar. The results given in Table 3 and Figures 1 and 2 indicate dependence between the cement mortar composition and important engineering properties. One would conclude that the SAB cement is suitable for repair mortars with rapid initial set (35 minutes) followed by 10-minute period to reach a final set. The above argument is supported by dta summarized in Table 4. Compressive strength of the pastes (20×20×20 mm, w/c ratio of 0.5) after 6-hour early age hydration are non-measurable for PC and BFSPC pastes, while for SAB cement paste is 6.3 MPa. The 90-day strength values are 61.3 MPa (PC), 58.0 MPa (BFSPC) and 48.8 MPa (SAB cement), respectively. The 6-hour and 90-day compressive strength of SAB cement is sufficiently high for the mortars intended for repair works.

The ability of mortars prepared from the above cements to protect steel reinforcement against corrosion is illustrated in Figure 3. Corrosion of steel, if it occurs,

Table 4. Development of compressive strength (MPa) of pastes prepared from studied cements (w/c = 0.5).

Time	Type of cement		
	PC	BFSPC	SAB
6 hours	–	–	6.3
24 hours	11.3	6.6	11.3
7 days	41.6	29.7	19.3
28 days	51.9	38.5	29.5
90 days	61.3	58.0	48.8

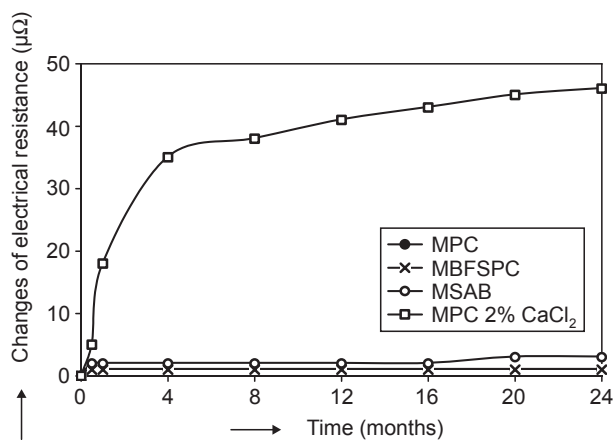


Figure 3. Change of electrical resistance of steel in mortars cured at 20°C/80 % R.H. - wet air. Note: Points of MPC are coincidental with those of MBFSPC.

is accompanied by the increase in electrical resistance that is evident for PC mortar with 2 % of chloride admixture. The SAB cement creates suitable conditions for steel passivation (MPC and MBFSPC as well). The evidence of this fact are a little (negligible) and unchangeable values of change of steel electrical resistance. This finding was verified by the measurements lasting two years.

Hydrate phase formation

Changes in physical-mechanical properties, shrinkage/expansion behaviour as well as elasticity module are connected with hydrate phase and pore structure development. Results of X-ray diffraction analysis of studied mortars are shown in Figure 4. High portlandite - $Ca(OH)_2$ content (abbreviated as CH: 4.92 Å, 2.62 Å, 1.92 Å) is typical for PC and BFSPC mortars. Contrary, portlandite in SAB cement mortar is missing. Conversion of unreacting belite (C_2S) or alite (C_3S) is typical for the doublet in the region of 2.76 and 2.73 Å. The presence of belite in mortar with SAB cement exhibits its considerably decreased conversion to hydration products. The high degree of clinker minerals conversion to gel-like hydrate phase of C–S–H type is evident for PC and BFSPC mortars. Quartz (Q) originates from siliceous sand and higher content of gypsum ($C\bar{S}$) (especially at 3.64 and 2.86 Å) comes from alone SAB cement. Calcite (Cc) at 3.03 Å represents by-product of cements hydration and quasi-carbonation product, respectively.

