Pergamon

Cement and Concrete Research 30 (2000) 1679–1683

CEMENT AND CONCRETE RESEARCH

Properties and behavior of limestone cement concrete and mortar

S. Tsivilis[a,*], G. Batis[a], E. Chaniotakis[b], Gr. Grigoriadis[a], D. Theodossis[a]

[a]*Chemical Engineering Department, National Technical University of Athens, 9 Heroon Polytechniou Street, 15773 Athens, Greece*
[b]*Department of Research and Development, Kamari Plant, TITAN Cement Company S.A., P.O. Box 18, 19200 Elefsis, Greece*

Received 17 April 2000; accepted 18 July 2000

Abstract

In this paper, the properties and the behavior of limestone cement concrete and mortar are studied. Portland limestone cements of different fineness and limestone content have been produced by intergrinding clinker, gypsum and limestone. In order to have compatible results, the produced cements were selected to have the same level of strength. Portland limestone cement, containing up to 20% limestone, presents satisfactory concrete strength and workability, while the sorptivity and the chloride permeability seems to be similar to the pure cement concrete. Limestone cement concretes indicate lower resistance to freezing and thawing compared with the pure cement concrete. Portland limestone cement, containing 20% limestone, shows the optimum protection against rebar corrosion. Furthermore, the limestone additions decrease the carbonation depth and the total porosity of the mortar.

Keywords: Portland limestone cement; Concrete; Properties; Mortar; Corrosion

1. Introduction

The use of Portland limestone cements seems to have many benefits, both technical and economical [1–3]. In addition, the European Prestandard prEN 197-1 identifies two types of Portland limestone cement containing 6–20% limestone (type II/A-L) and 21–35% limestone (type II/B-L), respectively [4]. It is expected that the future world production and use of Portland limestone cement will significantly be extended. The wide use of limestone cement requires a thorough knowledge of the cement and concrete properties.

As far as the cement is concerned, the research work is focused on three areas. The first one is the effect of limestone on the cement performance [3,5–7]. The second one deals with the participation of limestone in the hydration reactions of clinker [8–13], while the third one with the production process and specifically the intergrinding of clinker and limestone [5,14–16]. Although there is a disagreement in many partial topics, the knowledge level is satisfactory and continuously extended.

As far as the limestone cement concrete is concerned, the few available references are focused on two areas. The first one is the effect of limestone on the concrete properties and behavior [1,17–23]. The second one deals with the "thaumasite problem", correlated with the use of limestone cement concrete and calcareous aggregates. Recent research work shows that Portland limestone cement pastes are susceptible to the thaumasite form, due to sulfate attack at 5°C, after only a few months of exposure to sulfate solutions [24–29].

Taking into consideration the above remarks and the attractive benefits of Portland limestone cement, it is of great importance to investigate the performance of limestone cement concrete. More specifically, the effect of limestone content on the concrete properties and the corrosion behavior of mortar are investigated. This work is a part

Table 1
Chemical and mineralogical composition of clinker

Chemical composition (%)		Mineralogical composition (%)	
SiO_2	21.96	C_3S	61.59
Al_2O_3	5.15	C_2S	16.48
Fe_2O_3	3.78	C_3A	7.27
CaO	65.95	C_4AF	11.50
MgO	1.76	Moduli	
K_2O	0.56	LSF	94.20
Na_2O	0.12	SR	2.46
SO_3	0.52	AR	1.36
		HM	2.14

* Corresponding author. Tel.: +30-1-772-3262; fax: +30-1-772-3188.
E-mail address: stsiv@central.ntua.gr (S. Tsivilis).

0008-8846/00/$ – see front matter
PII: S0008-8846(00)00372-0

Table 2
Chemical composition (%) of limestone

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	LOI
0.55	0.40	0.17	53.47	1.02	0.03	0.01	43.13

of a project, developed in our laboratories, concerning the properties of limestone cement and concrete.

