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Effect of lime putty addition on structural and durability properties of concrete

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Abstract

The effect of lime putty addition on main structural and durability properties of concrete was studied. Different types of cement were used for concrete preparation: a Portland cement, a pozzolanic cement and a Portland cement with the addition of 20% fly ash. The measured concrete properties were compressive strength, setting times, length change, porosity, carbonation depth and degree of steel bar corrosion. It was found that the lime putty addition has a positive effect on the properties of concrete that contain pozzolans and a slightly negative effect on the properties of pure Portland cement. This behavior was correlated with the availability of active silica of cementitious materials. The active silica of pozzolans reacts with the added calcium hydroxide giving constituents, which improve the concrete stability and durability.

Keywords: Concrete; Durability; Fly ash; Lime putty; Strength

1. Introduction

In the beginning of the 20th century, there was usage of hydrated lime as an admixture in poured concrete [1]. The principal advantages for this admixture were improved watertightness and impermeability, thus, the main concrete applications referred in foundations, dams, tunnels, reservoirs, bridge footings, highway pavements, silos and stadiums. However, this use has largely disappeared due to increased strength and finer grinding of Portland cement and the introduction of the chemical admixtures.

Nowadays, the use of environmentally friendly materials and energy saving is more urgent than ever. It has been well established [2,3] that sustainable development of the cement and concrete industries can be achieved by complete utilization of cementitious and pozzolanic by-products, such as fly ash, slag and silica fume, produced by thermal power plants and metallurgical industries. These materials, in order to give strength components and to exhibit their activity, require calcium hydroxide that usually receive from cement hydration. However, the need for increased use of supplementary cementing materials in concrete requires more available calcium hydroxide, and, thus, a fresh investigation on lime putty addition in concrete is needed. This addition has been already proved beneficial for durability properties [4].

The subject of this work is to investigate the effect of lime putty addition in concrete in the presence of supplementary cementing materials. Besides the effect on usual structural properties, such as strength and volume stability, the durability of concrete incorporating lime putty and other supplementary materials should be taken into account. A Portland cement was used as the control material and then a pozzolanic cement and a Portland cement with addition of 20% fly ash were used in concrete production. The lime putty addition varied from 0% to 25% of the cement weight. The concrete properties that were examined were physical and structural properties, such as slump, setting time, length change and compressive strength. Durability properties, such as porosity, carbonation depth and reinforcement corrosion, have been also examined. The use of lime putty as admixture in concrete production in parallel with supplementary cementing materials improves these concrete properties. As lime putty is a rather low-priced material, its

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Table 1
Chemical analyses of the cements and fly ash[a]

1%	Cement OPC	Cement PPC	Fly ash
SiO_2	20.71	31.49	33.30
Al_2O_3	4.93	7.86	17.10
Fe_2O_3	3.65	5.82	6.40
CaO	64.21	47.51	27.10
MgO	1.60	1.75	3.60
SO_3	2.95	2.88	5.20
K_2O	0.54	1.10	1.40
Na_2O	0.17	0.30	0.70
L.O.I.	0.80	0.90	4.80

[a] The methods specified by the European Standards, EN-450, EN-196 and EN-451 were followed for chemical analyses.

addition in concrete becomes attractive and from an economical point of view as well.

2. Experimental

2.1. Materials and mixture proportions

Three types of cementitious materials were used for the production of experimental mixtures: an ordinary Portland cement (CEM I 42.5, according to European Standard EN-197), denoted as OPC, a commercial composite Portland cement with pozzolans (CEM II 32.5, according to EN-197), denoted as PPC, and a laboratory prepared mix-ture of OPC with 20% fly ash, denoted as OPC-FA. The fineness of the cements (Blaine's test) was 3500 and 4200 cm^2/g for OPC and PPC, respectively. The fly ash produced in Greece by Public Power (Ptolemais). It was treated and milled, and its residue on sieve 45 μm was 26%. An oxide analysis of the materials is given in Table 1.