Results of thermal analysis (Figure 5) support information on phase composition development given by X-ray diffraction analysis. PC mortar is characterized by an endothermic peak at 180°C indicating prevailing C–S–H phase decomposition. $Ca(OH)_2$ dehydroxyla-

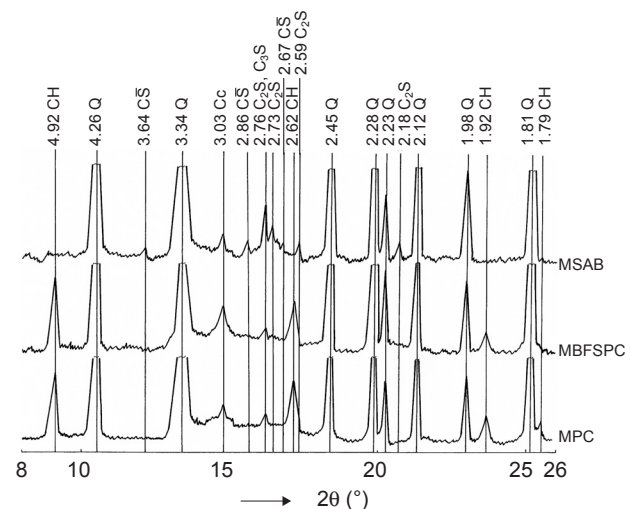


Figure 4. X-ray diffraction patterns of studied mortars after 90 days at 20°C/100 % R.H. - wet air.

tion is conveyed by the presence of endothermic peak at 500°C. The endotherm at 780°C is connected with CaCO₃ dissociation. Practically identical thermograms were obtained for MBFSPC mortar. The interpretation of thermogravimetric curve in the region of decomposition of the cement hydration products for SAB cement mortar is more complicated because of the fact that decomposition temperatures of C-S-H, gypsum and ettringite lie close together. Nevertheless, one would conclude that the presence of gypsum at 120°C is clear. The main part of this large peak is represented by gypsum (Table 5). As regards Ca(OH)₂ dehydroxylation and CaCO₃ dissociation for SAB cement mortar - unlike PC and BFSPC mortar - these decompositions are practically negligible (Figure 5, Table 5). In addition, the small CaCO₃ dissociation is shifted to 720°C. The total ignition loss is the lowest in SAB cement mortar of all mortars in accordance with the real assumption.

The results of XRD and thermal analysis are closely coherent to those of chemical analysis (Table 6). The CaO content in MSAB is by 2.68 % and 14.09 % lower than those in MBFSPC and MPC. Contrary, SO₃ content

in MSAB is higher by 3.75 % and 3.61 % compared to those of MBFSPC and MPC. The contents of the above constituents give lower Ca(OH)₂ and higher C \bar{S} in MSAB relative to those in the mortars with BFSPC and PC, as proved by XRD and thermal analysis.

Table 5. Results of thermal analysis of studied mortars after 90 days at 20°C/100% R.H. - wet air.

Type of cement mortar	Water bound in hydration products (%)	CaO bound in		Total ignition loss (%)
		Ca(OH) ₂ (%)	CaCO ₃ (%)	
MPC	3.6	3.4	3.6	7.5
MBFSPC	3.0	3.1	3.2	6.5
MSAB	3.6*	2.2	1.0	5.1

* hydration products + gypsum

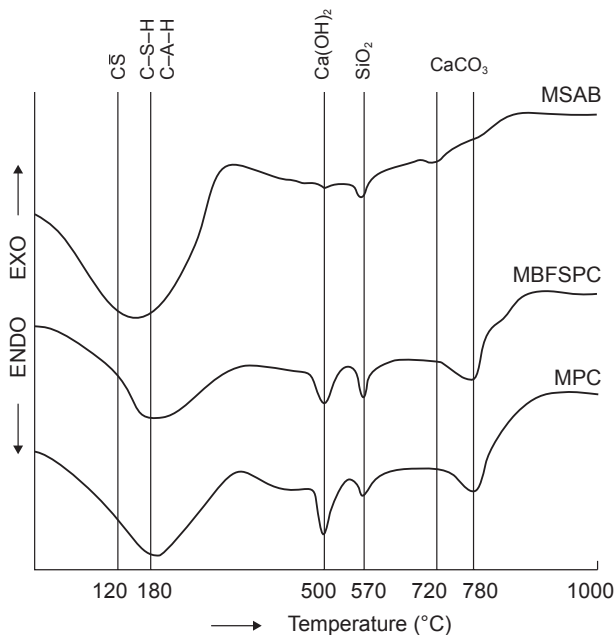


Figure 5. DTA curves of studied mortars after 90 days at 20°C/100 % R.H. -wet air.