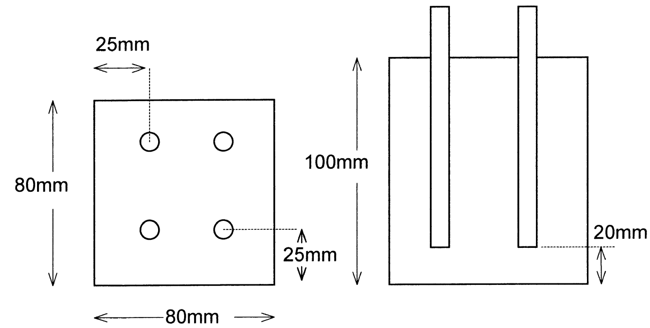

Fig. 1. Specimen's shape and dimensions (corrosion tests).

2. Experimental

2.1. Materials and cement production

The chemical and mineralogical composition (Bogue) of the used clinker is shown in Table 1. The chemical analysis of the limestone is given in Table 2. The main constituent of the limestone is calcite containing also dolomite and quartz as minor constituents.

The limestone cements have been produced by intergrinding clinker, limestone and gypsum (5% per clinker weight), in a pro-pilot plant ball mill of 5 kg capacity. The codes of the samples as well as their properties are given in Table 3. The cements LC1–LC4 contain 0%, 10%, 15%, and 20% limestone, respectively, and have the same 28-day compressive strength (48–51 N/mm^2, strength class 42.5R of prEN 197-1). The cement LC5 contains 35% limestone (strength class 32.5R of prEN 197-1).

2.2. Concrete production and properties

The concrete production was carried out in a mixer of 50 l capacity. The mix proportions and the aggregate grading are given in Table 4.

The slump (ASTM C 143), the flow (BS 1881) and the density of the fresh concrete were tested. Concerning the hardened concrete, the compressive strength after 7 and 28 days (ASTM C 39), the resistance to freezing and thawing (ASTM C 666), the sorptivity [23] and the chloride permeability (ASTM C 1202) of concrete specimens were tested.

2.3. Preparation of mortar specimens and corrosion monitoring

The W/C ratio was 0.50 and the calcareous sand:cement ratio was 3:1. Prismatic specimens ($80 \times 80 \times 100$ mm) were made and four cylindrical steel bars (12×100 mm) were embedded in each one, as shown in Fig. 1. Each bar has a properly attached copper wire. Both the top surface of all specimens and the part of steel bars which protrudes over the concrete, are covered with an epoxy glue to protect the bars from atmospheric corrosion.

The specimens were partially immersed in a 3% wt NaCl solution, up to a height of 25 mm, in order to accelerate the corrosion process. After immersing all speci-

Table 3
Characteristics of the tested cements

Sample	Composition (%)		Sp. surf. (cm^2/g)	Compressive strength (N/mm^2)			
	Clinker	Limestone		1 day	2 days	7 days	28 days
LC1	100	0	2600	11.9	21.3	35.3	51.1
LC2	90	10	3400	11.2	20.9	36.3	47.9
LC3	85	15	3660	12.9	22.7	37.7	48.5
LC4	80	20	4700	14.9	24.3	38.0	48.1
LC5	65	35	5300	9.8	17.0	26.2	32.9

Table 4
Concrete mix proportions and aggregate grading

Sample	W/C	Cement (kg/m^3)	Aggregate (kg/m^3)	Aggregate grading (%) Size fraction (mm)					
				30–15	15–7	7–3	3–1	1–0.2	0.2–0
LC1–LC4	0.70	270	~1940	30	22	8	15	15	10
LC5	0.62	330	1905	30	22	8	15	15	10

Table 5
Concrete properties

Sample	Slump (mm)	Flow (mm)	Unit weight (kg/m^3)	Compressive strength (N/mm^2) 7 days	28 days
LC1	130	460	2400	26.7	31.9
LC2	120	440	2395	21.9	27.4
LC3	120	420	2400	22.5	27.3
LC4	110	420	2394	22.1	28.0
LC5[a]	110	400	2390	21.6	26.6

[a] Plasticizer (Pozzolith 390 N).

