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Strength and durability aspects of calcined kaolin-blended Portland cement mortar and concrete

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Abstract

Economic and sustainability arguments require carefully assessing the potentialities of indigenous resources for the production of mortar and concrete for the construction industry. In Vietnam, significant efforts should be bestowed on urban development, coastal protection and harbour construction works. In a joint Vietnamese-Dutch co-operation program, the practical use for this purpose of relevant resources in Northern Vietnam is assessed experimentally. This paper concentrates on kaolin, which is widely available in this region. The key issues this paper is dealing with are the effects of partial replacement of Portland cement by calcined kaolin in mortar and concrete on compressive strength as well as on durability characteristics of mortar and concrete mixes pertinent to the coastal environment. Workability measures are also mentioned. Data are therefore presented on compressive strength development over a maximum curing period of 180 days of mixes in which the water to binder ratio was varied between 0.40 and 0.53. Moreover, partial replacement was considered in the range from 0% to 30% by weight. The results of this study render possible the assessment of optimum replacement percentages of Portland cement by calcined kaolin, and the associated strength gain. Additionally, this paper reports on the performance aspects of similarly blended mortar and concrete specimens stored for a period of one year in a low concentration of a sodium sulfate solution. It could be concluded that a strength gain due to blending will be accompanied by improved durability in this environment. © 2001 Published by Elsevier Science Ltd.

Keywords: Blending; Compressive strength; Concrete; Durability; Kaolin; Pozzolan; Mortar; Sulfate resistance

1. Introduction

In many countries around the world, kaolin and clay are used for producing active pozzolanic admixtures. These pozzolanic admixtures are used for reducing the Portland cement content in mortar and concrete production [1–4]. The positive effects exerted by such pozzolanic admixtures on properties of Portland cement mortar and concrete have been emphasized in many studies [5–7]. In addition to a strength gain, it was shown that such admixtures could improve the sulfate resistance of the Portland cement mortar and concrete [8,9]. However, what can be expected in a specific situation will depend on the mineralogical and chemical composition of the mineral admixture.

For the present purpose interesting indigenous resources as alumina-rich clays and kaolin are abundant and widespread through many districts in Northern Vietnam. A limited survey of such mineral resources employed in Northern Vietnam is presented in Table 1. This study therefore focuses on the degree to which kaolin could replace Portland cement in mortar and concrete production in Northern Vietnam. The key issues in emphasizing the potentialities of kaolin for this purpose are the compressive strength and the durability in a low-concentration sodium sulfate solution. On the strength testing of kaolin-blended pastes, mortars and concretes has been reported earlier. For more details, such as on the characterization of the kaolin as a proper pozzolanic material, the reader is referred to these publications [3,4,10]. For a more elaborate report on the durability aspects, also encompassing flexural testing and a more concentrated sulfate solution environment, see [10]. The experiments are continued in Vietnam, particularly focusing on concrete. The results of this investigation will be reviewed later.

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Table 1
Chemical composition of local mineral resources in Vietnam: Kaolin (K), Clay (C)

Composition (%)	Region in Northern Vietnam					
	Hai Hung (K)	Quang Ninh (K)	Thanh Hoa (K)	Son Tay (K)	Tuyen Quang (C)	Vinh Phu (C)
SiO_2	45–63	43–70	48	54–55	50–60	44–46
Al_2O_3	24–35	21–33	31	27–29	36–42	34–37
Fe_2O_3	0.8–1.3	0.1–0.7	1.8	0.8–0.9	2.5–3.5	0.9–3.0
CaO	0.3	0.5–1.2	1.3	1.1–1.5	0.5	0.6–0.7
MgO	0.4–1.2	0.2	0.7	0.3–0.6	1.5–1.8	0.5
K_2O	1.3–3.5	0.2	3.1	0.8–5.9	0.6–0.8	–
TiO_2	0	1.0	–	–	0.8–3.0	–
LOI	7.0	14	15.5	13–15	9–11	14

This paper particularly aims at assessing by means of the outcomes of a test program on trial mixes the possibilities of using these natural resources of Northern Vietnam for the indicated purpose, i.e. the extent to which the Portland cement can be blended by kaolin in the production of durable mortar and concrete in low-sulfate solution environment.