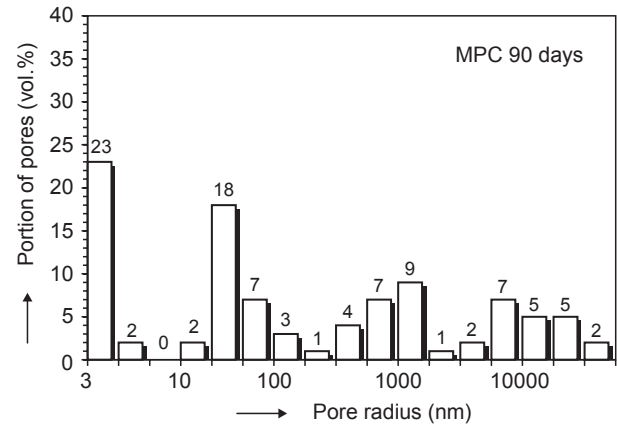


Figure 6. Relation between portion of pores and pore radius of MPC mortar after 90 days at 20°C/100 % R.H.-wet air.

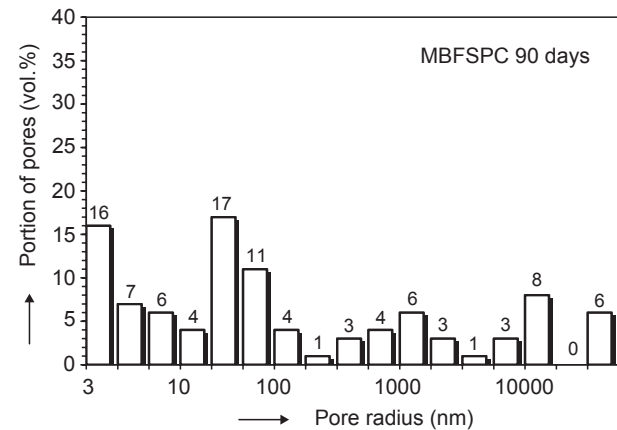


Figure 7. Relation between portion of pores and pore radius of MBFSPC mortar after 90 days at 20°C/100 % R.H.- wet air.

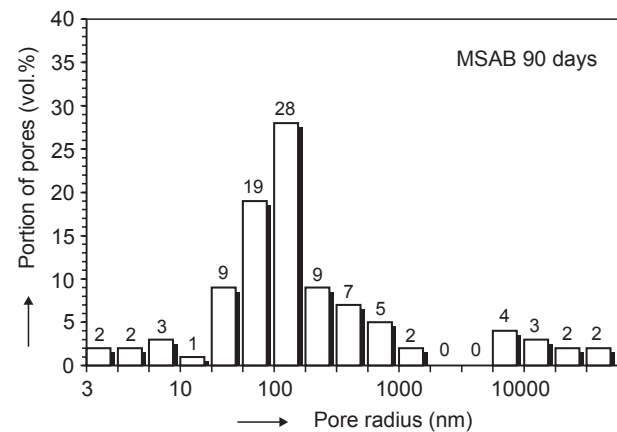


Figure 8. Relation between portion of pores and pore radius of MSAB mortar after 90 days at 20°C/100 % R.H.- wet air.