Concrete mixtures were produced with all types of cements adding lime putty by 0 (reference sample), 5, 10, 15, 20 and 25 wt.% of cementitious materials. A high-purity lime (CaO > 98%) was used. The amount of free water of lime putty (55%) was deducted from the mix water. According to prEN 459-1:2000 in clause 3.5, "hydrated lime is produced in form of a dry powder or putty or as a slurry". In the present work, we used hydrated lime in the form of putty. Note that in Greece, the majority (80–85%) of hydrated lime is produced in the form of lime putty. The water-to-cementitious materials ratio, W/CM, was 0.61, and the cementitious materials content was 320 kg/m^3 of concrete. No plasticizer or other chemical admixture were used. Limestone aggregates, including fine (42%), medium (19%) and coarse (39%) aggregates, were used. The coarse aggregate maximum size was 1 1/2 in. The slump of the mixtures varied from 9 to 10 cm.

2.2. Tests

2.2.1. Compressive strength

Cubic specimens of 15 cm were prepared and cured in a chamber at 20 ± 2 °C and a relative humidity greater than 95%. The specimens were tested, according to BS 1881: Part 116:1983, at 3, 7, 28, 90, 180 and 360 days after casting using six specimens at each age.

2.2.2. Initial and final setting time

The test was performed according to ASTM C403-92. Time of initial or final setting is defined as the elapsed time, after initial contact of cement and water, required for the mortar sieved from the concrete to reach a penetration resistance of 3.5 MPa (500 psi) and 27.6 MPa (4000 psi), respectively.

2.2.3. Determination of length change

The term length change is referred to an increase or decrease in the linear dimension of a test specimen, measured along the longitudinal axis, due to other causes than the applied load. The test was performed according to ASTM C490-96 and ASTM C157-93, with modification of using the mortar from the concretes after screening with sieve ASTM No. 4 (4.75 mm). The length change refers to the period between 24 h and 28 days, and the specimens during this period were immersed in lime-saturated water.

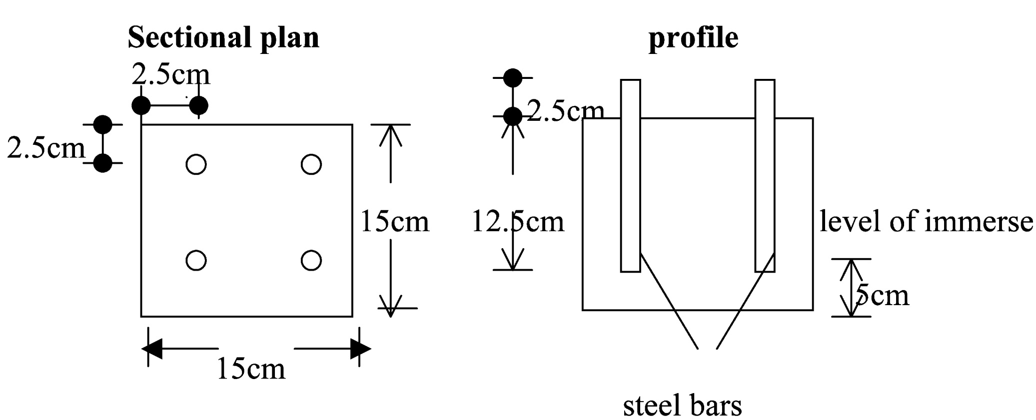

Fig. 1. Schematic representation of reinforced concrete specimens for corrosion tests.

2.2.4. Voids in hardened concrete

The percentage of voids in concrete was determined according to ASTM C642-97.

2.2.5. Carbonation in accelerated conditions

Three-month-old specimens, cured under water at temperature of 20 ± 2 °C, were used. The specimens were prisms of 10 × 10 × 30 cm covered with a gas-tight paint on the four sides, leaving the two opposite sides of 10 × 30 cm free for carbonation. They were placed in a chamber with a controlled CO_2 concentration of 50%, temperature of 20 ± 2 °C and relative humidity of 45–55%. The carbonation depth of the specimens was measured after 5, 10, 15, 30 and 45 days by taking slices of 2 cm from each end of the specimens, and it was determined by means of a phenolphthalene indicator. For each mixture, the average carbonation depth of the two measurements is reported [5].