2. Materials

The materials on which a more extensive study in Vietnam is based are a coarse aggregate of crushed rock (granite, limestone, etc.), very fine sand of fluvial origin, and a Portland cement (P) similar to ASTM type I (and to CEM I 32R). Since the present experiments were conducted in The Netherlands, the indigenous resources of Vietnam were replaced by local alternatives. The size of the graded sand was in the 0.15–0.60 mm range. A naphthalene sulfonate-based superplasticizer (SP) type TM OFT-3 was used to reduce the water demand in the mortar and in the concrete mixes. The SP content fluctuated between 0.4% and 2.0% by weight of the Portland cement.

Calcined kaolin (K) was produced by incinerating a kaolin at 800°C for two hours in an electrical oven. To that end, the kaolin powder was stored in the oven before heating up, and after the incineration period left to completely cool down. Compositional details and particle size distributions of the Portland cement and the calcined kaolin used for the experiments are presented in Tables 2 and 3, respectively. Normal consistency and setting times were measured for Portland cement pastes up to 40% by weight of the Portland cement replaced by calcined kaolin. Results are presented in Table 4. The pozzolanic index of the calcined kaolin (i.e. 93.5%) was determined according to ASTM C595-81 [3,4,10].

Table 2
Chemical and mineral composition of Portland cement and kaolin

Composition	Content K(%)	Content P(%)
Free water at 105°C	1.1	
LOI at 800°C	11.9	
SiO_2	46.6	21.0
Al_2O_3	35.7	5.0
Fe_2O_3	0.5	3.0
CaO	0.35	64.0
MgO	0.35	2.0
K_2O	1.65	0.6
TiO_2	0.26	
P_2O_5	0.11	
Na_2O	0.07	
C_3S		63
C_2S		13
C_3A		8.8
C_4AF		9.0
SO_3		3.0

Table 3
Particle size distribution of aggregates and calcined kaolin

Sieve size (mm)	Accumulated percentage by weight retained		
	Crushed granite	Sand	Calcined kaolin
16	1.92		
8	88.42		
4	99.03		
2	100.0		
0.6		4.2	
0.425		40.2	
0.3		65.1	
0.15		82.7	
0.08			5.68
0.06			8.28
0.045			11.78
0.02			28.74
0.01			40.48
0.005			57.18

Table 4
Normal consistency and setting times of calcined kaolin-blended Portland cement paste

Code	P (%)	K (%)	W/(P + K)	Setting time (min)	
				Initial	Final
P	100	0	0.25	215	275
PK1	90	10	0.30	210	270
PK2	85	15	0.33	215	280
PK3	80	20	0.36	215	280
PK4	75	25	0.38	220	285
PK5	70	30	0.41	225	290

3. Mix proportions

Mortar mixes were made consisting of one part of binder and 2.75 parts of sand by weight. In these mixes, the Portland cement was replaced for 10%, 15%, 20%, 25% or 30% by weight with calcined kaolin. The amount of mixing water in each mix was adjusted to obtain in accordance with the requirements of ASTM C109-80 a consistency of 105–115 mm. For details, see Table 5. Mixes were cast in $40 \times 40 \times 160$ mm^3 steel moulds. After casting, the moulds were covered by plastic sheets to prevent water loss, and were thereupon stored under controlled conditions of about 20°C and 99% RH. After a period of 22–24 h, the specimens were de-moulded and re-stored in the moist room until the time of testing at 1, 3, 7, 28, 60 and 90 days. The tests are intended to reveal the effect of a variation in the degree of Portland cement blending on the level and the development of the compressive strength of mixes with similar workability.

To determine the effect of the water to binder ratio on the strength of a mortar, mixes were prepared with the same blending percentages, but composed of one part of binder and two parts of sand. The water to binder ratio amounted in the successive mixes to be 0.40, 0.44, 0.47, 0.50 and 0.53. The content of SP was adjusted in the various mixes to ensure workability, i.e. a flow of 105 to 115 mm, as measured according to ASTM C595-81. A survey of the mix proportions is presented in Table 6. The test aimed at revealing the level and the development of the compressive strength resulting from variations in the water to binder ratio.