Pore structure development

The results of pore structure analysis are shown in Table 7. Micropore and total pore radius median as well as total porosity of SAB cement mortar are higher than those found in PC and BFSPC mortar. The results of pore size distribution (Figures 6, 7 and 8) prove differences in decisive pore portions of the mortars: SAB cement mortar has the largest portion of pores with 10^2 - 10^3 nm of pore radii and that in PC and BFSPC mortars is found in the range of pore radii < 10 nm and 10 - 10^2 nm, respectively. Pore structure of SAB cement mortar is coarser than those of PC - based mortars. This is mainly caused by rapid hardening of SAB cement and consequent formation of higher content of early-age hydration products in a volume unit of bulky mortar. It results in early strength growth but also the formation of larger pores relative to the hydrate phase and pore structure formed in PC and BFSPC mortar. Larger volume of pores contributes to strength drop of SAB cement mortar with time of hydration when hydrate phase volumes in PC - based mortars become as rich in a volume as that in SAB cement mortar. The above finding is evidently confirmed by the comparison of 90-day compressive strength of the mortars: while that of SAB cement mortar is 33.8 MPa, that of BFSPC and PC mortar are 40.2 and 66.2 MPa. Prism compressive strength dependence

on physical, chemical and pore characteristics of studied mortars is clearly illustrated in Figure 9. The close coherence between total porosity and absorption capacity and the strength of the mortars is the one important notion.

CONCLUSIONS

The following conclusions are applicable to the particular mortars and test methods employed:

1. Rapid setting of SAB cement is due to quick conversion of $C_4A_3\bar{S}$ to hydration products at early age hydration.
2. The 90-day compressive strength, absorption capacity and total porosity of mortar with SAB cement are comparable with those of BFSPC mortar. Shrinkage reducing properties of SAB cement are significant unlike PC behaviour. Elasticity moduli of SAB cement mortar are similar to those of that made with BFSPC.
3. Mortars made from PC and BFSPC are richer in $Ca(OH)_2$ compared to SAB cement mortar. Contrary, SAB cement mortar has increased gypsum content and decreased carbonation.
4. SAB cement mortar exhibits sufficient protective properties against steel reinforcement corrosion.

Table 6. Chemical composition of studied mortars cured 90 days at 20°C/100 % R.H. - wet air.

Type of cement mortar	a. Ignition loss (wt.%)		f. Composition of soluble portion (wt.%)					
	b. Soluble portion (wt.%)		g. Oxide content related to cement binder (wt.%)					
	c. Insoluble portion (wt.%)		SiO ₂	CaO	Fe ₂ O ₃	Al ₂ O ₃	MgO	SO ₃
MPC	a. 5.18							
	b. 22.67	f. 4.96	14.42	0.73	1.66	0.20	0.70	
	c. 70.60	g. 21.88	63.61	3.22	7.32	0.88	3.09	
MBFSPC	a. 4.55							
	b. 21.34	f. 5.24	11.14	1.58	1.97	0.78	0.63	
	c. 72.82	g. 24.56	52.20	7.40	9.23	3.66	2.95	
MSAB	a. 5.96							
	b. 23.13	f. 4.55	11.45	1.98	3.06	0.54	1.55	
	c. 70.91	g. 19.67	49.52	8.56	13.22	2.33	6.70	

Table 7. Pore structure parameters of studied mortars kept 90 days at 20°C/100 %R.H. - wet air.

Type of cement mortar	SSA (m ² /g)	V _{MP} (mm ³ /g)	V _{TP} (mm ³ /g)	Macro (%)	M _{MP} (nm)	M _{TP} (nm)	BD (kg/m ³)	TP (%)
MPC	5.75	36.41	46.15	21.09	37.25	66.13	2 390	11.02
MBFSPC	6.40	46.33	55.86	17.08	35.83	50.35	2 692	13.07
MSAB	2.98	73.43	83.21	11.75	122.62	139.52	2 738	18.55

SSA - specific surface area of pores, V_{MP} - volume of micropores (in the range of 3.7-7 500 nm), V_{TP} - volume of total open pores (in the range of 3.7 nm - 0.06 mm), Macro - portion of macropores (above 7 500 nm), M_{MP} - micropore radius median, M_{TP} - pore radius median, BD - bulk density, TP - total porosity (in the range of 3.7 nm - 0.06 mm)

5. The 6-hour and 90-day compressive strength of SAB cement indicates that this cement is suitable for special repair works in civil engineering.
6. Considering the differences in the formed hydrate phase and pore structure between the SAB cement and BFSPC, the results show extended opportunity of BFSPC substitution by SAB cement, particularly if rapid setting of SAB cement will be slowed down in the future.