2.2.6. Corrosion of steel bars in reinforced concrete

Concrete cubes of 15 cm were prepared and four steel bars of STIII 12 mm in diameter were placed symmetrically to the four angles as shown in Fig. 1. The specimens were immersed in a 3.5% NaCl solution at a depth of 5 cm. All specimens were cured for 7 days in a chamber at 20 ± 2 °C

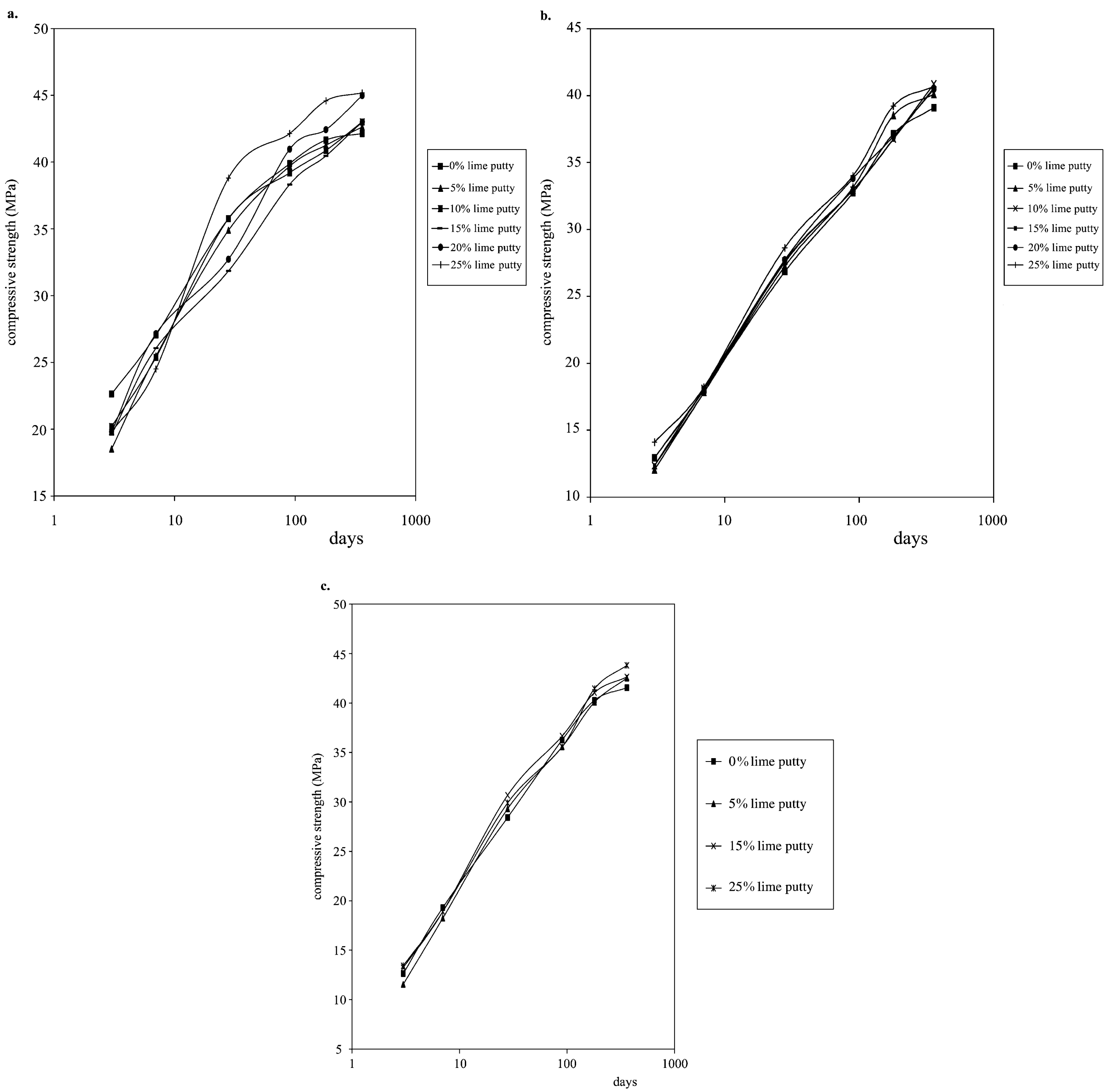

Fig. 2. Effect of lime putty addition on compressive strength of concrete for different cementitious materials. (a) OPC; (b) PPC; (c) OPC-FA.