Table 6
Freezing and thawing tests

Sample	W_0[a]	W_{14}	W_{42}	W_{75}	W_{108}	W_{141}	W_{174}	W_{207}
LC1	8.011	8.072	8.107	8.120	8.057	8.057	7.982	3.150
LC2	8.022	8.126	8.147	8.075	7.714	4.067		
LC4	7.952	8.005	8.019	7.985	7.210	1.148		

Sample	W_0	W_{28}	W_{61}	W_{94}	W_{127}	W_{160}	W_{193}
LC3	7.918	8.018	8.053	8.039	7.929	7.215	2.456
LC5	7.904	8.000	7.907	7.498	5.972		

[a] W_x = specimen weight (kg), x = number of cycles of freezing and thawing.

mens in the corrosive solution, the following measurements were carried out:

- Corrosion half-cell potential vs. Saturated Calomelan Electrode (SCE), periodically.
- Gravimetric mass loss of the rebars after 9 and 12 months exposure.
- Mean carbonation depth, after 9 and 12 months, using phenolpthalein indicator, sprayed across a vertical section of the specimen.
- Porosity of the specimens, after 9 months exposure, using a Carlo Erba 2000 Hg porosimeter.

3. Results and discussion

The concrete properties are given in Table 5. The mixes with limestone cement, although having higher fineness, indicate a satisfactory workability. The slump of the mixes was in the range 110–130 mm (class S3 of prEN 206). A

Table 7
Sorptivity of the tested samples

Sample	LC1	LC2	LC3	LC4	LC5
S ($mm/min^{0.5}$)	0.237	0.238	0.226	0.220	0.224

Table 8
Charge passed through the concrete specimens (rapid chloride permeability test)

Sample	LC1	LC2	LC3	LC4	LC5
Charge (C)	6100	5800	6000	6400	6600
Permeability class	High	High	High	High	High

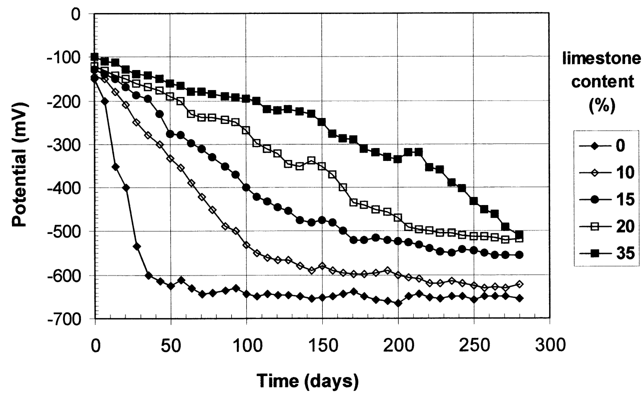

Fig. 2. Corrosion potential vs. exposure time and limestone content.

plasticizer (Pozzolith 390 N) was used in concrete containing cement with 35% limestone (LC5). Concerning the compressive strength, all the mixes belong to the class C20/25 of prEN 206.

The results of the freezing and thawing tests (for one specimen per sample from the three tested) are given in Table 6. The number of cycles of freezing and thawing to produce a 25% loss in the mass of the specimen is 207, 141, 193, 141, and 108 for the samples LC1, LC2, LC3, LC4, and LC5, respectively. The limestone cement concretes indicate lower resistance to freezing and thawing compared with the pure cement concrete. This fact may be attributed to the high value of the W/C ratio (Table 4). The use of an air-entrained agent is expected to improve the resistance to freezing and thawing.

The results of the sorptivity tests are given in Table 7. It is seen that the limestone cement concretes indicate similar sorptivity with the pure cement concrete.