Acknowledgement

The authors are thankful to the Slovak Grant Agency (project No. 2/6108/27) for the support of this work.

References

1. Mehta P.K.: World Cem.Tech., 144 (1978).
2. Moir G.K., Glasser F.P. in: 9th Int.Congr. Chemistry of Cements, p.125-152, New Delhi 1992.
3. Glasser F.P., Zhang L.: Cem.Concr.Res. 31, 1881 (2001).
4. Quillin K.: Cem.Concr.Res. 31, 1341 (2001).
5. Blanco-Varela, M. T., Martínez-Ramírez, S., Gener, M. Vázquez, T.: Mater. de Construc., 55, 27 (2005).
6. Lawrence C.D.: P.C.Hewlett - Lea's Chemistry of Cement and Concrete, 4th ed., p.421-470, Arnold, London 1998.
7. Sharp J.H., Lawrence C.D., Yang R.: Adv.Cem.Res. 11, 3 (1999).
8. Uchikawa H.: World Cem., 47 (1994).
9. Uchikawa H.: World Cem., 49 (1994).
10. Taylor H.F.W.: Cement Chemistry, 2nd ed., Thomas Telford, London 1997.

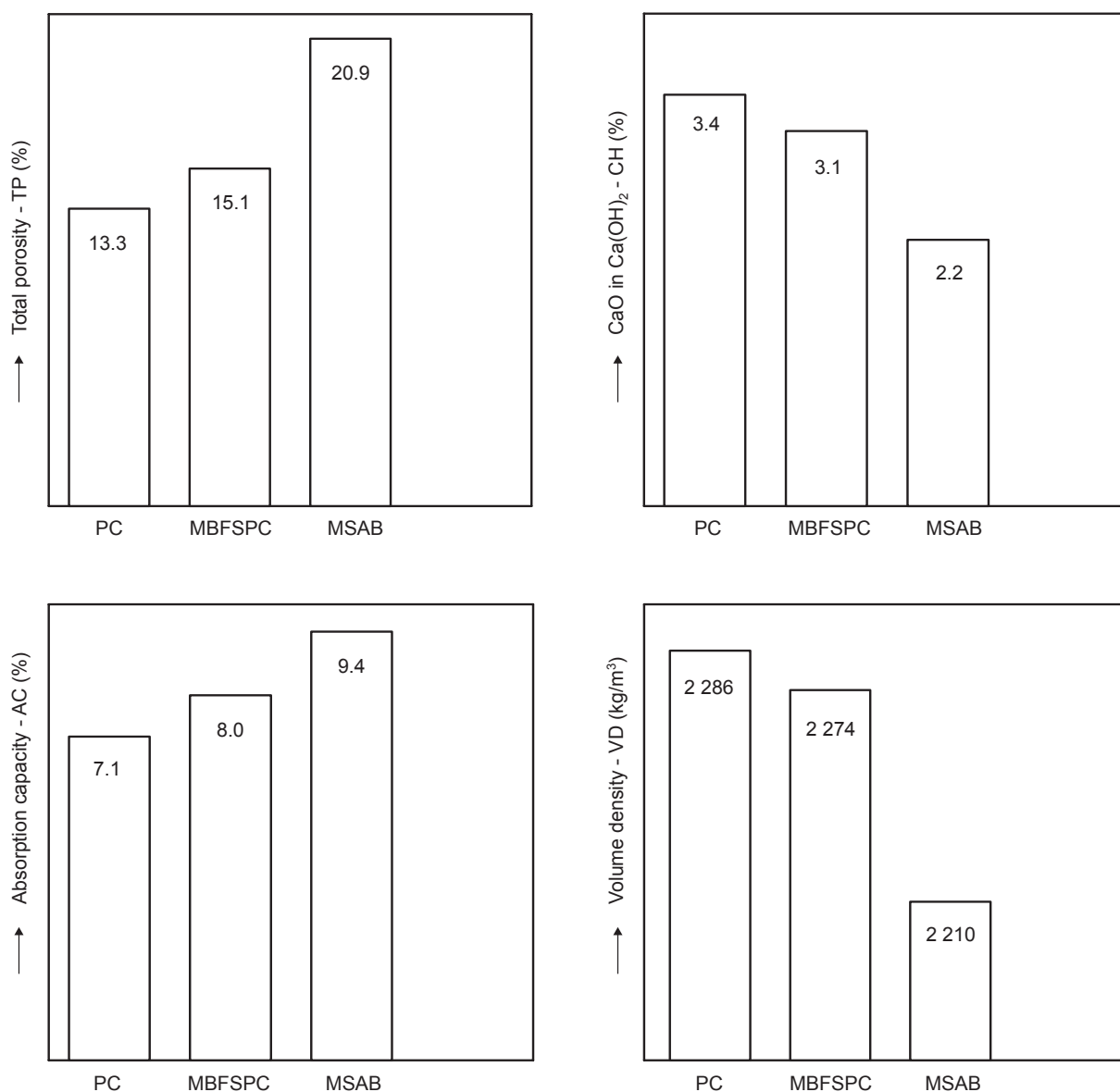


Figure 9. Physical, chemical and pore characteristics of mortars related to compressive strengths (MPC: 66.2 MPa, MBFSPC: 40.2 MPa, MSAB: 33.8 MPa) after 90 days at 20°C/100 % R.H. - wet air.

11. Kurdowski W., George C., Sorrentino F. in: 8th Int.Congr. Chem.Cem., p.292, Rio de Janeiro 1986.
12. Arjunan P., Silsbee M.R., Roy D.M.: Cem.Concr.Res. 29, 1305 (1999).
13. Strigáč J., Krištín S., Sahu S., Palou M.T., Majling J. in: 10th Int.Congr.Cem.Cem., p. 3v009, Gothenburg 1997.
14. Zhang L., Su M., Wang Y.: Adv.Cem. Res. 11, 15 (1999).
15. Palou M.T., Majling J., Dovál M., Kozánková J., Mojumdar S.C.: Ceramics-Silikáty 49, 230 (2005).
16. Strigáč J., Palou M.T., Krištín J., Majling J.: Ceramics-Silikáty 44, 26 (2000).
17. Beretka J., de Vito B., Santoro L., Sherman N., Valenti G.L.: Cem.Concr.Res. 23, 1205 (1993).
18. Sherman J., Beretka J., Santoro L., Valenti G.L.: Cem. Concr.Res. 25, 113 (1995).
19. Živica V., Janotka I.: Build.Res.J. 47, 117 (1999).