and relative humidity greater than 90% [6] before being immersed in the NaCl solution. The corrosion activity of the reinforcing steel can be qualitatively estimated, regardless of the specimens' size or the depth of the concrete cover by monitoring the change with time of the half-cell potential of the steel bars. For all specimens, the corrosion potential of reinforcing bars with a $Cu/CuSO_4$ half cell was measured (according to ASTM C876-91), as well as the weight loss of reinforcing bars after remaining of the specimens in the aggressive environment for 300 days.

3. Results and discussion

3.1. Compressive strength

In Fig. 2, the compressive strength results from all tested concrete specimens are presented. It is obvious that the lime putty addition did not influence significantly the compressive strength in concrete made by these cementitious materials. However, the compressive strength of OPC concrete exhibits a significant variation in the presence of lime putty taking either higher or lower values than that of the OPC concrete without lime putty. On the contrary, the concretes that incorporate pozzolanic materials, either in cement (PPC) or as additive in concrete (OPC-FA), show no such scattering, presenting, in addition, little improvement on the compressive strength especially at late ages and with various lime putty contents. It must be noted that the particular pozzolanic materials used in this work contained relatively high amounts of calcium oxide themselves, thus, the effect of the lime addition would not be so significant as in the case of low-calcium pozzolans. In the latter case, a more pronounced effect would be expected.

In order to investigate further this effect, cement pastes with lime putty content of 0%, 5%, 10%, 15%, 20% and 25% by cement weight were prepared. The pastes examined under X-ray diffraction (XRD) and thermogravimetric analysis (TGA) after interrupting their hydration at 3, 28 and 90 days. No new reaction product was identified on the X-ray patterns in the samples with lime putty for all types of cementitious materials, as they compared with typical hydrated cements [7,8]. From XRD and TGA results, it is pronounced the higher content of $Ca(OH)_2$ in the pastes with lime putty. On the other hand, a relatively higher content of calcium silicate hydrate (CSH) from the beginning of hydration was observed in pastes that incorporate pozzolanic materials. The rather faster formation of CSH in these materials in the presence of lime explains the relative improvement in strengths.

3.2. Initial and final setting time

The results of the initial and final setting time are presented in Fig. 3. In the case of OPC concrete, both the initial and final setting times were increased as the lime putty addition was increased. On the contrary, the setting times decreased when the lime putty was added in the concretes with pozzolanic materials. These results are in agreement with the observations presented in Section 3.1, and they can be explained as due to the faster formation of strength-carrier components (mainly CSH) originating from pozzolanic reactions.

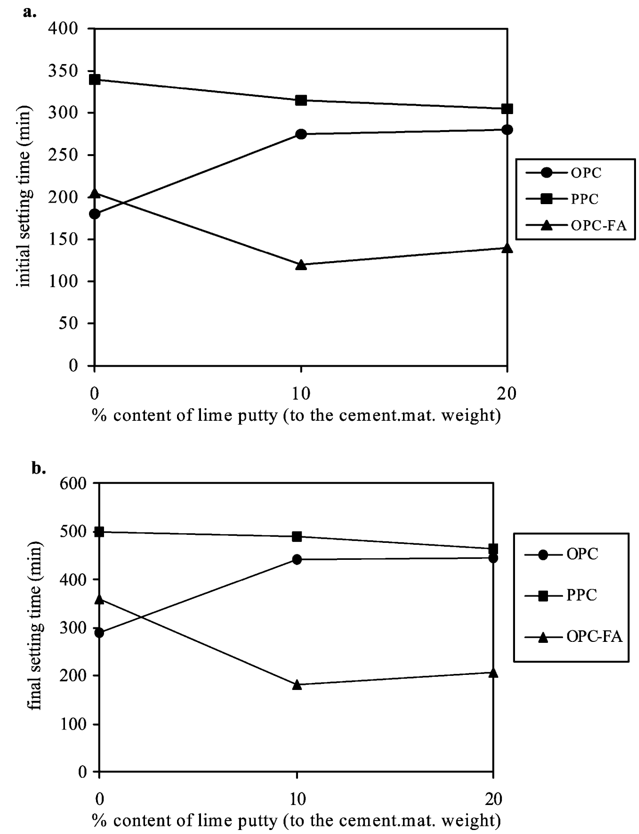

Fig. 3. Effect of lime putty addition on initial (a) and final (b) setting time of concrete.