Table 6
Strength of kaolin-blended Portland cement mortar at various water binder ratios[a]

Code	K (%)	W/ (P + K)	SP (%)	Compressive strength (N/mm^2) at ages (days)			
				7	28	60	90
M7	0	0.53		25.5	36.2	41.3	43.7
M8	10	0.53		25.9	38.5	43.8	44.5
M9	15	0.53		28.4	40.0	43.4	45.0
M10	20	0.53		28.2	40.2	44.3	44.2
M11	25	0.53		27.5	38.1	42.5	43.4
M12	30	0.53		26.8	35.7	39.6	43.0
M13	0	0.50		29.3	38.3	44.5	47.0
M14	10	0.50		30.4	41.3	46.0	46.7
M15	15	0.50		31.3	42.1	44.7	46.9
M16	20	0.50		29.4	42.7	45.1	45.3
M17	25	0.50		29.1	39.9	43.6	45.3
M18	30	0.50		26.8	38.1	42.1	44.9
M19	0	0.47		31.5	39.5	46.3	48.0
M20	10	0.47		31.9	43.6	46.9	47.4
M21	15	0.47		32.6	44.1	45.2	47.4
M22	20	0.47		30.4	44.0	47.0	46.8
M23	25	0.47		30.2	42.8	43.9	45.6
M24	30	0.47		29.0	38.7	43.6	45.1
M25	0	0.44	0.5	35.4	41.8	46.6	50.5
M26	10	0.44	0.5	38.0	45.9	48.5	51.2
M27	15	0.44	0.5	36.6	46.3	47.8	51.4
M28	20	0.44	0.5	35.7	45.4	48.7	50.6
M29	25	0.44	0.5	33.8	44.7	47.3	50.5
M30	30	0.44	0.5	31.7	40.6	43.9	47.1
M31	0	0.40	1.3	40.0	44.0	48.7	51.4
M32	10	0.40	1.3	42.4	47.2	50.9	54.2
M33	15	0.40	1.3	41.9	48.1	51.1	54.9
M34	20	0.40	1.3	41.4	49.0	52.0	53.8
M35	25	0.40	1.3	39.6	47.7	51.3	53.5
M36	30	0.40	1.3	35.5	42.1	47.5	50.8

[a] Binder: Sand = 1:2, P: Portland cement, K: Calcined kaolin, SP: Superplasticizer, W: Water.

Table 5
Strength of ASTM C348-80 mortar made with kaolin-blended Portland cement[a]

Code	K (%)	W/(P + K)	Compressive strength (N/mm^2) at ages (days)					
			1	3	7	28	60	90
M1	0	0.48	3.98	12.93	16.56	23.68	28.16	29.74
M2	10	0.48	3.51	13.17	18.99	25.19	29.20	31.23
M3	15	0.50	3.40	12.24	18.17	26.24	30.94	32.10
M4	20	0.51	3.34	10.86	18.13	25.42	29.98	32.16
M5	25	0.52	2.40	9.63	16.30	23.25	28.45	32.28
M6	30	0.53	2.15	9.51	15.45	22.48	27.97	30.40

[a] Binder: Sand = 1: 2.75, P: Portland cement, K: Calcined kaolin, W: Water.

Table 7
Mixture proportion of kaolin-blended Portland cement concrete[a]

No.	Code	K (%)	W/(P + K)	Mixture proportion of concrete (kg/m^3)					
				P	K	S	A	W	SP
1	A1	0	0.44	328		655	1300	144	4.92
2	A2	10	0.44	295.2	32.8	649	1300	144	4.92
3	A3	20	0.44	262.4	65.6	643	1300	144	4.92
4	A4	30	0.44	229.6	98.4	637	1300	144	4.92
5	B1	0	0.36	501		501	1257	180	5.01
6	B2	10	0.36	450.9	50.1	493.3	1257	180	5.01
7	B3	20	0.36	400.8	100.2	485.6	1257	180	5.01
8	B4	30	0.36	350.7	150.3	477.9	1257	180	5.01
9	C1	0	0.32	583		423	1269	186	5.83
10	C2	10	0.32	524.7	58.3	412	1269	186	5.83
11	C3	20	0.32	466.4	116.6	401	1269	186	5.83
12	C4	30	0.32	408.1	174.9	390	1269	186	5.83

[a] P: Portland cement, K: Calcined kaolin, S: Sand, A: Crushed granite, W: Water, SP: Superplasticizer.