20. Janotka I., Krajčí L.: Bull.Mater.Sci. 23, 521 (2000).
21. Mojumdar S.C.: J.Therm.Anal.Calorim. 64, 1133 (2001).
22. Drábik M., Gálíková L., Hanic F., Sharp J.H.: Chem.Pap. 51, 363 (1997).
23. Janotka I., Krajčí L.: Adv.Cem.Res. 11, 35 (1999).
24. Janotka I., Krajčí L., Ray A., Mojumdar S.C.: Cem.Concr. Res. 33, 489 (2003).
25. Mojumdar S.C., Raki L.: J. Therm. Anal. Calorim. 85, 99 (2006).
26. Mojumdar S.C., Raki L., Mathis N., Schimdt K., Lang S.: J. Therm. Anal. Calorim. 85, 119 (2006).
27. Mojumdar S.C., Mazanec K., Drábik M.: J. Therm. Anal. Calorim. 83, 135 (2006).
28. Mojumdar S.C., Raki L.: J. Therm. Anal. Calorim. 82, 89 (2005).
29. Mojumdar S.C., Raki L.: Ceram.Trans. (Ceramic Nanomaterials and Nanotechnology IV), 172, 11 (2006).
30. Janotka I., Krajčí L., Mojumdar S.C.: Build. Res. J. 53, 121 (2005).
31. Chowdhury B., Mojumdar S.C.: J. Therm. Anal. Calorim. 81, 179 (2005).
32. Janotka I., Mojumdar S.C.: J. Therm. Anal. Calorim. 81, 197 (2005).
33. Mojumdar S.C.: Res. J. Chem. Env. 9, 23 (2005).
34. Mojumdar S.C., Chowdhury B., Varshney K.G., Mazanec K.: J. Therm. Anal. Calorim. 78, 135 (2004).
35. Mojumdar S.C., Ray A., Drábik M., Cigan A., Hanic F., Capek P.: Sol. St. Phenom. 90-91, 365 (2003).
36. Janotka I., Mojumdar S.C.: Sol. St. Phenom. 90-91, 309 (2003).
37. Janotka I., Mojumdar S.C.: Mater. de Constr. 53, 17 (2003).
38. Drábik M., Galikova L., Mojumdar S.C.: Key Eng. Mater. 206-213, 1867 (2002).
39. Drábik M., Mojumdar S.C., Slade R.C.T.: Ceramics-Silikáty 46, 68 (2002).
40. Janotka I., Krajčí L., Mojumdar S.C.: Ceramics-Silikáty 46, 110 (2002).
41. Mojumdar S.C., Janotka I.: Acta Phys.Slov. 52, 435 (2002).
42. Drábik M., Mojumdar S.C., Galikova L.: Cem.Concr.Res. 31, 751 (2001).
43. Mojumdar S.C.: Challenges Coord. Chem. New Cent. 5, 453 (2001).