3.3. Length change of concrete specimens

The results from the length change experiments are shown in Fig. 4. When the lime putty is added in concrete made by OPC, a smooth increase in the length change of the specimens is observed. However, when pozzolanic materials are contained in the concrete, a rather significant decrease in the length change is observed. It seems that in the latter case, the faster formation of strength components as a result of the reaction between lime and pozzolanic materials improve the total stability of concrete.

3.4. Concrete porosity

In Fig. 5, the concrete porosity as a function of lime addition and cement type is given. The specimens were 28 days old. A significant increase is observed for OPC concrete porosity as lime content increases. On the other hand, for concrete incorporating pozzolanic materials, a

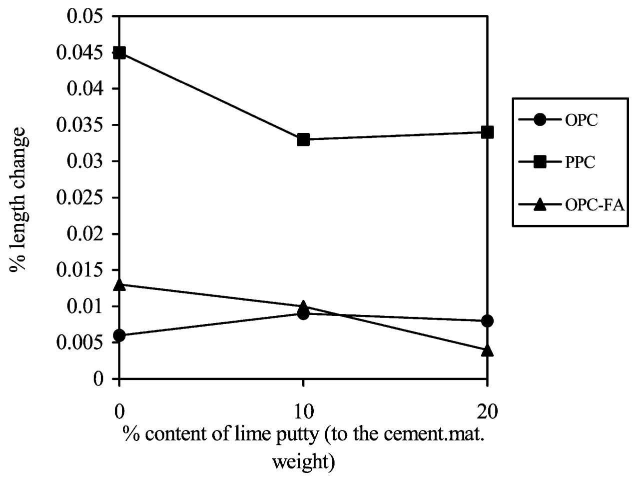

Fig. 4. Effect of lime putty addition on length change of hardened concrete.

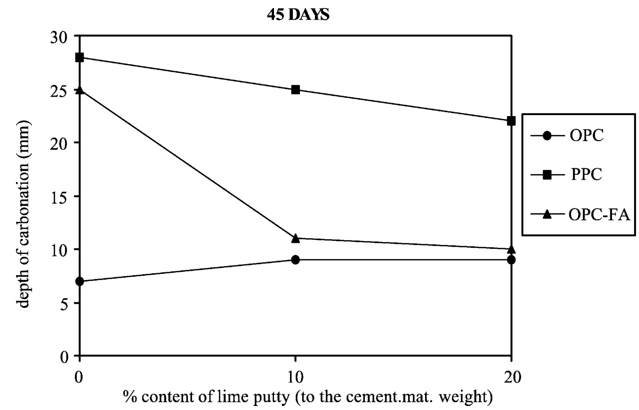

Fig. 6. Effect of lime putty addition on concrete carbonation for different cement types.

decrease in porosity is observed as lime content increases. This result is due to acceleration of the pozzolanic activity in the presence of lime, and further beneficial improvement on durability properties should be expected.

3.5. Carbonation results

The carbonation depth of the concrete specimens after 45 days at the carbonation chamber is presented in Fig. 6. The carbonation depth for the OPC concrete slightly increases as lime addition increases, whereas in the case of concrete incorporating pozzolanic materials, a significant decrease is observed. As given in the literature [5,9–11], carbonation depth decreases as calcium components increase or diffusivity (which depends on porosity) decreases. It seems that in the case of lime putty addition in concrete incorporating pozzolanic materials, calcium concentration increases and porosity decreases with the final result of the significant reduce in carbonation depth.