Table 8
Properties of kaolin-blended Portland cement concretes

No.	Code	Slump (mm)	Density (kg/m^3)	Compressive strength (N/mm^2) at ages (days)					
				3	7	28	60	90	180
1	A1	50	2402	29.7	33.9	46.6	52.0	52.1	56.0
2	A2	50	2400	32.3	44.2	57.5	62.5	67.8	69.5
3	A3	5	2393	31.0	46.8	60.5	65.3	68.1	70.1
4	A4	0	2392	26.0	45.9	57.6	62.2	68.4	68.9
5	B1	200	2445	48.1	59.1	68.6	78.6	85.0	90.9
6	B2	180	2419	48.5	59.7	72.6	81.3	83.5	88.5
7	B3	45	2396	43.8	63.1	70.5	80.3	78.3	81.3
8	B4	0	2368	33.9	54.5	62.3	63.9	69.5	71.7
9	C1	210	2445	57.6	66.9	78.9	84.9	90.8	95.9
10	C2	180	2418	55.7	72.9	86.0	90.8	93.7	96.3
11	C3	0	2378	43.7	63.1	76.5	80.3	80.0	83.1
12	C4	0	2345	34.7	51.9	60.7	63.1	71.9	73.8

In case of the concrete mixes, Table 7 presents the compositional details, whereby S, A, and W denote sand, coarse aggregate, and water, respectively. Three water to binder ratios were involved, i.e. 0.44, 0.36 and 0.32. Replacement percentages by weight of the Portland cement were 10, 20 and 30. Concrete mixes had different workability levels, indicated by the respective slump values presented in Table 8. The concrete specimens were cast in $100 \times 100 \times 100$ mm^3 steel moulds. The storage procedure was similar as in the case of the mortar specimens.

The composition of the mortar specimens for durability testing is specified in Table 9. Basically, the mix design scheme of the aforementioned reference specimens was followed. Three parts of sand and one part of binder by weight were mixed, however. Two levels of the water to binder ratio were investigated (with some variation among the mixes). Specimens were cast in similar prismatic moulds, and subjected to the same storage regime for the first 22–24 h. Thereupon, re-storage under these conditions was maintained for another 27 days. Finally, the test specimens were either placed in the 0.2 M $MgSO_4$ solution, or in water. Restored specimens were saturated with water, because this

Table 9
Compositions of mortars for durability testing[a]

No.	Code	P (%)	K (%)	SP (%)	W/(P + K)
1	D	100	0		0.48
2	D1	90	10		0.49
3	D2	80	20		0.51
4	D3	70	30		0.53
5	DS	100	0	1.5	0.41
6	DS1	90	10	1.5	0.41
7	DS2	80	20	1.5	0.43
8	DS3	70	30	1.5	0.45

[a] Binder: Sand = 1:3, P: Portland cement, K: Calcined kaolin, SP: Superplasticizer, W: Water.

was considered relevant under Vietnamese climatic conditions. The sulfate solution was changed every two weeks during the first three months, and thereupon changed every month during the residual testing period. Compressive strength testing of the specimens was carried out after different periods of storage under these conditions. Flexural tests were additionally conducted. Also a more concentrated sodium sulfate solution environment was incorporated in the test program. For additional information pertaining to these aspects, see [10].

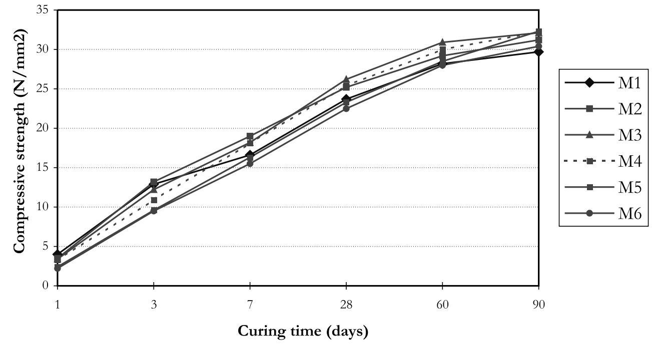

Fig. 1. The compressive strength development of Portland cement mortars in combination with calcined kaolin.

4. Results and discussion

Data in Table 4 demonstrate the normal consistency of calcined kaolin-blended Portland cement pastes to be affected by the replacement percentage. Effects increase at higher blending percentages. Over the replacement range of 10–40%, the consistency varied from 0.30 to 0.45. Further, the test results reveal the setting times of calcined kaolin-blended Portland cement pastes in the lower replacement range (i.e. 10–20%) to be hardly affected by blending. Beyond this range, the initial and final setting times increase by about 15% and 10%, respectively, at the 40% replacement level. This is obviously due to the lower cement and higher water contents involved.