The results of the rapid chloride permeability test are given in Table 8. Concerning the cements containing up to 20% limestone, the total electrical charge passed through the tested specimens was near 6000 C. The LC5 indicates the higher chloride permeability. All the concretes are classified as high permeabilty to chloride ions and this fact is mainly attributed to the high W/C ratio used.

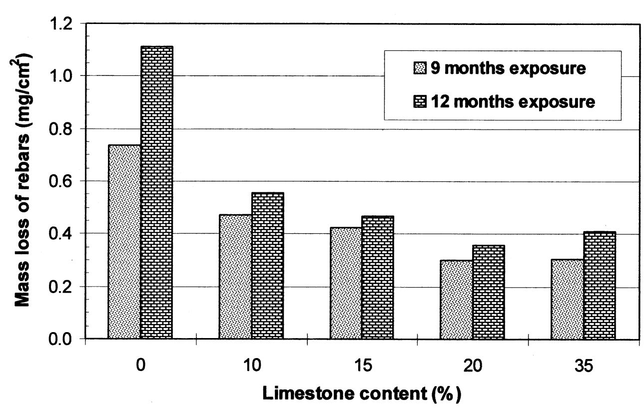

Fig. 3. The effect of the limestone content on the mass loss of rebars.

Table 9
Carbonation depth and total porosity of the cement mortars

	Carbonation depth (mm)		Total porosity (%)
Sample	9 months	12 months	9 months
LC1	3	5	15.3
LC2	0	0	11.6
LC3	0	0	12.2
LC4	0	0	12.5
LC5	0	0	13.1

Fig. 2 presents the corrosion potential vs. exposure time and limestone content. The limestone cement specimens indicate a clear decrease of the corrosion potential, compared to the pure cement specimens. The potential decrease is an indirect indication that the Portland limestone cements actually provide anti-corrosive protection. The anti-corrosion effect is greater as the limestone content increases. As a matter of fact, corrosion potential should be considered only as a measure of specimen's trend for corrosion and not as an absolute measure of corrosion itself.

Fig. 3 presents the mass loss of rebars (average value of four specimens), expressed as mg/cm^2 of surface of rebars. It is shown that there is an explicit decrease of corrosion in specimens with limestone. The mass loss of rebars decreases as the limestone content increases up to 20%. The mass loss of specimens with 20% and 35% limestone is approximately the same, in the frame of statistical analysis.

Concerning the carbonation depth (Table 9), all types of Portland limestone cements used had not carbonated at exposure time of 9 and 12 months. The specimen of pure cement had carbonation depth 3–5 mm. In addition, the specimens with limestone had lower porosity compared with the pure cement specimen (Table 9).

The corrosion behavior of the limestone cement concrete may be attributed to the lower total porosity and the negligible carbonation depth. The above phenomena lead to a significant reduction of the corrosion potential resulting in reduced mass loss of the used rebars.

Previous studies have shown that Portland limestone cements seem to have many benefits concerning their mechanical and physical properties. Reviewing all the above measurements, it is concluded that Portland limestone cements, containing up to 20% limestone, indicate competitive concrete properties and improve the corrosion performance of the concrete.

4. Conclusions

The following conclusions can be drawn from the present study.

• Portland limestone cements indicate competitive concrete properties and improve some aspects of the durability of the concrete.

• Limestone cement, containing up to 20% limestone, presents satisfactory concrete strength and workability, while the sorptivity and the chloride permeability seems to be similar to the pure cement concrete. Limestone cement concretes indicate lower resistance to freezing and thawing compared with the pure cement concrete.

• Portland limestone cement, containing 20% limestone, shows the optimum protection against rebars corrosion. The limestone additions decrease the carbonation depth and the total porosity of the mortar.

Acknowledgments

The authors would like to acknowledge Dr. C. Meletiou, Civil Engineer, TITAN Cement, for the significant contribution at the stage of concrete tests.

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