3.6. Corrosion test results

The results of the measurements of the half-cell potentials are given in Fig. 7. In this figure, the E_{cor} trend of the

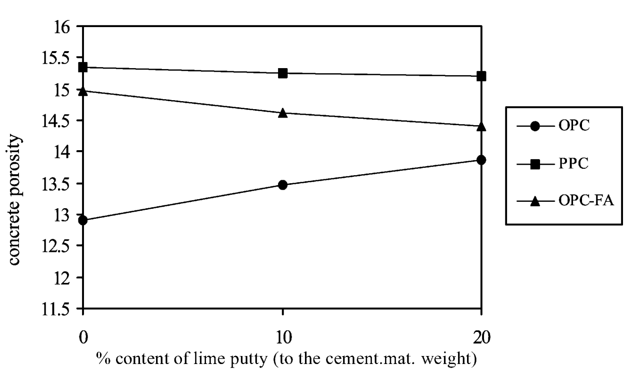

Fig. 5. Effect of lime putty addition on concrete porosity.

different types of samples is shown. After curing, in early ages, steel rebars showed free corrosion potential in the range of -200 to -300 mV. Later, more negative potential values were observed. Small fluctuations of the potential values were observed corresponding to a more or less steady state values in the range of -400 to -550 mV. These values are typical when there is a greater than 90% probability that corrosion of reinforcing steel bars is occurring at the time of measurement. The similarity in the corrosion potential curves and the small differences in the specimens of the same type of cement do not permit quantitative prediction of the effect of lime putty addition on the corrosion of reinforcement.

The corrosion rate of reinforcing steel bars was estimated by the mass loss measurements vs. exposure time. The results of the weight loss of reinforcing bars after remaining of the specimens in the aggressive environment for 300 days are given in Fig. 8. In general, the addition of lime putty does not influence the corrosion degree of the reinforcing bars for the OPC concrete. When pozzolanic materials are used in concrete production, and without lime putty addition, a higher weight loss of the bars is observed. However, a significant decrease in the weight loss of steel bars is observed when lime is added to the concrete with pozzolanic materials; this is very clear for the PPC, where more experiments were performed. Corrosion of reinforcement is a composite process that depends mainly on concrete cover quality [9]. As observed also in porosity and carbonation results, a denser structure is created when both pozzolanic materials and lime putty are added in concrete decreasing the permeability of harmful constituents into concrete mass and thus prolonging the lifetime of the structure.

4. Conclusions

The lime putty addition in concrete improves the compressive strength development when pozzolanic materials are used in parallel. The compressive strength of OPC