The compressive strength of the calcined kaolin-blended Portland cement mortars was determined in accordance with ASTM C349-77. Data are presented in Table 5. All mechanical data here and throughout the rest of this paper are the average of three identical tests. The test results reflect to what degree the blending percentage has affected the compressive strength level and development of the mortars. Blending reduces the 1-day strength at all replacement levels. The 3-day strengths of the blended mixes at 10% and 15% replacement levels are similar to the ones of the plain mix. This tendency continues for more mature mixes, revealing the optimum shift to higher replacement levels. The strength is found increased due to blending up to 25% replacement levels at 90 days. This is visualized in Fig. 1.

The results in Table 6 show the strength of calcined kaolin-blended Portland cement mortars to diminish with an increase in the amount of mixing water. The strength of blended Portland cement mortars also depends, however, on the replacement percentage of the Portland cement by calcined kaolin, and on the curing time. At a 10–20% partial replacement level, the compressive strength of mortars increases at 7 days and beyond for water to binder ratios between 0.4 and 0.53. At the 30% replacement level, the mortar strength at all levels of the water to binder ratio generally shows a decline at 7 days and beyond.

In summarizing it can be stated that the strength of calcined kaolin-blended Portland cement mortars with the same water to binder ratio is improved at increasing partial replacement levels up to 25% by weight for periods of 60 days or longer. At a partial replacement level of 30%, the data reveal the calcined kaolin-blended Portland cement mortars to display lower strength at all ages and for all water to binder ratios.

Table 8 and Fig. 2 present relevant compressive strength data for the concrete specimens. Within the framework of the test conditions, blending has a negative effect on the compressive strength of young concrete (i.e. at 3 days) and a positive effect on the compressive strength of more mature concrete at 7 days and beyond. This effectiveness of blending in improving compressive strength does not seem significantly influenced by the water to binder ratio, although the most favorable results are obtained for series A, with a water to binder ratio of 0.44. As to the compressive strength, a blending percentage somewhat exceeding 10 could be optimum. Because of economic reasons this level could be increased, however, to 20% by weight of the Portland cement without a dramatic drop in strength.

Table 10 presents the compressive strength data of the water-saturated mortar specimens after storage in the low-concentration sodium sulfate solution during a period of one month to one year. The test results reveal the strength of the blended mortars at 10% and 20% replacement levels by weight to be stable during the storage of one year in the 0.2 M $MgSO_4$ solution. However, the compressive strength of mortar D3, with 30% calcined kaolin, slightly declined during storage in this environment. The use of a superplasticizer raised the compressive strength of the mixes DS1, DS2, and DS3 to a higher level. This is primarily due to a reduction in the water to binder ratio. These mixes manifested a strength increase during storage in the sulfate solution. The combined effect of the superplasticizer and the calcined kaolin becomes apparent in the relatively large strength gain of the blended mixes with respect to the plain one (DS).