ÚČINNOSŤ A VÝZNAM SULFOALUMINÁTOVÉHO - BELITOVÉHO CEMENTU S VYSOKÝM OBSAHOM $C_4A_3\bar{S}$

IVAN JANOTKA, ĽUDOVÍT KRAJČI,
SUBHASH C. MOJUMDAR*

Ústav stavebníctva a architektúry, Slovenská akadémia vied
Dúbravská cesta 9, 845 03 Bratislava, Slovensko
*Faculty of Forestry, University of Toronto,
33 Willcocks Street, Toronto, Ontario, M5S 3B3, Canada

Sulfoaluminátové-belitové (SAB) cementy predstavujú atraktívnu skupinu nízkoenergetických cementov z hľadiska úspory energie a zníženého uvoľňovania CO_2 do atmosféry pri ich výrobe. Ich hydraulická aktivita však nezodpovedá aktivite Portlandského cementu (PC) a potrebuje vylepšenie pred samotným použitím. Účinnosť SAB cementu s 50,3 hmot. % C_2S , 20,2 hmot. % $C_4A_3\bar{S}$, 19,5 hmot. % C_4AF a 9,7 hmot. % $C\bar{S}$ a porovnáva s účinnosťou Portlandského cementu obsahujúceho 67,6 hmot. % C_2S , 5,1 hmot. % C_2S , 9,2 hmot. % C_3A , 10,6 hmot. % C_4AF a 5,9 hmot. % $C\bar{S}$ ako aj s účinnosťou Portlandského troskového cementu (BFSPC) obsahujúceho 30 hmot.% vysokopečnej trosky. Zhotovili sa malty s hmotnostným pomerom cementu a kremičitého piesku 1 : 3 a vodným súčiniteľom 0,5. Hranoly veľkosti 40×40×160 mm sa uložili na 90 dní do prostredia s relatívnou vlhkosťou 100 % pri 20°C. Prešetrovanie pasivačnej schopnosti cementov trvalo v rovnakých úložných podmienkach až 2 roky. Výsledky ukázali, že sulfoaluminátový-belitový cement z hľadiska fyzikálno-mechanických vlastností (pevnosť, dynamický modul pružnosti), dĺžkových zmien a pasivačných schopností sa kvalitatívne približuje k Portlandskému troskovému cementu, napriek rozdielностям vo vývoji hydratovanej fázy a pórovej štruktúry. Rýchly nárast počiatkových pevností SAB cementu a porovnateľné pevnosti po 90 dňoch hydratácie s Portlandským troskovým cementom poukazujú na to, že SAB cement je využiteľný pri rekonštrukčných a sanačných postupoch, pričom prirodzenej konkurencii medzi SAB cementom a Portlandským troskovým cementom v praxi nateraz bráni najmä rýchly počiatok a doba tuhnutia SAB cementu.