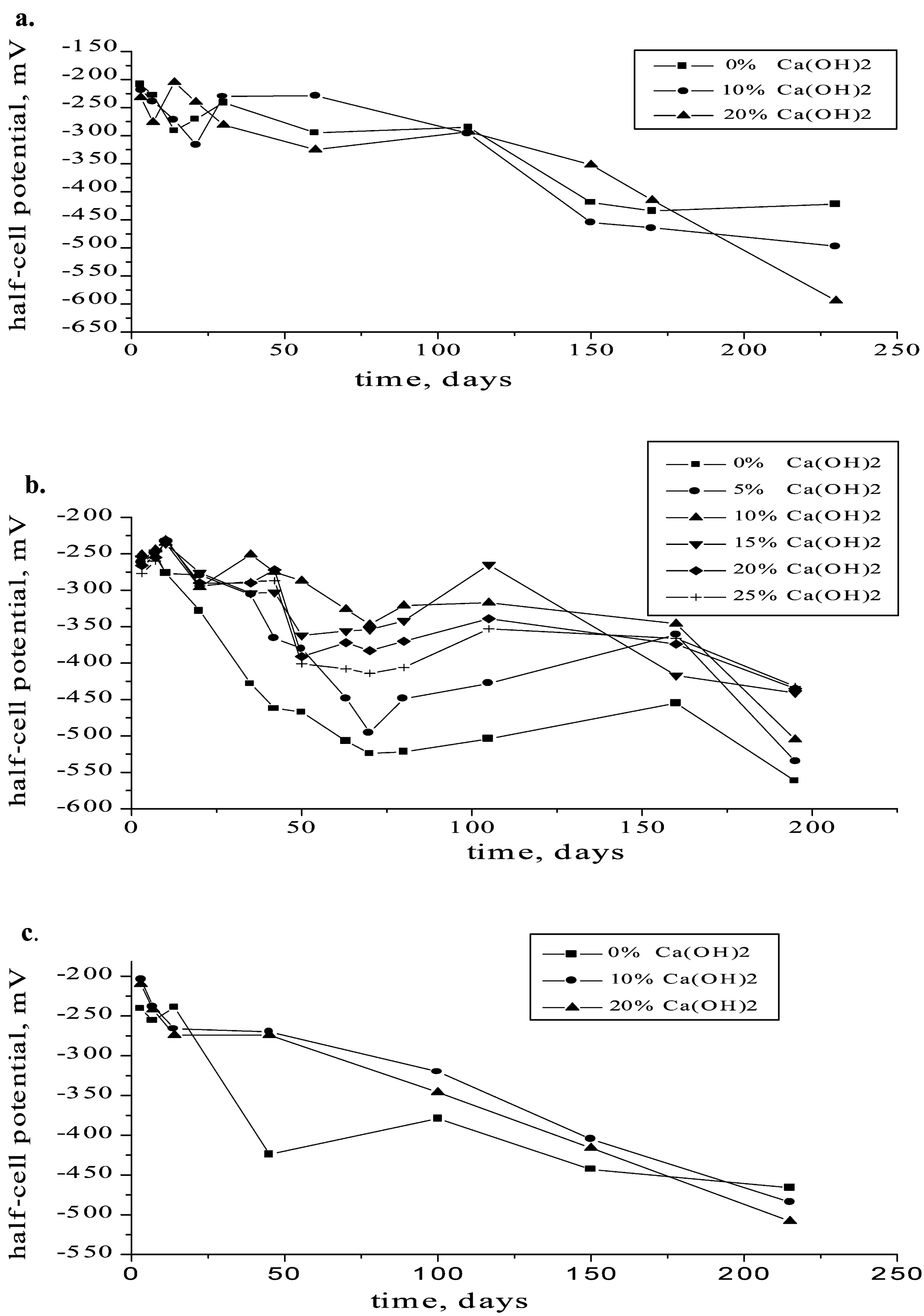

Fig. 7. Half-cell potentials of reinforcing bars of concrete immersed in 3.5% NaCl solution. (a) OPC; (b) PPC; (c) OPC-FA.

concrete exhibits a significant variation in the presence of lime putty taking either higher or lower values than that of the OPC concrete without lime putty. The concretes that incorporate pozzolanic materials, either in cement or as additive in concrete, show no such scattering and, on the contrary, they exhibit a steady improvement, especially at late ages. This is correlated with the rapid formation of CSHs as the result of the acceleration of the pozzolanic activity. Signific-

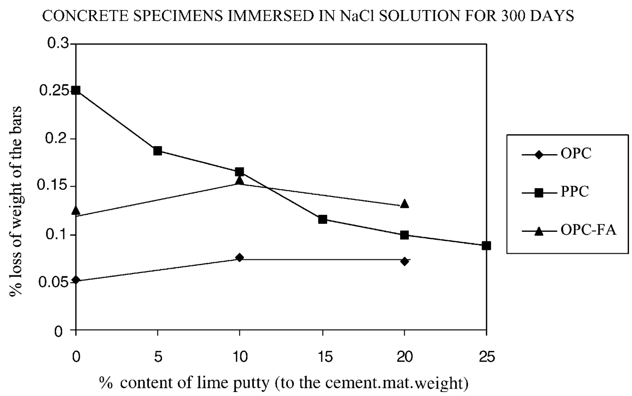

Fig. 8. Effect of lime putty addition on corrosion resistance of reinforcing bars.

ant improvement is also observed in concrete stability. However, this early activity shortens the setting time and thus influences the properties of fresh concrete.

When lime putty is added in concrete that contains pozzolanic materials, a significant improvement in durability is observed. A denser structure is created, which is responsible for the lower degree of concrete carbonation and corrosion of reinforcement due to chloride attack. Thus, an extended concrete service life is expected. The above results are positive for the usage of hydrated lime as an admixture in concrete, when pozzolanic materials are also incorporated in the concrete mixture.

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