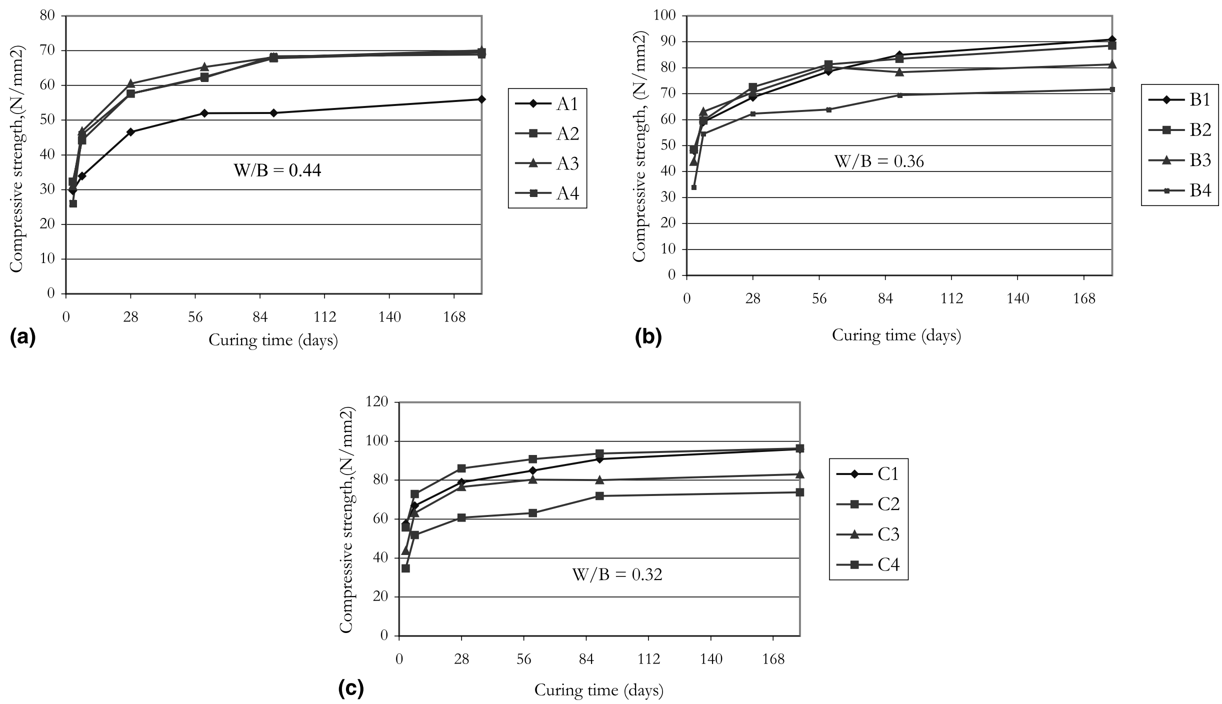

Fig. 2. The relationship between compressive strength and curing time of calcined kaolin-blended mixes for different water to binder ratios.

Table 10
Compressive strength (Rc) of specimens in 0.2 M $MgSO_4$ solution

No.	Code	Rc before exposure (N/mm^2)	Rc of specimens (N/mm^2) after exposure at age (days)				
			28	90	150	240	360
1	D	19.5	26.7	27.2	31.3	30.9	29.5
2	D1	20.7	27.5	29.5	28.9	29.8	30.2
3	D2	22.6	28.5	28.9	28.5	28.5	30.5
4	D3	20.7	28.1	28.5	26.1	27.3	26.0
5	DS	22.2	32.0	31.7	33.5	34.9	33.2
6	DS1	26.8	34.8	35.4	36.6	40.4	40.2
7	DS2	27.1	36.2	33.5	36.9	40.4	40.0
8	DS3	25.9	30.8	32.4	36.6	37.0	37.5

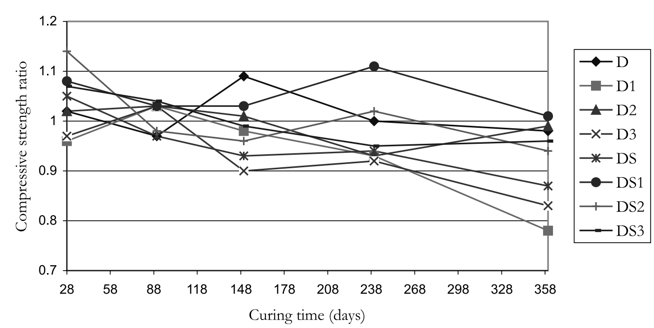

Fig. 3. Compressive strength ratio of mortar specimens in a 0.2 M $MgSO_4$ solution to specimens in water.

The compressive strength ratio of the specimens in the 0.2 M $MgSO_4$ solution and of similar specimens subjected to a prolonged storage in pure water is given in Fig. 3. As stated before, the specimens were all stored in water for 28 days at the start of durability testing. Thereupon, 50% of the specimens was stored in the sodium sulfate solution. The slight increase that has been recorded for the specimens stored in water causes the strength ratio to display a global declining trend. Nevertheless, the superplasticized mixes with 10% and 20% by weight of calcined kaolin performed relatively well. It should be mentioned here that the test program also encompassed measurements of the flexural strength and of mass. These data were published separately [10]. Table 11 presents the flexural strength data in the sulfate solution. Global outcomes are in agreement with the compressive strength data presented in this paper. Nevertheless, degradation will first become manifest at the specimen's surface (spalling), so that the flexural strength will be more affected than the compression test. This became primarily apparent, of course, in the environment of a highly concentrated sodium sulfate solution. Tables 12 and 13 present the data on mass changes. Mix D in water solely reflects the process of continued hydration (hardening), whereas D in the sulfate solution combines this with the reaction between the lime and the sodium sulfate in the solution (sulfate attack). In the blended mixes also the pozzolanic reactions contribute to a mass gain. The superplasticized mixes all score lower, as a result of the lower porosity and accompanying reduced diffusivity. Mass drops in the

Table 11
Flexural strength (Rf) of specimens in 0.2 M $MgSO_4$ solution

No.	Code	Rf before exposure (N/mm^2)	Rf of specimens (N/mm^2) after exposure at age (days)				
			28	90	150	240	360
1	D	4.3	6.0	6.3	6.5	7.0	7.1
2	D1	5.0	6.3	6.7	7.1	7.1	7.1
3	D2	4.4	6.5	6.9	6.8	6.6	7.2
4	D3	3.8	6.4	6.9	6.6	7.1	7.0
5	DS	4.8	6.3	7.3	7.4	8.0	8.2
6	DS1	5.3	7.2	7.3	7.9	8.1	8.1
7	DS2	5.1	7.3	7.6	7.9	8.4	8.5
8	DS3	4.6	7.2	7.3	7.5	7.7	7.6

Table 12
Mass changes of specimens in water

No.	Code	Mass change of specimens (%) at age (days)				
		28	60	90	120	150
1	D	0.981	1.592	1.833	1.776	2.186
2	D1	1.083	1.657	1.823	1.657	1.988
3	D2	1.101	1.494	1.840	1.603	2.149
4	D3	1.241	1.643	1.870	1.689	2.118
5	DS	0.821	1.126	1.342	1.106	1.415
6	DS1	0.908	1.308	1.334	1.326	1.598
7	DS2	0.861	1.328	1.466	1.265	1.576
8	DS3	1.097	1.487	1.655	1.450	1.655

Table 13
Mass changes of specimens in 0.2 M $MgSO_4$ solution

No.	Code	Mass change of specimens (%) at age (days)				
		28	60	90	120	150
1	D	1.881	2.252	1.880	1.396	1.713
2	D1	2.054	2.405	2.607	2.570	2.996
3	D2	2.352	2.667	2.445	2.260	2.408
4	D3	2.580	2.886	3.430	3.482	2.597
5	DS	1.461	1.662	1.351	0.986	1.260
6	DS1	1.296	1.768	1.731	1.659	2.002
7	DS2	1.619	1.800	1.836	1.745	1.927
8	DS3	1.891	2.222	2.036	1.886	2.148

development process (not due to measurement variation) reflect spalling reducing flexural strength to a more significant degree as compression strength.

Research into durability aspects is continued in Vietnam on concrete specimens. These data will be published at a later occasion.

5. Conclusions

The addition of calcined kaolin to Portland cement increases the normal consistency of blended Portland cement mixtures. Blending Portland cement by 10–20% calcined kaolin by weight will not significantly alter setting time, but exceeding this range will cause a significant increase.

The compressive strength of young mortars, say from 3 to 7 days, is improved by blending the Portland cement with 10% of calcined kaolin by weight. The optimum Portland cement replacement level increases with maturity of the mortar for all water binder ratios. In the 7–28 days range, 15–20% of the Portland cement can be replaced, while this increases to 20–25% for mature mortars. The compressive strength of mortars under optimum blending conditions will have a higher compressive strength than that of the plain mortar with the same amount of mixing water.

Mix proportions of mortars affect the strength development of the blended mortars. Higher strength increase values can be achieved for blended mortars with a sand to binder ratio of 2.75 than for mortars with a ratio of 2.

Superplasticized mixes reveal higher strength because of the reduced water to binder ratio. The use of a superplasticizer seems to have no significant effect on optimum blending conditions, however.

For concrete the optimum blending conditions seem to be between 10% for the lowest water to binder ratio (0.32), and 20% for the highest water to binder ratio (0.44). Continued experimental work on concrete in Vietnam should increase the reliability of these outcomes, however.

Optimum blending percentages based on technological arguments could be somewhat increased because of economic reasons in areas without serious durability risks.

In coastal areas for which the low-concentrated sulfate environment could be considered representative, the Portland cement could be replaced by up to 20% by weight of calcined kaolin in mortars. In case of superplasticized mortars, a roughly 20% increased compressive strength can be accounted for (with a considerably smaller increase in flexural strength). Without superplasticizer, the compressive (and flexural) strength will be on the same level as in the plain mix.

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